SIAT
Symposium on International Automotive Technology 2017
Smart, Safe & Sustainable Mobility

ARAI 50
YEARS OF BUILDING AUTOMOTIVE EXCELLENCE
1966-2016

TRB
Technical Reference Bulletin

FOREWORD

Indian automotive industry is growing at a rapid pace, throwing challenges before automotive engineers to design and develop eco-friendly, fuel efficient and safer mobility. The focus of Indian Government on reducing air pollution, encouraging electric mobility coupled with thrust on reducing road accidents and fatalities through smart and intelligent solutions has also driven industry to advance their R&D efforts. SIAT 2017 organized on this backdrop will be ideal platform for the researchers around the globe to put forth and deliberate their ideas to address India specific and global challenges faced by the automotive sector.

The present edition of SIAT 2017 is an apt forum for harnessing ideas, technologies and applications of various fields and domains to the very purpose of achieving Smart, Safe and Sustainable mobility; which is the theme of SIAT 2017. This edition of SIAT assumes special significance, since ARAI turned 50; a month prior to this Symposium's schedule. SIAT 2017 is going to be a memorable one, considering the grand finale of ARAI's Golden Jubilee, coinciding this event.

I am sure, SIAT 2017 being held from 18 - 21 January 2017 at ARAI, Pune, will provide perfect opportunity for engineers and technologists around the world to exchange ideas and innovations. The concurrent SIAT Expo will help delegates explore the innovative products and services showcased by global OEMs, component manufacturers and suppliers in automotive field.

On the occasion of SIAT 2017, the Organizing Committee is pleased to bring out this Technical Reference Bulletin. This edition of the Bulletin, containing technical articles and advertisements, will enrich the delegates and will serve as a reference for understanding current advances in applied technology.

I am thankful to all the authors for sharing their knowledge and innovations through this Technical Reference Bulletin and also thankful to the OEMs and suppliers for showcasing their products and services through advertisements. Lastly, I acknowledge the perseverance of the team that worked for bringing out this edition and hope SIAT 2017 to be a remarkable and memorable milestone for global community in the pursuit of sustainable mobility and will serve as a reference and cherished event in professional endeavors to all the delegates!

ARAI welcomes all participants of SIAT 2017 and wish them a pleasant stay.

Mrs. Rashmi Urdhwareshe
Chairperson SIAT 2017, Advisory Committee,
Director - ARAI

Smart, Safe & Sustainable Mobility

SIAT

Symposium on International Automotive Technology 2017

SIAT 2017
18-21 January 2017

SIAT EXPO 2017
18-21 January 2017

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EDITORIAL

The recent technological advances in the mobility sector are throwing up new challenges for the human race. While the Automakers are busy tackling these challenges in their own way, the Government too is trying to catch up with them by trying to make automobiles manufacturing the main driver of the 'Make in India' initiative. It also plans to promote eco-friendly cars in the country and has also formulated a Scheme for Faster Adoption and Manufacturing of Electric and Hybrid Vehicles in India, under the National Electric Mobility Mission 2020 to encourage the progressive induction of reliable, affordable and efficient electric and hybrid vehicles in the country.

With this background SIAT 2017 has come up with a theme of "Safe, Smart and Sustainable Mobility". The Technical Reference Bulletin (TRB) being presented is collection of technical articles and case studies which deliberate on the theme of SIAT 2017. This particular issue of the Technical Reference Bulletin is all the more significant since it is being published on the eve of ARAI's Golden Jubilee year.

The articles are broadly categorised as Regulatory Trends, Automotive Safety, Simulation Techniques, Automotive Electronics, Intelligent Transport, Skill Development, Emission, Noise, Vibration & Harshness, Advanced Materials, Advanced Powertrain, Testing & Instrumentation, etc. The collection is work of individual's in their expert domain and future potential areas of necessities. There are 35 technical articles received from experts from various fields of automotive engineering. We sincerely hope that the content of articles would yield interest among the automotive fraternity and would be helpful in their day to day activities.

Our heartfelt thanks are to all the authors for sparing their valuable time to contribute to the technical articles for this bulletin. We acknowledge and appreciate all the organizations for the advertisements representing their products and services.

My sincere thanks are to Chairperson, SIAT 2017 advisory committee, Director ARAI for giving me this opportunity and for her support. I also extend my thanks to A.A. Deshpande, Convenor SIAT 2017 for his cooperation. On behalf of Technical Reference Bulletin Committee, I appreciate and value the contribution put in by ARAI colleagues in bringing this TRB.

I would like to thank the members of Technical Reference Bulletin Committee, who have taken great interest for the tasks involved in shaping this bulletin and express my appreciation for their earnest and conscientious activities, and sincere efforts. We would also like to thank M/s VGA Digital Printers Pvt. Ltd, Pune for their timely service and support in bringing out the TRB.

Mr. Rahul Mahajan
Co-ordinator, SIAT 2017 - TRB Committee
General Manager - ARAI

Editorial Committee

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ARAI VIEW


MOST POWERFUL. MOST CELEBRATED.
OVER 3 MILLION SOLD WORLDWIDE.#
CRUZE
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• Most Powerful Car in its Class - 122.1kW Power*
• MyLink Touchscreen Infotainment System
• Electric Sunroof
CHEVROLET CRUZE
FIND NEW ROADS
CHEVROLET

1966-2016

ARAI

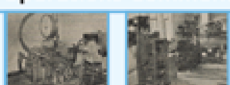
Progress through Research

Journey ... MAKE ...

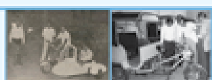
1966
ARAI Foundation

1975
Automotive abstract started

1976
- Component, Vehicle & Engine Testing started
- Operations Commenced



1977
2-Wheeler Side Car & Powered Cycle-Rickshaw developed



1978-80
- 1st Logo
- Auto Electrical Lab
- Material Lab
- Diesel Engine Conference

1982
- Logo redesigned
- Chassis Dynamometer Lab

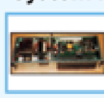
1983
Electric Vehicle development for Handicapped

1985
- First SIAT (Symposium of Indian Automotive Technology)
- IDC development for Mass Emissions Measurement

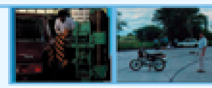
1987-89
- CMVR based Certification commencement
- Patented cumbustion chamber for 2 stroke engine

1990
Fatigue, Emission & Advance Engine Development Facility establishment

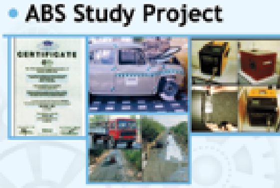
1992
Electronic Engine Management System for Passenger Car



1993
- Automotive Electronics and Safety & Homologation Labs establishment
- Export Homologation Services begin



1996
- Crash Testing & Calibration Labs establishment
- ISO 9001 certified 1st R&D Institute in India
- ABS Study Project



1997
- Logo redesign
- CMVR-TSC & AISC Secretariat setup

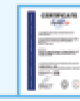
1998
Partner in development of 2 seater series electric hybrid vehicle

1999

NABL (ISO/IEC17025) accrediation initiated

2003
- NVH, CAE Lab & Indigenously made Sled Facility establishment
- Patent for CNG/LPG Technology

2004



- ISO 14001, OHSAS 18001 accredited, IMS deployed
- Loaded mode test methodology for in-use 2-Wheeler testing
- Ganesh Temple

- New Emission La...
- Facility for Drop...

2005
- Regional Ce... Operationa...
- 1st I&C Cen...
- ARAI Acade...
- SAE Interna... Environmen...
- Golden Peac... for Quality
- Barcelona A... Automotive...
- New Logo w...

1970 | 1980 | 1990 | 2000

The Automotive Resea...

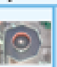
Research Institution of ...
with the Ministry of Heavy Industries...

Celebrating Golden Jubilee

y Towards
IN INDIA

YEARS OF BUILDING AUTOMOTIVE EXCELLENCE
1966 - 2016

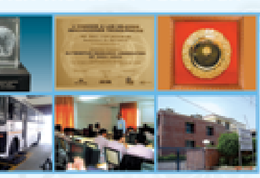
2006
- ab establishment under NATRiP
- o, Pressure & Fire Test



2007
- SIAT 2007 inauguration by then President Hon'ble Dr. A. P. J. Abdul Kalam
- AQM of Pune City
- CISPER EMC Chamber establishment
- RCN transfer to NATRiP

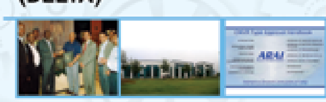
2008
- Nano Particle Emission Study
- Size India Anthropometry Study
- 2D Road Profile Survey

- entre North (RCN)
- l
- tre of India establishment
- my started-25 Students
- ational Award for
- ntal Excellence
- cock National Award
- Award for
- e Innovation
- vith motto of research

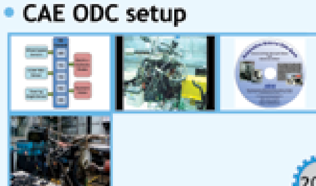


2009
- New Engine Lab establishment under NATRiP
- Study on 10% Ethanol blend of gasoline for emission and material
- Regional Centre South (RCS) Office started
- Korea representative appointment

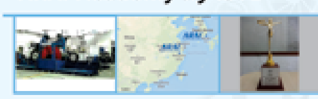
2010
- Benchmark International consulting Project for Nigerian Govt.
- Forging Industry Division attached
- CMVR-TA Handbook interactive CD
- 1st Intl. Conf. on Auto. Material & Manufacturing (AM&M)
- 1st Intl. Engine Development project from concept
- Online e-Type Approval facility (DELTA)



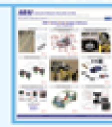
2011
- Duel Fuel Engine
- Material Databank
- Integrated Safety Systems
- Hardware in Loop Capability
- HCNG Engine
- HCCI Engine
- Accredited by LTA & NEA, Singapore
- CAE ODC setup



2012
- Tyre Testing Facility enhanced
- China representative appointment
- Best Learning Centre Award to ARAI Academy by ISTD



2013
- Vehicle Duty Cycle Study
- Appointed by RDW, Netherlands for COP audits



2014
- First indigenous full clutch test rig
- 3D Road Profile Survey
- Forging Research Lab at FID
- Tech. Roadmap commences
  - HEV Technology Development
  - Light Weight Passenger Bus Technology Development

2015
- Another EMC chamber added
- Design guidelines for Light Weight City Bus
- I&C Centre, Nasik establishment
- Gasoline Direct Injection Strategies
- Building of Prototype EV-SCV
- Business Excellence ARAI Model (BEAM) implemented
- EV/HEV testing infrastructure project under FAME started
- 10 years of Academy-200 students, 30+ PIPs per year
- 3 Cyl. CRDi EuroIV Diesel Engine

2016
- Battery Development with ISRO initiated
- ARAI-HTC dedicated to the Nation
- Study on 20% Ethanol Blend
- Light Weight Forging Research Project
- Light Weight Bus Prototype Development
- CSR of ARAI

rch Association of India
the Automotive Industry
s & Public Enterprises, Govt. of India

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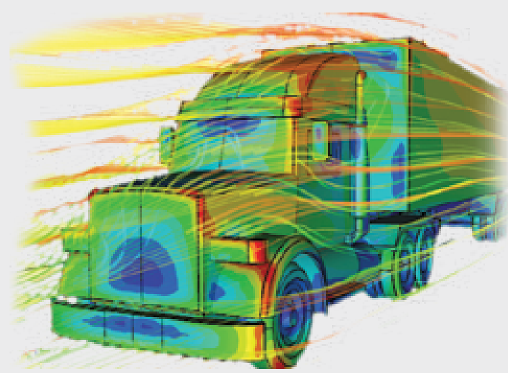

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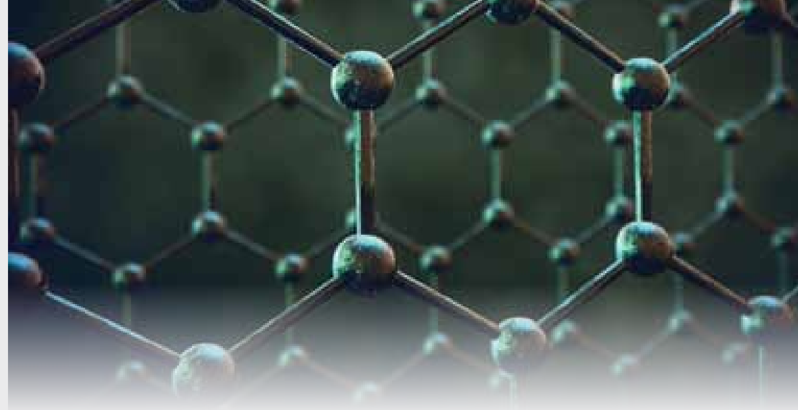

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ABOUT FEV

The FEV Group, with headquarters in Aachen, Germany, is an internationally recognized vehicle development services provider. FEV's expertise ranges from consulting to the development and testing of innovative vehicle concepts all the way up to readiness for serial production. Besides engine and transmission development, vehicle integration, calibration, and the homologation of state-of-the-art gasoline and diesel engines, increasing importance is being placed on the development of hybrid and electric powertrains as well as alternative fuels. The experts also focus on the advancement of electronic control systems, plus continued vehicle networking and automation.

The FEV Testing Solutions product portfolio complements this offering by producing cutting-edge test bench measuring equipment in addition to software solutions that help make development more efficient and transfer significant process steps from the road to the test rig—or even to a computer simulator.

As a global service provider, the company offers these services to its transport industry customers anywhere in the world. The FEV Group employs over 4,000 highly-qualified specialists in high-tech development centers near its customers at 35 locations on four continents.


AUTOMOTIVE
ELECTRONICS

TRB
Technical Reference Bulletin

Comparison of Conventional Lead and Advanced Lead Based Batteries for Low Voltage Mild Hybrid Application in India

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Mahindra & Mahindra Ltd., Chennai, India

INTRODUCTION

Stringent emission norms has led to faster adoption of hybrid electric vehicles. Mild hybrids are a good solution for vehicles where the cost/benefit ratio is highly favourable. A mild hybrid comes with features such as idle stop and start, power boosting and regenerative braking. Start-Stop systems turn off the engine during stops in traffic and afford a saving in fuel. The usual 12 V starters do not have the power to restart the engine without delay, noise, and vibration. With a more powerful electrical motor, the engine rpm can be increased quickly and smoothly up to starting speed, and then the fuel injection systems can be activated. Another important function of mild hybrids is capturing braking energy effectively. The Motor / Generator should have the potential to absorb the kinetic energy of the vehicle during a rapid stop. Mild hybrids (with manual transmissions) have limited regenerative braking potential. However, the battery power and battery energy can be increased to match the growth in Motor/Generator and maximize the regeneration potential. With sufficient energy in the battery and installed M/G providing low speed motor assist or low speed launch assist is possible. In case of a diesel hybrid, the motor can provide cold start of the diesel, fuel cutoff at deceleration, idle shut-off, and other critical functions.

> *Due to lower cost, high safety, production from domestic materials, and totally recyclable, advanced batteries pose as a promising solution for low cost mild hybrids*

To improve the fuel economy, one of the essential considerations is to adopt an energy storage system that is capable of sufficiently supplying and receiving electrical energy. It should cope with high-power discharging and charging operations due to various driving conditions, such as starting, assisting and regenerative braking. In terms of fuel economy, mild hybrids can achieve approximately 5% through start / stop and 10% with regeneration. For a low voltage mild hybrid solution Lead-acid batteries remain a cost effective solution although most of the hybrids available in the market are at predominantly higher voltage levels and use Li-ion and NiMH batteries.

Lead acid batteries are highly reliable for automotive applications and are capable of high discharge rates. In terms of technology, they are mature and inexpensive (low cost per watt hour) and are simple to manufacture. Apart from these, they have an edge over other rechargeable battery systems on low maintenance requirements and recycling chain. Despite these advantages, Lead-acid batteries have a low energy density i.e. low energy to weight ratio and are slower to recharge when compared to other battery types. They allow only a limited number of full discharge cycles and have a small window for PSoC cycling. They form deposits on the negative electrodes which hinder their performance and life over time. Positive

Grid corrosion, Positive Active Material shedding, poor dynamic charge acceptance are also the major shortfalls of lead batteries which lead to rapid degradation and shorter life. The formation of deposits infuriate under the operating conditions which cycle at a high charge and discharge currents while remaining in a partially charged state (HRPSoC).

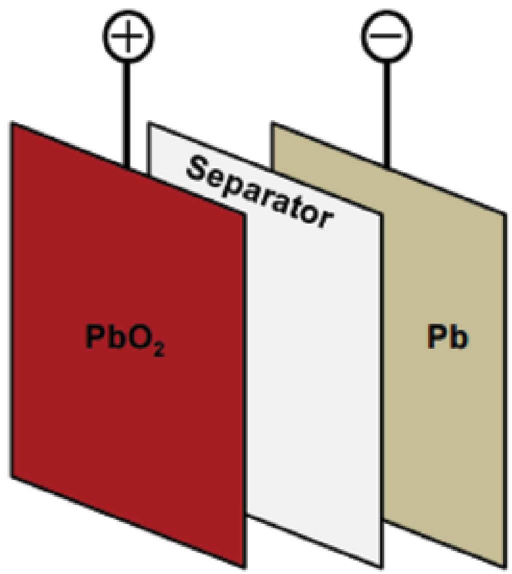

Figure 1 : Lead Acid Cell

DRIVE CYCLE DERIVED FOR A MILD HYBRID VEHICLE

The drive cycle represented by the battery current shown in Fig. 2 is a simplified derivation from real world observations. In real world there may be further deviations due to driver behaviour, vehicle state and overall traffic. It has continuous charge and discharge cycles comprising of crank (engine start), alternator / generator for battery charging, engine assisting, supplying board-net and regeneration. In city drive, the average vehicle velocity dictates the ability of the battery to optimize usage of hybrid modes. In highway, there is a high probability of a battery getting charged very fast. The major downside of using conventional lead acid batteries is that the expected charge acceptance is poor which leads to rapid degradation and short life.

FAILURE MODES IN LEAD ACID BATTERIES/ CHALLENGES FACED

The challenges faced in a mild hybrid vehicle when using standard lead acid batteries are frequent cycling causing faster degradation of material and capacity loss especially since it is operating in partial state of charge and design

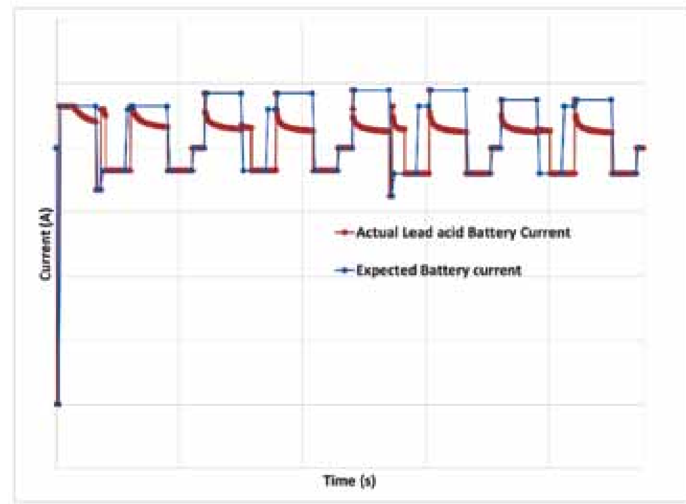

Figure 2 : Drive Cycle Derived for a Mild Hybrid Vehicle

boundaries are beyond the scope for this application. The temperature of the battery increases rapidly due to frequent discharge cycles and this could lead to rapid aging or degradation (so proper ventilation scheme may be required). The acceptance of charge in lead batteries is mainly dependent on temperature and state of charge of the battery. Often it is observed that the batteries do not accept rapid high charge power at regenerative events where maximum power is available to absorb. Temperature, set point voltage and C rates are important factors which affect the amount of energy going in and out of the system. And these factors play a key role in determining the state of charge of the battery system which is an extremely critical parameter. Proper battery management system is required to monitor these critical parameters and ensure the battery is always in safe operating zone and gives its best performance resulting in better fuel economy.

ADVANCED LEAD BATTERIES

To overcome the major hurdles / issues faced while adopting conventional lead batteries, several researches are carried out on battery chemistries and have resulted in the new and improved advanced lead batteries. Addition of carbon to traditional lead acid batteries in the negative plates has resulted in improvements in battery performance under high-rate partial-state-of-charge (HRPSoC) operation, increased charge power and charge acceptance and improved cycle life. The carbon-modified lead battery is termed as “Advanced” VRLA battery by East Penn Manufacturing.

The battery available capacity has been found to increase on cycling and the increase in capacity observed in standard battery is the result of recovery charging procedure.

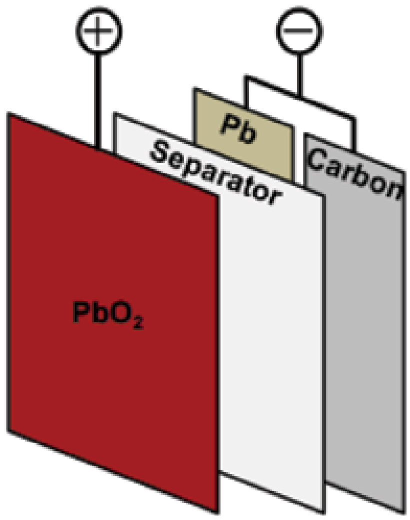

Figure 3 : Schematic Representation of a Single Cell for an "Advanced" Lead Acid Battery

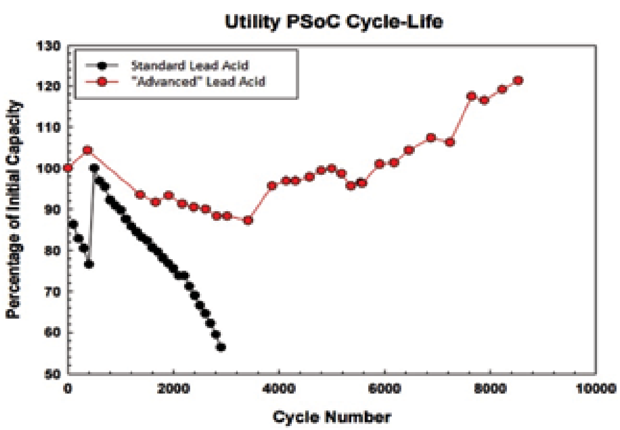

Figure 4 : Capacity as a Function of Cycle Life (Source : Sandia Report SAND2011-8263)

Advanced lead batteries improve cycle life dramatically and require minimal modification in existing industrial-scale manufacturing processes. They offer a potential low-cost, high performance energy storage solution for mild hybrid applications. In a typical NEDC cycle, it was observed that the amount of charge acceptance is significantly higher for advanced lead batteries especially during coasting and recuperation events. This leads to substantially higher energy balance. The Fig. 5 & 6 show the increase in charge current and in turn SOC for an advanced battery when compared to that of a conventional lead acid battery.

Charge Acceptance Test were done on a mild hybrid vehicle while in generation / alternator charging mode. If "X" is the average charging current seen in conventional lead battery for 60s of charging, the below table shows that advanced lead batteries are far superior in charge acceptance when compared to conventional lead batteries.

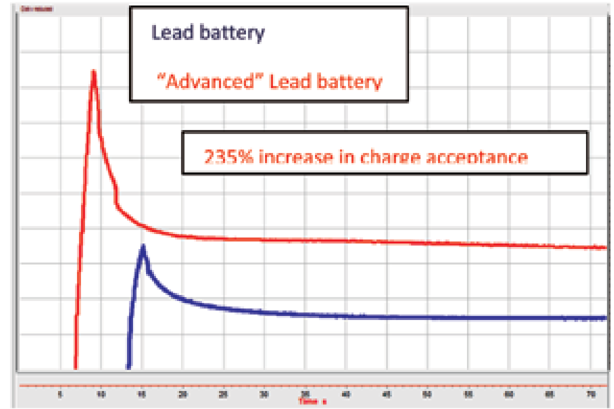

Figure 5 : Battery Charging Currents during Generator Mode in Advanced Lead and Conventional Lead Batteries

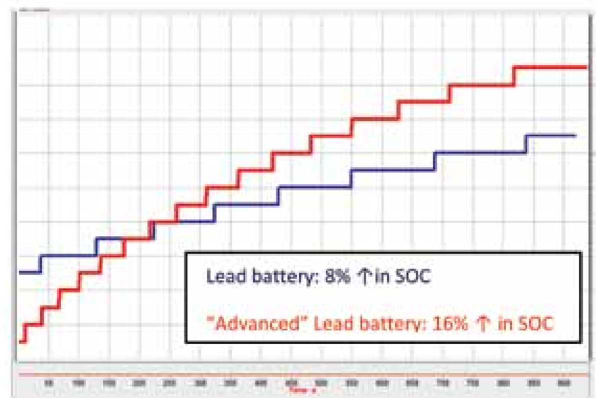

Figure 6 : State of Charge Vs Charging Time

Table 1 : Lead Acid Vs Advanced Lead Acid

Charge Acceptance	Lead Acid	Advanced Lead acid
Peak current (regeneration)	2.25*X	5.15*X
10s Average current (coasting)	1.35*X	3.05*X
60s Average current (alternator charging)	"X"	2.35*X

SUMMARY

The new generation of advanced Lead based batteries show improvements in terms of battery performance under high-rate partial-state-of-charge (HRPSoC) operation and longer cycle life, as well as increased charge power and charge acceptance. The advanced batteries for micro / mild hybrids are as good as other advanced chemistries and have long enough cycle life at HRPSoC cycling. Due to lower cost, high safety, production from domestic materials, and totally recyclable, advanced batteries pose as a promising solution for low cost mild hybrids.

Comprehensive HEV / EV Solution Covering Full HEV/EV Drive System

Tushar Sambharam, Ashok Khondge
ANSYS Inc., India

Tushar Sambharam
tushar.sambharam@ansys.com

INTRODUCTION

The concerns over climate change have grown significantly in last several years. World leaders are forced to look into ways to reduce greenhouse gas emissions as part of Paris agreement. We are witnessing great momentum in promotion and adoption of electric mobility in India. Government of India has been actively collaborating with industry to develop the technology and infrastructure required for adoption of Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs). Government of India has launched FAME (Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India) as a part of National Electric Mobility Mission Plan 2020. The government is planning to allocate Rs.750 crores for year 2015-16 and 2016-17 for technology development, adoption and promotion and the development of infrastructure.

Clearly, the development of electric mobility is at forefront and automotive engineers are faced with challenges of developing a technology in quick time that is cost effective and reliable. The EV/HEV powertrain development does not have any legacy of experience similar to conventional powertrain. The conventional powertrain has evolved over more than 100 years of trials and incremental improvements. EV/HEV powertrain does not have any historical data to rely on and automotive engineers are challenged with designing new electric powertrain technologies almost entirely from scratch. The effective implementation of numerical simulation can help automotive engineers developing EV/HEV powertrain technologies in cost effective and reliable manner.

Numerical simulation has been historically applied to individual components to study either electrical/mechanical or thermal performances. However, studying individual physics in silos is not enough to predict real life conditions. Further, performance study of individual component is not accurate as it gets affected by how and where it is connected in a system. Thus an adopted simulation technology should provide (a) Breadth of Physics: To accurately predict reliability of the components with due consideration to all physics involved and their interactions (b) Scalability: To be able to take the model of the designed components and place it in a subsystem or system for performance evaluation.

Key components in the design of electric drive train are battery (cell and pack), electric traction motor/ generator and Power electronics. The design of these HEV components involves complex physical problems and an enormous amount of challenging system integration. Below, the challenges in development of individual components are discussed as well as relevant considerations of electromagnetics EMC/EMI.

“*The design of these HEV components involves complex physical problems and an enormous amount of challenging system integration*”

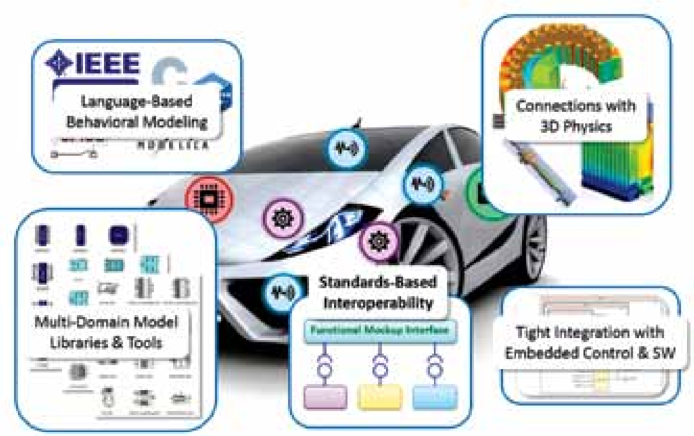

Figure 1 : HEV/EV Vehicle System

BATTERY

Battery pack of an EV/HEV powertrain needs to store large amount of energy needed for the primary drive and auxiliary systems. This requires EV/HEV battery pack to provide order of magnitude more energy than batteries used in conventional vehicles. One of the focus research area is to increase the capacity of the battery cells while reducing the space taken by the overall pack. However, with increase in energy densities, thermal management becomes extremely critical from the safety and performance perspective. At the same time, as large amount of energy being stored on-board, it is essential to study the reliability of the pack assembly under all eventualities such as different drive conditions, external heating, car crash, over-charging, over discharging etc.

Electrochemistry modelling using a 3D CFD simulation can help engineers to arrive at an appropriate design of the battery cell that can deliver the required performance. CFD simulation can also be used to arrive at optimal cooling system to meet the thermal constraints. A structural integrity analysis on the full assembly can help to predict the possibility of toxic contents of battery spilling out and causing thermal run-away process or explosion. A parametric/optimization analysis can be done at all above stages to optimize the size or placement of the battery back while staying with the bounds to the performance.

TRACTION MOTOR / GENERATOR

For years, automakers invested relatively little time and money in electric machine (that is, the electric traction motor/generator) design because the internal combustion engine was so widely used. These conventional engines accomplished what they needed to: Consumer requirements were met, emissions regulations were not as stringent, and oil prices were not a concern. Today all that has changed, with a huge amount of interest in new motors and a correspondingly huge pressure on companies to develop the most efficient, cost-effective electric design.

General purpose motors are designed to give best performance at a particular speed as they operated more or less at a fixed speed. However, automotive traction applications demand the motor performance to be good on a wide range of speeds. Thus optimization of motor needs to ensure the efficiency and power gain on the overall operating range of the machine. At the same time electric machines have to operate under harsh operating conditions such as extreme hot and cold temperatures, severe vibrations, harsh duty cycles and rough road conditions.

Simulation in electric machine design can be applied from very early concept level to final prototype level. An analytical design of electric machine can be developed at the early stages for quick rejection or reduction of design space. A detailed FEA simulation can be carried out to study performance of the machines with high level of accuracy. Advanced analysis techniques can be applied to determine outputs such as machine torque at various speeds, efficiency map of the machine on overall operating range of the machine as well as optimization

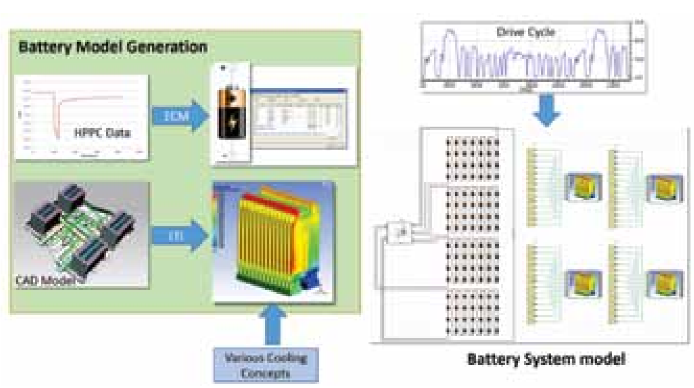

Figure 2 : HEV/EV Battery Pack Simulation Workflow

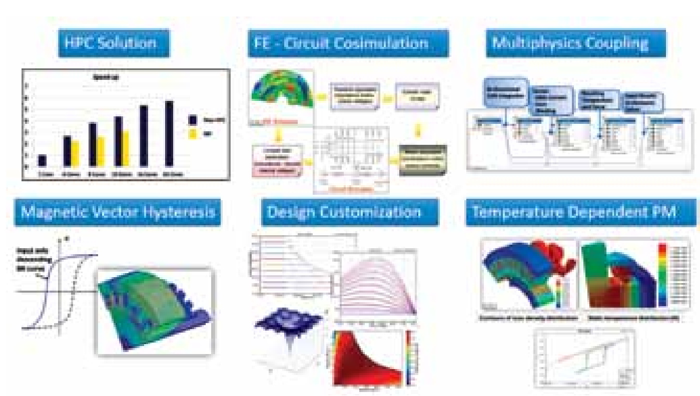

Figure 3 : Traction Motor Design Overview

of the control techniques of the motor and its impact on overall performance.

Electromagnetic simulation can then be tied up with structural and thermal simulations where electromagnetics serves as a source for these simulations to predict thermal and structural reliability and noise resulting from the machine while at the same time checking impact of this on overall machine performance.

POWER ELECTRONICS

Power electronics is responsible for controlling power drawn from battery and supplied to the motor. It judges the power requirements of motor based on a feedback taken from machine for speed, position, temperature etc. A correct implementation of this control loop is essential to achieve maximum efficiency at all speeds and thus longer operation of battery charge. The switching devices that are part of power electronics such as IGBT (Insulated Gate Bipolar Transistors) needs to be designed to take up large amount of power while switching ON and OFF at high frequency. Thermal management of these devices is a challenge as their performance can deteriorate rapidly with temperature. Due to high speed switching, electromagnetic interference and compatibility (EMI/EMC) issues can create significant problems in the design of these devices. If unaccounted, EMI can destroy control signals and prohibit motor from operating.

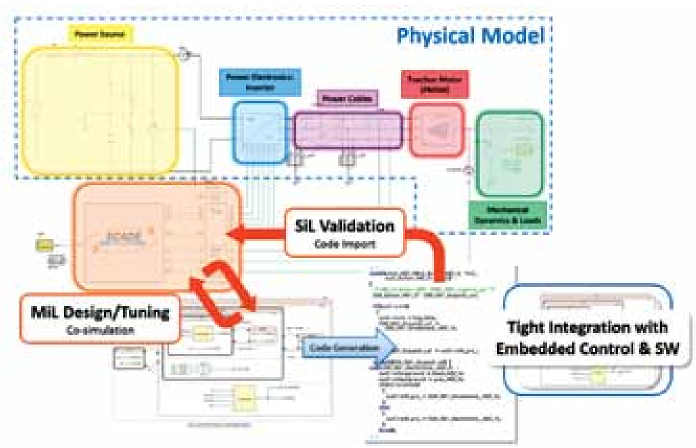

Figure 4 : Motor Controller with Power Electronics

Thermal impact on IGBT can be considered by accurate modelling of IGBTs in circuit simulation. The characterization of IGBTs allows specifying performance characteristics at different operating temperatures. A 3D CFD analysis of IGBT pack together with heat sink and cooling channels can be processed through a parametric analysis to arrive at a Linear Time Invariant (LTI) thermal model of the IGBTs. The electrical characterized model together with thermal model can be used to determine temperature dependent performance variables. The thermal data can also be used to perform thermal-structural analysis in FEA to determine thermal stresses. The characterization of IGBT can also be used to determine conducted emissions resulting from switching. At the same time, a CAD model of power inverter can be taken to the electromagnetic field solver to determine radiation patterns and field intensity at different locations. Using these simulations, both conducted as well as radiated emissions can be traced to the source.

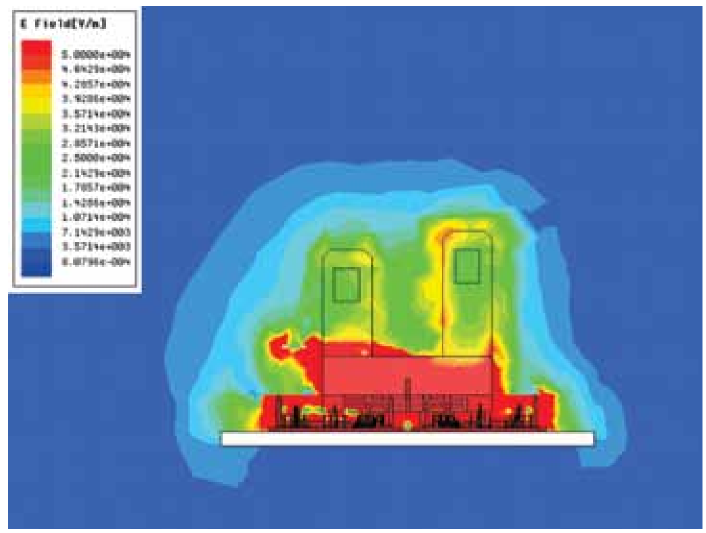

Figure 5 : EMI/EMC of IGBT

SYSTEM INTEGRATION

While the study of individual components gives insights into their performance, the real performance of the components has to be studied in a system environment as the interconnection between different components can adversely affect their performance. For example,

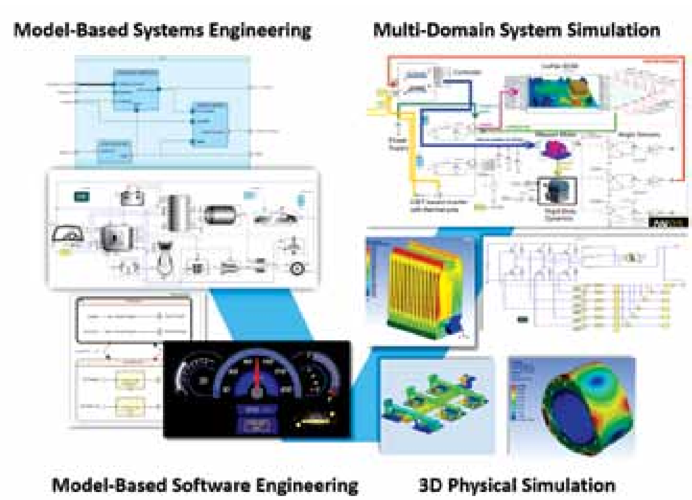

Figure 6 : System Modeling Approach

the amount of power drawn for motor depends on the efficiency of the machine as well as accuracy of the control algorithm. The inefficiencies in these components can adversely affect the temperatures of the battery pack.

It is essential to bring together models of different components from different domains and to be able to connect them together to form a sub system and full system. A system developed in such a way can predict if the components can work together in a coherent and tightly coupled way to attain highest overall efficiency with a wide range of loading or operating conditions.

SUMMARY

The design of EV/HEV powertrain requires addressing design challenges arising from complex interactions of different physics as well as inter-connectivity of different components of a subsystem/system. The design challenges can be appropriately addressed by adoption of a simulation technology that is multidisciplinary and scalable. The effective use of simulation can help to arrive at a design that is reliable, efficient and cost effective with shorter design cycles and reduced time to market.

TRB
Technical Reference Bulletin

ESP® – Electronic Stability Control for India

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INTRODUCTION AND MOTIVATION

Human error is the cause for a large portion of road accidents. Due to external circumstances, such as an obstacle suddenly appearing on the road or driving at inappropriately high speeds, the vehicle can reach its critical limits and it becomes uncontrollable. The lateral acceleration forces acting on the vehicle reach values that overtax the driver. Electronic systems can make a major contribution towards increasing driving safety.

The Electronic Stability Program (ESP®) is a closed-loop system designed to improve vehicle handling and braking through programmed intervention in the braking system and/or drivetrain. The integrated functionality of the ABS prevents the wheels from locking when the brakes are applied, while TCS inhibits wheel spin during acceleration. In its role as an overall system, ESP® applies a unified, synergistic concept to control the vehicle's tendency to "plow" instead of obeying the helm during attempted steering corrections; and at the same time it maintains stability to prevent the vehicle breaking away to the side, provided the vehicle remains within its physical limits.

STATE OF THE ART

In 1995 Bosch was the first supplier to introduce electronic stability control (ESC) for the Mercedes-Benz S-Class. Since then, Bosch has produced more than 10 million systems worldwide which are marketed as ESP® - Electronic Stability Program.

A study performed by the University of Iowa at the National Advanced Driving Simulator showed a strong impact of ESP® on vehicle stability. The primary question was "Does the presence of an ESP® system aid the driver in maintaining control of the vehicle in critical situations? Based on all analyses completed there was a 24.5 percentage point reduction between situations in which the drivers lost control with the system present and situations without ESP®. This constitutes an 88% reduction in loss of control. Based on the study results it was concluded that there is significant and meaningful safety benefit associated with driving a vehicle equipped with an ESP® system.

"Based on the study results it was concluded that there is significant and meaningful safety benefit associated with driving a vehicle equipped with an ESP® system"

Based on their accidentology by Volkswagen (VW), ESP® is considered to avoid 80% of the accidents caused by skidding. VW concludes that the safety benefit of ESP® is even greater than that of the Airbag. According to VW a 100% installation rate would result in Germany in a 20% reduction of road fatalities and this even with an ESP® installation rate of already 53% in 2003.

Toyota estimated that the accident rate of vehicles with ESP® for more severe accidents is approximately reduced by 50% for single car accidents and reduced by 40% for head on collisions with other automobiles. The casualty rate of vehicles with ESP® showed an approximately 35% reduction for both types of accidents.

Real world accidents of vehicles with and without ESP® were compared (with control methods). Confidence intervals are very large suggesting that either sample sizes are small or there is a large variation of the population. Subject to this concern, overall effectiveness (in stability related accidents) was found to be 22%. On wet roads it was 32% and on icy roads it was 38%. Loss of control is a factor in 18% of all accidents and 34% of all fatal accidents. Hence ESP® is judged to reduce all accidents by 4% and fatal accidents by 7%.

Analysis of accident databases to estimate effectiveness of electronic stability programs (ESP®): It is estimated that 60% of skidding accidents involve excessive steering input by the driver. These cases could be influenced by ESP®. Between 20% and 25% of all German car accidents involve skidding. Therefore about 12% could be influenced by ESP®. This suggest similar findings to Sweden – ESP® could prevent about 5% of all car accidents. A reduction of up to 9% in truck accidents is possible.

GLOBAL STUDIES OF ESP® EFFECTIVENESS

There are various studies done on the effectiveness of ESC and all studies are based on different approaches and databases, to list few are below

- 1998 RESIKO study GDV (German insurers): 28% of all accidents involve loss of control by the driver. 60% of all fatal accidents involve sideways skidding
- 2002 Swedish National Road Administration: All accidents (except rear-end impacts on dry roads) reduced by 22%
- 2002 Daimler-Chrysler: Single vehicle loss-of-control accidents reduced by 42%
- 2003 Toyota: Severe single vehicle accidents reduced by 50%
- 2004 Volkswagen: Fatalities reduced by 35%
- 2004 Ford (Europe): Single vehicle accidents reduced by 13-35%, depending on accident scenario.
- 2004 University of Iowa driving simulator research: 34% improvement in maintaining control of the vehicle.
- 2004 NHTSA: Single vehicle accidents for cars reduced by 35%. Single vehicle accidents for SUVs reduced by 67%
- 2004 IIHS: Single vehicle accidents reduced by 41%. Fatal single vehicle accidents reduced by 56%
- 2004 LAB (Laboratoire d'Accidentologie, de Biomécanique Renault and PSA): Single vehicle loss-of-control accidents reduced by 44%
- National Agency for Automotive Safety and Victim's Aid (Japan) Single vehicle accidents - 44%, Severe accidents - 62%

The results of the ESP® studies show remarkable safety benefits across the globe. There is no such study published yet in India based on Indian roads and driving behavior, this present paper describes loss of control accidents and the effectives of ESP® for India. It is also important to note that ESP® cannot prevent all accidents or adjust for all driver errors. ESP® helps in mitigating the loss of control accidents.

ESP® - WORKING PRINCIPLE

The electronic stability program is a system that relies on the vehicle's braking system as a tool for "steering" the vehicle. When the stability-control function assumes operation it shifts the priorities that govern the brake system. The basic function of the wheel brakes – to decelerate and/or stop the vehicle – assumes secondary importance as ESP® intervenes to keep the vehicle stable and on course, regardless of the conditions.

Specific braking intervention is directed at individual wheels, such as the inner rear wheel to counter understeer, or the outer front wheel during oversteer, as shown in Fig. 2. For optimal implementation of stability objectives, ESP® not only initiates braking intervention, but it can also intervene on the engine side to accelerate the driven wheels. Because this "discriminatory" control concept relies on two individual intervention strategies, the system has two options for steering the vehicle: it can brake selected wheels (selective braking) or indirect accelerate the driven wheels. Within the invariable limits imposed by the laws of physics, ESP® keeps the vehicle on the road and reduces the risk of accident and overturning. The system enhances road safety by furnishing the driver with effective support.

Below are examples comparing vehicles with and without ESP® during operation "on the limit". The driving maneuvers reflects actual operating conditions, and is based on simulation programs designed using data from vehicle testing. The results have been confirmed in subsequent road tests.

MG Yaw moment, FR Wheel forces, β Directional deviation from vehicle's longitudinal axis (side-slip angle)

The Fig. 1 is the typical maneuver by the driver of the passenger car to drive through the curve and the series of dynamic response without ESP® etc. to the driver input is as follows:

1. Driver steers, lateral force buildup in the car
2. Incipient instability because side-slip angle is too large
3. Counter steer, driver loses control of car
4. Car becomes uncontrollable

The car is uncontrollable and off the track due to oversteering, this can be corrected by the ESP® system which keeps the vehicle on track and improves directional stability under all operating conditions, furthermore these dynamics of loss of control is clearly explained with the real world accident case in this paper.

MG Yaw moment, FR Wheel forces, β Directional deviation from vehicle's longitudinal axis (side-slip angle).

As Shown in Fig. 2 the loss of control due to oversteer can be mitigated by ESP® systemand the series of dynamic response with ESP® to the driver input is as follows:

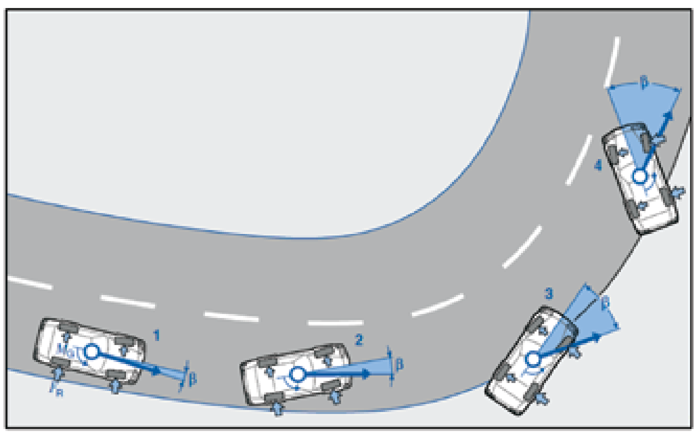

Figure 1 : Lateral Dynamic ESP® Response on Passenger Car without ESP®

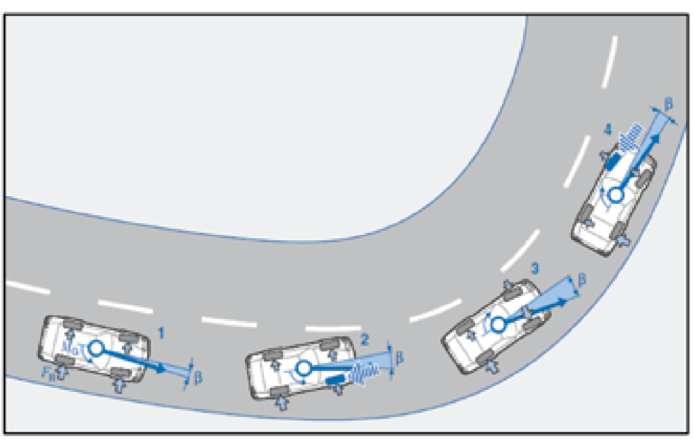

Figure 2 : Lateral Dynamic Response on Passenger Car with ESP®

1. Driver steers, lateral force buildup
2. Incipient instability, ESP® intervention at right front
3. Vehicle remains under control
4. Incipient instability, ESP® intervention at left front, complete stabilization

The car is controllable and on the track, the oversteering is corrected by the ESP® system which keeps the vehicle on track by braking intervention at right front wheel. In case of incipient instability, ESP® intervention at left front achieves complete stabilization there by improving directional stability under all operating conditions.

ESP® enhances driving safety by providing the following assets:

- Enhanced vehicle stability; the system keeps the vehicle on track and improves directional stability under all operating conditions, including emergency stops, standard braking maneuvers, coasting, acceleration, trailing throttle (overrun), and load shift
- Increased vehicle stability at the limits of traction, such as during sharp steering maneuvers (panic response), to reduce the danger of skidding or breakaway
- In a variety of different situations, further improvements in the exploitation of traction potential when ABS and TCS come into action, and when engine drag torque control is active, by automatically increasing engine speed to inhibit excessive engine braking. The ultimate effects are shorter braking distances and greater traction along with enhanced stability and higher levels of steering response

Further information detailed description of ESP® components, functions and dynamics is well explained by the author Van Zanten in SAE paper.

METHODOLOGY

The current study is aimed to give an overview about loss of control car accidents on Indian Highways and estimation of ESP® benefit. The analysis is based on 993 cases from Road Accident Sampling System India (RASSI- data sets till Aug 2015). A total of 470 accidents involving car were analysed for the benefit of ESP®. The ESP® accident avoidance potential was estimated afterwards based on single case analysis using the evidence and the coded variables from the data collected from on spot accident scene. At first the accident situation is analysed using the type of accident to determine the most conflict situations in which cars involved in accidents. The type of accident describes the conflict situation leading to the collision, thus this parameter is used to identify the loss of control accidents.

Many of the serious accidents happen through loss of control in critical driving situations. When the vehicle goes into a skid, either by oversteering (Fig. 3 : Vehicle is spinning rear axle of the vehicle is sliding towards the outside of the curve). Yaw velocity is too large) or understeering (Fig. 4) the front axle of the vehicle slides towards the outside of the curve, Yaw velocity is too small).

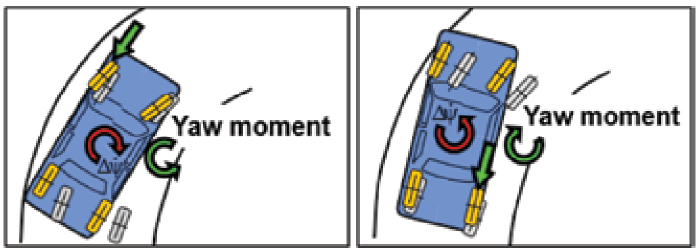

Figure 3 : Oversteering *Figure 4 : Understeering*

Especially with vehicles of an elevated center of gravity like sport utility vehicles (SUV) and light trucks (LT) the loss of control with subsequent skidding may even lead to a rollover. The severity of rollover accidents is extremely high.

To determine the loss of control accidents, all accidents involving cars with loss of control due to skidding before collision and rollover (No collision with any opponent – before collision) were selected. The above cases can be identified by close examination of accident scaled sketches and pictures taken during the on-spot investigation also from the type of accidents.

In parallel for each accident its relevance for a passenger car ESP® was proofed. This was done by excluding accident scenarios whereas a benefit from this safety system is not given or where other root causes were identified – these are as follows:

All accidents involving cars with loss of control due to

- Tire burst or blow out tire (before loss of control)
- Driver distraction due to sleep (driver did not wake up prior to loss of control)
- Sudden physical disability

Thus the Field of effect for the ESP® is defined as "All relevant car accidents whereas ESP® intervention possible". Linking underreporting comparison Police and RASSI documented accidents on Indian highways - SH/NH to estimate the realistic unbiased value. Later extrapolation of RASSI sub sample to accident situation in India based on official accident statistic (MORTH) was done. Finally mapping of underreporting on SH/NH to India and the benefit of ESP® relevant accidents, fatalities & injured persons is projected to Indian highways.

All, the accidents in the RASSI database can be classified by the type of accident, which describes the conflict situation which resulted in the accident. Hence it is the first step to identify root causes of accidents during pre-crash phase. Every accident within the RASSI database is classified by different types of accident which is defined in an accident classification system.

As shown in Fig. 5, highest shares (39%) of accidents on Indian highways with passenger car involvement are accidents in lateral traffic; nearly 13% of the accidents are driving accidents and the major cause is loss of control.

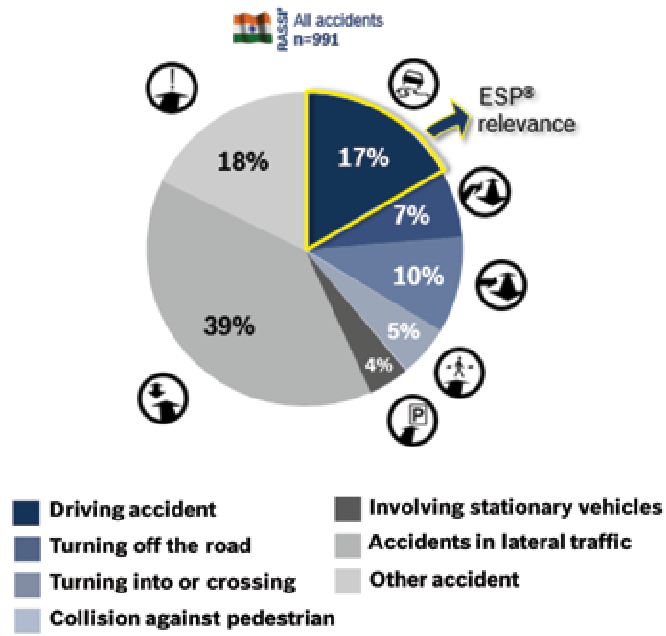

Figure 5 : Accidents with Casualties by Type of Accident

LOSS OF CONTROL ACCIDENT SITUATION INVOLVING CARS

The most critical situations encountered with car involving accidents in loss of control prior to crash are during Type 1 : Driving Accident - A driving accident occurred when the driver lost control over his vehicle because he chose the wrong speed according to the run of the road, the road profile, the road gradient or because he realized the run of the road or a change in profile too late. Driving accidents are not always single vehicle accidents where the vehicle leaves the road. A driving accident can also lead to a collision with other road users.

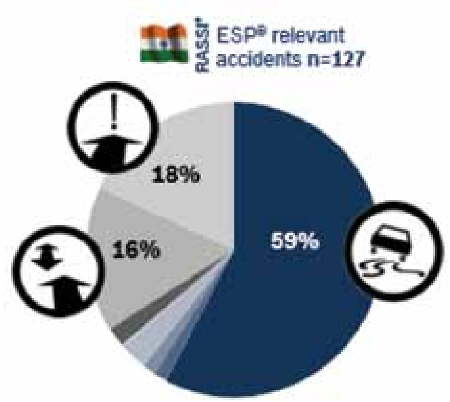

Figure 6 : Loss of Control – ESP® Relevant Accidents with Casualties by Type of Accident

The driving accidents contribute nearly 59% of all loss of control accidents, followed by 18% accidents by other accident, which involves sleep and drowsiness, turning around, backing up, accidents between two parking vehicles, objects or animals on the road, sudden vehicle defects. Nearly 16% are due to improper overtaking on undivided roads, accidents due to turning into or crossing the road, accident caused due to turning off the road, accidents due to head on encounters due to improper usage of lanes on an undivided roads and accidents encounter front rear impacts on the same lane of the road.

Benefit estimation of ESP® – Extrapolation for India analysis of RASSI database with the total sample size of 991 all cases were considered. This is considered as 100% sample size for the present study. The first level of filtering of relevant accidents for passenger car involvement and loss of control. The single case was schematically analysed for evidence of loss of control and the data from reconstruction is also used to filter the specific skidding cases, these are obtained by accident description, pictures, scene diagram. Nearly 47% of the all RASSI cases one way or the other cars were involved. With the next level of filtering we found closed to 13% of the cases were skid due to oversteer or understeer. The next was to identify the police reported and underreported cases, this was majorly done by comparison of Police and RASSI documented accidents on SH/NH.

SUMMARY AND OUTLOOK

Currently in India ESP® is an option and not OE fitted as standard, this led to limited availability of data to see the direct benefit of cars fitted with ESP® as standard fitment.

Nearly 25,000 occupants inside car died in car accidents in India alone, this constitutes 17% of all fatalities are from passenger cars involved accidents in India for the year 2015.

Loss of control on straight roads, Falling asleep (panic wakeup) and overtaking situation are main initial situations. Only a minor share occur during bad weather or street conditions. Every second relevant accident characterized with object collision or with vehicle leaving carriageway. A high Accidents in lateral traffic Driving accident Turning off the road Turning into or crossing Collision against pedestrian Involving stationary vehicles Other accident underreporting of relevant loss of control accidents is determined.

The benefit of ESP® in India will be published in detail in the upcoming publications. It is recommended to validate the results of these analyses by further studies on a larger scale to confirm the results of this study considering the national database including rural and urban accident data.

■■■

MISRA : An Overview

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Programming Research

INTRODUCTION

In the early 1990s it became obvious that electronics were becoming increasingly important in cars, and that software was becoming increasingly important in electronics. With this recognition came another understanding - that software reliability was an absolute imperative for both commercial and safety reasons. Today that challenge is even greater as the amount of software within a car can now extend to as much as 100 million lines of code.

> *MISRA is a very sound coding guideline that is widely adopted by developers implementing safety critical designs across a wide variety of industries and applications*

MISRA (the Motor Industry Software Reliability Association) is a consortium formed from representatives of different companies working in the automotive industry. It was set up initially with some UK government backing, to look at the challenges posed by the increasing use of software in motor vehicles and to provide guidance on how embedded software should be developed. A steady stream of documents has been published addressing various aspects of software engineering. One of the first, produced in 1994, was entitled “Development Guidelines for Vehicle Based Software”, an automotive-specific interpretation of the then emerging IEC 61508 standard, “Functional Safety of Electrical / Electronic / Programmable Electronic Safety-related Systems”. This document was effectively superseded with the recent publication of the ISO 26262 standard, Road Vehicles, Functional Safety.

After the funded project ended, work continued on a number of fronts but perhaps most significantly in the development of coding standards. Working groups were established and, over the years, have published a series of documents containing guidelines to address some of the problems inherent in the C and C++ languages.

C AND C++

C and C++ are by some distance the most widely used languages for embedded software development. (Recent research by VDC shows C being used by 70% of the embedded systems companies surveyed and its derivative, C++, in 42% .) C has been implemented for virtually every processor. It provides a wide range of resources and libraries, is supported by a wide range of tools, and there is a plentiful pool of developers.

C was designed as a small, high level language to replace assembler. It has since evolved to become an application language, but its suitability for use in safety-critical environments was never a primary consideration. A C program which compiles and conforms fully to the requirements of the ISO language standard may still include code which will exhibit completely unpredictable behaviour - this is clearly unacceptable in an application such as a car braking system! The dangers can be substantially reduced by applying restrictions to the way in which the language is used and this has been the essential aim of the MISRA coding guidelines.

CODING STANDARDS

In their simplest form, coding standards are often created as a way of defining a set of consistent coding practices. Although uniformity of style can be a valuable discipline within a software project, such issues are frequently a matter of personal preference. They do not address the important attributes of software quality such as reliability, portability or maintainability. A more fundamental role of coding standards is to define a safer sub-set of the programming language by framing a set of rules which eliminate coding constructs known to be hazardous.

The C language allows the developer to do many things which are essentially incorrect. It is all too easy to write code which conforms to the requirements of the language standard but which will result in either program failure (i.e. a crash) or in undefined behaviour. Common examples might be code which results in accessing memory outside the bounds of an array or an arithmetic operation which results in integer overflow.

Clearly it is of paramount importance to identify such 'bugs'. Some may be identified by a compiler although a dedicated static analysis tool will generally be far more effective. However the primary aim of coding rules is not generally the identification of such problems but prevention. Rules which admonish the developer not to make obvious "mistakes" are usually unhelpful and may even provoke derision! The fundamental aim of a coding rule should be to restrict use of the language so as to prevent the developer from doing things which are either intrinsically 'wrong' or potentially dangerous. For example, it is possible in the C language to declare and define functions in two different ways. The 'old' (Kernighan and Ritchie) syntax which was a feature of early versions of the language is still supported but has now been superseded by 'function prototype' syntax. The use of K&R syntax is prohibited in MISRA-C simply because it can so easily be misused and introduce bugs. Many software defects can be avoided simply by adopting some sensible restrictions on language use.

THE MISRA CODING GUIDELINES

The MISRA coding guidelines are now accepted world-wide as the benchmarks for developing safety-critical software in C and C++. They have been widely accepted because they are concise and readable and because they focus on essential issues.

Each document contains a set of coding rules, but the rules are preceded by several chapters of background information that are just as important to anyone who would like to develop robust code. The guidelines emphasize that adherence to coding rules is just one ingredient in a successful software development process. Any programming project has to be integrated into a disciplined engineering environment, with a documented development process and the use of appropriate compilers and validation tools.

MISRA C : 1998

The first set of coding guidelines published by MISRA appeared in 1998. Two MISRA members, Ford and Rover, had asked PRQA to help them to create their own coding standards. This work formed the basis for what became the first edition of MISRA C: "Guidelines for the Use of the C Language in Vehicle Based Software". This version contained 127 coding rules and it made an immediate impact. Some 13 years later, it is still being used in the maintenance of many legacy systems.

MISRA C : 2004

As MISRA C became widely adopted, areas were identified where it needed to be improved and clarified. A new version was published in 2004. It was structured rather differently and contained a few additional rules but preserved the essential flavour of the original version. Significantly, the modified title referred to "critical systems" rather than just "vehicle based software" - reflecting the fact that MISRA C was now widely used outside the motor industry.

MISRA C++ : 2008

While C remains the dominant programming language in safety critical systems, there has been a steady increase in the use of C++. In response to popular demand, a new working group was established and MISRA C++ appeared in 2008. C++ is a much more complex language than C and has a range of additional issues which require a larger set of 228 rules.

MISRA AUTOCODE

One of the growth areas in systems development is the use of modelling tools. Automatically generating code from a model is a process that is fast and flexible, especially when it comes to incorporating changes later in the product development cycle.

The application of coding guidelines in the context of automatically generated code can be a source of confusion.

Rules developed for manual code development are not always appropriate for auto generated code. MISRA has therefore published additional guidelines which address the issue of how the MISRA-C:2004 rules should be applied in a code generation tool.

However, the quality of auto generated code is not the sole responsibility of the code generation tool. It may also reflect the design of the model from which the code has been generated, and so a number of documents have also been published which provide design and style guidelines in the application of modelling languages such as Simulink and Targetlink.

MISRA AC is now a few years old and far removed from the current version of the tools offered by its vendors. This document has been deprecated and no longer supported by MISRA from 1 June 2014. MISRA AC AGC will remain available and supported for legacy users of MISRA C:2004. It should be noted that the current version MISRA C:2012 integrates requirement for automatically-generated C code.

MISRA C : 2012 MORE COMMONLY KNOWN AS MISRA C3

MISRA C : 2012 was first published in April 2013 and marks a further step forward in the development of the MISRA C Guidelines. After 14 years of experience drawn from many thousands of users and organisations, lessons are still being learned. This, the third edition, adds some new rules, addresses some loopholes and improves the description and explanation behind existing rules including some precise guidelines on how to deviate for rules – not applicable for mandatory rules.

MISRA C : 2012 extends support to the C99 version of the C language (while maintaining guidelines for C90), in addition to including a number of improvements that can reduce the cost and complexity of compliance, whilst aiding consistent, safe use of C in critical systems. Improvements, many of which have been made as a result of user feedback, include: better rationales for every guideline, identified decidability so users can better interpret the output of checking tools, greater granularity of rules to allow more precise control, a number of expanded examples and integration of MISRA AC AGC. A cross reference for ISO 26262 has also been produced.

MISRA SAFE AND SECURE

There is a perception that MISRA C is only safety-related and not security related, as MISRA C defines a language subset. Safety – related standards require the use of a language subset, and thus MISRA C is associated with high integrity or high reliability requirements.

With the growing concern of the IoT (Internet of Things) and to justify the viewpoint that MISRA C:2012 is equally applicable to security–related applications, MISRA C carried out a coverage comparison in response to the publication of ISO/IEC 17961:2013 – the C Language Security Guidelines published by the C standard committee (ISO/IEC JTC1/SC22/WG14). The result of this comparison was published as Addendum 2 to MISRA C:2012 which shows that for freestanding applications, MISRA C:2012 already had excellent coverage.

However, the comparison work highlighted a small number of areas where the MISRA C coding guidelines could be enhanced and this resulted in MISRA C:2012 Amendment 1. This amendment sets out new guidelines as an extension to MISRA C:2012 to improve the coverage of the security concerns highlighted by the ISO C Secure Guidelines. Several of these new guidelines address well known security vulnerabilities related to the use of untrustworthy data.

MISRA COMPLIANCE AND DEVIATION PERMITS

In April 2016, MISRA C published MISRA Compliance:2016. This document which sets out a framework for achieving compliance with MISRA coding guidelines and includes guidance on a robust and structured process for the use of deviations.

Claiming compliance with MISRA has always been subject to debate, as it has been recognised that there are occasions when it it is impracticable or unreasonable to follow the requirements of a guideline. This leads to the concept of approved violations (deviations) and what the effect is on compliance. Many approaches have been used from no deviations allowed to using deviations for any area that does not comply

MISRA Compliance:2016 aims to define what is meant by MISRA Compliance, provides clearer guidelines on the use of deviations and also a mechanism for modifying the classification of guidelines to match the need of the project. It introduces the concept of establishing pre-approved ‘permits’ to help streamline the deviation process.

It supersedes the compliance, deviation and process requirements previously published in various MISRA coding guidelines. Associated with this, MISRA C:2004 Permits (also published in April 2016) presents a number of deviation permits covering commonly-encountered use cases for use with the MISRA C:2004 guidelines. It should be used in conjunction with MISRA Compliance:2016.

STATIC ANALYSIS

Unfortunately, the decision to adopt coding guidelines is frequently undermined by the practical difficulties inherent in enforcing such a policy. It has been observed that many companies invest considerable effort in compiling a set of coding guidelines only to find that the document subsequently gathers dust on a shelf.

The MISRA coding guidelines recognize the fact that effective enforcement of coding rules can rarely be achieved by manual code review. Traditional code inspections are hugely time consuming and not always reliable. However, most coding rules are amenable to automatic enforcement with a tool.

Some embedded compilers provide a certain level of rule enforcement. Dedicated static analysis tools usually go much further; as well as identifying specific rule violations they may also identify other coding problems, calculate source code metrics or conduct an in-depth dataflow analysis of code to identify subtle run-time errors.

Not every MISRA rule is automatically enforceable; there are a handful of rules which address issues of documentation or which are framed so as to require an element of subjective judgment which a tool cannot provide. However the vast majority of MISRA rules can be very effectively enforced automatically.

Static code analysis is a technology which is fast, powerful, reliable and repeatable. Being a tool that can be exercised on the desktop by an individual programmer, it also avoids the confrontation and embarrassment which can easily be a feature of manual code reviews.

SUMMARY

Since publication of the first version of MISRA-C in 1998, MISRA has established a reputation as a world leader in developing coding standards for embedded software development.

C and C++ are not ideal languages for safety critical code; but it is now widely accepted that they can be used effectively to develop reliable software if a sub-set of the language is defined in a coding standard and if static analysis tools are used to provide consistent enforcement.


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Emerging Trends in Automobile Industry

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In India, the auto industry is one of the largest industries and is one of the key sectors of the economy. Today, India is emerging as one of the world's fastest growing passenger car markets and second largest two-wheeler manufacturer. It is also home to the largest motorcycle manufacturer and the fifth largest commercial vehicle manufacturer.

> *Some auto makers believe that in 10 years, fully autonomous driving will be sophisticated enough for regular use*

The advent of newer technology & globalization has only paved the way for this sector to grow & flourish in the future. Not too many people know automotive trends the way the staff does at The Ohio State University's Centre for Automotive Research (OSU CAR). This interdisciplinary research centre at OSU's College of Engineering focuses on advanced electric propulsion and energy storage systems, engines and alternative fuels, intelligent transportation and vehicular communication systems, autonomous vehicles, vehicle chassis systems, and vehicle safety.

TRADITIONAL AUTOMOTIVE INDUSTRY

"One of the biggest trends in automotive engineering is improving engine efficiency and fuel economy, this includes downsizing, down-speeding, direct fuel injection, and boosting."

Reducing fuel use and emissions from vehicles doesn't mean that everyone needs to drive a compact car. Technologies are available to improve vehicle efficiency no matter if the vehicle is a small compact or a heavy-duty pick-up truck. In fact, the standards are designed with this in mind, setting appropriate performance requirements based on the footprint of the vehicle. As a result, recent trends show fuel economy is improving across all categories of vehicles and carbon emissions are dropping after a period of stagnation throughout the 90's and early 2000's. These technologies, which can improve engine efficiency and overall vehicle fuel economy, are being adopted by many manufacturers to meet fuel economy requirements. For example, gasoline direct injection is expected to reach 38% market share for 2014, despite only being introduced in the market in small numbers in 2007. Kia, Daimler, and BMW are already using the technology in most of their production vehicles, but other automakers haven't adopted the technology at the same rate.

GDI technology is often paired with turbocharging and engine downsizing to allow for even greater efficiency gains from using a smaller displacement engine. Diesel continues to shake off its it high polluting image with more models entering the market every year equipped with modern emission controls. These vehicles often come with impressive Km/lit ratings in part due to the greater efficiency of diesel engines and the higher energy content of diesel. But, make sure you do an apple to apple comparison when comparing diesel and gasoline vehicles for their climate emissions. For example, a diesel vehicle with a fuel economy rating of 36 Km/lit produces the same amount of global warming emission as 30 Km/lit gasoline vehicle.

One trend that is apparent from EPA's analysis is that manufacturers tend to get the most improvements out of diesel's in the smaller vehicle segment, while the carbon emissions advantage for larger vehicles is diminished – indicating a possible focus on power over fuel economy for larger vehicles. However, it's difficult to make predictions, especially about the future. Sure, it's an ironic remark about the accuracy of superfluous prognostication but that doesn't stop human beings from seeking to peer past the horizon. One way to qualify the passage of time is through technology eras, each hallmarked by the progression of transportation from steam engine to internal combustion, jet propulsion, and so on.

WHAT'S IN STORE FOR THE AUTOMOTIVE WORLD IN THE NEXT FEW YEARS?

Head's up: the cars of the not-so-distant future are being made today. Automakers have been hard at work testing tech that will appear in the car of tomorrow for some time, and we're seeing the results already. Ten years ago, cars with built-in Bluetooth, Navigation, and Parking Sensors were the domain of top luxury vehicles. Now even the most affordable econo-box has these things, as options at the very least. Next year, we can expect even more everyday technology features to come as standard equipment, notably online access. General Motors has been blazing a trail with its On Star connectivity for decades, offering in-car connectivity for all sorts of services. This can now turn cars like the Chevrolet Camaro into a roving 4G LTE hotspot. Similarly, FCA and its vehicles access the interwebs through Uconnect for all their connectivity needs. Table 1 shows what features are present in the most basic versions of cars now compared to 10 years ago.

Table 1 : Scenario Comparison

10 Years Ago	Today's Scenario	
Air Condition	Power Window	ABS
Power Window	Power Steering	Infotainment System
Air Bag	Automatic Climate Control System	In built GPS
In built Audio System	Air Bag	Steering Mounted Controls
Adjustable Seats	Reverse Parking Assist	Rear View Camera

As is turns out, many autonomous functions have crept into our lives under the label of Advanced Driver Assistance Systems (ADAS) features: things like lane keep assist, adaptive cruise control, and self-braking systems. With a connected car network, your car would sense the disabled one instantly, applying the brakes before you could even see the problem. The car's awareness of its surroundings even further, experimenting with LiDAR (Light Detection and Ranging) systems allowing the car to "see" the world around it in real time. In the Table 2, we can see what level of autonomous behaviour are offered on high level cars today.

Table 2 : Autonomous Features of Cars

Autonomous Features
Adaptive Cruise Control
Automatic Emergency Braking System
Lane Keeping and Changing Assistance
Obstacle Warning & Night Vision Camera
Autonomous Reverse & Parking Assistance
Forward Collision Warning System
Autonomous Driving over Voice Command
RADAR & LiDAR for Autopilot

Figure 1 : Lane Departure Warning System

WHAT LIES BEYOND?

Short of the massive class schism predicted by Fritz Lang's Metropolis, cars should certainly still be around by 2026, but they will have certainly changed enormously. Automakers like Audi and Mercedes-Benz believe that in 10 years, fully autonomous driving will be sophisticated enough for regular use. Perhaps we'll even have the legalities and moral quandaries of self-driving cars sorted out by then. If so, cars will have to be accommodating for the hands-off moments. Volvo, heavily exploring self-driving car technology, is preparing for this eventuality with ideas like its Concept 26 design study. This demonstrates how a car's cabin will be configured to change depending on the driving mode - kick back and relax, watch a film, or connect to the Internet and work in a mobile office.

This idea still seems fanciful today, despite the great leaps we've seen in recent years. Bosch's vision of autonomous driving is more realistically rooted, believing that full autonomy will be relegated to highways, with drivers needing full control only around local streets. The future may be impossible to predict, but we're the ones making it. It's up to us to decide what we want to be. Now we not only have the choice of colour but we also find technologies in our vehicles that require todays automotive engineers to be at the forefront of mechanical, electrical/ electronics, software and controls engineering disciplines. The automotive industry really is a tremendously fun and exciting place to work and the progress that has been made over the past few years is remarkable - with considerable improvements in performance, economy, emissions, quality, safety, quality and features and technology, all while vehicle pricing has held at very affordable levels and within reach of millions of customers around the world.

