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INVESTIGATION ON GEAR RATTLE PHENOMENON IN AUTOMOTIVE DRIVELINE: FOCUS ON CLUTCH MODIFICATION

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ABSTRACT

The demand for passenger comfort in automobile industry is increasing more and more. Noise, vibration and harshness (NVH) is one of the most important vehicle attribute reflecting the quality perception of a vehicle. Gear rattle is main issue to be solved related to power train noise. This work aims to investigate gear rattle phenomenon for front wheel drive (FWD) for a passenger car application, with modification in clutch. The work attempts to predict resonance frequencies of driveline which is linked to gear rattle by linear modal analysis. Vehicle measurement will be made to check the gear rattle amplitude levels. The vehicle measurement resonance frequencies to be correlated with the simulated modal analysis. The influence of clutch in comparison with Dual mass flywheel (DMF) for gear rattles was simulated in terms of gearbox resonance frequency will be validated by test measurement.

Keywords: clutch, front wheel drive, gear rattle, modal analysis, DMF.

1. INTRODUCTION

Automotive driveline is a fundamental part of a vehicle. It transforms power from engine to vehicle. There are two types of driveline setups: The front wheel drive and the rear wheel drive. The transfer of torque from engine to tire is so important in automotive vehicle in terms of NVH perspectives. Engine is the main source for all the torsional vibrations issues since torque produced by the combustion engine is not cyclic. Based on number of cylinders of engine, the torque harmonics generated. Engine torque harmonics are transferred to the driveline. The clutch is a key member in driveline which reduces the acyclic behavior of transmitted torque. It has a greater influence in determining torsional vibrations issues such as shuffle, judder and gear rattle. The gear rattle is a noise produced in gearbox due to movement and vibration in unloaded parts such as synchronizers. Hugo, Vinicios *et al* (1) describes the term gear rattle makes reference to the sound induced by impacts between the unloaded gear mesh pairs in the transmission. It can be noticed on manual transmission vehicles in neutral condition (idle rattle) related to the engine firing frequency. Impacts occur with greater intensity on diesel vehicles, once that torque irregularities are increased with the adoption of this fuel.

2. SCOPE AND METHODOLOGY

This work intends to predict resonance frequencies of a front wheel drive by linear modal analysis. The influencing part of driveline which reduces the gear rattle issue is identified based on the mode shapes of the simulation. The works consist of following steps.

a) Creation of models of driveline in simulation software and perform numerical calculations.

b) Correlation between test measurement and simulation for resonance frequency of gear rattle.

c) Solution by clutch modification to solve the gear rattle issue.

d) Measurement on vehicle with proposed design solution.

3. DRIVELINE MODEL AND MODAL ANALYSIS

Typical Front wheel drive is represented in Figure-1. It can be modeled by mass moment of inertia and torsional stiffness by multi degrees of freedom for Modal analysis. Ergun et al [2] carried out a study of the torsional vibration of the driveline of a vehicle using theory of vibrations. The natural frequencies of the system were calculated by approximating it to a four inertia system.

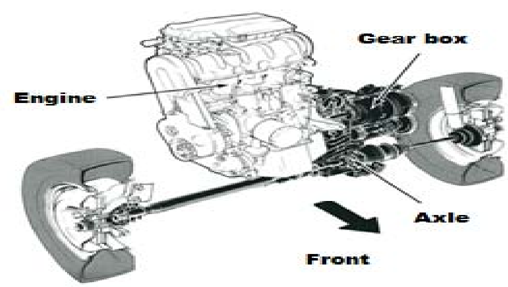

Figure-1. Front wheel drive.

In this work LMS AMESimv1310 is software is employed to create Modal analysis 1d simulation model as shown in Figure-2.

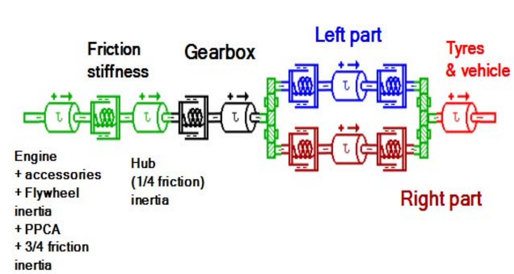

Figure-2. Front wheel drive clutch with FWD Modal analysis model.

