Case study

Ford motor company

Ford leverages Adams FMI co-Simulation method to optimize tradeoff between fuel economy and NVH

Authors

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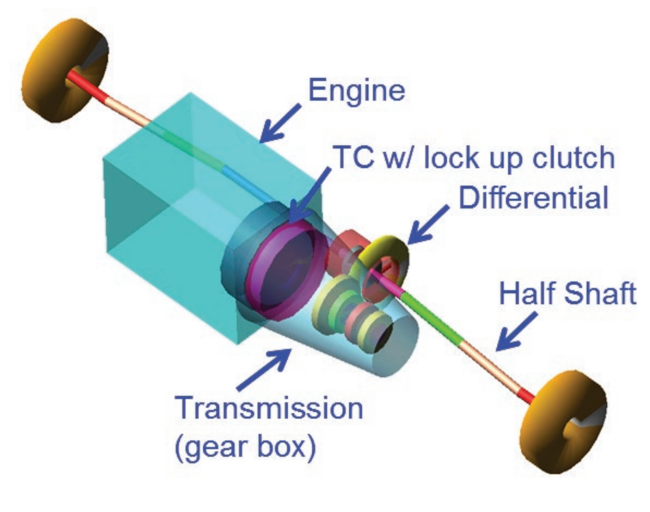
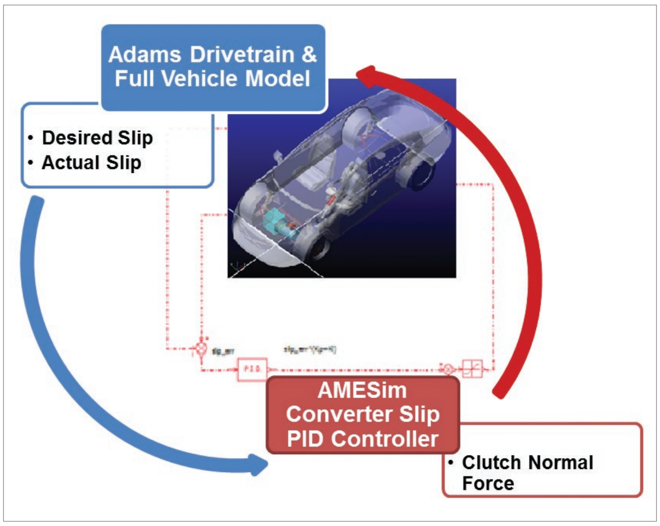
Noise/vibration/harshness (NVH) and fuel economy often must be traded off against each other during the vehicle design process.

For example, lugging is a condition that typically occurs when the vehicle is in high gear with an engine speed of below 2000 rpm. When the driver steps on the gas pedal under these conditions, the engine struggles to give motion to the vehicle while generating relatively little torque so acceleration is low. Lugging produces high levels of low frequency inputs because of the low firing frequency at low engine speeds and high loads. These low frequency inputs are frequently experienced by the driver and passenger as seat track vibration, steering wheel vibration and interior cabin boom sound.

One of the primary methods by which engineers attempt to control lugging is through the torque converter which transmits and amplifies the torque from the engine to the transmission using fluid coupling. The torque converter consists of a pump, turbine, impeller and stator contained within a cavity filled with transmission fluid in addition to a lockup clutch and damper assembly.



Drivetrain model



Adams and AMESim FMI co-simulation

The clutch is electronically controlled to provide the desired level of slip. When required, the clutch locks up and provides a direct connection between the engine and transmission, resulting in near 100% efficiency and the best fuel economy. In lock-up mode, engine torque fluctuation is transmitted directly to the transmission, potential causing the drivetrain to generate vibration and noise. Slipping the torque converter increases damping, reducing sensitivity of the driveline vibration to the engine torque excitation and improving NVH performance. On other hand, slipping increases losses due to fluid coupling and clutch friction which decreases fuel economy.