These are the kinds of technical solutions that are being combined to give us increasing levels of autonomous capability in the cars we are seeing launched right now and which will facilitate fully autonomous vehicles - not just cars but also Heavy Goods and Public Service vehicles. This needs to be done now before these technologies truly proliferate and potentially untrained, unqualified individuals endanger themselves and others by working on electric or hybrid vehicles which operate at lethally high voltages, or meddle with autonomous systems which drivers and passengers will be relying on to keep them safe.

THE NEW WORLD OF CONNECTED CARS

You don't see them at first, but your car gets a signal from the other car that it's directly in your path and warns you of the potential collision, or even hits the brakes automatically to avoid an accident. Good thing car companies and the government are already working to try to make this a reality. All of this communication and pre-emptive vehicle assistance leads us into our next future technology. The idea of a self-driving car isn't a new idea. But a truly self-driving car means exactly that, one that can drive itself, and they're probably closer to being a reality than you might think. In California and Nevada, Google engineers have already tested self-driving cars on more than 200,000 miles (321,869 kilometres) of public highways and roads. By using lasers, radars and cameras, the cars can analyse and process information about their surroundings faster than a human can. GPS and other in-car displays are great for getting us from point A to point B, and some high-end vehicles even have displays on the windshield, but soon cars will be able to identify external objects in front of the driver and display information about them on the windshield.

Figure 2 : Connected Cars Concept

AUGMENTED REALITY DASHBOARDS

Sciences are coming together for matching the expectations of next generation vehicles. Augmented Reality Dashboards – AR for short, will function in a similar way for drivers. BMW has already implemented a windshield display in some of their vehicles which displays basic information, but they're also developing augmented reality dashboards that will be able to identify objects in front a vehicle and tell the driver how far they are away from the object. The AR display will overlay information on top of what a driver is seeing in real life. So, if you're approaching a car too quickly, a red box may appear on the car you're approaching and arrows will appear showing you how to manoeuvre into the next lane before you collide with the other car. Toyota has produced working concepts of their AR system that would allow passengers to zoom in on objects outside of the car, select and identify objects, as well as view the distance of an object from the car using a touch-screen window. Augmented reality may not be here yet, but if these car companies have their way, we'll be seeing it in our future cars a little way down the road.

IT'S ALL COMING TOGETHER FOR ELECTRIC CARS!!

Even if you work the auto industry, you probably didn't expect the current rush to develop, build, sell, and drive electric vehicles. But there's no denying it. A series of technology developments, market disruptions, and wake-up calls are hastening an inevitable shift from fossil fuel engines to electric power in cars and trucks. Battery technology is the greatest enabler of the shift to fully electric-powered vehicles. Lower electricity cost means less expensive cars. With range anxiety now a "thing" and a common deterrent to full-electric car purchases, larger capacity batteries are needed for adequate driving range. Battery technology is the greatest enabler of the shift to fully electric-powered vehicles. Lower electricity cost means less expensive cars. With range anxiety now a "thing" and a common deterrent to full-electric car purchases, larger capacity batteries are needed for adequate driving range. The cost of lithium-ion battery power has dropped by about 80 percent in the last eight years. One kilowatt of power that cost roughly $1,000 in 2008 is now closer to $200.

Figure 3 : Enabler for Fully Electric-Powered Vehicle-Battery Technology

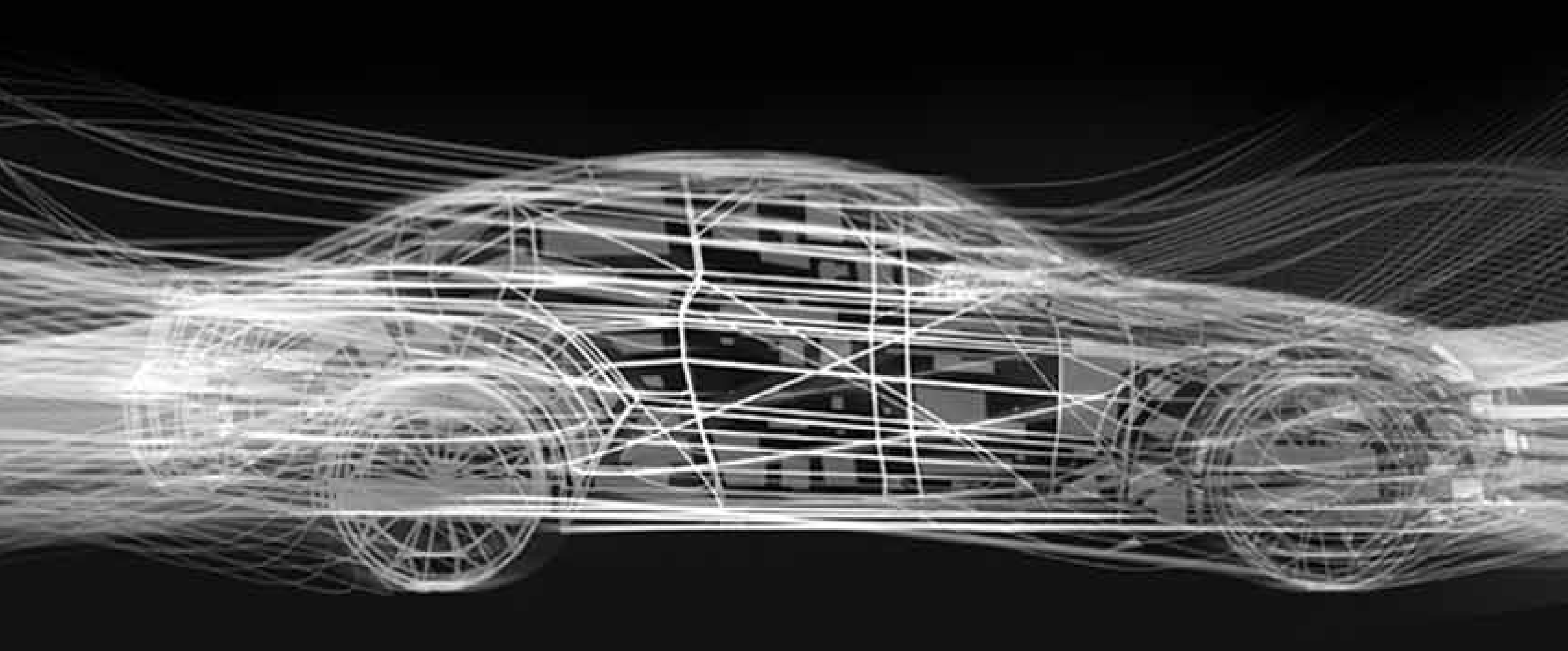
Continued battery technology advances plus the impending construction of huge new battery factories could bring prices down to $100 per kilowatt in the next few years.

In Europe, a group of nine auto manufacturers are currently researching and testing body panels that can store energy and charge faster than conventional batteries of today. The panels would capture energy produced by technologies like regenerative braking or when the car is plugged in overnight and then feed that energy back to the car when it's needed. Not only would this help reduce the size of hybrid batteries, but the extra savings in weight would eliminate wasted energy used to move the weight from the batteries. Toyota is also considering lightweight energy storing panels, but they're taking it one step further and researching body panels that would capture solar energy and store it in a lightweight panel. Whether future body panels collect energy or just store it, automotive companies are considering new ways to make our cars more energy efficient and lightweight.

Autonomous vehicle technology is developing hand in hand with the switch to electrification. Auto manufacturers are working fast to develop autonomous capabilities just to stay up with their competitors. Combining hybrid and all-electric power with autopilot and auto-assist features gives manufacturers showcase platforms. Tesla's success overall, especially the huge demand demonstrated by the nearly 400,000 Tesla Model 3 reservations, sent a message about the potential for entry-level electric, autonomous cars. Insurance companies and law enforcement cite human error as the causative factor in most accidents (as many as 9 out of 10), which is why car makers and government entities believe that self-driving cars will mean fewer accidents, injuries, and fatalities.

Ride-sharing and ride-hailing shift our assumptions and expectations from car ownership to car availability. When people no longer see the need to own cars, or reduce the number they currently own, their expectation will be for safe, quiet, inexpensive vehicles. All these factors that support electric, autonomous vehicles. Environmental impact by itself could carry the transition to electric powered vehicles. As the world increasingly shifts to the belief in man-made climate change and takes responsibility for halting further damage to the environment, zero emissions vehicles are an obvious step. Cheaper battery power, the concomitant shift to self-driving cars, demonstrated market demand, a focus on mobility rather than vehicle ownership, and cleaner energy all add up to electric cars gaining market share faster than anyone expected.

AUTOMOTIVE SAFETY



Application of Motion Analysis of High Speed Photography in Crash Testing & Quality Control with ISO 8721 : 2010

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INTRODUCTION

Motion tracking analysis is widely used in crash testing in order to analyse the motion of various elements like the dummy, the seat belt, the steering wheel column, the air-bag deployment, These analyses are used by the automobile manufacturers and suppliers for their own needs, but standards like EuroNCAP also require target tracking in videos. For instance, EuroNCAP standard requires target tracking to measure the head rebound velocity as well as the seat belt dynamic deflection in a Whiplash test. The protocols precisely define the position of the targets which should be used.

> *Motion tracking software tools provide a powerful way to analyse crash tests, but it is required to take care of image analysis constraints to make sure the final measurement is correct*

Motion tracking software tools provide a powerful way to analyse crash tests, but it is required to take care of image analysis constraints to make sure the final measurement is correct.

- First of all, the characteristics of the camera should be properly chosen and care should be then taken to achieve the best possible quality of the video. The tracking software should also be properly chosen, and care should be taken to do the tracking.
- ISO 8721 and SAE J-211/2 regulations define protocols to check the quality of the measurements.

ACHIEVING THE BEST QUALITY OF THE VIDEO AND TRACKING

Choosing the Camera

First of all, the camera should be chosen properly to achieve the final desired result. Two specifications should be taken into account; the camera rate and the resolution. The camera rate should be high enough to enable to track the motion of the object under test. High speed cameras are commonly used in crash testing, usually 1000 images/s or 2000 images/s. Up to 4000 images/s rate cameras are used for air-bag static tests. The resolution is then an important part, since it defines the final resolution of the analysis. Dividing the metrical dimension of the field of view by the number of pixels of the image provided by the camera enables to evaluate the resolution of the measurement. For instance using a 1024*1024 camera with a 1m*1m field of view provides about 1 mm per pixel, and there is no hope of reaching 1 micro-meter resolution of a motion in such a video. So the field of view should be carefully chosen knowing the camera which is used for a specific analysis. Zooming can of course also be used.

Once the camera characteristics and position have been properly chosen, other features should be taken into account to achieve the best possible images quality since it will have a direct impact on the final result.

Achieving the Best Possible Quality of the Video

The precision of the final results will be linked to the quality of the video. It will be possible to correct some image defects due to a bad acquisition thanks to post-processing, but it is very important to try and get the best possible video quality before running the test.

In order to obtain a good image quality, a few factors should be taken into account during the acquisition. For instance:

- **The image exposure :** the image exposure will have an important effect on the quality of the tracking. An over-exposed or under-exposed image will make it more difficult to achieve a good accuracy since the image will have a lower contrast and it will be more complex for the algorithm to detect the difference between a target and the background. This can be addressed by adjusting various parameters, such as the exposure time, the aperture and the sensor sensitivity of the camera correctly, as well as the lighting
- **The reflections :** Reflections in the image can also affect the quality of the tracking. A reflection usually has a high contrast and it can move in the image independently of the object motion. So the tracking may be affected if a reflection occurs near the target to track, the position and orientation of the light should thus be adjusted in order to avoid reflections as much as possible. A mat painting on targets or objects could also help to avoid reflection.
- **Depth of field :** The more blurred the image to be treated, the more difficult it will be to achieve a good tracking accuracy. For this reason, setting the depth of the field, mainly depending on the aperture of the lens, is a very important task. A large aperture will lead to a short depth of field.
- **Motion Blur :** High motion speed of objects in the scene can lead to motion blurring in the images, due to the time integration of the camera. This blur may result in an inaccuracy in the measurement of the objects or targets positions and should therefore be limited as much as possible. Choosing a low integration time allows to better freeze the movement within each image.
- **Camera time synchronisation :** In the case of three-dimensional measurements, several cameras must be used to observe the motion from different angles of view, and allow the analysis software to compute the 3D positions using space calibration and triangulation algorithms. All camera should be perfectly time-synchronised, in order to be sure to acquire the target positions at exactly the same time. Hardware synchronisation of cameras should be used, either with an external trigger, or setting up one camera as a master to drive the others.

But it is worth noting that not only the quality of the video is important to have good results in the analysis of a “crash test”: the choice of the software for the analysis is decisive in the precision of the results.

CHOOSING THE TRACKING SOFTWARE AND USING THE MAIN FEATURES

It is of course very important to have a good tracking of the points. Here are some recommendations on the tracking, and the corresponding necessary tracking software features:

- 2D tracking can be used only when the motion can be approximated to be an actual 2D motion. Otherwise 3D analysis should be performed using more than one camera.
- In the case of a 2D tracking, the depth of the motion with respect to the reference plane where the spatial calibration has been performed needs to be taken into account to correct scale and parallax effects.
- The software should provide a lens calibration feature, to correct any distortions in the images,
- When the camera cannot be placed perpendicularly to the plane of interest, there is a projection and perspective effect which also needs to be corrected. It is therefore essential that the software be able to make a perspective correction to avoid misalignment between the camera and the plane of motion.
- Sub-pixel resolution should be used to improve the measurement resolution when the quality of the video enables it. An important feature of the software is the ability to do a subpixel tracking to gain accuracy in the calculations. It is worth noting, however, that a subpixel analysis does not guarantee the precision of the measurement, but it is one of the elements that will limit this precision.
- Some points may not be seen during the test since they are completely hidden or become hidden during a part of the test. A way to solve this issue is to define them using other points which can be tracked all over

the test. For instance, the H point, or Hip-point,which is the pivot point between the torso and the upper leg portions of the body,is generally not visible on the video. It can though be tracked using two points on the hip. When using such a feature in a tracking software, it should be ensured that the two reference points and the point to track are on a same rigid boy. Also, in the case of 2D tracking, the three points should be in the same plane.

QUALITY CONTROL

To ensure the quality of the measurements in crash tests, several regulations have been developed, like ISO 8721 and SAE J-211/2 regulations. They define a method to compute indices which will enable to evaluate the quality of the measurement.

- ISO 8721 : Road vehicles – Measurement techniques in impact tests – Optical instrumentation.

  This standard calculates a parameter, known as the distortion index, to determine the quality of the measurement chain. This evaluates the quality of the test, taking into account all the recording devices used, the image analysis system and any data analysis and correction procedures that evaluate and enhance the measurements.

- SAE J-211/2 : Instrumentation for Impact Test– Optical instrumentation (2014).

  The SAE J-211/2 standard defines several criteria for evaluating the quality of the measurement chain. Unlike ISO 8721: 1986, SAE J-211/2 does not give an overall measurement for the test, quality is evaluated for different components of the measurement chain.

- ISO 8721 : Road vehicles – Measurement techniques in impact tests – Optical instrumentation (ISO, 2010).

This version of ISO 8721 replaces the 1986 version. The objective of the standard is the same as in its previous version, but incorporates the concept of analysis according to separate components of the SAE J-211/2 standard. In this way this new version offers the possibility of finding the component which is the cause of a poor quality of the measurement chain. It also enables to compare the results of several laboratories in a simpler way.

The standard can be applied for several different configurations like 2D or 3D analyses with on-board or off-board cameras. In addition, it provides a special application case for successive tests without any change in the equipment of the measuring chain from one test to the other. In this latter case, the user must carry out a preliminary test which for a first evaluation of the quality of the measurement chain. According to the results, the user may decide whether to make changes in the configuration of the test or not. Then, this preliminary test can be reused for the rest of the tests, which prevents to repeat several calculations for each test.

ISO 8721 : 2010 makes it possible to calculate several indices which will indicate the quality of several components of the measurement chain. Each index must meet a minimum quality criterion defined by the standard. The conformity of each test with the norm will also depend on expected quality values which may depend on each type of test.

These expected quality values are:

- **Location accuracy :** the desired accuracy of the object or target being measured.
- **Allowed point motion :** defines the maximum motion from one image to the next, in the object space.
- **Allowed accuracy relation :** defines the allowed accuracy relation between the accuracy perpendicular to the camera base in the direction to the object and the accuracy in the other two directions.
- **Accuracy value limit :** defines the desired accuracy relation of the reference distances being measured (accuracy value).

Traumatic Seat Belt Abdominal Fat Stranding Diagnosis on the CT Scan as a Potential Tool for Injury Causation Analysis

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INTRODUCTION

The seatbelt is the most important safety device in the vehicle-saving lives. In a frontal crash, the seatbelt dissipates occupant kinetic energy in a controlled manner while transferring the dynamic load on the stronger skeletal regions. Several factors can lead to occupant submarining which shifts the loading on the human body from the desired location to undesired location. One such factor is a fully reclined seatback in a moving vehicle which tends to move the occupants pelvis forward with a backward tilt. The abdominal subcutaneous fat stranding pattern provides an important clue regarding the pre-crash lap belt positioning and occupant kinematics during the crash phase. A similar study presented in the year 2013 by the INOVA Fairfax Hospital CIREN Center explains the role of CT scans to determine the seatbelt use and its positioning. This knowledge encourages more design features preventing the out-of-positioning of the occupant. The abdominal fat stranding band shows the extent of belt motion on the abdomen by marking the start and end boundary. The subcutaneous fat density change due to the seatbelt loading facilitates its identification on the CT scan. Fig. 1 shows the example of seatbelt loading mark on the CT scan.

> *"The fat stranding analysis provides insight on the occupant kinematics and resulting injury dynamics."*

CASE HISTORY

A young belted female in her twenties sustained severe head and neck injury in the frontal crash. She was asleep at the time of the crash with her seatback reclined. Fig. 2 shows the schematics of the crash scenario that shows the frontal impact on her car while impacting the rear of the truck.

Fig. 3 shows the frontal damage profile of her car. Fig. 4 shows her body orientation and location before the impact using

Figure 1 : Example of Seatbelt Loading Mark on the CT Scan

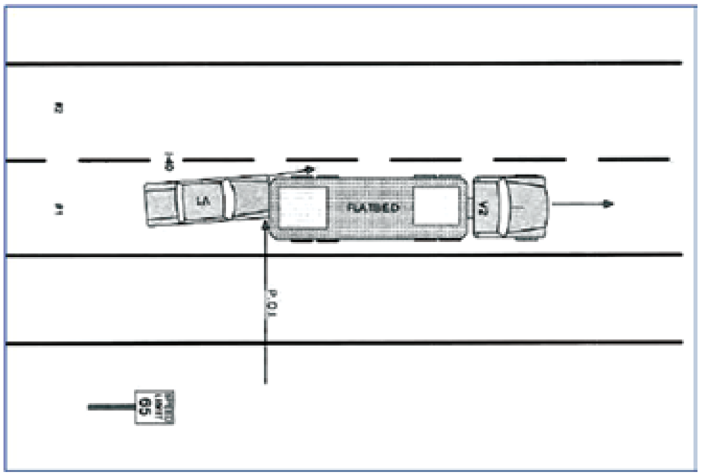

Figure 2 : Schematics of the Crash from the Police File

a surrogate in an exemplar vehicle. She was 1.76 m (5 ft 8 inch) in height and weighed around 59 Kg and was using the available seatbelt at the time of the crash. As a result of this crash, she sustained severe head and neck injuries including the incomplete spinal cord injury at the C4 level. Table 1 shows her neck injuries based on CT and MRI scans and report. The concomitant tracheal injury produced subcutaneous emphysema at the level of osseous injury. She also sustained SDH (Subdural Hematoma), SAH (Subarachnoid Hemorrhage) and cerebral contusion as a result of this accident with no skull fracture.

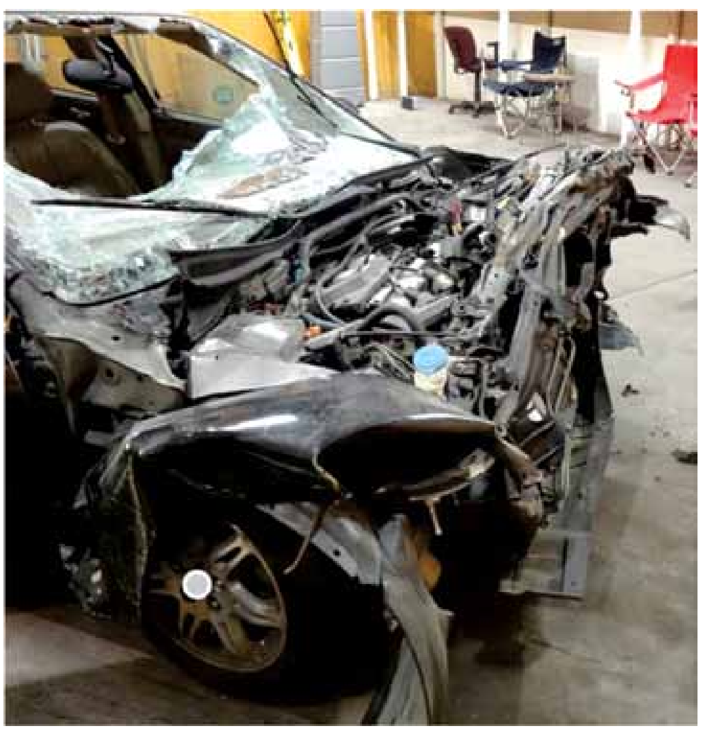

Figure 3 : Vehicle Frontal Crush Profile

Figure 4 : Pre-crash Body Position and Orientation on the Fully Reclined Seat (Surrogate Study in an Exemplar Vehicle)

Table 1 : Neck Injury Pattern

Neck Injury Diagnosis based on CT and MRI scans
• Increase in C3-C4 and C4-C5 disc space
• Anterolisthesis of C3 over C4 (Grade1)
• Anterolisthesis of C4 over C5 with anterior tilt
• Subluxation of bilateral facet joints at C3-C4 and C4-C5 level
• Fracture of left transverse process of C4 Vertebrae
• Significant focal Kyphosis at C3, C4 and C5
• Increased posterior disc space at C3/C4 and C4/C5
• Focal disruption of PLL (Posterior Longitudinal Ligament)
• Extensive posterior subcutaneous tissue injury
• ALL (Anterior Longitudinal Ligament) intact at all the levels
• Spinal cord contusion at C3-C4 and C5 level

DISCUSSION

Based on the vehicle inspection from inside and outside along with her injury pattern, it was evident that she slid forward on the seat pan beneath the lap portion of the seatbelt. Her upper torso that was inclined on the fully reclined seatback was subjected to dynamic load with components parallel and normal to the reclined seatback. The normal component caused her upper torso to rotate about the lap portion of the belt which was on her abdomen due to her submarining. This unfavorable kinematics caused her anterior neck to interact with the locked shoulder belt producing the scenario of clothesline neck injury. The absence of skull fracture and facial fracture indicates that her brain injury was pure shear type caused by the angular acceleration. Her head experienced a high change in angular velocity based on the rotation point that was below C4 in the cervical spine. The SDH and SAH are brain surface injuries that are more likely caused due to angular acceleration causing severe shearing injuries at the surface of the brain. The rearward tilt of her pelvis, as caused due to the fully reclined seatback, increased the risk of her submarining on the seat pan. Fat stranding analysis of her abdominal region corroborates her submarining on the seat pan. CT scans indeed provide invaluable information regarding the post-traumatic anatomical changes. It allows the trauma physicians to see specific injuries at different locations on the body. The biomechanical engineer uses this information to derive important information for the injury causation analysis. The CT scan provides the boundary conditions for the injury causation analysis. The amount of subcutaneous fat varies between individuals, and it overlies more rigid structure in context to the seatbelt routing on the body. For example, it overlies bony chest and body pelvis that causes its compression between the belt webbing and the bony structure. In the abdominal area, it overlies abdominal muscles. The lap belt exerts the load on the occupant while loading the fat causing change in its structure and density. The CT scan is sensitive to change in tissue density that can be exploited for the fat stranding analysis. Fig.5 shows the relevant area under investigation for the lap belt induced fat stranding. The A.S.I.S (Anterior Superior Iliac Spine) is the desired location for the lap belt to exert loading and without submarining remains at that position for the entire impact phase.

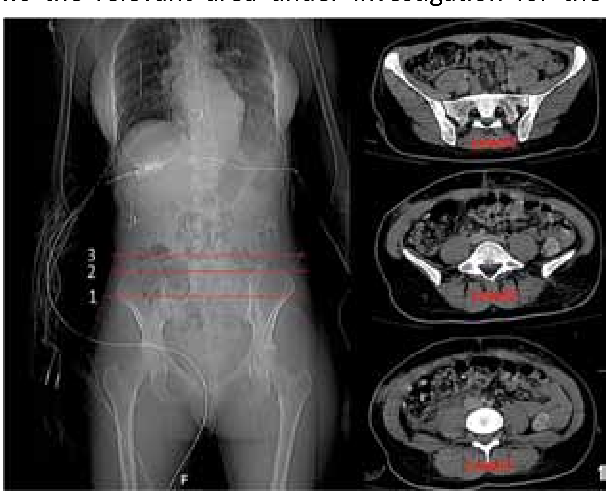

Figure 5 : Axial CT Scans at Different Levels Starting at the A.S.I.S (Level 1) [Patient File]

This location should be the start point of fat stranding analysis followed by analysis in the cranial direction. Fig. 6, 7 and 8 are the axial CT scans at desired levels which show the fat stranding in the subcutaneous layer. This type of analysis provides objective evidence of the initial position of the belt on the abdominal and its final position after submarining. This information also provides insight regarding the failure of the seatbelt to engage at A.S.I.S (Anterior superior iliac spine) with the tilted pelvis along with the relative motion of the belt and the underlying hard tissue. Fig. 6 indicates no fat stranding at the level of A.S.I.S more likely due to the rearward pelvic tilt that facilitated unhooking of the lap belt at this level. Fig. 7 and 8 shows the fat stranding at level 2 and 3 indicating the lap belt loading on the abdomen while moving upwards on the abdomen.

Figure 6 : No Subcutaneous Fat Stranding at Level 1 Demonstrating Unhooking of the Lap Belt

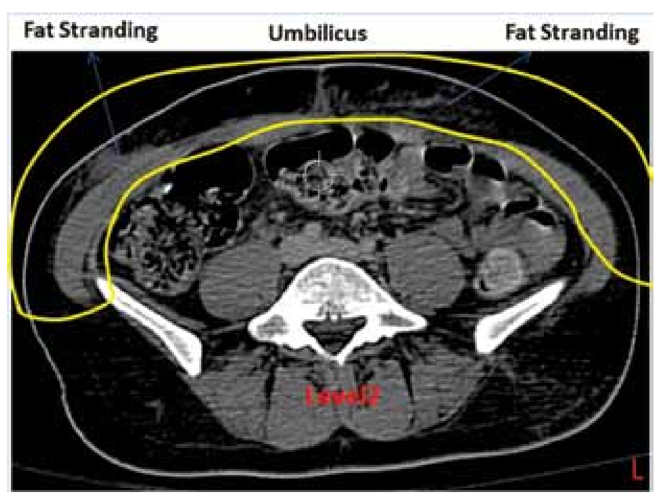

Figure 7 : Fat Stranding Visible at Level 2

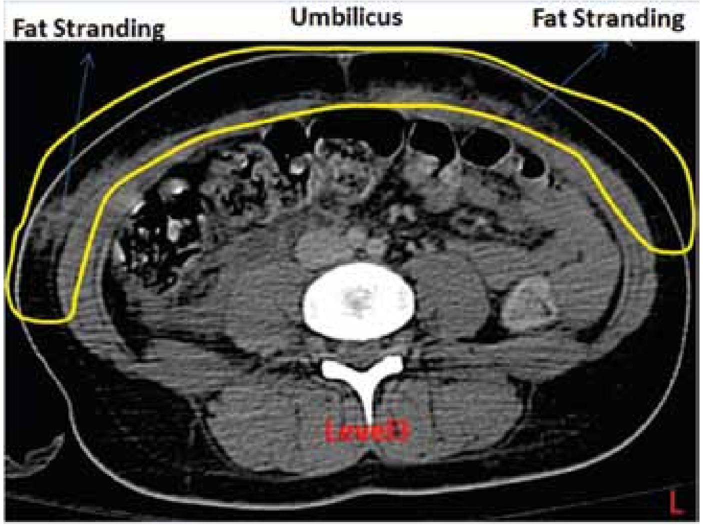

Figure 8 : Fat Stranding Visible at Level 3

RECOMMENDATION

Abdominal fat stranding in the subcutaneous layer due to seatbelt load provides valuable information regarding occupant kinematics in a crash scenario. This information can be used by the treating physician to diagnose the extent of abdominal injury based on the level of fat stranding band. The study of fat stranding and its level of the abdomen benefits the patient from early worries of serious underlying injuries. It is also a valuable CT scan study for the biomechanical engineer assisting injury causation analysis.

CONCLUSION

The abdominal fat stranding analysis in reported case study assisted the injury causation analysis by providing an objective evidence of submarining. This study also facilitates in identifying the pre-crash position of the lap belt on the occupant. Lack of fat stranding at the A.S.I.S in association with other crash factors investigated indicates that lap belt failed to hook the pelvis due to its backwards reclined configuration that more likely exacerbated the rearward pelvis tilt. This type of information facilitates the injury causation analysis that enhances the injury prevention strategies.

Smart, Safe & Sustainable Mobility SIAT

Adoption of Best Practices for Mitigation of Road Accidents in India

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ROAD ACCIDENTS: A CAUSE OF DEEP CONCERN

Road traffic fatality is an appalling global problem that affects all sectors of the society. About 1.2 million people die globally each year as a result of road traffic crashes – that is nearly 3,200 deaths a day. Half of those who die on the world's roads are vulnerable road users: pedestrians, cyclists and motorcyclists. It is predicted that globally, annual road traffic deaths would increase to around 1.9 million by 2030, if no measures are adopted. Indian roads, which account for the highest fatalities in the world, became yet more dangerous in 2015 with the number of deaths rising nearly 4.6% to 1,46,133. Globally this accounts for 12% of total crash fatalities. This also translates to 400 deaths a day or one life snuffed out every 3.6 minutes.

> *"The lessons learnt from high-income countries show that many cost-effective interventions can have a positive impact in the short term"*

The Table 1 below gives the total number of vehicles and road deaths caused in some of the Indian states in year 2015. According to this provisional police data provided by states, Uttar Pradesh recorded the maximum number of road deaths. These States also account for major share of total number of vehicles in India.

The vehicular population in the above five sates account for 44% of total registered vehicular population in India, while in terms of deaths occurred due to road accidents in India these states account for a total 46% of the deaths. These statistics show a positive relation between total number of vehicles registered and number of deaths occurring due to road accidents. However, this may not always be true. It is true that when low and middle income countries like India motorize quickly, a lag in the introduction of safety measures can result in more road traffic deaths, including deaths of pedestrians and other vulnerable road users. When countries invest adequately in road safety, however, there is no simple correlation between the number of vehicles and the number of fatalities. In fact, many high-income countries continue to motorize but, with adequate attention to road safety, have managed to constantly reduce the number of road traffic fatalities.

The number of deaths caused due to road accidents is disturbing in India. The following five key risk factors are

Table 1 : Road Accident Statistics in Indian States

State (in Millions)	Registered Road Accident	Vehicles Deaths
Uttar Pradesh	17.04	17,666
Tamil Nadu	19.23	15,642
Maharashtra	21.48	13,212
Karnataka	12.06	10,856
Rajasthan	10.07	10,510

observed in India that have caused huge number of road traffic deaths and injuries:

- Drunken driving
- Speeding
- Failing to use motorcycle helmets
- Failing to use seat-belts
- Failing to use child restraints

Government of India is focusing on the measures to be adopted for reducing number of accidents and deaths caused due to road accidents. Being a signatory to the Brasilia declaration, the Minister of Road Transport & Highways has set a goal of reducing road fatalities by 50% by 2020 in India. The task of achieving this target, however needs concerted efforts on all fronts namely Education, Enforcement, Bringing in stricter rules and its implementation, and bringing in safer and cleaner vehicles through advanced engineering & technological means. This mammoth task is further complicated with the projected increase in the number of vehicles coming on road in the cities, towns and villages of the country.

Increased number of vehicles on road can never help reduce the traffic accidents. Singh in one of his articles says that statistics indicate traffic accidents as a primary cause of accidental deaths in Indian cities. The main reasons for these problems are the prevailing imbalance in modal split, inadequate transport infrastructure, and its suboptimal use. Public transport systems have not been able to keep pace with the rapid and substantial increases in demand over the past few decades. Bus services in particular have deteriorated, and their relative output has been further reduced as passengers have turned to personalized modes and intermediate public transport.

Further, younger generation and teenagers are found to be inspired to buy vehicles in higher proportion or are influenced to drive vehicles owned by other family members. This particularly has led to increase in vulnerability and it would continue to prove dangerous unless they are made aware of the related hazards and importance and criticality of road safety.

NATIONAL ROAD SAFETY POLICY OF INDIA

The Government of India (GoI) is deeply concerned about the growth in the number of road accidents, injuries and fatalities in recent years. It recognizes that road accidents have now become an endemic public health issue, whose victims are mainly the vulnerable road users. GoI further recognizes the need for a holistic approach as road accidents occur due to a combination of issues with respect road, driver (or road user) and vehicle. It also recognizes that regardless of jurisdictions, the Central and State Governments have a joint responsibility in reducing the incidence of road accidents, injuries and related deaths.

In light of this, the Government of India, through its National Road Safety Policy, states its commitment to bring about a significant reduction in mortality and morbidity resulting from road accidents. The National Road Safety Policy of India outlines the policy initiatives to be framed or to be taken by the Government at all levels to improve the road safety activities in the country.

The Government of India is committed for implementation of National Road Safety Policy through following schemes:

1. Raise Awareness about Road Safety Issues
2. Establish a Road Safety Information Database
3. Ensure Safer Road Infrastructure
4. Steps to ensure that safety features in both motorized and non-motorized vehicles in line with international standards
5. Strengthen the system of driver licensing and training to improve the competence and capability of drivers.
6. Safety of Vulnerable Road Users
7. Road Traffic Safety Education and Training
8. Enforcement of Safety Laws
9. Emergency Medical Services for Road Accidents with speedy and effective trauma care and management
10. HRD & Research for Road Safety
11. Strengthening Enabling Legal, Institutional and Financial Environment for Road Safety

Another significant step taking by the GoI in connection to improving road safety is the constitution of Road Safety Bill. This bill is a result of the Ministry's commitment to halve the number of road accident fatalities by the end of this decade. Efforts are being made for its effective implementation with positive results.

IMPLEMENTATION STRATEGY

The Government of India intends to establish a dedicated agency viz. a National Road Safety Board to oversee the issues related to road safety and evolve effective strategies for implementation of the Road Safety Policy. The Government has also decided to establish a National Road Safety Fund to finance road activities through the allocation of a certain percentage of the oil/diesel cess.

WAY FORWARD

While significant achievements towards the goal of reducing number of accidents and deaths, prevention of injuries and crashes could be achieved by implementation of each of the Policy statements of National Road Safety Policy, further concerted efforts will be required to achieve mission of saving lives, preventing injuries, and reducing crashes through all of the tools available - including public awareness campaigns, technical innovation, research into human behavior, and enforcement of laws.

In achieving this mission best global practices adopted by the National Highway Traffic Safety Administration (NHTSA) of USA could be studied and adopted by India, which will help in achieving the targets set in terms of reduction in road accidents, road fatalities and injuries.

As a preliminary step, an action plan needs to be framed in line with global best practices in improving road safety. Also, as India is a contracting party to UNECE's convention on Road Traffic 1949, we can look up to the conventions and legal instruments of the working party on road traffic safety of the UNECE (WP. 1) and adopt regulations and best practices that well complement our objectives to reduce road accident fatalities.

GLOBAL BEST PRACTICES

The National Highway Traffic Safety Administration (NHTSA) was established by the Highway Safety Act of 1970, as the successor to National Highway Safety Bureau.

Objective of NHTSA –

- Reduction of deaths, injuries and economic losses resulting from motor vehicle crashes.
- Setting and enforcing safety performance standards for motor vehicles and motor vehicle equipment, and through grants to state and local governments to enable them to conduct effective local highway safety programs.

Responsibilities of NHTSA -

- Investigation of safety defects in motor vehicles
- Set and enforce fuel economy standards
- Help states and local communities reduce the threat of drunk drivers
- Promote the use of safety belts, child safety seats and air bags, investigates odometer fraud
- Establish and enforce vehicle anti-theft regulations and provide consumer information on motor vehicle safety topics.
- Conduct research on driver behavior and traffic safety, to develop the most efficient and effective means of bringing about safety improvements.

The NHTSA focuses on five main aspects of Road Safety such as Driving Safely Vehicle Safety, Research, Data and Laws & Regulations.

Driving Safely & Vehicle Safety - While Driving safely addresses the ill effects of aggressive driving, distracted driving, drowsy driving and impaired driving, vehicle safety deals with vehicle safety equipment, recalls and defects, tires and vehicle thefts.

Research - The Research carried out by NHTSA covers following almost all aspects with regard to Road safety issues such as Biomechanics & Trauma, Behaviors and Attitudes, Crash Avoidance, Crash Injury Research, Crashworthiness, Vehicle Crash test data base, Driver Simulation, Enhanced Safety of Vehicles (ESV), Event Data Recorder (EDR), Human Factors/ Engineering Integration, Child Seat Research, Public Meetings and Vehicle Research & Testing (VRTC).

Data - The NHTSA compiles Data for following:

- National Automotive Sampling System (NASS)
- National Driver Register (NDR) and Problem Driver Pointer System (PDPS)
- Special Crash Investigations (SCI)
- State Data Programs
- Traffic Records
- Fatality Analysis Reporting System (FARS)

Laws and Regulations - NHTSA deals with Laws and Regulations relating to Motor Vehicle Safety and Highway Safety.

A similar holistic approach is required to be adopted in India as well to counter the hazards of road traffic accidents. A framework needs to be develop that can strategically assist in significant improvement in road safety within the country.

RECOMMENDATIONS

As mentioned in the earlier section an action plan with a holistic approach is the need of the hour to reduce road accident fatalities in the country. This action plan must consist of a set of responsibilities to be taken up systematically by stakeholders in order to collectively achieve the international road safety goals.

The recommendations for the action plan have been put under 4 strategic wings of road safety framework :

1. Education
2. Engineering
3. Enforcement
4. Emergency medical aid

Education - In spite of the significant improvements in road safety achieved in the last few years, the current number of deaths and injuries is still unacceptably high. Road safety measures, aimed at achieving this safety goal by preventing traffic crashes and reducing their severity, are traditionally referred as the three E's: Enforcement measures, Engineering measures and Education measures. From the experiences of the best performing countries, it has becomes evident that for road users in general, and for children and teenagers in particular, a holistic approach is needed in which the three E's are combined.

1. Capacity building workshops for motor vehicle inspectors - In India road crash investigation typically falls under the responsibilities of motor vehicle inspectors/traffic police who are expected to scientifically gather and report information on road traffic crashes. In reality, most of the time such accident reports lack crucial information regarding the actual cause of accident and technical errors are often observed in collision and condition diagrams. The crash investigation report are seen as important evidence in identifying road crash causes and related counter measures for crash avoidance.

   There is immense need to scientifically equip the concerned officers to carry out crash investigation effectively. Capacity building workshops for motor vehicle department is one way to achieve this objective. A program has to be chalked out for effective conduction of the workshops along with performance targets for evaluation of effectiveness of the program.

2. Awareness campaigns for teenagers - Traffic education has been one of the fundamental aspects of improving road safety. This measure could be used for all kinds of road user groups and for all sorts of road safety issues. It ranges from training young moped riders to 'driver improvement' of convicted drivers.

   Considering the importance of road safety awareness campaigns, association with schools, colleges and NGOs should be considered to conduct effective awareness campaigns for improving road safety all over the country.

3. Certified road safety education programs for transport vehicle drivers - Transport vehicle crashes have been observed as a critical area of concern requiring immediate action. Certified road safety courses may be seen as one of the measures to help motivate drivers to adopt safe driving practices. Hazards of drunken driving, driver fatigue and over speeding are some important areas that need to be focused in such road safety education programs.

Engineering - Engineering is undoubtedly an integral part of road safety. Many areas under engineering have been identified where focused efforts have to be made.

1. Establishment of Crash Investigation Team - As mentioned in the earlier sections, importance of scientific crash investigation in India cannot be overemphasized. Therefore there is crucial requirement to provide technical support to the concerned officials for effective conduction of crash investigation. In this direction, a scientific crash investigation committee needs to be established to provide assistance in crash investigation through development of standardized procedures, formats, reports and drawings.

2. Establishment of Crash Database Center - Presently the Transport Research Wing of MoRTH carries out statistical analysis of road crashes in India and publishes annual reports with state-wise road crash numbers. A systematic database center needs to be established to analyze this data on road traffic accidents and extract crucial findings from scientific accident data analysis.

3. Road Safety Evaluation - Considering the importance of network infrastructure safety, there is a need for the transport planning agencies and municipal corporations of various states to engage in safety evaluation of road network. A regular assessment of this type will help identify the shortfalls in the existing infrastructure that trigger road crash risks. This study would further help in identifying effective ways to curb crash risks and implement safety measures.

4. Research & Development - Road safety has always been a venue for extensive research ranging from developing scientific crash investigation methods to development of safety standards in network design. Research is the backbone for improving safety performance of any aspect of traffic, be it, road user, vehicle or network design.

Influence of human behavior on road accidents such as driver fatigue, distracted driving, development of intelligent systems such as collision control system, cruise control system etc., for vehicles on Indian roads, Improvement in network design that can counter crash risks are some areas that require research focus in India.

Enforcement - Road Safety Laws & Regulations require to be reviewed periodically keeping in view the growing vehicle usage in India along with the consequently increasing road crash fatalities. It is important to understand how international laws could be made useful in India that can help mitigate crash risks. A committee needs to be established that can constantly work on developing road safety laws and regulations for country on the basis of international practices. Also an efficient mechanism to effectively implement the laws should also be worked out by this team.

Emergency Medical Aid - Although most of our efforts lie in reducing crash risks and related fatalities, zero avoidance of road crashes still remain an optimistic vision. Therefore it is important to strengthen the "golden hour" medical services that are provided during a crash incident along national and state corridors.

Planning & effective implementation of emergency green corridor, fast and improved supply of medical aid, facilities for on-site first aid etc., are the areas identified that require immense work to be carried out.

CONCLUSION

Rising numbers of fatalities on the roads in India are linked to development and motorization but occur in large part because road safety concerns are not being adequately addressed as the transport systems develop. While road transport is vital to countries' development, maximizing the efficiency of road transport systems without adequate attention to safety leads to loss of life, health and wealth. In the past few decades, important lessons have been learnt from the experience of high-income countries; these lessons should be used to mitigate the impact of increased motorization on human life.

Australia, North America and several countries in Europe where a comprehensive approach to road safety (the "safe system approach") is used have indeed seen marked decreases in road traffic deaths and serious injuries. These results were achieved, however, only after decades of "holistic action".

India, the developing country, where road safety management is generally weaker, should expect to invest similar amounts of time and effort to obtain similar results. This doesn't mean that injuries and fatalities cannot be reduced in the short term: in fact, the lessons learnt from high-income countries show that many cost-effective interventions can have a positive impact in the short term.

An establishment of a responsible National Road Safety Authority under the ambit Ministry of Road Transport & Highways, which would encompass all the key aspects of road safety, on the likes of National Highway Traffic safety Administration (NHTSA) of United States of America is the need of the hour, if India is to significantly reduce the ever increasing road accidents, road accident deaths and injuries.

Smart, Safe & Sustainable Mobility
SIAT

Rollover of Sleeper Coach Bus : Concerns and Challenges

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INTRODUCTION

Road transport is the most commonly used way of transportation in India and in many countries. A passenger bus plays an important role in public transport. The capacity of carrying more passengers compared to other road transport medium is unfavorable in the event of major bus accident.

"Though rollover crash occurs less frequently, the higher risk of serious injuries and fatalities makes the study of rollover analysis and providing solution becomes imperative"

A large number of road accidents take place every year causing many fatalities and severe injuries to the vehicle occupants. If adequate attention is given to injury prevention, by making the vehicles inherently safer, this problem can be reduced. Among the various modes of vehicle crashes, rollover crashes are often very severe and threatening to vehicle occupants. Though rollover crash occurs less frequently, the higher risk of serious injuries and fatalities makes the study of rollover analysis and providing solution becomes imperative.

CONCERNS AND CHALLENGES

Sleeper coach buses generally travel during night time; because of less visibility, high speed and driver's tendency to sleep in night time, the chance of fatal accidents is high. Also mass and C.G. of sleeper buses is high when compared to that seating buses; higher pitch of window pillars, for better visibility to passengers, in sleeper buses reduces the strength of superstructure. Overall sleeper coach buses are vulnerable to accidents compared to seating buses. But irony is that, worldwide no standard is available to address these concerns of sleeper bus rollover.

In India, AIS-031 states the methods to evaluate the strength of the structure of the passenger bus and thereby guiding the safe manufacturing of coach. In the same way, AIS-119 laid for special requirements for sleeper coaches coming under Type IV of the Bus Body Structure vehicles bearing of more than 13 passengers or above excluding driver. General understanding is that the sleeper coach bus has higher strength, as it has more structural member of berth, compared to seating bus. But, extension of survival space at the upper berth, which is close to the first impact, has increased the chance of structural intrusion in the survival/residual space. This plays crucial role in development of crashworthy superstructure of sleeper coach buses.

The superstructure of the vehicle must be of capable to ensure that during and after it has been subject to rollover -

- No displaced part of the vehicle intrudes into the residual space, and
- No part of the residual space projects outside the deformed structure.

The rollover test on a complete vehicle is the most preferred way of testing because of better accuracy of results and good repeatability. There are minimum assumptions in this method. But it is the most expensive method as precise instrumentation is required during testing and manufacturer has to sacrifice the complete bus. Furthermore the method will not provide any solution if the structure does not meet the requirements of the regulation. Now a days CAE methodology is very well developed and is widely used for evaluation of impact scenarios in automotive industry.

RESIDUAL SPACE DELINEATION FOR SLEEPER COACH BUS

As the residual space is extended in case of sleeper coach buses, the main challenge is to make the structure strong enough to meet the requirements of AIS 119 in case of rollover of buses. Thus residual space delineation is crucial parameter for evaluation of crashworthiness of sleeper coach buses in case of rollover.

The residual space is the space within passenger compartment which is sweptback when the transverse vertical plane outlined in Fig. 2. Residual space dimensions are defined with respect to reference point 'SR'. SR point is positioned on top surface of cushion and at 150 mm from side structure. Other dimensions of transverse vertical plane are derived from 50th percentile dummy dimensions. The transverse vertical plane is then moved from the front most berth to the rearmost berth connecting all the SR points. Depending upon berth size, there are two residual spaces: single berth residual space and double berth survival space. Residual space outlined in Fig. 1 represents longitudinal arrangements for berth as per AIS119.

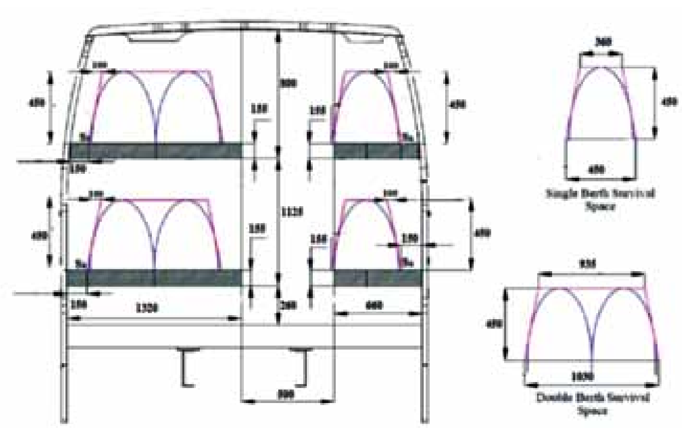

Figure 1 : Residual Space Templates for Longitudinal Layout

CASE STUDY

Finite Element Modelling

As rollover mechanism of sleeper coach is same as that of buses with seats (AIS-031), rollover analysis of sleeper coach is carried out using correlated simulation method. Rollover impact takes place on the sides of the bus, the main load bearing members are the superstructure members of the bus. The parts of the bus model lying below the position of center of gravity contribute very little in absorbing kinetic energy. The major part of kinetic energy is absorbed by the superstructure members in the form of deformations. Hence the energy absorbing components of superstructure were modelled in detail. To keep computational time reasonably low and at the same time maintaining accuracy, minimum element length used is 5 mm. Triangular elements are avoided as possible as and Quad elements are preferred for accurate results. Welding connections are modelled by 1D elements. Residual space is modelled as deformable element and connected using rigid and spring elements. After developing a detailed finite element model of the sleeper coach, overall mass and CG of the model is matched with actual sleeper coach bus prototype. Fig. 2 shows FE model for the sleeper coach.

Figure 2 : FE model of Sleeper Coach Bus

Rollover Simulation of Sleeper Coach Bus

ARAI has developed a validated methodology for generation the FE model and FE setup of seating bus as per AIS 031. FE analysis for seating bus is carried out using non-linear FE software; results are been closely correlated with physical rollover tests. This methodology is now very well established and is widely deployed for evaluation of bus rollover. Based on the confidence on the methodology, ARAI is now successfully using CAE for certification of buses as per AIS 031.

The same methodology is used for setup preparation and analysis of sleeper coach bus. Ground is modelled 800 mm below the platform by using rigid wall definition. Bus model is rotated along with platform about the bottom edge of stopper plate till the stability angle is reached, then rotate the model alone about the top edge of stopper plate till it just touches to the ground. An initial velocity and gravity is applied to all the components of the model. Fig. 3 shows the just before impact condition.

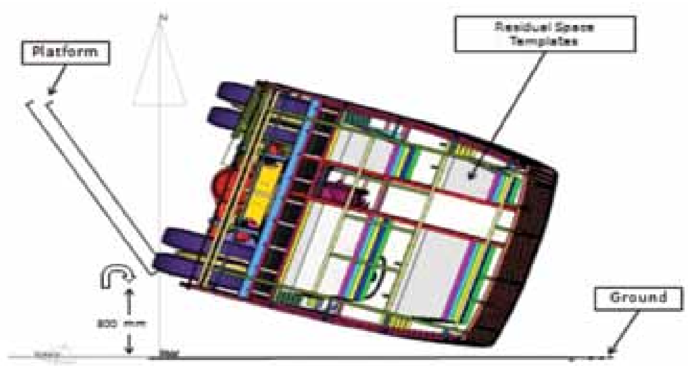

Figure 3 : Final Position of Bus Rollover

Elasto-plastic material model is assigned to realize the plasticity effect once stresses induced crosses yield stress.

Material property are as follows:
Density = 7860 kg / m3
Young's Modulus = 210 GPa
Yield Stress = 250 MPa
Poisson's Ratio = 0.290
Tensile Strength = 410 MPa

Rigid material is assigned to the impact floor, engine, tyres and other non-deformable parts

Validation of numerical simulation with respect to bus rollover is done by verification by analytical calculation of total energy.
Total energy of simulation = 96 kJ
Potential energy of bus when
CG at highest position = m x g x Δh
Mass = 13100 Kg
Gravity due to acceleration = 9810 mm /sec^2
Δh = 750 mm

Fig. 4 and Fig. 5 depict simulation results of deformation of bus during rollover. It was found that the residual space

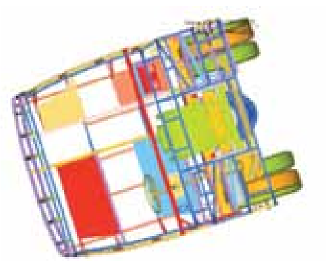

Figure 4 : Un-deformed

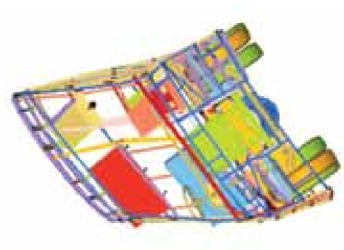

Figure 5 : Deformed

modeled as templates are penetrating into side structural members of the bus and hence structure does not meet the above requirements of standard specified earlier.

Intrusion in terms of % of initial clearance between superstructure and template are given in Table 1.

Table 1 : Intrusion in Terms of % of Initial Clearance at Templates

Berth No	1	2	3	4	5	6
Upper Berth	-57	-50	-47	-46	-46	-45
Lower Berth	-57	-50	-49	-45	-43	-43

STRUCTURAL MODIFICATIONS

Diagonal Members in Berth Structure

A diagonal member as shown in Fig. 6 directly transfer the impact load to floor structure, thus helps to improve strength of body superstructure. Two rectangular cross section members at upper and lower berth structure were added at every berth structure.

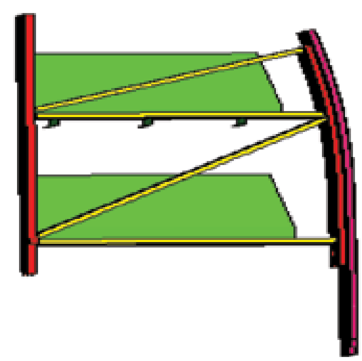

Figure 6 : Diagonal Members in Berth Structure

Thickness Increase of Vertical Pillar

Thickness of vertical pillars was increased by 20%, this had improved bus body superstructure strength.

Stiffeners at Plastic Hinges

Stiffeners were added at the locations Fig. 7 where plastic hinges got developed, this helped to transfer impact load to floor and then to chassis.

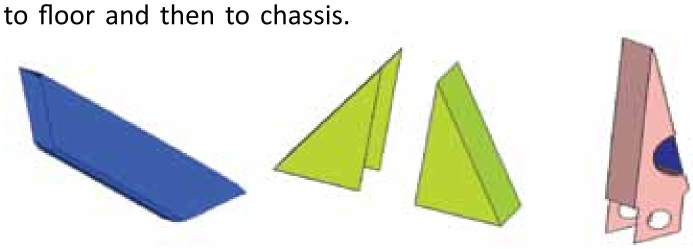

Figure 7 : Stiffeners

Rollover Analysis on Modified Structure

Simulation of bus rollover was carried out as per AIS-119 and following results were obtained after modification and super structure strengthening.

Fig. 8 shows that the residual space modeled as templates is not penetrating into the side structural members of the bus, thus fulfilling the requirement of AIS-119. Clearance in terms of % of initial clearance between superstructure and template are given in Table 2.

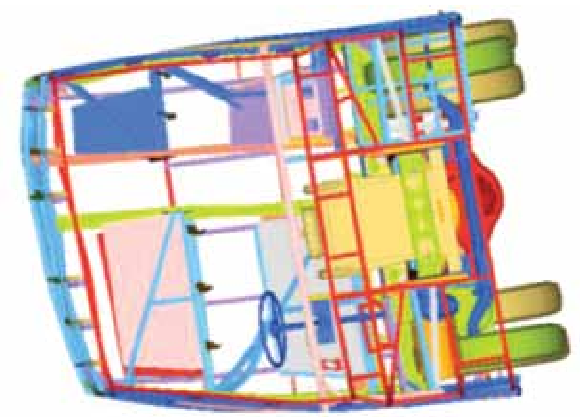

Figure 8 : Deformed Structure

Table 2 : Clearance in Terms of % of Initial Clearance

Berth No	1	2	3	4	5	6
Upper Berth	85	79	79	76	70	68
Lower Berth	74	69	69	65	61	58

CONCLUSION

- Residual space was developed for sleeper coach buses to address passenger safety in case of rollover.
- Upper berth in sleeper coach buses increases chances of intrusion.
- With appropriate changes in superstructure design, it was possible to meet the requirements as per AIS 119.
- Simulation based certification could be a cost effective option for Type Approval of sleeper coach buses as per AIS 119.

Current Helmet Scenario for Tropical Countries

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In low and lower-middle income countries, the main form of transportation is motorcycle. In few countries, progress in economy has suddenly increase in the number of motorcycles. Motorcycle markets in these countries have rapidly developed particularly rapidly. As a general rule, the poorer the country the higher the motorcycle fleet growth rate. Due to increase in motorcycles on the roads, there will be an increase in risk of accidents, if standardized helmets are not used.

Motorcyclists are 26 times more likely to die in an accident than the passenger car driver. Wearing an appropriate helmet improves their chances of survival by 42% and helps avoid 69% of injuries to riders.

"Wearing an appropriate helmet improves their chances of survival by 42% and helps avoid 69% of injuries to riders"

CHALLENGES

Evidence that wearing a proper helmet significantly improves the chances of surviving an accident is overwhelming. Yet a large number of riders persist in riding without helmets, or with the chinstrap undone.

Some of the reasons for avoiding to wear helmets are:

- Peer pressure among young riders, e.g. ridiculing helmet-wearers
- Helmets are only needed for long trips
- Helmets are considered hot and uncomfortable, e.g. tropical climates
- The damaging effect on women's hairstyles
- The issue of special headgear, e.g. turban

Need of harmonized helmet standards and regulations

Motorcyclists are more prone to die in an accident than car passengers (NHTSA, 2015). This can be reduced by implementing a set of standards and other regulatory activities.

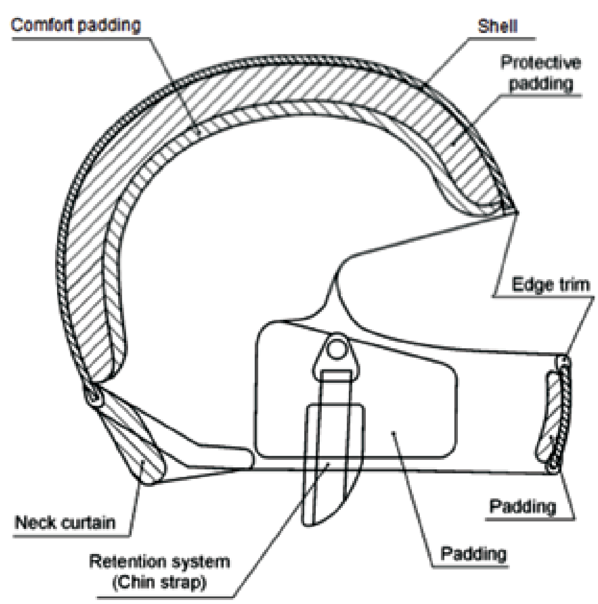

Figure 1 : A Typical Helmet Structure
Source: UN Regulation No. 22

DEVELOPMENT OF HELMET STANDARDS AND REGULATIONS

At early days, all helmet standards were closely allied with motorcycle racing. Successive research into accident and improvement of helmet properties has ledto improvement in the quality of helmets and it is benefitted both the racer as well as motorcyclist.

The first investigation of helmet effectiveness was done in the United Kingdom and Northern Ireland in 1940's. The results were helped to develop an outline for the making of helmet standards. It was followed by British Standard 2001:1953 - Protective Helmets for Motor Cyclists (Yoganandan, 1998). Succeeding helmets were embossed with the British Standards Institute (BSI)certification.

At the global level, UNECE, in the context of the "1958 Agreement on the type approval of vehicles, equipment and parts 16", created a motorcycle helmet regulation in 1972, which is in its series of amendments. UN Regulation No. 22 provides uniform conditions for the approval of protective helmets for drivers and passengers of motorcycles.

Although there are so many global helmet standards, many countries still prefer to adopt national standards. This situation can be observed in low and middle income countries. Thus there is the need to harmonize standards.

THE PROBLEM OF NON-HARMONIZED STANDARDS

If countries are following different standards for the regulation of protective helmets, it creates barriers to trade and progress and so safety improvements. Differences in standards may increase expenses to manufacturers and can delay progress.

The problem is the varying levels among standards. Different standards and regulations works on different levels of performance. Some country standards may omit tests that others require. Below table illustrates differences between some existing standards.

Different national regulations also create barriers to trade, requiring manufacturers to design helmets to meet each individual standard and to test them in each country. These costs are passed on to the consumer.

Although it might be feasible to design a protective helmet that can meet all existing regulations, most likely it would be expensive, particularly if it had to be tested according to many different national standards.

Concerns regarding use of helmet in tropical countries

There are certain concerns with helmet in low as well as lower-middle income tropical countries. These issues hinder the growth of helmet usage. Researchers conducted a survey of issues in use of helmet. Some key issues are highlighted here:

- Weight is the primary concern to avoid use of helmet. People feel pressure on neck. They also feel that it creates back pain
- Available helmets are poor in vision. Its visibility decreases during rainy season. Glare of incoming light of vehicles causes difficulty in vision
- Also some respondents complained that helmets are poor in aesthetic as well as in ventilation
- Continuous and prolonged use of helmet can increase hair loss as well as baldness. They also mentioned that helmet damages the hair style
- People also have concern about audibility. It is greatly reduced during its use. Also communication with pillion rider is a cumbersome task
- People need to carry it everywhere when not in use

WHAT TROPICAL COUNTRIES CAN DO?

There are few steps to improve helmet usage of tropical countries. These steps can introduce a tropical-friendly helmet.

- Available helmets to tropical consumers are hot, heavy, uncomfortable and with no ventilation
- Current standardized helmets are safe, but these are not suitable for tropical conditions. Not all international standards allowed for ventilation. Revision of international helmet standard as per the environmental conditions can be done
- Tropical helmets should be light in weight, head coverage area, proper peripheral vision, adequately ventilated and with open hearing areas
- Cost of helmet can be reduced with the fulfillment of standards. Helmets should not be expensive, so they can be wear every day with a common man
- Quality and standardized helmets should be widely available everywhere

A CASE STUDY : THE VIETNAM HELMET STORY

In 2007, traffic accidents killed around 14,000 Vietnamese, of which 60 percent were motorcycle riders and other caused severe injuries. These numbers were not only emotional but also economic. In early years, cost of road accidents were US$900 million each year, which is equal to 2.7% of the country's gross domestic product.

Regardless of risks, motorcycles are the primary mode of transportation. As the economy sped up rapidly, the number of motorcycles on the road steadily climbed. Standardized helmet reduces the risk of death up to 40% and the risk of serious injury by 70%. Because of crowded streets, the country had a high traffic fatality rate.

Table 1 : Comparison of Tests Included in Different Motorcycle Helmet Standards or Regulations of Low Income Tropical Countries

Standard Test Description	Malaysia MS 1:1996	Singapore SS 9:1992	Thailand TIS 369-2520	Viet Nam TCVN 5756:2001	Indonesia SNI 1811-2007	India IS 4151:1993	UN Regulation No. 22.05
Extent of shell/extent of coverage	✓	✓	×	✓	✓	×	✓
Shell stiffness test	×	×	✓	×	×	×	✓
Internal projections Evaluation	✓	✓	×	✓	✓	×	✓
External projections test	✓	✓	✓	✓	✓	×	✓
Visor test	×	×	×	✓	×	✓	✓
Peak flexibility test	×	×	✓	×	×	✓	×
Peripheral vision test	✓	✓	×	✓	✓	×	✓
Retention system effectiveness	×	✓	×	×	✓	×	✓
Retention system strength	✓	✓	✓	✓	✓	✓	✓
Retention strap slippage	×	✓	×	×	✓	×	✓
Retention strap Abrasion	×	✓	×	×	✓	×	✓
Retention system release by pressure	×	✓	×	×	×	×	✓
Retention system release by inertia	×	✓	×	×	×	×	✓
Retention system ease of release	×	✓	×	×	×	×	✓
Durability of quick release retention system	×	✓	×	×	×	×	✓
Impact test	✓	✓	✓	✓	✓	✓	✓
Oblique impact test	×	✓	×	✓	✓	×	✓
Chin guard test	×	✓	×	✓	✓	×	✓
Penetration test	✓	✓	✓	✓	✓	✓	×
Flammability test	×	×	×	✓	✓	×	×
Helmet marking requirements	✓	✓	✓	✓	×	×	✓
Information label requirements	✓	✓	✓	✓	×	×	✓
Rigidity Test	×	×	×	×	×	✓	×
Audibility Test	×	×	×	×	×	✓	×

PROGRAM EXECUTION

In mid-90's, the Vietnamese government had decided to take step upon motorcycle safety. Accordingly, mandatory helmet law implemented and imposed only a minor fine for noncompliance.

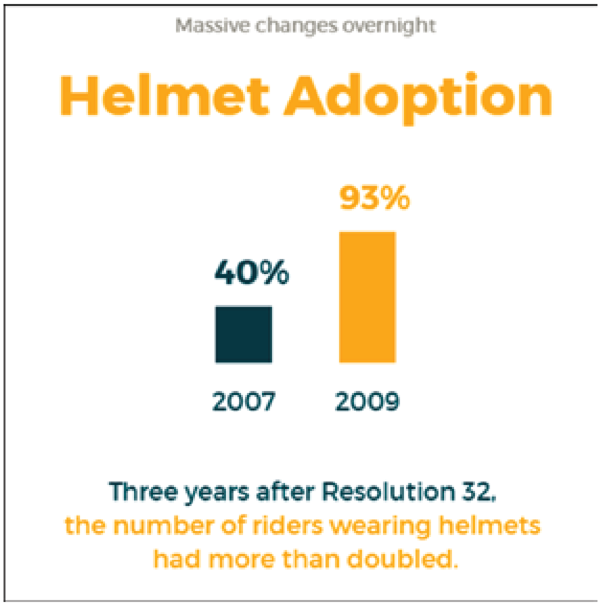

Figure 2 : Helmet Adoption Statistics

In 2007, Vietnam's Prime Minister Nguyen Tan Dung introduced a new compulsory helmet law, "Resolution 32," which made use of helmet became mandatory for all motorcycle drivers and passengers. Following this strong lead, the law went into full effect nationwide. The inaugural "Helmet Day" was held on December 15, 2007.

IMPRESSION

The government established a system to track road traffic injuries and deaths. From a sample of hospitals, after the law enforcement, it is observed that 16 % reduction in head injuries and 18% reduction in the death.

The police also monitored implementation of the law. Researchers analyzed the police data. The police data may be missed unreported injuries and fatalities. This may generate under estimates. A global study found that a systematic implementation of law can greatly reduce traffic injuries, the health system, and the economy.

REASONS FOR SUCCESS

The success of the 2007 helmet law was made possible by strong implementation of law and its enforcement. Since then, policy makers have closed nooks and given the proper form of helmet law.

Figure 3 : Risk Statistics After Implementation of Helmet Law

Government also helped agencies to cater high quality and climate-friendly helmets. But at the same time, less expensive, low-quality helmets also flooded the market. The government took strong action against sub-standard helmets. Trade and customs officials helped to clamp down on the import of helmets that deceptively claim their adherence to quality standards.

CONCLUSIONS AND RECOMMENDATIONS

Some millions of passengers can be prevented from grave injuries as well as death by the proper use of safety helmets. Not only a proper helmet wearing law but also its implementation improve the safety of motorcycle riders.

Source: "How it works and how to join it" series, Part of WP. 29, The United Nations, Motorcycle Helmet Study & Vietnam Government website (Open Source), Transport and Communications Bulletin for Asia and the Pacific No. 79, 2009.


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Modeling Vibrations and Noise in a Gearbox using COMSOL Multiphysics

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INTRODUCTION

Predicting the noise radiation from a dynamic system gives designers an insight into the behaviour of moving mechanisms early in the design process. For example, consider a gearbox in which the varying gear mesh stiffness causes sustained vibrations. These vibrations are transmitted to the gearbox housing and the vibrating housing further transmits the energy to the surrounding fluid resulting in the acoustic wave radiation.

"Predicting the noise radiation from a dynamic system gives designers an insight into the behaviour of moving mechanisms early in the design process."

Here this entire problem is modelled in three stages:

CONTACT ANALYSIS

As a first step, the variation of gear mesh stiffness in a mesh cycle is computed using the contact analysis.

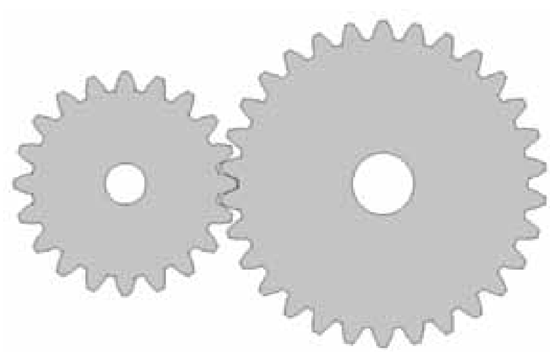

Figure 1 : Model Geometry of a Gear Pair for Computing the Gear Mesh Stiffness

MULTIBODY ANALYSIS

In the second stage, the computed gear mesh stiffness is used in gear pair nodes in order to compute the dynamics of gears and the vibrations in the housing.

ACOUSTICS ANALYSIS

In the end, a spherical domain enclosing the gearbox housing is created in order to perform frequency domain analysis to compute the sound pressure levels outside the gearbox.

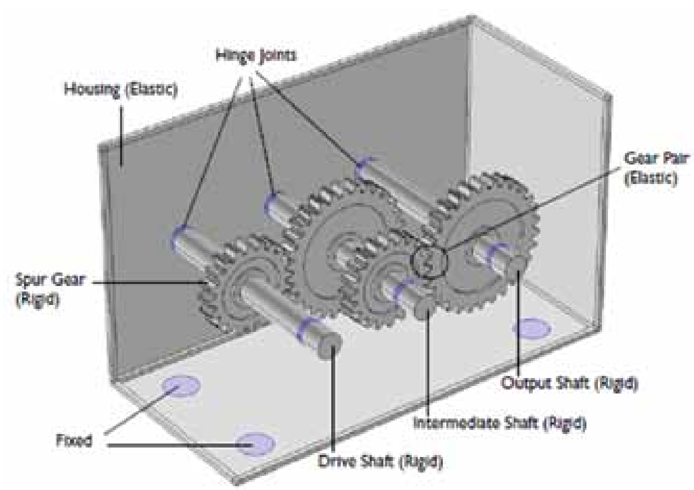

Figure 2 : Model Geometry of the Gearbox Where the Fixed and Hinged Locations are Highlighted

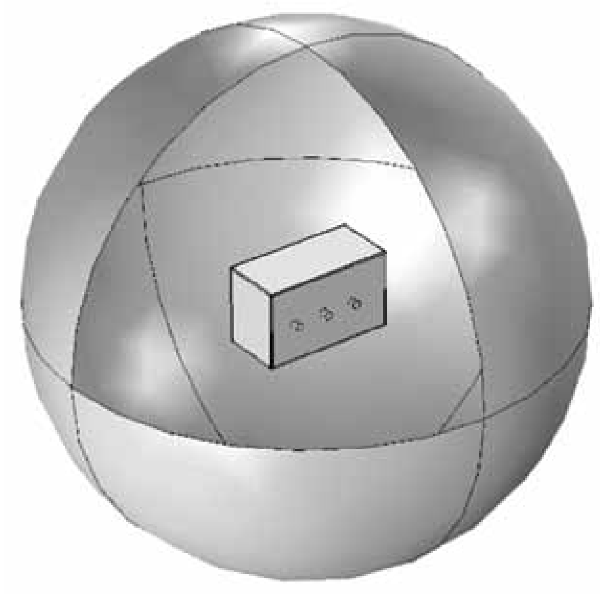

Figure 3 : Model Geometry of Theacoustic Domain Enclosing the Gearbox

The normal acceleration computed on the housing is used as a noise source for the acoustic domain.

STEP-1 : CONTACT ANALYSIS - COMPUTATION OF THE GEAR MESH STIFFNESS

In the gearbox, as shown in the Fig. 2, there are two pairs of spur gears and both of them are of the same size and made up of same material. Hence the gear mesh stiffness can be evaluated for any single pair of gears. Moreover, in order to reduce the computation time, the cross-section of gears, as shown in Fig. 1, is used to compute the gear mesh stiffness.

GEAR PROPERTIES

The properties of the wheel and pinion are given in the Table 1. The structural steel is used as a material for the gears.

Table 1 : Gear Properties

Properties	Wheel	Pinion
Number of teeth	20	30
Pitch diameter	50 [mm]	75 [mm]
Pressure angle	25 [deg]	25 [deg]
Gear width	10 [mm]	10 [mm]

CONTACT METHOD

A contact, using penalty method, is modeled between the two gears.

CONSTRAINTS

The pinion and wheel rotations about the out-of-plane axis are prescribed. They are incrementally increased in such a way that the pinion is rotated for two mesh cycles. The wheel rotation is computed using the gear ratio as well as it accounts for some twisting which essentially gives rise to the contact forces.

GEAR MESH STIFFNESS

The wheel is given a twist and the required twisting moment is computed on the hinge joint. The torsional stiffness of the gear pair can be computed using the above information and the stiffness along the line of action can then be defined using torsional stiffness, pitch radius, and pressure angle.

The gear mesh stiffness is different for different positions of gears in a mesh cycle. Hence, both the gears are rotated parametrically to compute the variation of gear mesh stiffness in a mesh cycle.

STEP-2 : MULTIBODY DYNAMICS - VIBRATIONS IN A COMPOUND GEARBOX

The gearbox considered here has a drive shaft connected to an intermediate shaft and the intermediate shaft is connected to the output shaft. Both ends of the shafts are connected to the elastic housing through hinge joints. The housing is mounted to the ground at the locations shown in the Fig. 2.