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The engine crank shaft inertia is with it is accessories is connected to the Single mass flywheel .Clutch cover assembly is bolted with the flywheel .Therefore all the inertia connected to the flywheel is considered as a single mass. Gearbox is considered as single mass since the output shaft and its related rotating parts are reflected in to the input shaft by the respected gear ratio. The completed Front wheel drive of the passenger car is modeled with 6 mass systems. With the clutch damper stiffness 16.5 Nm/°, 5 natural frequencies were obtained as shown in Figure-3.

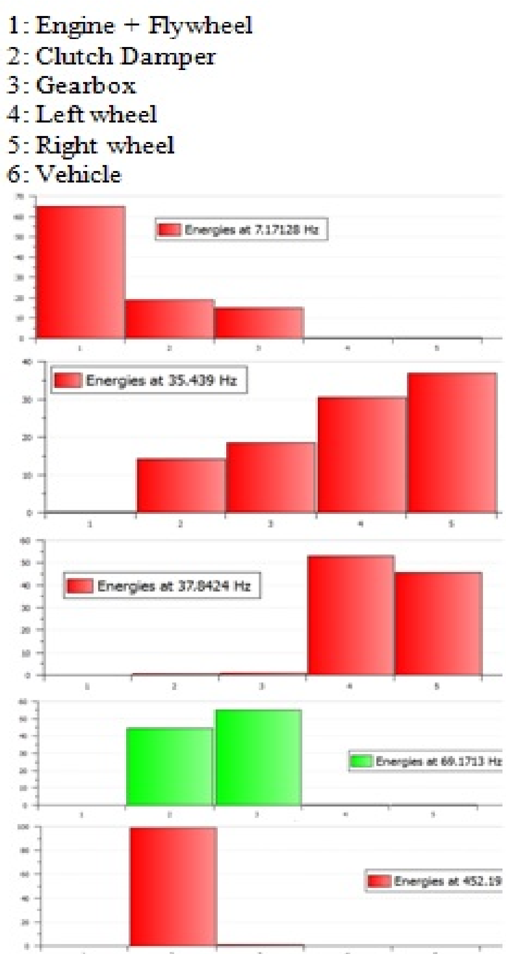

Figure-3. Modal analysis resonance frequencies (clutch).

These five resonance frequencies are corresponded to each phenomenon in the vehicle. The first frequency 7 Hz which is responsible to vehicle shuffle. Liu, J. and Fox, J. (3) states, this low frequency can be excited when a reversal of torque occurs in a vehicle's drive train. It usually occurs during a throttle tip-in or tip-out event, or a static engagement shift event. Second and third mode corresponds to left and right wheel resonance which results to Booming. The fourth mode in the modal analysis 69 Hz corresponds to gear rattle where the gearbox and clutch inertia is phase opposite with flywheel and wheels. The present work focus on this gear box resonance mode.

4. VEHICLE MEASUREMENT

Basic instrumentation layout is shown in Figure-4. Which consist of speed sensors and microphone .The gear rattle noise can be captured through microphone fitted on driver seat. Speed sensor fitted on flywheel and gearbox input shaft is measures the speed fluctuations. Torsional acceleration is derived from speed measurement. This represents the vibration level at engine and gearbox.

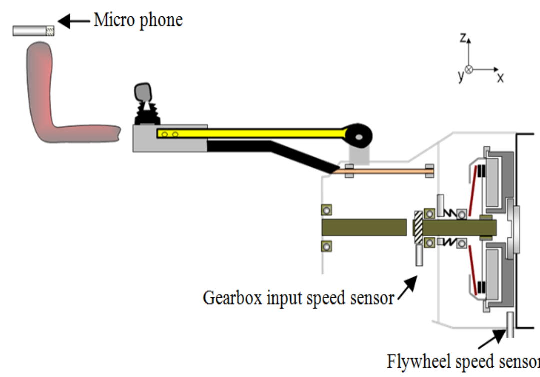

Figure-4. Vehicle instrumentation layout.

