Modeling of Engine Block and Driveline Vibration as Affected by Combustion

Gamma Technologies, Inc

2002 GT-SUITE User Conference
October 2002
Introduction

• Engine is suspended in the vehicle frame on several flexible mounts, whose purpose is to isolate the vibrations between the engine and the frame.

• Mounts have to be stiff to resist engine recoil at high torque operation, and at the same time they need to be tuned to have low natural frequency to avoid resonance with the engine excitation.

• Despite this, some of the engine vibrations still get transmitted to the frame, especially at idle.
Introduction

- The excitation of the system comes from the cylinder pressure, which acts on the cranktrain components.
- An important parameter influencing engine vibration is combustion. The resultant cylinder pressure causes a thrust force against the cylinder liner wall, producing block recoil in the mounts.
‘EngBlockRecoil’ Template

• 'EngBlockRecoil' Template
  – Attributes of engine mounts specified
  – Connects to the ‘EngineCrankTrain’ to calculate the angular displacement, velocity, and acceleration of the engine block as well as the torques on the block.
  – Works in both GT-Power and GT-Crank
‘EngBlockRecoil’ Object

GT-POWER
‘EngBlockRecoil’ Object

GT-CRANK
Example: Block Vibration

- Of particular interest is irregular combustion because such combustion is known to correlate with increased engine vibration and frame excitation.
- The following modes of combustion considered on a 4 cylinder engine:
  - Baseline: repeatable stable combustion
  - Misfire in one cylinder at regular intervals
  - Random variation in combustion from cycle to cycle and from cylinder to cylinder
Example: Block Vibration

• Combustion provides (more or less) periodic excitation to the engine block sitting on mounts
• Irregular combustion introduces excitations at lower frequencies, which can couple into the mount natural frequency
• Such coupling into suspension frequency is very undesirable and needs to be controlled or eliminated.
• Analysis shown here can be used to address the root cause of the problem.
Regular (Stable) Combustion

- Full load, 1000 RPM.
- Illustrates the effects of engine recoil, produced by fluctuating torque.
- Recoil changes the effective engine RPM as well as the instantaneous engine volume.
- Effect of block recoil vibrations on pressure diagram (most noticeable at the firing TDC).
EFFECT OF ENGINE BLOCK RECOIL ON CYLINDER GAS THERMODYNAMICS
Misfire in One Cylinder

- Full load, idle engine condition.
- Misfire in cylinder 3:
  - Each cycle (every 4\textsuperscript{th} firing)
  - Every 5\textsuperscript{th} cycle (every 20\textsuperscript{th} firing)

- Misfire introduces lower excitation frequencies, which couple into suspension natural frequencies (especially in the case of misfire every 5\textsuperscript{th} cycle).
Block Angle Fluctuations -- Misfire Each Cycle

Block Angular Displacement vs Time

regular
Misfire 1

Angle, deg

Time [sec]
Block Angle Fluctuations -- Misfire Each 5th Cycle

Block Angular Displacement vs Time

/EngBlockRecoil Engine-Block:Block

regular
Misfire 5

Time [sec]
Block Angular Velocity Fluctuations

Block Angular Velocity

- Baseline
- Cyl 3 Misfire every 5th

Angular Velocity, RPM

Time, sec
Cranktrain Speed Fluctuations

Cranktrain Speed_1

Baseline  Cyl 3 Misfire every 5th

Cranktrain RPM

Time, s

3.0  3.2  3.4  3.6  3.8  4.0
Random Combustion

• Idle engine condition.
• Random combustion characterized by 50% burn location and 10-90% burn duration (normal distribution with prescribed standard deviation was imposed on burn duration and location by means of ‘SignalStatistical’ control component).
• Wide range of forcing frequencies is introduced into the excitation torque, leading to noticeable engine and frame shaking.
• A spectral plot of the block vibrations over the range of irregularities shows the frequency of individual engine cycles, and also the suspension natural frequency, excited by random combustion.
Cylinder Pressure Dispersion

Variation in Pressure between Cylinders
Cylinder Pressure vs Crank Angle - Last Cycle of Simulation (Std.Dev.=5 deg)

- Cylinder01
- Cylinder02
- Cylinder03
- Cylinder04

Pressure [bar]

Crank Angle [deg]

-180 BDC
0 COMPR
0 TDCE
180 BDC
180 POWER
360 EXHAUST
360 TDC
540 INTAKE
540 BDC
10-90% Burn Duration Fluctuations in Cylinder #1
50% Burn Point Fluctuations in Cylinder #1
Block Vibration Amplitude vs. Level of Combustion Variability
Conclusions

- The “engine vibration” analysis described here include investigation of the motions of engine in its mounts. It can easily be extended to the study of the transmission of forces and torques between engines and their mounting structures and vibration of parts within engine.