SHAFTS, GEARS, AND HOUSING

All the shafts and gears are assumed rigid, whereas the gear mesh is assumed elastic. The stiffness of the gear mesh is computed in the first part of the model. The housing is assumed flexible and made up of structural steel material.

Constraints and Loads:

- The drive shaft rotates with an angular velocity of 600 rad/s
- An external torque of 100 N-m is applied on the output shaft

STEP-3 : ACOUSTICS ANALYSIS - VIBRATIONS IN A COMPOUND GEARBOX

MULTIBODY-ACOUSTICS COUPLING

In order to couple multibody and acoustics physics, if the exterior fluid is air or any other lighter fluid, one-way coupling can be assumed. It implies that the vibration from gearbox housing impacts the surrounding fluid whereas the feedback from the acoustic waves to the housing is neglected.

FFT SOLVER

The multibody dynamics is solved in the time domain whereas the acoustics is solved in the frequency domain. Therefore FFT solver is used to convert the housing accelerations from time to frequency domain.

DOMAIN EQUATIONS

This model solves the acoustics equations in the frequency domain which is slightly modified version of the Helmholtz equation for the acoustic pressure.

BOUNDARY CONDITIONS

The following boundary conditions are applied in the acoustic domain.

- The normal acceleration of the gearbox housing is applied on the interior boundaries
- The spherical wave radiation condition and the far-field calculation is applied on the exterior boundaries

MODEL PARAMETERS

The domain material is chosen as air. The following parameters are used in the model:

- The excitation frequency is 2000 Hz
- The size of enclosing sphere is 0.5 m
- Far field results are evaluated at a distance of 2 m from the center

RESULTS AND DISCUSSION

The von-Mises stress distribution in the gear pair during the contact analysis is shown in Fig. 4. It can be seen that the stresses are high at the contact points as well as at the roots of the teeth.

Fig. 5 shows the variation of computed gear mesh stiffness with the pinion rotation. It is computed for two mesh cycles and it can be seen that it is periodic in mesh cycle. Within a mesh cycle, the gear mesh stiffness increases in the beginning, and later it decreases. This happens because of the change in the contact ratio which switches from 2 to 1.

The variation of the contact force in both the gear pairs is shown in the Fig. 7. It can be seen that the contact force continuously changes as the gear rotates and the mean value of contact force on the second gear pair is higher than that for the first gear pair.

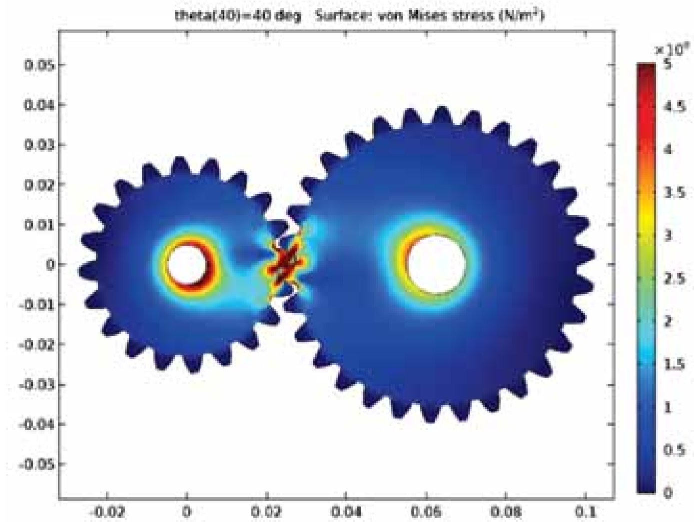

Figure 4 : Von-Mises Stress Distribution in the Gear Pair at a Particular Position in Mesh Cycle

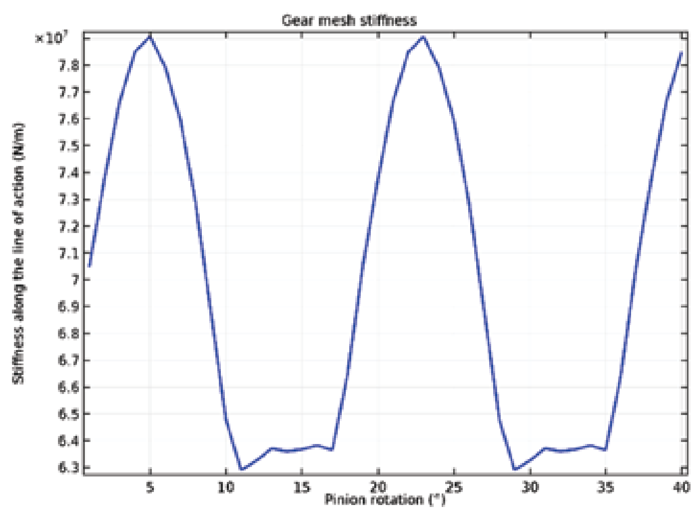

Figure 5 : The Variation of Gear Mesh Stiffness with Pinion Rotation

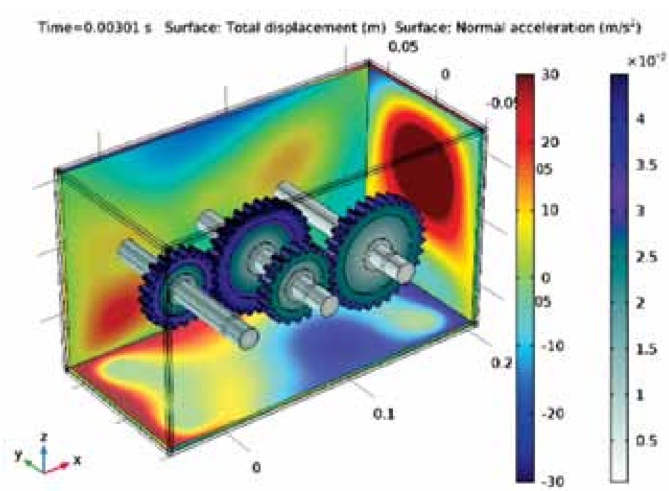

Figure 6 : The Displacement in Gears and the Normal Acceleration in the Housing at a Particular Instance

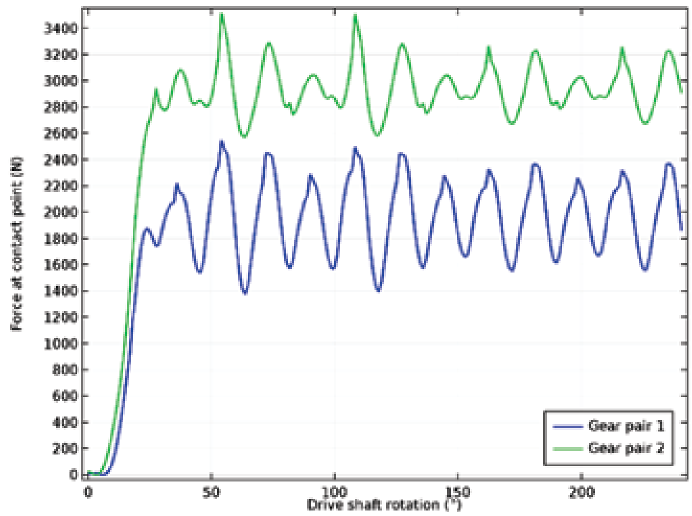

Figure 7 : The Variation of Contact Forces

Fig. 8 shows the frequency spectrum of the variation of normal acceleration at a particular location on the housing. In the frequency content, it can be seen that there are two dominant frequencies near 550 Hz and 2000 Hz at which the housing is vibrating.

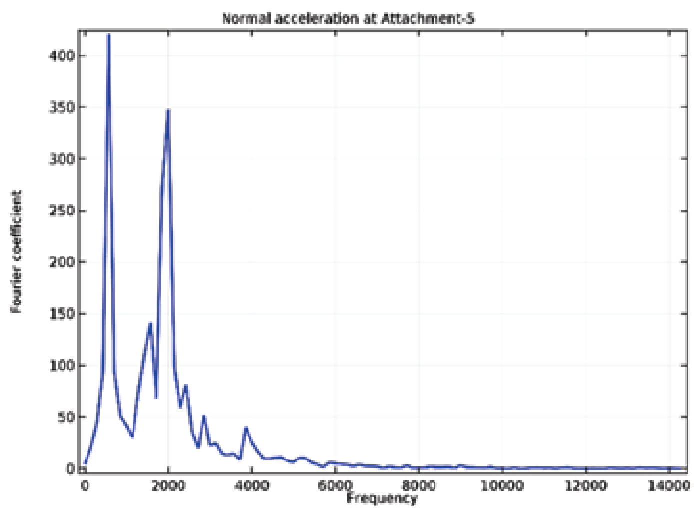

Figure 8 : The Frequency Spectrum of the Normal Acceleration at a Particular Location on the Housing

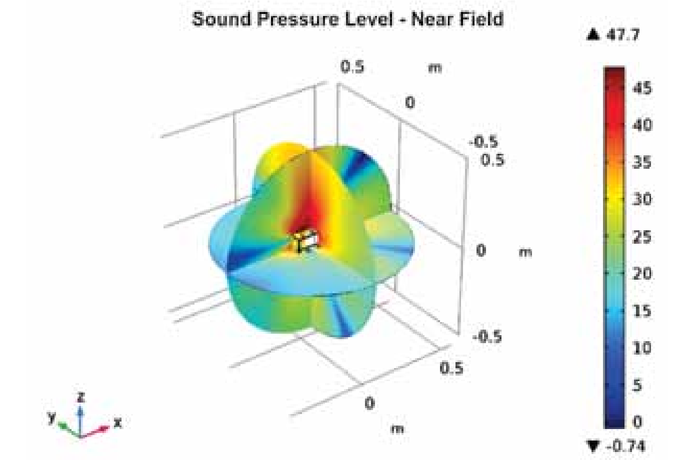

Figure 9 : Sound Pressure Level (dB) in the Near-field Region at 2000 Hz.

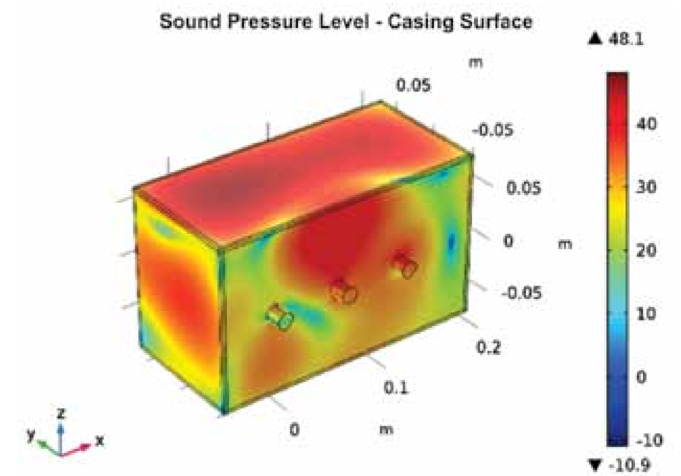

Figure 10: Sound Pressure Level (dB) on the Casing Surface at 2000 Hz.

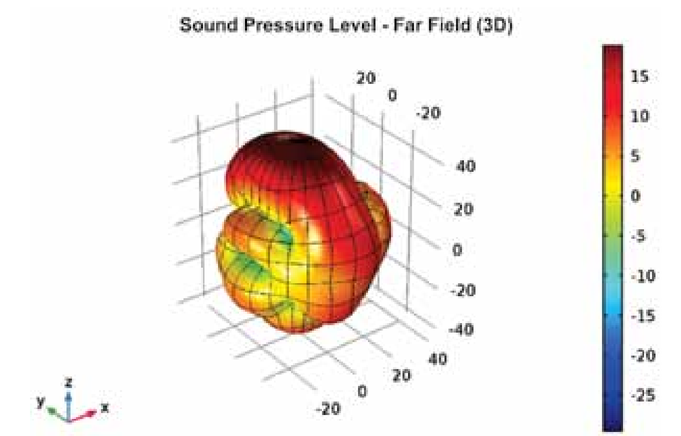

Figure 11: Far-field Sound Pressure Level (dB) at a Distance of 2 m at 2000 Hz

Fig. 9 shows the sound pressure level (SPL) in the acoustic domain. Different values of SPL can be seen at different locations in acoustics domain where the maximum value of SPL is at the top of the gearbox. The 3D far-field plot of the sound pressure level is shown in Fig. 11. This gives an idea of the dominant directions of noise radiation.

SUMMARY

This paper describes a technique to couple multibody and acoustics simulation in order to accurately compute the noise radiation from a gearbox. This technique can be used early in design process of the gearbox and hence the design can be improved in such a way that the noise radiation are minimal in the operation speed of the gearbox.

High Frequency NVH Solutions using Statistical Energy Analysis (SEA)

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Noise and Vibration is often associated as one of the first impression quality criterion while assessing quality of a product High frequency NVH problems like vehicle in-cab noise, aero-acoustic noise, enclosure design building acoustics and HVAC duct noise are challenges for today's designers. SEA based simulation is emerging as a promising alternative to address these problems reliably in early design cycle.

Recently, ARAI has developed capability for SEA based high frequency noise simulations aided by conventional CAE tools to provide much needed complete frequency range solutions for automotive and non-automotive applications.

NEED FOR HIGH FREQUENCY NVH SOLUTION

For the structures with high frequency excitations, it is not technically or economically feasible to estimate the responses using the traditional Finite Element Method (FEM) and Boundary Element Method (BEM). Firstly, computational model size becomes huge demanding excessive computational resources with longer solution times. Secondly, high frequency modes are sensitive to small variations of the system properties and lack of precision in modeling introduces uncertainty and non-reliability.

> *"SEA based simulation is emerging as a promising alternative to address high frequency NVH problems reliably in early design cycle"*

Limitations of Conventional NVH Simulation Tools (For High Frequency Analysis)

- Excessive computational resources
- Longer solution time
- Inability to model uncertainty

Features of SEA

- Quick analysis and solution
- Modest computational resources
- Sensitivity of property variations taken into account
- FEM models created for other analysis can be readily used
- Useful in early vehicle development where prototype is not available

In SEA approach the uncertainty factor is in-built considering statistical behavior of a population of systems. SEA model is thousand times smaller (very few degrees of freedom) than its conventional equivalent. It is quick to build and analyze using modest computational resources.

SEA is very effective in new product development cycles where concepts are still evolving and prototypes not available. Many new vehicles are based on previous-generation vehicle with enough NVH similarities. For those problems benchmark vehicle test information incorporated in SEA analytical models helps in quick solutions.

TYPICAL HIGH FREQUENCY NVH APPLICATIONS

Vehicle Interior Air Borne Noise Solutions

a) Sound Package Optimization

Conventionally sound package optimisation is done at very late stage of vehicle development and it mainly involves benchmarking, evaluation of predecessor or competitor vehicle and validation on vehicle prototype through trails and error iterations. It adversely affects product delivery time lines leading to penalty of cost and time. For getting quicker solution in early phase SEA becomes handy tool. Many new vehicles are based on an existing platform/ previous-generation vehicle and have enough similarities from an NVH standpoint for which the main noise transfer paths from sources of interest are already understood via test results and existing targets.

SEA uses the analytical models and test information from the earlier vehicles to guide development of the new vehicle. For reliable SEA results different noise sources like engine, exhaust, intake, tyre patch noise and vibration inputs from suspension locations should be included in model. These source data are obtained from test on vehicle at static and dynamic conditions. The effect of changes to materials, gauge thickness, sound package, or geometry changes on the interior noise levels can be predicted with good accuracy. Diverse vehicle body styles and sound package variant concept scan be analysed effectively.

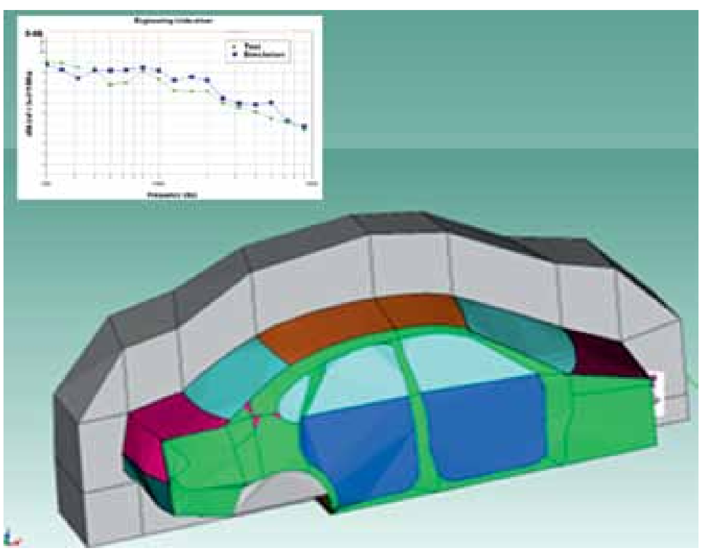

Figure 1 : Vehicle Sound Package Simulation

b) Acoustic Seal Design

Door seals and pass through play vital role in improving sound insulation inside the cabin. These can be effectively analyzed and quick iterations are possible by unique Hybrid FE-SEA approach.

c) Noise Path Analysis

Critical noise paths through which energy is transmitted from source to the target location can be predicted by SEA. Relative contribution and rank of each path helps in exploring design solutions.

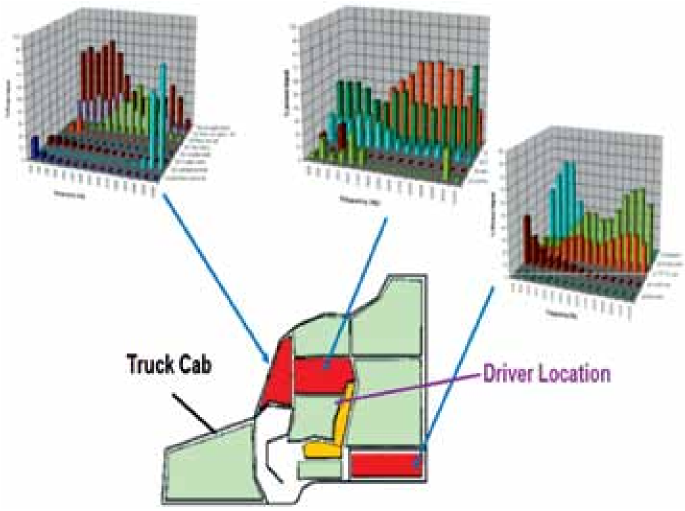

Figure 2 : Vechicle Noise Path Analysis

d) Fire Wall Acoustic Design

Vehicle Dash panel or any partition panels in building acoustics can be designed for better insulation of airborne noise sources.

Panels are optimized for geometry, damping treatment and type of insulating material for betterment of transmission loss at critical frequencies.

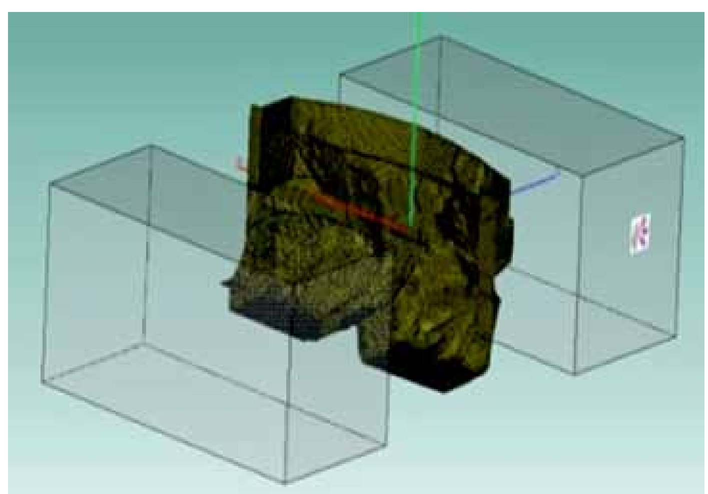

Figure 3 : Firewall Simulation

HIGH FREQUENCY AERO-ACOUSTIC SOLUTIONS

Aero-acoustic noise sources like wind noise, side mirror noise, turbulent boundary layer noise can be addressed by coupled CFD-SEA solution with good accuracy.

ACOUSTIC ENCLOSURE DESIGN

Acoustic enclosures for diesel gensets, compressors and engine partial covers can be designed for lower noise emissions with optimum absorbing treatment. Interaction between closed cavity, acoustic and thin metal panels is modeled by classical SEA approach. Path contribution and sensitivity analysis can be carried out on enclosure to find out major contributors to exterior radiated noise. Quick Optimization is possible using parametric iterations on noise path modifications (ducts, partitions), acoustic treatment thickness, leakage minimization and acoustic louver design based on preceding results.

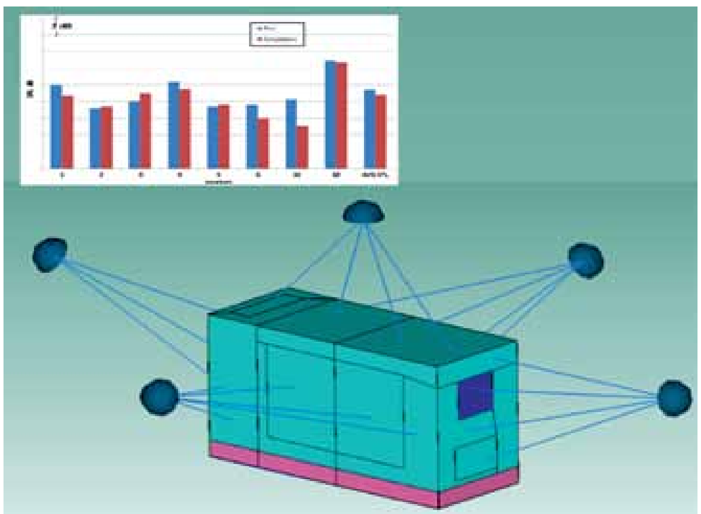

Figure 4 : Acoustic Enclosure Design

LARGE DUCT / PLENUM DESIGNS

HVAC/ industrial ducts can be analyzed above plane wave cut off frequencies capturing diffuse fields. Reliable solutions possible for layout optimization and acoustic lining design. Ready to use design charts showing effect of acoustic lining thickness, length and duct cross section on Insertion loss prediction can be arrived at through SEA simulation.

ACOUSTIC MATERIAL CHARACTERISATION FOR SEA INPUTS

Accuracy of SEA predictions depends largely on precise test inputs like acoustic material BIOT properties,transmission loss, Insertion loss evaluation and noise source characterisation at component and system level. These test parameters are evaluated accurately at ARAI using state of the art test facilities and material evaluation test rigs.

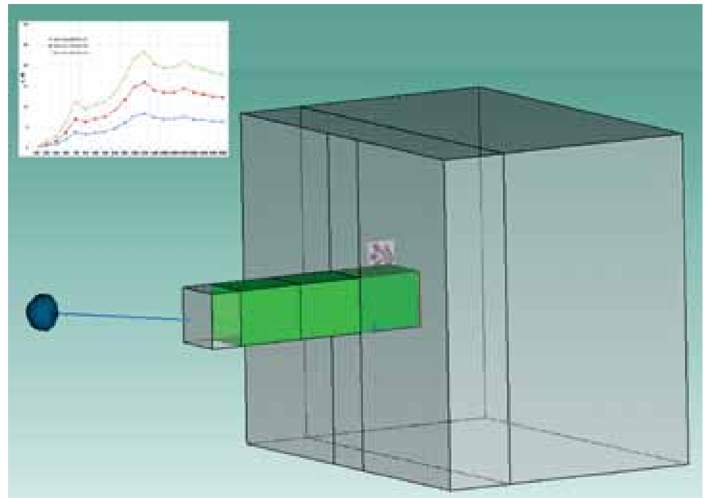

Figure 5 : Large HVAC Duct Simulation

Intrinsic Parameters		Unit	Value
Flow Resistivity	(σ)	[Ns/m⁴]	11858
Porosity	(ϕ)	[-]	0.98
Tortuosity	(α_∞)	[-]	1.7
Viscous Length	(Λ)	[μm]	72.5
Thermal Length	(Λ')	[μm]	362

Figure 6 : BIOT Parameter Evaluation Setup

CONCLUSION

SEA simulation technique supported with state of art test infrastructure with can be reliably used in developing world class, quieter and better products addressing high frequency problems.

Structure Borne Noise Optimization of Diesel Engine by Simulation

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INTRODUCTION

The objective of this study is to reduce the radiated noise of diesel engine by 3 dB (A) in the frequency range up to 3 kHz. The engine speed is in range from 800 rev/min to 2200 rev/min. To investigate design modifications that would reduce radiated noise and vibration of the engine, whilst being cost-effective to implement. This would enable the engine to achieve a longer production life cycle and provide future vehicle platforms with a more refined powertrain. Engine Specification is Described in Table 1.

> *"The hybrid approach of structural modifications and material changes used; helped in reducing noise level of engine to meet set noise level targets with a minimal increase in overall mass"*

Table 1 : Engine Specification

Type	Diesel Engine
Configuration	3 cylinder, in-line air-cooled
Displaced volume	2980 cc
Stroke	100 mm
Bore	125 mm
Firing order	1-3-2

METHODOLOGY

The detailed methodology followed for noise prediction and refinement is shown in Fig. 1.

DATA ACQUISITION OF ENGINE

The 3 Cylinder Air cooled 50 Hp Engine is tested in Hemi-Anechoic chamber on a test bed with full load and no load condition. The Microphone Positioning is kept on Engine as Shown in the Fig. 2.

Sound Intensity and Noise Source Identification Sound intensity mapping technique is done for noise source identification.

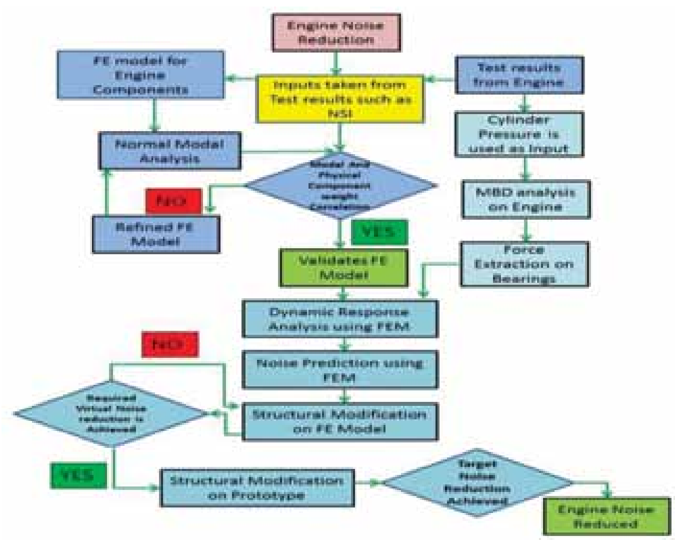

Figure 1 : Methodology for Noise Prediction and Refinement

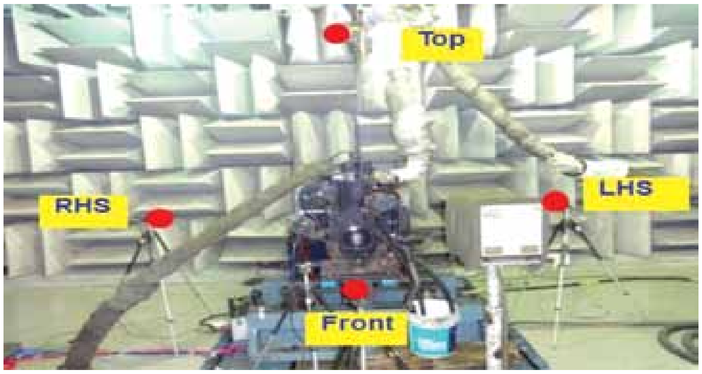

Figure 2 : Engine on Test Bed

Engine structure borne sources are mainly crankcase, timing gear cover, tappet cover, cylinder head and accessories like fuel pump, alternator. Spectral content of overall noise level of the sources depend upon its modal properties, surface area and its vibration velocities during operation. It is easy to reduce overall noise level if percentage contribution of each radiating component is known. The sound power evaluation was carried out using ISO 3744 to quantify the noise in terms of its level and spectral content. The maximum SWL of 98 dB(A) is observed at rated rpm full load condition. The results of sound intensity mapping is shown in Fig. 3. The crank case, Fan and Cylinder head with Tappet cover are top three noise ranking components. The engine component vibration measurement using accelerometers is also carried out to identify the structural resonance and its co-relation with radiated noise.

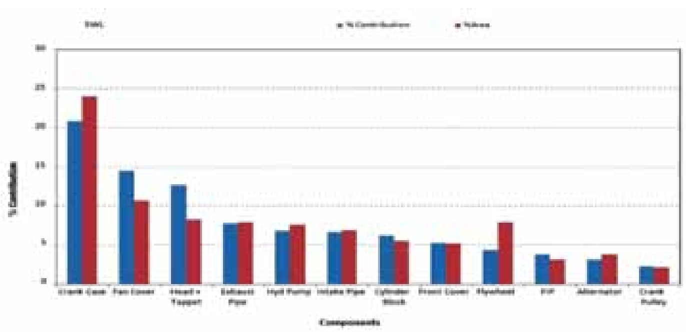

Figure 3 : Results of Noise Source Contribution

FINITE ELEMENT MODELING

The CAD models are converted in to finite element models by meshing, assigning material and property for the components. Meshing is divided in to two types: Structural meshing and Acoustic meshing. The FE model of engine assembly is shown in Fig. 4.

MODAL ANALYSIS AND CORRELATION

Component level modal analysis was performed for each of the major components in the engine assembly. Predicted results were compared against experimental modal test results and FE refinement is carried out to establish correlation. Fig. 5 shows modal testing set up of crank case. The resonant frequencies, mode shapes and damping coefficients were obtained for frequencies up to 3 kHz. Fig. 6 shows the correlation for FE modal analysis and experimental modal testing for crank case. The comparison shows good correlation in terms of frequencies. The correlation methodology described is used for all the remaining engine components.

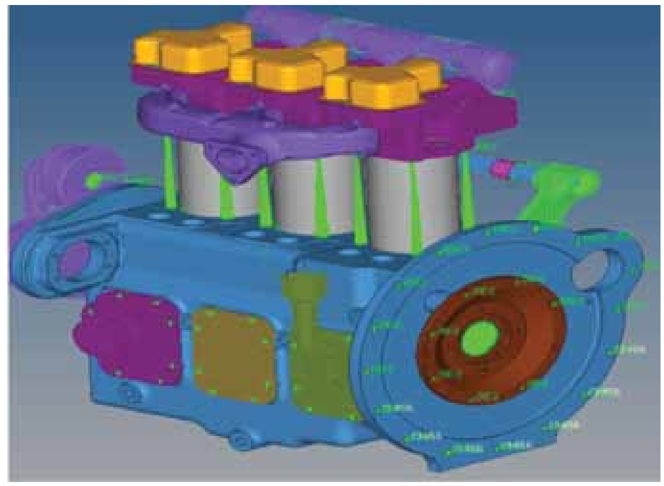

Figure 4 : FE Model of Engine Assembly

Figure 5 : Modal Testing of Crankcase

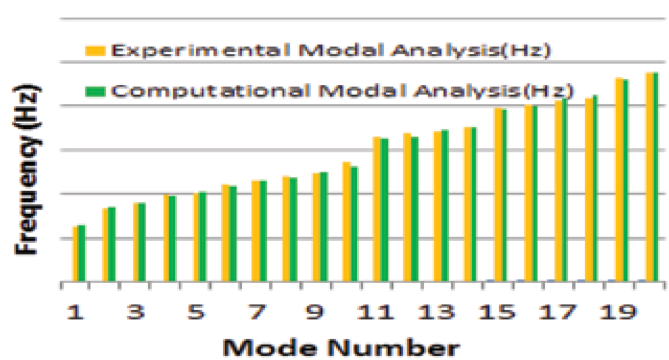

Figure 6 : Modal Correlation of Experimental and FE Result

DYNAMIC LOAD CALCULATIONS

The excitation loads acting on the engine were calculated for each of the main journal bearings using by ENGDYN. ENGDYN is used to predict the time- domain response of the 3D vibration of the coupled crank train and cylinder block system with non-linear oil films at each of the main journal bearings. The mass and stiffness matrices used for the dynamic model are derived by static condensation of the finite element model. The cylinder pressure data loading was provided from measurement data at critical engine speeds. Dynamic simulations were performed at engine speeds from 800 to 2200 rev/min at step of 200 rpm intervals. The 3D Crank shaft model is integrated with ENGDYN 1D model of crankshaft as shown in the Fig. 7. The Bearing force data is calculated at main and big bearing end at different engine speeds. The Bearing force of main bearing end at 2150 rpm is shown in the Fig. 8.

Figure 7 : 3D Crank Shaft Model Integrated with 1D Model in ENGDYN

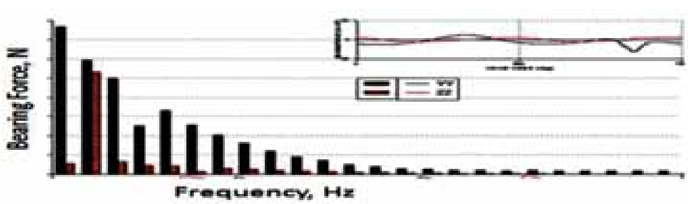

Figure 8 : Bearing Force at Main Bearing end at 2150 rpm

FORCED RESPONSE AND ACOUSTIC ANALYSIS

The excitation loads calculated by ENGDYN are used as input to perform modal frequency response analysis to predict the vibratory response of the complete engine. Based on vibration results provided by the structural analysis, the acoustic transfer function of radiated acoustic power is calculated using Actran software. The first step consists in the acoustic mesh creation. The mesh is built using classical meshing criteria. Only eight linear elements are required per wavelength thanks to specific elements characterized by reduced dispersion error.

ADAPTIVE PERFECTLY MATCHED LAYER (APML)

Perfectly matched layers (PML) at low frequency, the PML layer thickness shall be enough to absorb longest acoustic wavelength. At high frequency, the PML layer thickness shall be small enough to capture shortest acoustic wavelength. APML are added to the model, for three purposes:

1. Reduced meshing effort for modeling sound radiation problems
2. Optimized computation time for the each desired frequency
3. It generates different BC mesh surfaces for each frequency band Fig. 9 : Shows the ISO Field Point Set Up used for Prediction of Sound pressures from powertrain assembly and field points represents microphones.

Figure 9 : ISO Field Point Mesh Around the Engine Assembly

NOISE PREDICTION OF THE BASELINE ENGINE

Noise radiation of engine was predicted by obtaining SWL spectra from all sides of the engine assembly for the existing baseline model. Fig. 10 shows radiated sound power levels for critical speeds of engine at full load. Imposing frequency dependent displacement boundary conditions on engine assembly acoustic mesh and predicted virtual SWL of base model for the desired frequency range using modal ATV approach. From the results critical frequencies were identified with the corresponding mode shapes on basis of maximum sound power. Predicted sound level spectrum is in close agreement with baseline engine measured results. Dominating frequencies identified in NSI results were also observed in predicted SWL spectrum of baseline engine.

DESIGN OPTIMIZATION STUDY

A number of design modifications were carried out on upgraded engine assembly and analyzed under similar loads and boundary conditions as that of the baseline engine analysis to compare the results in terms of noise levels. Three of these modifications are described in this paper. The Optimization is done on component level and sound power is compared.

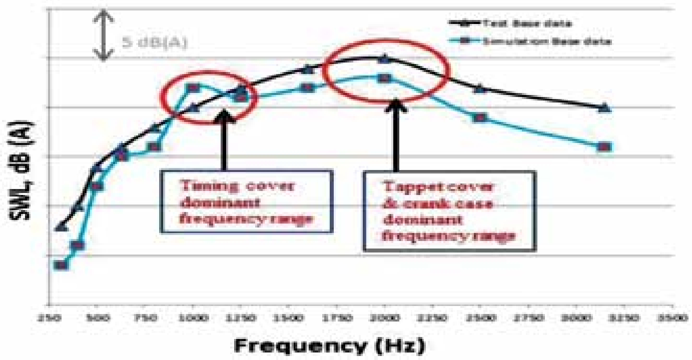

Figure 10 : SWL Spectrum of Base Engine Assembly

Modification 1 - Modifications on crankcase: Taking inference from SWL spectrum of base engine, it was observed that crankcase was one of the major contributors. At dominant frequencies (at range of 2.1 to 2.5 kHz), high strain energy was observed at wall locations and it was consistently at higher side and hence it was identified area for structural modification. Additional ribs were added on external wall of the crankcase to increase structural stiffness and reduce high strain energy. Fig. 11 shows details of modifications carried out at crankcase wall region.

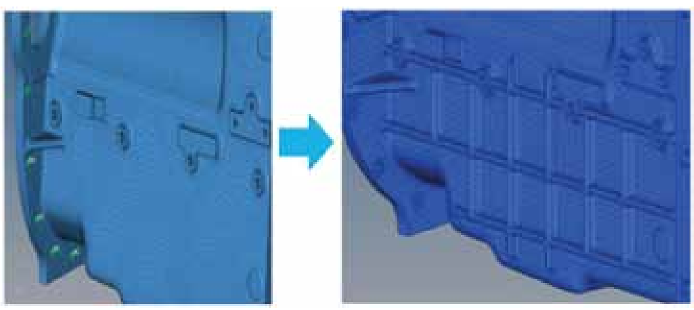

Figure 11 : Additional Ribs Outside Crankcase

Various modification such as addition of ribs internally on crankcase, different cross section were tried externally, increase in wall thickness of side panels was checked, but no significant reduction in sound power was achieved. Therefore, it was decided to incorporate structural changes related to only external ribs in the crankcase. Total radiated sound power of the baseline design and modification 1 were compared and more than 8 dB (A) reduction in Sound power has been observed as shown in Fig. 12. But the overall SWL from engine assembly will be reduced by 0.8- 1 dB (A). By incorporating above modifications there was increase in the overall mass by 2%.

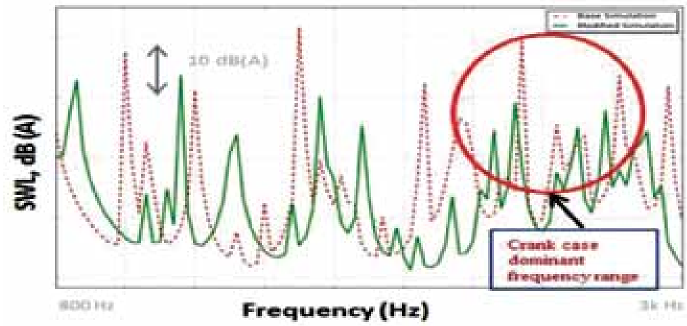

Figure 12 : SWL Comparison for Base Design and Modification-1

Modification 2 - Tappet cover is the 2nd noise contributing component and it is a sheet metal component. Tappet cover contribution frequencies (at range of 2 to 2.1 kHz) in the overall SWL spectrum were identified. High strain energy locations on tappet cover corresponding to dominant frequencies were investigated. Structural modifications were carried at high strain energy locations for further noise reduction. Various structural modification iterations were tried to check their effect on SWL. The optimization on the tappet cover is done by using visco-elastic material. The Damped material (polystyrene layer) consists of 3 layers of metal – Viscoelastic – metal combination will reduce the structure borne noise and dissipates the energy as frictional heat. This Damped material will completely damp the noise coming from the Tappet. Total radiated sound power of the baseline design and modification 2 were compared and more than 10 dB (A) reduction in Sound power has been observed. But the overall SWL from engine assembly level will be reduced by 0.7- 0.9 dB (A).

Modification 3 – Timing cover is the 3rd noise contributing component and it is a casting component. Timing cover contribution frequencies (at range of 1 to 1.2 kHz) in the overall SWL spectrum were identified. High strain energy locations on timing cover corresponding to dominant frequencies were investigated. Structural modifications were carried at high strain energy locations for further noise reduction. Fig. 13 Shows details of modifications carried out at Timing cover region.

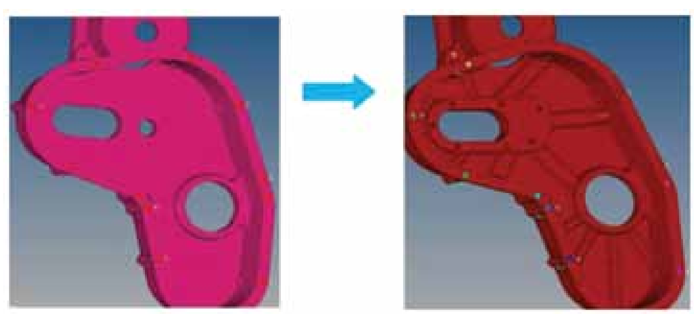

Figure 13 : Additional Ribs Added Inside Timing Cover

Various modification such different cross section were tried internally, increase in wall thickness of timing cover panel was checked, but no significant reduction in sound power was achieved. Therefore, it was decided to incorporate structural changes related to only internal ribs in the timing cover. Total radiated sound power of the baseline design and modification 3 were compared and more than 10 dB (A) reduction in Sound power has been observed as shown in Fig. 14. But the overall SWL from the Engine assembly will be reduced by 0.5- 0.7 dB (A). By above modifications there was increase in the overall mass by 1%.

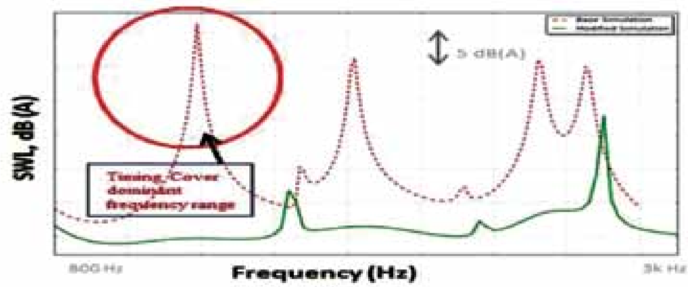

Figure 14 : SWL Comparison for Base Design and Modification-3

NOISE PREDICTION OF BASE AND MODIFIED ENGINE

Noise radiation of engine was predicted by obtaining SWL spectra from all sides of the engine assembly for the existing baseline model and modified model. Fig. 15 shows radiated sound power levels for critical speeds of engine at full load. Total radiated sound power of the baseline design and modified engine were compared and 3 dB (A) reduction in Sound power has been observed. All the design optimization solutions from crankcase, tappet cover and timing cover were incorporated in the modified model.

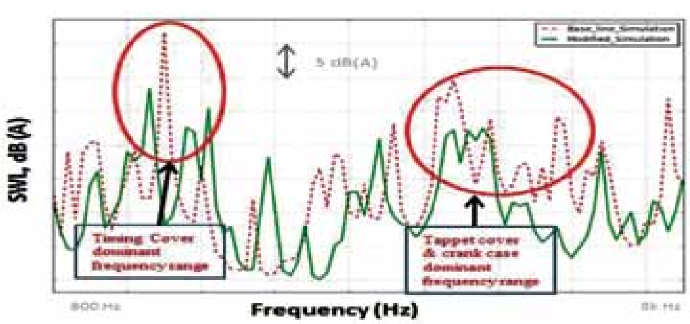

Figure 15 : SWL Comparison for Base Engine and Modified Engine Model

SUMMARY

Simulation and test approach was demonstrated for reducing radiated engine noise. The NVH performance of the baseline engine has been evaluated using CAE simulation tools. Radiated noise from the crankcase, tappet cover and timing cover has been predicted and the critical modes having severe effect on radiated noise levels of the engine has been identified. The modifications which are feasible from manufacturing point of view have been considered and analyzed. The hybrid approach used has helped in reducing noise level by 3 dB (A) with 3% increase in weight of the engine. In the present work, only structure borne noise was considered for analysis. Future work will concentrate on identification and reduction of high frequency noise. At high frequency, air borne noise is dominant and future work will aim at effective use of SEA technique to reduce high frequency noise.

Barry James
www.romaxtech.com

Driveline NVH Simulation and Testing :

Correlation Studies To Establish Integrated Validation Strategies

Barry James
Romax Technologies

INTRODUCTION

Romax Technology has a market-leading simulation software that allows designers and manufacturers to assess and optimize NVH characteristics while also maintaining or improving efficiency and durability, and in a single environment: a powerful integrated approach optimized for design improvements. Issues can be identified at the design stage, checking basic analyses for NVH at a concept level, saving time and money.

> ***If test and simulation are compared only at the end of the system development, then it is not possible to work out where discrepancies may arise, hence the need to perform correlation at each level***

Volkswagen Group is one such company that Romax Technology have supported to provide a holistic approach to their design process using RomaxDESIGNER software for gearbox simulation, to perform fast and accurate NVH analysis at each stage of the design and validation.

Europe's biggest carmaker, Volkswagen Group delivers over 10 million cars to customers each year and has annual group sales revenue (2015) of €202.5 billion. Almost one in four new cars (24.8%) in Western Europe are made by Volkswagen, a group which comprises 12 leading brands from seven European countries: Volkswagen Passenger Cars, Audi, SEAT, ŠKODA, Bentley, Bugatti, Lamborghini, Porsche, Ducati, Volkswagen Commercial Vehicles, Scania and MAN.

Its challenge was to develop a reliable validation strategy for gearbox noise, vibration and harshness (NVH) to allow design changes to be made with confidence, and satisfying the demanding needs of the market-leading brands.

Romax' whole system simulation environment offers both a prevention and cure strategy for transmission NVH issues. Design from the earliest concept stages with NVH in mind for confidence from the start or use advanced analysis and optimization processes to improve the NVH performance of existing designs, whilst never having to compromise on efficiency or durability.

Figure 1 : Mode Shape

Employing over 15,000 people, Volkswagen's primary transmission site at Kassel, Germany, supplies about four million manual and automatic transmissions every year. Volkswagen engineers at Kassel have used RomaxDESIGNER software for more than five years, to support the effective production of gearboxes and to ensure the required NVH quality is achieved. Kassel's Acoustics and System Simulation department focuses on NVH correlation and simulation: "Our main challenge is gear whine, and the need to support our high acoustic standards," says Carsten Schmitt, PhD student of Volkswagen's postgraduate program. "NVH is such an important issue in the industry today because of the rise in electric motor developments, and the simultaneous increase in the production of complex gearboxes. We use RomaxDESIGNER so that we can perform accurate simulation of these new gearbox designs, and assess the NVH performance."

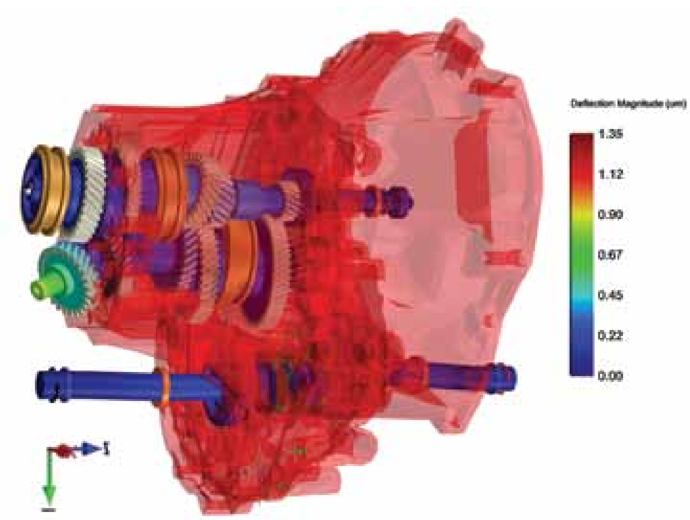

Figure 2 : Mode Shape with Housing

CHALLENGE

With continued pressure to reduce development time and costs, along with ever-higher consumer expectations and the rise of electric vehicles (EVs) and hybrids, the need to understand and solve NVH issues has become greater than ever. Companies want to quickly and accurately assess the effects of design changes as early as possible in the development cycle - before the process moves into expensive physical prototypes and testing.

Developing a reliable validation strategy for gearbox noise, vibration and harshness (NVH) to allow design changes to be made with confidence, and satisfying the demanding needs of the market-leading brands.

FROM TRIAL AND ERROR TO SIMULATION FOR DEVELOPMENT

Previously, sporadic correlation studies on the main parts of a gear box would be conducted based on eigen frequencies, which allowed for little correlation guarantee. "We have a requirement to develop simulation models that are representative of the real world, so that our design changes can be made with confidence," says Schmitt. "This gave rise to the need for an integral validation strategy, which we investigated in RomaxDESIGNER. We have already used the software for over five years on multiple projects. The speed and unique system-level simulation which RomaxDESIGNER offers stand it apart from other products currently available on the market."

AN INTEGRAL VALIDATION STRATEGY

The strategy developed by Volkswagen focuses on a step-by-step process, allowing correlation between measurement and simulation along the acoustic transfer path at each of the following stages: gear excitation, shaft systems, bearings, gearbox housing, and whole vehicle testing. "If test and simulation are compared only at the end of the system development, then it is not possible to work out where discrepancies may arise, hence the need to perform correlation at each level. This gives us an understanding of exactly where problems are occurring, so that we can resolve validation errors quickly and easily, and avoid time-consuming investigatory work," Schmitt explains. "And Romax software plays a big part in this investigation. Only with RomaxDESIGNER can we quickly and accurately investigate gear whine phenomena on a system level – looking deeper into models to work out where the problems are. This is what allows us to meet high expectations for NVH within even the most cutting-

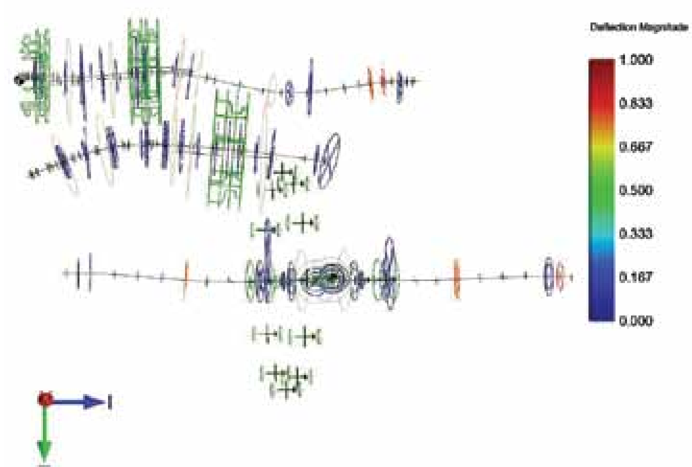

Figure 3 : Schematic Diagram

edge system designs. Romax's unique system level view is a huge benefit to us, as well as its easy-to-use bearing catalogues, which make it easy to model gearboxes even if you are not a bearing expert, and its reliable and accurate transmission error calculations."

A STEP-BY-STEP PROCESS

The gears are validated first, with testing and simulation performed across a range of loads. The gear contact pattern is checked; poor correlation indicates either incorrect micro-geometry in the simulation, or deviations in the manufacturing process. The next stage is shaft system validation, which consists of modelling single parts and assemblies, then performing finite element analysis (including pretest analysis and experimental modal analysis, if necessary). This is again validated against test data, and if this is unsuccessful the model must be updated in RomaxDESIGNER. Whenever correlation is not successful, changes can be made which will improve the process for the future, as Schmitt explains: "In the first run we did, we found that the model did need updating. The updates that we performed, including accounting for Young's modulus and part-to-part stiffness connections, improved the correlation significantly."

The third stage is correlating the bearing stiffness, and the final step is the correlation for the gearbox housing, for which there are two options, as Schmitt explains: "The validation can be performed by building up the components separately using different tools and testing each individually, and then adding together to make the final model. Alternatively, a single model can be created in RomaxDESIGNER, which means just one experimental modal analysis, one correlation analysis, and only one model to update. We found that there was little difference between the methods, so the full housing assembly was done in order to save time and effort – this is a very useful way of doing the correlation."

"Now we have developed the framework, we are confident that the work that we have put into this implementation will enable time and cost savings for future projects, as well as maintaining our customer's trust in our ability to deliver their requirements," Schmitt concludes. "We have developed a clear strategy to perform straightforward model updating procedures, and extended the validity and trust of our Romax gear whine models. Our design changes are not reliant on trial and error, but are based on proven, trustworthy simulation."

BENEFITS SUMMARY

- Resolve validation errors quickly and easily through an understanding of exactly where they occurred, removing the need for time-consuming investigatory work
- Obtain and maintain customer trust – deliver exactly what they require, with confidence
- Meet increasing demands for NVH which satisfy cutting-edge gearbox designs, e.g. for electric motors or complex gearboxes
- Know that design changes are made not relying on trial and error, but based on proven, trustworthy simulation

ROMAX FOR NVH: WHAT YOU NEED TO KNOW

- Moving away from 'traditional' design and analysis approaches to consider all elements of NVH optimization
- Taking a whole-system view - to solve NVH issues faster, earlier and in optimal ways
- Gear whine, gear rattle, efficiency and durability are analysed simultaneously; when combined with Design of Experiments functionality, multiple iterations can be assessed automatically
- Reducing prototype and development costs: bringing quieter higher quality products to market faster.


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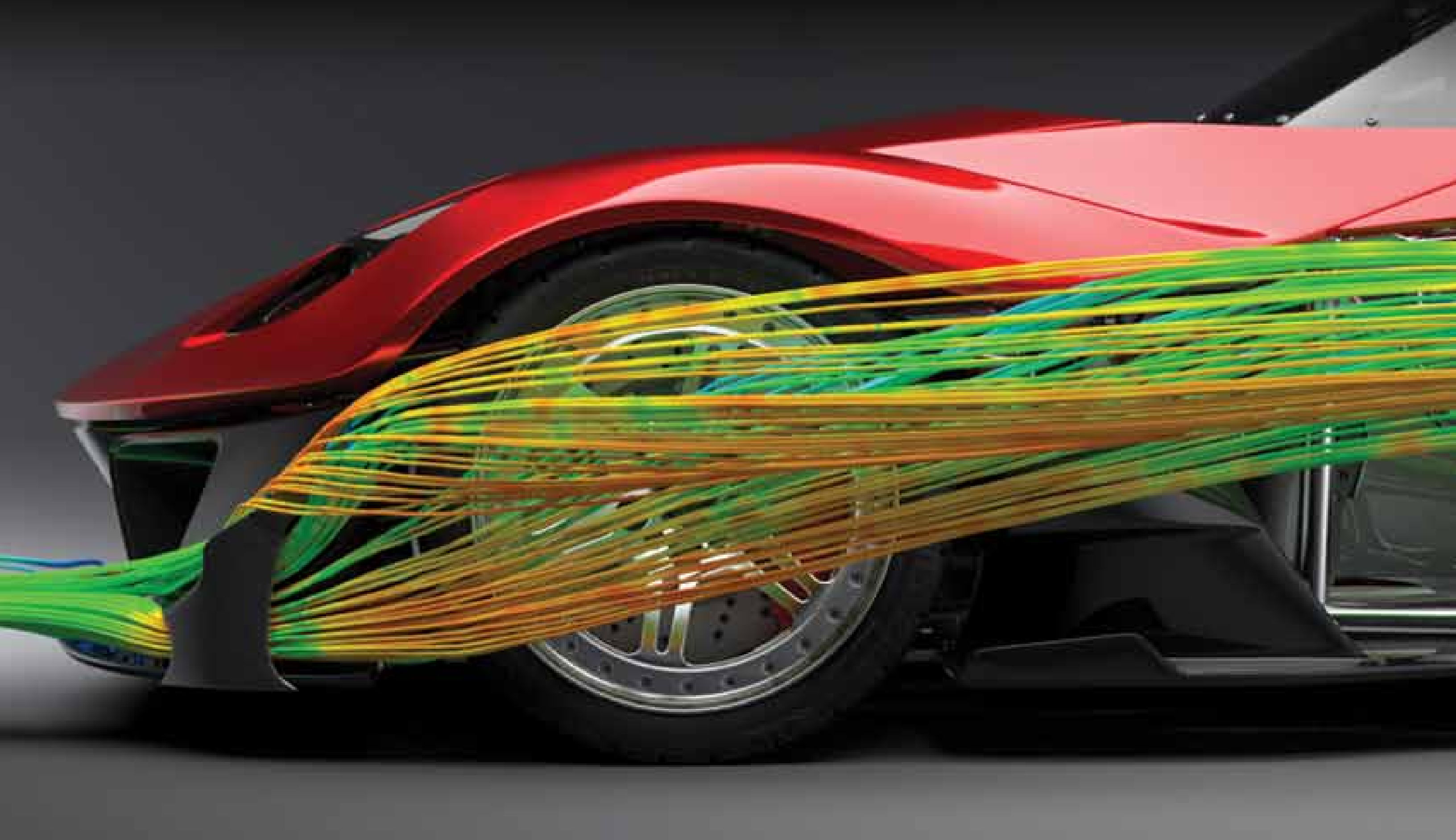
SIMULATION TECHNIQUE

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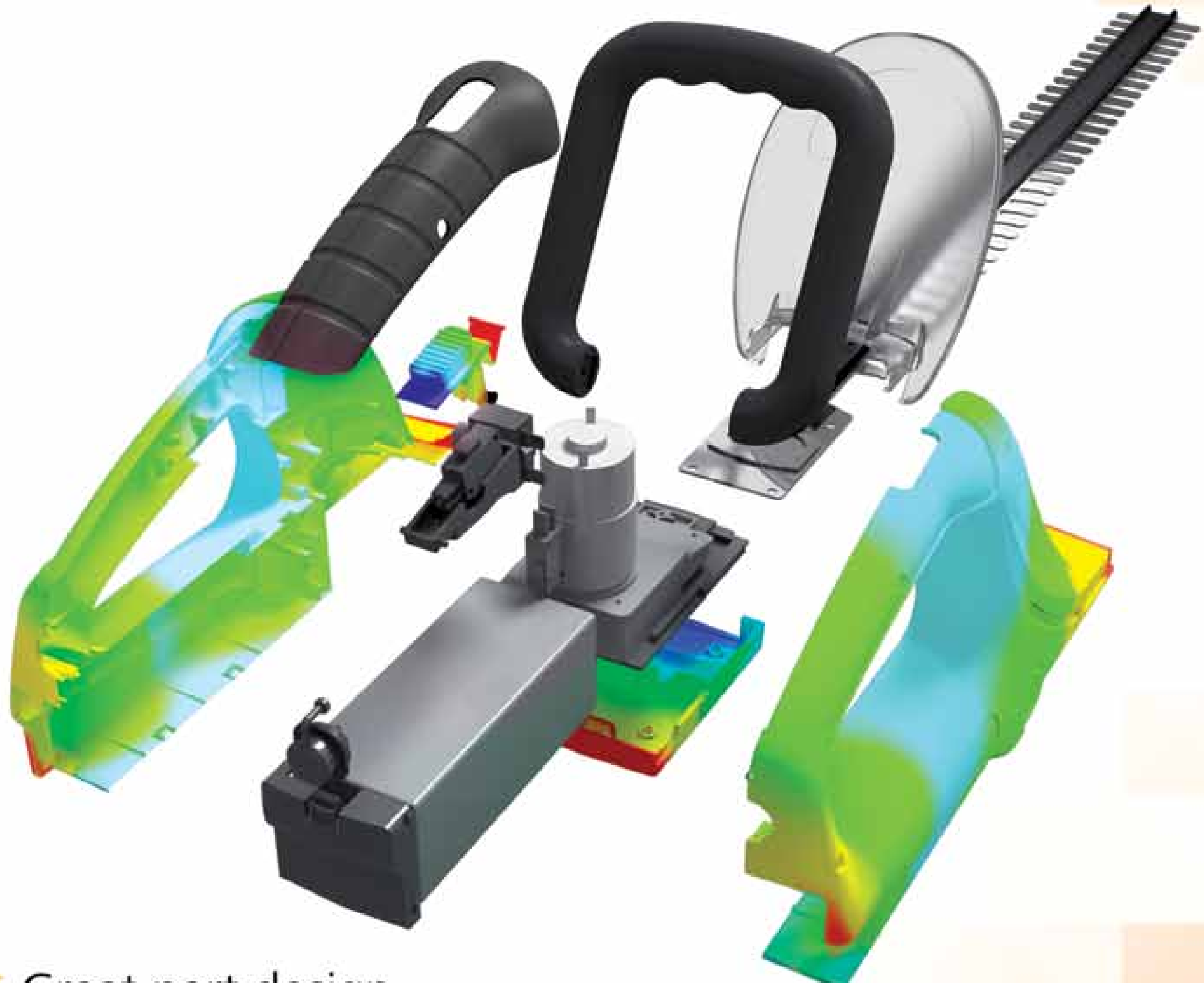

Benchmark Your Injection Molding Simulation

Dr. Russell Speight, Dr. Franco Costa
Autodesk Australia Pty Ltd.

Dr. Russell Speight
www.autodesk.com.au

Injection molding is continually demanding more from designers, as mold design changes after the mold is already built are expensive. Injection molding simulation is cost-effective compared to manufacturing physical prototypes and offers great benefits to those using it early in the manufacturing process.

The use of CAE for injection molding simulation has progressed from flow-front prediction in the late '70s to full simulation of the injection molding process, its variants and associated processes. Injection molding simulation benchmarking is the comparison of predicted and actual process parameters. Typically, an extensive study is carried out on a mold, machine and material combination, where filling pattern, injection pressures and part warpage are reviewed. Best practice requires that the inputs and outputs from an injection molding simulation agree as closely as possible to the actual conditions of a real-life molding machine. Injection molding is continually demanding more from designers, as mold design changes after the mold is already built are expensive. Injection molding simulation is cost-effective compared to manufacturing physical prototypes and offers great benefits to those using it early in the manufacturing process. Simulation of injection molding, by software like Autodesk Moldflow, has a higher return on investment than simulation of other plastic manufacturing processes. The objective of benchmarking is to gain confidence and experience in modeling, material and simulation capability, and to then use simulation results to guide future design. An important reason for benchmarking is to confirm simulation results when users are first introduced to injection molding simulation applications.

SIMULATION ACCURACY

The accuracy of injection molding simulation, by software like Autodesk Moldflow, is influenced by many factors. For example, predicted filling patterns, the location of weld lines and hesitation marks. Modeling of wall thickness is important and needs to include changes made towards the end of the design cycle. If it does not, the CAD model used as a basis for the simulation model may differ significantly from the actual mold. Predicting the pressure required to fill a mold (assisted with machine selection) requires modeling of the runner, sprue and gating design. In addition, if simulated injection pressure is compared to a measured nozzle pressure, then the pressure drop in the nozzle and the contraction into the nozzle tip must be accounted for. This can be done either by including the nozzle body and contraction in the simulation model (assigning a property similar to hot runners) or by performing an air-shot experiment. In an air-shot experiment, the molding machine injection unit is retracted away from the mold and an injection shot is performed at typical injection speed, but with polymer extruding freely out of the nozzle tip rather than flowing into the sprue or hot runner.

Predicting the ejected part's final warped shape requires an accurate reflection of the process settings in the simulation; in particular, packing time and packing pressure (or pressure profile), cooling time, and any relative difference in coolant temperatures. These factors have a strong influence on shrinkage and warpage. The discretization of the geometry into finite difference grids, finite elements or finite volume cells also plays a key role in simulation accuracy. The mesh size must also be considered with respect to the type of numerical solution being used.

Simulation inaccuracies can arise due to errors in:

- Software: incorrect coding of a mathematical expression and/or its associated boundary conditions
- Geometry: the real part is not reflected in the import of geometry and the subsequent discretization used to define the computational domain
- Material data: inappropriate data for the materials used to produce the part
- Input data: processing conditions used in the simulation differ from those used in the manufacturing process
- Post processing: manipulation of calculated data for post processing
- Experimental data: poor experimental technique, poor instrumentation or transducers

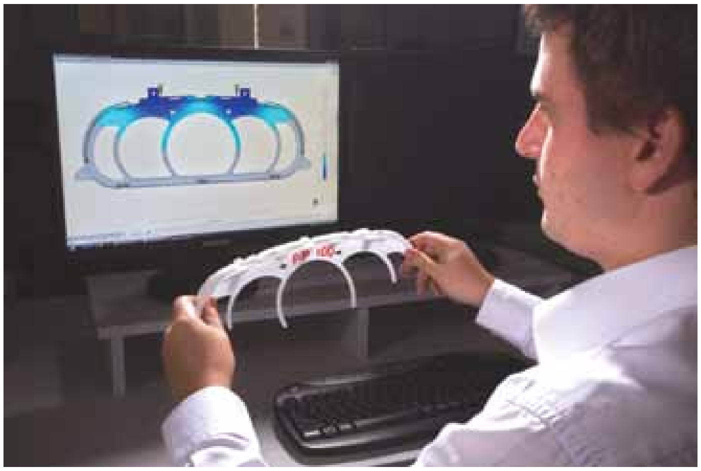

Figure 1 : Comparing Physical Testing with Digital Simulation. An Important Reason for Benchmarking is to Confirm Simulation Results When Users are First Introduced to Injection Molding Simulation Applications.

EXPERIMENTAL ACCURACY

Molding machines are continually advancing, and a wide range of machines are available. It is important to understand both injection molding machine fundamentals and the actual machine being used, including its capability, screw movements, check-ring valve performance, material preparation (drying), nozzle pressure (or hydraulic injection pressure multiplied by the screw intensification ratio) or cavity pressure, shot-to-shot variations, venting, sensor types, and reliability.

To help detect machine problems, movement and check-ring valve performance, process monitoring and machine performance should always be reviewed prior to the start of a benchmark. Material drying can cause process instability issues and melt viscosity differences. The ideal relationship between nozzle melt pressure and hydraulic injection pressure is the ratio of piston to screw area. This is referred to as the screw intensification ratio or gain, and is typically equal to 10. However, it may vary considerably depending on screw and piston geometries. The apparent screw intensification ratio also may vary due to temperature changes compressing the hydraulic oil, frictional effects between the screw and barrel, and the influence of polymer melt compression during the filling process.

Benchmarking

Injection molding simulation benchmarking requires an appreciation of simulation technology and knowledge of the assumptions made in the simulation.

Filling Inputs

The most important input that influences filling pattern is mold geometry, so an accurate representation is essential. The most important influences on injection pressure are geometry, switch-over from velocity- to pressure-control stages, material viscosity and injection speed (profile or constant).

Geometry

Time is often spent analyzing the results of simulation of an intricate feature only to find that the feature was not modeled correctly. An actual molded part should be reviewed for obvious errors. Tool life also should be considered, since several modifications may have been made. The model used for the injection molding simulation may be from the part design, so the moldmaker's shrinkage allowance will not be included in any dimensions. Nozzle, runner and gate geometries also are not always included in a simulation model, and these features can have a considerable effect on simulation results, particularly pressure to fill.

Velocity to Pressure Control Transfer

Switch-over from velocity to pressure control is set by screw position or time. The full geometry must be modeled accurately or percent volume filled or automatic options selected. Molding simulation often uses the latter, so it is essential to verify that this is a reasonable approximation of the molding machine's settings.

Viscosity

When a material is not present in the materials database, it is common practice to choose a material with a similar melt flow index (MFI) or viscosity, from the same polymer family, with similar filler levels, or from the same manufacturer. A 10% difference in filler weight can be expected to yield a 10% difference in pressure prediction. However, as much as a 40% difference in pressure can be expected with material data from a different manufacturer, because viscosity is also indirectly affected by the material's thermal properties.

Injection Velocity

The correct injection velocity (flow rate profile) is also important. The flow rate used in the simulation can be determined from readings on two cavity pressure sensors. The difference in position between the sensors and the difference in time for the flow to reach each of the sensors is used to determine an injection speed for the simulation. However, injection speed calculated in this way will show poor agreement with measured pressures.

Packing / Holding Pressure

There are many built-in features to ease injection molding simulation, such as a default automatic packing/holding pressure profile that uses 80 percent of the maximum injection pressure for 10 seconds. The actual pressure profile is often overlooked.

SUMMARY

Benchmarking of injection molding simulation requires a systematic approach to eliminating problems after comparing simulation with molding practice. Therefore, when comparing simulation results, provided by software like Autodesk Moldflow, to those obtained on the molding machine, it's essential to pay attention to the factors that may cause errors: machine capabilities and response time; material preparation, characterization and stability; measurement methods (pressure or deflection); geometry inaccuracies; process setting variations; and inputs to simulation software. Even without perfect agreement, simulation can provide great insight into performance sensitivities to process, geometry and material that can then be used by engineers to improve product design and process settings for actual production.

Figure 2 : Autodesk Moldflow Material Testing Lab. Best Practice Requires that the Inputs and Outputs from an Injection Molding Simulation Agree as Closely as Possible to the Actual Conditions of a Real-life Molding Machine.

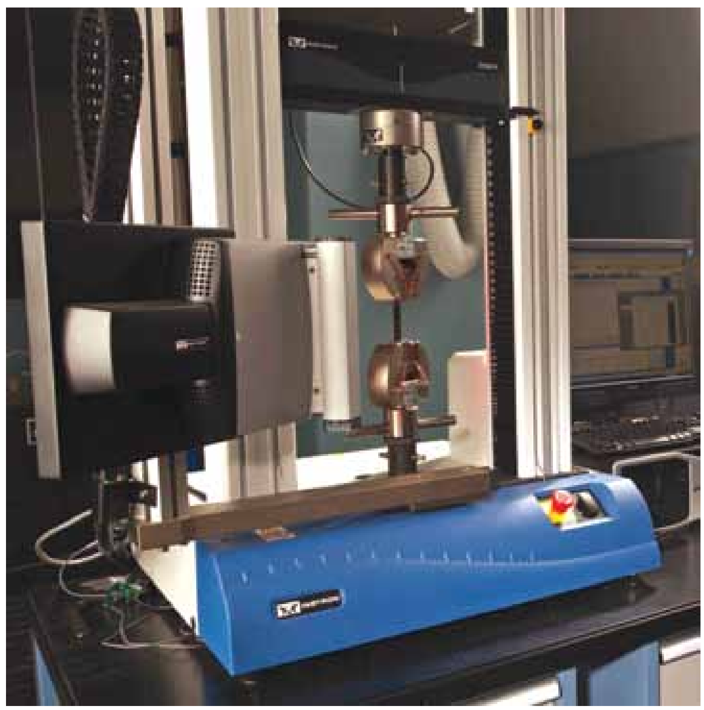

Figure 3 : This Lab is Fully Equipped to Mold and Machine Mechanical Plaques for the Manufacture of Tensile Test Samples. It has Made Measured Mechanical Data More Readily Available Through the Use of Both Optical (for Longitudinal Direction) and Contact Extenso Meters (for Transverse and Thickness Directions).


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Mastering the Challenges Faced in Joining of Formed Components of Different Materials

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With increasing pressure to reduce the weight of vehicles to meet the demanding pollution norms, automotive companies across the world are exploring the possibility of use of high specific strength materials which can reduce the weight of vehicles by maintaining the strength & safety aspects of vehicles. This demands the use of different materials for different components of vehicle. Now the biggest challenge in assembly of such lightweight vehicles is the joining of metal formed components of different materials. Although the concept of mechanical joining such as riveting etc. & use of resistance spot welding for joining is already gaining popularity & in use in shop-floor, there are still some major challenges need to be addressed before the concept of use of different materials for different auto-components becomes feasible reality. The typical challenges are identifying & making the new materials, new material coatings, identifying the right material combinations for components to be joined, what should be the right thickness of the components to be joined etc. To address these challenges, one needs to do extensive study of optimization of welding process to find out the optimum parameters. For example, before you start making body panels, with first joining tests itself usually requires two to four hundred material thickness combinations, study of the suitability for joining, the optimization of joining parameters and the mechanical behavior of these joints is required to be determined.

> *“The biggest challenge in assembly of such lightweight vehicles is the joining of metal formed components of different materials”*

These challenges can be addressed with the help of simulation study, as the physical experimental work involves a lot of cost, time & resources. This article discusses various techniques which can be used to join the dissimilar metals & validation of those joining techniques by simulation. Also it talks about how one can optimize the joining process, do joint tests (tensile, shear etc.) & highlights the importance of accounting the manufacturing history in (pre-stresses) in vehicle's structural simulation such as crash tests etc.

As we all know joining is an essential operation of any automotive BIW stage. It is estimated that typically additional rivet & filler material requires up to 3 kg weight. The lightweight concept requires an assembly without any additional material. Also light-weighting means use of different materials for different components. Such multi-material requires mechanical joining which has to be free from issues such as corrosion, delamination & leakage etc. Fig. 1 shows different joining techniques which addresses all these key points.

LASER WELDING

Fig. 2 & 3 show the validation of laser welding carried out by simulation work using Simufact Welding. The simulation study was carried out to predict the distortion, residual stresses & changes in micro-structure. Also the effect of laser welding on dimensional accuracy, surface quality, and strength & fatigue life can also be studied.

