International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 9, November- 2012

Power Train Torsional Vibration's Simulation and Correlation with Physical Measurement

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Abstract

This paper describes the methodology of correlation of simulation and actual measurement on vehicle. Simulation is considered as an essential activity to save time and cost of building physical prototyping hardware. Torsional vibration data acquisition, for different test conditions is done simultaneously at all the three location i.e. engine output, gearbox output and axle input.

Data analysis and results are drawn to understand and quantify the torsional vibrations along the power train at various measurement locations. Reliable and Robust computer simulation driveline model is developed for providing a fast, reliable and economical solution during vehicle development stage. Torsional Vibrations of driveline can be optimized by Design of Experiment (DOE) using simulation model by different combinations of inertia, stiffness and damping properties of driveline

1. Introduction

Man, as a mechanical system, is extremely complex and its mechanical properties readily undergo change. There is a very little reliable information on the magnitude of forces required to produce mechanical damage to the human body. As in the case for many other dynamic systems, the human body has been found to exhibit resonances when exposed to vibration stimuli such as ground transportation vehicles. While the tolerance of humans to the same level of vibration varies from individual, the frequency dependence shows the same functional dependence and displays a marked increase in sensitivity

The present work on analysis of torsional vibration of driveline in SUV vehicle is motivated due to the following:

1) Increasing demands to shorten development cycles means that less time is available for both testing and mathematical modeling.
2) Requirement of evaluation of torsional vibration of driveline as a system by computer simulation before the physical prototype and its testing takes place.
3) In vehicle prototype development, the performance of the vehicle can be evaluated with each prototype being developed for different test, but is the expensive way.
4) Requirement of computer simulation (virtual prototyping) for providing a fast, easy, reliable and economical solution prior to vehicle testing.

2. Objectives of the study.

Following are the objectives of the present investigation:-

- Generation of torsional vibration data simultaneously at different locations of driveline under different test conditions of vehicle under consideration.
- Analysis of generated data for finding the high torsional vibration zones for each drive line aggregate viz. engine, gear box, propeller shaft, differential
- Generation of data for torsional stiffness of driveline aggregates through experimental setup for giving input into the computer simulation.
- Generation of driveline model in the software for simulation of torsional vibration in different conditions.

3. Methodology of the present study.

The methodology adopted to carry out the present work is as follows:-

- Selection of rear wheel drive, Vehicle for torsional vibration measurement.
- Vehicle Preparation: Depending upon the location of measurement the fixtures are manufactured for sensor mounting.
- Vehicle Instrumentation: Vehicle is instrumented with magneto resistive angular speed measuring sensors to measure the angular velocity for different locations.
- Data Acquisition: Instrumented vehicle is driven in each gear as per devised test condition to collect the Torsional vibration data.

- Data Analysis: The collected data is post processed using software tools to understand and quantify the Torsional vibrations along the Power train at various measurement locations
- Creation of models of driveline in different gear positions in simulation software and perform numerical calculations

4. Mathematical Model of drive line.

4.1 Model with two masses

Masses m_1 and m_2 connected with spring constant k damping constant d

Differential equation for two mass system

$$m_1\ddot{\theta}_1 + d(\dot{\theta}_1 - \dot{\theta}_2) + k(\theta_1 - \theta_2) = F\cos\omega t$$

& $m_2\ddot{\theta}_2 + d(\dot{\theta}_2 - \dot{\theta}_1) + k(\theta_2 - \theta_1) = 0$ $(\theta_1 - \theta_2)$ is relative angular displacement between two masses. Put

$\theta_i = u_i\cos\omega t + v_i\sin\omega t$ with i =1,2

$$\begin{Bmatrix} k-\omega^2 m_1 & -k & \omega d & -\omega d \\ -k & k-\omega^2 m_2 & -\omega d & \omega d \\ -\omega d & \omega d & k-\omega^2 m_1 & -k \\ \omega d & -\omega d & -k & k-\omega^2 m_2 \end{Bmatrix}$$

$$\text{X}\,.\begin{Bmatrix} u_1 \\ u_2 \\ v_1 \\ v_2 \end{Bmatrix} = \begin{Bmatrix} F \\ 0 \\ 0 \\ 0 \end{Bmatrix}$$

System with n number of masses coupled together [2]

$\sum_i k_{ij} - \omega^2 m_i$ Main diagonal term of the matrix.

