DTR VMS Ltd – RIEG ATDM

Rubber Anti-vibration Mounting Solutions for Electric Vehicles

Rob Wardrop CEng MIMechE DIS
29th June 2018
Abstract

This paper will discuss some of the unique challenges posed for the modelling, mount design and environmental aspects for electric vehicle power-trains compared to the requirements of conventional internal combustion engine vehicles.
Contents

- Introduction to DTR
- Product History and Development
- Electric Vehicles - DTR Experience
- High Frequency FEA Modelling & testing
- System Analysis
- Twin Shot Moulding
- Summary
Manufacturing Facilities

- **Anti-Vibration Products - Manufacturing Plants**
  - Trowbridge, UK
  - Yangsan, Korea
  - Jinju, Korea
  - Qingdao, China
  - San Louis Potosi, Mexico
  - Bursa, Turkey
  - Passirano, Italy
  - Grezzago, Italy
  - Czestochowa, Poland
  - Belo Horizonte, Brazil

- **Support Companies**
  - Bukjung, Korea – Rubber Mixing
  - Yangsan, Korea – Metal Stampings
  - Yangsan, Korea – Aluminium Die Casting
Based in the South West of England (Wiltshire)

Formerly part of Avon Rubber & Avon Automotive, acquired by DTR in 2009 - can trace its roots back to 1848 when the original business (Spencer Moulton) became the 1st company in Europe to vulcanise rubber

Hosted RIEG ATDM in June 2014.
Full design and development capability
- Global programme execution experience
- Powertrain mounting systems particularly
  - Active powertrain mount systems
  - Semi-active and advanced passive mounting systems
  - Pendulum systems
- Durabush, multilink suspension and subframe bush expertise

Design & development
- Powertrain system modelling
- Hydraulic mount and bush model development
- FEA and optimisation capability

Prototyping
- Full prototyping capability using production representative equipment

Validation
- 3-axis testing with environmental testing
- 2 axis torsional and radial testing for bushes
- High frequency testing up to 2kHz
- Active system HIL rig
- Vehicle lab for setting up customer and development vehicles
Customers
Why have hydraulic rubber mounts?

Consider an internal combustion engine mount

What are it’s functions?

Locate the engine
Isolate engine vibrations

Engine vibration
Mount
Reduced vibration on chassis
Why have hydraulic rubber mounts?

How do rubber mounts give us isolation?

Simple spring mass system
Sources of Vibration – What affects what?

- 3 principle sources of vibration that affect the vehicle –
  - **Air-borne** – eg, Sound waves on body panels, tyre noise, exhaust pipe vibration
  - **Structure-borne** – eg, Engine mass, suspension, drive shafts
  - **Fluid-borne** – eg, coolant system, heater system, brakes

- Specific vehicle dynamic- frequency response ranges include –

<table>
<thead>
<tr>
<th>Car Dynamic</th>
<th>Frequency response (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary (suspension) ride</td>
<td>1-5Hz</td>
</tr>
<tr>
<td>Engine displacement &amp; rotation</td>
<td>5-25Hz</td>
</tr>
<tr>
<td>Wheel-hop</td>
<td>10-20Hz</td>
</tr>
<tr>
<td>Body panels</td>
<td>25Hz</td>
</tr>
<tr>
<td>Cabin resonance</td>
<td>70-130Hz</td>
</tr>
<tr>
<td>Tyre cavity resonance</td>
<td>200-250Hz</td>
</tr>
<tr>
<td>Gear whine</td>
<td>500Hz</td>
</tr>
</tbody>
</table>
Tesla Benchmarking

**Tesla Model X**

**Overview**

**Manufacturer** Tesla, Inc.
**Assembly** Tesla Factory in Fremont, California

**Body and chassis**

- **Class**: Full-size, luxury, crossover SUV
- **Body style**: 5-door[2] SUV
- **Related**: Tesla Model S

**Powertrain**

- **Electric motor**: Dual Motor AWD
  - 90D: 259 hp (193 kW) front and rear
  - P90D: 259 hp (193 kW) front, 503 hp (375 kW) rear
- **Transmission**: Single-speed transaxle gearbox
- **Electric range**
  - 90D: 90 kWh (320 MJ)
  - P90D: 90 kWh (320 MJ)
- **Dimensions**
  - **Wheelbase**: 116.7 in (2,965 mm)
  - **Length**: 198.3 in (5,036 mm)
Tesla Benchmarking – System overview

**Front drive system**

- Double isolated mass system
- Double isolation mounting system (tie rod)
E-Motor Mountings - Double Isolation Effect – FEA analysis

~400Hz

Eigenmode because of bracket (4kg)