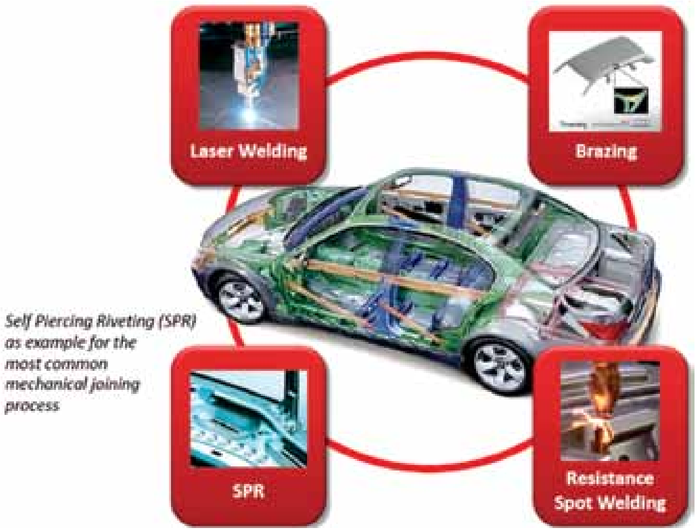


Figure 1 : Different Joining Techniques

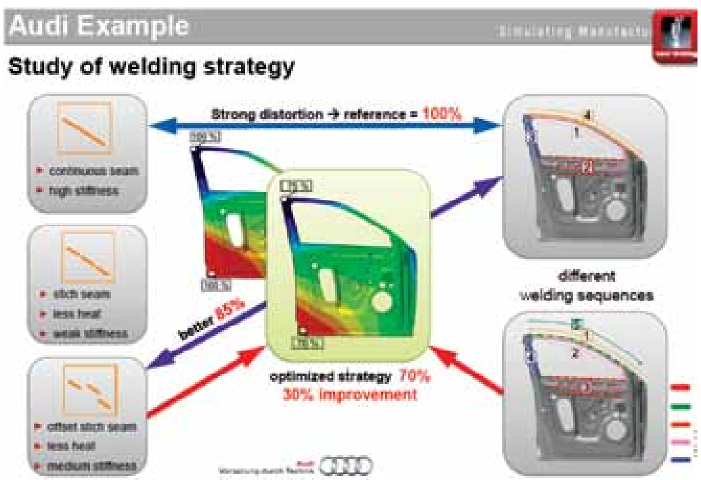


Figure 2 : Study of Welding Strategy

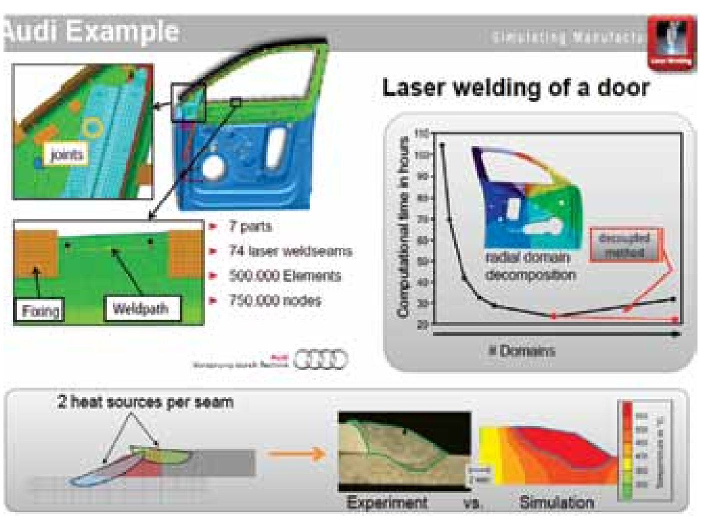


Figure 3 : Laser Welding of a Door

BRAZING

Brazing process is used to join the roof top of car & Simufact welding was used to carry out the simulation of brazing process to predict distortion, surface quality problems, and geometric deviation in the area of roof rack holes. Fig. 4 shows the distortion results.

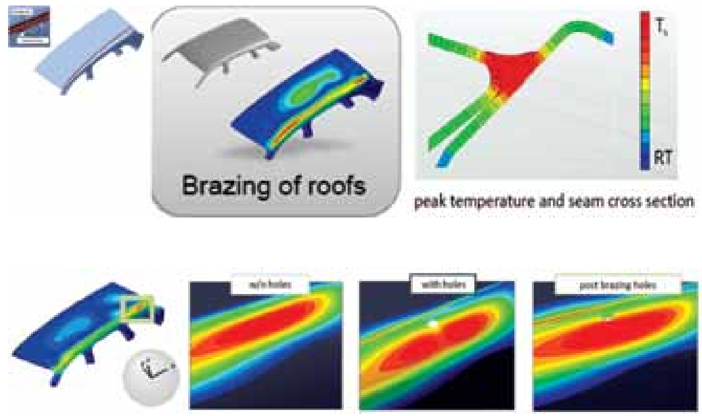


Figure 4 : Brazing of Roofs and Distortion Results

RESISTANCE-SPOT WELDING

Resistance spot-welding is another welding technique used to join the dissimilar metals. Simulation carried out by Simufact Welding to predict temperature distribution, effective stress distribution & also micro-structural changes as shown in Fig. 5.

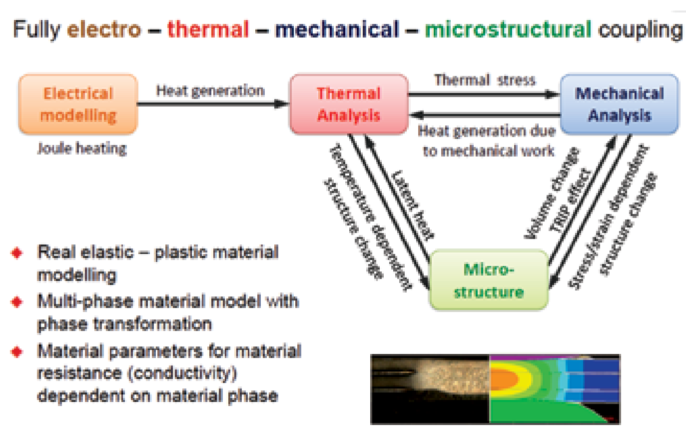


Figure 5 : Resistance Spot Welding

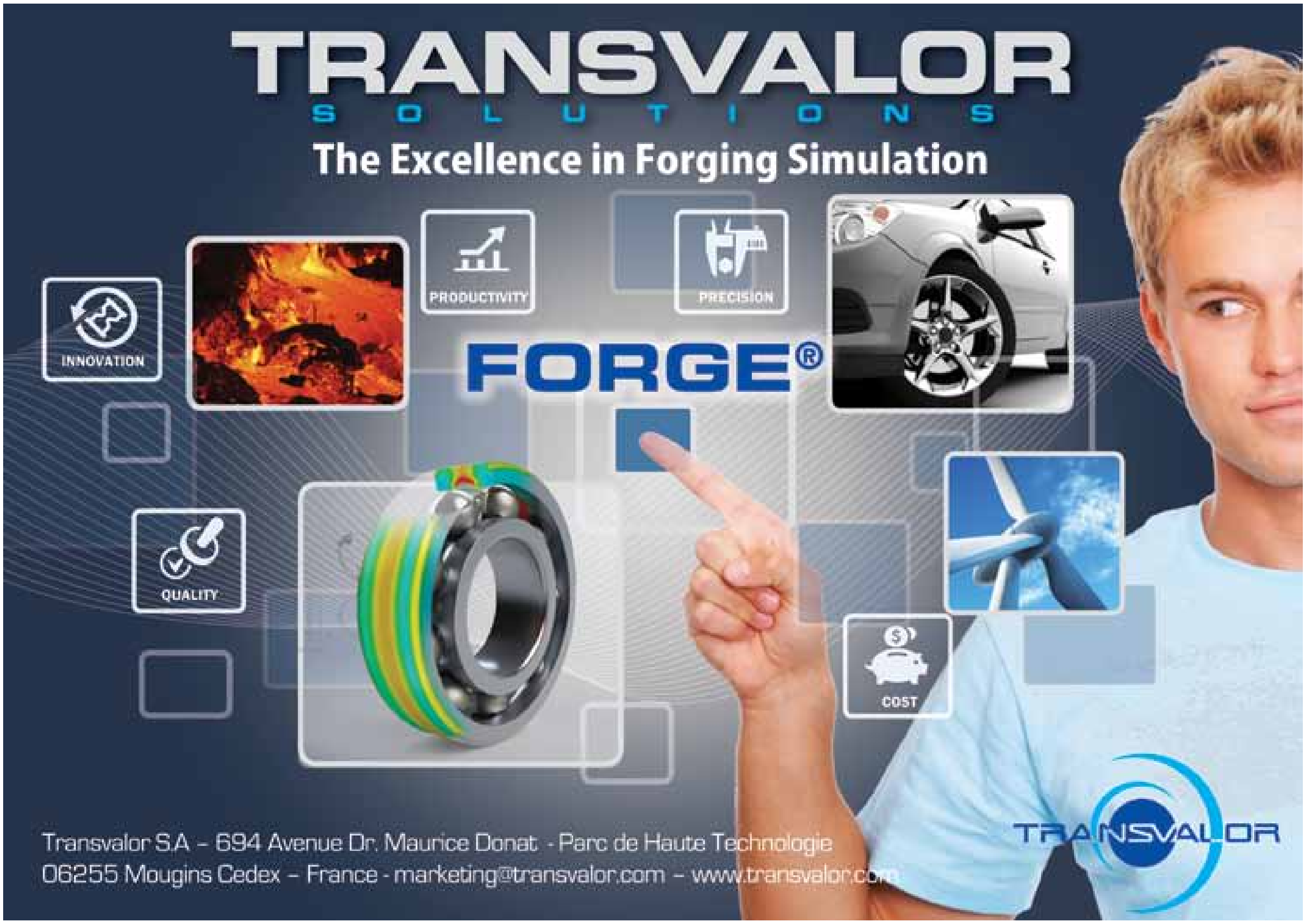
MECHANICAL JOINING (SELF-PIERCING RIVETS)

Metals such as Aluminium which has difficulty in welding can be joined together by mechanical joining process such as self-piercing rivets which are gaining popularity in the industry. Simufact simulations can be used to simulate the piercing operation & to do the shear test of joints as shown in Fig. 6.

Figure 6 : Self Piercing Riveting

CONCLUSION

Simulation can be of great help to design, study & validate the joining process before it goes into production. This is very important for cars made up of multi-materials for light-weight concepts.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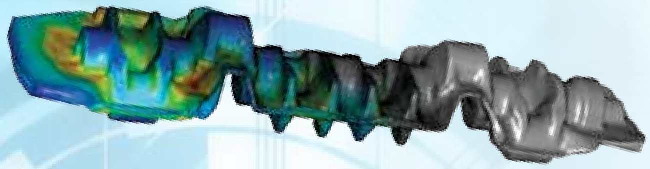

Benefits of Virtual Manufacturing for Modern Forging Companies

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Time to time, numerical simulation has become a crucial tool to understand and analyze the manufacturing processes. This is one of the reasons why 'process-oriented' simulation software have been developed since past 30 years leading today to robust & reliable solutions.

> *"Today, virtual manufacturing is one of the key factors to reduce costs and optimize processes."*

However, the ambition has changed over the time. Nowadays forging designers are not simply interested in visualizing the metal flow but they expect simulation technique to provide deep insights on the global manufacturing chain. Therefore, questions related to metallurgy, heat treatment, tooling lifetime, resistance to thermal or mechanical fatigue and prediction of in-use properties are among the most relevant centers of interest.

Figure 1 : Simulation Keys to Product Improvement

FOUR KEYS FOR PRODUCT IMPROVEMENT & COST REDUCTION

Today, virtual manufacturing is one of the key factors to reduce costs and optimize processes. Not only technical but also economic aspects are to be considered by the forging industry.

The manufacturing costs are driven by different cost centers including labor, purchasing machinery & tooling. Design simplification and reduction of the number of operations contribute to major savings.

Processing costs should also be considered very carefully. In this way, simulation deeply helps designers and quality engineers to improve the metal yield, reduce stress on tooling and limit tonnage on forging equipment.

Motivated by the constant willingness to lower the costs, simulation-based designs become essential to supply the most competitive quotations with strong guarantee on the final product's quality.

THE TRADITIONAL BENEFITS OF SIMULATION FOR DESIGNERS

Forging designers benefit from reliable solutions to simulate conventional forging and an extended range of processes such as extrusion, open die forging, ring rolling and hot rolling. Cold forming processes are obviously also in the scope of simulation including cold heading for fasteners, deep drawing, fine blanking and impact.

Among the most traditional results it is possible to understand how the metal flows to prevent under fillings, folds & laps. Grain flow calculation and central looseness tracking provide guarantee upon the quality of the forged part.

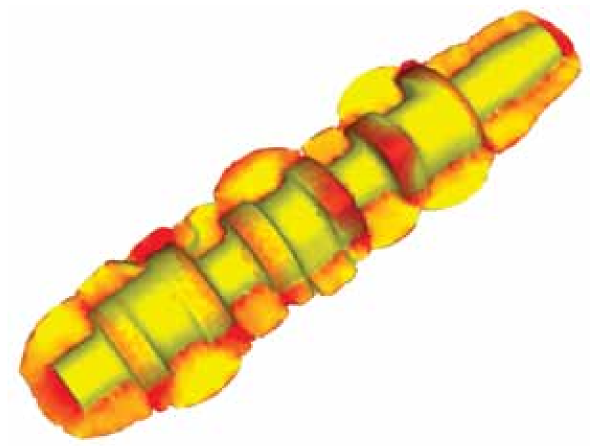

Figure 2 : Temperature on Camshaft Forging

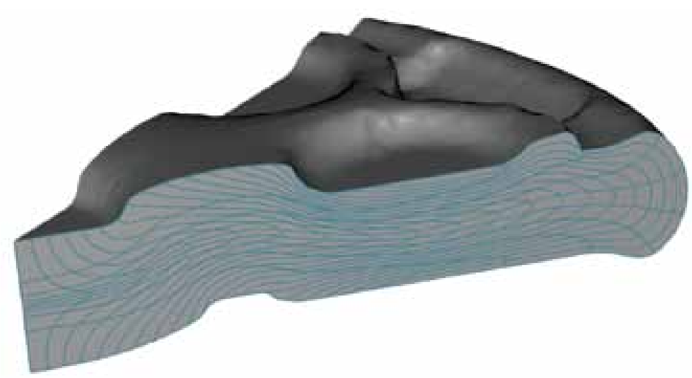

Figure 3 : Grain Flow on Steel Automotive Part

SIMULATING THE MANUFACTURING PROCESS CHAIN: 'FROM BILLET TO FINISHED PART'

Today the value is not only in simulating the forming stages but in taking into consideration the whole sequence of operations occurring prior and after forging. In the light of this, Transvalor has enriched its FORGE® simulation software with functionalities related to induction heating, surface treatment, trimming and volume heat treatment.

Simulating the complete manufacturing chain is the key starting point for those aiming at predicting the final in-use properties of the forged part. With induction heating simulation, the designer precisely controls the initial billet temperature prior to forging. In the forging stages, every single part property (strain, stress, phases & grain size) is calculated and carried forward to the deformation stages.

Final heat treatment simulation will enable to determine product hardness, residual stress distribution and possible geometrical distortions. More details about induction heating & heat treatment are given in the following dedicated paragraphs.

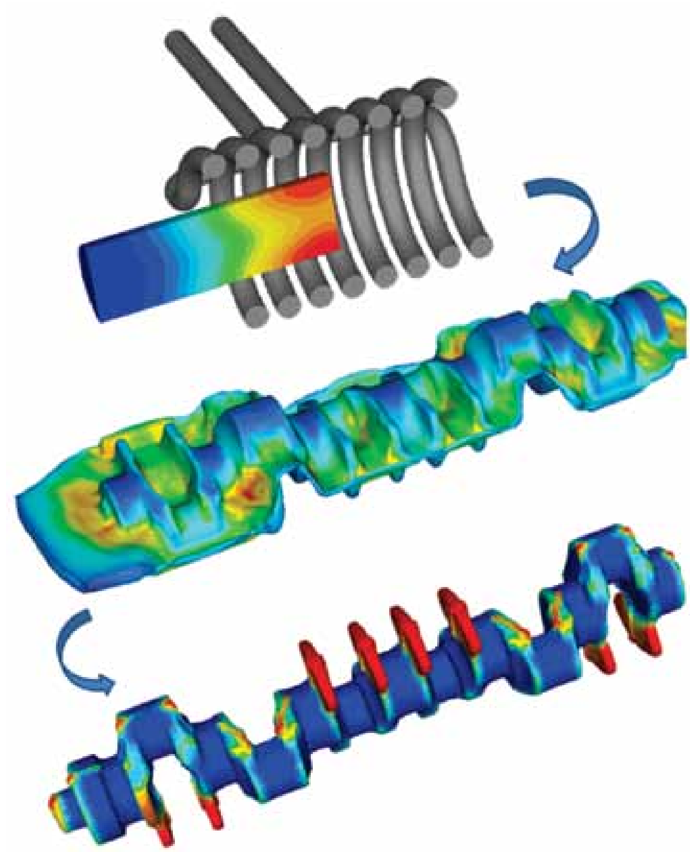

Figure 4 : Simulation of the Complete Manufacturing Chain from Induction Heating through Forging and Final Heat Treatment

YIELD & PROCESS IMPROVEMENT BY AUTOMATIC OPTIMIZATION

Among the latest techniques at the disposal of forging designers, the so- called 'automatic optimization' is one of the most attractive. Behind the word 'optimization' many aspects are taken care of since obviously every forging company tries to optimize its production on daily-basis. On a practical point of view, optimization aims at reducing the production costs and at improving the product's quality.

What simulation can bring is the automated way to test various input conditions and based on an objective function determine the best output results. In other words, the engineers have the possibility to set a value range related to various input conditions (e.g. cut-weight, billet temperature, etc.) and then let the software run several generation of simulations until the optimum set of conditions are obtained. The final so-called the 'best candidate' is the simulation which fulfills the most of the requested objectives.

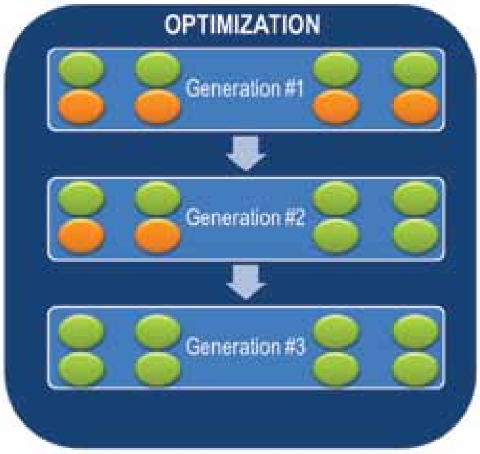

Figure 5 : Genetic Algorithm Setting the Principle for Automatic Optimization

Yield improvement is one of the typical optimization. The objective is to get the smallest cut weight together with the guarantee of a complete filling without any laps by the end of forging.

The example on Fig. 6 illustrates the net result of an automatic optimization sequence conducted with FORGE® software. Applied on a heavy crankshaft, this sequence leads to a significant cut-weight reduction of nearly 13%.

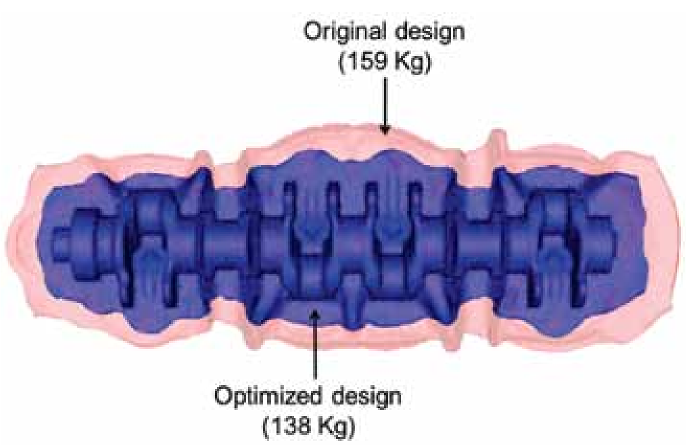

Figure 6 : Example of Yield Improvement by Automatic Optimization Applied on a Heavy Crankshaft

Forging designers benefit from a solid and reliable solution offering a wide range of optimization including: tooling failure, die wear, metallurgical properties, friction & heat transfer coefficient identification.

INDUCTION FOR BILLET HEATING & SURFACE HARDENING

Intensive developments have been conducted for the simulation of induction heating. The primary aim is on induction forge heating with the objective of simulating the temperature build-up into the billet. By modeling with FORGE®, one can take into account of various process parameters (e.g. current intensity, frequency, nominal power) enabling engineers to use simulation in a predictive way.

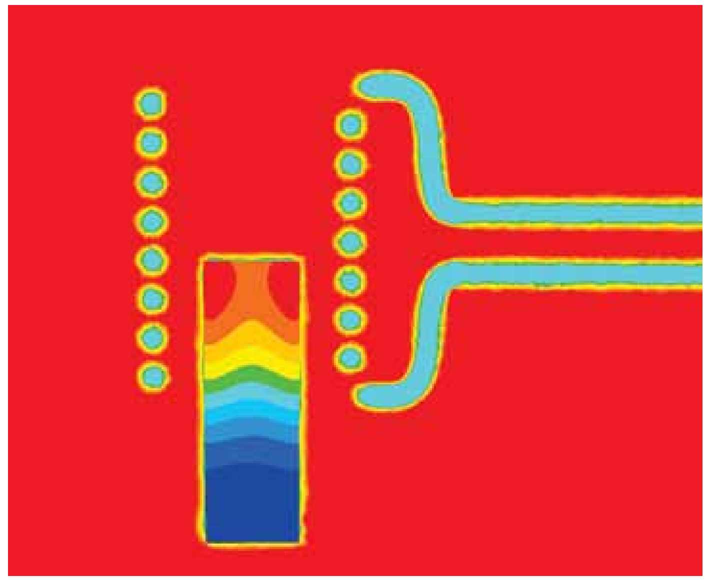

Figure 7 : Temperature Field in the Billet (from Surface to Core) During Induction Heating

Therefore multiple alternatives can be tried out enabling the test of coil design (e.g. number & size of the spires) and location of magnetic field concentrators. In addition, 'real life' conditions such as billets or bars travelling into a heating tunnel or mobile coils & concentrators can be easily taken into account by simulation.

Besides the pure predictive objective, FORGE® simulation provides major information related to the electrical consumption as well. Fig. 8 shows that the electrical power dissipated into the work piece is significantly lower than the maximum nominal power given by the generator.

Typically, engineers will look forward maximizing the performances of the heating equipment and determining the optimal electrical power in order to make the largest energy savings.

Furthermore, induction is commonly applied to surface heat treatment for steel components. A very localized heating is applied in specific area followed by a sudden cooling aiming at creating local martensite. In this matter, engineers expect a double response from the simulation: - the usual prediction of the temperature evolution and an accurate representation of the steel phase transformation.

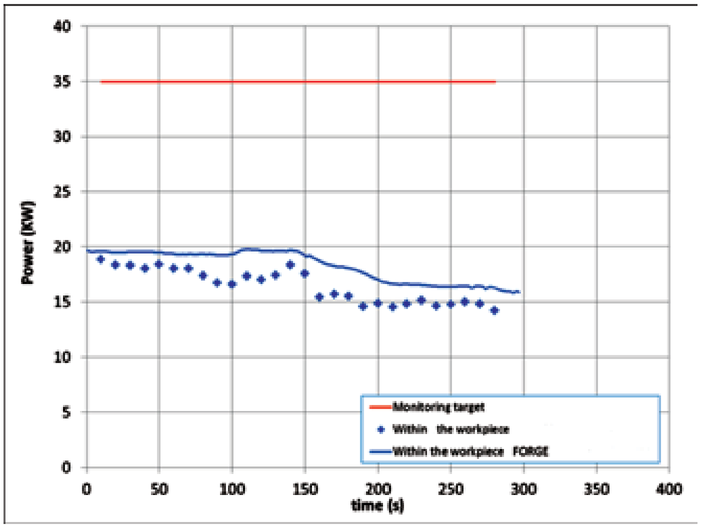

Figure 8 : Comparison between the Nominal Power and the Electrical Power Dissipated into the Billet (Simulation vs Experiment)

Fig. 9 illustrates the example of induction heat treatment applied on a Gear Component.

The frequency is one of the main drivers among the process parameters. However, it presents a difficult dilemma since as when the frequency increases the heating time is shortened, but the preferential heated area is changing from the tooth's base to the tooth's tip.

Figure 9 : Gear Surface Induction Hardening

FORGE® simulations have been conducted in order to define the optimum frequency which provides enough toughness at the surface together in ductility elsewhere. Fig. 10 shows the martensite distribution resulting from a frequency set at 20,000 Hz with a penetration depth approaching 1 mm.

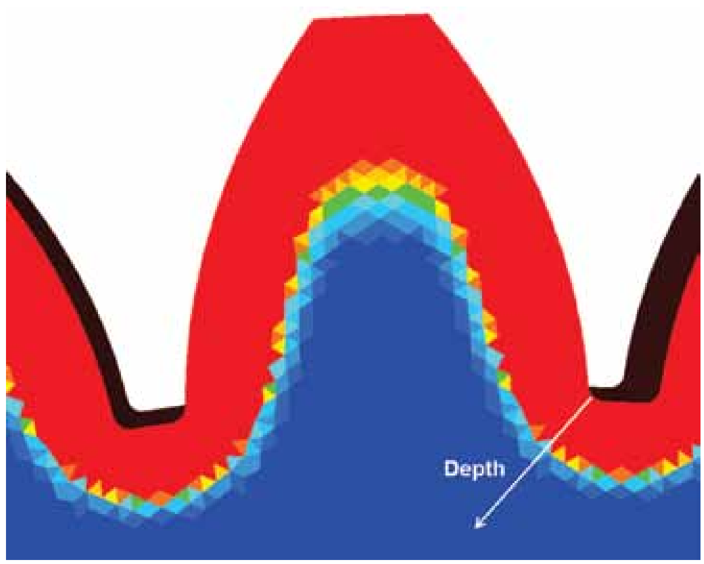

Figure 10 : Martensite Evolution in the Depth of the Tooth Gear

ANTICIPATING METALLURGY & MICROSTRUCTURE EVOLUTION

Mastering the part's properties implies a control of the metallurgical states during the entire manufacturing chain. Initially driven by the aerospace industry, the will to understand the microstructure of forged parts has now permeated many other industries such as the automotive and nuclear sectors.

Controlling the microstructure and anticipating its evolution using simulation is essential to deliver the best quality products. However, as shown on Fig. 11, many parameters have their influence on microstructure evolution.

To simulate the recrystallization phenomena and grain growth during thermo-mechanical processes, most of the commercial software relies on macroscopic approach based on the JMAK model (Johnson-Mehl-Avrami-Kolmogorov) which describes the grain nucleation and grain growth. In addition, phase transformation for alloyed steel are easily calculated assuming appropriate material data such as TTT & CCT diagrams. The model accounts for static dynamic and meta-dynamic recrystallization which are occurring respectively during heating, forming and resting stages. This macroscopic model is well documented and fast to

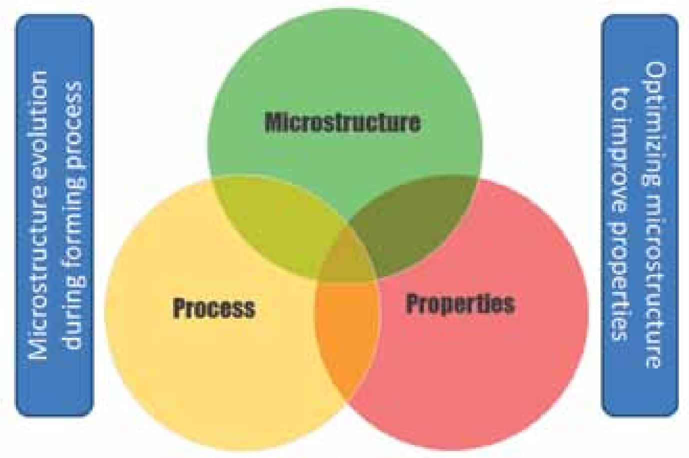

Figure 11 : Influence on Microstructure Evolution

compute, but it requires relatively long and expensive experiments to determine the suitable parameters for every given material.

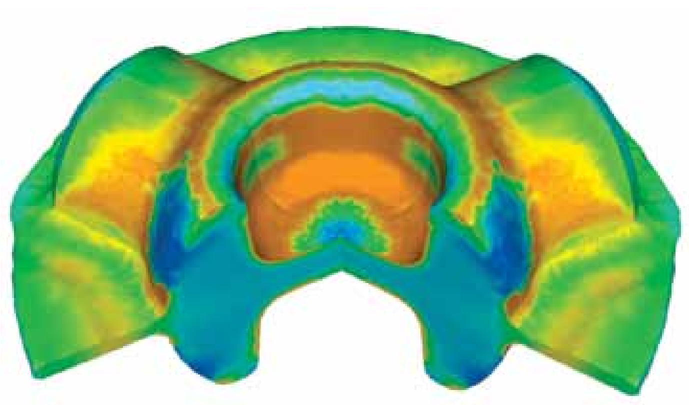

Figure 12 : Average ASTM Grain Size by End of Forging

As opposed to the macro-scale model, Transvalor has extended a multi-scale approach and consequently has worked closely with academic & research institutes to develop 'mean field' and 'full-field'. These are more sophisticated models and aims at considering the physical phenomena such as density of dislocations and grain boundary migrations. The mean field models have been elaborated in association with the German RWTH Aachen University and the French research center CEMEF from Mines ParisTech. Both models consider an average density of dislocations and an equivalent spherical grain diameter. Output results are grain size, recrystallized fractions, nucleation rate and the evolution of the dislocation density. As the rheology of material is coupled with the microstructure, these models imply an impact on the flow stresses.

This coupling is now introduced into FORGE® software with the opportunity to get material behavior depending

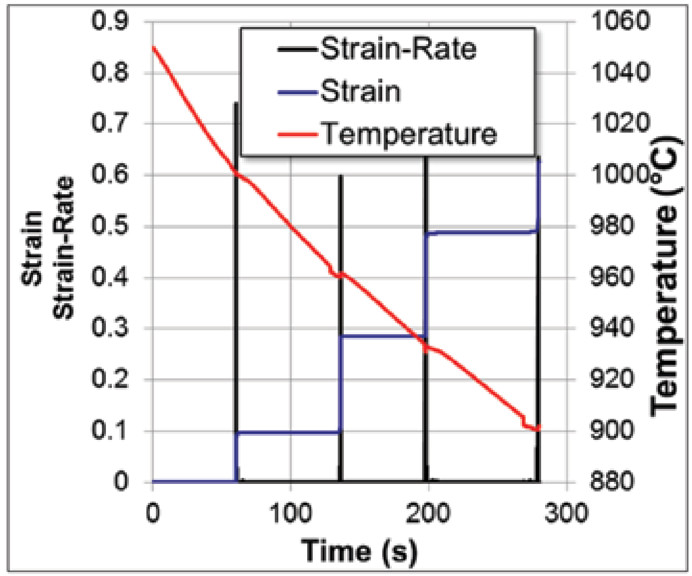

Figure 13 : Strain and Strain Rate Variation due to Microstructure Evolution

on microstructural evolution (Fig. 13).

With the 'full-field' model, the scale of analysis moves to the grain or cluster of grains. We are talking about a meso-scale level. Such approach cannot be conducted on the entire part as the number of grains would be nearly infinite, but rather the focus would be on specific areas of forging. As shown in Fig. 14, the full-field model considers the topology and the morphology of the grain using an

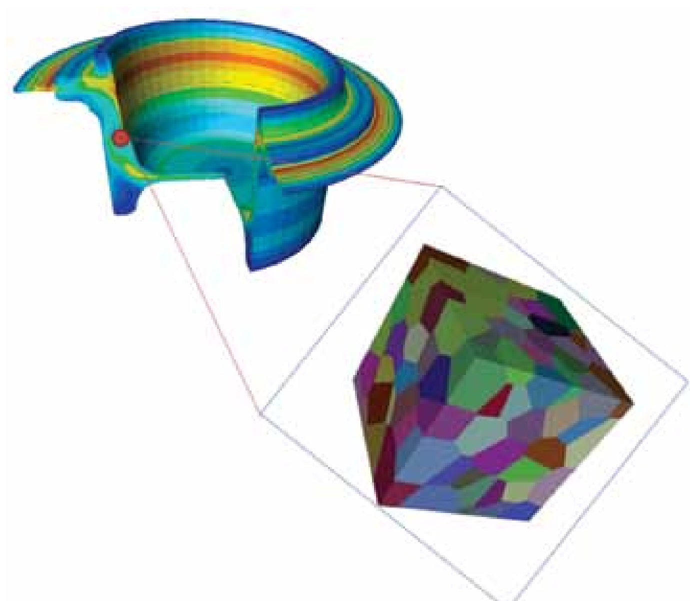

Figure 14 : Representation of the Full Field Approach at the Grain Level with a Representative Volume Element (RVE)

innovative RVE (Representative Volume Element).

Complex physical phenomena such as crystal plasticity can be investigated. The study is conducted on a poly-crystal in order to simulate the movement of the grains' boundaries during nucleation and grain growth.

Transvalor has fully implemented this approach in its latest software named DIGIMU®.

NOVELTIES & FUTURE TRENDS

The 2016 report "Adressing the bottlenecks of FEA simulation" from the independent research firm Tech-Clarity clearly identifies the next challenges for software editors in the field of finite element analysis. The majority of recommendations are applicable to the 'process-oriented' software dedicated to the forging industry and we can quote the following ones:

- automate tedious & time-consuming preprocessor tasks
- use meshing tools that provide automation as well as flexibility
- reduce time to evaluate multiple iterations
- select tools that can work with multi-CAD
- improve the readability of the output results
- technical support is essential

In the light of this, Transvalor's strategy of development for its FORGE® software is reflecting the same orientation with a complete redesigned graphical user interface that speaks to the engineers and provides a unique experience. Today, a forging sequence (e.g. furnace heating - upsetter – blocker - finisher-trimming - heat treatment) can be modelled as a global project where every forming stage is 'connected' to the others. Therefore, the designer is able to start the project calculation and the part with its associated results will be transferred automatically from one stage to the subsequent one. This smart procedure significantly reduces the number of manual operations and it eliminates the usual cross-checks applied between each simulation.

On the R&D area, ongoing efforts are placed on metallurgy and microstructure. As this kind of modelling highly depends on the quality of the material data, strong connections are now established with material software based the CALPHAD methods.

In this matter, FORGE® software has recently introduced the possibility to predict phase transformation for titanium alloys and sustains research work upon heat & surface treatment. After recent introduction of carburizing and tempering simulation, further developments will allow nitriding and carbo-nitriding simulation.

CONCLUSIONS

Today, virtual manufacturing for the forging industry is a key opportunity. Simulation exerts a strong leverage effect for an effective innovation, lower production costs and delivery of higher quality parts.

Moving to virtual manufacturing it is a major breakthrough that brings multiple benefits which are :

- evaluate at no risk, smart design choices in the process development cycle
- make more productive products
- differentiate your products from the competition
- supply parts with proven in-use properties
- stay one step ahead of traditional foreign forging competitors
- Maintain deep technological knowledge within your organization.

■■■

Significance of Simulation in Manufacturing Process Design

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INTRODUCTION & BACKGROUND

Virtual manufacturing is the process of constructing model of a system in virtual environment (computer) and performing various tests, experiments by altering various input parameters for the purpose of understanding the behavior of the system. In today's competitive world "right first time" is essential during development of component, where manufacturing environment is very complex. To survive in competitive market, to understand the process, use of a virtual environment is helpful for simulating individual manufacturing processes and the total manufacturing system.

In today's competitive world "right first time" is essential during development of component, where manufacturing environment is very complex.

By driving compatibility between the product design and the assembly plant process, these virtual tools enable the early optimization of cost, quality, and time to help achieve integrated products, process and resource design, and affordability.

Fig. 1 shows development cycle of computer simulation. It starts from 1947 by implementing Monte Carlo then so on, still developments are in progress.

Rapid development in high speed computing and processing hardware, has enabled FEM codes be used in many engineering analysis. There are a number of reliable general purpose FE modelling packages available such as ANSYS, NASTRAN, DYTRAN, MARC, LSDYNA that can predict stresses in both tool and work piece.

Simulation requires certain amount of understanding and consideration while performing simulation.

I. Simulation is majorly based on finite element analysis, which is an approximate method by itself.

II. The method of formulation decides the accuracy of the output, such as element size.

III. The exactness of the input parameter to the formulation decides the accuracy of the output result.

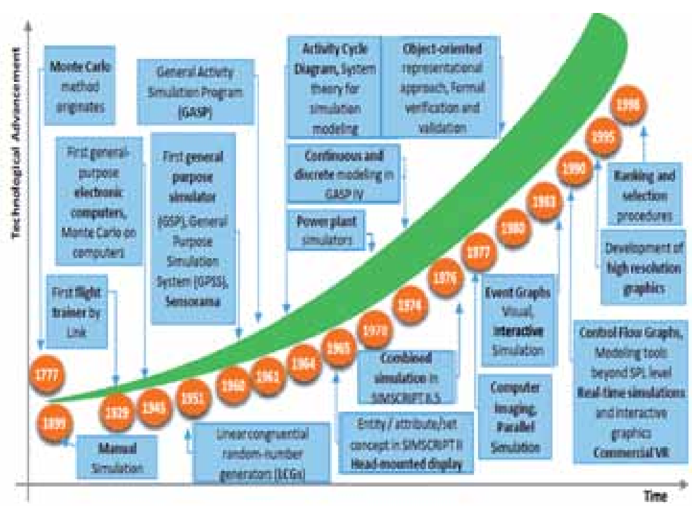

Figure 1 : Development Cycle of Manufacturing Simulation

So, process input parameters should be correct and reliable.

IV. It is always recommended to verify the initial study with actual trial to find out the correlation.

V. For new development the results can be benchmarked with a similar known case.

VI. Simulation by itself cannot solve engineering problems. Based on the output results, suitable inference for problem solving can be initiated. However a confirmatory test on the decided solution can be verified before actual implementation.

The development of powerful computer-based simulation techniques, such as those based on the finite element method, has provided a vital link between advances in tooling and equipment design, on one hand, and an improved understanding of materials behavior on the other. Inputs to finite-element codes include the characteristics of the workpiece material (flow stress and thermal properties) and the tool/workpiece interface (friction and heat transfer properties), as well as workpiece and tooling geometries. Typical outputs include predictions of forming load; strain, strain rate, temperature contour plots; and tooling deflections. This information can serve a number of design functions, such as selection of press capacity, determination of success or failure with regard to material workability or formability, and estimation of likely sources of tooling failure (abrasive wear, thermal fatigue and so on).

Process simulation techniques also provide a method for preform and die design through the ability to determine metal flow patterns without constructing tooling or conducting expensive in-plant trials. In addition, the output from process simulations can be helpful in selecting variables that are useful in process control (for example, ram speed or load monitoring) or finished-product quality control. The advent of these computer-based technologies will help in eliminating the hidden costs of trial-and-error design and in increasing productivity in the metalworking industries.

BENEFITS OF SIMULATION

- Shorter time to development
- Less shop floor trials
- Less material waste
- Improved quality
- Optimized process

PRODUCT DEVELOPMENT CYCLE

Following flow chart will show the product development cycle followed by all manufacturing industries to manufacture the component.

Process as shown in Fig. 2, is generally followed for all new part development in manufacturing industry. Process design was carried out once machining drawing was received. After process design, 3D CAD modeling of different stages was prepared. CAD model was transferred to CAM to generate the program. From the CAM program, die manufacturing

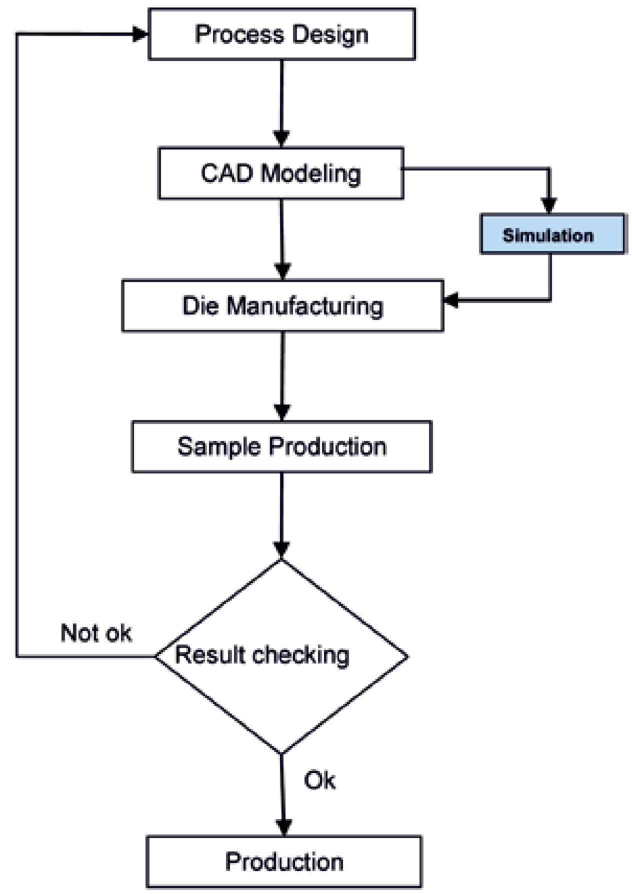

Figure 2 : Standard Traditional Forging Process

takes place. Using these dies, sample production takes place. After this, forged components undergo various checking parameters such as quality checking, defects checking etc. If samples meets the quality criteria, then dies are taken for production, above mentioned cycle is repeated if found otherwise.

This iterative process can be eliminated by use of simulation as a tool. Number of iterations can be tried out using simulation until defect free component is produced. Once process is established without any defect then CAM program can be released for further processing.

SIMULATION PARAMETER

Input parameters required for simulation software are shown in Fig. 3.

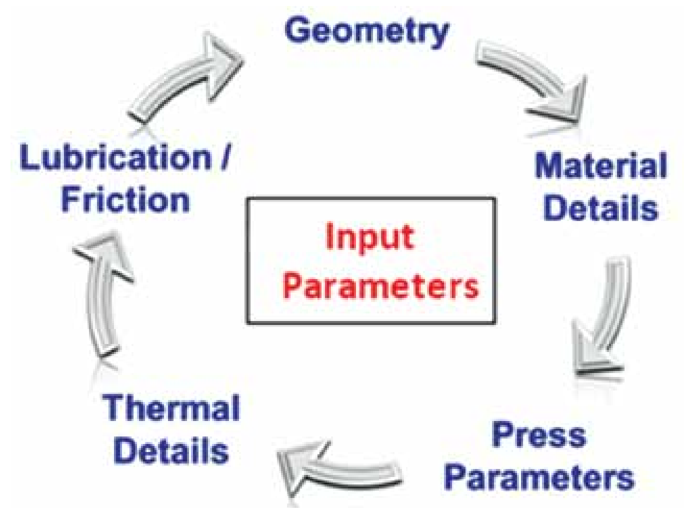

Figure 3 : Simulation Parameters

FORGING SIMULATION

In the field of forging as manufacturing process, developments of new components are intricate due to complex shapes, large number of process parameters like temperature, input material, lubrication, labor, force/energy etc. These parameters are responsible for process variation which and require great amount of control. In developing a process, the design engineer has to consider both the technical and economical limits in order to obtain competitive forgings. The need of the hour is shorter development time with highest quality. All these requirements can be achieved with the help of reliable computer simulations. Simulation technology helps us to reduce number of trials, predict metal flow, determine tonnage capacity, analyze defects, analyze temperature distribution etc. In totality, it helps us to improve productivity and achieve first time right.

"FORGE NXT 1.0" is very much useful tool for bulk metal forming simulation. There are various features of simulation tool, which helps to optimize the manufacturing process. Various features of simulation software's along with example are given below.

Fill up Analysis and Die Stress Analysis

Fig. 4a shows an under filling in marked circle area on counterweight of crankshaft, where as Fig. 4b shows deflection on same area of counterweight where under filling found. To overcome this counter weight fill up should be balanced.

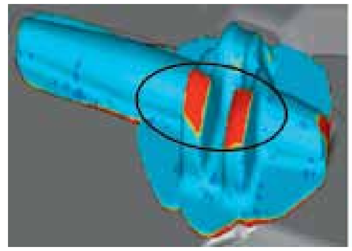

Figure 4a : Under Filling

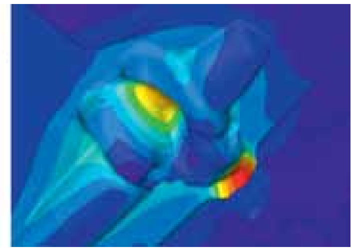

Figure 4b : Stress Analysis

Temperature Analysis

Fig. 5 shows rolling 6 stages, after each stage billet rotated by 90^0. Initial temperature was 1150^0C and it rises gradually to 1220^0C after 6 blows. Any point of time during the process temperature can be analyzed. Similarly stress, effective strain, pressure etc. also be analyzed with this tool.

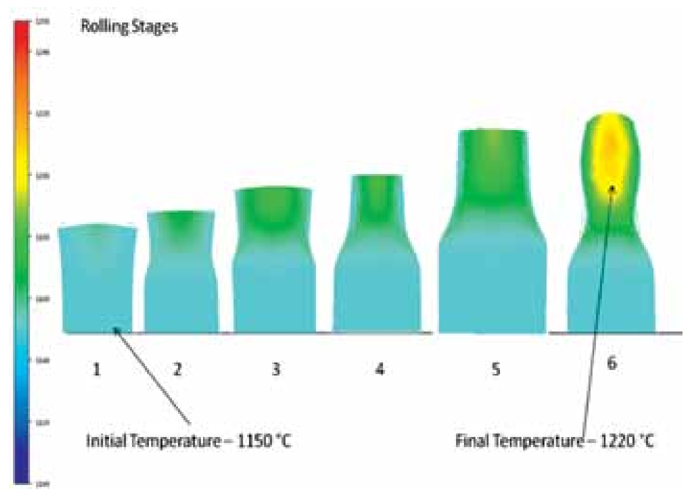

Figure 5 : Temperature Analysis for Rolling Stages

Point Tracking

Point tracking is very much useful for defect elimination. It helps to find out root cause analysis. For e.g. In Fig. 6a various points have been marked where lap generated during forging, followed by reverse point tracking. Result

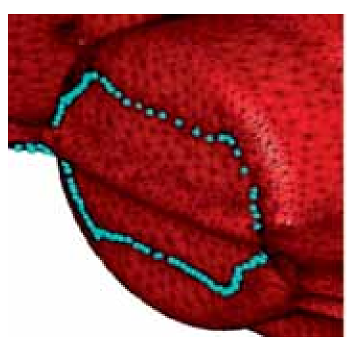

Figure 6a : Point Marked in Crack Area

Figure 6b : Result of Point Tracking

of reverse point tracking is shown in 6b, which shows root cause of defect generation.

Point tracking also used for plotting graph between any points for comparison. For e.g. Fig. 7 shows graph which is plotted between Stress Vs Strain for three points at 1100^{0}C.

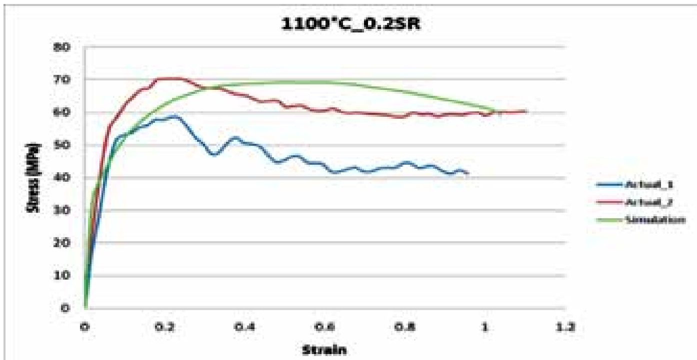

Figure 7 : Graph Comparison between Various Points

Grain Flow Analysis

Manufacturing through forging is preferred over casting due better strength. Uniform grain flow provides better strength in forging components. Below Fig. 8a & 8b shows comparison of actual grain flow verses simulated grain flow, in which found good co-relation between them.

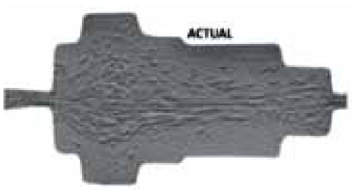

Figure 8a : Actual Grain Flow

Figure 8b : Simulated Grain Flow

Heat-treatment Simulation/Grain Size Prediction

For heat-treatment simulation input parameters are geometry, TTT curve, heat transfer coefficient etc. As a output simulation gives phase transformation in steels and hardness number in HRC/HV as shown in Fig. 9. Simulation is capable of simulating carbon deposition that is case carburizing process.

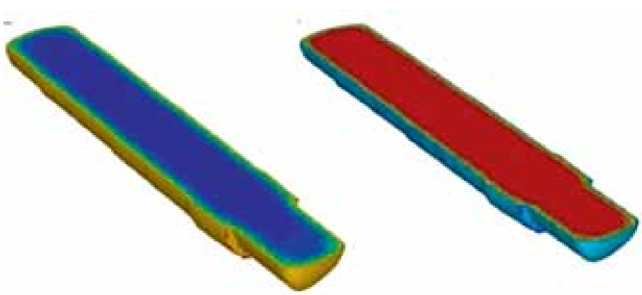

Figure 9 : Heat-treatment Results

Rolling Simulation

Fig. 10a shows cross rolling simulation and Fig. 10b shows ring rolling simulation. Cross rolling process is new concept which is mainly used for forging two components in one go.

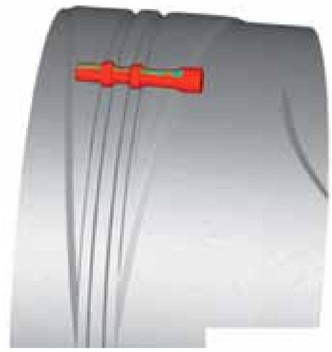

Figure 10a : Cross Rolling

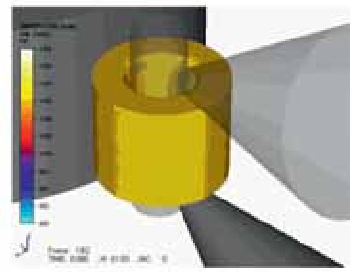

Figure 10b : Ring Rolling

CASE STUDY

Problem Definition : Defect Elimination

During forging of “low pressure valve body” forging lap or metal flow crack was generated. Metal flow crack/lap is shown in Fig. 11a & 11b marked with back circle.

Figure 11a : Simulated Crack

Figure 11b : Actual Crack

In modified design, all thumb rules viz. flash thickness and land width calculation, parting line radius, fillet and corner radius, stock size calculation and complexity factor etc. were applied. Orientation of forging was also a cause of concern and it was decide to alter the same. To understand the reason of crack, various modules viz. reverse metal flow, point tracking etc. was used. After studying all above parameters, it was decided to change pre-from shape.

Above figures shows modified forging process, Fig. 12a shows upset operation and Fig. 12b shows finisher operation. The modified process results into eliminating forging defect, additionally number of blows reduced and hold up of component was minimized. Thus effective

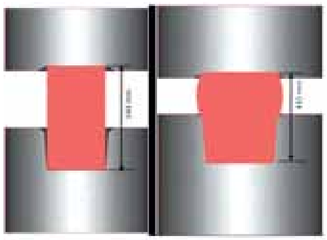

Figure 12a : Upset Forging

Figure 12b : Finisher Forging

use of simulation software helps to optimize the forging process, minimize material scrap or improve yield, and hence reduced the overall cost of manufacturing.

Physical trial was carried out with modified process. Inputs such as position of billet, number of blows, lubrication, energy per blow etc. was considered from simulation. A batch of 50 components was forged. All the samples were found to be satisfactory without any forging defect; this establishes good correlation with predicted results. Fig. 13a & 13b shows final shape of forged component from simulation and physical trial.

Figure 13a : Simulation

Figure 13b : Actual

Table 1 : Frequency Range of Components

Parameters	Existing Process	Modified Process
Initial Billet	RCS 300	Dia 340
No. of heats	1	1
Stages	Pre-form + Finisher	Upset + Finisher
No. of Blows	15	8
Hold-up	Oversize	Within in tolerance
Defects	Lap, non-uniform flash	No lap, uniform flash
Cut weight	385 kg	385 kg

CONCLUSIONS

- Computer simulation was able to capture the defects occurred in existing forging process.
- Simulation results gave insight about the forging process and it helped to find the possible reasons for the defects.
- Optimum solution achieved by modifying the process through iterative forging process simulation.
- All the forging defects (i.e. folds, cracks, etc) were removed by using proper modification in forging process.
- Modified forging simulation process helped in reducing number of blows as well as hold up of component, which helps in less machining stock of components. The benefits of this exercise are reduction in cost, increase in productivity without any forging defects.
- Results of the simulation were validated by shop-floor trials and excellent correlations in the results were established.

Simulation – The Key to Manufacturing Success in Today's Digital World

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INTRODUCTION

It's the twenty first century; an era wherein technology has moved so fast ahead that no one ever imagined that we would have an access to the entire world through a 5x2" device called 'smart phone'. Such is the power of technology and that has become the differentiating factor in today's world.

> *Simulation give wings to the designers imagination wherein they do not only get answers to their design options but also take more informed decision right at early stage of manufacturing*

So, the story goes the same for manufacturing as well. Manufacturing has gone through an era of metals and no one would have ever dreamt three to four decades ago that plastics would be an integral part of manufacturing and certainly the key driving force for more customer friendly and cost effective products. It's true and the testimonial lies in the amount of 'metal to plastic' conversion that we see around us. It also meant that plastic processing technology too had to keep pace with the fast change for the good. And the entire pressure to meet this change finally reflected onto core R&D, designers and developers.

Plastic experts and consultants have all been a part of this journey and they strongly believe that technology again were the front runners which brought this revolution. Injection molding was the more obvious solution but it's limitation to 'predict defects at the end' was a hindrance to its growth and this was the time when 'SIMULATION before manufacturing' became a more adaptable and precise solution. Since then 'Plastic flow simulation' has helped manufacturers to make better products quicker than the stipulated timeframe and in a more cost-effective manner. SIMULATION does not only aid robust design and manufacturing but compliment designer's experience with better insight into their 'WHAT-IF' scenarios; they give wings to the designers imagination wherein they do not only get answers to their design options but also take more informed decision right at early stage of manufacturing wherein the risk for any design change is minimum and with no additional or unwanted cost.

CONVENTIONAL APPROACH TO PRODUCT DEVELOPMENT AND THE NEED OF THE HOUR

Looking at the typical product development process, going from conceptualization all the way to product usage in the field, the ability to make a design change or improve a product's performance declines over time. This is because the cost of each design change goes up as more and more constraints are placed on the product. Traditional design processes concentrated the of the product development effort in the testing stage. Here, physical prototypes are often used for testing and validating the product prior to advancing to the manufacturing stage. Statistics clearly show industry leaders explore design changes earlier in the cycle during the design and engineering phase or

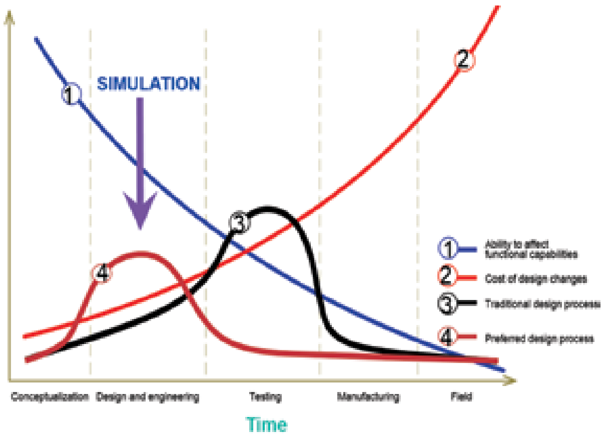

Figure 1 : Typical Product Development Process

even during conceptualization. This is enabling those best-in-class companies to look at a wider variety of design variables faster and at a lower cost than they can with physical prototypes.

SIMULATION tools are a key contributor to this shift because they allow designers to gain insight into how their product will perform before they need to invest time and money into building and testing physical prototypes in the shop.

CHALLENGES TO PRODUCT DEVELOPMENT FOR INJECTION MOLDING

- One has to be early into the market before competition; hence time to market is key which means early delivery
- To be a preference to customer, one has to be cheaper; which means product has to be cost effective
- Selection of material plays a significant role in making a robust product while at the same time without compromising on aesthetic and functional requirements. With numerous material options in the market, selection of the material becomes more challenging
- Information flow is key in injection molding since product is not manufactured by a single source; there is a risk to lost manufacturing information
- Defects in injection molding are only understood right at the end of product development cycle, which is at the trials; and changes to the product at this stage is a huge addition to cost and significant delay in delivery

The most prompt solution to all these challenges would mean to capture product and manufacturing deficiencies right at the beginning of the product development cycle. This is where a 'plastic flow simulation' comes more than handy in capturing troubleshooting or product failures at this stage. Through this information one can take decisive decisions to make necessary design or mould changes and then again validate through simulation itself.

ADVANTAGES OF PLASTIC FLOW SIMULATION

- By simulating issues early in the development stage, time to market is cut down
- Helps in cost saving by eliminating need of multiple trials. Optimizing part thickness again becomes a source of cost saving
- Enhances product quality in terms of robustness, aesthetics, life, etc.
- Can be used to optimize process at production stage hence helping in achieving a more consistent, sustainable and defect-free production
- Options of optimizing cycle time again helps to save on machine hour rates and further assists on quicker delivery
- Validating material through virtual simulation again eliminates need of validation through physical trials
- Eliminates need of physical prototypes

KEY HIGHLIGHTS OF PLASTIC FLOW SIMULATION SOFTWARE

Plastic flow simulation falls under FEA\FEM category of softwares. The recipe remains the same wherein the 3D part model is first taken into the software environment and is converted into a finite element model through pre-processor. This activity is most commonly termed as 'meshing'. Followed to this the boundary conditions are assigned depending upon the type of injection molding process and on the final result desired. Then the process parameters are assigned. The most important aspect would be to select the material. Material varies in its type (crystalline, semi-crystalline and amorphous) and further on the manufacturer and their derived grades. In addition, polymers are often composed of fillers in varying degrees depending upon the physical properties desired out of the polymer. It is very key to capture the properties of the material since it will play a key role in capability of the software to predict accurately. Once this is taken care of analysis is triggered and the software algorithm or so called 'solvers' runs in the background. Once the solvers computes, the results are intimated by the software via means of animations, images, plots, tables, etc. This is termed as the 'post-processor' wherein the software communicates the computed results to the user. Based on the result interpretation, the user or the concerned team arrive to a conclusion and then take decisions to move on with the part design\mold or to make changes and again go through the same cycle. One of such plastic flow simulation software available in the industry is Autodesk Moldflow. Users and companies have adopted this software and find this very handy in detecting manufacturing issues early in their development process.

The major competencies of plastic flow simulation are as following:

Gate Location Analysis

Generally, the gate location is a mold designer's call and more often it is a follow up practise. The material entry point is a key question for all manufacturers since the latter results might have roots in here. Moreover, a wrong selection of gate location can spoil all the work of design; hence there is more than a reason to have a preliminary 'Gate location' analysis. In addition, complex and huge part geometries with non- symmetricity can make the selection tougher by mere experience. Simulation software suggest possible gate locations considering many factors such as balanced fill, minimum pressure, minimum temperature drops, etc. Software also suggest locations for combination of multiple gates.

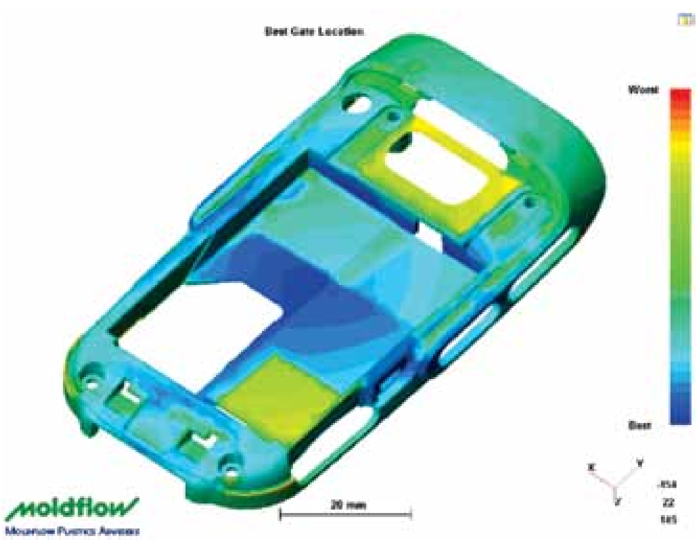

Figure 2 : Gate Location Analysis

Fill Analysis

The most important question that has to be answered is for sure 'How will the part fill?'. Studying the Fill results is key since the information on Short Shot, Hesitation, Race tracking, etc., will be inferred from the results here. The prediction of filling pattern is key and the most basic feature. Prediction accuracy again depends upon the material characterization, the type of mesh used, and so many other factors. A 'Fill' analysis leads up to several results such as 'Fill Time', Temperature results, Pressure results, Tonnage, etc. The key aesthetic related results such as Weld lines, Air traps are also driven from a Fill analysis.

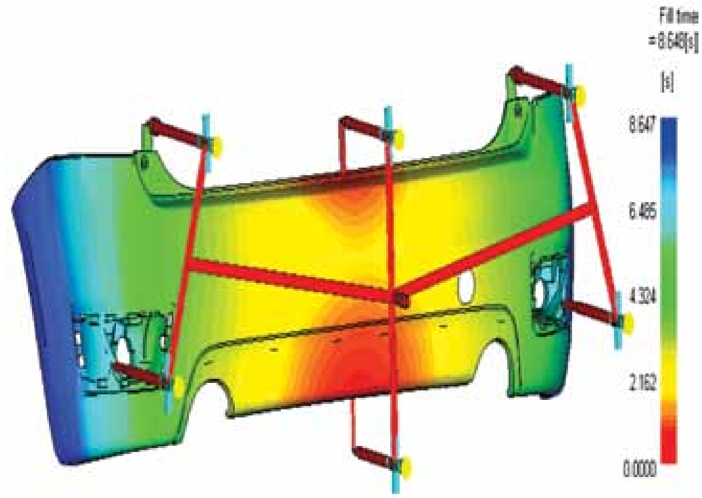

Figure 3 : Fill Analysis

Pack Analysis

Pack analysis compounded with the Fill analysis is definitely required since it evaluates the 'Sink Mark' results. Aesthetics is a prime concern for sectors such as automotive, consumer goods (appliances), aerospace, etc. Sink mark is key for any aesthetic product, especially with a polished surface. More than this, software calculates the pressure distribution on the entire part during packing and derives the 'volumetric shrinkage' distribution across the part. The uniformity in shrinkage distribution will play a

Figure 4 : Pack Analysis

decisive role in parts structural performance in terms of dimensions (Warpage).

Cool Analysis

The most common practise in the industry in order to compress the cycle time is by using cooling channels. Cooling channels not only help to maintain a lower temperature in the mold as per material manufacturer's requirement but also helps to eliminate hot spots in the part mold which could otherwise lead to longer cycle times than required. The results of Cool analysis help users to understand the effectiveness of the cooling layout but also assist to locate locations which would require additional attention for cooling. A planned methodology for mold designing would require a prior Cool analysis to have a better planning of cooling channels before the holes are drilled into the mold.

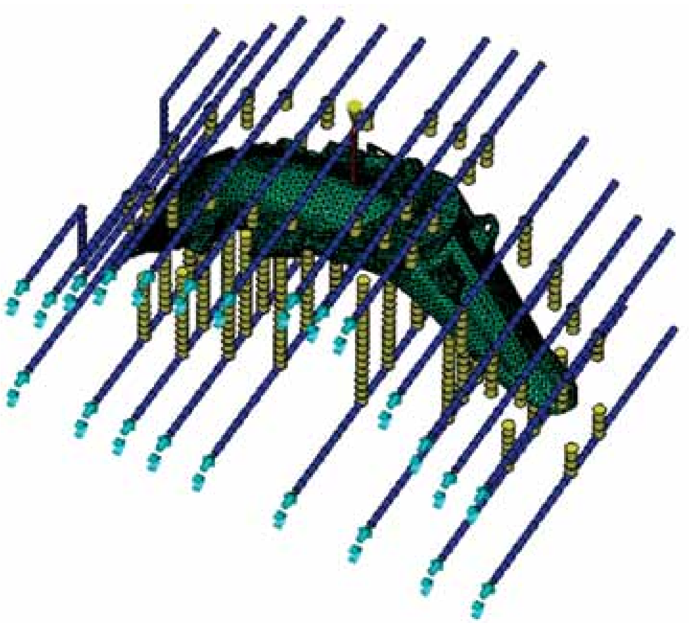

Figure 5 : Cool Analysis

Warpage Analysis

Most of the parts manufactured have to finally work in an assembly. This makes their dimensional stability as one of the prime requirements. Warpage is a common issue at shop floors and at times the issue can be so severe that it can lead to heavy consumption of time in reworking on a solution. In addition, plastic parts have variable shrinkages and the same applies from grade to grade. More than often the root cause of warpage is never discovered and a 'hit & trial' approach is taken to correct it. This 'Fitment' aspect of plastic parts can be handled well if guidance is taken from a run simulation. Manufacturers not only take the chances out of last moment surprises but are also in a better position to handle the warpage much before tooling is done.

In addition such softwares can handle sequential flow simulation. They have capabilities to simulate all sorts of feed systems, both 'cold' and 'hot'.

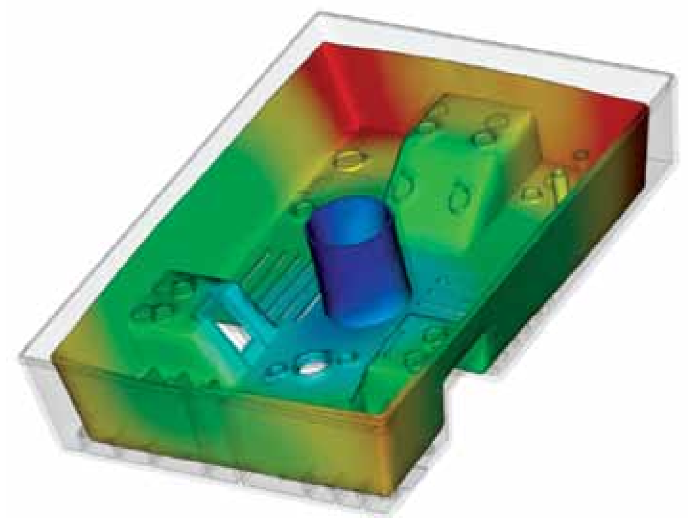

Figure 6 : Warpage Analysis

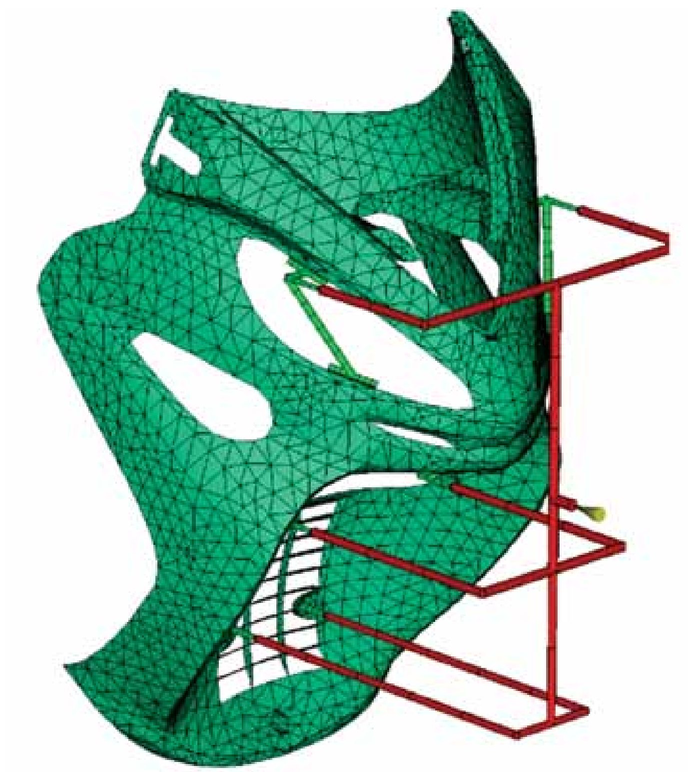

Figure 7 : Sequential Flow

There are many more capabilities to a plastic flow simulation software and they go hand to hand with the ongoing technologies in the injection molding industry.

Figure 8 : Gas Assisted Injection Molding

Injection molding itself has now been modified into several processes to achieve more manufacture- friendly products. Further, Injection molding processes are

- Gas assisted injection molding
- Thermoset injection molding
- 2-shot sequential overmolding
- Co-Injection molding
- Microcellular injection molding, etc.

With such advance technologies, plastics are moving fast ahead into this new era of digital manufacturing. Industry is welcoming them since they are credited to bring a new revolution to the way we have been practicing manufacturing.

■■■

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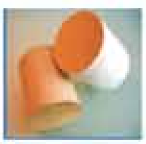

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Catalyst Design for HDD Engines Capable to Fulfill BSVI Legislation

Dr. Alain Ristori
Umicore AG and Co. KG, Germany

INTRODUCTION

Over the last 20 years, many countries, starting with Europe and the US, have implemented more and more stringent emission legislation. These emission standards have been achieved mainly via improved engine-out emissions (e.g. through the application of measures such as EGR, improved engine design, fuel injection system and engine control) and the implementation of advanced catalyst technologies. The application of exhaust gas aftertreatment for heavy duty vehicles has culminated today with Euro VI/US 2010 regulations. These legislations require complex Aftertreatment Systems (ATS) including Diesel Oxidation Catalysts (DOC), Diesel Particulate Filters (DPF), devices for Selective Catalytic Reduction (SCR) and last but not least an Ammonia Slip Catalyst (ASC). Within these systems the DPF is effectively mandated in order to meet the particulate matter limit whereas the SCR allows to reach the NO_x legislation limit. The initial requirements for a standalone DOC through former legislation have been for HC, CO and soluble particulate matter conversion over the ESC and ETC cycles.

> *"Euro VI/US 2010 regulations. These legislations require complex After treatment Systems including Diesel Oxidation Catalysts, Diesel Particulate Filters, devices for Selective Catalytic Reduction and an Ammonia Slip Catalyst"*

This paper explores the different after treatment system approaches able to cope with the specific Indian market conditions. Every system proposal will be discussed with respect to performance, cost and robustness.

CATALYST SYSTEM DESIGN FOR BSVI

The majority of all systems which are used today to fulfill EUVI / US 2010 standards can be described in a principal way as follows (Fig. 1).

Aftertreatment System Requirement

The SCR catalyst will provide the adequate NO_x conversion while the filter will convert the soot mass. This filtration process is in fact one key point for the system design.

SCR Catalyst

Usually the SCR technologies on the market are separated in two technology families-one is zeolite based, in which the zeolite is containing iron or copper as active component& the other family is non-zeolite based in which vanadium is used as active component. As we can see in the Table1,

Figure 1 : Principal System Layout Four Euro VI/US2010 Heavy Duty ATS.

these technologies compared for various parameters. In synthetic gas bench measurement Fig. 2 we can observe the comparative study of the sensitivity to NO_2 for Cu-SCR, Fe-SCR & V-SCR with respect to NO_x conversion.

Table 1 : Typical System Layout Four Euro VI/US2010 Heavy Duty on Road

SCR Technology	Thermal resistance	Sulfur resistance	NOx conv. Low NO2 Low T°/High T°	NOx conv. 75% NO2 Low T°/High T°
V-SCR	Max 580°C	Excellent	Medium/Medium	Low/Medium
Cu-SCR	> 700°C	> 500°C needed for desulfation	Good/Medium	Medium/Medium
Fe-SCR	> 700°C	Good	Medium/Excellent	Excellent/Excellent

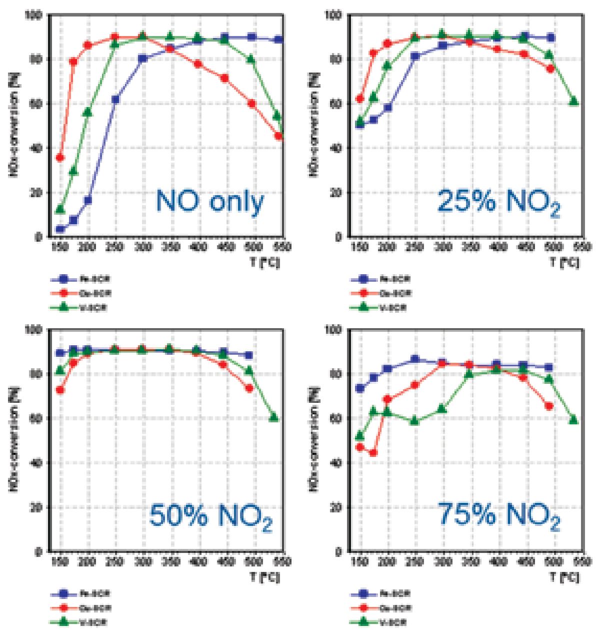

Figure 2 : SCR Comparison on NO_x Conversion with Different NO_2 / NO_x Ratios, NH3 / NO_x Ratio : 0, 9

As a conclusion the SCR technologies available on the market have both advantages and drawbacks depending on the end application.

DOC + CDPF Catalysts

DOC and CDPF catalytic pre system is defined to provide NO_2 for the continuous filter regeneration at low temperature and for the SCR system. If the trap regeneration is also relying on oxygen based high temperature regeneration, the DOC and CDPF will also be optimized for creating heat up when some diesel fuel is injected in the exhaust gas. The choice of the DOC and CDPF will be hardly depending on the way the particulate trap is regenerated.

The Fig. 3 shows the influence of the Platinum to Palladium ratio on the DOC and CDPF characteristics.