$-\sum_j k_{ij}$ first and forth matrix term

$\pm\omega\sum_j d_{ij}$ Second and third matrix term

4.2 Percentage damping

Instead of the damping procedure described above, the simulation program also allows for application of a percentage frequency-dependent damping: Where, ψ has an appropriate value, e.g. 0.1 for 10%.

$$d_{ijper} = \frac{\varphi . k}{2\pi\omega}$$ i.e. frequency dependent

4.3 Transmission Ratios

The effect of transmission ratio is considered by applying the transmission ratio to subsequent masses and reducing the inertia, stiffness and damping parameters as:

$$m_i \to u_i . m_i$$

$$k_{ij} \to u_{ij}^2 . k_{ij}$$

$$d_{ij} \to u_{ij}^2 . d_{ij},$$

$$R_{ij} \to u_{ij}^2 . R_{ij}$$

$$F_i \to u_i . F_i$$

Beginning with a single reference mass whose transmission is set to 1, the program proceeds through the model and assigns a transmission value to each mass and spring, u_i and u_{ij} [2]

- Finding out the Correlation index between experimental and simulation results.

5. Vehicle Preparation

The torsional vibration data is collected at three points first at engine output, second at gearbox output and lastly at differential input. as shown in below Fig 1

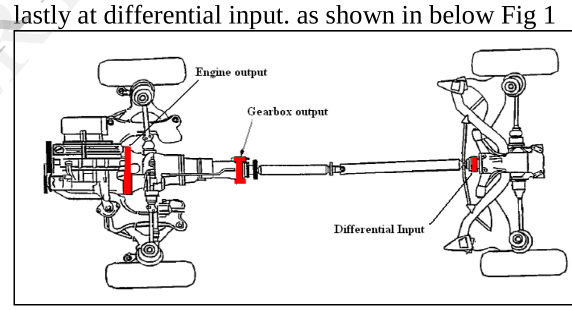

Fig1.Typical instrumentation for driveline torsional vibration data collection

The collected data is post processed using software tools to understand and quantify the Torsional vibrations along the Power train at various measurement locations. Complete analysis enables to know the Torsional vibration flow across the driveline and helps to identify the area which needs the improvement.

Following analysis is 3D order analysis for peak angular acceleration Vs engine RPM for engine out. This represents angular acceleration (torsional vibration) with respect to orders and engine RPM. Also we can quickly find the dominating orders.

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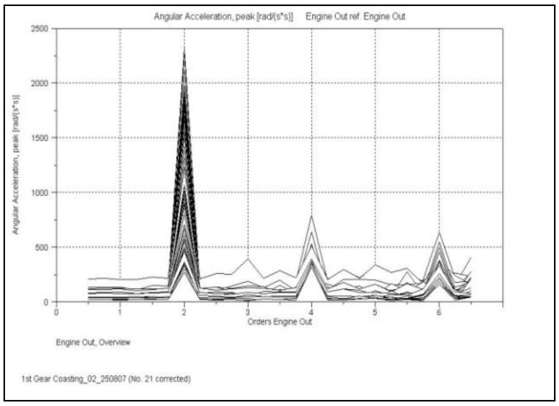

Fig-2 Angular Acceleration Vs Order Analysis plot

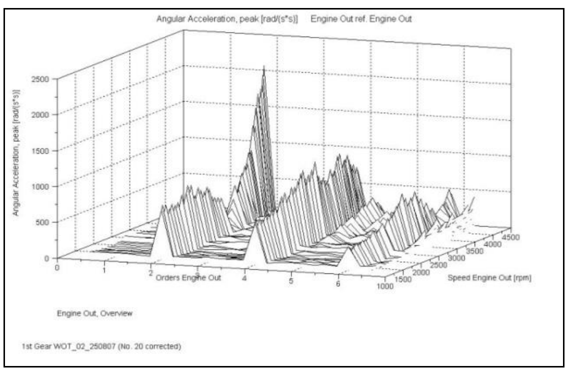

Fig.3 3DAngular acceleration Vs Engine RPM for the first gear

6. Results from Experimental Analysis of Torsional Vibrations

Torsional vibration data analysis is done for two following conditions

I Second order 2D vibration angle analysis Vs engine RPM far all three location engine out, gearbox out and axle input.

II Second order 2D angular acceleration analysis Vs engine RPM for all three location engine out, gearbox out and axle input.

Simulation software allows user to create model of vibrating system. Model of vehicle driveline is made with help of software tools. Initializing an excitation is accomplished with directly via a RAS measurement Channel then Numerical calculations in the frequency domain may then be performed on the model. The direct comparison of simulation curves with test data (Experimental Analysis) makes optimal adjustment

Parameters like inertia, stiffness and damping properties of driveline components are adjusted to get optimal results. So in this way we can reduce the vehicle development time of simulation.