Double Isolation Effect

Frequency [Hz]
- big bush FEA (2x)
- Tesla Mount FEA
DTR Production Experience on EVs

- DTR Korea – Chevrolet Bolt facts:
  - Parts designed and developed by DTR Korea
  - Manufactured by DTR Korea
  - Customer Assembly – USA
  - Products – Front Mount, Rear Mount, Rear Bracket
  - Used in Chevrolet Volt / Opel Ampera E
DTR Production Experience on EVs

- Karma - Revero
  - Although brought in to the project at a very late stage, DTR has been heavily involved in developing the Revero
  - NVH tuning, system and mount development has covered both the IC range extender and the electric powertrain
UK based OEM

- DTR VMS have developed and are now supplying all of the rear subframe and suspension bushes

- Significant increase in loadings on all bushes and increased vehicle weight, compared to IC vehicles
IC Engine versus Electric Motor – Key Challenges

- Several differences between Internal Combustion (IC) Engines and Electric Motor’s (E-Motor)

- Potential benefits
  - Stiffer mount could be used without the need for hydraulic mount to control ride, because isolation targets are at higher frequencies
  - No idle
  - Potentially less heat generated as an electric motor is more efficient, reduced temperatures

- Potential challenges
  - High frequency noise
  - Control of larger torque reactions (applied from 0kmph with vehicle containing heavy batteries).
  - Large travel requirements in small package (general concern for all rubber metal components!)
  - Hybrid vehicles combining problems of IC engines and electric motors
HF Dynamic Stiffness Simulation

conventional gearbox mount

Testing: 3g
HF Dynamic stiffness – Design improvement

Wings reduce the dyn. Stiffness in 1st Eigenmode (@800 Hz) ~ 50 %
--> improves Isolation

Testing: 3g
• Dynamic Stiffness Simulation of Z-Block

Testing: 3g

100 Hz
High Frequency Test capability

- DTR UK’s high frequency test machine was made to DTR’s specification using components from Ling Dynamic Systems (now part of Brüel & Kjær).
- It is based on a LDS single axis electromagnetic shaker combo with a 1500kg floating reaction mass.
- Pre-loads are applied through an airspring system.
- It has a maximum frequency of 3000Hz, maximum acceleration of 60g bare table and maximum sine force peak of 11.5kN.
• **Comments**

• Fixture design is critical to achieving accurate results and all our HF fixtures are designed to be as simple, stiff and light as possible. We use FEA to ensure they are stiff enough to avoid resonances in the frequency range of interest.

• We use modal analysis to better understand the dynamic behaviour of our components and fixtures. Results can be fed back into design improvements.
Summary of DTR High Frequency Capabilities

- Ability to predict and measure high frequency behaviour of rubber components
- Good correlation of simulated dyn. stiffness and measurements
- The vibration modes of rubber can be visualised
- Design countermeasure features (wings) to disturb or cancel the rubber modes.
- Improved mount performance
- Reduces the time of product development
- Hydraulic behaviour is possible to include in simulations
Systems Analysis

- IC Development
- Hybrid powertrain simulation
  - Ride control
  - Noise isolation
- Electric vehicle simulations
  - Vehicle correlation
  - Tip in – Tip out condition and optimisation
Hydramount models

- Time domain models allow for simulation of non-linear components
  - MRE FEA analysis output integrated into simulations
  - Ride channel for mount primary resonance
  - Non-linear diaphragms, including airsprings
  - Decoupling
  - Cavitation
  - Bypass valves

- Output - optimisation of dynamic properties including
  - Tuning and damping levels of hydramount
  - Secondary resonances for simulation up to 400Hz
  - Knock
6 degree of freedom analysis with hydramounts

- Powertrain dynamic response in frequency range 0 – 30Hz
- Tune hydramount dynamic properties for best control of powertrain modes
- Force transfer through mounts up to 400Hz for minimising cabin noise
- Animation of powertrain movement
13 degree of freedom analysis with hydramounts

- Model extended to include chassis, wheels, tyres and vehicle suspension
- Able to simulate realistic road inputs at tyres
- Measure vehicle response at the seat rail position
- Ride and low frequency vibration evaluation
- Optimise hydramount damping
- Understand influence of wheel hop
Example – System mounting design – Hybrid powertrain