Figure 3 : Influence of the Pt/Pd Ratio on the DOC and DPF Features

Ammonia Slipcatalysts (ASC)

The ASC is placed after the SCR for reducing the potential excess of ammonia. The Fig. 4 shows a typical ASC behavior with respect to removing ammonia.

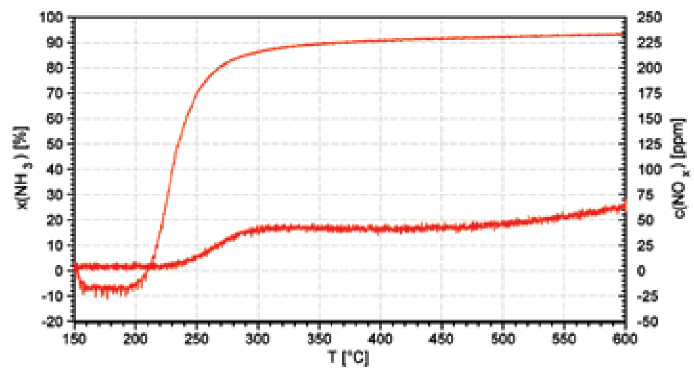

Figure 4 : ASC Light Off Test on Synthetic Gas Bench with 300 ppm NH3

SYSTEM OPTIMIZATION FOR BSVI

With Passive Filter Regeneration

Such system will rely as much as possible on the soot oxidation by NO_2 at low temperature. The filter regeneration does not require any increase of temperature by injecting fuel in the exhaust. The Vanadium SCR can be used as no temperature higher than 600°C should be endured by the SCR. As the pre system (DOC + CDPF) is optimized for forming NO_2, the Fe-SCR is also a choice despite of its high sensitivity to NO_2 concentration. The passive regeneration requires sufficient temperature so that the presystem can generate sufficient NO_2 concentration. It can be fitted on engine emitting high NO_x raw emissions, with or without EGR. The long haul trucks are usually very well adapted to passive filter regeneration.

With Active Filter Regeneration

Some application, especially some city buses and some small HDD applications will probably require filter regeneration. The zeolite technologies (Fe and Cu) are by far more thermal resistant and are recommended for the active regeneration way. Being less sensitive to NO_2, the Cu-SCR is a good candidate for the active way. In such case, the sulfur sensitivity is compensated by the regular temperature exposure generated during the filter regeneration.

SIMULATION STUDY

Dataset for the Simulation Study

Table 2 : Dataset for Simulation Study

Dataset for Simulation study	
Engine displacement	6,7L
Emission Cycle	Hot WHTC
Silmulation#1	
EO NOx	6,7 g/Kw-hr
Avg. Inlet SCR Temp.	247 Deg.C
Urea Dosing Set Temp.- 180 Deg. C	180 Deg. C
(Active Regeneration) NO2/NOx -	35%
(Passive Regeneration) NO2/NOx -	40%
Ageing Method	Oven Ageing
SCR Voluems	1,6 X Engine Swept Volume 2,0 X Engine Swept Volume 2,2 X Engine Swept Volume
Silmulation#2	
EO NOx	4,0 g/Kw-hr 7,5 g/Kw-hr

Simulation Results with the Original Engine Raw Emissions

The Fig. 5 shows the comparison between the three SCR technologies with different SCR volume and NO_2 / NO_x ratio.

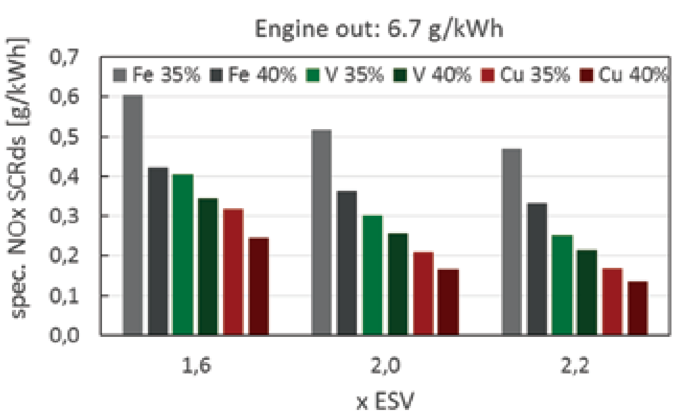

Figure 5 : SCR Technology Comparison with Different Volumes and NO_2 / NO_x Ratios

For the same SCR volume, the Cu-SCR has the highest NO_x conversion and is less depending on the NO_2 / NO_x ratio. The second best SCR is Vanadium based. The Fe-SCR shows a clear dependency to NO_2. Increasing the NO_2 / NO_x ratio from 35% to 40% leads to 30% NO_x tailpipe decrease. A higher NO_2 concentration would certainly contribute to an even lower NO_x tailpipe level.

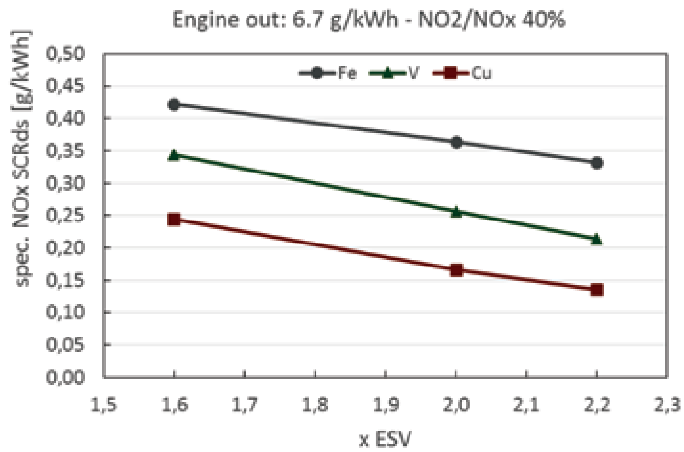

Figure 6 : SCR Volume Comparison for the Same NO_x Tailpipe Target (0,25g/kWh)

The Fig. 6 shows the SCR volume needed to achieve the same NO_x tailpipe with different SCR technologies

Simulation Results with Scaled Engine Raw Emission

The Fig. 7 shows the comparison between Fe and Cu SCR for active systems. The NO_2 / NO_x ratio has been fixed to 35% as the pre system is more optimized for supporting heat up of the filter by burning hydrocarbon than generating NO_2.

For systems with active filter regeneration, The Cu-SCR shows a clear advantage in comparison to Fe-SCR.

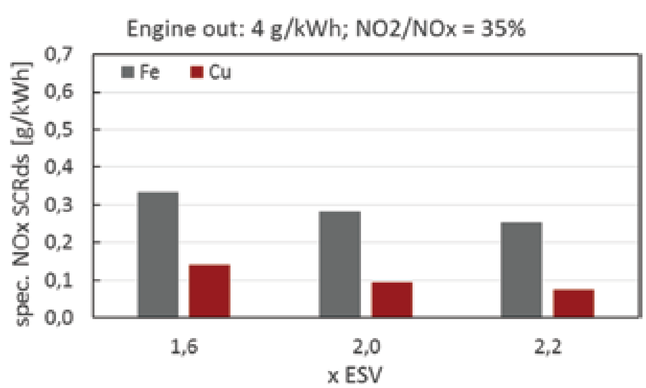

Figure 7 : SCR Technology Comparison for Active Systems with Different Volumes and NO_2 / NO_x Ratios

The Fig. 8 shows the comparison between Vanadium and Iron SCR for passive systems. The Cu SCR is not part of the comparison as it cannot be recommended in such conditions because of its sensitivity to sulfur which requires high temperature desulfation measures.

With 40% NO_2 / NO_x ratio, the Vanadium technology has a better NO_x conversion than the Iron SCR.

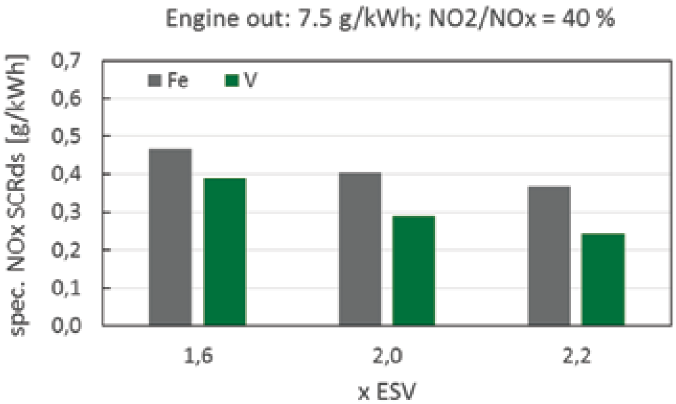

Figure 8 : SCR Technology Comparison for Passive Systems with Different Volumes and 40% NO_2 / NO_x Ratio.

EXPERIMENTAL STUDY

In parallel to the modeling study, one experimental investigation has been run. The goal was to confirm that the tendencies observed by simulation are confirmed on the engine bench.

Aftertreatment System Setup

Table 3 : Experimental Study with 3 different ES V Engines - WHTC Cycle

System#1 NO_2 / NO_x - Optimised Active Regeneration	35%
System#2 NO_2 / NO_x - Optimised Passive Regeneration	45%
System#3 NO_2 / NO_x - Optimised Passive Regeneration	As much as possible
Oven Ageing	100B580 w 10% H_2O

Engine Setup : The engine is the same as the one used for the simulation work.

System Comparison

With Low NO_2 / NO_x (35%)

The Fig. 9 shows comparison between the three SCR technologies with different ESV with active regen and 35% NO_2 / NO_x.

With such low NO_2 / NO_x ratio, the Cu-SCR is by far the best performing technology still being with 1,3 x ESV better than V- and Fe-SCR with 2,5 x ESV. For this engine application, a NO_x tailpipe engineering target of 400mg/kWh NO_x would be achieved with 1,3 x ESV Cu-SCR and 2,5 x ESV V-SCR. The Fe-SCR is not able to reach this target.

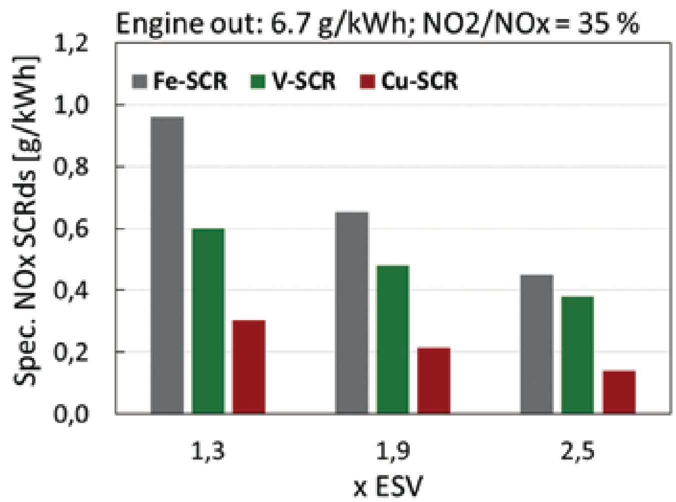

Figure 9 : SCR Technology Comparison for Systems with Different Volumes and 35% NO_2 / NO_x Ratio

With Optimal NO_2 / NO_x (45%)

The Fig. 10 shows the comparison between the three SCR technologies with different ESV for passive Regen and 45% NO_2 / NO_x ratio.

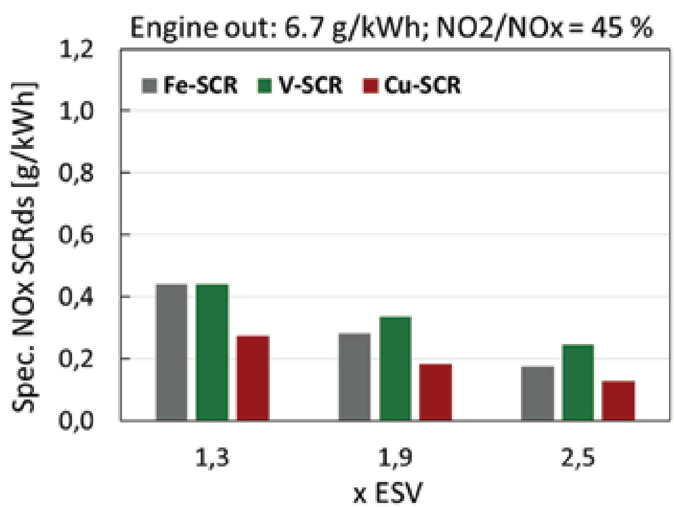

Figure 10 : SCR Technology Comparison for Systems with Different Volumes and 45% NO_2 / NO_x Ratio

With Excess of NO_2 optimal (NO_2 / NO_x 55%)

The Fig. 11 shows the comparison between the three SCR technologies with different ESV and 55% NO_2 / NO_x ratio. This ratio could be reached for one system optimized for passive filter regeneration strategy using large DOC or high precious metal loading.

The excess of NO_2 is still beneficial for Fe- and Cu-SCR while it has a huge negative impact on the V-SCR performance. With such NO_2 / NO_x ratio, the Cu-SCR is again the best technology but the Fe-SCR is also performing very well.

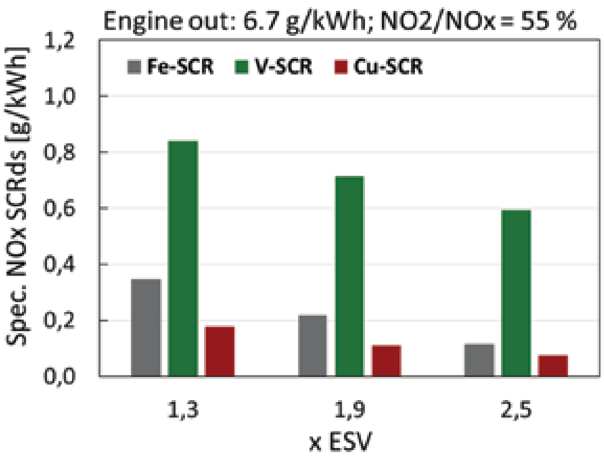

Figure 11 : SCR Technology Comparison for Systems with Different Volumes and 55% NO_2 / NO_x Ratio

SUMMARY

In this paper, we have investigated with modeling and experimental data the use of different SCR technologies for fulfilling the BSVI legislation. Both simulation and experimental data did show the same trend.

Indian is a particular market with some unique requirements: The average speed in city driving conditions is one of the slowest in the world which can somehow compromises the use of passive filter regeneration. On the other hand the long haul truck are equipped with small engines and are usually used at weight load capacity which is favorable for passive system regeneration. In addition to this, there is a risk of misfueling with adulterated fuel containing potentially a high amount of sulfur. To that purpose the after treatment system must be designed with robust technologies.

For Long Haul Trucks and Applications with Passive Regeneration Strategies

The Vanadium SCR is well known for its robustness against poisons and is definitely a good choice for applications with sufficient temperature for ensuring a good passive filter regeneration in real driving conditions. The DOC and CDPF must provide a sufficient amount of NO_2 to ensure a good passive soot generation and a good NO_x conversion efficiency on the V-SCR. Usually Pt only or Pt rich formulations fulfill that requirement with a limited precious metal amount.

On a system cost perspective, this system has some obvious advantages by combining a cost effective SCR technology with low precious metal loading oxidation catalysts. Moreover, it does not require any additional hydrocarbon dosing system for generating heat up in front of the filter.

For Small Delivery Trucks and City Busses Applications with Active Regeneration Strategies

For cold application like small HDD vehicle or city buses, the Copper SCR is more adapted as it can be used in combination with active filter regeneration. Moreover, the periodical heat up of the system will allow the SCR to recover from any sulfur poisoning. The DOC and CDPF are based on Pd rich technologies. The precious metal amount must be sufficient for fulfilling the heat up requirements.

On a system cost perspective, the used of a high end Cu-SCR technology in combination with a lower NO_x tailpipe allows to reduce the SCR volume. The system precious metal amount is higher than for passive regeneration ATS. The PGM cost is lowered by the use of Palladium. This strategy requires in addition some features to increase the inlet CDPF temperature for burning the soot and also desulfate the Cu-SCR. Its higher grade of sophistication makes that system more costly than a passive one. On the other hand, this approach is able to fit with 100% of the Indian Market applications.

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EU Certification Gasoline	EU- 3	CEC RF-02-99	CEC RF-02-99, Ox. < 0.1% CEC-RF-02-99, Ox. 0.8 - 1.2 % CEC RF-02-99, Ox. 2.3%
EU Certification Gasoline	EU-4	CEC RF-02-03	CEC RF-02-03, Ox. < 0.1% CEC RF-02-03, Ox. 0.7- 1.0 %
EU Certification Gasoline	**EU-5**	**CEC RF-02-08 E5** **CEC RF-01-08 E85**	**CEC RF-02-08 E5** **CEC RF-01-08 E85**
EU Certification Gasoline	**EU-6**	**tbd**	**EU-6 Certification Gaoline E10**
US Certification Gasoline	CFR	CFR § 86.213-04	Cold CO, High Octane 86.113-04
US Certification Gasoline	CFR	CFR § 86.113-04	EPA test fuel acc. to par. 86.113-04
California Cert. Gasoline	CARB RFG Ph	CEC RF-11-A-96	CEC RF-11-A-96
California Cert. Gasoline	CARB LEV III	n/a	LEV III Premium / Regular E10
US Certification Gasoline	EPA Tier 3	n/a	EPA Tier 3 Premium / Regular E10

Diesel

Fuel Type	Version	Official Fuel Code	Haltermann Designation
EU Certification Diesel	EU- 2	CEC RF-03-A-84	CEC RF-03-A-84
EU Certification Diesel	EU- 3	CEC RF-06-99	CEC RF-06-99, S < 10mg/kg CEC-RF-06-99, S ca. 50 mg/kg
EU Certification Diesel	EU-4	CEC RF-06-03	CEC RF-06-03
EU Certification Diesel	**EU-5**	**CEC RF-06-08 B5**	**CEC RF-06-08 B5**
EU Certification Diesel	**EU-6**	**tbd**	**EU-6 Certification Diesel**
US Certification Diesel	CFR	CFR § 86.113-94	Test Fuel 2-D by CFR Title 40 § 86.113-94
US Certification Diesel	CFR	CFR § 86.113-07	Test Fuel 2-D (HC) CFR Title 40 § 86.113-07
			Test Fuel 2-D (LC) CFR Title 40 § 86.113-07
US Certification Diesel	CFR	CFR § 86.131398	Test Fuel 2-D by CFR Title 40 § 86.1313-98

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ETS RACING FUELS

Meeting the CO_2 Targets : Lubricants & Alternative Fuels

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Research & Development Center, Indian Oil Corporation Limited, India

INTRODUCTION

Most industrialized countries have either established programmes or are bringing in norms to address the transportation related GHG (green house gases) emissions. In India, efforts for curtailing GHG from auto mobiles have resulted in CO_2 emissions targets set at 130 g CO_2 /km for 2017 and are likely to tighten again by 2022. OEMs are introducing a number of fuel economy innovations including start-stop systems, smaller and turbocharged engines, advances to timing and combustion and the use of new materials to make the vehicle lighter. Apart from these strategies the use of right kind of lubricants and fuels too play an important role in attaining the fuel economy targets. Studies have shown that FE gains through lubricant route are the least costly (Fig. 1).

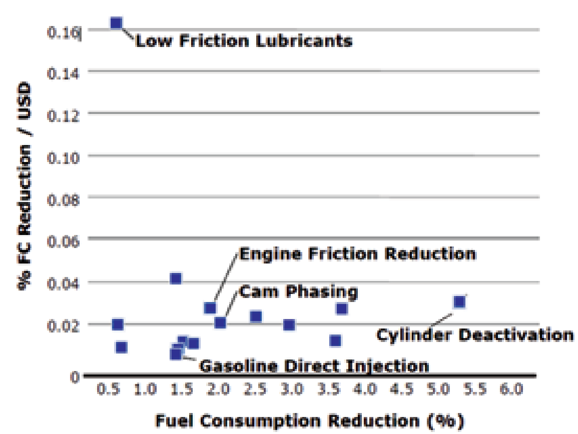
In today's smaller, more complex engines, lubricants must work much harder to keep engines clean for longer, while protecting the engine, after treatment devices and at the same time ensure optimum fuel economy performance. From 2003, automakers have started to offer vehicles capable to run with two fuels and any mixture in between instead of offering vehicles capable to run only with one fuel. These vehicles called flexible fuel vehicles (FFV) or simply flex fuel vehicles are increasing their presence due to the customer benefits of choosing the fuel as a function of price, availability and performance.

> *The use of optimized lubricants along with flex fuels is slated to be an effective strategy for achieving the CO_2 emissions targets for OEMS*

Considering the large scale capital investments & time delay required for incorporating any hardware changes in the assembly line of automobile manufacturing, the use of optimized lubricants along with flex fuels is slated to be an effective strategy for achieving the CO_2 emissions targets for OEMS.

LUBE DERIVED FUEL ECONOMY

Friction reduction within the engine is a feasible strategy for attaining all over fuel gains. OEMs achieve reduced



Source: From North American Fuel Economy Testing, T. Miller, 15th Annual Fuels & Lubes Asia Conference Data from U.S. Department of Transportation Report RIN 2127-AK29

Figure 1 : Cost Vs Fuel Efficiency Improvement Methods

friction in the engine by shifting the balance of boundary and hydrodynamic lubrication during normal operating conditions towards the hydrodynamic regime. The new engine designs allow the use of lower viscosity lubricants to reduce frictional losses in the hydrodynamic regime.

In addition to the driving cycles and engine types, viscosity and additive chemistry of the lubricant oils also significantly impact the fuel economy performance. Fuel economy improvement has been demonstrated to be most closely related to two engine oil parameters: friction modifiers and engine oil viscosity. One of the routes to gaining a fuel economy benefit is to move to the lower viscosity grade oils. However, as the oil viscosity is reduced, the engine hardware can potentially run into wear and durability issues. An alternative strategy is to optimize the lubricant viscosity profile using viscosity modifiers (VMs) such that, at a fixed HTHS150 (High temperature high shear @ 150°C) viscosity, the viscosity at lower temperatures is minimized. In this case the frictional losses are minimized at the temperatures typical of regular operating conditions that are below 150°C, while providing engine protection at peak temperatures of about 150°C.

Lowering the viscosity of lubricant and adding a friction modifier like molybdenum dialkyl dithiocarbamate (MoDTC) are popular scheme for friction reduction especially in a gasoline engine. Lowering viscosity may have a limit and at the same time lubricants with the same HTHS150 viscosity can deliver FEI (Fuel Economy Improvement) of various magnitudes due to a different viscosity-temperature profile. Therefore suitable dosage of FM (Friction Modifiers) tends to improve the FEI characteristics especially at lower operating temperatures. Recently, viscosity grades below SAE 20 were proposed for SAE J300, and SAE 16 grade was introduced. In addition to the use of lower viscometric oils, optimum use of VM (Viscosity Modifier) & FM additives will ensure fuel economy benefits over long drain intervals.

Passenger Car Segment

It is generally accepted that improvements in engine oil derived fuel economy is influenced by reduction in kinematic viscosity and high shear viscosity. A comparative study in terms of FEI between an in-house developed 5W30 (with improved FM dosage) & commercially available industry grades (15W40, 5W40 & 5W30) for passenger car diesel engines confirms the same. Table 1.depicts the viscosity comparison for the different oils developed as per SAE J300.

The candidate oil when evalauted on a chasis dyno (MIDC-Modern Indian Driving Cycle) showed a disntinct fuel economy improvement of 5.86% w.r.t. 15W40. The candidate oil has also performed extremely well in the durability tests.

Table 1 : Viscosity Characteristics of Different Oils

Oil Viscosity (Performance Levels)	**KV @ 100C, cSt**
Industry 15W40 (CH4)	14.60
Industry 5W40 (A3/B4)	13.76
Industry 5W30 (A5/B5)	11.1
Candidate 5W30 (A5/B5)	11

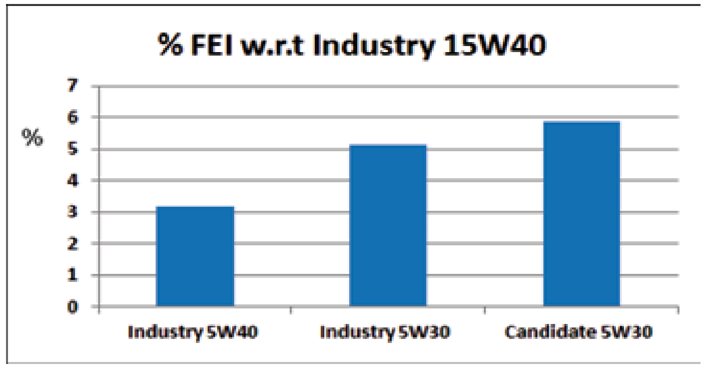


Figure 2 : FE Improvement w.r.t. 15W40

LCV & Heavy Duty Segment

Research data indicate that apart from the lubricant's VI improver type and performance additives the predominant impact on diesel engine fuel economy, as it relates to a truck in on-highway type operation is the high temperature lubricant viscosity. Engine tests (for fuel economy studies) simulating different driving conditions (hilly terrain & flat roads) for different viscosity grades is presented in Fig. 3.

The presented data suggest that the high temperature viscosity determines the outcome of the test to a greater degree than the low temperature viscosity.

Chassis dyno test using the Delhi Bus Driving Cycle (DBDC) (Fig. 4) on a LCV (greater than 3.5 tons GVW) comparing two different lubricants clearly showed that a well formulated engine oil meeting the CI4 plus performance yielded better fuel economy of 3.3% compared to the market reference CH4 engine oil.

Natural gas (NG) engines are too becoming very popular especially in the heavy duty and stationary engine segment. The lubrication requirements for gas engines differ

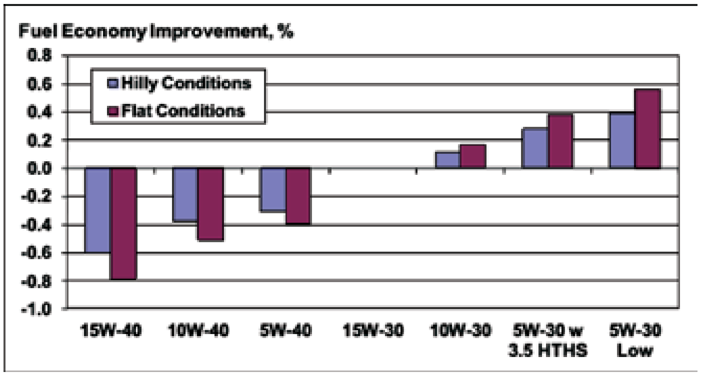


Figure 3 : The Official Volvo D12D FE Results for Different Viscosity Grades (SAE 2011-01-2124)

Table 2 : FEI CI4 Plus 10W30 Engine Oil

Oil Spec	KV @100C cSt	% FE Improvement (DBDC)
15W40 (CH4)	14.61	--
10W30 (CI4 Plus)	11.46	3.3%

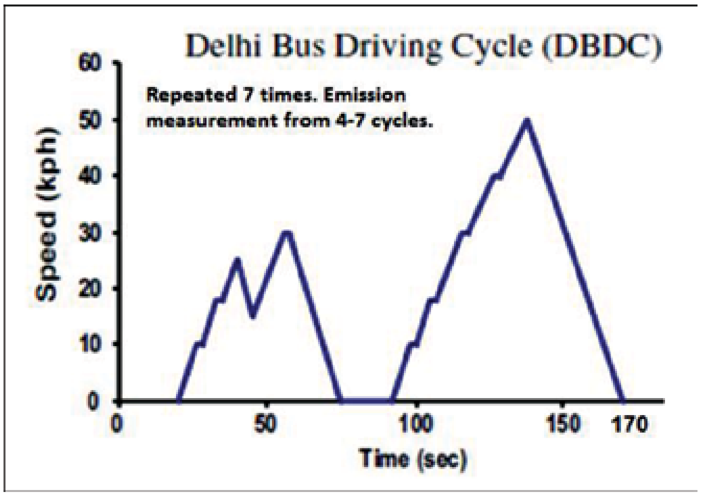


Figure 4 : Delhi Bus Driving Cycle (DBDC)

significantly from its liquid counterparts as the engines run hotter and thereby wear protection as well as oil consumption rates are major design parameters for the gas engine oil formulations. The use of lower viscometric oils for better fuel economy is gaining momentum in NG engines as well. A study conducted in-house shows significant reduction in fuel consumption for 15W40 (Oil A) viscosity grade over the traditionally used 20W50 (Oil B).

It is observed that the gain in BSFC for (Oil A) is more prominent at low speed and load conditions (Fig. 5). This behavior can be explained by the fact that at low engine

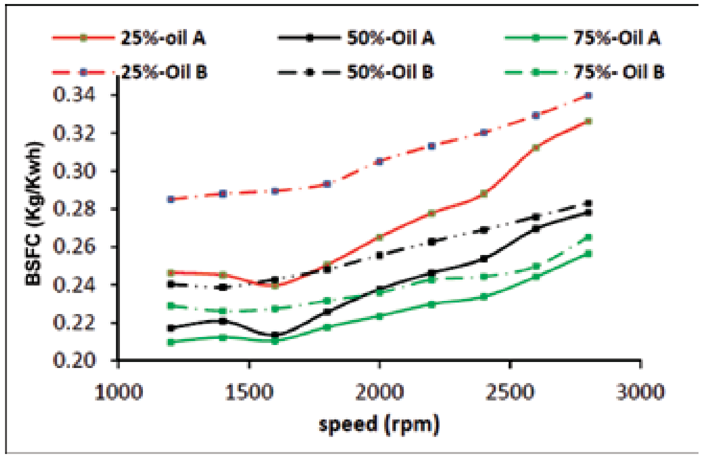


Figure 5 : BSFC at Different Speed and Load Conditions

speed and load condition the in-cylinder temperatures are comparatively lower which affects the viscous drag forces. Low viscosity oils offer lesser viscous drag and therefore better fuel economy can be obtained. But as the speed and load increases the operating temperatures increase which reduces the effects of viscous drag and thereby the benefits of using low viscosity oil is found to be diminishing.

ALTERNATIVE FUELS DERIVED FUEL ECONOMY

Consistent efforts are being made for the use of bio fuels (Ethanol, Bio diesel), compressed natural gas (CNG), liquefied petroleum gas, hydrogen etc. as alternative fuels for internal combustion engines. Gaseous fuels are seen as promising due to their clean burning characteristics and reduced carbon related emissions.

Use of hydrogen blends to improve efficiency : Studies conducted on a spark ignition bi-fuel passenger car engine of Bharat Stage - IV compliance using gasoline, CNG and 18 % v/v of HCNG reveal the obvious benefits of using gaseous fuels in terms of CO_2 mitigation and better BSEC(Brake specific energy consumption). From Fig. 6 & 7, it is clear

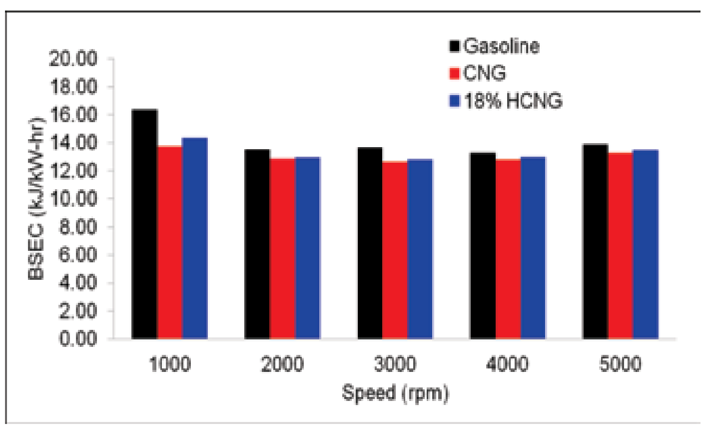


Figure 6 : Brake Specific Energy Consumption

that the average value of energy consumptions for CNG and HCNG are approximately 15% lower than gasoline at idling condition. This is attributable to the higher calorific value of gaseous fuels.

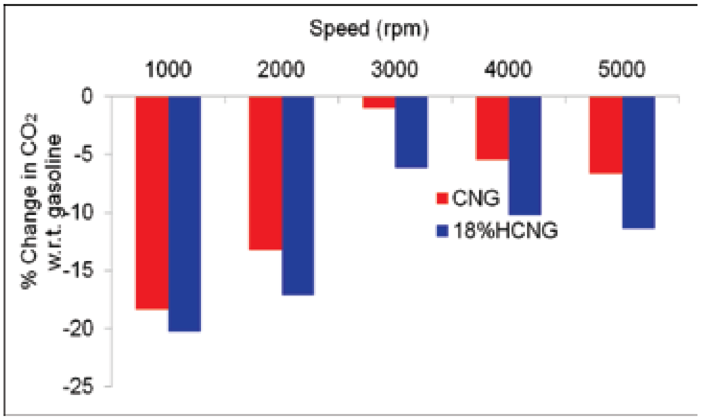


Figure 7 : Percent Change in CO_2 Emission w.r.t. Gasoline

It is seen that CNG and HCNG fuels reduced the CO_2 emissions significantly, ~20% reduction at idle (1000 rpm), ~10% reduction at rated torque condition of 3000 rpm and ~15% reduction at 5000 rpm. This is due to the lower consumption of fuel (as calorific value on mass basis for gaseous fuels is higher) and reduction in carbon to hydrogen ratio.

Varying blends of ethanol in gasoline: The recent notification by MoRTH(Ministry of Road Transport and Highways), has increased the permissible limits of blending of ethanol with gasoline from 5% vol. to 10% vol. The increased limit on RVP (Reid vapor pressure), VLI (vapor lock index) and oxygen content allows blending of ethanol up to 10% to leverage the benefit of higher RON for ethanol over gasoline.

A study conducted for E5, E10 & E20 (20% ethanol blended gasoline) on a MPFI engine reveals comparable BSFC values with E10 but substantial benefit in CO_2 emissions at part load conditions (refer Fig. 8, 9).

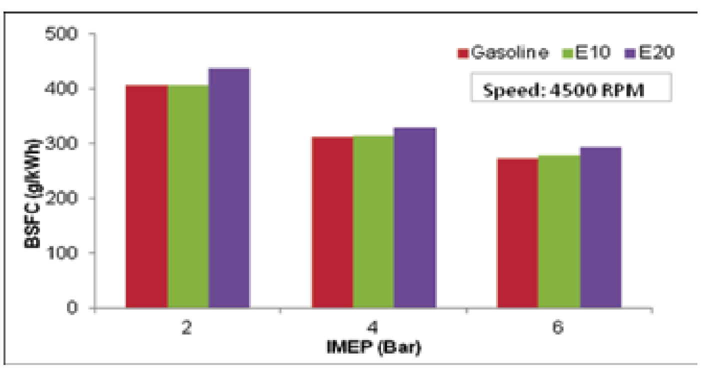


Figure 8 : CO_2 Values: E10 Fuel Shows Reduction

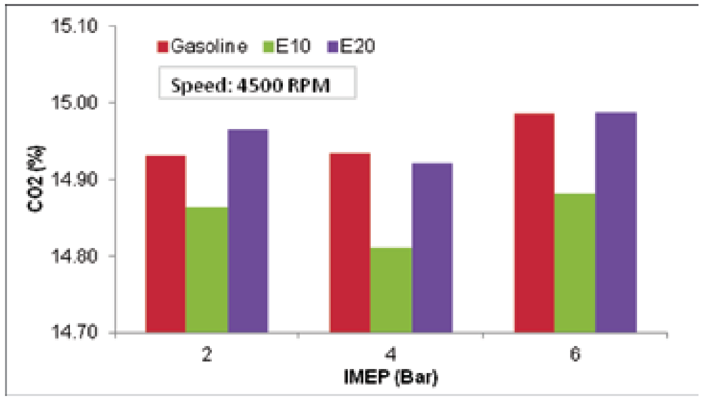


Figure 9 : BSFC for EBG- E10 Similar Values as Gasoline

Higher octane number of ethanol and oxygen in the blends compensates the lower calorific value of ethanol. Ethanol blends optimize the air-fuel ratio and improves the combustion and therefore increases the value of combustion peak pressures. Hence, increasing the ethanol concentration in the fuel reduces the fuel and brake specific energy consumption of the engine.

CONCLUSION

The use of low viscosity lubricants will become widespread with the increasing need to lower fuel consumption and CO_2 emissions. However, the fuel economy improvement effect will differ from engine to engine and thereby optimizing the additive dosage (especially FM & VM) for the particular application will be of prime importance. With respect to alternative fuels, the benefits of using them will greatly depend on the ease of availability, material compatibility challenges and engine optimizations. Nevertheless, in the current scenario of ever tightening fuel efficiency norms, the employment of suitable fluid engineering for IC engine operation is definitely a feasible strategy that is to be adopted by all stake holders.

Hydrocarbon SCR of NOx from Automobile Diesel Engine Exhausts using Silver Base Catalysts

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INTRODUCTION

Removal of NO_x from the exhaust gases of lean-burn and diesel engines is a major challenge to fulfill future restrictive standard emissions. Presently urea-SCR technology is being used for heavy duty diesel vehicles. Though it is well proven technology, the key limitation is necessity to carry urea tank on board as well as urea slip causing secondary pollution. Hence hydrocarbon selective catalytic reduction (HC-SCR) of NO_x would be attractive alternative for the removal of nitrogen oxides, carbon monoxide and unburned hydrocarbon from automotive emissions especially for diesel passenger cars. Numerous studies dealt with this topic over a wide variety of catalytic systems such as metal oxides, zeolites and noble metal supported aluminas, which have been found to be active for this reaction depending on the running temperature. Out of these, Ag/Al_2O_3 is one of the most active and selective for the SCR of NO_x to N_2. The main advantage of this system is its inherent thermal and hydrothermal stability, and its wide operating window observed for the selective conversion of NO to nitrogen particularly in presence of heavy hydrocarbons and hydrogen.

"Ag / Al_2O_3 is one of the most active and selective for the SCR of NO_X to N_2"

The lean-burn engine exhausts typically contain water and SO_2. The presence of water is usually known to cause deactivation of the catalyst. However this deactivation is known to be reversible upon removal of water from the feed. Deactivation of the catalyst due to SO_2 in the exhaust gases is one of the major limitations of this catalyst system for its practical applications and has been correlated to the formation of sulphate species, typically silver sulphate species leading to irreversible catalyst deactivation Therefore it becomes essential that the catalysts should be stable and active in the presence of water vapor and SO_2. Another limitation of Ag/Al_2O_3 catalyst is very narrow temperature window for NOx reduction. Hence there is need to develop efficient catalyst for HC-SCR with (i) sulphur & water tolerant, (ii) wide temperature activity for NOx conversion and (iii) 100% selectivity for N_2 for entire temperature range of activity.

Our group has worked on two strategies for modification of Ag/Al_2O_3 catalyst for fulfilling the above criteria (i) support modification to improve sulphur tolerence and (ii) bimetallic catalyst for improving temperature range of the activity as well as N_2 selectivity and the results are reported here. The influence of these additives on the nature of adsorbates have been monitored by in situ FTIR spectroscopic measurements (using DRIFT) with further comparison of catalytic performances in terms of NO conversion to nitrogen.

CATALYST PREPARATION

Alumina-supported silver catalyst (2 wt% Ag, labeled as AgAl) was prepared by impregnation of commercially available boehmite (AlOOH) with aqueous silver nitrate solution and subsequent calcination in air at 773 K for 6 hrs.

Support modification with 1 wt% SiO_2 (AgSiAl) or 1 wt% TiO_2 (AgTiAl) was carried out by dissolving $Si[OC_2H_5]_4$ or $Ti[OC_4H_9]_4$ in isopropyl alcohol. This solution was added to boehmite dispersed in isopropyl alcohol under constant stirring. The solution was evaporated and the dried at 373K. To this dried sample aqueous silver nitrate solution was impregnated and subsequently calcined at 773 K for 6 hrs.

Bimetallic catalyst 1 Ag-1Au/Al_2O_3 was prepared by successive impregnation method. Initially 1 wt% Au/Al_2O_3 was prepared by deposition-precipitation method using urea. This 1 wt% Au/Al_2O_3 catalyst (dried at 80°C for 12 hrs) was further impregnated with aqueous $AgNO_3$ solution to get bimetallic 1% Ag - 1% Au/Al_2O_3 catalyst. The catalyst was dried at 80°C for 12 hrs and then calcined at 500°C for 6 hrs and labeled as AgAuAl. For comparison the monometallic catalysts 1% Ag/Al_2O_3 (AgAl) and 1% Au/Al_2O_3 (AuAl) were prepared by impregnation and deposition precipitation method respectively.

CATALYTIC ACTIVITY TESTS

The SCR of NO by propene was carried out at atmospheric pressure in quartz tubular down flow reactor (inner diameter 4 mm). Catalyst powder (750 mg, particle size < 180 µm) was placed in the reactor and a thermocouple was inserted in the center of the catalyst bed to measure the temperature. Prior to the reaction the catalyst was activated at 773 K for 3 hrs in He flow. The typical reactant gas mixture consisting of NO (1000 ppm), C_3H_6 (2000 ppm) CO_2 (10%) and O_2 (5%), 0 or 5% H_2O, 0 or 20 ppm SO_2 gas and balance He were fed from independent mass flow controllers. The online analysis of the effluent gases was carried out by monitoring the relative masses m/z = 30 (NO), 28 (N_2), 44 (N_2O, CO_2), 41 (C_3H_6) and 46 (NO_2) as function of time using a mass spectrometer, a chemiluminescence NO_x analyzer and a micro GC (Varian CP 4900) equipped with a molecular sieve 5Å and a Porapack Q column. The gas hourly space velocity (GHSV) was maintained at 20000 h^{-1} (W/F =0.05 g h L-1).

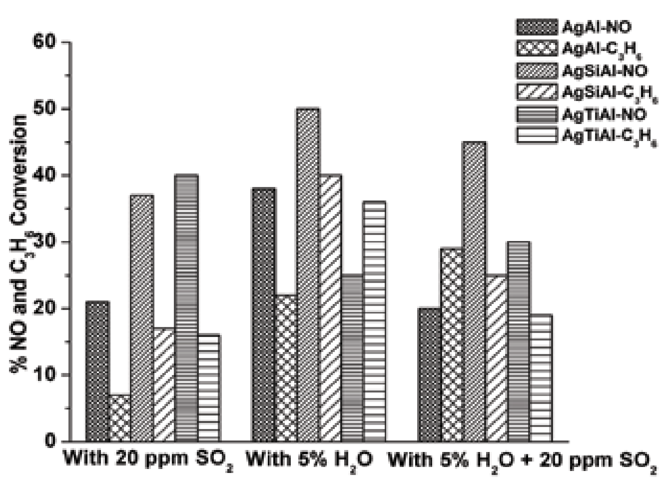

Figure 1 : Effect of SO_2 (dry conditions), H_2O and H_2O+SO_2 on conversion of NO_x and C_3H_6 on AgAl, AgSiAl and AgTiAl at 623 K. Reaction Conditions : 1000 ppm NO, 2000 ppm C_3H_3, 10% CO_2, 5% O_2, 20 ppm SO_2, 5% H_2O and He Balance

The influence of H_2O and simultaneous addition of H_2O+SO_2 in the feed on the NO conversion to N_2 over the support modified Ag/Al_2O_3 samples is illustrated in Fig. 1. In the presence of water in the feed, maximum NO conversion to N_2 for AgAl was 38% which increased to 50% for AgSiAl and decreased to 25% for AgTiAl. The corresponding propene conversions are also reported in Fig. 1. Contrarily to previous measurements in the absence of water, CO is significantly formed irrespective of the catalyst composition. The CO formation in presence of water in case of AgAl, AlSiAl and AgTiAl was found to be 134, 425 and 265 ppm respectively confirmed by online GC. AgTiAl is more sulphur resistant than AgAl, however the most prominent observation is probably the remarkable behavior of AgSiAl with a higher conversion level than that observed in the absence of SO_2 and H_2O. Now regarding the selectivity behaviour, SO_2 and H_2O addition induce a weak effect on the selectivity of AgTiAl and AgSiAl. On the other hand, a strong detrimental effect is noticeable on AgAl. Hence, such observations evidence significant changes in catalytic properties after Si and Ti-modification. AgTiAl is more sulphur resistant than AgAl, however the most prominent observation is probably the remarkable behavior of AgSiAl with a higher conversion level than that observed in the absence of SO_2 and H_2O. The higher conversion in case of AgSiAl is correlated to the in situ formation of hydrogen due to steam reforming of propane resulting in the increase of NOx conversion.

CATALYTIC ACTIVITY OF MONOMETALLIC AND BIMETALLIC CATALYSTS

SCR activity of bimetallic AgAuAl catalyst was compared with monometallic AuAl and AgAl catalysts. The NO to N_2 conversion curves of catalysts treated in H_2 at 250°C (Step I) are presented in Fig. 2A. Monometallic AuAl and bimetallic AgAuAl catalysts showed 100% selectivity for N_2 over a complete temperature range whereas AgAl catalyst showed less than 100% selectivity for N_2 up to 275°C with formation of N_2O. A typical volcano-type profile was obtained for NO conversion on AgAl catalyst which was previously ascribed to the involvement of NO_2 as intermediate. The spill-over of NO_2 from the metal to activated hydrocarbon onto the support was proposed.

The volcano-type curve can be explained by kinetically limited reaction at low temperature (NO conversion to NO_2) whereas thermodynamic unfavoured NO_2 formation at high temperature.

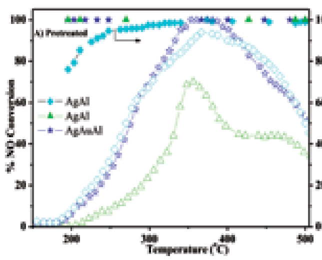

Figure 2a

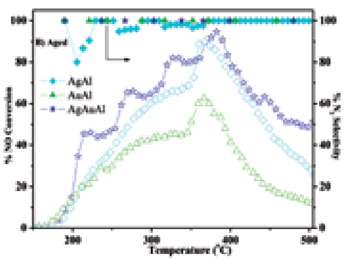

Figure 2b

SCR Activity of Catalysts After (a) Pretreatment at 250°C in H_2 and (b) Ageing in Reaction Feed at 500°C Overnight. %NO Conversion (Open Symbols) and N_2 Selectivity (filled Symbols). Reaction Feed : 300 ppm NO, 300 ppm CO, 300 ppm C_3H_6, 2000 ppm H_2, 100 ppm $C_{10}H_{22}$, 10% CO_2, 10% O_2, 5% H_2O, He Balance, GHSV = 50,000 h-1

At low temperature, the AgAl catalyst showed highest NO conversion whereas AgAuAl catalyst presented marginally lower conversion and AuAl catalyst showed significantly lower NO conversion. The SCR activity of pretreated AgAuAl and AgAl catalysts around 350°C was comparable with maximum NO conversion of 100% and 96% respectively. However the maximum NO conversion for AuAl catalyst was considerably lower (70%). Above 400°C, AgAuAl and AgAl catalysts exhibited similar conversion curves with decreasing NO conversion with increase in temperature. The three catalysts were then aged overnight under reaction feed at 500°C before a second temperature-programmed reaction was carried out. Clearly the catalytic activity (Fig. 2B) was altered after ageing procedure. AgAuAl catalyst had shown improved low temperature activity compared to pretreated catalysts under H_2 at 250°C. However there was no improvement in low temperature activity for AuAl and AgAl catalysts. After ageing AgAuAl catalyst has shown better low temperature activity (222°C) with 40% NO conversion compared to AgAl (14%) and AuAl (~2%) catalysts. Higher maximum NO conversion (95%) was obtained on AgAuAl catalyst compared to AgAl catalyst (78%) and AuAl catalyst (70%). There was marginal increase in temperature corresponding to maximum NO conversion after ageing in case of AgAuAl and AgAl catalysts. A decrease in high temperature activity (above 400°C) was evidenced for AgAuAl and AgAl catalysts. A reverse tendency was observed for AuAl with increase in high temperature activity after ageing which is in agreement with the previous report. Previous studies by other groups reported lower NO conversion on bimetallic Au-Ag/Al_2O_2 catalyst compared to monometallic Au/Al_2O_3 catalyst (45% NO to N_2 conversion at 500°C). This difference can be assigned to the presence of hydrogen in the reaction mixture in present study.

The above results clearly indicate the higher efficiency of bimetallic AgAuAl catalyst compared to monometallic AgAl and AuAl, where AuAl has contributed to improved higher temperature activity and complete selectivity for N_2 over entire temperature range whereas AgAl has contributed to reforming reaction leading to hydrogen generation improving low temperature activity.

The two strategies for modification of Ag/Al_2O_3; support modification and addition of second metal has led to several improvements as follows:

(i) sulphur tolerence, (ii) water tolerence (iii) low temperature activity (iv) wider temperature range for HC-SCR activity (v) complete N_2 selectivity over entire temperature range of activity.

Further work for optimising the catalyst composition of bimetallic system on modified support is in progress.

Technical Reference Bulletin

Methanol Economy in India

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> *The Methanol Economy promises to help India to mitigate its petroleum import costs and at the same time counter problem associated with global warming due to excess CO_2 emissions*

INTRODUCTION

Methanol also known as methyl alcohol (CH3OH) is an oxy hydrocarbon fuel. Methanol is the simplest alcohol, being only a methyl group linked to a hydroxyl group. It is a light, volatile, colorless, flammable liquid with a distinctive odor very similar to that of ethanol. This alcohol has less content of carbon than ethanol and thus produces less pollution than conventional fossil fuels. One of the distinct advantages of employing methanol as a sustainable source of fuel is the diverse array of feedstocks from which this simple alcohol can be produced. Besides industrial production from natural gas and coal, methanol can be made from agricultural waste and even atmospheric CO_2 among a host of other viable sources – all can be converted into methanol, as an effective way to store and distribute the energy from each source.

India has high ash coal with 45 to 50 % ash content. This can be converted to syngas i.e. CO + H_2 which can then be further converted to methanol. Various types of biomass have been considered, but on the shorter term coal appears to be the only viable alternative raw material for large scale methanol production. In fact, methanol has been produced from coal for many years in China. The technology for making methanol from coal is thus well proven. Basically coal is reacted with oxygen and steam in a gasification reactor thereby generating a synthesis gas containing H_2, CO and CO_2 and minor amounts of inert gases such as nitrogen, argon and methane.

Methanol can be used for following applications

1) As a blend with Gasoline (upto 15%) in petrol vehicles
2) As a dedicated fuel (upto 85%) in petrol vehicles - termed as M85
3) As a fuel for cooking stoves
4) As a raw material for producing various chemicals
5) As a source of Di-Methyl Ether (DME) a clean fuel for diesel vehicles.

Organic methanol, produced from wood or other organic materials (bioalcohol), has been suggested as a renewable alternative to petroleum-based hydrocarbons. Low levels of methanol can be used in existing vehicles without major modifications with the minor addition of corrosion inhibitors. Methanol is used to fuel internal combustion engines. Pure methanol is used in racing cars. The chief advantage of a methanol fuel is that it could be adapted to gasoline internal combustion engines with minimum modification to the engines and to the infrastructure that delivers and stores liquid fuel.

ARAI EXPERIENCE ON METHANOL

ARAI had developed a methanol three wheeler in 1997 under DHI funding and successfully demonstrated the operation of the same. In addition to emission benefits like reduction in CO, HC and NOx emissions, there are benefits in terms of fuel consumption as well. Slight emissions of aldehydes are seen which are below safe limits.

GLOBAL EXPERIENCE ON METHANOL

In the US, the Open Fuel Standard Act of 2011 was introduced in the US Congress to encourage car manufacturers to build cars capable of using methanol, gasoline, or ethanol fuels. The European Fuel Quality Directive allows up to 3% methanol with an equal amount of cosolvent to be blended with gasoline sold in Europe. China uses more than one billion gallons of methanol per year as M15 transportation fuel in low level blends for conventional vehicles and high level blends in vehicles designed for methanol fuels. Similar approach can be tries in India to blend 15% methanol in Gasoline.

Figure 1 : Methanol Taxi Fleet in China

METHANOL TAXI FLEET IN CHINA

In India, methanol needs to be notified as an automotive fuel by MORTH. Specifications for the fuel need to be worked out by BIS. Test agencies like ARAI need to work out the testing procedures.

ADVANTAGES AND DISADVANTAGES OF METHANOL

Methanol is readily biodegradable in both aerobic (oxygen present) and anaerobic (oxygen absent) environments. Methanol will not persist in the environment. The half-life for methanol in groundwater is just one to seven days, Since methanol is miscible with water and biodegradable, it is unlikely to accumulate in groundwater, surface water, air or soil.

Methanol is poisonous to the central nervous system and may cause blindness, coma, and death. However, in small amounts, methanol is a natural endogenous compound found in normal, healthy human individuals.

METHANOL EMISSIONS

Methanol has many fuel properties that make it cleaner burning in gasoline engines. Besides containing oxygen for improved fuel combustion, methanol also has a high blending octane value for smoother burning, a lower boiling temperature for better fuel vapourisation in cold engines and no sulphur contamination which poisons catalytic converter operation. For India, the blending of methanol in gasoline is one of the quickest and lowest cost means for both displacing high cost petroleum energy consumed in the existing vehicle fleet, and also for reducing vehicle emissions that lead to air pollution such as ozone, carbon monoxide (CO), PM and air toxics. Methanol also provides a means of improving the octane of premium gasoline without increasing its already high aromatics content. Unlike aromatics, the use of methanol for octane in gasoline has been shown to have environmental benefits, as methanol blends reduce HC, CO, PM and air toxic emissions from most vehicles. Based on the oxygen content, adding 7 volume percent methanol to the fuel blend (equivalent to 3.5% oxygen by weight) would reduce the CO by about 15% and the HC emissions by about 12% as compared to having no oxygen in the fuel. At this oxygen level, the NOx also decreased by approximately 5%. Using the octane from the methanol to further reduce the aromatics in the gasoline would reduce all of the emissions even further. A significant advantage of reformulating gasoline with methanol is that the emissions benefits occur immediately across all classes and ages of vehicles using the cleaner burning gasoline. This generally provides immediate air pollution benefits without the need to wait for new emission reduction technology to penetrate the vehicle fleet population.

Applications of Methanol

1 **Fuel Cells :** Direct-methanol fuel cells are unique in their low temperature, atmospheric pressure operation, allowing them to be miniaturized to an unprecedented degree. This, combined with the relatively easy and safe storage and handling of methanol, may open the possibility of fuel cell-powered consumer electronics, such as laptop computers and mobile phones.

2 **Methanol Stoves :** Methanol is also a widely used fuel

in camping and boating stoves. Methanol burns well in an unpressurized burner, so alcohol stoves are often very simple, sometimes little more than a cup to hold fuel. This lack of complexity makes them a favourite with reduce risk of leaking or spilling for replacement of LPG in India.

3 **Methanol Injection :** Methanol is mixed with water and injected into high performance diesel and gasoline engines for an increase of power and a decrease in intake air temperature in a process known as water methanol injection. This can be deployed for existing 8000 – 10000 municipal diesel buses.

4 **Flex Fuel Vehicles :** Methanol flexible fuel vehicles (FFVs), capable of running on any combination of methanol (up to M-85, a blend of 85% methanol and 15% unleaded gasoline) and gasoline in the same tank were sold in the U.S.

5 **Other Chemicals and fuels :** The main applications for methanol are the production of formaldehyde (used in construction and wooden boarding), acetic acid (basis for a.o. PET-bottles), MTBE (fuel component and replacement for the very volatile diethyl ether) and more recently for the formation of methyl esters in the production of bio-diesel.

6 **Methanol for Power :** Methanol is an attractive emerging fuel for electricity generation. During times of great electricity demand such as hot summer days, turbine engines are often used as "peak generators" to bolster the electric grid's capacity. Methanol had been demonstrated to be a viable replacement to oil as a fuel for these crucial backup generators, as well as a more environmentally friendly way of improving their performance. Around the globe, several projects are underway to incorporate methanol into existing, dual-fueled gas turbines. Methanol's low heating value, low lubricity, and low flash point make it a superior turbine fuel compared to natural gas and distillate, which can translate to lower emissions, improved heat rate, and higher power output. Recent methanol-to-power demonstration projects have shown the viability of this technology, especially for island nations and other areas not situated near gas pipelines. India can generate several MW of power through this renewable route.

7 **Indian Railways** is the largest user of diesel, about two million MTPA. Indian Railway can substitute diesel with methanol dual fuel engines which can be adapted on 6000 diesel locomotives. This can lead to significant savings.

SUMMARY

"The Methanol Economy" promises to help India to mitigate its petroleum import costs and at the same time counter problem associated with global warming due to excess CO_2 emissions. India can use its abundant coal reserves to produce Methanol through gasification. Abundant non-edible biomass can also be gasified to produce Methanol. On the utility front India would like to explore the possibilities in using Methanol and DME as a transportation fuel in road transport, shipping and our gigantic rail network. Indian Railways consumes 3 billion liters of diesel every year. We need to look to cheaper and less polluting alternatives. National Institute for transforming India (NITI Aayog) has constituted an Expert Group to evolve a road map document for India to adopt Methanol Economy. The three groups under Production, Utilization and R&D will explore various techno commercial angles to enhance production of Methanol through Natural gas, High ash content coal and through Bio, Agri and Municipal Solid Waste. It is drawing out a technical road map to adopt both Methanol and DME as a transportation fuel, Chemical feedstock & power generation.

REGULATORY TRENDS

Future Regulatory Trends for Automotive Vehicles in India

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Standards have always been a strategic part of an industry. Adherence to standards helps in ensuring safety, reliability and environment care. The automotive standards/ regulations in India are governed by the Ministry of Road Transport & Highways (MoRT&H) which is the nodal ministry for regulation of the automotive sector in India. Along with MoRT&H, Ministries such as Ministry of Environment & Forests (MoEF) and Ministry of Petroleum & Natural Gas (MoP&NG) play a vital role in the formulation of environment protection and fuel related automotive regulations and standards in India.

Indian Motor Vehicle Act, was first enacted in year 1914 which was subsequently replaced by Motor Vehicles Act, 1939 and later by Motor Vehicles Act 1988. Under this Act, specific mandatory requirements in the form of Rules (Central Motor Vehicle rules – CMVR) are framed by the MoRT&H.

MoRT&H has constituted two technical committees to recommend and advise the ministry on issues relating to Safety and Emission Regulations. These committees are:

- Central Motor Vehicles Rules-Technical Standing Committee (CMVR-TSC)
- Standing Committee on Implementation of Emission Legislation (SCOE)

> *ARAI has developed an E-Services module for the benefit of end users, wherein, continuously updated information regarding Central Motor Vehicle Rules is provided*

Institutional framework for developing automotive regulations is as shown in the flow chart below:

Central Motor Vehicles Rules-Technical Standing Committee (CMVR-TSC) was constituted by Government in year 1997. This committee advises MoRT&H on various technical aspects related to CMVR. This committee has played a major role in development of the safety regulations for vehicles and auto components in India, for the last 3 decades. This committee receives recommendations from other technical committees, such

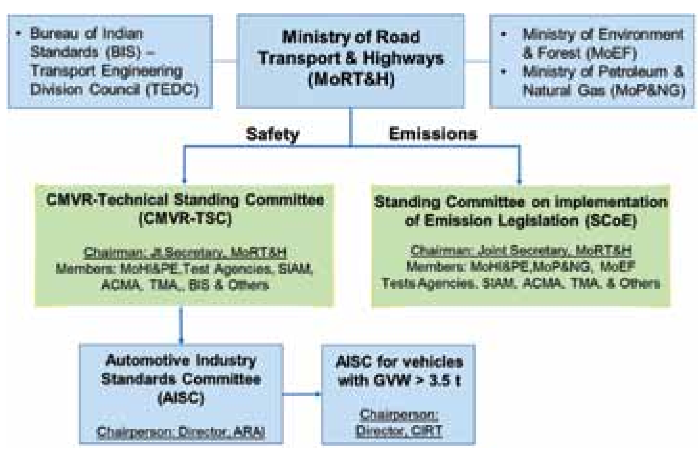

Figure 1 : Institutional Framework for Developing Automotive Regulations

as Automotive Industry Standards Committee (AISC) and Bureau of Indian Standards (BIS), and finalises and approves safety recommendations made by such committees.

Standing Committee on Implementation of Emission Legislation (SCOE) is another parallel technical committee along with CMVR-TSC that was set-up by MoRTH to advise the Government in the matters related to emission norms for new and in-use vehicles. This committee gives recommendations on test procedures and the implementation strategy for emission norms in the country to MoRTH.

Automotive Industry standards (AIS) and Indian Standards (IS) formulated by AISC and BIS respectively, which are recommended to CMVR-TSC and emission norms recommended by SCOE are notified by the Government of India through General Statutory Rules/Statutory Order under CMVR.

Besides, the inputs from the above technical committees, significant technical input is drawn from discussions during WP.29 sessions held in Geneva. A national standing committee on matters related to WP.29 was formed in February, 2003. Indian delegation, actively participates in the WP.29 and working groups sessions under WP.29, viz. Working Party on Brakes and Running Gear (GRRF), Working Party on Lighting and Light-Signalling (GRE), Working Party on Passive Safety (GRSP), Working Party on Pollution and Energy (GRPE), Working Party on Noise (GRB) and Working Party on General Safety Provisions (GRSG), and valuable experience gained in WP.29 participation is used while upgrading our national standards.

ARAI provides technical secretariat services to the above committees and plays an important role in the formulation of technical standards.

With growing number of automobiles on the Indian roads, it is pertinent to address the issue of road safety with new developments in technology. India is committed to reduce the number of road fatalities through implementation of safety regulations. Another key national necessity is to reduce fossil fuel use and look for alternate energy sources and to improve air quality.

The following Tables would give an overview of some important regulations covering vehicular safety and emission norms for immediate future.

i) Table 1: For Year 2016-17

ii) Table 2: For Year 2017-18

iii) Table 3 : For Year 2018-19

iv) Table 4 : For Year 2019-20

v) Table 5 : For year 2020-21

The following connotations have been used for identifying different category of vehicles:

A: Agricultural tractors

C: Construction Equipment Vehicles

L: 2 and 3 wheeled vehicles

M: Passenger vehicles

N: Goods vehicles

T: Trailers and Semi-trailers

R: Agricultural trailers

(Note: For detailed definitions of the vehicles, refer AIS-053 and IS 14272 -Automotive Vehicles - Types-Terminology).

In view of the huge investment in the automotive sector and the concerns for safety and emissions, it is important for professionals in Automotive Industry to keep track of the future regulatory norms and the allied technologies for appropriate design considerations, in their overall development plan of products. This also helps the stake holders in the smooth implementation of norms and thereby making the industry globally competitive.

ARAI has developed an E-Services module for the benefit of end users, wherein, continuously updated information regarding Central Motor Vehicle Rules is provided. The module is updated periodically to include new regulations. For more details please contact the Author.

Table 1 : Norms for Year 2016-17

Sr. No	Subject/Standard	Date of Implementation	Applicability	Ref. Notification
1.	Child Restraint System (AIS-072) Driver of M1 to ensure use of CRS	1st April 2016	Non transport M1	G.S.R.291 (E) dated 24th April 2014 (Final)
2.	Mechanical Couplings (AIS-091(Part 1))	1st April 2016	Combination of N2, N3, T3 , T4	S.O. 1558 (E) dated 18th June 2014 (Final)
3.	Close coupling device (AIS-092)	1st April 2016	If fitted combination of N2, N3, T3 & T4	
4.	Wheel rims for trailers (IS: 9438)	1st April 2016	T	
5.	Mass Emission Standards Bharat Stage IV (BS IV)(UN GTR 2)	1st April 2016	L1 &L 2 (New Models)	G.S.R. 431 (E) dated 4th July 2014 (Final)
6.	Mass Emission Standards Bharat Stage IV (BS IV)	1st April 2016	L5 (New Models)	GSR 487 (E) dated 12th June 2015 (Final)
7.	Speedometer	1st April 2016	L, M & N	G.S.R.291 (E) dated 24th April 2014 (Final)
8.	Construction Equipment vehicles - Product identification number (AIS-136)	1st April 2016	CEV	G.S.R.133 (E) dated 29th January 2016 (Final)
9.	Max. GVW and Max. Safe axle weight for Airport Passenger Bus (Tarmac Bus)	6th April 2016	Tarmac Buses	S.O. 1328 (E) dated 6th April 2016 (Final)
10.	Mass Emission Standard for Bio-Diesel	11th April 2016	L5, M & N	G.S.R. 412(E) dated 11th April 2016 (Final)
11.	Axle Load – Modular Hydraulic Trailer (MHT)	18th April 2016	MHT	S.O.1434 (E) dated 18th April 2016 (Final)
12.	Amphibian Bus	12th May 2016	Amphibian Bus	S.O.1722 (E) dated 12th May 2016 & S.O.2970 (E) dated 14th Sep 2016 (Final)
13.	Airport Passenger Bus (Tarmac Bus)	13th June 2016	Tarmac buses	G.S.R. 594(E) dated 13th June 2016 (Final)
14.	Retro-fitment of hybrid electric system kit to vehicles (AIS-123 (Part 1 & 2))	24th June 2016	M & N	G.S.R. 629(E) dated 24th June 2016 (Final)
15.	Conversion of vehicles for pure electric operation (AIS-123 (Part 3))	24th June 2016	L5, M, N1 & N2	G.S.R. 629(E) dated 24th June 2016 (Final)
16.	Mass emission standard for flex-fuel ethanol - (E100) vehicles	12th July 2016	L, M & N	G.S.R. 682(E) dated 12th July 2016 (Final)
17.	Technical specifications to be submitted by the vehicle manufacturer	14th Sept 2016	All	G.S.R 880 (E) dated 14th September 2016 (Final)
18.	Fitment of Light-weight box on Motorcycle	1st Oct 2016	L1 & L2	G.S.R. 473(E) dated 2nd May 2016 (Final)
19.	Spray Suppression Devices (AIS-013 (Rev.1))	1st Oct 2016	* N, T3 & T4 (New Models)	S.O. 411 (E) dated 9th February 2016 (Final)

20.	Revised Standard for Electric Power Train vehicles Construction and Functional Safety Requirements (AIS-038 (Rev. 1)) Measurement of Electrical Energy Consumption (AIS-039 (Rev. 1)) Method of Measuring the Range (AIS-040 (Rev. 1)) Measurement of Net Power and The Maximum 30 Minute Power (AIS-041 (Rev. 1))	1^{st} Oct 2016	L, M & N	S.O. 411 (E) dated 9^{th} February 2016 (Final)
21.	Requirement for Bumpers (IS 15901:2010)	1^{st}Oct 2016	M1	S.O. 411 (E) dated 9^{th} February 2016 (Final)
22.	Minimum Ground Clearance (IS 9435: 2004)	1^{st}Oct 2016	M1	S.O. 411 (E) dated 9^{th} February 2016 (Final)
23.	Interior Noise (IS 12832-2010)	1^{st}Oct 2016	M2, M3, N2 & N3	S.O. 411 (E) dated 9^{th} February 2016 (Final)
24.	Location, identification and operation of Controls, Telltales and Indicators of two wheeled vehicles (AIS 126)	1^{st}Oct 2016	L1 & L2 (New Models)	S.O. 411 (E) dated 9^{th} February 2016 (Final)
25.	Vehicle Recall	1^{st}Oct 2016	All	G.S.R. 595(E) dated 13^{th} June 2016 (Draft)
26.	Testing fees at authorised testing stations	28^{th}Nov 2016	Transport Vehicles	G.S.R. 1095(E) dated 28^{th} Nov 2016 (Final)
27.	Brakes for Agricultural Tractor & Trailer (AIS-043)	1^{st} January 2017	A & R1 to R4	S.O. 1473 (E) dated 22^{nd} April 2016 (Final)

* Note : please refer the appropriate standard and notification for vehicle category applicability

Table 2 : Norms for Year 2017-18

Sr. No	Subject/Standard	Date of Implementation	Applicability	Ref. Notification
1.	Bus Body Code (Phase 1)	1^{st} April 2017	M2, M3	G.S.R. 895 (E) dated 20^{th} September 2016 (Final)
2.	Mass Emission Standards Bharat Stage IV (BSIV) (UN GTR 2)	1^{st} April 2017	L1 &L2 (Existing Models)	G.S.R.431 (E) dated 4^{th} July 2014 (Final)
3.	Mass Emission Standards Bharat Stage IV (BS IV)	1^{st} April 2016	L5 (Existing Models)	GSR 487 (E) dated 12^{th} June 2015 (Final)
4.	Protective devices against unauthorized use (AIS-075)	1^{st}April 2017	M & N	S.O. 411 (E) dated 9^{th} February 2016 (Final)
5.	Vehicle Alarm Systems and Immobilizers (AIS-076)	1^{st}April 2017	M1& N1 (having GVW ≤ 2 ton)	S.O. 411 (E) dated 9^{th} February 2016 (Final)
6.	Performance Requirements of Lighting and Light-Signaling Devices for Agricultural Tractors (AIS-062(Rev.1))	1^{st} April 2017	A	G.S.R. 880 (E) dated 14^{th} September 2016 (Final)
7.	Testing and approval of sleeper coaches (AIS-119 (Rev.1)	1^{st} April 2017	Sleeper Coaches	G.S.R. 905 (E) dated 23^{rd} September 2016 (Final)

8.	Declaration of value for emission, pass by noise of horns values in form 22	1st April 2017	All	G.S.R. 953 (E) dated 5th October 2016 (Final)
9.	Average fuel consumption	1st April 2017	M1<3.5 T	S.O. 1072 (E) dated 23rd April 2015 (Final)
10.	Fuel Efficiency norms	1st April 2017	M1	G.S.R. 954 (E) dated 4th October 2016 (Final)
11.	Provisions for Vehicle Carriers	1st April 2017	Articulated Vehicles, Truck Trailer, Tractor Trailer	G.S.R. 963 (E) dated 7th October 2016 (Final)
12.	Automotive Trailer Code (AIS-113)	1st April 2017	T3 , T4	G.S.R. 876 (E) dated 9th September 2016 (Draft)
13.	Automatic Headlight On (AHO) and Day time Running Lamp (DRL)	1st April 2017	L1, L2	G.S.R. 188 (E) dated 22nd February 2016 (Final)
14.	Fitment of AC in Truck Cabins	1st April 2017	N2 & N3	G.S.R. 1034 (E) dated 2nd November 2016 (Final)
15.	Spray Suppression Devices (AIS-013 (Rev.1))	1st Oct 2017	* N, T3 & T4 (Existing Models)	S.O. 411 (E) dated 9th February 2016 (Final)
16.	Location, identification and operation of Controls, Telltales and Indicators of two wheeled vehicles (AIS 126)	1st Oct 2017	L1 & L2 (Existing Models)	S.O. 411 (E) dated 9th February 2016 (Final)
17.	External Projections (AIS-120)	1st Oct 2017	M1 (New Models)	S.O. 411 (E) dated 9th February 2016 (Final)
18.	Requirements for Behavior of Steering Mechanism of a Vehicle in a Head on Collision (AIS-096)	1st Oct 2017	M1 & N1 less than 1.5 t (New Models)	S.O. 1139 (E) dated 28th April 2015 (Final)
19.	Requirements for the Protection of the Occupants in the event of an Offset Frontal Collision (AIS 098)	1st Oct 2017	M1 less than 2.5 t (New Models)	S.O. 1139 (E) dated 28th April 2015 (Final)
20.	Approval of Vehicles with regards to the Protection of the Occupants in the event of a Lateral Collision (AIS-099)	1st Oct 2017	* M1 & N1 (New Models)	S.O. 1139 (E) dated 28th April 2015 (Final)
21.	Additional Safety Features – Airbags	1st Oct 2017	M1 (New Models)	G.S.R. 1014 (E) dated 26th October 2016 (Draft)
22.	Use of LNG as Automotive fuel (AIS 024 and AIS 028)	1st Oct 2017	M2, M3, N2 & N3	G.S.R. 1066 (E) dated 15th November 2016 (Draft)
23.	Mechanical Coupling (AIS-091(Part 2))	1st Oct 2017	A	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
24.	Front Coupling (AIS-109)	1st Oct 2017	A	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
25.	Type approval and certification of agricultural tractors	Date of Final Notification	A	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)

26.	Reflectors (AIS-057 (Rev 1))	1st Oct 2017	*M2, M3, N, T (Existing Models)	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
27.	Bulbs of the lighting and light-signaling devices (AIS-034 (Part 1) (Rev. 1))	1st Oct 2017	A	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
28.	Lighting and light-signaling devices (AIS-030 (Rev. 1))	1st Oct 2017	A	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
29.	Rear view mirror specification and installation requirements (AIS-001(Part 1) (Rev.1) & AIS-002 (Part 1) (Rev. 1	1st Oct 2017	L1, L2, L5, M & N (New Models)	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
30.	Anti-lock braking systems	1st Oct 2017	M1 & M2	G.S.R. 880 (E) dated 29th August 2016 (Draft)

* Note: please refer the appropriate standard and notification for vehicle category applicability

Table 3 : Norms for Year 2018-19

Sr. No	Subject/Standard	Date of Implementation	Applicability	Ref. Notification
1.	Bus Body Code (Phase 2) (Complete Bus Body Code)	1stApr 2018	M2, M3	G.S.R. 895 (E) dated 20th September 2016 (Final)
2.	Anti-Lock Braking Systems (IS 14664: 2010)	1stApr 2018	L2 (New Models)	G.S.R. 310 (E) dated 16th March 2016 (Final)
3.	Road Ambulances (AIS 125(Part1))	1stApr 2018	* L & M	G.S.R. 868 (E) dated 8th September 2016 (Final)
4.	Motor Caravans (AIS 124)	1stApr 2018	M	G.S.R. 868 (E) dated 8th September 2016 (Final)
5.	Additional Safety Features – Speed Alert System to alert river in case of over speeds; seat belt reminder; manual override for central locking system; vehicle reverse gear sensor	1st Apr 2018	M1	G.S.R. 1014 (E) dated 26th October 2016 (Draft)
6.	Additional Safety Features – vehicle reverse gear sensor	1st Apr 2018	M2, M3 & N	G.S.R. 1014 (E) dated 26th October 2016 (Draft)
7.	Provision of vehicle location tracking device and emergency button (AIS-140)	1st Apr 2018	*Public Service Vehicle	G.S.R. 1095 (E) dated 28th November 2016 (Final)
8.	Reflectors (AIS-057 (Rev 1))	1st Apr 2018	*M2, M3, N, T (Existing Models)	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
9.	Rear view mirror specification and installation requirements (AIS-001(Part 1) (Rev.1) & AIS-002 (Part 1) (Rev. 1	1st Apr 2018	L1, L2, L5, (Existing Models)	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
10.	Rear view mirror specification and installation requirements (AIS-001(Part 1) (Rev.1) & AIS-002 (Part 1) (Rev. 1	1st Oct 2018	M & N (Existing Models)	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)

11.	Truck Body Code (Phase 1)	1st Oct 2018	N2 & N3	G.S.R. 1034 (E) dated 2nd November 2016 (Final)
12.	Agricultural Trailer Code (AIS-112)	1st Oct 2018	A	G.S.R. 1033 (E) dated 2nd November 2016 (Draft)
13.	Requirements for the Protection of Pedestrian and other Vulnerable Road Users in the event of a Collision with a Motor Vehicle (AIS-100)	1st Oct 2018	* M1 & N1 (New Models)	S.O. 2412 (E) dated 3rd September 2015 (Final)
14.	Additional Safety Features – Airbags	1st Oct 2018	M1 (Existing Models)	G.S.R. 1014 (E) dated 26th October 2016 (Draft)

* Note: please refer the appropriate standard and notification for vehicle category applicability

Table 4 : Norms for Year 2019-20

Sr. No	Subject/Standard	Date of Implementation	Applicability	Ref. Notification
1.	Truck Body Code (Phase 2)	1st Oct 2019	N2 & N3	G.S.R. 1034 (E) dated 2nd November 2016 (Final)
2.	Anti-Lock Braking Systems and Combined Braking System (IS 14664: 2010)	1stOct 2019	L2 (Existing Models)	G.S.R. 310 (E) dated 16th March 2016 (Final)
3.	External Projections (AIS-120)	1st Oct. 2019	M1 (Existing Models)	S.O. 411 (E) dated 9th February 2016 (Final)
4.	Requirements for Behavior of Steering Mechanism of a Vehicle in a Head on Collision (AIS-096)	1st Oct 2019	M1 & N1 less than 1.5 t (All Models)	S.O. 1139 (E) dated 28th April 2015 (Final)
5.	Requirements for the Protection of the Occupants in the event of an Offset Frontal Collision (AIS-098)	1st Oct 2019	M1 less than 2.5 t (All Models)	S.O. 1139 (E) dated 28th April 2015 (Final)
6.	Approval of Vehicles with regards to the Protection of the Occupants in the event of a Lateral Collision (AIS-099)	1st Oct 2019	* M1 & N1 (All Models)	S.O. 2412 (E) dated 3rd September 2015 (Final)

* Note: please refer the appropriate standard and notification for vehicle category applicability

Table 5 : Norms for Year 2020-21

Sr. No	Subject/Standard	Date of Implementation	Applicability	Ref. Notification
1.	Emission standards – Bharat Stage VI (BS-VI)	1st April 2020	L, M & N	G.S.R. 889 (E) dated 16th September 2016 (Final)
2.	Requirements for the Protection of Pedestrian and other Vulnerable Road Users in the event of a Collision with a Motor Vehicle (AIS-100)	1st Oct 2020	* M1 & N1 (All Models)	S.O. 2412 (E) dated 3rd September 2015 (Final)

* Note: please refer the appropriate standard and notification for vehicle category applicability


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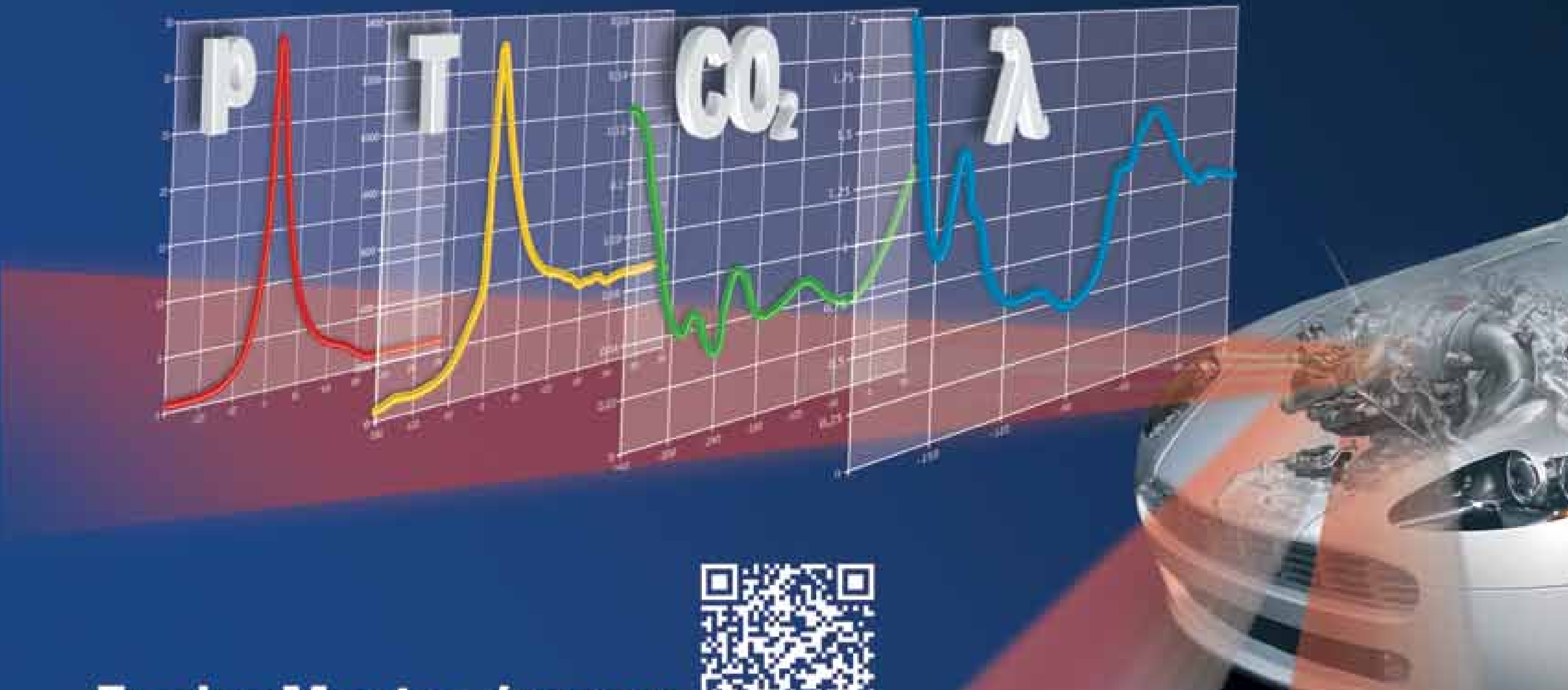
- crank angle resolved without gas extraction
- optical indication for highly dynamic transient phenomena
- various probes available for production and test engines



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M.S. Inter air cooling system

S.S. Inter air cooling system

Exhaust back pressure controller

Thermal shock testing ring

Thermal shock chiller, thermal shock heating unit

Auto fuel Priming & blow down unit

Level sensor

Mist generator / demist cattle

Intake air depression controller

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Automotive Optical Engine Indication

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ABSTRACT

The increasing environmental and economic awareness of the consumer requires a further reduction of fuel consumption. Current and future legislations for the certification of vehicles, e.g. about particulate matter or NOx emission, will be based closer on the actual driving behaviour of the end user. The fast optical indication gives deeper insight into the complex combustion process, especially at transient engine conditions under real driving operation. High-speed endoscopic imaging of the injection spray and the luminous emissions of soot under certain engine conditions will be described. Image analysis of high-speed cinematography reveals quantitative data, such as spray geometry, flame propagation speed, soot temperature and concentration. To receive further information about crank angle resolved transient behaviour of the air/fuel ratio or the EGR rate an optical in-cylinder probe is applied. Here, the measurement technique is implemented in a modified spark plug, so no engine modifications are needed.