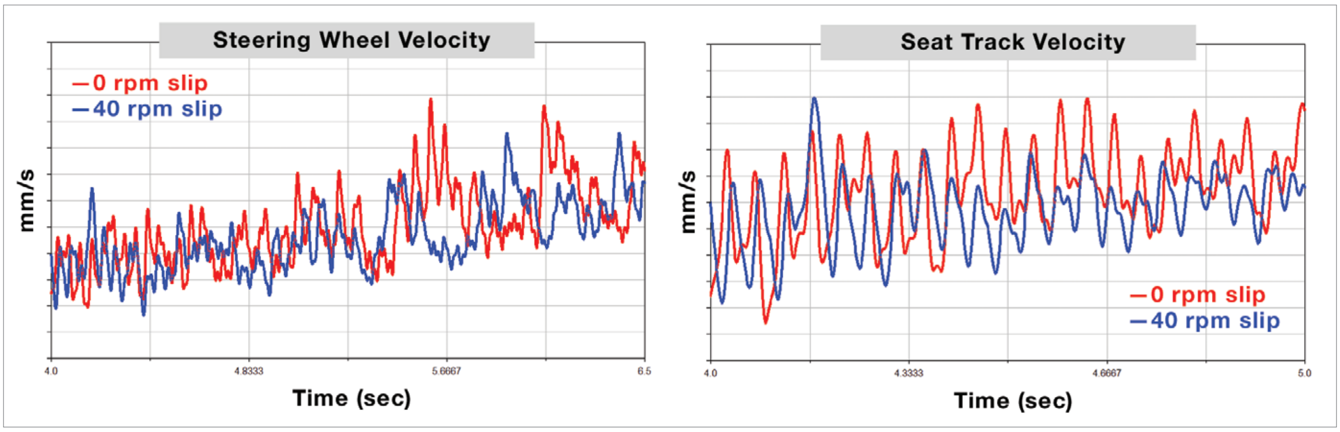
Challenge

When developing a new vehicle model, engineers are responsible for meeting a wide variety of often conflicting performance targets. Fuel economy and NVH are two of the most important categories of targets. With regards to lugging, NVH engineers are typically responsible for holding torsional vibration amplitudes at the transmission output shaft below a target value. The NVH team naturally would prefer a large amount of slip in order to help meet their targets while the team responsible for fuel economy would like slip to be as low as possible to meet their targets. Up to now it has not been possible to determine torsional vibration amplitudes with high levels of accuracy until a prototype vehicle is built and tested in the late stages of the product development process. However, at this late stage, the design is frozen and changes are quite expensive and could potentially delay production. Ford was looking for a method to simulate the effects of different torque converter designs so that engineers could make intelligent tradeoffs upfront in the design and development stages.

Solution/validation

Ford engineers addressed this challenge by taking advantage of a new capability of MSC Software's Adams to support the Functional Mock-Up Interface (FMI) tool independent open standard for model exchange or co-simulation. The FMI standard makes it possible to create a virtual product from a set of models of the physical laws and control systems assembled digitally. The FMI instance of a model is called a Functional Mock-Up Unit (FMU). An FMU is a formatted file containing an XML formatted model description file, dynamic link libraries and model data files. FMI can be used for model exchange or co-simulation. The Adams FMI support extends the Adams/Controls Co-simulation support of Matlab and Easy5 to all software utilizing the FMI Co-simulation standard.

In this case, Ford engineers used an Adams 3D drivetrain and full vehicle model as the co-simulation master with an AMESim 1D converter slip controller model as the co-simulation slave with the goal of optimizing converter slip to meet the vehicle lugging NVH target while maximizing fuel economy. A drivetrain model was created in Adams/Driveline including an I4 Gasoline Turbocharged Direct Injection (GTDI) engine with three mounts, a torque converter with a lockup clutch, a six-speed gearbox with internal shafts and planetary gear sets, and a front driveline with differential, link-shafts, half-shafts, constant velocity joints and wheels. The driveline model was incorporated into a full vehicle model using Adams/Car. The vehicle model includes the chassis, suspension, steering, brake and wheel subsystems. The AMESim torque converter model is a proportional-integral-derivative (PID) controller that provides the normal force on the converter clutch based on the difference between the actual slip and the desired slip.



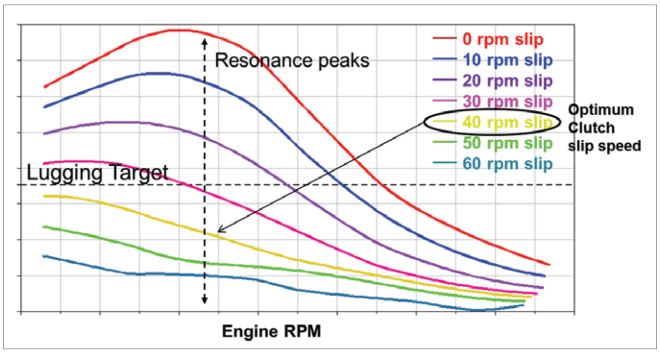
Steering Wheel and Seat Track Vibration are drastically reduced by slipping Torque Converter

Results

"We ran the model for different values of desired slip rpm across a broad range of engine rpm," Mario Felice said. "The simulation results showed that a slip of 30 rpm or lower would fail to meet the NVH target while a slip of 40 rpm or greater would meet the target. The simulation showed that 40 rpm slip was the optimal value that would meet the NVH target and would result in the best trade off with fuel economy." Engineers further studied the reduction in torsional vibration amplitudes generated by the clutch damper behavior and the torque converter slip. They also compared vibration at the steering wheel and seat track with 0 rpm and 40 rpm slip. The results showed that steering wheel and seat track vibration are drastically reduced by slipping the torque converter. "Next steps will include increasing the sophistication of the torque converter model by modeling the hydraulic system to provide more accurate predictions of normal force as a function of time," Felice said. "We also plan to validate the model with physical testing results. Then we will integrate the co-simulation into the design process so that the torque converter design can be optimized early in the product development cycle."

About Ford

The Ford Motor Company is an American multinational automaker that sells automobiles and commercial vehicles under the Ford brand and luxury cars under the Lincoln brand.



Torsional vibration at transmission output shaft vs. engine rpm vs. slip rpm

Key highlights:
Product: Adams
Industry: Automotive
Benefits:
This case study successfully demonstrates the FMI integration approach for vehicle lugging NVH assessment
Effectively coupled AMESim Converter Controller model with Adams Driveline and Vehicle model
An Optimum Torque Converter slip speed was determined meeting lugging target requirement while balancing with fuel economy
Simulation results showed drivetrain torsional vibration along with vehicle vibration (steering wheel & seat track) were effectively reduced with converter slip

> **We ran the model for different values of desired slip rpm across a broad range of engine rpm. The simulation results showed that a slip of 30 rpm or lower would fail to meet the NVH target while a slip of 40 rpm or greater would meet the target"**

Mario Felice,
Manager, Global Powertrain NVH & Systems CAE Dept, Ford Motor Company

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