Powertrain Durability Test Specification Generation Tool

Presentation by:
Prerak J. Chitnis
Sri Harsha Dannana
Introduction

- **Durability**: Testing component till end of life
- **Powertrain** consists of Engine, Gearbox assembly, Propeller Shaft and differential axle assembly
- Powertrain is designed for 15 years* of car life.
- Accelerated testing is required for
  - physical validation of components with long design life
  - reducing product development time

* tentative value
Accelerated Testing for Automobile

15* Years of Car life

Based on Domain knowledge and past experience

Few thousand Km of actual road load data collection

Test Specification Generation using Matlab

Accelerated Life Testing

2,50,000* Km of actual vehicle (System Level)

2,000* Km of actual vehicle (System Level)

Equivalent cycles On Test rig (Component Level)

* tentative value

© Copyright, Confidential, Tata Motors Ltd
Challenges

• Customer correlated testing
  – Under-Testing means more warranty claims
  – Over-Testing means Bulky and Costly component

• Damage Correlation
  – Failure observed on test rig should replicate the failure observed on road

• Complexity of variable parameters
  – Variable parameters like driving style, road conditions, etc.
What has been done with Matlab?

10 Days
Time Saving
per iteration
Process Flow

Old Process
- 15 Days
  - S/W 1
  - S/W 2
  - S/W 3
- New Process
  - Windows Application using MATLAB
  - 1 Day
  - S/W 1

Steps:
- Anomaly Correction
- Frequency Analysis & Filtering
- Road Load Mix Creation
- Gear detection & Decomposition
- Gear file smoothening
- Markov Matrix
- Engine Torque Calculation
- Joint Probability Function
- Torque/Speed Cycle

Before:
- S/W 1
- S/W 2
- S/W 3

After:
- S/W 1

Improvement:
- From 15 Days to 1 Day
Advantage with Matlab

Old Process

Raw data in format 1
Software 1
Raw data in format 2
Software 2
Processed data in format 1
Software 1
Result data in format 3
Software 3

New Process

Software 1

Raw Data

No software License issue
Matlab Standalone Executable GUI

- Anomaly Correction
- Frequency Analysis & Filtering
- Road Load Mix Creation
- Gear detection & Decomposition
- Gear file smoothening
- Markov Matrix
- Engine Torque Calculation
- Joint Probability Function
- Torque/Speed Cycle
- Result data in format 3

© Copyright, Confidential, Tata Motors Ltd
Matlab GUI created
Matlab Central

- Few of the standard components of GUI were taken from the “Matlab Central” to reduce the coding time during development

- Upickfiles:

Source: Ref [2]

© Copyright, Confidential, Tata Motors Ltd
Raw Data Collection

- Actual road load data is collected using instrumented vehicle.
- Driveline Parameters of interest are speed, torque, temperature, gear position, etc.
- External Parameters of interest are road gradient, driver profile, loading condition, etc.
Customer profile mapping

Note: Below distribution is a sample assuming 2000km of Service road data with arbitrary customer usage profile

<table>
<thead>
<tr>
<th></th>
<th>CITY (27%)</th>
<th>GHAT (4%)</th>
<th>ROUGH ROAD (1%)</th>
<th>NH (11%)</th>
<th>SH (31%)</th>
<th>EXPRES SWAY (21%)</th>
<th>OFF-ROAD (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LADEN (25%)</td>
<td>135</td>
<td>20</td>
<td>5</td>
<td>55</td>
<td>155</td>
<td>105</td>
<td>25</td>
</tr>
<tr>
<td>UNLADEN (20%)</td>
<td>108</td>
<td>16</td>
<td>4</td>
<td>44</td>
<td>152</td>
<td>84</td>
<td>20</td>
</tr>
<tr>
<td>OVERLOAD (15%)</td>
<td>81</td>
<td>12</td>
<td>3</td>
<td>33</td>
<td>93</td>
<td>63</td>
<td>15</td>
</tr>
<tr>
<td>ECIE (20%)</td>
<td>108</td>
<td>16</td>
<td>4</td>
<td>44</td>
<td>124</td>
<td>84</td>
<td>20</td>
</tr>
<tr>
<td>PARTLOAD (20%)</td>
<td>108</td>
<td>16</td>
<td>4</td>
<td>44</td>
<td>124</td>
<td>84</td>
<td>20</td>
</tr>
</tbody>
</table>
Instrumentation and Data Collection