7. Physical Data Collection

The experimental set up as shown in figure 4 is used to find out torsional stiffness of a given component. Component can be coupled with this instrument by making suitable adapter flanges at both ends of the component. One end of the component is held rigidly and at other end torque is step by step induced through hydraulic pressure. On board system is provided to measure the torque induced and corresponding angular displacements at both ends over the length of shaft. Acquired data is post processed to find out the torsional stiffness of the given component

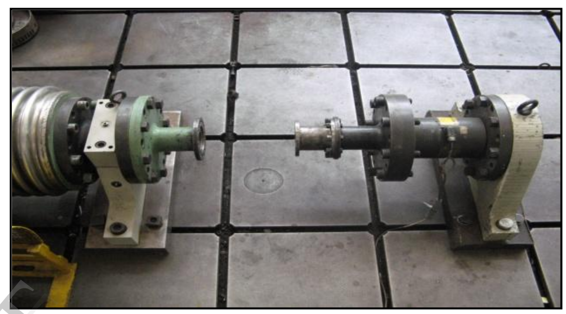

Fig.- 4 Test rig for Stiffness Measurement on Rotary actuator

8. Driveline Model Creation-

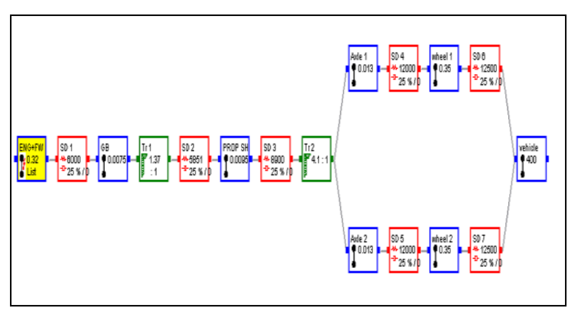

Fig.5 Final simulation model

The final simulation model after entering the input data such as- a) mass moment of inertia is in kg m². Spring Constants / Stiffness
b) damping d = ψ · c / (2 π · ω), with ψ representing the relative dependence (e.g. 0.1 for 10%), c is the spring constant and ω the angular frequency.
c) Transmission-The simulation program allows for insertion of a transmission element including

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transmission ratio between two constituent elements of a simulation model

d) Force List -The vibration amplitude is calculated as a function of the rotational speed. For the calculation, the values of the excitation force as a function of the rotational speed are entered in a so-called force list.

9. Correlation of Simulation Results With Experimental Analysis

The signature of the plot form simulation results and experimental results matches, this shows that the prediction from the simulation model holds good with the results from physical measurement on the vehicle. The co-relation between the experimental and simulation results is found to be 98%

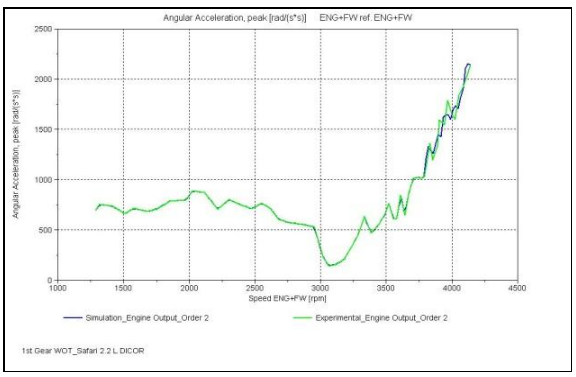

Fig-6 Plot for the correlation between experimental and simulation results

9. Discussion

The co-relation index at engine out in all the test conditions is holding well within 97% with experimental results. At gear box out the co-relation index is found to be 76% with experimental test results. The effect of coulomb friction and structural damping might be leading to the different simulations results as compared experimental tests. At rear axle in the co-relation index is 71% matching with the experimental test results, the difference between the gear box out and the rear axle out co-relation index is 5% , although this difference is very less the effect of body structure and propeller shaft joint angles need to be looked into for obtaining the better co-relation

10. Conclusion

As discussed in the above section the entire process is divided into two activities viz. experimental torsional vibration testing on SUV and simulation of same. Each activity plays an important role towards accurate analysis and prediction of torsional vibrations. From the above workout following results are presented

- Torsional vibration data acquisition, for different test conditions is done simultaneously at all the three location i.e. engine output, gearbox output and axle input.
- Data analysis and results are drawn to understand and quantify the Torsional vibrations along the Power train at various measurement locations.
- Reliable and Robust computer simulation driveline model is developed for providing a fast, reliable and economical solution during vehicle development stage.
- Torsional Vibrations of driveline can be optimized by Design of Experiment (DOE) using simulation model by different combinations of inertia, stiffness and damping properties of driveline.
- The correlation index for engine output is 0.972, gearbox out is 0.76 and for rear axle is 0.71 are achieved between simulation and experimental results.

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