Speed sensor fitment in bell housing to focus on flywheel ring gear is shown in Figure-5.

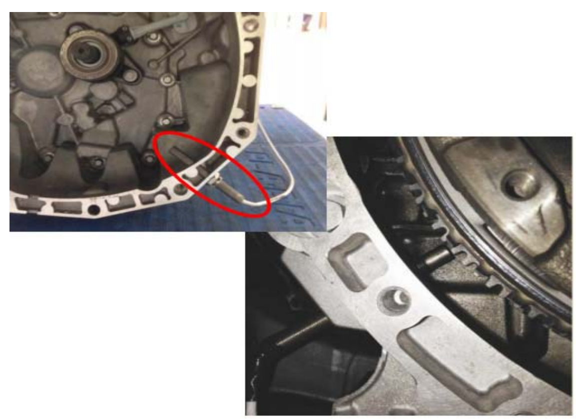

Figure-5. Vehicle instrumentation layout.

5. RESULTS COMPARION AND CORRELATION

Vehicle considered for the investigation is 3 cylinder diesel with the maximum engine torque of 180 Nm. Torsional acceleration is calculated by vehicle speed measurement which compromise order analysis. Time domain data of speed measurement is converted into frequency domain by water fall diagram with the spectral analysis and dominant order 1.5 acceleration is tracked and the same is plotted in Figure-6.

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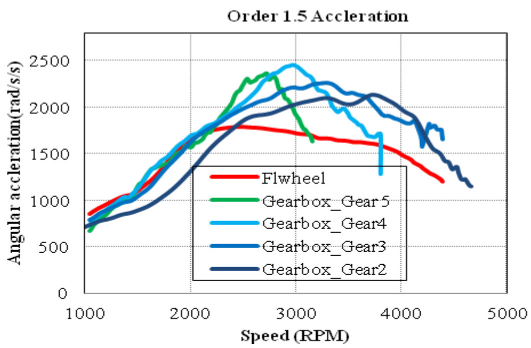


Figure-6. Vehicle measurement angular acceleration vs speed (clutch).

Compare to flywheel acceleration gearbox acceleration is high on certain speed range. This varies depends on the gear engaged. The speed ranges where the maximum amplitude of gearbox acceleration happening is corresponds to the gearbox resonance which produces gear rattle noise. Resonance frequency of gearbox for each gear engaged is compared with simulation in Table-1. The simulated mode 4, gear box resonance frequency matches closely with vehicle test resonance frequency which confirms gear rattle noise issue is the effect of gearbox resonance. Simulated resonance frequency is exactly matching for gear 5. Even for the lower gears the simulation is not varying too much from the test.

Table-1. Gear box resonance frequency comparison.

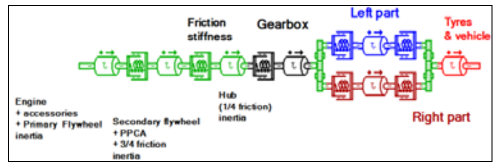
Gear engaged	Test		Simulation
	Speed (Rpm)	**Hz**	**Hz**
Gear 5	2700	69	69
Gear 4	3000	75	73
Gear 3	3500	88	77
Gear 2	3950	99	82

6. CLUTCH MODIFICATION

In order to change the gearbox resonance from the driving range clutch dampers are replaced with Dual mass flywheel. The DMF is two independent masses separated by springs. This splits the inertia between the engine and the transmission to keep the vibration and resonance below the engine idle speed. Typical Dual mass flywheel is shown in Figure-7.

Figure-7. Dual mass flywheel.

Modal analysis with Dual mass flywheel is made with the stiffness of 12 Nm/°. The clutch damper stiffness is considered with very high value.