Multiple mounting system options compared

Ride control simulation

Powertrain noise simulation

<table>
<thead>
<tr>
<th></th>
<th>Front mounts</th>
<th>Rear mounts</th>
<th>Mid mounts</th>
<th>Time for seat rail peak acceleration to drop below 0.15 m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak loss</td>
<td>Kd at 30Hz</td>
<td>Peak loss</td>
<td>Kd at 30Hz</td>
</tr>
<tr>
<td></td>
<td>angle</td>
<td>N/m m</td>
<td>angle</td>
<td>N/m m</td>
</tr>
<tr>
<td>ALLOWABLE LIMITS</td>
<td>0.4</td>
<td>0.2</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td>4 rubber bushes</td>
<td>3</td>
<td>269</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>Hydragbush at rear</td>
<td>3</td>
<td>265</td>
<td>27</td>
<td>902</td>
</tr>
<tr>
<td>4 higher damped rubber bushes</td>
<td>6</td>
<td>315</td>
<td>6</td>
<td>591</td>
</tr>
<tr>
<td>6 plain rubber bushes</td>
<td>3</td>
<td>280</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>Mid position bushes with higher damping rubber</td>
<td>3</td>
<td>289</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>2 high dynamic stiffness hydramounts</td>
<td>3</td>
<td>269</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>2 mid dynamic stiffness hydramounts</td>
<td>3</td>
<td>289</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>2 low dynamic stiffness hydramounts</td>
<td>3</td>
<td>269</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>2 ultra low dynamic stiffness hydramounts</td>
<td>3</td>
<td>289</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>2 hydragbushes</td>
<td>3</td>
<td>289</td>
<td>3</td>
<td>542</td>
</tr>
<tr>
<td>4 rubber bushes with additional oil damper at NTA</td>
<td>3</td>
<td>269</td>
<td>3</td>
<td>542</td>
</tr>
</tbody>
</table>

4 plain bushes with 3 degrees loss angle do not provide enough ride control

4 plain bushes with high loss angle (6 degrees) meet ride requirement

Damping target is exceeded with any type of hydraulic mount
The powertrain torque excitations and static loads for a range of vehicle speeds were applied to a 6 degree of freedom Simulink model.

Forces under the powertrain mounts were found.

Simulations included low load, comfort acceleration and full torque effects on mounting system.

Noise levels in cabin were calculated from powertrain mount forces using vehicle body transfer functions.

Rigid body analysis valid for frequencies < 400Hz.
Vehicle Correlation - RDM Mount used in test vehicle and simulation

● Front mounts

Front Z Dir. (Unloaded)

Load (N)

Displacement (mm)

+ve torque direction

RDM

Tip-in torque 0-6290Nm over 0.2 seconds applied to RDM

● Rear mounts

Rear Z Dir. (Unloaded)

Load (N)

Displacement (mm)

Large linear travel, sharp progression into snubbing

Static rate increased significantly

Small linear travel, progressive snubbing

Engine

Output = acceleration of chassis at seat rail

Counter load
Vehicle Correlation - RDM Mount used in test vehicle and simulation

Test result

Simulation result

Seat rail acceleration (z)

Confidential and proprietary information of DTR VMS – Do not distribute or duplicate without the express written permission of DTR VMS
Tip-In / Tip-Out Noise Simulation

- Electric powertrain applications bring high torques with very rapid application
- Additional challenges for controlling shake/clunk noise due to powertrain mount travel limiters (snubbers) during Tip-in/Tip-out
- Tuning mount progression characteristics important
- Simulation and mount system specification optimisation capability
Tip-in results – Optimisation

Max mount force due to 6290Nm dynamic load

Mount force due to 6290Nm static load

Reduce rear snubber gap so that front and rear snubber contact at same time

Increased stiffness early in snubber travel with linear increase in stiffness.
Dual compound moulding capability

- Moulding with 2 different compounds during the same moulding cycle.
- 2 Injection heads on rubber moulding press
- Allows for different compound characteristics for different functions
  - E.g. main spring and snubbers with different hardness/damping
- DTR are currently making prototype samples using dual compound process
Summary

- DTR has a long history of working with rubber to develop solutions to resolve the issues with IC engines

- As they evolve, we are gaining experience in E-motor vehicles, hybrid and pure EV.

- We have a global team developing tools to support the development of mounting strategies to resolve the new issues with E-motor vehicles,
  - High Frequency modelling
  - System analysis
  - Vehicle testing
  - Twin shot moulding

- DTR are developing mounts specifically for the E-motor vehicles, these are subject to patent applications & hence specific design details cannot be divulged here.
Summary

- **Internal Combustion**
  - Idle shake
  - High temperatures
  - Lower frequency issues
    - 2nd and 4th order input
  - Hydraulic mass damping mounts
- **Electric Vehicle**
  - No Idle
  - Less demanding thermal requirements
  - Higher frequency issues
    - 48th order inputs
  - Dual isolation mounts (Dual isolation modes less of a problem as frequencies passed through quickly)
    - Twinshot moulding
  - Gradual torque build-up (usually!)
  - Manageable travel requirements
- **Of course hybrid vehicles have the worst of both situations!**
Thank you!