> *The fast optical indication gives deeper insight into the complex combustion process, especially at transient engine conditions under real driving operation*

INTRODUCTION

Engine indication is typically referred to as cylinder internal pressure measurement. From the crank angle resolved pressure evolution engine and combustion relevant quantities are derived. The approach presented here is similar to that, but based on optical measurements. Instead of the pressure, a series of high-speed images and highly time resolved infrared absorption data are recorded. From these data again several quantitative measures are derived, like spray geometry, flame propagation speed, soot temperature, cylinder-internal lambda value and EGR rate.

QUANTITATIVE HIGH-SPEED ENDOSCOPIC IN-CYLINDER IMAGING

For the optimization of near-production engines endoscopic high-speed imaging can be applied to visualize in-cylinder phenomena. Key-hole imaging using endoscopes is a minimally invasive technique to monitor real-time in-cylinder processes such as fuel spray injection, ignition, combustion, and soot formation. The access to the combustion chamber is maintained by compact size pressure sealed window inserts. Fig. 1 shows the typical layout of LaVision's EngineMaster inspex endoscopic imaging system.

Crank angle synchronized high-speed color cameras primarily record a crank angle based movie of the processes in the combustion chamber. Additional image processing routines generate quantitative temporally resolved data from these images. This leads to a comprehensive picture of the in-cylinder processes, which are beyond simple plain movie generation.

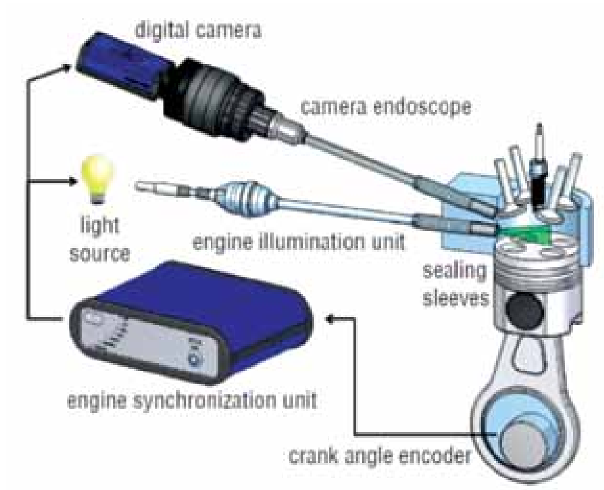

Figure 1 : Layout of an in-cylinder Endoscopic Imaging System

IN-CYLINDER SPRAY CHARACTERIZATION

During the injection, direct visualization of the spray evolution helps understanding the correct mixture formation and to avoid wall wetting. The in-cylinder spray breakup significantly depends on the internal pressure and nozzle temperature, which is hard to predict. Flash boiling drastically changes the spray pattern and propagation length. Fig. 2 shows an example of different spray geometries at different in-cylinder pressures.

Figure 2 : Spray Pattern at Varying in-cylinder Pressure

From image processing the spray cone angle and shape can be quantified as it propagates over crank angle (Fig. 3).

Wall and piston wetting is the major source of unburnt hydrocarbon (HC) and particulate matter (PM) emission. Even though pressurized spray chambers are an important tool for the development of a fuel injector and the correct injection timing, the in-cylinder conditions and flow field can only be monitored directly inside a fired cylinder. The example in Fig. 4 shows the fuel spray impinging on the piston surface. During the combustion phase, the sooty diffusion flames are clearly visible as a major source of PM emission.

Figure 3 : Spray Pattern at Varying in-cylinder Pressure and Quantitative Spray Cone Analysis

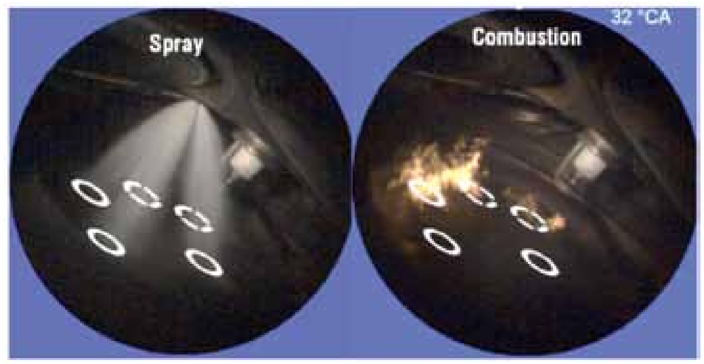

Figure 4 : Fuel Spray Impinging on the Piston followed by a Sooty Flame in the Same Cycle

IGNITION AND FLAME PROPAGATION

The ignition process itself is highly dynamic and underlies strong cyclic variations. By image processing of the flame growth, the flame propagation speed can be determined directly from a series of high-speed endoscopic images. A dynamic threshold scheme for image binarization automatically adapts to the varying intensity during flame evolution. The area covered by the flame is then converted to an equivalent flame radius (Fig. 5).

The flame speed, i.e. the growth rate of the equivalent flame radius (Fig. 6), and flame timing can be analysed from a sequence of consecutive engine cycles.

COMBUSTION AND SOOT FORMATION

During the combustion premixed and diffusion flames are visible and can be distinguished from each other, using the color information. Calibrating the flame color and luminosity at a known Tungsten reference light source allows to calculate flame temperature and soot concentration (KL-value) from these images. The example in Fig. 7 shows the temperature distribution of a sooty flame.

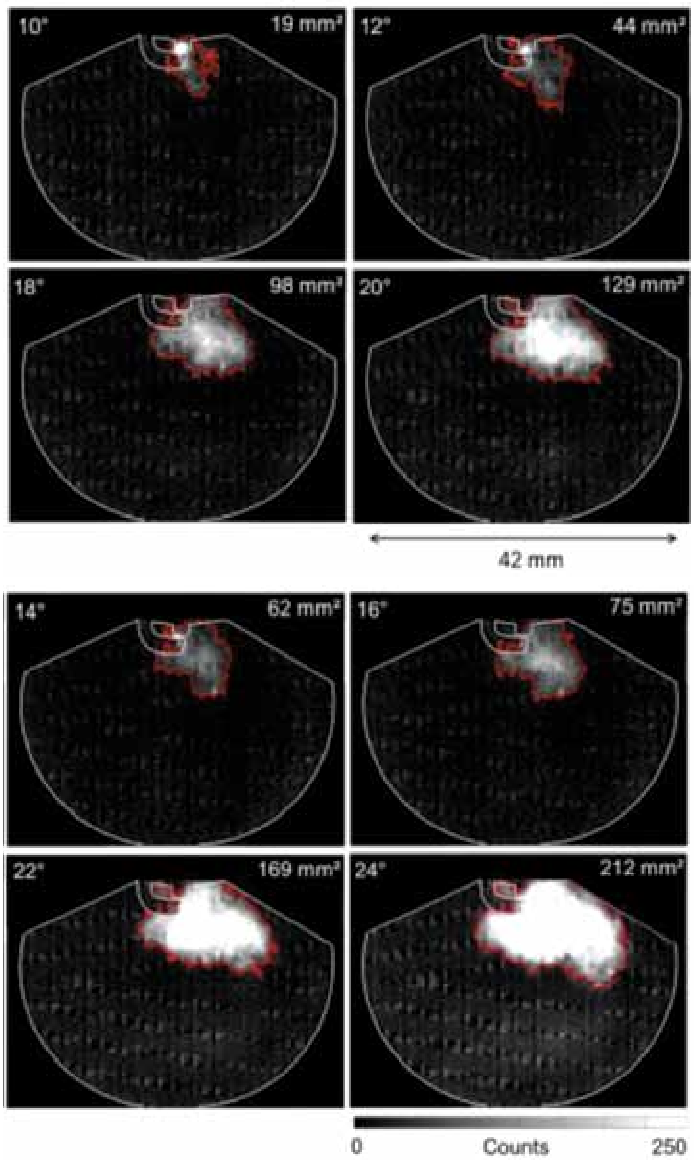

Figure 5 : Endoscopic High-speed Cinematography. The Red Line Indicates the Projected Flame Boundary, The Corresponding Projected Burnt Area is Indicated in the Upper Right-hand Corner of Each Image

COLD START ANALYSIS

Finally, recording a sequence from the very beginning of an engine start, reveals a clear understanding of the processes taking part for the majority of PM emissions during cold start conditions. The images show a pool fire in the first cycle, then sooty diffusion flames near the walls in the second cycle, turning to normal low emission combustion in the following cycles.

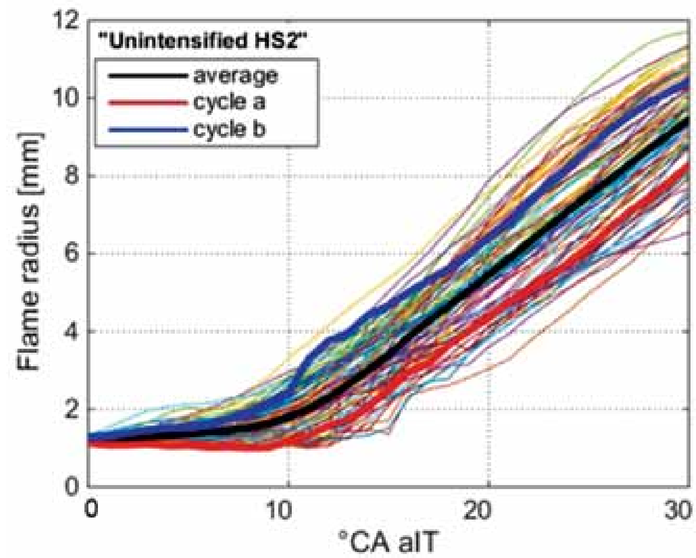

Figure 6 : Equivalent Flame Radius for 200 Consecutive Cycles (Colored Lines) and the Multi-cycle Mean of These Cycles (Solid Black Line)

Figure 7 : Soot Temperature Derived from Color Images

MEASUREMENT OF CYCLE RESOLVED GASEOUS ENGINE-OUT EMISSIONS

Going from constant to transient engine conditions requires techniques which can measure hundreds of consecutive cycles with crank angle resolution to analyse short time phenomena. LaVision's ICOS (Internal Combustion Optical Sensor) systems provide simultaneous optical indication of local air/fuel-ratio and the EGR-rate. A version of the system to measure gas temperature is also available. These systems use an optical measurement technique implemented in a modified spark plug (Fig. 9), so only the original spark plug needs to be replaced and no modifications of the engine are necessary. These systems are specifically designed to be used in engine test bed environments for research as well as near production engines as shown in Fig. 10.

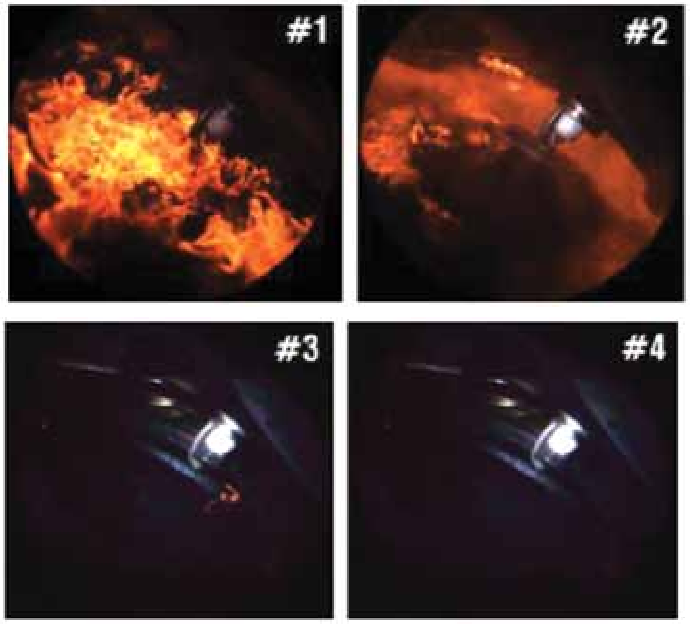

Figure 8 : First Four Cycles of a Cold Start with Visible Pool Fire from Piston and Wall Wetting

Figure 9 : ICOS System and M12 Spark Plug Probe

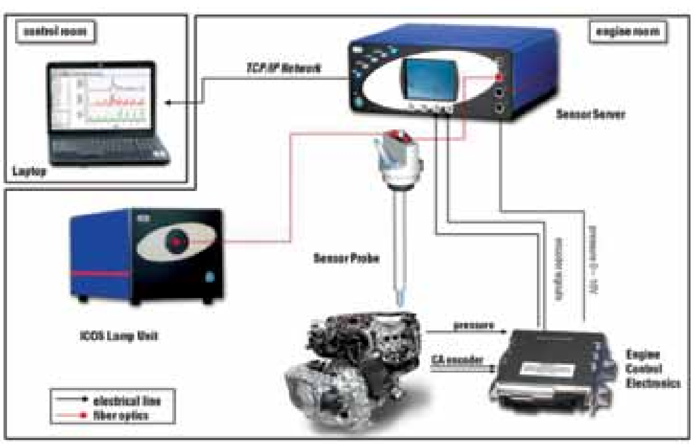

Figure 10 : Layout of an ICOS System with Spark Plug Probe in Engine Test Bed Environment

TIP-IN OPERATION

An example of a common transient engine operation during real driving conditions is the tip-in. This is a load change caused by the operation of the vehicles accelerator pedal. Measurements of tip-ins after gear change were carried out on a near production line engine at a transient test rig with the ICOS system and M12 spark plug probe (Fig. 10). Fig. 11 shows the exhaust emission behavior during the first second of a tip-in, covering approximately 17 cycles. From this diagram it can clearly be seen that individual engine cycles have strong contributions to certain emissions, most notably the 2nd combustion cycle were extremely high HC emissions occur. In order to find the emission sources the individual cycles must be analyzed.

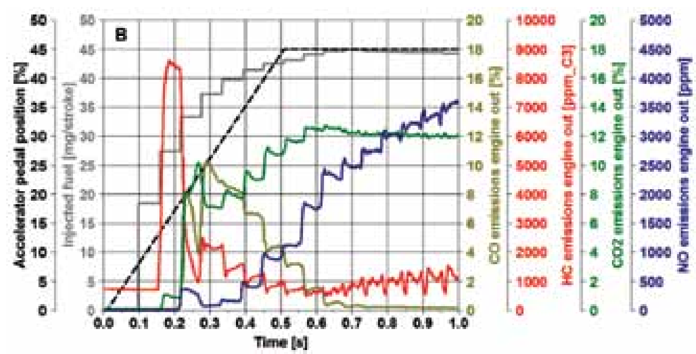

Figure 11 : Example of Engine tip-in Showing Accelerator Pedal Position, Injected Fuel Mass as Well as CO, HC, CO_2 and NOx Emissions.

LAMBDA VALUE AND MIXTURE FORMATION

Fig. 12 shows the measured crank angle resolved local lambda value for the first 40 cycles of the tip-in. It can be seen that the first cycle the mixture is too lean while the

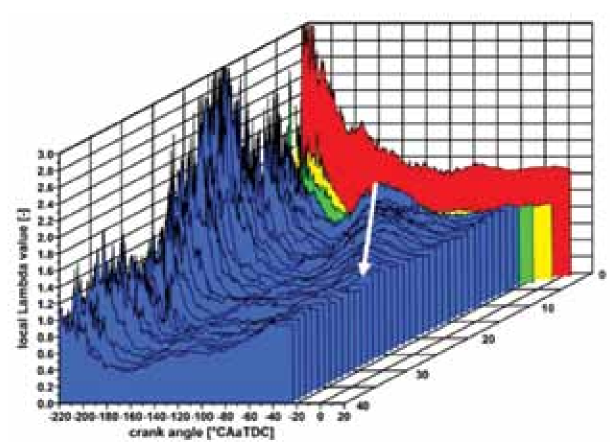

Figure 12 : Crank Angle Resolved Development of the Lambda Value at the Spark Plug Position for the First 40 Cycles of an Engine Tip-in

next two cycles have a rich mixture. All the following cycles converge towards a lambda value of 1 at the ignition time. This indicates the first unburned cycle to be the reason for the strong HC emission. Furthermore the lambda value development up to ignition changes continuously over the first 25 cycles. The white arrow indicates a rise in local lambda value before ignition which shifts to later crank angles during the tip-in. Approximately 30 cycles into the tip-in the lambda value development up to ignition becomes stable. This change in mixture formation is explained by ECU controlled valve timing changes.

EGR RATE AND VALVE TIMING

The EGR rate measurement also takes place directly inside the combustion chamber utilizing the crank angle resolved CO_2 concentration measurement of the optical ICOS probe. The effect of the valve timing changes can also be seen in the measured EGR rate, shown in Fig. 13. The EGR rate varies during the first 30 cycles after the tip in starts. The variable valve timing changed the internal EGR-rate from approximately 18% down to 10% during the tip-in, before the rate raised up over 20% after cycle 30, when the tip-in ends and the electronics switched back to constant engine conditions. Once constant operation (fixed valve timing) is reached both the EGR rate and also the lambda value curve become stable.

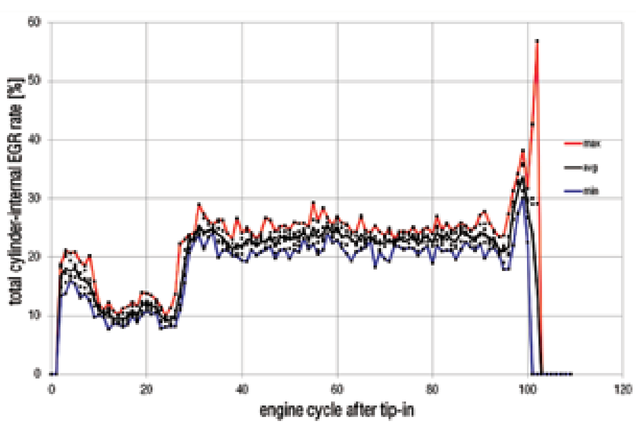

Figure 13 : In-cylinder Measured EGR-rate for 100 Consecutive Cycles Covering the Entire Tip-in Procedure. EGR Rates for 10 Repeated Tip-ins are Plotted. Average, Maximum and Minimum Values are Highlighted by the 3 Curves

OPERATION STABILITY

When the engine is in stable operation as in the presented example after approximately 30 cycles from the start of the tip-in statistical information regarding in the combustion stability can be gained by optical indication at high temporal

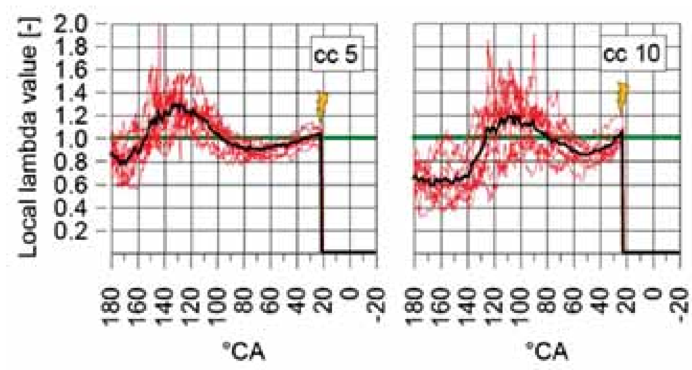

Figure 14 : Variations in the Lambda Values During Compression for Combustion Cycles #5 and #10 During 10 Repeated Tip-ins. Black Curve shows Average Over 10 Cycles and Red Curves Represent Individual Cycles

resolution. Fig. 13 shows the spread in the EGR rate during 10 repeated tip-in operations. The variation of the EGR rate is constant during the entire tip-in operation including the transient regime were the valve timing is varied.

An example of variation in the lambda value and mixture formation during two tip-in cycles is shown in Fig. 14. In combustion cycle 5 (cc5) of the tip-in the spread in the lambda curves up to ignition is reduces. In comparison to that the variation in the lambda curves in cycle 10 (cc10) is stronger over the entire compression.

CONCLUSION

With the use of highly time resolved in-cylinder optical indication individual cycles which have high contributions to the engine emission under transient operation can be analysed. This is required to find short term phenomena emission sources and subsequently to validate countermeasures. It was shown that minimally invasive endoscopic imaging and ICOS optical sensors provide such information. These techniques were used to analyse the fuel spray, mixture formation and the combustion in a near production engine operating under highly transient tip-in operation.


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Plant 2: Village Javale, Dist. Satara,
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Cyclic Variation in Unsteady RANS Engine Simulations

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INTRODUCTION

Modern engine technologies can exhibit high cycle-to-cycle variability. Many numerical studies, primarily LES, have been done on this topic. Researchers have successfully used Large Eddy Simulations (LES) to capture this cyclic variation with CFD. However, LES is computationally expensive. The current work demonstrates that using RANS turbulence models can also exhibit cyclic variation if the simulation approach minimizes numerical viscosity.

> *Use of an unsteady RANS turbulence model does not always yield an ensemble average result*

For modern engines, it is critical to model mixing accurately. Unfortunately, the very nature of CFD can be at odds with this goal. A fundamental problem with CFD is that numerical errors almost unilaterally over-predict mixing. The numerical viscosity that leads to this over-prediction of mixing can come from upwinding in the spatial derivatives, large cell sizes, large time-steps, and mesh changes during the simulation to handle moving geometries. It is critical to minimize the amount of numerical viscosity (i.e. numerical error) in a simulation, and, perhaps more importantly, to understand the magnitude of the error from any numerical viscosity that cannot be eliminated.

Another issue related to predicting mixing in CFD is that of turbulence. Turbulence is usually modeled by enhancing viscosity to account for either the effects of the fluctuating velocity (RANS) or the effects of the sub-grid velocity (LES). A common misconception is that a RANS simulation will always give the ensemble average field and therefore the simulation will be insensitive to similar perturbations. While it is true that the larger turbulent viscosity in a RANS simulation does act to destroy smaller scales, there are some cases, such as an IC engine, where these perturbations can lead to larger-scale chaos-like flow patterns.

This work will also demonstrate that perturbations in initial conditions, boundary conditions, or numerical settings can give run-to-run variability in simulations consistent with cycle-to-cycle variability in an actual engine.

For the current work, three studies are performed to show that the use of an unsteady RANS turbulence model does not always yield an ensemble average result. The first study is a basic cylinder-in-cross-flow case. The second study focuses on global mixing parameters as exhibited in the TCC (Transparent Combustion Chamber) engine. The third study examines cyclic variability in a GDI engine.

NUMERICAL CONSIDERATIONS

- Numerical Viscosity
- Numerical Differencing Scheme
- Cell Size
- Time Step Size
- Flow Alignment

CFD SETUP

The CFD code CONVERGE was used for all simulations performed in this work. Adaptive Mesh Refinement (AMR) is used to place additional grid resolution where it is needed. The SAGE detailed chemistry solver is used for the GDI cases. A detailed mechanism consisting of 110 species and 488 reactions, successfully used in other studies to describe similar gasoline combustion, is also used for this study. In order to speed up the detailed chemistry solutions, the multi-zone model is used during the combustion event. The computational cells are grouped into zones based on temperature and equivalence ratio in the multi-zone approach.

SIMULATIONS

Cylinder in Cross Flow

The first study performed involves simulating a cylinder in crossflow using a RANS turbulence model in an unsteady setting. This canonical flow configuration is well understood to shed vortices in the wake of the cylinder for Reynolds numbers (based on cylinder diameter) greater than about 150. This type of vortex shedding simulation has been done before with RANS, but it is shown here to explain some of the cycle-to-cycle variation found in some RANS engine simulations.

Table 1 gives information about the simulation setup. Table 2 describes the relevant numerical settings used for the three different simulations performed.

Table 1 : Cylinder in Crossflow Simulation Parameters

Cylinder Size	1 cm
Domain Size (2-D)	10 cm x 80 cm
Base Grid size	1 cm
AMR and Cylinder Refinement	3 levels of refinement
Inflow Velocity	50 m/s
Turbulence Model	Standard K-ε

Table 2 : Individual Simulation Parameters

Case	Scheme	Base Grid Size	Smallest Cell
1	1st order upwind	10 mm	1.25 mm
2	2nd order central	10 mm	1.25 mm
3	1st order upwind	0.2 mm	0.025 mm

The Reynolds number for this setup is 3.3e4, which is in a regime where the wake is turbulent, yet characterized by alternate shedding unsteady vortices. The size of the cylinder and the speed of the flow were chosen because they are representative of flow velocity and geometry (e.g. valve/seat area) in an engine. By using a RANS turbulence model, the effective Reynolds number of the flow will decrease significantly, yet it will still be in a regime where vortex shedding is expected.

Fig. 1 shows the resulting vorticity field for each of the three cases run. The simulations were run long enough to reach a pseudo steady-state. For Case 1, the solution does reach a true steady flow, whereas both Cases 2 and 3 reach a cyclic solution with vortices shedding behind the cylinder.

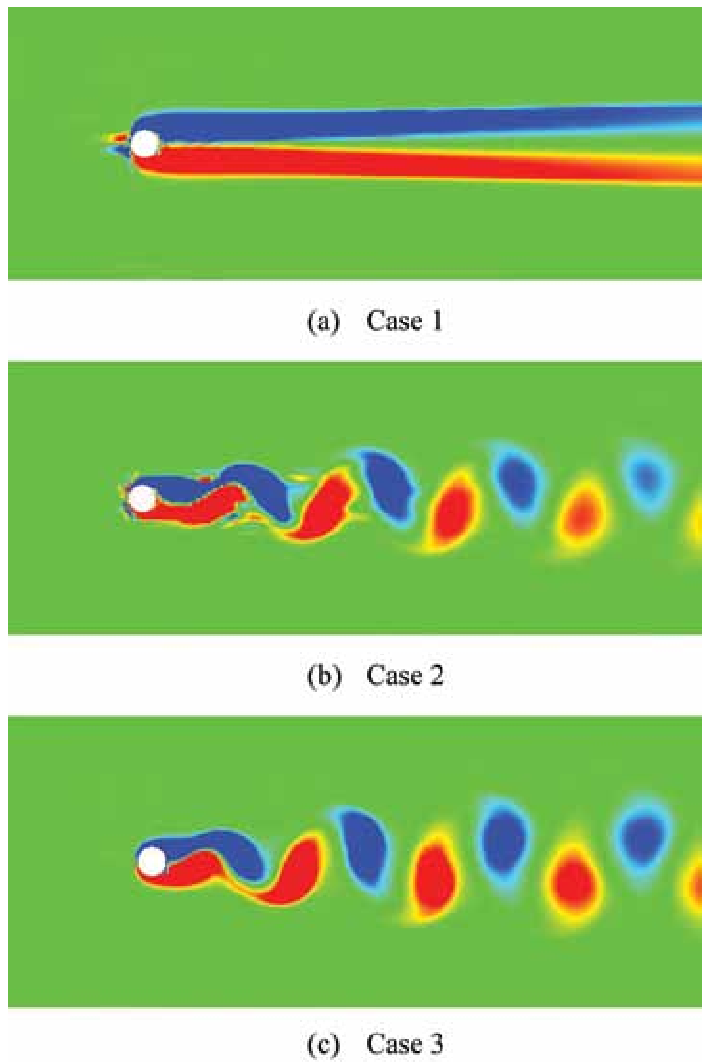

Figure 1 : Images of Vorticity for the Cylinder in Cross Flow Simulation (a) 1st Order Coarse (b) 2nd Order Coarse (c) 1st Order Fine

To understand these results, it is helpful to estimate the effective viscosity of these flows. There are three contributors to the effective viscosity of the flow: molecular viscosity, numerical viscosity, and turbulence viscosity. For all cases run, the molecular viscosity (that of air) was small enough to essentially be irrelevant since a RANS turbulence model was being used. Fig. 2 shows the turbulent viscosity for case 2. The turbulent viscosity varies spatially, but for rough estimation purposes the turbulent viscosity will be considered to be 5e-4 m2/s for all three cases. The numerical viscosity is different for each case. For first order numerics, the numerical viscosity can be roughly estimated as u*dx/2 (this is a very rough estimate, but should be sufficient for our purposes). Using this estimate (based on the smallest dx in the domain), case 1 has a numerical viscosity of around 3.1e-2 m2/s and case 3 has a numerical viscosity of around 6.2e-4 m2/s.

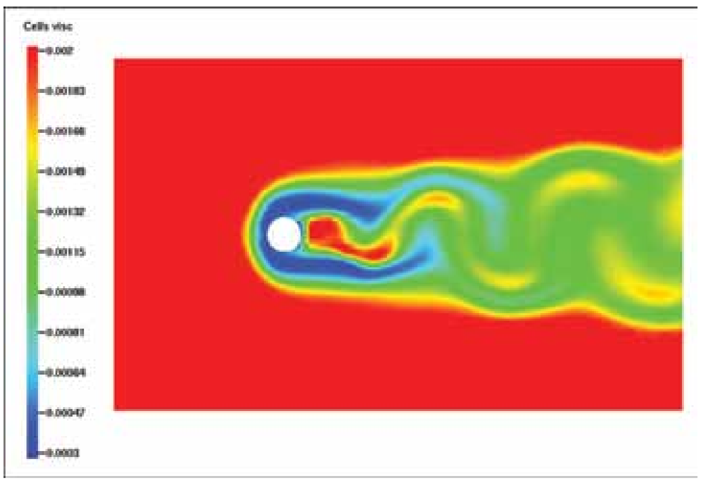

Figure 2 : Turbulent Viscosity near the Cylinder for Case 2

Using these estimates for numerical and turbulent viscosity, the effective Reynolds number is about 20 for case 1, 1200 for case 2, and 540 for case 3. As expected for these Reynolds numbers, case 1 does not shed vortices but both cases 2 and 3 do exhibit vortex shedding. The frequency of the shedding vortices for both Case 2 and Case 3 is about 1100 s-1, which corresponds to a Strouhal number of 0.22. This correlates well with the expected Strouhal number of about 0.2 for Reynolds numbers in this range.

The important thing to note for this study is that Cases 2 and 3, which have less numerical diffusion than Case 1, result in an unsteady solution, i.e., they do not give an ensemble averaged flowfield, even when using a RANS turbulence model. The turbulent viscosity does act to destroy the smaller scales, but it also allows larger scales to exist, even if they are time-varying.

Another point of importance to be illustrated by this example is the phasing of the vortex shedding. In a physical experiment of the cylinder in crossflow, slight variations in the flow around the cylinder trigger the onset of the vortex shedding. The period of the shedding is predictable, but the phasing is not. In the simulations performed for this study, the field is initialized with a velocity of 50m/s everywhere in the domain. It is numerical perturbations that produce the onset of the vortex shedding. Since this flow is inherently not stable, any perturbation, no matter how small, will influence the onset of the shedding. The frequency of the shedding will not be influenced by small numerical perturbations, but the phasing of the shedding will be impacted.

There are many sources of numerical perturbations in a CFD simulation: roundoff, random numbers, solving equations to tolerance, sweep direction for iterative methods, parallel domain decomposition, etc. Solution methods treat cells on processor boundaries differently than cells not on a processor boundary. These solution techniques solve to within tolerances, but will yield a slightly different solution if the processor boundaries are in different places.

TCC ENGINE

The second study performed involves simulating the Transparent Combustion Chamber (TCC) engine from the University of Michigan. This engine consists of a two valve head with a pancake combustion chamber (flat head, flat piston). The engine is designed with quartz windows to visualize the three dimensional flowfield. Table 3 summarizes the engine geometry.

Table 3 : Engine Configuration for the TCC Engine Experiment Used for Comparison with Simulation

Bore	92.0 mm
Stroke	86.0 mm
Connecting Rod	234.95 mm
Compression Ratio	10.0:1
Engine Speed	800 RPM

Results from three sets of flow-only simulations are presented here to show the impact of cell size and numerical differencing scheme on repeatability and accuracy of the predicted flowfield. For this study, Adaptive Mesh Refinement (AMR) has been disabled to demonstrate that any non-repeatable behavior is not a result of changes in the mesh. There is, however, one level of refinement on the valve angles, on the valve seats, and around the spark plug. For all three cases, the k-ε turbulence model is used.

Table 4 gives a description of the grid size and differencing scheme used for each of the three cases.

Table 4 : Numerical Parameters used for the TCC Engine Study that Affect Turbulence or Numerical Viscosity

Case 1	First order differencing 1mm base grid, 0.5mm embedding
Case 2	First order differencing 2mm base grid, 1mm embedding
Case 3	Second order differencing 1mm base grid, 0.5mm embedding

The port configuration in the TCC engine promotes tumble, and therefore tumble motion is used to compare the effects of inputs on the bulk flow. Note that 0 deg. ATDC represents TDC firing, even though this case does not include combustion. For all histories of tumble presented, the tumble drops drastically during compression, so that all cases have very little tumble near TDC firing. However, the value of the maximum tumble is critical because this motion is converted into turbulence during the compression process.

There are two pieces of information presented here: first, the repeatability of the tumble history of each individual case and, second, the comparison between the averages of the tumble histories of the three cases. Note that the first cycle for each case was discarded to remove effects of initial conditions.

Fig. 3 shows the repeatability of tumble histories for each case. Notice that for cases 1 and 2, the tumble histories are very repeatable, with the histories of each cycle being essentially indistinguishable. For case 3, however, it is evident that each cycle produces a different tumble history, with no trend toward a "converged" history. If turbulent viscosity by itself were sufficient to damp out cyclic variability, then the results in case 3 would be repeatable, which they are not. It is only when the numerical viscosity from first order numerics is added, as in cases 1 and 2, that the overall effective viscosity is sufficient to damp out any cycle-to-cycle differences. This increase in numerical viscosity yields what appears to be an ensemble average, but it is not the correct average.

The comparison shown in Fig. 3 illustrates the critical differences produced by the alternate numerical methods.

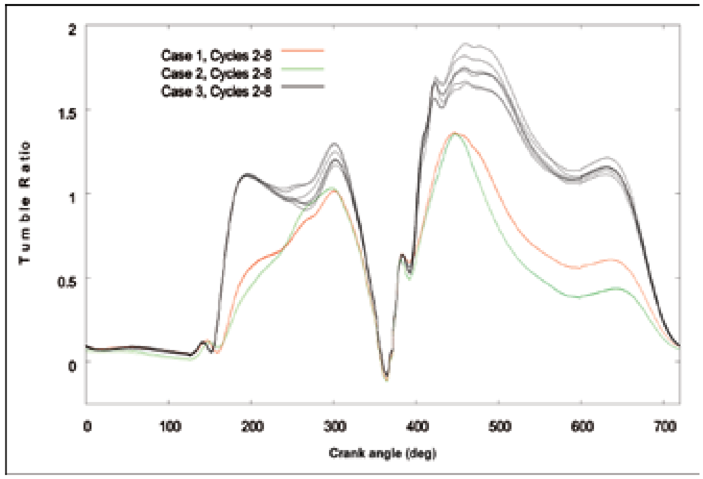

Figure 3 : Tumble Ratio Histories of Cycles 2 through 8 for each of the Three Cases Simulated

Case 3 shows the largest amount of cycle-to-cycle variability in tumble, but also predicts the highest magnitude of tumble. In general, numerics with more artificial viscosity will smear out the flow and yields lower magnitude of bulk flow quantities, as is the case in this comparison. Even though Case 3 has the least amount of repeatability, it is presumed to be the most accurate.

As mentioned earlier, the breakdown of tumble into turbulence during the compression stroke is critical to the subsequent combustion. All properly formulated combustion models rely on accurate prediction of turbulence, and are therefore heavily dependent on getting the turbulence right. Getting the bulk flow tumble predicted accurately is therefore critical for accuracy in simulating combustion.

The comparisons carried out illustrate two things. First, using a RANS turbulence model with higher order numerics can show cycle-to-cycle variation. Second, even though the higher-order numerics are not as repeatable as first-order upwinded differencing, the increase in predicted tumble is significant. When using LES, it is expected that the cycle-to-cycle variation exhibited in Case 3 would be even more pronounced.

These comparisons have shown that a RANS turbulent viscosity alone does not add sufficient stability to a typical engine flow to get ensemble repeatability. Only when erroneous numerical viscosity is added is the chaos removed from the system and the solution becomes repeatable from cycle-to-cycle.

The other contributors to numerical viscosity discussed earlier in the paper can have a similar effect. The CFD user is usually cognizant of the cell size and differencing scheme being used, but is often completely unaware of the other internal workings of the code that are causing numerical viscosity, e.g. mesh morphing and TVD switching to first order.

The lack of repeatability as shown in Case 3 can be disheartening for an engineer trying to simulate the effect of a change in parameter by comparing runs of only a single cycle. If the effect of varying the parameter is less than the cycle-to-cycle variability predicted by unsteady RANS, then a single cycle result will not provide a significant basis for conclusions to be made! It is imperative, therefore, to have a good understanding of the RANS cycle-to-cycle variability that will be predicted for a given numerical configuration (mesh size, differencing method, etc.) and to estimate the uncertainty in results due to cyclic variability.

GDI ENGINE

The experimental activities discussed in this study were carried out at Argonne National Laboratory (ANL) on a single-cylinder research engine. The engine design is representative of a modern GDI engine used for automotive applications. Engine specifications are listed in Table 5. The engine has a 4-valve, 40° pent roof combustion chamber design with a central spark plug and injector.

Table 5 : Specifications of the Single Cylinder GDI Engine at ANL

Displacement	0.626 L
Bore	89.04 mm
Stroke	100.6 mm
Compression Ratio	12.1 : 1
Intake Valve MOP	100 °CA ATDC
Exhaust Valve MOP	255 °CA ATDC
GDI Injector	6 hole, solenoid
Injection Pressure	150 bar
Spark System	Coil-based, 0.7 mm gap
Fuel	EPA Tier II EEE

Two operating conditions were studied at 2000 RPM, 6 bar IMEP, consisting of one stoichiometric case (Case 2) and one dilute case (Case 1) with 18% EGR. Table 6 lists the main specification of the two cases examined in this paper.

Table 6 : Specifications of the Examined Test Cases

Test Case	**1**	**2**
Engine Speed [RPM]	2000	2000
EGR [%]	18	0
Relative air fuel ratio, λ	1	1
Start of Injection (SOI) [°CA ATDC]	-300	-300
Duration of Injection (DOI) [°CA]	65	58
Spark Advance (SA) [°CA ATDC]	-40	-24
COV_{IMEP} [%]	7.8	1.4

In this study, RANS numerical simulations are performed with local fixed embedding and AMR. In all the cases simulated in this study, the base grid is set to 4 mm and additional mesh refinements deliver a local grid size of 0.5 mm during the gas-exchange and combustion phases, and 0.125 mm at the spark plug location during the ignition event. Typical simulations for this study are run on 48 cores with an average computational time of 2.5 days per engine cycle. Combustion is simulated using detailed chemistry (iso-octane mechanism with 110 species and 488 reactions).

Previous studies have shown that the cyclic variability can be significantly reduced by increasing numerical viscosity. While this has the effect or making the pressure trace converge quickly to a cyclic stable solution, it has been shown that the accuracy of the numerical result itself was penalized.

Furthermore, when a numerical investigation is carried out for cases that are unstable, reducing the validation effort to simply matching the experimental average pressure or rate of heat release trace does not deliver much value to the numerical analysis.

Fig. 4 and 5 show the comparison between numerical and experimental pressure trace data for both of the GDI cases examined in this study. The experimental dataset includes 500 consecutive cycles while the numerical dataset includes 21 consecutive cycles for both cases.

Case 1 is characterized by the highest experimental COVIMEP (˜ 8%, as listed in Table 6). The numerical results also show large fluctuation of the pressure trace, with pronounced leaning towards below-the-average cycles (see Fig. 4). The calculated numerical COVIMEP is approximately 10% (note that additional simulated cycles may affect this result). Case 2 is characterized by a significantly lower COVIMEP (1.4%, as listed in Table 6). As can be seen in Fig. 5, the numerical results give a similar COVIMEP of approximately 1%.

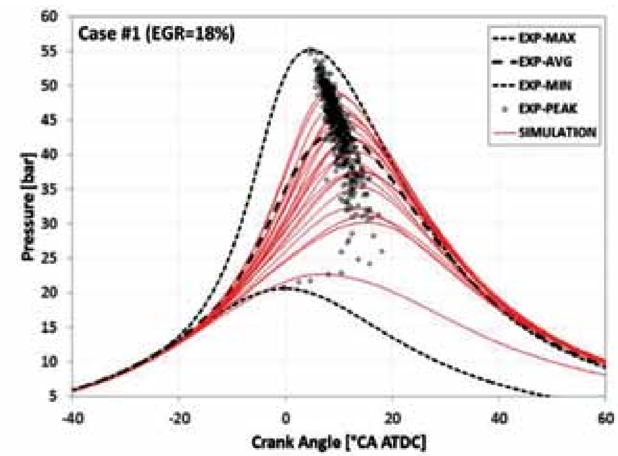

Figure 4 : Comparison between Numerical and Experimental Pressure Traces for Case 1 (21 Simulated Cycles vs. 500 Experimental Cycles)

The fact that a RANS simulation can reproduce experimental cycle-to-cycle variations may be viewed as surprising or incorrect to many researchers. However, this view comes from the mistaken belief that a RANS model will always

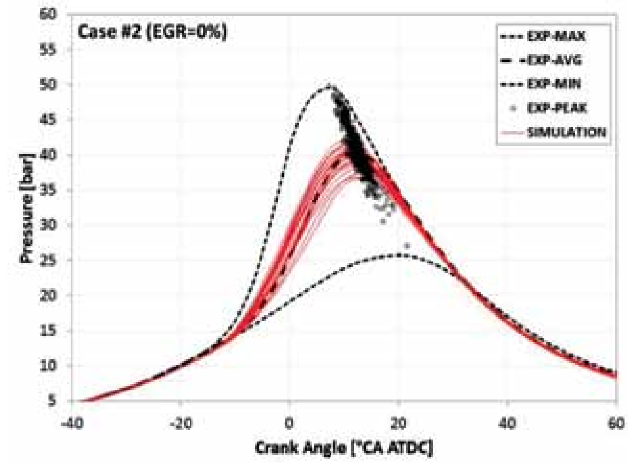

Figure 5 : Comparison between Numerical and Experimental Pressure Traces for Case 2 (21 Simulated Cycles vs. 500 Experimental Cycles)

reproduce the experimental ensemble average. As has been demonstrated in this paper by the cylinder in cross flow simulations, this view is incorrect.

This comparison illustrates the danger in making an analysis of a parameter variation based on a single cycle simulation, especially when the effect of the change in parameter is less than the cycle-to-cycle variability seen in an unsteady RANS simulation of the engine.

Efficient Engine System Solutions for Emerging Indian Automotive Requirements

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INTRODUCTION

The Indian market requirements are driven mainly by emission regulations (Bharat Stage - VI), Noise, Fuel economy benefits. In addition to that Government is extending subsidies to enable electric mobility like FAME (Faster adaptation and manufacturing of Hybrid and Electric Vehicles in India). Appropriate technologies are required to meet such specific needs. There are different types of systems, technologies available to improve power, torque of an engine without compromising the requirements like emission, noise, and the fuel consumption. Expectations of engine manufacturers from suppliers are not only the products and systems but also the development support.

> *There are different types of systems, technologies available to improve power, torque of an engine without compromising the requirements like emission, noise, and the fuel consumption*

DIFFERENT ENGINE SYSTEMS & PRODUCTS

Variable Cam Timing System (VCT)

Continuous variable valve/cam timing helps to advance or retard the valve timing of an engine depending upon the combustion requirements. Adaption of VCT increases power, increases torque, reduces emission & reduces the fuel consumption of an Internal Combustion (IC) engine.

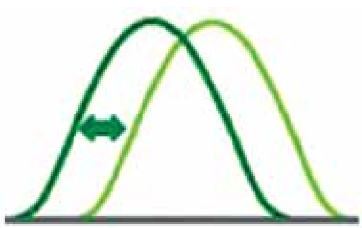

Figure 1 : Cam Timing

Performance of the VCT system is determined mainly by the parameters like the flexibility at the engine start, control accuracy and the shift performance. Oil consumption is also a key parameter, which values the performance of the system. The system can be used at both Intake and exhaust cam shafts, depends on the engines power, torque, emission requirements. Such systems are mainly seen in over head cam (OHC) engines. The cam phaser is driven by timing drive and facilitated by metered engine oil or electric motor to shift the cam shaft.

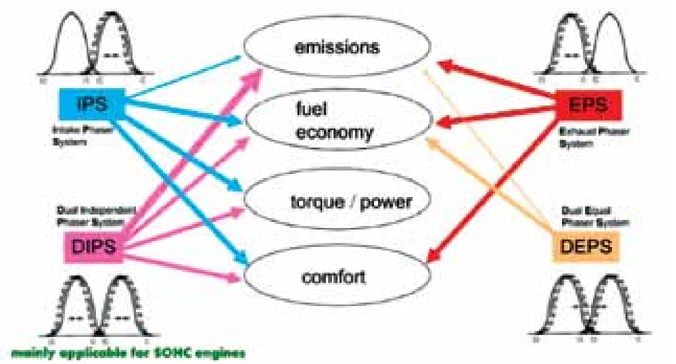

Figure 2 : Phaser Systems

Hydraulic VCT System

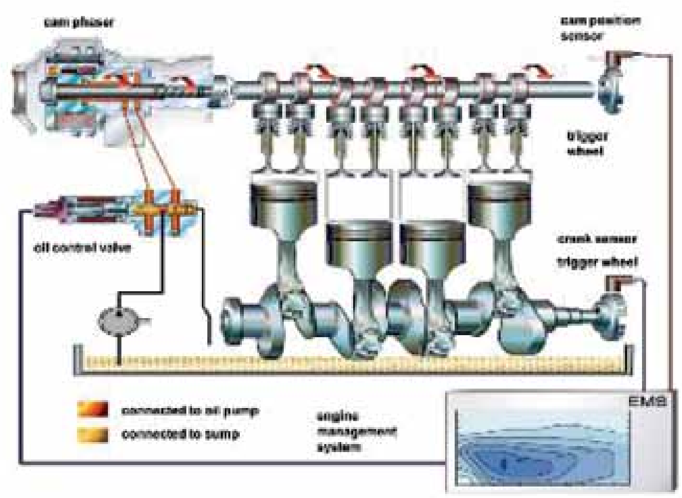

Figure 3 : Hydraulic VCT System

The hydraulic VCT system consists of two key components namely cam phaser and oil control valve (OCV). Based on the engine's shift requirements, the OCV delivers the required oil to the phaser, which is mounted on the valve cam shafts. The solenoid part of OCV is energized and controlled by the engine's Electronic Control Unit (ECU).

The system uses the engine oil it self for the shift function, hence the OCV can be provided with additional filters, to ensure function and durability. The oil control valve can either be separate (Fig. 5) or integrated with the VCT (Fig. 6).

In this VCT system OCV is remotely mounted on engine and separate oil paths connect the OCV and the cam phaser. Cam phaser is mounted with a separate bolt on the cam shat and gets drive by the timing belt or chain drive.

The oil control valve can be integrated with the special bolt, holding the oil valve in it, namely central valve. The hydraulic spool in the central valve is controlled by the central solenoid, which is connected to the ECU.

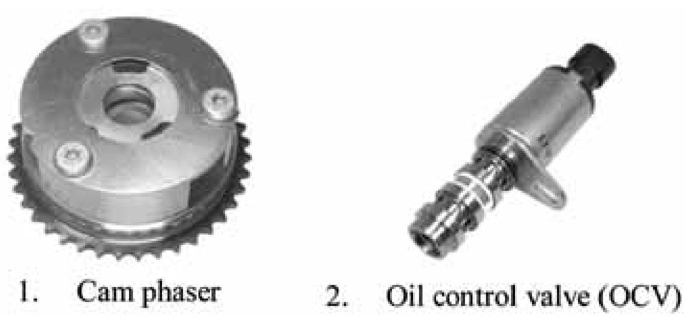

Figure 4 : Cam Phaser and Oil Control Valve

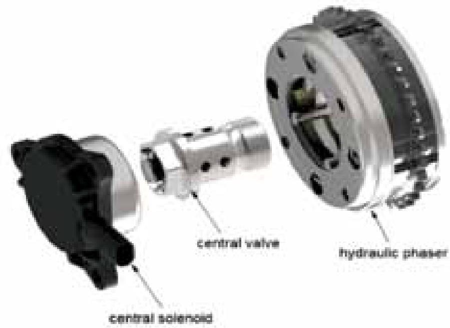

Figure 5 : Separate Oil Control Valve

Electric VCT

The Electric VCT system has an electric motor and a gearbox to provide the continuous variable cam timing. Based on the signals from the ECU, the electric motor drives the shifting gear, which is mounted on the cam shaft.

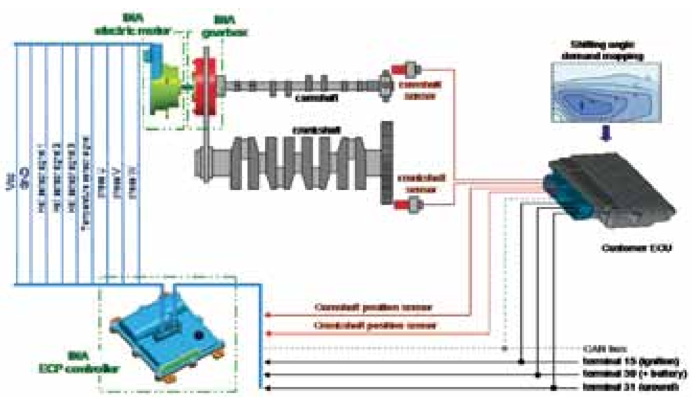

Figure 6 : EVCT System Schematic

The electric VCT being a compact phasing unit, has a powerful phasing capability and operates independent of oil supply system.

Switchable Valve Train System

The VCT system provides the flexibility in the valve timing, where as the Switchable valve train system enables the flexibility in the valve lift.

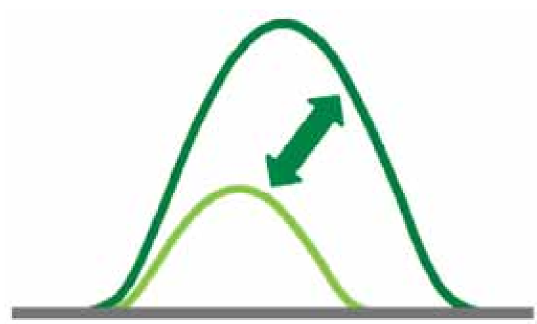

Figure 7 : Valve Timing

This further helps to achieve the benefits like valve deactivation, multiple stage valve lift variability. The switching function in the valve train component is performed through a lock – unlock mechanism in the valve train component (Switchable roller rocker arm or Switchable pivot element), which is energized through oil out of ECU controlled Oil control valve.

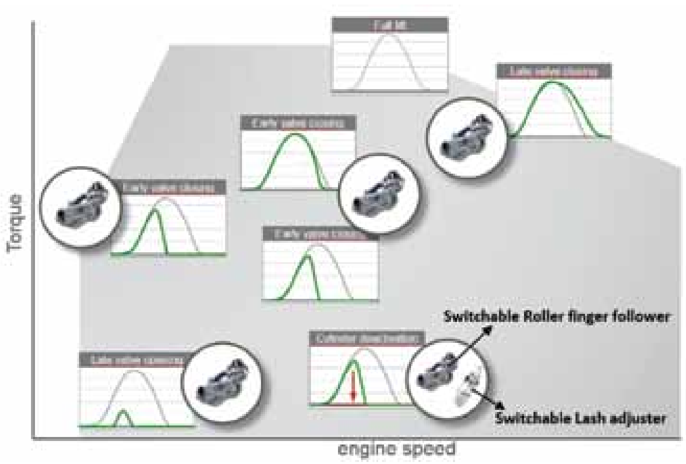

Figure 8 : Variable Valve Lift through Switchable System

Timing Drive System

There are 3 types of timing drives like Chain, belt and gear drive. In passenger vehicles predominantly seen are chain and belt drive.

Belt in Oil (BIO)

The latest belt drive systems, Belt-in-Oil system is alternative solution for chain drive system, which includes mechanical tensioner (1), idler (2) and belt (3), which reduces friction and is quieter than traditional chain-driven components. Which will results in higher engine performance, lower emissions and improved fuel economy.

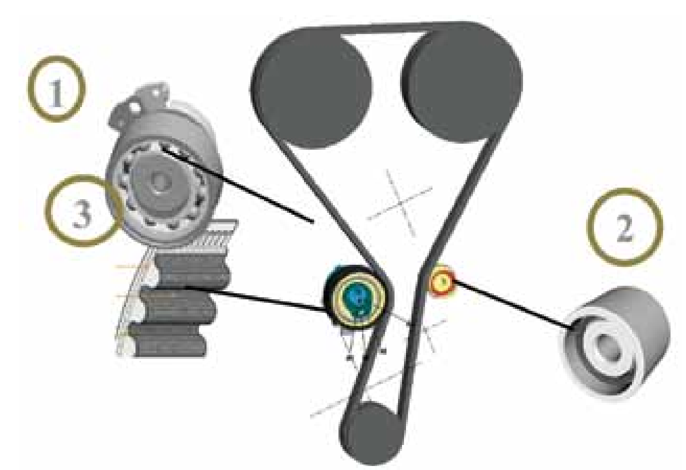

Figure 9 : BIO System

Chain Drive Systems

Likely to timing belt drive system, for developing the chain drive system we requires an in-depth understanding of systems due to its close interaction with other systems or components. The timing chain drive includes chains (bush, roller and silent), hydraulic tensioners (ratchet, non-ratchet), guide, blade, sprockets and oil gallery check valve. Schaeffler transferred its manufacturing technologies to the chain production process. For example, all chain pins are manufactured using high-precision grinding process from needle roller production.

Improved silent chain has very less elongation (within 0.15%) and which is below the actual customer requirements (below 0.4%). This is achieved because of improvements in pin (heat treatment and coatings), plate profile and high precision manufacturing of plates (inner and middle plates).

FEAD (Front End Accessory Drive) System

Belt Alternator Starter (BAS) System and Pulley Decoupler (PYD)

Belt Alternator Starter System have been widely for mild hybrid vehicles. These mild hybrid vehicles offer benefits like Boost operation, Recuperation, Faster and more comfortable engine starts via alternator, electric driving / power boost for better fuel economy. But, new challenges are faced for the belt drive configuration due to high power transfer via belt.

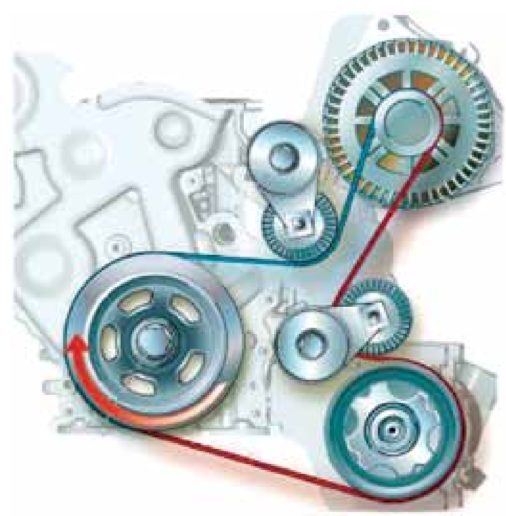

Figure 10 : Two Tensioners Classic Arrangement

In the entire system, the mild hybrid offers a noteworthy advantage with regards to driving dynamics and fuel consumption, which is achieved with assistance from the internal combustion engine via belt starter alternator. From the classic solution with two mechanical tensioners

(Fig. 10), there are already a few systems with 12-Volt systems in mass production. An alternative design requires only one tensioner, which can swivel about the alternator's axis of rotation. These, known as decoupling tensioners (Fig. 11). It has distinct advantages such as improved retention of pretension load in the slack run, lower the dynamic loads in the belt drive due to engine excitation.

This tensioner consists of a housing which is connected to the electric motor (alternator-motor) by a plain bearing and can be rotated by 3600 about the electric motor's axis. A tensioner pulley is permanently fixed to this housing. The second tensioner pulley is located on a moving lever and is spring-mounted against the housing by means of an arc spring assembly. This allows the tensioner pulley to create the necessary pre tensioning load and to compensate tolerance in the belt drive. Depending on the whether load torque is being applied to the electric motor (alternator operation or recuperation) or it is generating torque (belt start, boosts), the driving run occurs in either the right or left belt run and slack run on the other side.

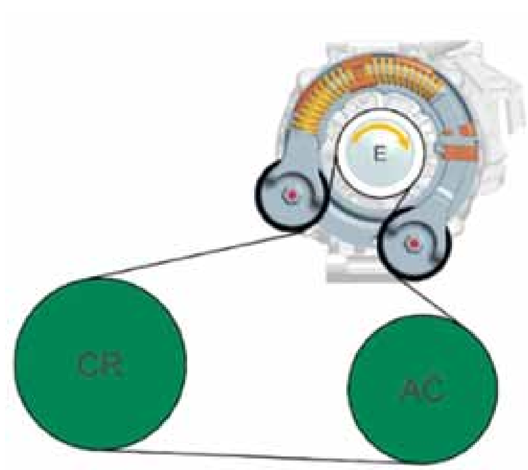

Figure 11 : Decoupling Tensioner

The reciprocating movement of entire tensioner about the electric motor's axis causes the driving half of the tensioner to be pressed away from drive and the other tensioner pulley to automatically retention the slack side by means of geometric connection, so that it is push into the drive. In a solution with two independent tensioners, this geometric connection does not exist, which leads to the slack slide tensioner receiving no additional support from the driving half tensioner for tensioning the slack side.

When power is transferred between belt alternator starter and engine, the decoupling tensioner automatically dampens vibrations in the belt drive due to its design. This function is dependent on the belt drive layout and the position of the accessories as well as on the internal

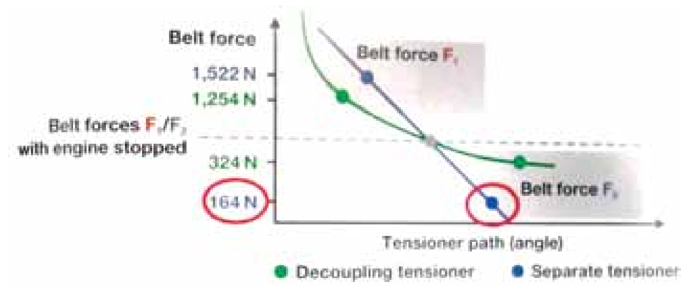

Figure 12 : Comparison of Belt Tension during Engine Start

combustion excitation. The example of mild hybrid with highly turbocharged 2litre 4-cylinder diesel engine shows the necessity of an additional decoupling of the belt drive by means of crank shaft decoupler (PYD-Pulley Decoupler). Some FEAD layouts have geometric limitations of installation space. This not only limits the working range of decoupling tensioner but also requires an additional guide pulley in the drive. Increased irregularities of the internal combustion engine excite the belt drive to higher vibrations, which no longer be managed by decoupling tensioner alone. Therefore, to reduce vibrations a direct decoupling on the crankshaft must be used via a decoupled belt drive. These requirements can be covered with the pulley de-coupler (PYD) as shown in Fig. 13. This decouples the belt drive from international irregularities of the internal combustion engine, with a specifically designed arc spring isolating the belt pulley from the crankshaft. The PYD is mounted directly on the crankshaft. It usually also contains torsional vibration damper, which is needed to limit the natural vibrations of the crank shaft in the upper speed range to a level permissible for durability and acoustic comfort.

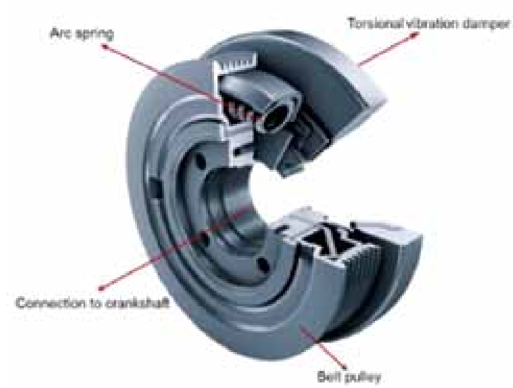

Figure 13 : Pully De-coupler

In comparison with de-couplers with elastomer springs, which use rubber layer for resiliency, the mechanical arc springs have a significantly higher torques and power outputs. Thus the increased power requirements for mild hybrid applications with belt start-stop can be covered. The characteristic curve can be flexibly adjusted by using multiple spring stages. This helps to avoid resonances during engine start and driving operation.

The system is designed in a way that durability requirements are optimally fulfilled throughout the operating life. The design takes into account:

- More than a million engine starts through sailing and stop-start operation, depending on the application
- A constant decoupling function over the engine's temperature range and vehicle life
- Decoupling of the belt drive throughout the functional range of the engine and alternator.

Thermal Management Module (TMM) System

The high thermodynamic efficiency of modern engines also proved disadvantages like: significantly less waste heat produced, which is however needed to heat the engine, transmission and, depending on the weather conditions & the vehicle interior. At the same time, the test cycles for determining CO_2 and exhaust emissions demand a cold start. To distribute initial heat produced in optimum manner, regarding passenger comfort and emissions, the product thermo management module as shown in the Fig. 14. As the engines warms ups the fuel consumption reduces. In the engine warm up phase, the module can completely shut off the coolant entering the engine or set a minimum volume flow. When the engine is at operating temperature, the coolant temperature can be regulated quickly to various temperature levels, depending the load requirements and external conditions.

The component has two coupled rotary slide valves that use a single drive. The module heats up the coolant at a rate that is up to 30% faster than the predecessor engine which has a wax-type thermostat. In fact the time required to achieve target oil temperature is reduced by 50%. Compact designs for smaller engines and vehicles and further development of functional integration are the focus for future applications. Development includes a multifunctional module with separate circuits for engine block and cylinder head (split cooling).

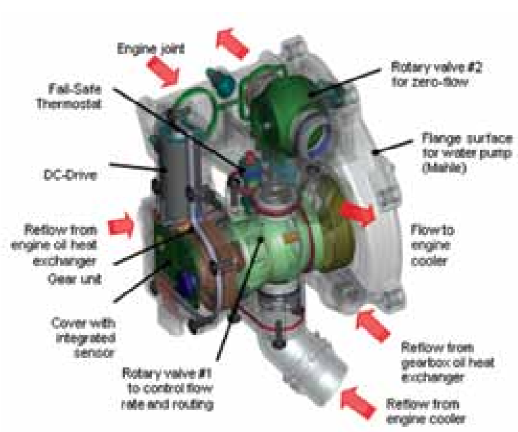

Figure 14 : Thermal Management Module (TMM) System

Engine System Level Engineering Benefits

It is well known that all the above stated systems are linked to each other, Hence it is vital to understand the influence of each and every system in to others, starting from the development stage. Being a systems supplier to various engine manufacturers, supplier considers the influence of separate systems in to each other and overall engine, then optimize individual products / systems, as shown in Fig. 15.

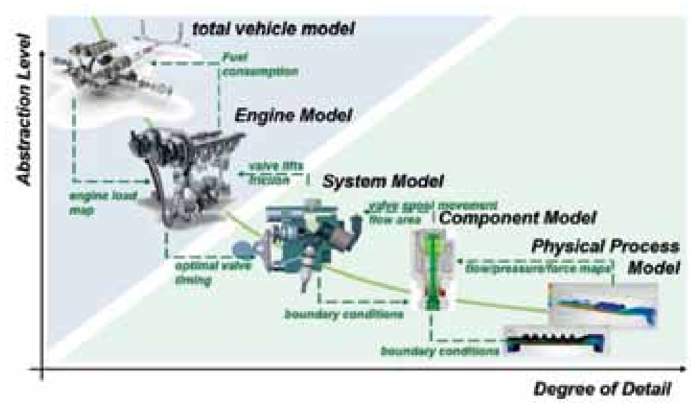

Figure 15 : Engine Systems Level Engineering for Automotive

System level engineering involves:-

- Detailed understanding the interface systems & its parts
- System level calculations
- System level DFMEA (predictions of failures & taking corrective actions during development)
- To analyze the effect on other interface system, if there is any change in one system.
- Following are interdependent systems, where performance of one is affecting due to any change in design of other, such as:-
    - Valve train system & Variable Cam Timing system
    - Chain / Belt Timing drive system & VCT system
    - Chain / Belt Timing drive system & FEAD Drive system (In case of BAS/ISG System)

- FEAD Drive system & Starter – Alternator system (In case of BAS/ISG System)
- Valve train system & Intake air management system
- Coolant & Oil systems

Benefits of System Level Product Engineering

- Correct selection of type of systems / components for better engine performance (based optimization to meet customer requirements)
- Reduction in development lead time
- Smooth & timely launch of new product (fast product development)
- Avoid / minimize field complaints
- More product life & reliability
- Faster diagnostic of the problem / issues (less stake holders to solve the system level issues)
- System level ownership

SUMMARY

Adaptation of affordable technologies enable a better optimized engine, suitable for emerging Indian requirements. However, a complete engine system level approach maximizes all the above benefits considering better integration of various technologies.

