22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

SOLUTION OF DYNAMICS AND ACOUSTICS BY VIRTUAL POWERTRAIN

P. Novotný[*], M. Zubík[**], A. Prokop[***], K. Řehák[****]

Abstract: *An advanced computational model suitable for the development of a modern powertrain in the field of noise and vibration is introduced. The advanced computational model of the powertrain is developed as a powerful tool for the solution of structural and also thermal and fatigue problems. The virtual powertrain is assembled, as well as numerically solved, in Multi Body System extended by user written subroutines. The virtual powertrain results are validated by measurements performed on compression ignition in-line six-cylinder engine.*

Keywords: Powertrain, dynamics, vibrations, acoustics, multibody.

1. Introduction

In today’s fast paced automotive market, the computational methods are prerequisites to ensure low levels of sound, vibration and harshness (NVH) of modern powertrains. The complexity of computational models is always very important issue. The paper will present new and advanced approaches for evaluation of different powertrain noise sources and their influence on vibrations transmitted to the interior or exterior of the car.

2. Modelling approaches

This work evaluates noise sources in a powertrain and presents ways how the dominant noise source can be reduced by advanced computational models. The considered features of the computational models can be summarized as follows:

- Elastic deformations of main components enabling an evaluation of outer surface vibrations.
- Interactions between engine subsystems (cranktrain, valvetrain, gear timing drive etc.).
- Steady state or transient solution.
- Non-linear behaviour of interactions between components (slide bearings, gear tooth contacts, cam tappet contacts, etc.)

All the numerical approaches presented are integrated into a commercial program ADAMS extended by FORTRAN subroutines written by the authors.

2.1. Powertrain component modelling

Flexible bodies represented by FE (Finite Element) models have crucial importance for powertrain dynamics simulations. The proposed computational model uses reduced form of FE flexible bodies and the Craig-Bampton reduction method (Craig, 1981) is used for reduction of the FE models.

---

[*] doc. Ing. Pavel Novotný, Ph.D.: Institute of Automotive Engineering, Brno University of Technology, Technicka 2896/2; 616 69, Brno; CZ, novotny.pa@fme.vutbr.cz

[**] Ing. Martin Zubík: Institute of Automotive Engineering, Brno University of Technology, Technicka 2896/2; 616 69, Brno; CZ, zubik@fme.vutbr.cz

[***] Ing. Aleš Prokop: Institute of Automotive Engineering, Brno University of Technology, Technicka 2896/2; 616 69, Brno; CZ, prokop.a@fme.vutbr.cz

[****] Ing. Kamil Řehák: Institute of Automotive Engineering, Brno University of Technology, Technicka 2896/2; 616 69, Brno; CZ, rehak@fme.vutbr.cz

Crankshaft and engine block FE models present the fundamental components. The other flexible parts using reduced FE models are a camshaft, valve springs and rockers.

2.2. Torsional rubber damper model

A rubber damper model assembled in Multibody system (MBS) includes only general properties like torsional and axial stiffness but with very important dependencies on frequency and temperature. The frequency dependency in time domain is modeled via a series of four Maxwell's members (spring and damper). The overall static stiffness values originate from a detailed solution of the three dimensional FE model. Parameters of Maxwell's members are fitted by Matlab software functions to satisfy frequency dependency of the rubber. More details about torsional rubber damper modelling can be found in literature (Novotny, 2009).

2.3. Body interactions via slide bearing model

The loading capacity of a slide bearing included in the model is considered in a radial direction and including pin tiltings, which means that radial forces and moments are included in the solution. The slide bearing forces are based on a numerical solution of Reynolds differential Eq. (1), including elastic deformations of shells. The hydrodynamic forces are stored in hydrodynamic databases. Basic form of Reynolds equation is

$$\frac{\partial}{\partial x}\left(\frac{\rho h^3}{12\eta}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{\rho h^3}{12\eta}\frac{\partial p}{\partial z}\right)-\frac{U}{2}\frac{\partial(\rho h)}{\partial x}-\frac{\partial(\rho h)}{\partial t}=0 \tag{1}$$

where p is pressure in oil film, h is oil film thickness, U is relative velocity of pin relative to shell, ρ is oil density, η is oil viscosity, x and z are coordinates and t is time.

The Reynolds equation is transformed into dimensionless coordinates, discretised by Finite Difference Method (FDM) and then numerically solved by Gauss-Seidel method employing Successive Over Relaxation (SOR) strategy. The pressure in oil film is integrated and the resulting forces are stored in reaction force databases. During the solution in time domain MBS solver reads the forces from databases for every solution time step.

2.4. Gear Timing Drive

A model of a gear meshing includes variable stiffness of meshing with backlash option. The variable stiffness of meshing gears enables to incorporate tooth meshing frequency, as well as its harmonic components. The computational model of meshing helical gear also includes all resultant forces between teeth (radial, axial and tangential forces). Detailed strategy and gear timing drive model influences can be found in a research works (Novotny, 2009).