1: Engine + Primary flywheel
2: Secondary flywheel
3: Clutch damper
4: Gearbox
5: Left wheel
6: Right wheel
7: Vehicle

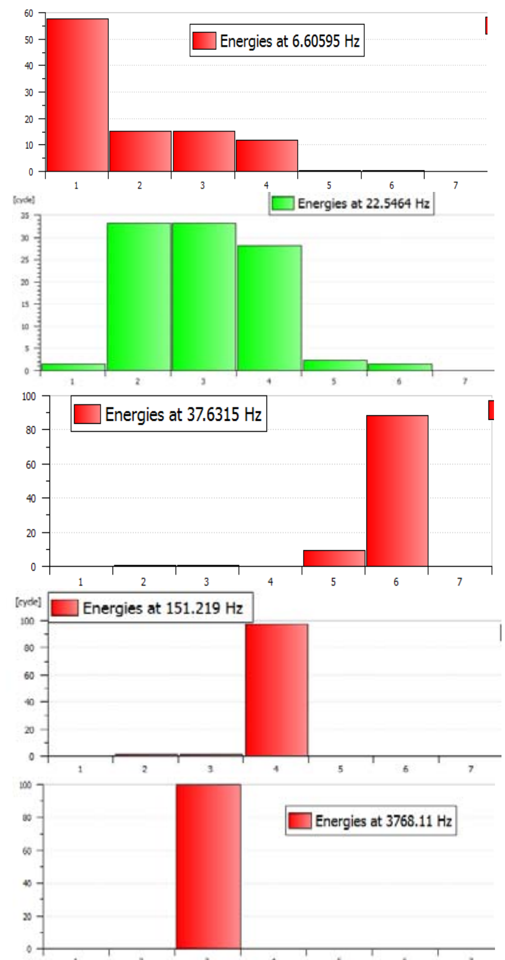


Figure-8. Modal analysis resonance frequencies (DMF).

Modal analysis model with DMF and Modal analysis resonance frequencies are plotted in Fig. 8. In the analysis results totally 5 resonance frequencies are shown. Resonance frequency of left and right wheel is almost equal to 37 Hz so only one wheel is plotted. The simulation results show that gearbox resonance shifted to 151 Hz which is at 69 Hz with the clutch damper. But DMF is resonating at 23 Hz which should be given importance. Vehicle test measurement with DMF shows significant improvement compare to clutch damper design. The angular acceleration of gear box is shown in Figure-9 confirms that there is no gearbox resonance and gear rattle issue.

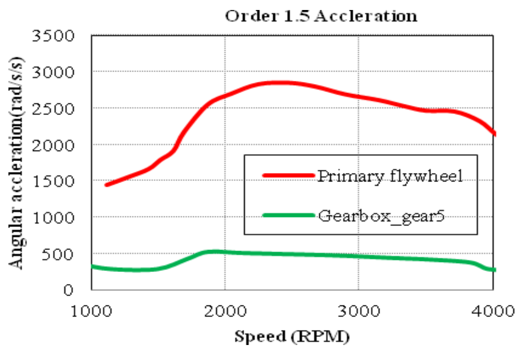


Figure-9. Vehicle measurement angular acceleration vs speed (DMF).

7. CONCLUSION AND FUTHER WORK PLANNED

a) Conclusions

A Typical passenger car with front wheel drive vehicle is studied for gear rattle issue and understood from linear modal analysis the gear rattle is linked in to the gearbox and clutch resonance frequency which is at 69 Hz. Dual mass flywheel is considered in replacement of clutch damper to avoid gear rattle in driving range. The gear box resonance was shifted to 151 Hz by the DMF. Gearbox acceleration level is reduced from 2500 rad/s² to 500 rad/s². Gear rattle issue is solved in driving range by Dual mass flywheel.

b) Further work planned

Non linear simulation model development is planned which will help in performing dynamic response analysis of driveline. Torsional acceleration levels of test measurement can be predicated with the non linear analysis model. This will help in reducing design iteration and proto development cost. Dual mass flywheel resonance below idle rpm needs to be studied with to avoid issues related to dual mass flywheel and idle.

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