Development of HEV / FCV Technology from Indian Perspective

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Rise in greenhouse gas emissions which is resulting into ozone layer depletion and global warming effect, it is the need of the hour to control CO_2 emissions by drastically reducing fossil fuel consumption from the vehicles. This need has already started trend towards extreme downsizing and down speeding of Internal Combustion Engines (ICE). These majors help to operate engine with high Brake Mean Effective Pressure (BMEP) levels leading to an efficient combustion and hence offering substantial fuel consumption reduction. In addition use of after treatment devices viz. Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF), Lean NO_x Catalyst (LNT), Selective Catalytic Reduction (SCR)is helping to a great extent for meeting emission norms till Euro - VI for automotive sector, Tier-IV and Stage IV for Off Highway Power sector.

To summarize : In case of passenger car vehicle segment engines having specific power in the range of 60 - 90 kW/lit and for Heavy Commercial Vehicle (HCV) /Light Commercial Vehicle (LCV) / Off Highway segment, engines having specific power in the range of 28 - 35 kW / lit are being designed to bring down CO_2 emissions close to 100 g /km apart from making them fuel efficient and emission compliant. However to address present global warming and greenhouse gas effect on large scale, there is need to achieve CO_2 emissions below than 100 g/km. Fig. 1 shows trend followed for meeting CO_2 emissions.

"HEV/FCV technology more sustainable and cost effective by enhancing overall efficiency and drivability"

Further CO_2 emission reduction is possible only when there will be an improvement in fossil fuel economy in the range of 25 -30 % from present levels. Also due to use of above mentioned technology for meeting present emission norms, cost of engine on serial production level is becoming very expensive too. Electrification is one of the attractive solutions in present scenario and technology options available; out of which most promising technology emerging out is the Hybrid Electric Vehicle (HEV)

Figure 1 : CO_2 Emission Reduction Trend

technology. While thinking of these technology options from the perspective of CO_2 emissions and fuel consumption reduction, drivability so called “Fun to Drive” should not get compromised. Successful implementation of this technology is greatly depend upon final cost of product on mass scale basis and its operating cost against present available mobility options. For present situation, the first level of electrification in terms of use of HEV has a large potential, since Fuel Cell technology which is a second level of electrification option;implementation and operating cost is still on much higher side.

By considering these facts and need of the present situation, efforts are required to make an efficient Hybrid Electric Vehicle which will have minimum cost implications.

Degree of Hybridisation (DOH) between 20-50% gives full flexibility of different modes of operations including full electric operations in part load as well as in full load conditions. This gives very high benefits of fuel economy improvement in the range of 15-25 % over base line results. Such targets can be achieved with full parallel / series – parallel (Mix or Complex) HEV configurations.

Amongst above mentioned two options, full parallel HEV architecture is having a good potential to get fuel economy improvement in the range of 15 -25 % with minimum cost implication against vehicles powered with conventional power plant. This is possible only when electric motor will act as a prime power plant and ICE will operate in it’s most efficient operating working region in stand-alone or in hybrid mode along with electric motor.

In order to get such an improvement in fuel economy, control strategy for electric drive train operations need to be very efficient. Due to this, State of Charge (SoC) of battery should deplete at lower rate and hence will

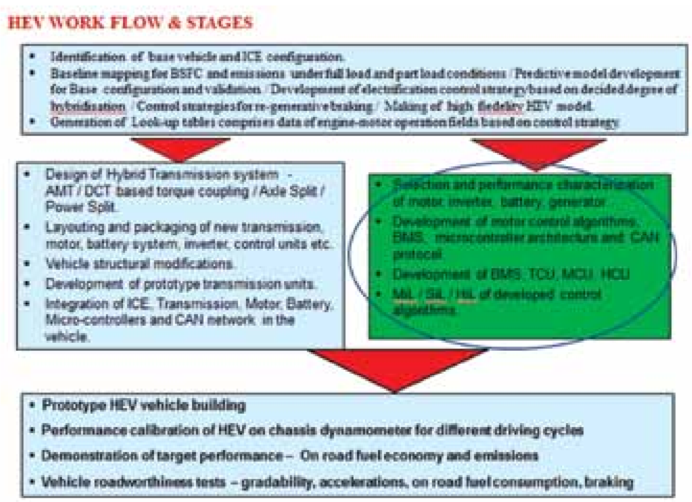


Figure 2 : HEV Development Process in Brief

allow for more electric operations than ICE mode of operations. For this reason, there is need to focus on an efficiency and drivability improvement of electric drive train used in EV / HEV and FCV applications. Fig. 2 shows overall development process for full parallel HEV. Encircled portion shows potential areas to work upon to improve an efficiency and drivability of an electric drive train.

Main objective should be to explore possible areas of improvement to make this technology more sustainable and cost effective by enhancing overall efficiency and drivability.

Following are areas need dedicated focus to meet the objectives mentioned herewith.

- EV / HEV / FCV Architectures / Electric Drives
- V/f, Direct Torque Control, Field Orientation Control, Fuzzy Logic Control of Asynchronous / Synchronous Electric Drives
- Advance Power Converters, Power Electronics, Control Systems, Mechatronics
- Parallel Computing Architectures / Micro Controllers & CAN protocols

ELECTRIC DRIVES FOR EV / HEV / FCV AND MOTOR CONTROL ALGORITHMS

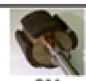
The success of modern EV/HEV/FCV is a function of three variables namely performance, efficiency and cost. To meet these diversified requirements, it is necessary to have extensive study and benchmarking of various mechanical, electrical and power electronics engineering aspects with more depth and breadth. This includes detail comparison between various architectures of EV/HEV/FCV. For design of such advance mobility options, there is need to focus more on entire electric propulsion system and its integration with the mechanical power plant or Fuel Cell based power plant by referring a comprehensive available data of modern EV/ HEV /FCV.

Detail study of Direct Current (DC)/Induction Motor (IM)/Permanent Magnet Synchronous Motors (PMSM)/ Brushless Direct Current (BLDC) / Switch Reluctance Motors (SRM) performance characteristics in both steady state and transient operations helps in selection of proper match suitable for HEV architecture selected and performance to achieve. Table 1 shows the comparison of decisive parameters for selection of an electric drive as a power plant.

Once drive technology is identified, it is utmost important to select / develop motor control algorithms. IM / PMSM/

BLDC and SRM are the most ideal candidates for vehicular operations. FOC is the best strategy for transient response for giving maximum Torque / Ampere against DTC and V/f controls.

Table 1 : Decisive Parameters for Electric Drive Selection

Electric Drive-Performance Characteristics	 DC	 IM	 PM	 SRM
Power Density	2.5	3.5	5	3.5
Efficiency	2.5	3.5	5	3.5
Controllability	5	5	4	3
Reliability	3	5	4	5
Technological Maturity	5	5	4	4
Cost	4	5	3	4
ΣTotal	22	27	25	23

For EV / HEV / FCV, improving SoC of battery is similar to improve the fuel economy of the conventional vehicles. Hence, when these vehicles run with DTC strategy, efforts should be in the direction of reducing current and torque ripples. This can be achieved by minimising THD content in the output voltage and current of inverter. Several attempts have been made to minimise current and torque ripples by various methods for reducing THD content in the output of an inverter. This includes use of SVM, use of combination of PI and SPWM control / use of Fuzzy logic to minimise torque and flux error bandwidth etc.

It can be seen that under different combinations of torque and speed under steady and transient state operations, DTC is having more ripple in three phase currents. Similar trend is obtained in case of torque ripples. However more uniform and regular oscillations in torque amplitude can be obtained with FOC. Though DTC is fast in getting desired response, it have inherent problem of coupling of stator and rotor fluxes. To overcome disadvantages offered by DTC, control based on field orientation technique is widely used. Such control not only allows changing the voltage amplitudes and frequency, but user get control over instantaneous position of voltage, current and flux vectors. Separately excited DC motor like performance is obtained due to de coupling effect of stator and rotor fluxes by using FOC Also time varying inductances are difficult to handle while solving the differential equations. FOC takes care of these aspects. These two features greatly improves dynamic performance of drive in terms of getting more torque / ampere.

To improve THD content during DTC operations, one of the solutions is to use multilevel inverter in case of DTC application. Symmetric 5 level and Asymmetric 7 level inverter configurations can be proposed for this purpose.

In order to further improve static and dynamic response of FOC, use of back stepping technique which is a systematic and recursive algorithm for nonlinear feedback control / use of series iron loss model in rotor flux orientation for removing effect of iron loss without increase in computational time / using space vector modulation with consideration of core loss / Feedback Linearisation Input-Output Decoupling Control is recommended.

Table 2 : Performance Comparison of DTC and FOC

Features	DTC	FOC
Steady-state behaviour for Torque	High Ripple and Distortion	Low Ripple and Distortion
Steady-state behaviour for Stator Current	High Ripple and Distortion	Low Ripple and Distortion
Magnitude of Stator Current	High	Low
Dynamic response for Torque	Quicker	Slower
Behaviour at Low Speed	Not good	Good
Parameter Sensitivity	Insensitive	Sensitive
Torque and Flux Control	Directly Controlled	Indirectly Control by Stator Currents
Coordinate frame	Stationary d-q	Synchronously Rotating d-q
Controller Stability	Very Good	Good
Switching Frequency	Variable	Constant
Current Control	No	Yes
Control Tuning	No PI controller required	PI controller required
Audible Noise	High Noise	Low Noise
Complexity	Lower	Higher

Based on simulations carried out, summary of comparison between performances obtained by three motor control strategies is made and shown in Table 2. Comparison is restricted only between DTC and FOC, since V/f found inferior on all fronts except simpler in implementation and giving better starting Torque behavior at very low speeds as obtained with DTC.

Following study presents EV/ HEV / FCV architectures, showing potential areas to work upon to make present technology more efficient and cost effective.

- In order to get fuel economy improvements more than 20%, use of electric drive operations need to increase than ICE operations. However, this depletes battery SoC rapidly. Plug-In HEV is option available for the same. But this calls for larger battery in size and dependency on charging grids. Both these lead to an increase in cost plus emissions due to extra electric load generations on account of charging grids.
- There is need to improve / optimize various losses during electric drive operations which will result in more torque with less current input. These losses are mainly ohamic losses, inverter switching losses, active current loss due to more THD present in the conventional inverter outputs, non-consideration of time varying inductances in motor control algorithms viz. V/f and DTC.
- Present Vehicles run mainly with FOC as the motor control algorithm irrespective of any driving conditions demand. This is mainly to maximize torque / ampere and hence to improve an efficiency of the vehicle. Its response time is more as compared with DTC.
- FOC is very precise in torque and speed control but very complex in nature. It performs extensive matrix transformations to deliver required output. This moderately de-rates the vehicle performance in accelerations and while climbing the gradients.
- During start / stop Operations on steep gradients, very fast response plus high starting torques are required from Motors. V/f provides all this flexibility with minimum efforts for implementation. V/f is the simplest control amongst all. However it is inferior on efficiency and controller stability parameters front.
- DTC is mostly used in an industrial applications though it is a vector control based. Need is there to use the same in the vehicular applications to take advantage of it's faster performance but with an improvement in it's efficiency.

IMPROVING FUEL ECONOMY ≥ 20% WITH COST EFFECTIVE FULL PARALLEL HEV ARCHITECTURE

In order to improve the fuel economy ≥ 20% on different driving cycles, there is need to change from rule based control strategy to strategies like Engine thermostat ON-OFF control strategy / real time optimization based control strategy. In Engine thermostat ON-OFF strategy which is easy to implement, electric motor will act as a main prime mover. In this case selected motor size should be sufficient to deliver performance of vehicle in normal cruising conditions. Here engine will be brought into the operations mainly to charge the battery and hence to maintain SoC in specified working limits apart from working in hybrid mode of operations with IM. However working in pure electric mode for most of the time, greatly depends on how fast SoC is depleting and making available power for electric operations. In order to happen this, reduction in depletion rate of SoC is very critical. This fact will allow for getting more operations in electric mode without bringing engine frequently into the operations. Also drivability needs to improve during electric mode of operations to follow precisely cycle demands.

Use of P 2.5 configurations where AMT based 7 / 9 speed transmission having side mounted electric motor along with above mentioned solutions will be a proposed full parallel HEV architecture to begin with.

Once with this FE in the range of 20-25% is realizable without having much cost impact, slowly volume will start increasing. This will help in reducing cost of power electronics, motor and battery technology. This will pave path for going for more complex parallel- series Plug-In kind of HEV configuration to get FE more than 25%.

FUTURE RECOMMENDATIONS

This is to highlight the areas to improve further FOC and DTC performance from efficiency and computational time point of view. This mainly involves use of series iron loss model in rotor flux orientation, using back stepping technique for nonlinear feedback control and application of feedback linearisation Input-Output Decoupling Control for estimation of rotor flux in case of FOC operations. On similar lines use of SVM, fuzzy logic is proposed for getting constant switching frequencies in case of DTC operations.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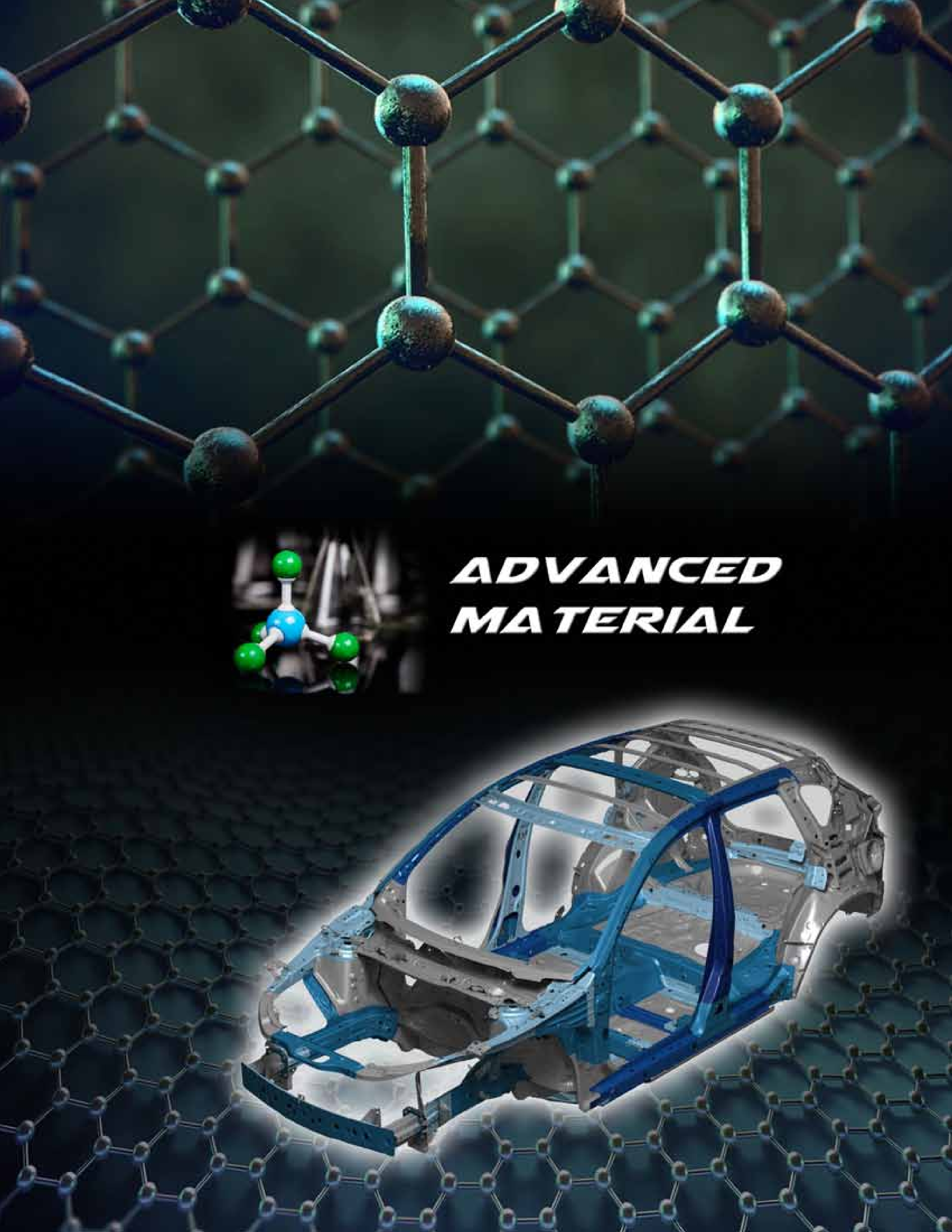
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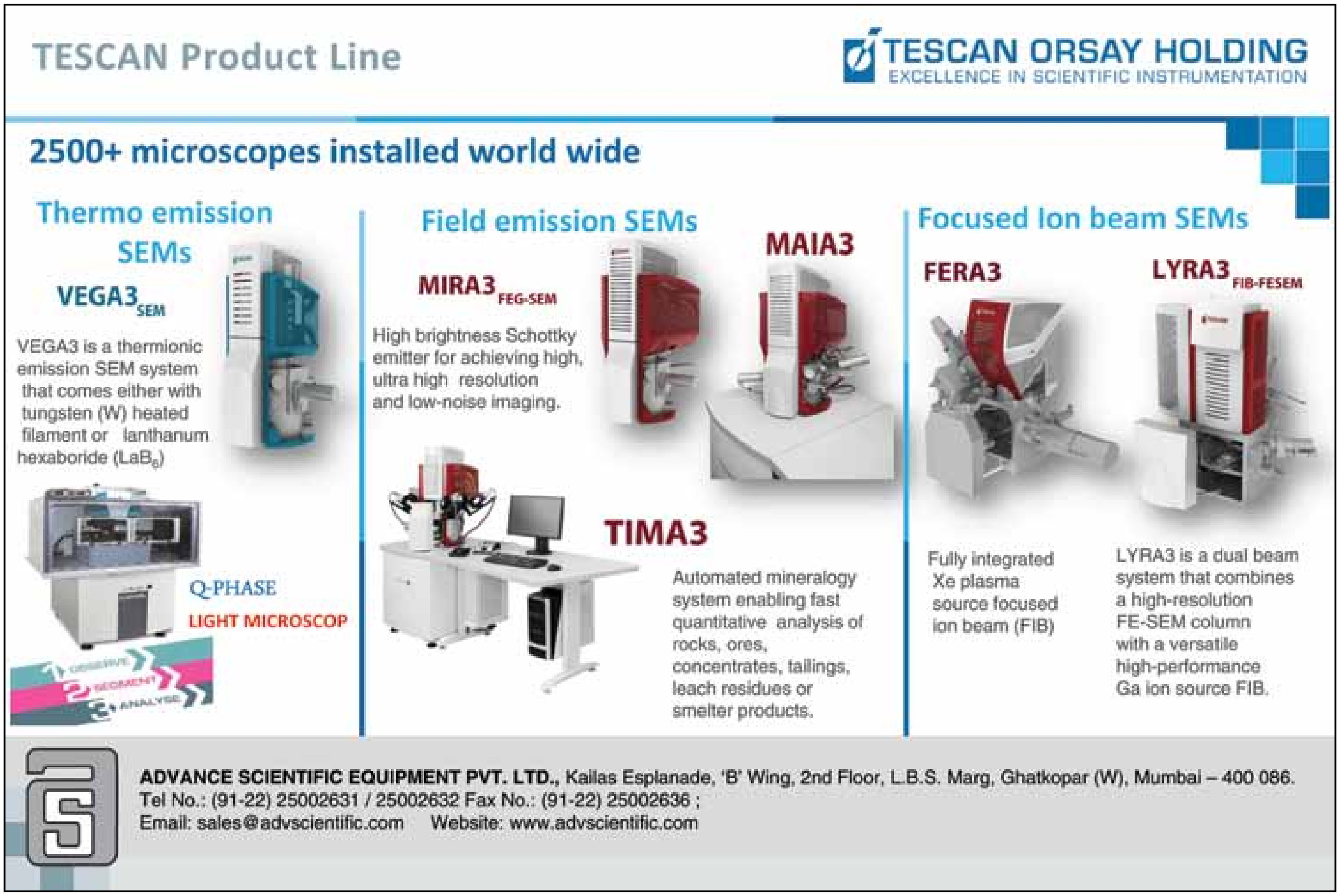
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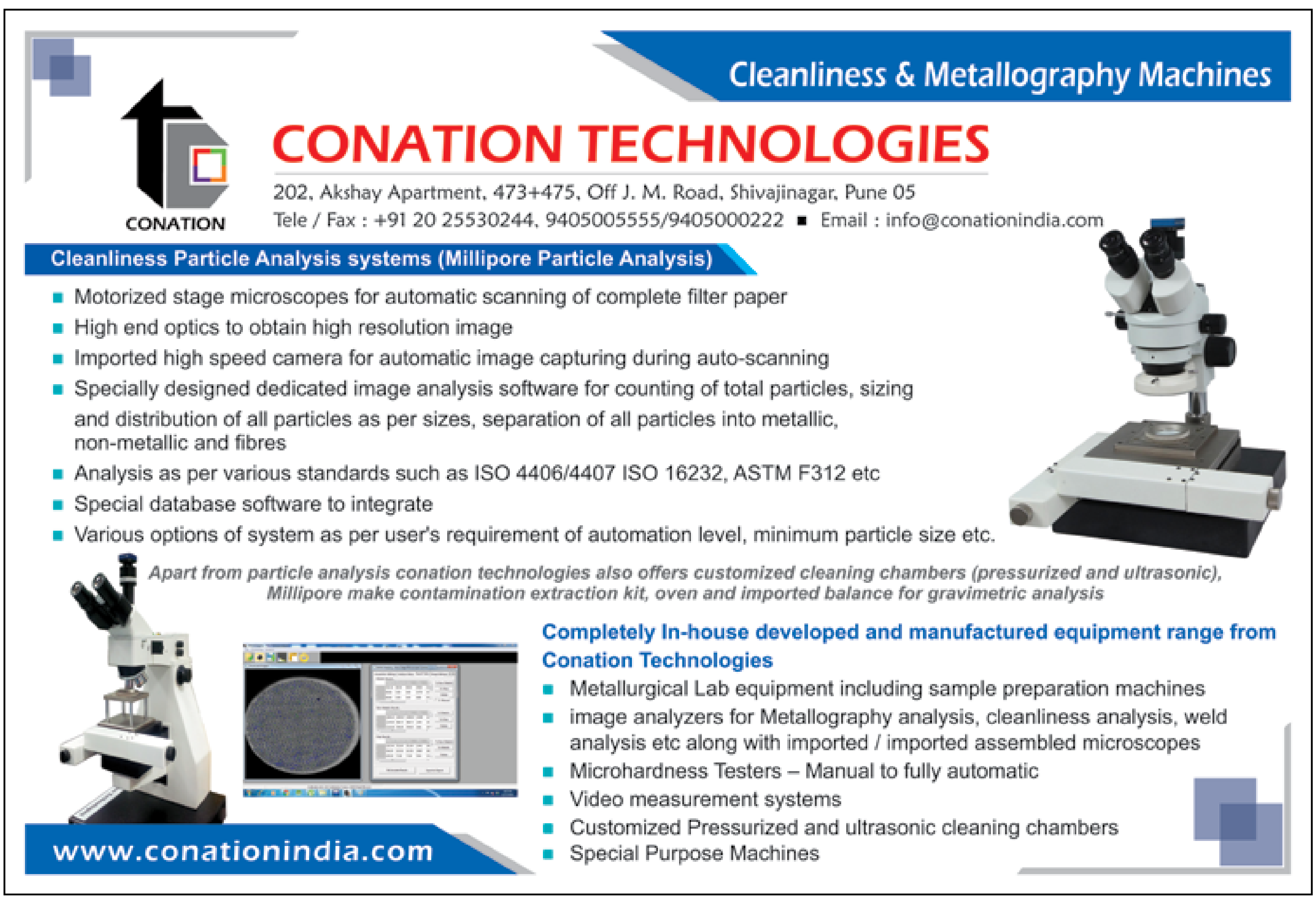
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Use of Aluminium for Light Weighting of Buses - A Step Towards Greener Environment

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"Kitnadeti Hai" is the driving mantra of automotive sells in India and also a significant entity to govern the taxes which nation pays in the form of import duty for importing fuel in India. If we succeed in reducing the fuel consumption of vehicles, we will be able to deliver a cleaner environment and also contribute to India's commitment made at Copenhagen Climate Change Summit - reducing its emissions per unit of GDP 20 to 25% below 2005 levels by 2020.

India is currently the world's 7th largest emitter of global warming pollution and 5th largest for emissions from fossil fuel combustion. India's total carbon emissions are about four percent of total global emissions. To move towards a low carbon economy, an indicative target of cutting the energy consumption by 21% was taken in India's 12th Five Year Plan. It is suggested that necessary actions in specific sectors, like urban public transportation, are required to reduce Green House Gas (GHG) emissions intensity. These promises represents important steps on a new pathway to real progress in reducing emissions and move towards low carbon global economy.

Large population of automobiles has significant impacts on climate change, with emissions of carbon dioxide (CO_2), methane and nitrous oxide, coming from the fuel consumed by automobiles Additionally, urban population is most affected due to these GHG emissions including high rate of respiratory, digestive, ocular and skin problems and significant number of them become victims of lung disorders.

> *"Studies shows that if 1 kg Aluminium used as against steel we can reduce 20 kg of CO_2 emissions over the life of vehicle"*

23% GHG emissions is produced by all transport sectors across globe. On the similar lines the major cause of air pollution in Indian cities is also due to transport sectors, out of which city buses contribute the most. City buses runs 200-250 km daily in city area with frequent starts and stops with full capacity of seated and standee passengers. The mass of the bus has functional relationship with the fuel economy and emissions, given that powertrain and drivetrain efficiency remains the constant. Over the lifetime of the bus marginal improvement in the fuel economy and emissions per kilometre travelled would have significant impact on the economics of providing bus service to passengers as business in addition to curbing GHG emissions.

The power required to move a vehicle has a direct co-relation with the mass of the vehicle. The higher the mass the more power is required to change its inertia state. It follows that any reduction in the mass of the vehicle would mean lesser power requirement for its movement. In realistic driving situations where there are several start and stops over a certain period of time, like in the case of city buses, the quantum of benefit increases over a large number of cycles.

It is thus logical to target city bus for light weighting for reducing the fuel consumption of bus. Light weighting can be achieved through various processes like new product design, weight optimization, change of material, process optimization and also my selecting advance techniques in manufacturing. Looking at the city buses in India, we find that the major weight of bus is of it's super structure which is made of steel. Normally, rectangular tubes are welded together to form a rigid super structure. If we can reduce the weight of this structure we can achieve all the goals resulting into Greener environment.

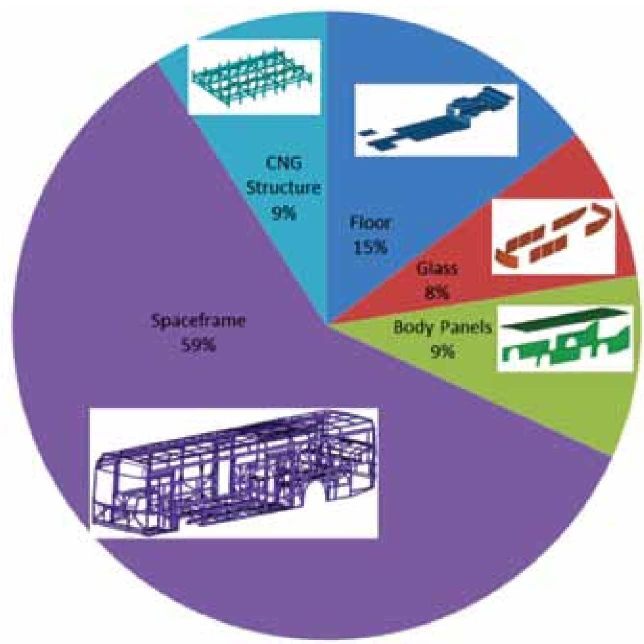

Figure 1 : Typical Weight Distribution in City Bus

We can replace this steel super structure with Aluminium super structure. Aluminium is easily and widely available in India as we are 2nd largest producer of aluminium in world after china. By promoting Aluminium in automotive industry we can grow the aluminium consumption capacity of India resulting in production of finished aluminium products in India which will reduce the import duty that we pay in importing finished aluminium products from developed nations.

Thus, use of aluminium in automotive sector is win-win situation for user and also for the nation in building a green environment around us as studies shows that if 1 kg Aluminium used as against steel we can reduce 20 kg of CO_2 emissions over the life of vehicle.

For steel buses major issue is corrosion. With the time structure starts corrode leading to frequent maintenance. In coastal area it is observed that, life of bus with steel super structure is less due to corrosion. Corrosion issue can be addressed to large extend by using aluminium. Corrosion is observed in Aluminium also- called "White Rust" but the rate of corrosion in aluminium is less as compared to steel. Galvanic corrosion is observed in aluminium at the point of contact between steel and aluminium. This can be avoided by good design and use of anti-corrosion coatings and sealants.

Looking at the strength point of view, we can get similar strength from aluminium joints by designing equivalent sections using simple engineering calculations.

With this thought we can take up light weighting of city buses further. As said, super structure of bus can be made of aluminium with joining technique like bolting/riveting and welding. Wide range of aluminium alloys are available including high strength solutions. Among those 6000 series alloy can be used for automotive. These alloys can be welded using TIG and MIG welding.

Both the joining methods are feasible having respective pros and cons. Initially, light weighting was driven by use of aluminium casting and sheets. But, looking at the applications we can use aluminium extrusions which can be used for the structure. Different shapes of components can be extruded so that we can use different shapes at different joints in super structure. For example, in super structure of bus cant-rail is critical joint which can be made stronger by using specially designed extrusions.

Currently, bus super structure is made of steel because it is cost effective for bus body builder as the cost of steel is less as compared to Aluminium. But, if we do cost analysis of bus over its life cycle, it is understood that, aluminium bus gives considerable saving over the entire life span.

Aluminium bus body super structure is a good solution in bringing down the emissions and benefiting the business of bus operator. With this view ARAI carried out R&D consortium project funded by Department of Heavy Industries which focused on developing Bus body super structure design using Aluminium. Project was carried out by consortium partners- The Automotive Association of India (ARAI), Aluminium Association of India and Indian Institute of India-Mumbai (IITB).

Main objective of project was,

- To design Aluminium superstructure complying to Bus Body Code (AIS:052) and meeting the strength requirements of Urban Bus Specification-II of MoUD (Ministry of Urban Development)
- To achieve Maximum weight saving in the superstructure design in order to increase fuel efficiency

- To prepare design guidelines for City bus
- To promote Aluminium consumption in India and to grow awareness of use of Aluminium in Buses.

Superstructure with various joining methodologies (viz. bolting, welding, adhesive bonding etc.) were developed and tested in the laboratory environment. Aluminium super structure with Bolting as joining technique was developed for 12 m low floor city bus which resulted in weight saving of 600 kg in super structure considering steel super structure as benchmark.

Figure 2 : Aluminium Bus Super Structure for City Bus

COST BENEFIT ANALYSIS OVER A LIFE SPAN OF BUS

In India, generally bus life span is 12 years.

- 100 kg of weight saving results in approximately 750 litre of fuel saving in bus life span. With 600 kg of weight saving, 9000 litre of fuel saving from a single bus can be achieved in its life span.
- If 10000 Urban buses are converted built with Aluminium superstructure considerable fuel saving can be achieved with 120 metric ton of CO_2 reduction in the entire bus life span.

Table 1 : Cost Benefit

No. of Buses	Approximate Diesel Savings (Ltr.)		Monetary Benefits in Bus Life Span (Rs. Crore)
	In 1 Year	In 12 Years Bus Life Span)	
1	750	9000	0.06
10000	75 Lakh	900 Lakh	585

- With use of Aluminium superstructure bus fuel economy improves by 2.5 to 3%.
- Above fuel saving reflects in monetary saving of Rs. 5.80 Lakh (approx.) with assumed diesel price of Rs. 65/litre for a single bus.
- Aluminium cost is 4 times higher than steel, this results in incurring additional cost of Rs. 3.26 Lakh for building bus superstructure using Aluminium which gets recovered in 5-6 years of bus life.
- Almost 97% of Aluminium can be recycled and after end of bus life this aluminium property gives push to achieve cleaner environment alongwith recycling cost benefit to bus operators.

SUMMARY

Thus, by promoting Lightweight of bus through the use of aluminium a step towards greener environment can be achieved with following tangible benefits.

- Reduce emissions resulting into greener environment.
- Reduce fuel consumption on vehicle.
- Promote Aluminium production.
- Increase the aluminium consumption capacity of India and bring aluminium extrusion manufacturers into main stream of transportation in a bigger way.
- Reduce import duty on importing finished aluminium products.

Heat Treatment Process Parameter Optimization using Dilatometry Technique

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INTRODUCTION

Automotive Industry is not only one of the biggest sectors in India but also a fast growing one. As per the recent announcement from the MoRTH, BS VI standards will be implemented in India soon. This calls for exponential increase in pace of innovation in component manufacturers and OEMs to meet the requirements and also to remain competitive by maintaining the cost of vehicle production.

One of the major areas to reduce the cost of the vehicle is to reduce component production costs and this can be achieved if significant energy is saved during the manufacturing process. There is a huge potential in developing cost effective production technologies in India without compromising the technical requirements. In parallel such technologies need to be made wide-spread in the Indian context to change the 'ground reality'.

Forging and heat treatment of steel components is one of the major energy intensive processes in the production cycle. In today's scenario heat treatment cycle in forging industries is designed through trial & error / thumb rule / experience / literature. Introduction of new materials and also chemistry modified materials is common and there is no scientific methodology available to forging industries for heat treatment optimization. Saving of a few kWs in the process can translate into a larger increase in energy efficiency because of the 'mass-production effects'.

"Dilatometry technique is used for the study of phase transitions in a material by measuring its linear strain"

QUENCHING DILATOMETER

Dilatometry technique is used for the study of phase transitions in a material by measuring its linear strain. Strain occurring because of microstructural changes is one of the important parameter used in studying the phase transformation. This technique is aimed at establishing direct link between discrete values of strain and specific microstructure constituents in materials. The experiments can be performed in controlled atmosphere i.e. Noble gases. Continuous Cooling Transformation (CCT) and Time Temperature Transformation (TTT) curves are obtained as the output. ASTM A1033 gives the standard practice for quantitative measurement and reports on hypoeutectoid carbon and low alloy steel phase transformations.

Working Principle :

- The sample is heated by induction principle
- Cooling is achieved by a combination of controlled reduction in the heating current and the injection of helium gas onto the sample
- Dimensional change is measured along the longitudinal axis of the sample and temperature change is measured by means of thermocouple welded to the surface of the sample midway along its length
- Depending on the output required, the sample is

subjected to thermal cycling whose duration can vary from seconds to hours. Refer Fig. 1 for a typical sample and quenching dilatometer available at ARAI-Forging Industry Division.

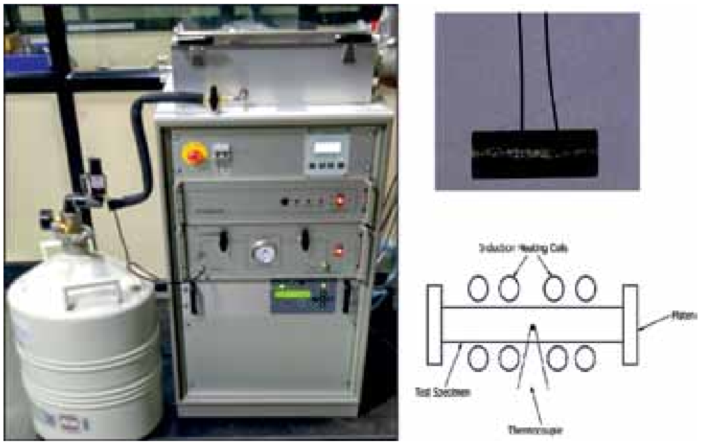

Figure 1 : 1RITA Quenching Dilatometer, Make : Linseis GmbH, Germany

Applications :

- **Heat Treatment :** Provides transformation diagrams that depict the microstructures developed during the thermal processing of steels as function of time and temperature. Such diagrams provide qualitative assessment of the effects of changes in thermal cycle on steel microstructure.
- **Selecting Steel Grades :** Dilatometry technique is useful in providing data for the prediction of microstructures and properties to assist in steel alloy selection for end-use applications.
- **Input in FEA Model :** This technique provides data for computer models used in the control of steel manufacturing, forging, casting, heat-treating and welding processes.
- **Phase Transformation Data :** Dilatometry technique is used to provide steel phase transformation data required for use in numerical models for the prediction of microstructures, properties, and distortion during steel manufacturing, forging, casting, heat treatment and welding.

Determination of Critical Temperatures :

Critical temperatures are those temperature at which austenite begins to form on heating i.e. Ac1 and the temperature at which the transformation from ferrite to austenite is completed i.e. Ac3. The critical temperatures can be determined from changes in the slope of strain versus temperature plot. Strain increases with temperature until Ac1 is reached and will begin to decrease with increasing temperature and after reaching Ac3 will again begin to increase with increasing temperature.

Critical Temperature for 40Cr4 :

The following graph (Fig. 2) shows the plot of Strain vs. Temperature with Delta- L on y-axis and Temperature on x-axis for determination of Ac1 and Ac3 temperature for 40Cr4. The enlarged portion shows the start and end of the phase transformation from ferrite to austenite. It can be observed that at 749.5°C the austenite begins to form and at 796.8°C all 100% austenite is achieved. Hence the critical temperatures for 40Cr4 are identified.

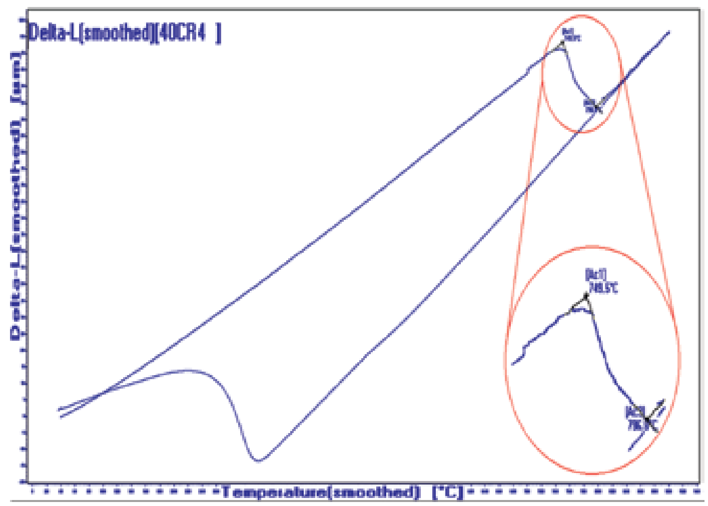

Figure 2 : Critical Temperatures for 40Cr4

Time Temperature Transformation (TTT) Curve :

Time Temperature Transformation (TTT) diagrams or Isothermal transformation diagrams are plots of temperature versus time. They are used to represent transformation kinetics for steels, but also can be used to describe the kinetics of crystallization in other materials. They are generated from percentage transformation vs. logarithm of time measurements, and are useful for understanding the transformations of alloy steel that is cooled isothermally.

Generating the Isothermal Transformation Curves:

The sample is heated to an austenitising temperature of Ac3 + 50°C, at a nominal rate of 10°C/s. The sample is then held at this temperature for a specific period of time until a single phase consisting of austenite is obtained. The sample is quenched to a isothermal hold temperature as per the user requirement. A cooling rate of at least 175°C/s shall be employed. As the sample is held at this isothermal hold temperature its dimensions are continuously measured until transformation is 100% complete. The sample is then quenched to room temperature. The microstructure and hardness of the sample can be analysed for phase study. The raw data is used to plot TTT Curve which is an integral part of the Quenching Dilatometer and the software used is WinZTU.

Effect of Isothermal hold temperature for 40Cr4 :

The following two graphs (Fig. 3) shows phase transformation at two different isothermal hold temperatures i.e. 340°C and 520°Cwith Delta-L on y-axis and Temperature on x-axis for 40Cr4. The enlarged portion of the curve explains the transformation during isothermal hold. For the isothermal hold temperature of 340°C the change in length is observed to be 60.9 µm whereas for the isothermal hold temperature of 520°C the change in length is observed to be 34.4 µm until the transformation is 100% complete. The effect of isothermal hold temperature on the phase transformation and dilation can be studied.

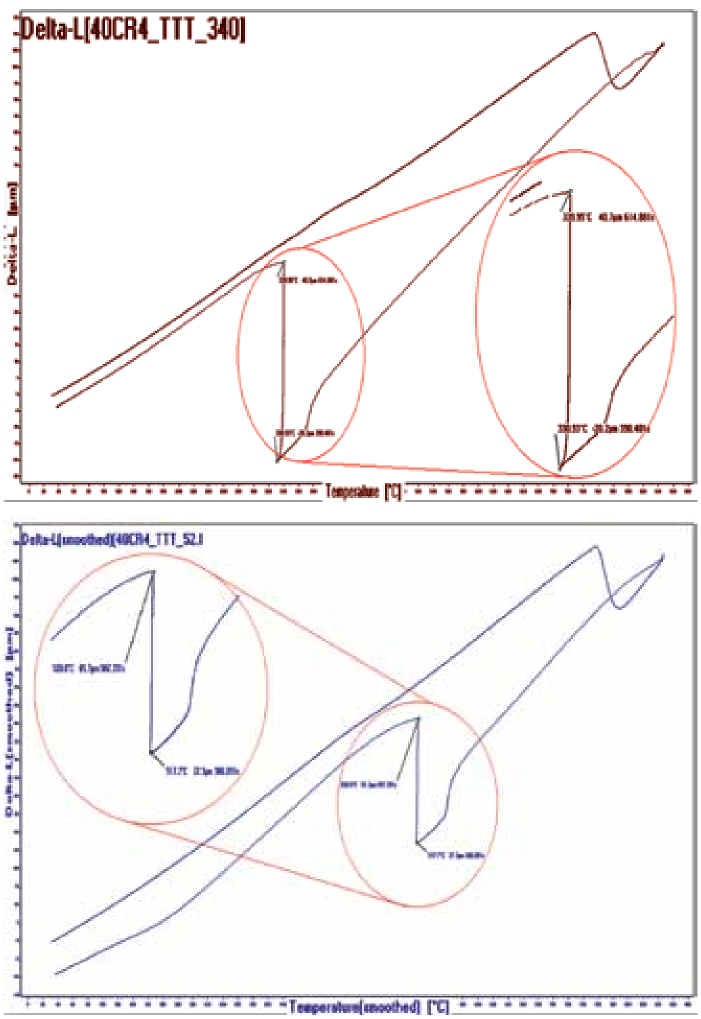

Figure 3 : Effect of Isothermal Hold Temperature for 40Cr4

Continuous Cooling Transformation (CCT) Curve :

Continuous Cooling Transformation (CCT) Diagram is used to represent which type of phase changes will occur in a material when it is cooled at different cooling rates. CCT diagram is often used for deciding the heat treatment parameters. For continuous cooling, the time required for a reaction to begin and end is delayed. Control can be maintained over the rate of temperature change depending on the cooling environment. Depending on the cooling rate i.e. fast or slow the required microstructure changes can be obtained.

Generating Continuous Cooling Transformation Curves :

The sample is heated to an austenitising temperature of Ac3 + 50°C at a nominal rate of 10°C/s. The sample is then held at this temperature for a specific period of time until a single phase consisting of austenite is being obtained. The sample is then quenched at nominal cooling rates of 0.05 to 250°C/s depending on the type of structure and the mechanical properties required.

Effect of Cooling Rate for 40Cr4 :

The following two graphs (Fig. 4) represent the Continuous

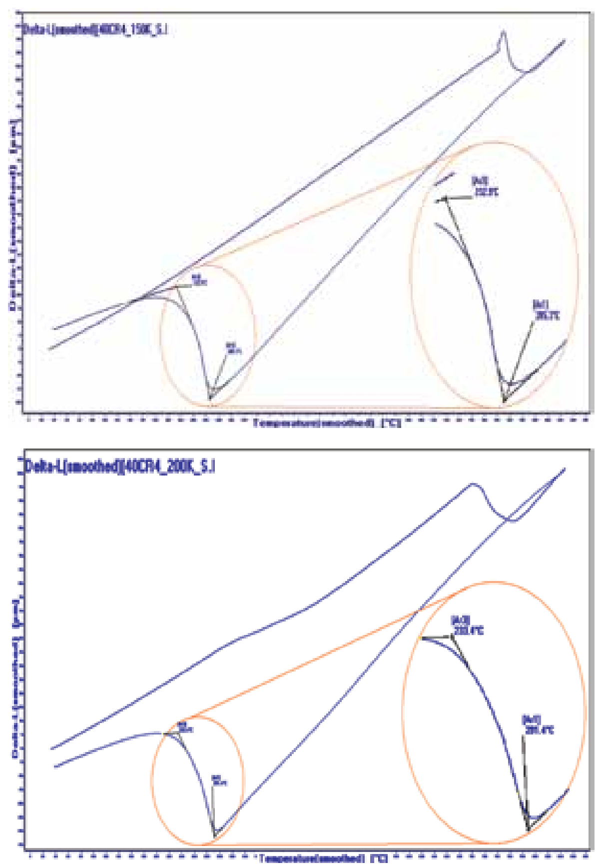

Figure 4 : Effect of Cooling Rate for 40Cr4

Cooling Transformation (CCT) curves with Delta-L on y-axis and Temperature on x-axis for 40Cr4 for two different cooling rates namely 150°C/s and 200°C/s. The enlarged portion represents the cooling rates employed for the sample. For the cooling rate of 150°C/s, austenite to ferrite transformation begins at 285.3°C and the transformation is complete at 232.9°C. Similarly for the cooling rate of 200°C/s, austenite to ferrite transformation starts at 291.4°C and the transformation finishes at 233.4°C. The effect of the cooling rate on the phase transformation of 40Cr4 can be studied.

CONCLUSION

Quantitative analysis of manufacturing process parameters is an important technique to achieve significant energy saving and also enhancing the end metallurgical properties. Dilatometry techniques quantifies the thermal cycle given to any product during its production cycle and thus quantifies the various phase transformation during the cycle. This data will assist the manufacturing engineers for optimization of cycle time/energy/end properties. The TTT and CCT data derived will also act as an Input for FEA software which predicts the metal forming or the end properties.

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Material Modeling and Failure Prediction of Polymers

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INTRODUCTION

Light weighting through replacement of metal to polymers has become extremely popular in many industries, because of the demand for lighter and efficient products. Polymers provide some of the advantages like low weight, shorter lead time, ease of producing complex shape/forms, consolidation of parts, net shape processing, and lower manufacturing costs.

> ***"Polymers have extremely non-linear behavior and their properties vary significantly with atmospheric conditions, hence it is very important to have accurate material models to design and analyze the polymer based products"***

Design and analysis of the polymer components for required life and strength requirements poses considerable challenges due to limited understanding of polymer-material modeling methods to predict the performance. This leads to an over/under designing of the polymer products with not appropriate factor of safety. There are many reduction factors that need to be considered in order to design the safe and reliable polymer components. In practice these factors lead to over or conservative design increasing the weight of the component.

Unlike metals, polymers have extremely non-linear behavior and their properties vary significantly with atmospheric conditions, hence it is very important to have accurate material models to design and analyze the polymer based products. There has been considerable research in past few decades related to the polymer material modeling and failure prediction; however there are no established approaches that can be applicable for wide variety of polymers. If a plastic object is subjected to more than one cycle of loading and unloading, each additional loading will add some more permanent deformation. This time dependent elastic and plastic deformations makes polymer behavior complex to simulate.

Analysts typically tend to use linear elasticity and metal plasticity models to simulate polymer behavior, which are simpler and quick in getting the results however accuracy is very low as it doesn't capture time dependent response. Also commercially available finite element tools has limited material models, which do not capture the effect of time, temperature and other atmospheric conditions, hence it is important to establish accurate material models based on experimental stress-strain data. Veryst Engineering's MCalibration and PolyUMod are some of the tools which can be used to establish the material models based on the test data with wide variety of material models that are not available in commercial FEA codes.

Current study presents a methodology to establish the accurate material models of the polymer and integration of these material-models into standard FEA tool ABAQUS for predicting the structural performance of the product. A detailed case study has been presented on a flexible hinge, which validates the methodology.

MATERIAL MODELS

Building a material model involves the following three steps:

1) Generating the experimental stress-strain data
2) Generating and calibrating the material models
3) Material model stability assessment

Experimental data is generated by performing the standard material level tests. Simple bi-axial and planar tension tests are some of the recommended tests to effectively capture the material behavior. Calibration involves visual judgment of the curve fit for entire strain range. It is mandatory to check the stability i.e. Drucker stability criterion to ensure the material stability in numerical analysis, which refers to a set of mathematical criteria that restrict the possible nonlinear stress-strain relations that can be satisfied by a solid material.

Three Network Model (TNM) and Parallel Network Model (PNM) are two popular methods to establish the material models. TNM helps to capture the response of thermoplastics precisely. TNM is a physically motivated model, originally developed to mimic the behavior of Ultra High Molecular Weight Polyethylene (UHMWPE), which has 3 parallel networks with multiple elastic and flow elements to capture the time and temperature dependent response. However TNM doesn't have the capability to capture anisotropic behavior, which can be predicted using PNM. PNM is an advanced material model for predicting the non-linear visco-plastic response of any polymer material. It has greater flexibility to combine elastic, flow components with temperature dependency and damage models.

Both of these advance material models require rate and temperature dependent stress strain data considering few loading and un-loading cycles to better capture hysteresis behavior. Fig. 1 presents a rheological representation of parallel networks, which consists of spring mass-damper systems. Spring represents instantaneous response and dash pot represents the time dependent response of the material.

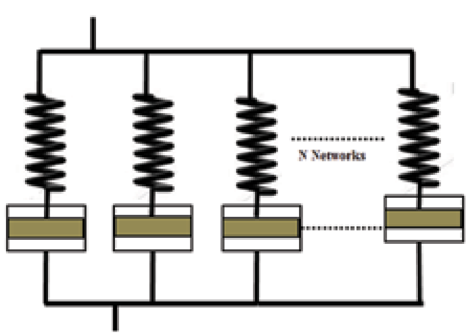


Figure 1 : Rheological Representation of Parallel Networks

METHODOLOGY

This section presents the material model development procedure with an example, wherein a thermoplastic Polysulfone material has been used for the demonstration. Polysulfone is high performance polymer, known for its toughness and stability at high temperatures. Fig. 2

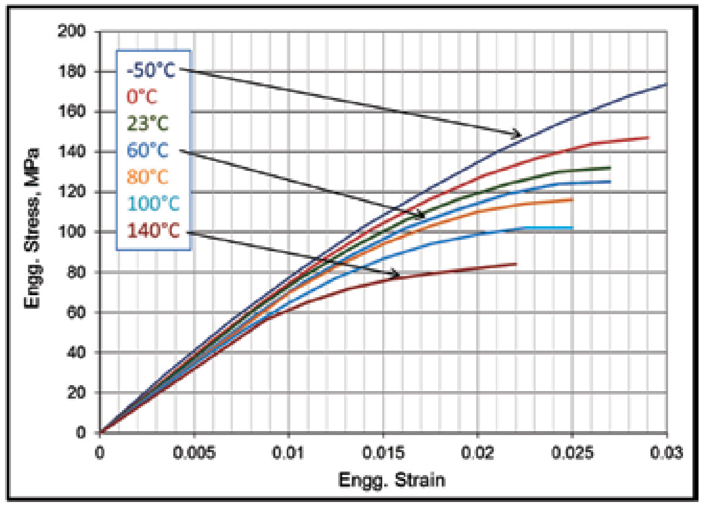


Figure 2 : Stress-strain Curves for Polysulfone at Different Operating Temperatures

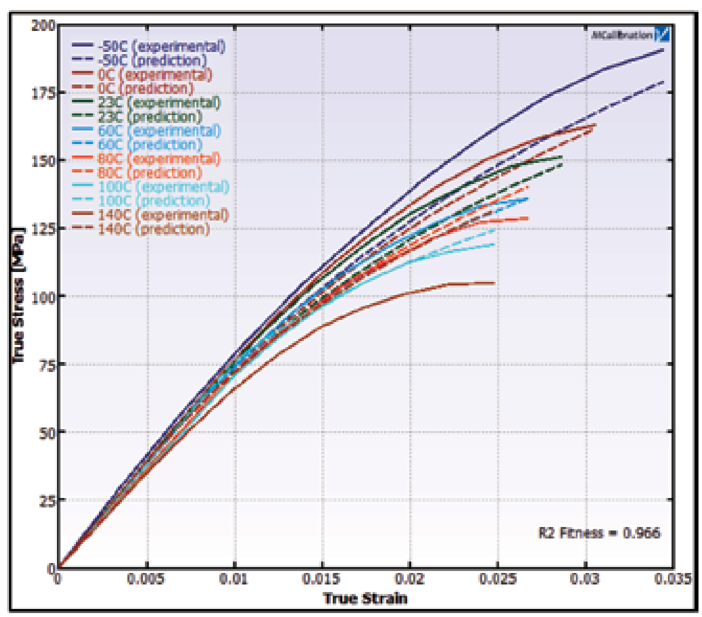


Figure 3 : Calibrated Material Model Response Using TNM

presents stress-strain data for Polysuflone at different operating temperatures obtained through standard experiments.

It is strictly not recommended to use the simple elasticity and metal plasticity models to capture the non-linear response of the polymer when the region of interest is at mid strain levels. As a best practice first TNM model was used to calibrate the material and it is observed that the predicted response in the given temperature range is not well capturing the material behavior from medium to high strain levels. This led to development of parallel network model. Fig. 4 presents the calibrated material model's response using the parallel network model method. Plots in Fig. 3 and 4 show that the PNM

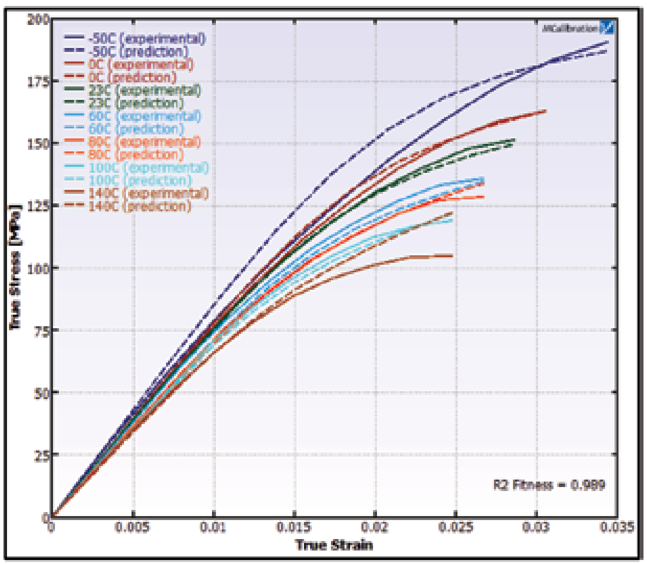


Figure 4 : Calibrated Material Model Response Using Parallel Networks

Evaluating the stability of the specified POLYUMOD-Parallel-Network model.
(The strains are engineering strains.)

Uniaxial Tension: stable for strains between 0 and 0.5.
Uniaxial Compression: stable for strains between 0 and -0.5.
Planar Compression: stable for strains between 0 and -0.5.
Biaxial Tension: stable for strains between 0 and 0.5.
Biaxial Compression: stable for strains between 0 and -0.5.
Shear: stable for strains between 0 and 0.5.
Volumetric Tension: stable for strains between 0 and 0.01.
Volumetric Compression: stable for strains between 0 and -0.1.

Analysis complete.

Figure 5 : Typical Stability Check and Material Model Response

results in a better curve fit over TNM; and PNM model satisfies required stability criteria well as represented in Fig. 5; using developed material model strains are stable in all the loading scenarios.

CASE STUDY

Flexible hinge helps to distribute the load and have some of the typical applications in automotive industry. In this case study a flexible hinge made up of Polysulfone has been considered to demonstrate the approach to predict the life and performance under the defined loads.

In the current application, flexible hinge experiences both thermal and mechanical loading. A thermal analysis has been performed initially in ABAQUS to understand the temperature gradient across the component and subsequent thermo-mechanical analysis to predict the stresses. Fig. 6 presents the boundary conditions applied in the finite element model; hinge predominantly experiences the bending load (1.26 radians of rotational displacement). Fig. 7 presents the temperature and stress distribution across the flexible hinge with highlighted life limiting location. Fig. 9 presents the variation of stress components at the life limiting locations during the cyclic loading on the flexible hinge.

As the loading profile varies across the minimum and maximum scenarios, component stresses are used to derive the mean and alternating stresses by identifying 2 peak locations to simplify the loading scenario for further life prediction. This needs stress transformation to consider mean stress correction using Walker mean stress correction generally recommended for polymers. It is observed that

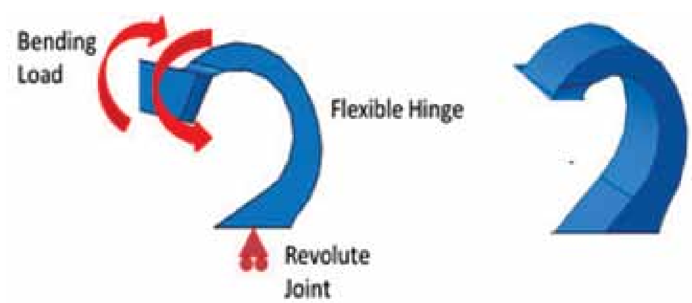


Figure 6: Analysis Configuration for the Flexible Hinge Structure

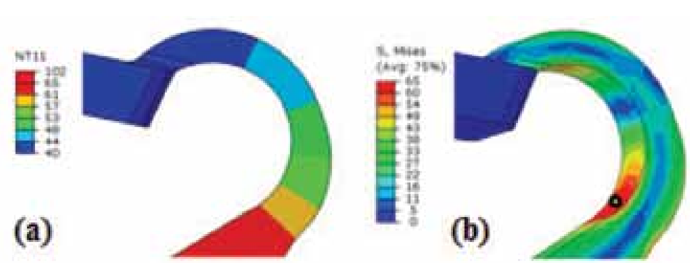


Figure 7 : (a) Temperature Distribution Across the Hinge; (b) Stress Distribution Across the Hinge

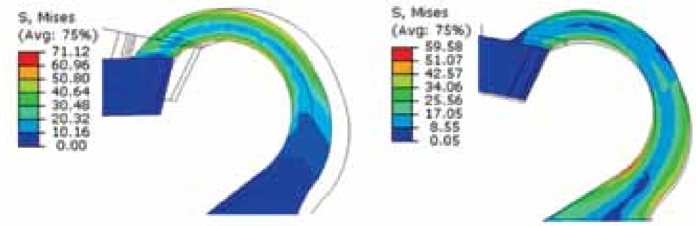


Figure 8 : Von-Misses Stress Distribution in the Flexible Hinge at the 2 Peak Time Points

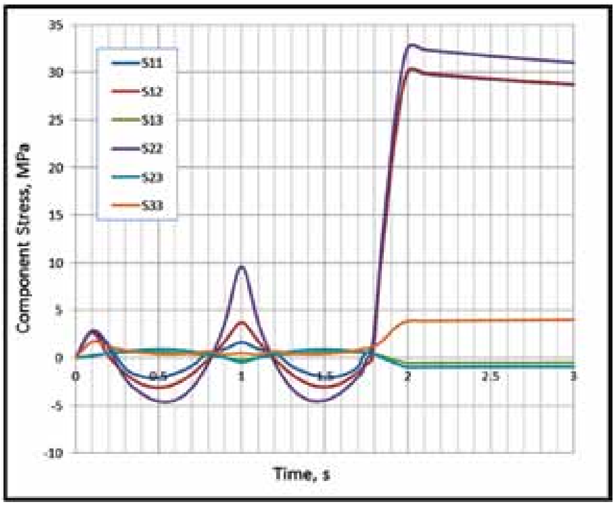


Figure 9 : Variation of Principle Stresses at a Life Limiting Location in the Flexible Hinge for the Loading Scenarios

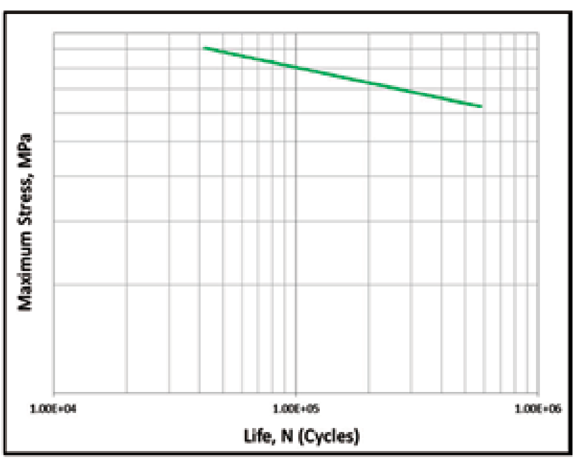


Figure 10 : Stress-life Data for Polysulfone from Testing

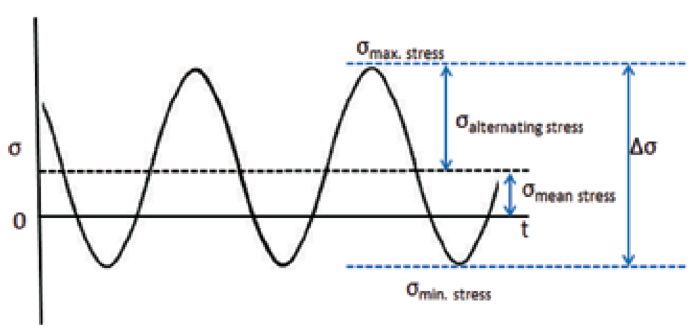


Figure 11 : Fatigue Cycle Definitions

the Goodman mean stress correction resulted in over estimation of life. It is predicted from the analysis that the component will be safe after 10000 cycles as per qualification test requirement.

Equations corresponding to the Walker method mean stress correction are represented in equations 1, 2 and 3.

$$\sigma_{ar} = \sigma_{max}^{1-\gamma} \quad \sigma_a^{\gamma} \qquad \dots \quad \text{equation 1}$$

$$\sigma_{ar} = \sigma_{max} \left(\frac{1-R}{2}\right)^{\gamma} \qquad \dots \quad \text{equation 2}$$

$$\sigma_{ar} = \sigma_a \left(\frac{2}{1-R}\right)^{1-\gamma} \qquad \dots \quad \text{equation 3}$$

Where,

σ_a is the alternating stress.

σ_m is the mean stress

σ_{ar} is the alternating stress when mean stress is zero (σ_m= 0)

Υ is fitting constant (material property)

To further validate these predictions, a simple test has been conducted, wherein the component is loaded as per boundary conditions used in the finite element analysis and it has successfully passed 10000 cycles. This verifies the approach and also built the confidence on the material model developed using MCalibration / PolyUMod. Fig. 12 presents the test setup used for performing the fatigue test on the flexible hinge using dynamic mechanical analyzer (DMA) machine from Bose.

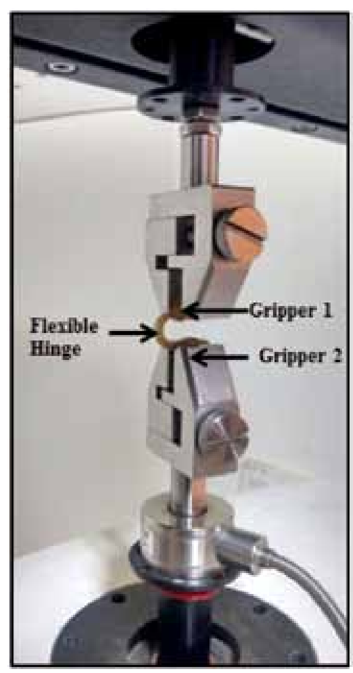


Figure 12 : Fatigue Test Setup

CONCLUSIONS

As shown in the study it is recommended to utilize appropriate viscoelasto plastic material models to accurately capture the instantaneous and time dependent response of the polymer through calibration and stability assessment prior to the finite element analysis. The demonstrated approach uses the unique Parallel Network Models in PolyUMod for subsequent stress prediction in ABAQUS. Predicted life using thermo mechanical analysis integrated with Walker mean stress correction yielded good correlation with test measurements, which verifies the methodology. This approach would be very useful to screen alternate materials and also to optimize the component design before going for actual testing thereby incorporating 'first time right' design.

Environmental Test Systems for Automotive Applications

Durability Test Solution

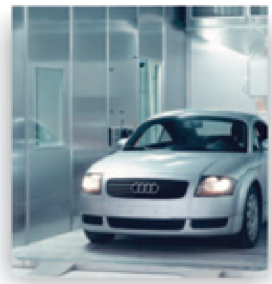
- ✓ Cold-Heat Climate Test Chamber with Road Simulator and Sunlight Simulation.
- ✓ Climatic Test Chamber with Multi-axis Shaker Table(MAST).
- ✓ Corrosion Test System with Vibration, Climate and Salt Spray.
- ✓ Endurance Strength Climatic Test Chamber.
- ✓ Thermal Shock Test Chamber.

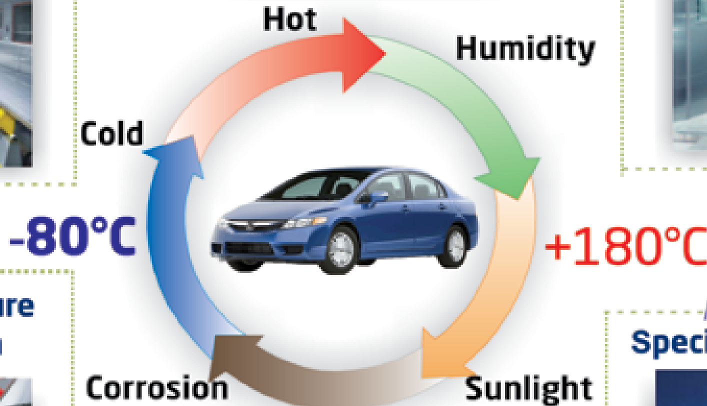
Performance Test Solution

- ✓ Climatic Test Chamber integrated with Dynamometer for vehicle testing.
- ✓ Altitude Simulation Test Chamber up to 3000 m above sea level.
- ✓ Cold-Heat Climate Test Chamber with

Emission Test Solution

- ✓ VT-SHED for measurement of Evaporative Emissions.
- ✓ Fuel Conditioning System for VT-SHED.
- ✓ Onboard Refuelling Vapour Recovery testing (ORVR).
- ✓ VT Mini SHED Chamber are used for permeation tests in fuel tanks or for HC emission tests in vehicle components carrying fuel.

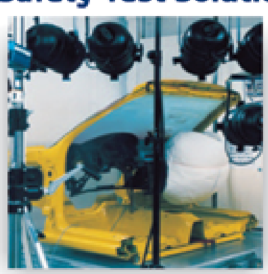




High Temperature Test Solution

- ✓ Ovens-reliable Heat Treatment Solutions for Automotive Components.
- ✓ Ovens for Heating, Drying, Curing of various car components like brake disk, gear boxes, sealing rings, gaskets etc.
- ✓ Continuous heating ovens integrated on a production conveyer system to optimize effective heat treatment process in Automotive production industries.

Safety Test Solution



- ✓ Airbag Testing Chamber integrated with climatic simulation.
- ✓ Climatic Chamber for Testing of safety components like brakes, Steering System, Power Train etc.
- ✓ Climatic Test for Belt & ABS, ESP etc.

Special Test Solution

- ✓ Climatic Test Chamber with integrated Measuring Robotic System for Haptic, Visual and Acoustic Qualities of Vehicle Cockpit Control Panels.
- ✓ Mobile Cold Hot Air Conditioning Mini-Station.
- ✓ Thermal Test Bench for testing and measuring the performance of Vehicle Air Conditioning Systems.

Environmental Simulation and air solutions for Functional Testing and Safety in the Automotive Industry...

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TESTING & INSTRUMENTATION

3D Scanning : Tool for Inspection & Benchmarking

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Amit Deshmukh, R. S. Mahajan
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INTRODUCTION

3D Blue Light Scanning is latest technology and has made progress in last few years. This advance technology of 3D Scanning and Inspection is becoming crucial tool for many applications like inspection of prototype parts & production parts to give results in very short time within very high range of accuracy. Also wherever required 3D CAD data can be generated from scan data. 3D Scanning tool can be used for all type of parts i.e. Plastic, Sheet Metal, Rubber, Casting, Forging etc. for different sizes of parts. ARAI Pune has started the 3D Scanning, inspection and CAD data generation services since 2015. The scanning technology used is of Non-Contact, Blue Light scanning done by Blue light scanner having camera and projector arrangement. This technology can be used for:

- 3D Scanning & Generating Point Cloud Data of the Object
- Data generated can be used for inspection of parts which gives comparison report for the Scan data and Design data of parts i.e. CAD data of the parts with the help of different inspection software
- 3D Scan data thus generated can be used for generating 3D CAD models of the objects
- Different software used for scanning are: Colin 3D, Inspection software Comet Plus,and CAD generation software Geomagic Design-X.

> *3D Scanning can be effectively used as Tool for parts/Prototype Inspection by comparing digitised scan data with design CAD data*

Scanning & CAD generation procedure:

3D Scanning Detailed process flow is given in below Fig. 1. It gives clear idea about the methodology for scanning procedure followed and CAD data generation steps

TYPICAL SCANNING SETUP

Scanning set up involves 3D Scanner Camera with Tripod stand, Rotary table for small parts scanning and Laptop for scan data processing. Rotary table has capacity for scanning of parts up to 110 Kg. Fig. 2 gives overall idea of the scanning set up.

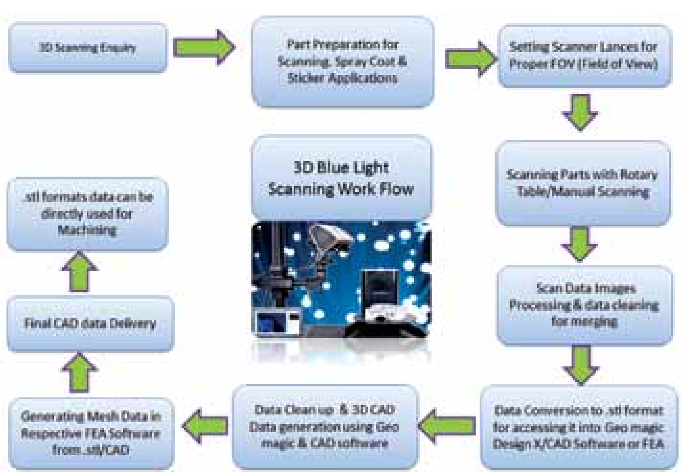

Figure 1 : Scanning & CAD Generation Work Flow

Figure 2 : Scanning Setup

SCANNING AS TOOL FOR QUALITY CONTROL

3D Scanning can be effectively used as Tool for parts/ Prototype Inspection by comparing digitised scan data with design CAD data. Below example gives overall idea about the inspection feasibility for deviations and same is given in colour plot. All types of parts can be inspected with the help of blue light scanner. Fig. 3 & 4 show colour plot for CAD/Design data comparison with physical model scan data.

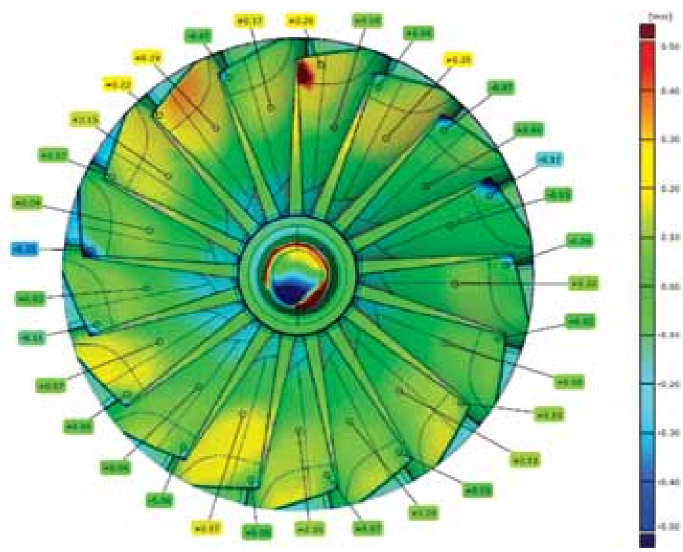

Figure 3 : Deviation Inspection

3D Scanning can be applied in following fields for variety of applications like Quality control, inspection of parts in very short time & CAD data generation where CAD data is not present :

1) Automotive
2) Aerospace
3) Consumer Appliances

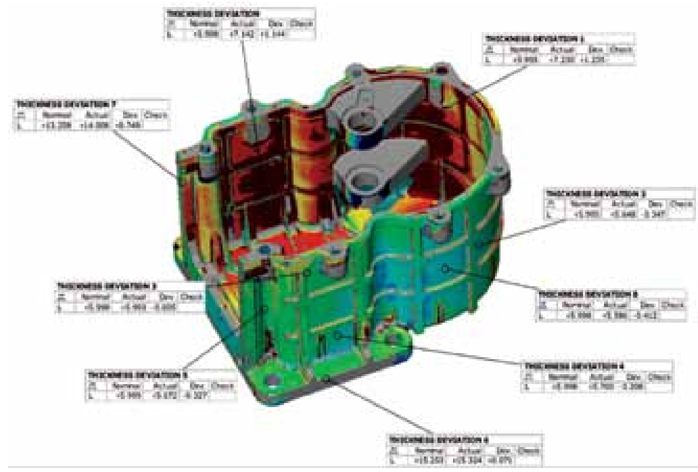

Figure 4 : Transmission Housing Inspection

4) Medical field
5) Railways etc.