Source: Ref [1]

© Copyright, Confidential, Tata Motors Ltd
Gear Detection

\[ \text{Gear Ratio} = \frac{\text{Engine Speed}}{\text{GearBox Speed}} = \frac{\text{GearBox Torque}}{\text{Engine Torque}} \]

- Gear-box output speed and Engine speed are measured parameters.
- Gear position can be estimated by calculating Gear Ratio from the measured speed parameters.
- Gear position is important to calculate unknown Engine Torque from the measured gear-box output torque.
• Ideally, Gear Ratio calculated from the Engine speed and Gear-box output speed should have one of the designed gear ratio value

• But in actual measured gear ratio values deviate from designed gear ratio values at few time instances like clutching and braking

• Data errors due to clutching and braking are detected and removed in gear file smoothening stage
Markov Matrix

- It is matrix representation of the gear shifting, in the ‘from-gear’ ‘to-gear’ format

<table>
<thead>
<tr>
<th></th>
<th>To 1</th>
<th>To 2</th>
<th>To 3</th>
<th>To 4</th>
<th>To 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 1</td>
<td>0</td>
<td>449</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>From 2</td>
<td>373</td>
<td>0</td>
<td>272</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>From 3</td>
<td>34</td>
<td>226</td>
<td>0</td>
<td>69</td>
<td>9</td>
</tr>
<tr>
<td>From 4</td>
<td>2</td>
<td>23</td>
<td>52</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>From 5</td>
<td>0</td>
<td>2</td>
<td>9</td>
<td>36</td>
<td>0</td>
</tr>
</tbody>
</table>

- Gear shift pattern is generated using Matlab code with minimum number of dummy shifts
Joint Probability Distribution

It gives the statistical representation of the engine power distribution over Torque and RPM range.

**Joint Probability Distribution Table**

<table>
<thead>
<tr>
<th>Torque</th>
<th>100</th>
<th>500</th>
<th>900</th>
<th>1300</th>
<th>1700</th>
<th>2100</th>
<th>2500</th>
<th>2900</th>
<th>3300</th>
<th>3700</th>
<th>4100</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>125</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>43</td>
<td>110</td>
<td>189</td>
<td>204</td>
<td>127</td>
<td>44</td>
<td>29</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>452</td>
<td>1014</td>
<td>946</td>
<td>429</td>
<td>192</td>
<td>129</td>
<td>26</td>
</tr>
<tr>
<td>-25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>2122</td>
<td>495</td>
<td>417</td>
<td>299</td>
<td>169</td>
<td>37</td>
<td>16</td>
</tr>
<tr>
<td>-75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-125</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

“hist3” MATLAB command to visualize engine power distribution in 3D.
Test specifications generated tell what should be the torque and speed parameter values on test rig for particular gear being tested.

Similar kind of procedure is followed for all driveline components test specifications development.
GUI snapshots
Conclusion

• The data processing and test-specification development time has been reduced **from 15 days to 5 days.**
• New process using Matlab shows **98% result correlation** with the old process.
• Multiple software and multiple licenses issue is resolved with standalone ***.exe saving huge money.**
• **Quality** of test specifications generated improved by running multiple iterations and optimization.
• Duplication of huge raw data in multiple formats is avoided which **reduced storage space** requirement.
• Matlab helps in **visualization** of difficult to comprehend data in much easier way.
References


Thank You!