VEHICLE LEVEL DIMENSION EXTRACTION AS PER SAE J 1100 (R)

SAE J 1100 (R) is Surface vehicle Recommended Practice for Motor vehicle dimensions. This SAE recommended Practice defines a set of measurements and standard procedure for motor vehicle dimensions. The dimensions are primarily intended to measure the design intent of a vehicle within a design environment (i.e. CAD). All dimensions can be measured this way. Dimensions can be measured with physical measurement tools but it will be very time consuming and relatively less accurate and highly dependent on skill set of operator.

In such case Scanning tool can be effectively used for measurement of the vehicle level dimensions as per SAE J 1100 (R). Vehicle level scanning is done for Interior and Exterior vehicle dimensions capturing, with all dimensions for ergonomics packaging study can be extracted from digitized scan data. It will give highly accurate measurements with less time compared to physical measurements.

Vehicle level scanning is done in different stages like: exterior Scanning for Overall vehicle level dimensions, Interior Vehicle scanning for capturing interior volume and inner details, Driver Co-Driver & Rear passenger ergonomic positions and dimensions. Fig. 5 shows the details of how scan data can be sued for getting ABC Pedal dimensions as per standard & with respect to Driver 'H' point. Similarly scan data gives exact dimensions & idea about the occupant position and different vehicle aggregates which defines the ergonomic comfort of all occupant. Below Fig. 6 & 7 give over all Idea about different dimensions extraction as per SAE J1100 guidelines.

1) Dimension extraction for PEDAL height & width in Plane N (Fig. 39-SAE-J1100)

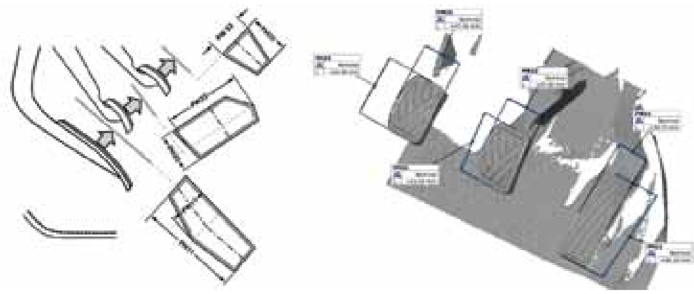

Figure 5 : Pedal Height & Width in Plane N

2) Dimension extraction for driver width accomodation (Fig. 29-SAE-J1100)

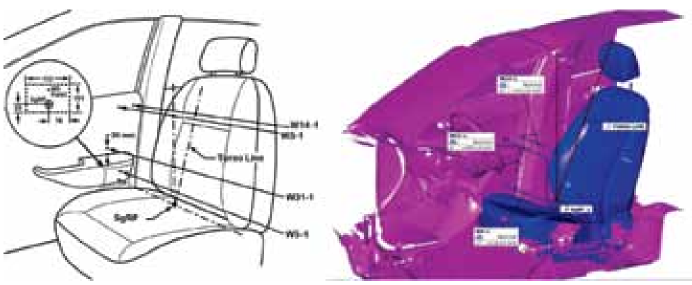

Figure 6 : Driver Seta Details

3) HMI measurement with driver @SgRP (Fig. 19-SAE-J1100)

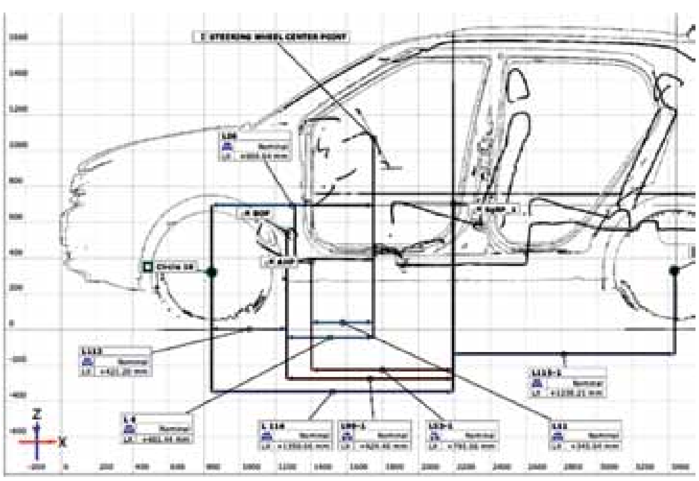

Figure 7 : HMI Measurement with Driver SgRP

3D CAD DATA GENERATION FROM SCAN DATA

3D CAD data generation from scan data i.e. point cloud or *.stl data is feasible with the help of different softwares like geomagic Design-X, UG,Creo-2 and catia V5. Accurate CAD data for lost design data parts as well as existing parts in developments for design modifications can be made with the help of scan data. High end Geo-Magic Design X software for processing the Scan point Cloud data in which processing of the Point cloud data for input to CAD generation like cleaning the data , remove the unwanted data from point cloud and create the final finished point cloud for CAD generation. This data then can be converted in CAD surface or solid data which can be imported in all CAD /CAE softwares.

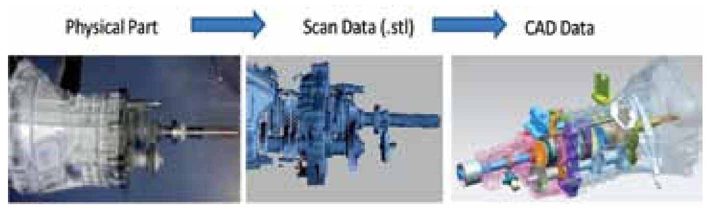

Figure 8 : Physical Part Scanning to CAD Generation

Fig. 8 show detailed scanning to CAD data generation work flow. Parts are scanned in assembly level and then individual parts are scanned and *.stl file is created which will be used for final 3D CAD data generation. CAD data thus generated can be used for Design modifications, 2D Drawings generation, GD & T analysis, FEA and 3D printing of the parts.


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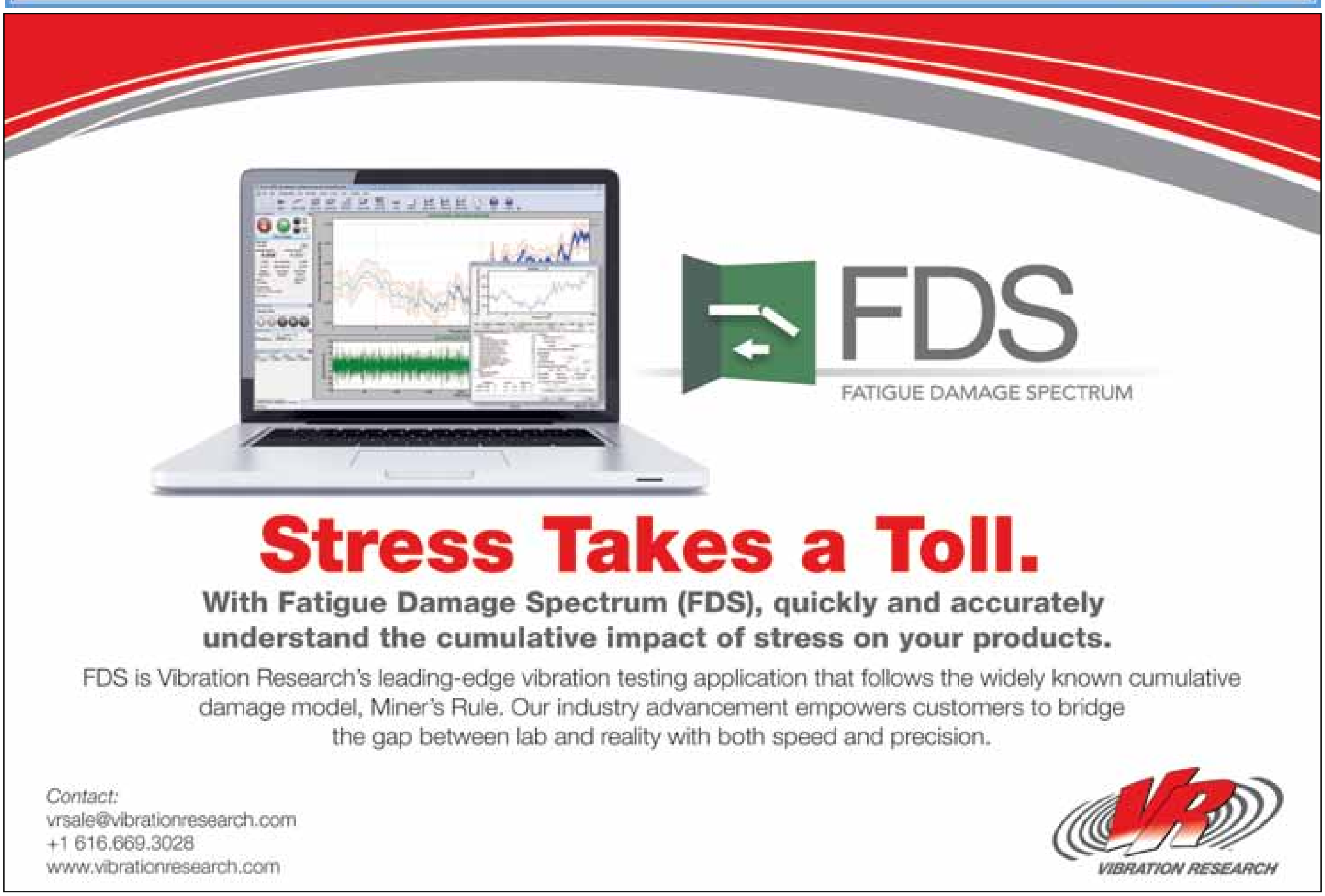
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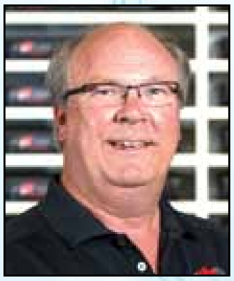
VIBRATION RESEARCH

Using the Fatigue Damage Spectrum for Accelerated and Reliability Testing, using FDS to Match Tests with End-use Environment



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BACKGROUND

Products in the field experience a wide range of vibratory environments. Running a test that incorporates these different vibratory environments would be more realistic that what is done in conventional situations.

The biggest challenge in assembly of such lightweight vehicles is the joining of metal formed components of different materials

Historically, random vibration tests were utilized to try to approximate the end-use environment. One of the shortcomings of random vibration tests is that random vibration tests produce a Gaussian waveform. This is problematic because real-life environments are not always Gaussian.

Another method sometimes used is to import a single time history file. Although this is a representation of the end-use environment, it is just that – a singular representation. The assumption, which is not valid, is that the product experiences only this unique time history throughout its life.

Repetitive Shock vibration tables (RS) produce high vibration and stress in a rapid series, high burst acceleration events. Although this is not representative of the end-use environment, it provides high non-Gaussian vibration. RS tests require a degree of knowledge to determine which failures are representative of the end-use environment.

An improvement of these methods is to try to combine multiple environments, while also considering the possibility that the real-life vibrations are non-Gaussian in nature. A method of trying to take all of these environments and experiences into consideration is to use a new tool called the Fatigue Damage Spectrum (FDS). Key questions to be considered and addressed are: Is it possible to design a test that accurately simulates the end-use environment of a product through its lifetime? Is it possible to confidently combine multiple, complex end-use environments into a single test profile? Is it possible to reliably accelerate a test and maintain an accurate simulation of imported field data?

ALTERNATE APPROACHES

Historically, random profiles have been generated using one of two methods. One method, called Average Import, the Fast Fourier Transform (FFT) of each block of data is averaged together to create a uniform average power of the test. In the other case, called Peak Hold, the FFT is based on the peak values of each block of data. These peak values are used to create the Power Spectral Density (PSD) plot. The problem with these methods is that they tend to under-test or over-test the product. In the Average Import method, the data is averaged resulting in reducing the effect of the very large peaks that will have significant impact on the product. This tends to under-test the product. On the other hand, the Peak Hold method tends to over-test the product. By using the peak values of the data across the frequency spectrum is to assume that the product is constantly being exposed to these peak values. In reality the product is only occasionally being exposed to these peak values.

When one compares the PSD of a data set using the FDS method to the PSD of the same data set when calculated using either the Average Import method or the Peak Hold method, one notices that the Peak Hold method over-tests the product while the Average Import method under-tests the product (Fig. 1).

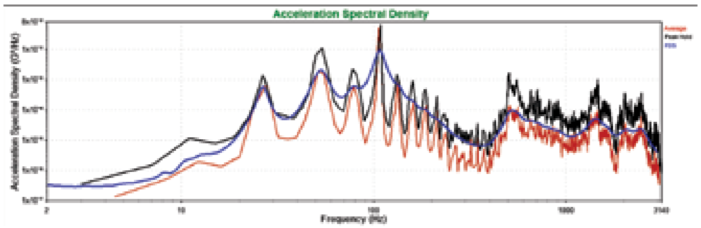

Figure 1 : PSD of a Data Set Plotted using Average Import, Peak Hold, and FDS Calculations

FDS METHODOLOGY

FDS Theory

Fatigue is the result of multiple repetitions of low-level stress applied to an object. Generally, fatigue happens in three stages: crack initiation; crack propagation; and final fracture. These three stages can clearly be seen in examples of aluminum beams that experienced various levels of fatigue during experimental testing (Fig. 2-4).

Figure 2 : Crack Initiation

Figure 3 : Crack Propagation

Figure 4 : Beam Fracture due to Fatigue

All structures experience fatigue as they are repeatedly exposed to adequate levels of stress. The FDS is based on Miner's Rule of Damage, which teaches that fatigue damage will accumulate over time until it reaches a level that causes a crack or other deformation of a product. So, regardless of how a product arrives at its life-dose of fatigue damage (ie: quickly or slowly), the product will experience a failure mode when it reaches its life-dose of fatigue damage.

A FDS is produced in the following way (Fig. 5).

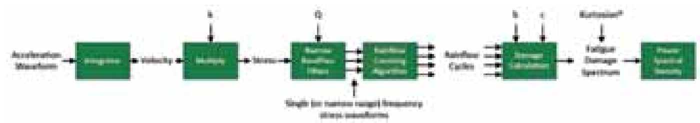

Figure 5 : Fatigue Damage Spectrum Calculation Flowchart

First, a PSD data file (acceleration waveform) is converted to a velocity waveform by an integration process. The original acceleration waveform is converted to a velocity waveform because the Henderson-Piersol method of calculating fatigue originally based their calculations on using a velocity waveform. They did so because it had been argued that stress (causing fatigue) is proportional to velocity. As true as that may be, Vibration Research Corporation has recently demonstrated that the PSD produced from the Fatigue Damage Spectrum calculation will be the same whether the Fatigue calculation is made based on acceleration, velocity, or displacement (Fig. 6-7). The reason this is true is because the final PSD is ultimately an equivalency of two waveforms. So whether the two waveforms during the process of calculating the PSD are acceleration waveforms or not, the plot showing the equivalency of the two acceleration units would be

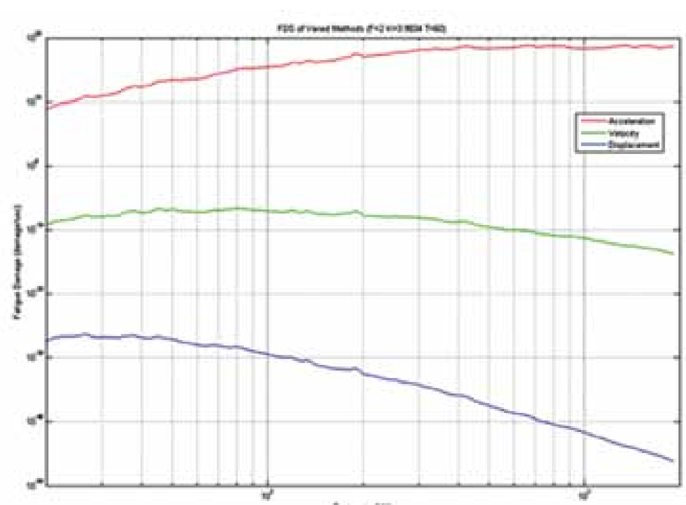

Figure 6 : Fatigue Damage Spectrum Calculated based on Acceleration, Velocity and Displacement Waveforms

the same as if the plot was showing the equivalency of two displacement or two velocity waveforms.

Secondly, the converted PSD data is run through a narrowband filter, utilizing a specific Q value (related to the sharpness of the resonance). Then a specialized calculation tool is used to determine the fatigue damage for the data filtered for each frequency band. This is accomplished by using a Rainflow counting algorithm to count the stress peak-valley cycles (Fig. 8).

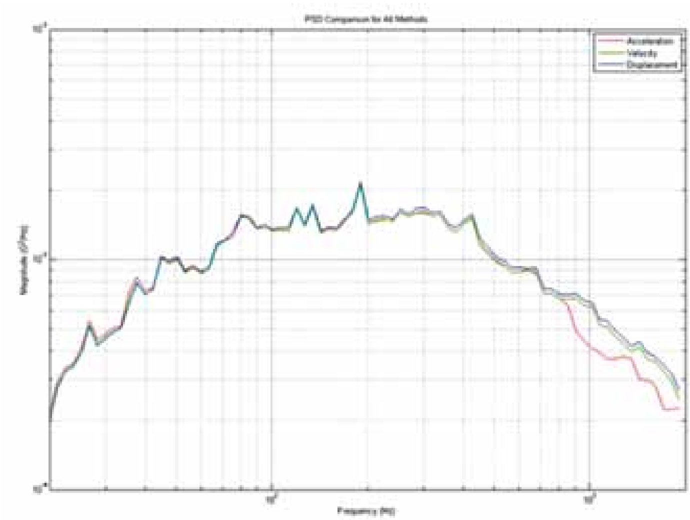

Figure 7 : PSD calculated based on Acceleration, Velocity, and Displacement FDS calculations. No matter which FDS method was used the final PSD was the same.

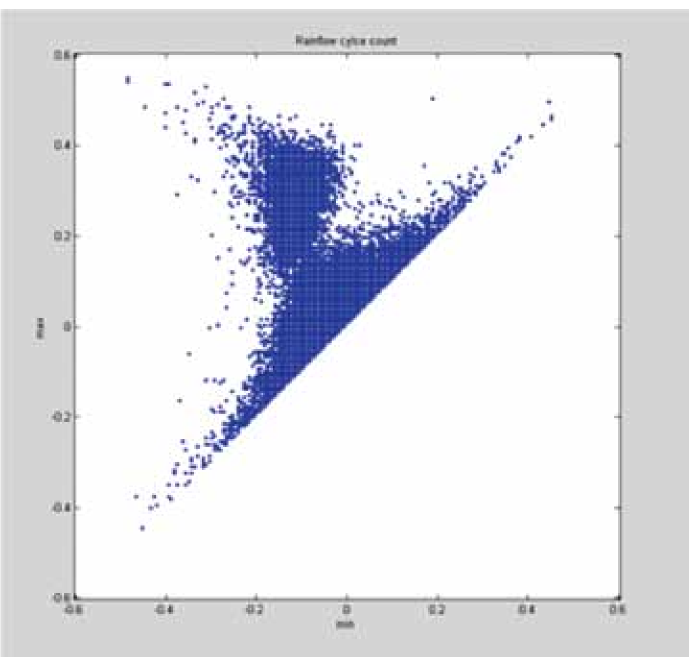

Figure 8 : Rainflow Cycle Count for a Data File from GM (E_01)

The stress cycle amplitudes are weighted non-linearly, because of the power law function found in Miner's rule ($N = cS^{-b}$). "The most commonly used method for calculating a reduction in test duration is the Miner-Palmgren hypothesis that uses a fatigue-based power law relationship to relate exposure time and amplitude". These cycles are accumulated to get the accumulated fatigue at that specific frequency, according to Henderson-Piersol's fatigue calculation method. At this point, since the Q of the resonance has been specified, as well as the "b" value (assumed to be the slope of the S-N curve for the material composing the Devise Under Test (DUT)), the fatigue damage value for each frequency can be calculated. The collective plot of all of these fatigue damage values is the FDS (Fig. 9).

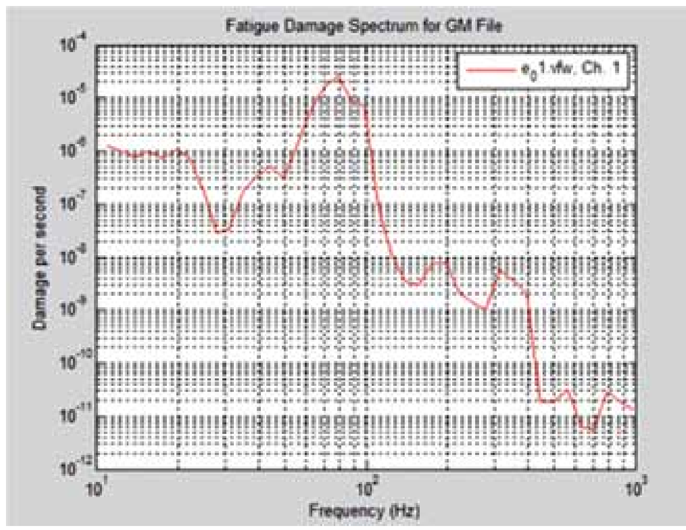

Figure 9 : Collective FDS Plot for GM Data File (E_01)

Water Bucket Analogy

To explain Fatigue Damage and the Fatigue Damage Spectrum in a different way, consider a "water bucket" analogy. The FDS is a plot of the amount of fatigue at every frequency in the spectrum that will bring the product to failure (Fig. 10).

That is, the total life-dose of fatigue for the object under test is the area under the FDS curve. To help visualize this

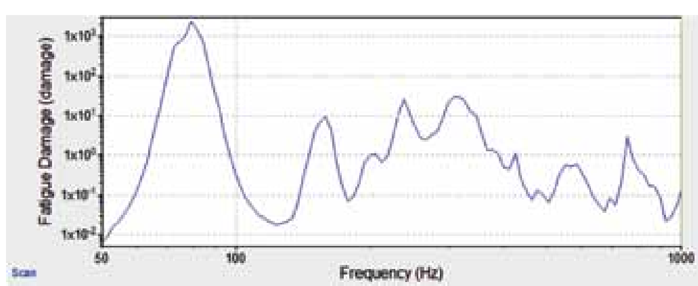

Figure 10 : Typical FDS Plot

idea from a different perspective, imagine if we flipped the plot upside-down. The inverted FDS plot is akin to a "bucket". If we fill the bucket with water (fatigue) then the object under test will be brought to failure when the bucket becomes full (life-dose of fatigue). The total life-dose of fatigue is represented by the amount of water needed to fill the bucket (Fig. 11).

Figure 11 : Inverted FDS Plot (Bucket) Filled with Life-does of Fatigue (Water) at Every Frequency

Now to accelerate the test (i.e. to bring the product to failure more quickly), we simply need to fill the bucket with water more quickly. The FDS test accomplishes this by applying a higher level of GRMS to the test. The goal is not to add more water to the bucket (increasing the amount of total fatigue), but to change the rate at which the water is added to the bucket (increase the rate at which fatigue accumulates).

METHODOLOGY DEMONSTRATED

Using FDS to Match Test to Environment

The Fatigue Damage Spectrum is a useful tool to evaluate the appropriateness of a test. Sometimes a test may not match very well to the environment. The FDS plot is helpful in evaluating the effectiveness and appropriateness of a test.

For example, an RS table is not always the best tool to conduct an appropriate test. Using the water bucket analogy, an RS table provides little control over how the buckets are filled. Ensuring the RS test is comparable to the end-use environment may require overflowing some buckets to ensure all the buckets are filled. Matching the test to the environment is critical. In this example the RS table would be a poor substitute as the majority of the damage in the end-use environment is below 100Hz (Fig. 10), while the RS table is applying the majority of the damage to the frequencies above 100 Hz (Fig. 12). Although an RS table is effective at higher frequencies where failures are caused by small components and leads with high resonant frequencies, it is not appropriate in every circumstance - as illustrated in this example.

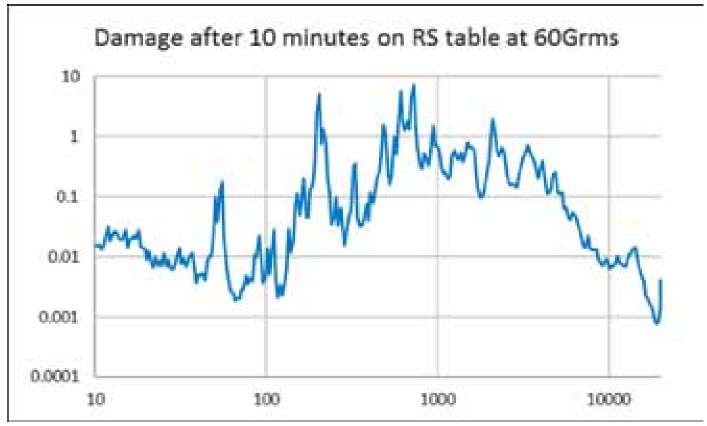

Figure 12 : Data from a Test on an RS Table

Reliably Simulating End-Use Environment with FDS

To illustrate how to create a random profile we utilize a data set from General Motors Corporation (GM). If the data set is imported into the Random Fatigue Damage Import with specified m (a material property value) and Q values, then a PSD and break-table can be created – generating a Random profile.

To illustrate that this new Random profile (generated from the imported recording using the Fatigue Damage import) simulates the end-use environment, the new random test was recorded for the same amount of time as the original recorded file. When the FDS of the originally imported GM file is compared to the FDS of the recording of the new Random profile, it is clear that the FDS plots are the same. This is shown as the original and simulated FDS plots of GM file D_01 are overlaid (Fig. 13). These plots show that a new Random profile produced using Fatigue Damage import can simulate the end-use environment (original GM file).

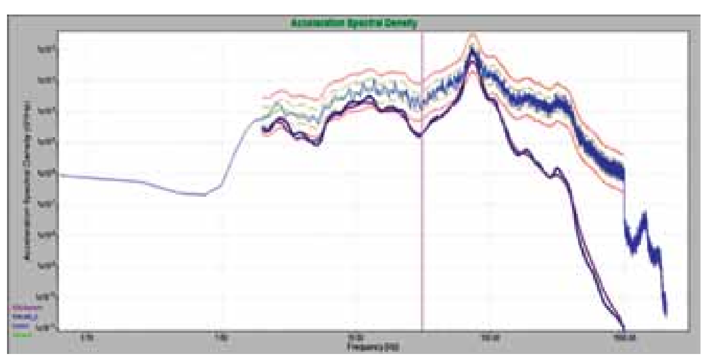

Figure 13 : FDS of Original GM File (D_01) and FDS of Recording of the Random Profile Generated from D_01. Note that the FDS Plots are very Similar, Indicating the Ability to Simulate an End-use Environment

Combining Multiple Vibration Environments

As previously demonstrated, a random profile can be generated to simulate the end-use environment of a product. However, a product often will experience vibrations in a variety of settings. It may be desirable to combine all of these experiences into one simple test. To illustrate how this can be accomplished, a set of thirteen recordings from GM were used. Each one of the thirteen recorded files was individually imported into the same FDS Import profile and combined to form a single PSD spectrum and break-table. In order to do this each loaded file must be given a Target Life. The Target Life values given in this example are pre-ordained values provided from GM based on their experience of how often such vibrations occur in the field (Fig. 14).

INPUTS		
FILENAME	REPETITIONS	Dyanmic amplification, Q = 10
A	400	Spring stiffness, K = 1
B	90	SN coefficient, A = 1
C	100	SN coefficient, C = 1
D	2000	SN exponent, b = 4
E	4000	
F	16	
G	200	
H	200	
I	8	
J	1800	
K	1200	
L	1800	
M	1600	

Figure 14 : GM's Thirteen Files with Specified Number of Repetitions Needed to Simulate Life-dose of Vibrations.

The combined value of all the Target Life values is approximately 603 hours. In order to accelerate the test, the Test Duration was set for sixteen hours (Fig. 15). From this example, using GM's thirteen files of different end-use environments, it can be clearly seen that test engineers can seamlessly combine many different test environments into one random vibration test.

Accelerating the Test

Not only do test engineers want to create random vibration tests that simulate the end-use environment, including the combination of many different end-use environments, but test engineers also want to be able to accelerate their vibration tests. Using FDS there are two ways to accomplish this goal.

Using FDS to Accelerate a Vibration Test:

As seen in the previous example, the vibration test can be accelerated by changing the Test Duration value to

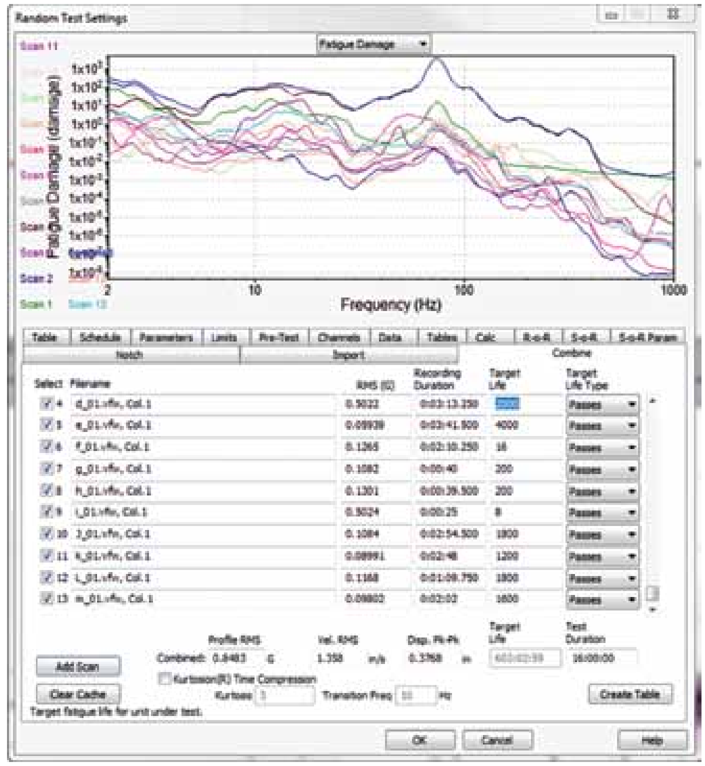

Figure 15 : The Test Duration for the Combined Thirteen Files is Set for 16hrs. When Accelerating the Test from 603hrs to 16hrs, the GRMS Increases from 0.3424G to 0.8483G

value smaller than the Target Life value. This results in an increase in the GRMS value for the tests. Essentially, the test is accelerated by increasing the GRMS in an intelligent manner. Other methodologies attempt to accelerate the test by increasing the GRMS value also, but they do not have the realistic calculation algorithms that are unique to the FDS calculation methodology.

Using Kurtosion® with FDS to Accelerate a Vibration Test :

The original Fatigue Damage Import of a file assumes a Gaussian distribution of the data. This is because the Henderson-Piersol method of computing Fatigue converts the FDS back into a PSD using a Gaussian distribution. By doing so, some of the large peaks that cause fatigue damage are removed from the test. Kurtosion® restores those large peaks to the test, making the distribution of the data to be non-Gaussian. The presence of the large peaks will cause the fatigue damage to accumulate more quickly. The total life-dose of fatigue is not increased, however (Fig. 16). The total life-dose of fatigue is simply accumulated more quickly.

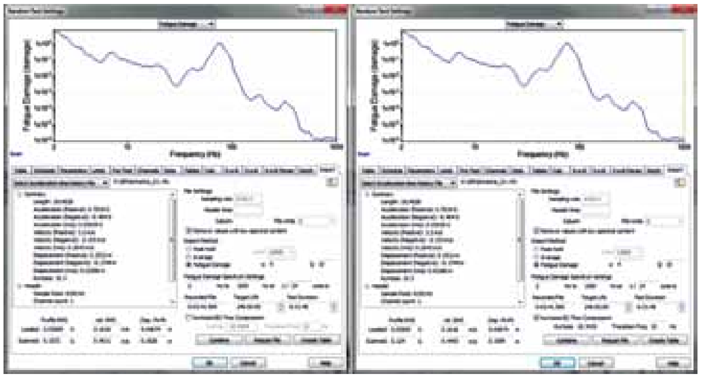

Figure 16 : The PSD and GRMS of the Imported GM E_01 File Using the FDS Import, When Target Life is Set for 246 hrs and the Test Duration is Set for Approximately 6.5 hrs. The figure on the Left is FDS Import without Kurtosion®. The Figure on the Right is the FDS with Kurtosion®. Note How the FDS Plots are Identical – Indicating That the Total Life-Dose of Fatigue Remains the Same Whether or not Kurtosion® is Enabled. Note also, that the GRMS Value Actually Decreased with Kurtosion® Enabled

Limitations of Methodology

As with all techniques, the FDS methodology has some limitations. One of the most important limitations centers on the material property value “m” that is used in the Fatigue Damage calculation. MIL STD 810 G offers a recommended “m” value, but it is best if the material properties of your DUT are known. Changes in “m” value can have significant impact on the FDS.

Secondly, the reliability of the FDS methodology is limited by the test engineer’s choice of files that are imported to create the PSD. Poor selection of files or an inaccurate “weighting” of the files will influence the FDS.

Finally, the FDS methodology is limited by the test engineer’s choice of “target life”. An inaccurate “target life” will wrongly set the FDS level.

CONCLUSION

Test engineers want to test a sample product to simulate a life-dose of fatigue. But to do so, using traditional methods can be long and tedious and can lead to either under-testing or over-testing of the product. But with a new Fatigue Damage Import methodology, the life-dose of fatigue for a product can be accurately simulated and rapidly accelerated.

This paper has shown that end-use environments can be compared to test environments using FDS to find a test that is suitable to the expected end-use environment. The test environment does not need to be representative of the end-use environment; it is sufficient to meet or exceed the measured damage. A test environment must simply be capable of damaging the product in the same frequency ranges as the end-use environment.

In addition, a realistic simulation of an original waveform can be successfully generated with random vibration’s Fatigue Damage Import feature.

Furthermore, the multiple environments that a product experiences on the field can be combined into a single fatigue damage test. In this way, the life-dose of fatigue of all possible environments can be combined and synthesized to produce a single random vibration test profile.

Finally, using the Fatigue Damage Import feature the life-dose of fatigue for a DUT can be achieved in a faster test time. In other words, random vibration tests can be accelerated using the Fatigue Damage Import by ultimately increasing the GRMS. Since the regular Fatigue Damage Import produces a Gaussian random vibration test, Kurtosion® can be added to the test to make a test have a non-Gaussian distribution. Adding Kurtosion® to a test does not increase the total fatigue damage experienced by the DUT, but simply causes the fatigue damage to accumulate more rapidly, without an increase in GRMS.

The Fatigue Damage Import feature of a random vibration test is a valid and innovative method to reliably achieve a life-dose of fatigue test and to accelerate random vibration testing.

■■■

Accelerated Structural Durability Evaluation of Chassis Mounted Components & Aggregates using Multi-axial Test Rig

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INTRODUCTION

Vehicle and component manufacturers are striving together to deliver a product which will perform exceptionally in any environment. For this, study of vehicle / sub-system performance and durability testing, as an aide in vehicle optimization,becomes very important. Vehicle and component level structural validation is carried out by running complete vehicle on proving ground or by carrying out in-lab standard sinusoidal testing as per defined design loads or by replicating actual field data using simulation technique as per customer usage pattern. Simplified approach of single and bi-axial testing with constant amplitude or block cycle loading is commonly used for durability testing. This simplified testing approach is well suited for the components where the loading directions are known. However in real field applications, vehicle and most of the components are subjected to random multi-axial loads. In this case traditional way of single or bi-axial testing may not create effect of simultaneous inputs & contribution of forces coming from all directions, which is major contribution factor in vehicle / component level damage. To meet this requirement& provide realistic replication of forces, concept of multi-axial testing is implemented.

Structural Dynamics Laboratory (SDL) of ARAI has developed customizable test rigs for carrying out structural durability testing of chassis mounted components in all three axis and modes irrespective of component size, mounting and orientation. This facility is extensively being used by heavy/ light commercial vehicle and component manufacturers for accelerated durability testing of chassis mounted components and cabins. This testing methodology provides precise control over the governing forces in an accelerated &controlled environment.

> *"This testing methodology provides precise control over the governing forces in an accelerated &controlled environment"*

MULTI-AXIAL TEST FACILITY& REQUIREMENTS

This customized test facility developed at SDL, ARAI consists of servo hydraulic test setup comprising of high performance rectilinear actuators, performing simultaneously to provide vector based motion for translational and rotational modes. Multi-axis test rig has actuators in vertical, lateral & longitudinal direction. Loading position and total numbers of actuators required for test are generally finalized considering loading path to the test component and objective of the testing For typical Heavy Commercial Vehicle (HCV) 6 DOF cabin test, setup configuration consist of total seven actuators, four invertical, two lateral and one in longitudinal direction to simulate the real time field data in X, Y & Z direction. In this case chassis frame is considered as mounting fixture both for actuator attachments and test components. Flexibility of placing the actuators and use of the actual chassis frame rather than additional fixtures proves advantageous for testing of variety of test components.

The test facility is capable of carrying out real time lab simulation of field data acquired on identified test components. Instrumentation and test matrix for field data acquisition is finalized jointly with the customer in such a way that it will encompass all the possible load cases the vehicle / component will experience over its lifes pan. Few instrumented channels are also selected for measurement of critical strain levels and acceleration levels for optimization of simulation results. Extensive data analysis is performed well before carrying out the actual drive file creation activity in terms of statistical, spectral parameters as well as rain flow, potential damage, level crossing etc to understand the data and correlation in between different components. Similar instrumentation is then mount on test components on multi-axial test rig for drive file creation activity. Multi-point, non-square type of Frequency Response Function (FRF) measurement is carried out on the test rig to decide the methodology for drive file creation for each type of field input data. The rig is designed to carry out structural durability testing for data with frequency content up to 50 Hz. Normally by using multi-axial test rig & simulation methodology, we could able to get good correlation to with field data and achieve test compression factor of 20 to 25 times in comparison with actual duty cycle to accelerate the test.

VERSATILITY OF TEST SETUP

Multi-axial test facility developed at SDL, ARAI is used for variety of applications. Use of actual chassis helps to maintain correct stiffness and enables the test components to be oriented as in actual condition, rather than being supported by additional fixtures. Depending upon the requirement of total weight, type of component, frequency response etc, most suitable type of actuators &servo-valves can be selected.

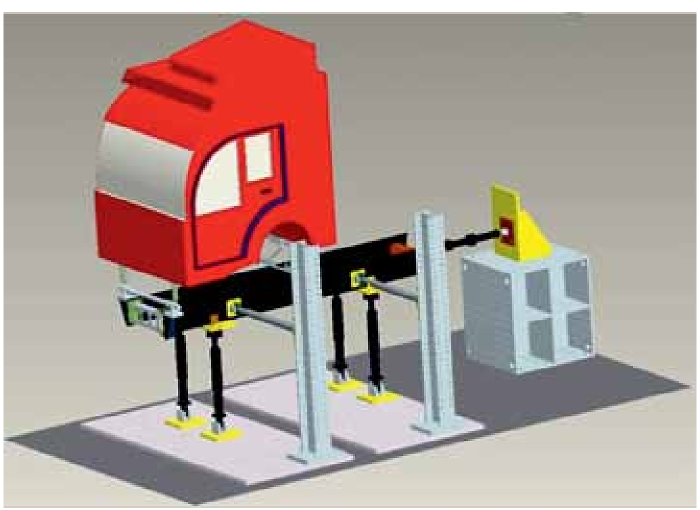

Figure 1 : Test Rig for Cab

This setup has already been proven for accelerated structural durability testing of variety of commercial vehicle, off-road backhoe loader vehicle as well as for simultaneous durability testing of chassis mounted test components such as spare wheel, battery mounting brackets, fuel tank, Exhaust system, Air intake system, muffler, cooling module, lamps, bumper etc.

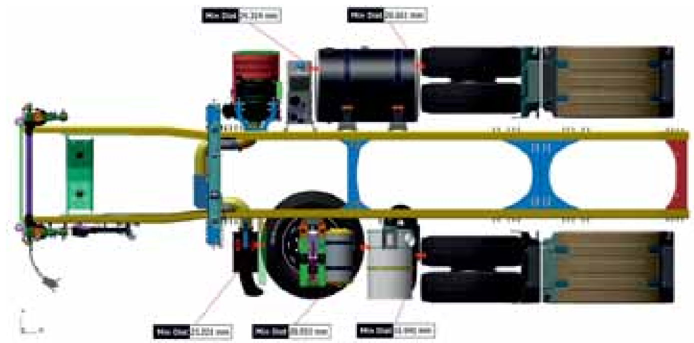

Figure 2 : Various Components Mounted on Chassis

Test rig is used for creation of drive file for acquired field data (acceleration, strain gauges, loads, displacement etc) using in-lab simulation technique. It accurately simulate the desired acceleration / strain of field data less than 10% SD error in the selected control channels. Another advantage one can achieve using this methodology is to accelerate the testing time by removing non-damaging part from the final drive file. Based on the initial data acquisition files and damage levels achieved on the rig by simulating the desired files are compared to achieve data compression retaining 95% of damage. Thus by using these cases, vehicle system's performance and life can be tested successfully.

Following are the few case studies provide insight of the facility and competency developed at ARAI:

CASE STUDY 1

Multi-axial structural durability test for Chassis mounted components

A Heavy Duty commercial vehicle manufacturer has approached to ARAI with the objective of validating various chassis mounted components. The paramount challenge for the OEM was to complete the validation of these parts in the shortest time frame with a realistic approach, also include design changes for components which have failed on the proving grounds before they are mass produced. To address these testing requirements, it was decided to finalize the duty cycle of the Vehicle as a whole. Finalization of parameters and location of sensors were finalized jointly with customer and accordingly instrumentation using suitable sensors such as accelerometers, strain gauges were carried out on identified test components. Activity of Road Load Data Acquisition (RLDA) of instrumented vehicle was carried out on selected torture tracks to measure vibration and strain levels to understand the transfer path. Data was acquired with 2 repeats to capture the repeatability scatter and also at different payload

Figure 3 : Chassis Mounted on Actual Test Rig

conditions. Acquired data was later processed and analyzed in terms of statistical & spectral parameters. During data analysis it was observed that forces in lateral as well as vertical directions contributed significantly in production of stress in the study components. Dominant Frequency causing major damage different vehicle components were between the ranges of 0 to 50 Hz with peaks observed at certain frequency level as given below:

Table 1 : Frequency Range of Components

Component	X axis	Y axis	Z axis
Muffler	2 & 16Hz	6 & 10Hz	2Hz
Spare wheel	2 & 24Hz	2 & 15Hz	2Hz
Fuel Tank		6 & 16Hz	2 & 22Hz
Battery Box		6, 17 & 19Hz	2, 17 & 19Hz

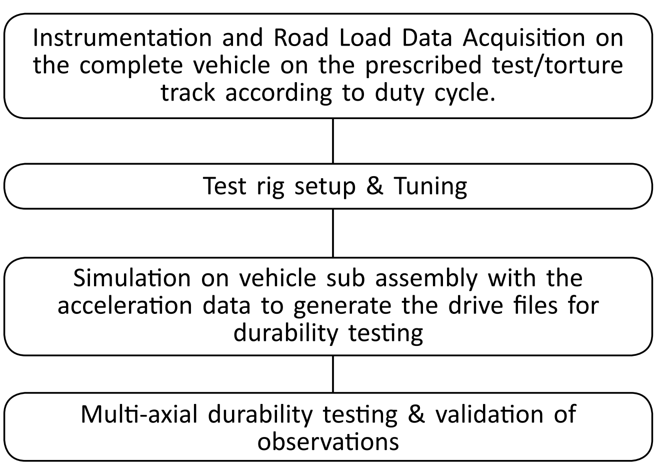

Figure 4 : Flowchart of Activities

Accordingly multi-axial setup was prepared with total 7 actuator. Test components such as spare wheel, bumper, air cleaner, battery bracket, fuel tank muffler etc. were mounted at its original position on chassis and then same complete length chassis was used for testing. Actuators were attached at most suitable locations and using mounting fixtures. Fixtures were designed and actuators were used in such a way that it allows all 6

Figure 5 : Fixtures & Actuator

degrees of freedom for movement during the test so that realistic replication of field data is possible. Similar instrumentation was mounted on all the test components to measure feedback data during in-lab simulation activity. Selected channels were bifurcated as control and monitoring channels using system FRF and coherence between the parameters. Objective was made to achieve optimal replication of field data for given frequency range. Suitable drive file was generated for each type of track/test condition and durability test was carried out with the finalized test recipe jointly decided by ARAI and customer. Failure observed during the durability testing were reported and the OEM compared the same with the failures observed from actual field testing which were found to be identical.

The Typical results of the simulation done on the existing seat for acceleration data is shown in Fig. 6.

Accelerated durability test for 200 hours was decided and carried out to simulate the design life of the test components. By using this methodology we were able to deliver and meet following objective :

- Developed simplified durability testing methodology keeping the same mounting location and stiffness of the test parts
- Drive files for durability were created using actual field data which ensures realistic way of testing

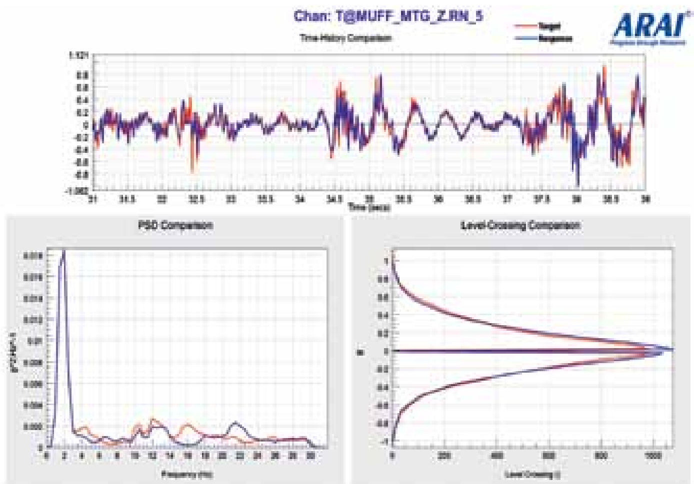

Figure 6 : Test Data

- Establish correlation for failures/test duration between lab test and on field
- Simulation testing of all chassis mounted components with very good level of correlation with actual field data
- Testing time was reduced significantly by removing non-damaging parts and retaining @95% of damage. Durability of @200 hours was carried out in 20 days of time including failure rectification, replacement etc.

CASE STUDY 2

Cabin Shake Test for Excavator

An Off-road vehicle manufacturer has decided to validate the design of a new, cost efficient Cabin of Excavator against a benchmark moniker. The use of 6 DOF Multi-Axis Test Rig was found suitable. Primary concern for the OEM was to observe performance of the rubber mounts at transmission joints and sturdiness of the cabin pillars. On the basis, it was finalized to use the chassis along with cabin and powertrain assembly for multi-axial testing. The excavator with benchmark cabin was instrumented with suitable strain gauges and accelerometers at the critical locations by ARAI on the basis of CAE data provided by the OEM. Further, Road Load data was acquired by ARAI on the OEM's test track performing tasks pertaining to its operational duty cycle. These tasks were then given priority as some occur often compared to others. Data acquired was then validated and concentrated covering all instances of high damage levels. Meanwhile, test setup with suitable actuators placed at appropriate positions to compliment the geometry of the vehicle, was being prepared. Being an off-road activity, dominant frequency for all tasks wasup to 40 Hz for all major channels.

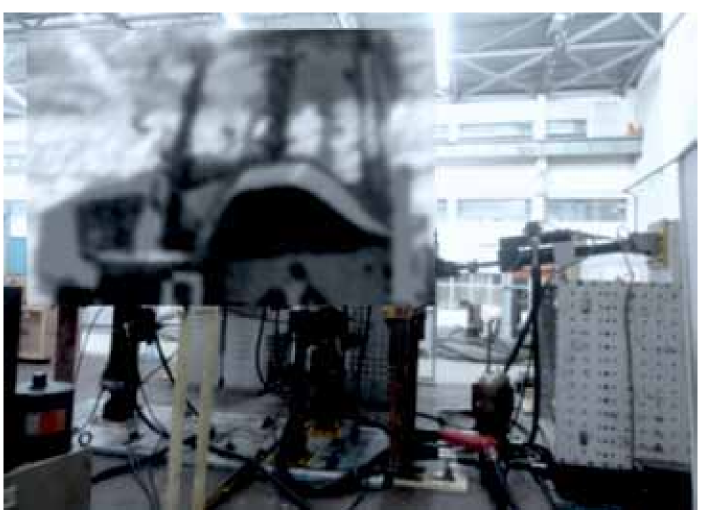

Figure 7 : Cabin Shake Test Setup

However the governing forces varied in direction and magnitude for every off-road task, resulting in different approaches to achieve good correlation for in-lab simulation. Simulation activity was carried out primarily in the band of 0.5 to 50 Hz. All control channels were simulated with good correlation using benchmark cabin. After summarizing the simulation results, a compressed durability matrix for 400 hours was devised. New-cost effective specimen was then installed and durability test was carried out for given duration. Typical simulation results are as shown in Fig. 8.

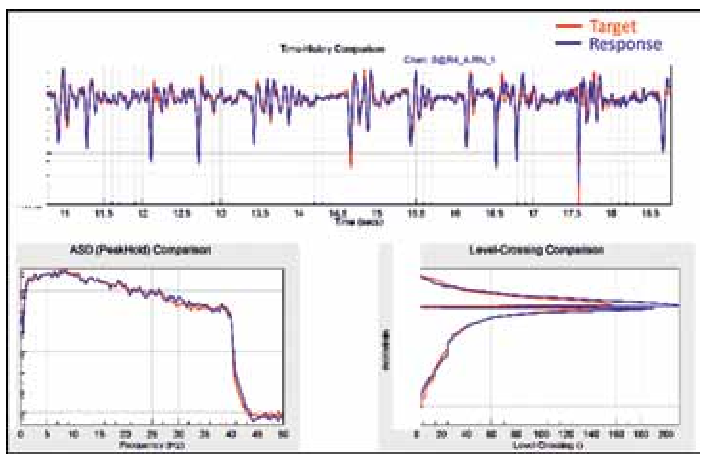

Figure 8 : Test Data

Simulation results shown above are showing good correlation at the dominant frequencies which was spread uniformly throughout the frequency range.

Failure observed were logged and intimated to the customer on a regular basis. Following this approach, some conclusions could be made:

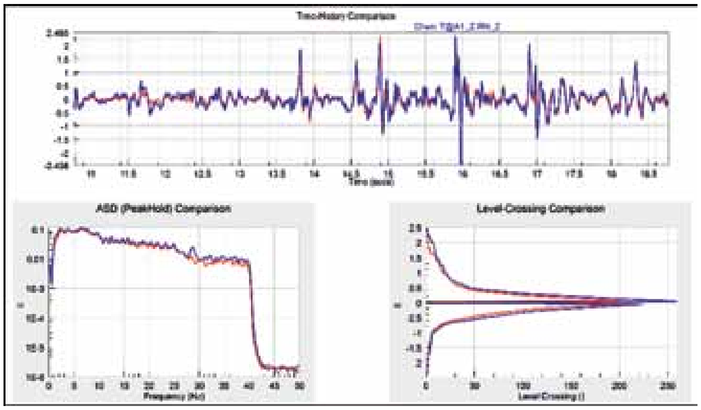

Figure 9 : Test Data

- Static Loads on rubber mounts were same as on field (by retaining complete assembly), hence performance on rig was very realistic.
- Comparison of failures between the proven and new designs could be made within a span of 40 days.
- Areas of design improvement (in the new cabin) were made clear after completion of test.

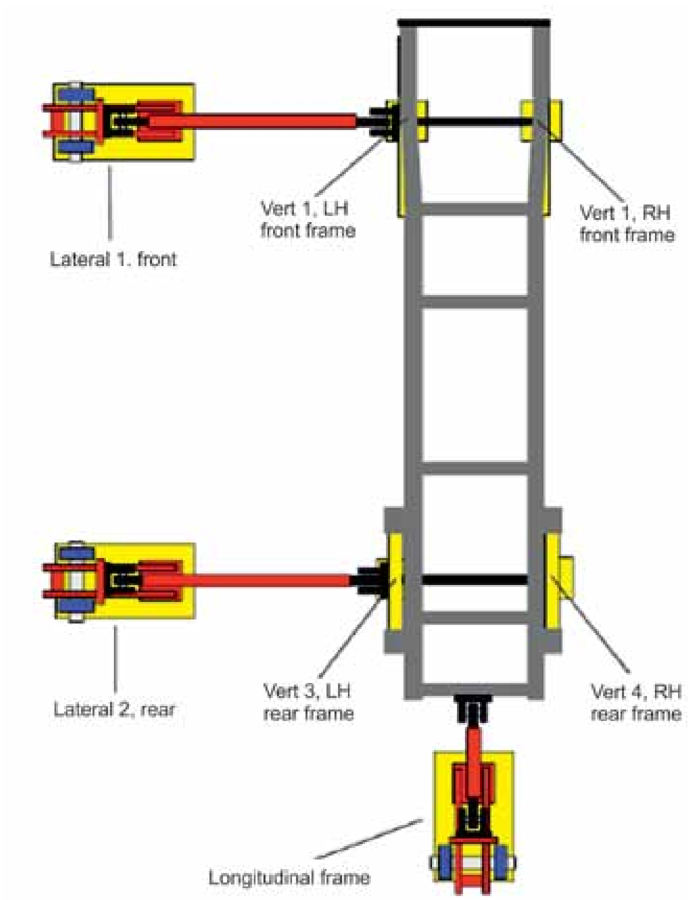

Figure 10 : Test Setup for Chassis

6 DOF multi-axial Servo Hydraulic simulation facility is available with SDL ARAI is having following technical specifications

Foot-printsize	:	Adaptable According to the vehicle dimensions
Max pay load	:	Based on actuators (Z : 4 actuators of 100 kN, Y : 2 actuators of 50 kN, X : 1 Actuator of 25 kN)
Degree of Freedom	:	6 DOF
Frequency response	:	50 Hz
Mounting	:	Fixtures coupled directly to Chassis
Excursion Specification	**:**	
• Max Displacement	:	+/- 120 mm
• Max Velocity	:	+/- 1.67 m/s
• Max Acceleration	:	+/- 11 g

CONCLUSION

Multi-axial simulation and durability using 6 DOF Servo Hydraulic Test Setup - is a versatile test approach for improving product reliability, reducing warranty costs and increasing customer satisfaction. This approach helps to gain competitive advantage over other products with the major benefits as listed below:

- Reduced product development time when product flaws are discovered early by performing multi-axis test prior to going for Design/Product sign-off.
- Increased Operating margin which directly results in improved reliability and reduction in majority of field failures.
- Multi-axis test results could be used for prediction of Actual Failure Rate.
- Verification of components on this can be useful to demonstrate reliability of multiple solutions and choose the one that best fits the design and company needs.

SKILL DEVELOPMENT

Advance Learning Method for Millennials

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INTRODUCTION

Businesses and organizations are not what it used to be a few years back because of the digital revolution. Almost every dimension of business has been significantly affected by the digital wave. In order to sustain, organizations need to be flexible and updated. The organization's workforce has to be well trained and new skills need to be acquired and mastered for the problems unknown in the ever changing business environment. Moreover, the millennials (those born between 1982 and 2000) are taking over the workforce pretty rapidly (Fig. 1).

> *"Microlearning events delivered in mobile devices seem to be the best foot forward in knowledge and skill enhancement"*

TRADITIONAL TEACHING METHOD

A Teaching Method comprises the strategies and methods which can be used for teaching by teachers/faculty to achieve the desired learning in students. These strategies are determined partly on subject matter to be taught and partly by the nature of the learner. For a particular teaching method to be effective and efficient, it has to be in relation with the nature/aptitude of the learner. The students should learn from fundamentals to applications in the classroom and from application to fundamentals outside the four walls of the classroom to create an appropriate balance. The traditional lecture is a method, where the teachers impart knowledge to students through verbal/visual communication. It gives full play to the teacher's leading role. But it loses the learning initiative and creativity. Challenge is to make lectures more effective and interesting, which will make assimilation of knowledge effective.

Figure 1 : Users with All Types of Digital Devices to Use Micro-Learning

Learning styles of most of the engineering students and teaching styles of most of the engineering professors are incompatible in several dimensions. Many of the engineering students are visual, sensing, inductive, and active whereas teaching style of most of the engineering professors are auditory, abstract (intuitive), deductive, passive, and sequential. These mismatches lead to poor student performance, professional frustration and a loss to society of many potentially excellent engineers. Few major limitations of traditional teaching methods are:

- Teachers often continuously talk for an hour without knowing students response and feedback

- The material presented is only based on lecturer notes and textbooks
- Teaching and learning are concentrated on "plug and play" method rather than practical aspects
- There is insufficient interaction with students in classroom
- More emphasis has been given on theory, without any practical and real life time situations
- Learning from memorization but not understanding
- Marks oriented, rather than result oriented
- It is a "one way flow" of information
- In the process of lecturing, the learners are more passive than be active in class
- The problem solving attitudes of students may disappear in the lecture method.

INNOVATIVE SYSTEMATOLOGY IN TEACHING

Since these traditional approaches do not encourage students to question what they have learnt or to associate with previously acquired knowledge, an innovative measure is required to encourage students to learn how to learn via real-life problems. Innovation is about doing useful things differently, Converting novel ideas and methods into solutions that meet new needs, or adding significant value to established products and services. Innovation in educational practice can improve student's learning and faculty productivity. Currently, many institutions are moving towards problem-based learning and project based learning (PBL) as a solution to producing graduates who are creative and can think critically, analytically, and solve problems.

For the same, whole teaching and learning process is divided into 4 phases by the authors, (Fig. 2) where improvements can be done to increase the knowledge transfer efficiency from teacher to student:

1. Planning
2. Activation
3. Knowledge Transfer (Active Phase)
4. Consolidation

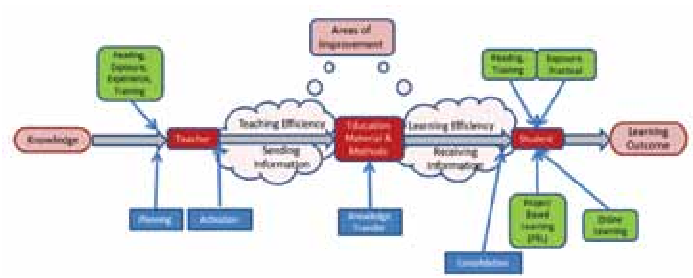


Figure 2 : Teaching Learning System Methodology

FOUR BOARD TEACHING (FBT) METHOD

One such methodology invented by authors is called Four Board Teaching (FBT) method. In this activity, students are divided in 4 teams preferably in a batch size of approximately 10-15 each. There is one board installed on each wall of classroom. Four similar topics are decided and one topic is assigned to each board. All these topics must be relevant to each other. In this particular case, 4 topics selected by authors are Carbon monoxide Emission (CO), Hydrocarbon Emission (HC), Nitrogen Oxides Emission (NO_x) and Particulate Matter (PM), which are 4 constituent of automotive emission.

In each round, teams are allowed to fill-up only 1/3 rd of the board related to different aspects of the topic. At the beginning of round, all teams will choose 1 member as a leader and assign 2 members of their team as writers. Thus writer's job is to write the content on 1/3 rd part of the board in a creative and interesting way, while other team members will give the content to them. Leaders and Writers will change after every round in order to give chance to every team member to contribute. This activity is divided in 4 rounds and after completion of every round, students will rotate clockwise and thus their topics will change accordingly.

Considering all the points written by students on all 4 boards, a PDF File is generated which covers the entire detailed description of all four topics. This PDF is basically cumulative wisdom of all students. This methodology shares the idea that students should work together in a team to learn and are responsible for their own as well as others learning. The use of this innovative method has the potential not only to improve education, but also to empower people, strengthen governance and galvanize the effort to achieve the human skill development goal.

Technology-assisted learning tools also known as e-modules are quickly changing the face of education and learning experience. These online learning courses allow the learners (students, industry professionals, teaching faculty, etc.) to choose the topic/s of their interest at the click of a button. Attractive audio-visuals, video lectures, and interactivities reinforce the learning. Quiz tests are added to check understanding and knowledge assimilation of the participant. Moreover, a strong technical SME support and practical exposure makes these e-modules a wonderful learning package.

By 2025, Millennials will make up around 75 percent of the workforce. It's interesting that the average attention span of the millennial generation is 90 seconds.

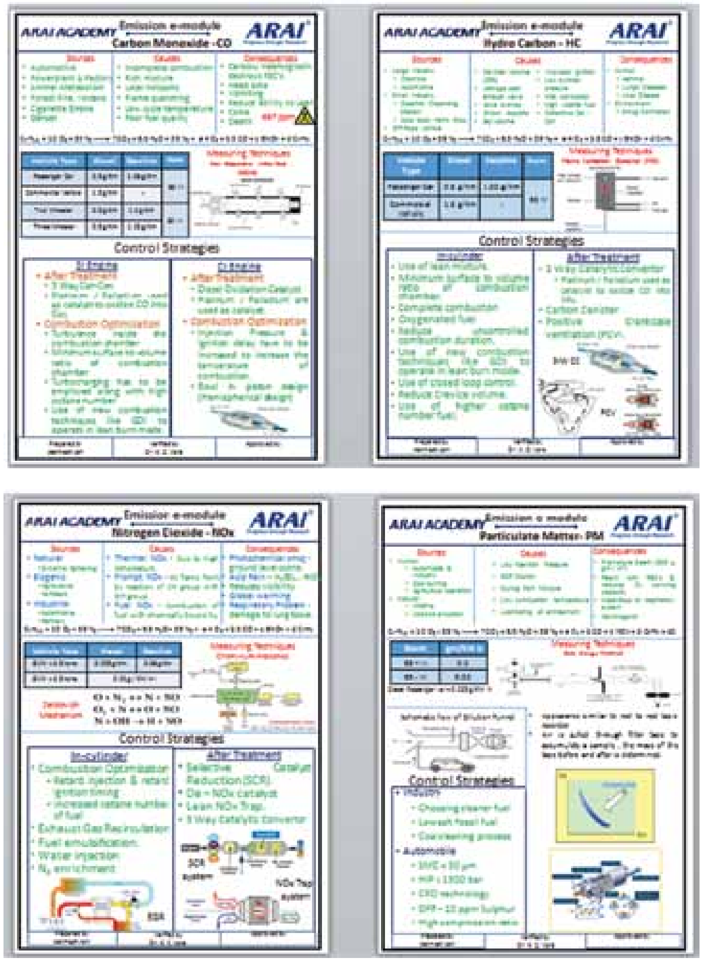


Figure 3 : Cumulative Conclusion of FBT Method - Case Study

Considering this, organizations need to understand the millennial mindset and their learning preferences, and create advanced learning methods.

ATTRIBUTES OF MILLENNIALS THAT INFLUENCE THEIR LEARNING

Technology Savvy : Millennials were born when the internet era was scaling to its peak. They do not know a world without internet as they were the first generation who grew up with technology. Millennials are digitally fluent and they have learnt to live with technology almost in every area of their life. They can steer through any device and technology at ease.

Short Attention Span : Millennials are easily bored and distracted. The average human attention span has fallen from 12 seconds in 2000, or around the time the mobile revolution began, to eight seconds . (Goldfish, meanwhile, are believed to have an attention span of nine seconds.) This shrink in the attention span is a key factor that affects how they learn.

Figure 4 : Types of Learners

Google Learners : One of the major ways by which millennials learn is by googling in their questions. Millennials like to pull information as and when they require it rather than information being pushed at them through long lectures and trainings. This insight demands re-orientation of our learning management solutions.

Just-in-time Learners : Millennials have zero tolerance for waiting. They prefer immediate support or help in their work place rather than a delayed classroom training. Doing is their ultimate goal and they view trainings a support for completing their task and not a place to just accumulate facts.

MIRCOLEARNING AS AN ADVANCED LEARNING SOLUTION

We need to develop learning solutions that cater to these behaviors. Microlearning is the latest and the advanced learning strategy that accommodates all these learning needs of the millennial generation and presents itself as the promising learning solution of the future.

WHAT IS MICROLEARNING?

Microlearning, as the name suggests, is a short learning event that just focuses on one topic. Contents are delivered in small bite-sized chunks. Microlearning is a trending learning strategy that closes the gap between skill and knowledge swiftly.

PRINCIPLES OF MICROLEARNING

Performance-based Learning : The first and the most significant process in creating microlearning events is to analyze the existing extensive learning materials and try to extract the actions that the learner should perform to increase the efficiency at work. Extraneous information are replaced with exact action points.

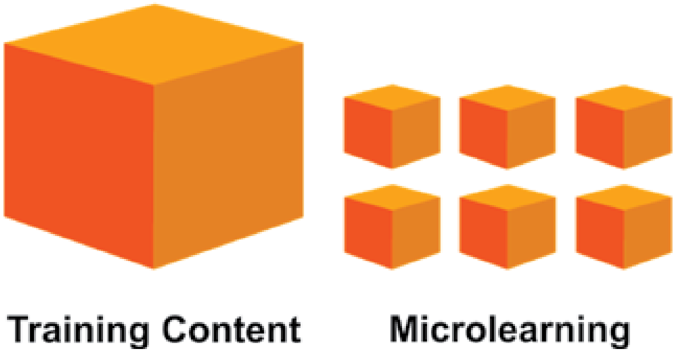


Figure 5 : Micro-Learning Concept

Granular Units : Though there is no fixed duration for a microlearning event, it is preferable for the learning event to be somewhere between 3 to 5 minutes. In cases of On Job Training (OJT), providing an intervention more than 5 minutes would not be advisable. Each unit should standalone and yet fall in line with the terminal objective of the course.

Bulleted List and Reference : Present the content in sub headings and bulleted list which allows the learner to skim through the content. Point the learner to the right resources if they are interested to learn more.

ADVANTAGES OF MICROLEARNING

Instantaneous Results : Knowledge or skill gaps are closed instantly through effective microlearning after which the learner canapply their learning immediately.

Learner-Centered : The learner takes the driver seat during the microlearning event, as they can select their preferred learning path.

Tackling the Forgetting Curve : Forgetting curve theory states that with time, the retention of the content decreases. This can be tackled by microlearning. As they are short and focused learning events, they can be used repeatedly. Microlearning can also be used as a supplement for training session and refresh the learner's memory.

Less Cognitive Load : The cognitive load is lesser in microlearning and hence the learner will be able to synthesis the content well enough to construct appropriate mental models.

Rapid Development Cycle : Unlike traditional lengthy trainings, microlearning events can be created within short duration. With the availability of numerous rapid authoring tools, the development time for microlearning events is drastically reduced.

Cost Effective : The creation cost of microlearning is much lower than the major e-learning courses. As these are granular units, the production cost is radically reduced.

Easy Content Updation : Constantly evolving content can be easily updated. New separate units can be created without affecting the other already existing microlearning units. This keeps the learning modules from becoming obsolete.

Varied Forms : Microlearning can be presented in various forms, namely, text, video, game, activity, scenarios and assessments. The form can be selected based on the learning styles of the learner.

All these advantages perfectly matches the millennials learning preferences.

MICROLEARNING DELIVERY METHOD – MOBILE DEVICES

Microlearning is best suited for mobile devices and hence to make the best use of microlearning, it should be delivered through mobile devices. In the book, 'The 2020 Workplace', the authors predict that the mobile phone will "become" the office and classroom. Pocket-sized classroom is the future. (Fig. 6)

Figure 6 : Micro-Learning Delivery Method - Mobile Device

MOBILE LEARNING AND ITS REWARDS :

Incessant Learning :

Mobile learning has redefined learning by nullifying the rule that employees ought to be present in a particular place and time to learn. This helps employees to learn on the go and according to their convenience. With mobile learning, learning becomes an incessant process extending beyond their office hours. Mobile learning provides flexibility to the learner as they can learn from anywhere and at any time.

Multi-Device Learning :

The same course can be delivered in multiple devices such as Smartphones, Tablets, iPods, and so on.

Tracking Learning :

A few years back tracking learning experiences was a challenge. But now with brand new specifications like Experience API, learners' experiences are tracked and recorded at ease. This helps the organization in managing their leaners. The tracked data can be used to analyze and improve the learning experiences.

Lower Dropouts :

As the content is delivered in various formats and using the microlearning strategy, the dropout rates in mobile learning is lesser compared to the traditional courses.

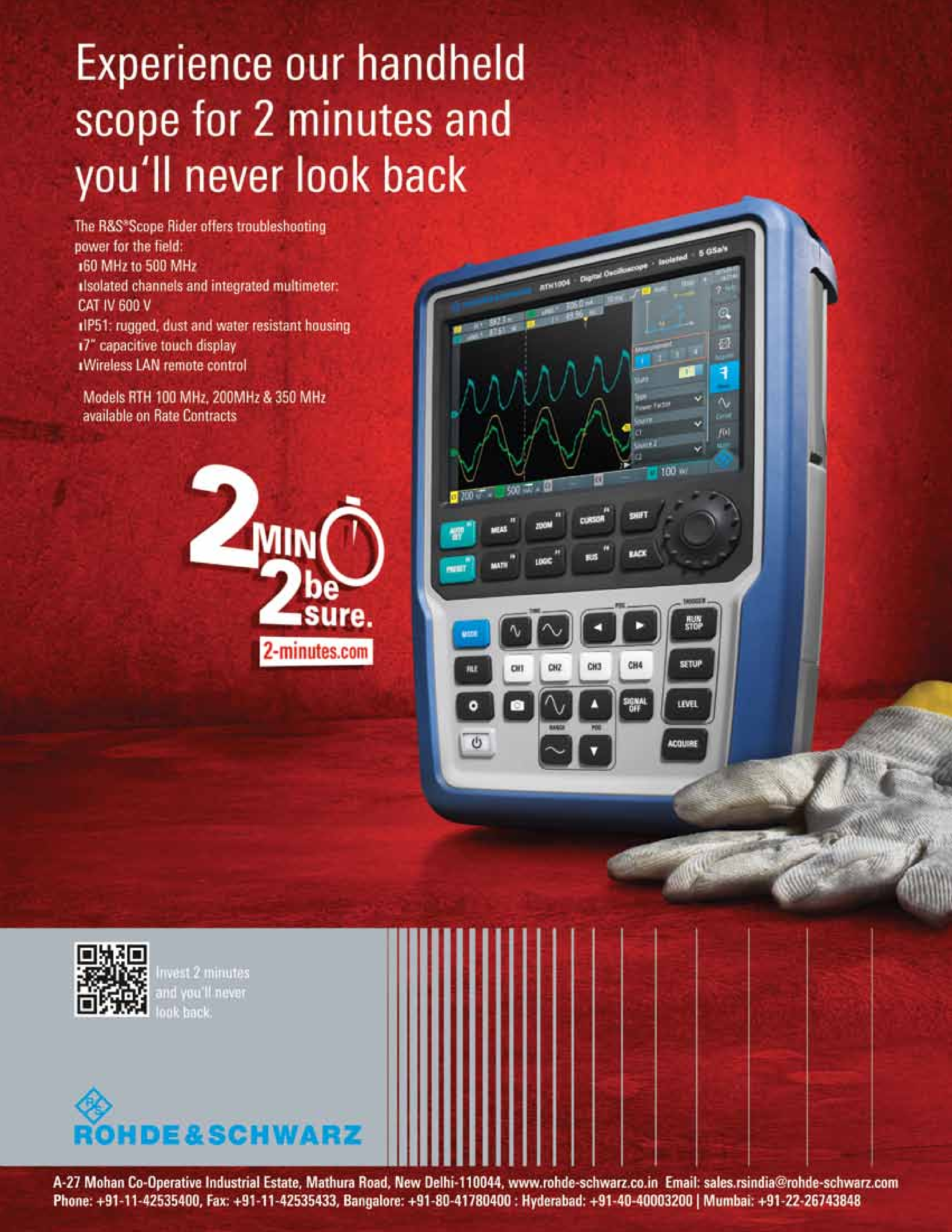
Collaborative Learning :

With the rise of social media, collaborative microlearning can be achieved in mobile platforms. It allows cooperation, which increases motivation of the learners to engage and learn from peers.

CONCLUSION

Advanced learning method that creates seamless integration of learning and doing is the expectation of the emerging generation and the organization. Microlearning is not the end-all-be-all solution. But to cater the millennial generation's learning needs and to help organization tackle the complexities that arise with them, microlearning events delivered in mobile devices seem to be the best foot forward in knowledge and skill enhancement. Pairing microlearning with mobile learning will yield best results for the future organizations.

■■■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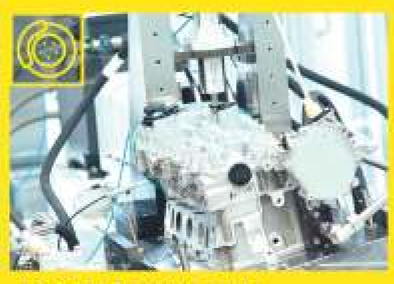

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