2.5. Fuel Injection Pump

When taking into consideration the powertrain NVH, the injection pump can highly influence the dynamics of powertrain parts. In particular, the valvetrain and the gear timing drive can be influenced by high peak torques of the injection pump.

Essentially, the used type of injection pump includes injection pistons. The movement of the injection piston is controlled by a cam profile. Each cam interacts with a roller tappet. This interaction (cam – roller contact) produces time dependent torques on a pump shaft in each pump section.

Influences on the other powertrain components are the main aims of an injection pump MBS model. Therefore, the model includes a rigid body with inertia moment corresponding to a shaft and reduced inertia moments of other pump parts. Resultant torque in dependence on time and corrected for engine speeds is entered into the rigid body.

2.6. Virtual Powertrain

An advanced computational model of the powertrain, i.e. a virtual powertrain, is solved in time domain. This enables to incorporate different physical problems, including various nonlinearities. The virtual powertrain is assembled, as well as, numerically solved in MBS ADAMS. ADAMS is a general code and enables an integration of user-defined models directly using ADAMS commands or using user written FORTRAN or C++ subroutines. The virtual powertrain includes all significant components necessary for NVH analyses. The included modules are a cranktrain module, single valvetrain modules and a camshaft component, a gear timing drive module, a torsional damper module and a fuel injection pump module.

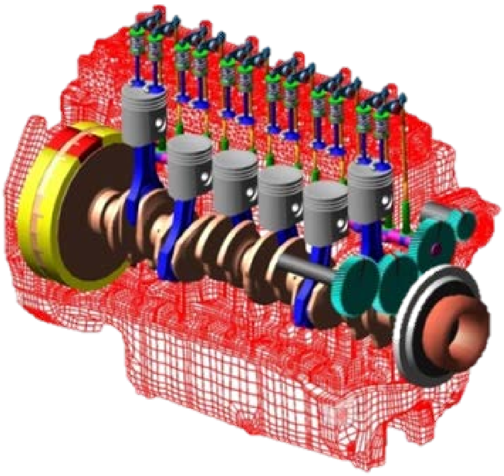

Fig. 1: Virtual powertrain assembled in multibody system

3. Validation of Virtual Powertrain Results

Proposed methods are applied to a turbocharged compression ignition (CI) six-cylinder engine. In general, powertrain surface vibrations and radiated noise are coupled.

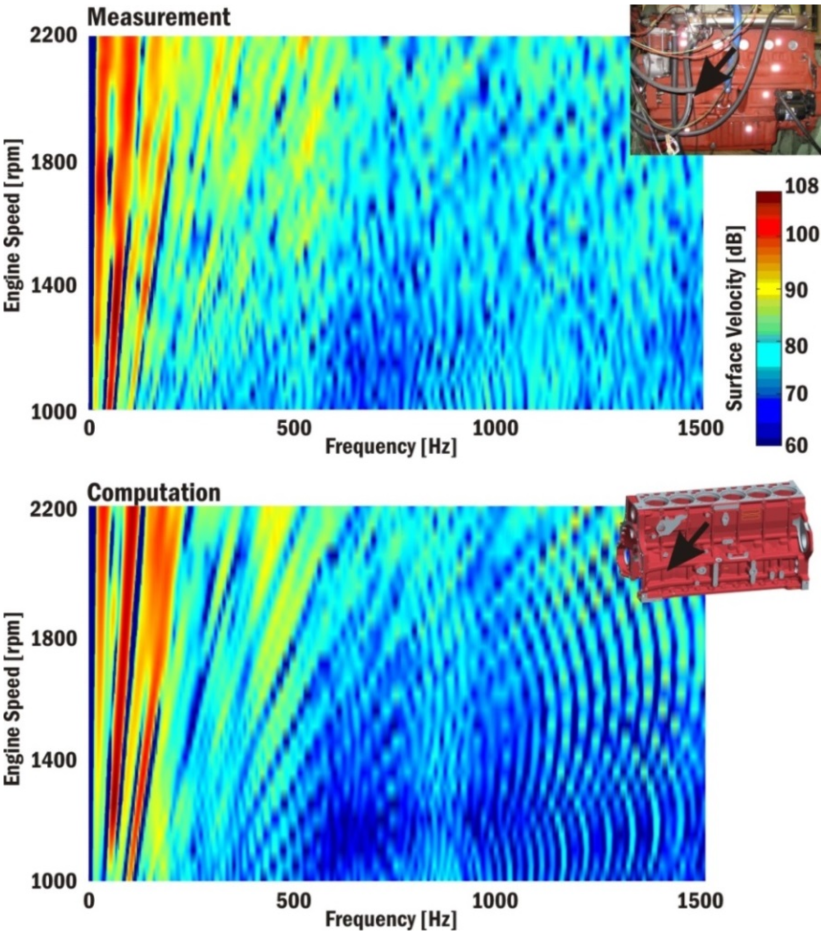

Fig. 2: Measured and calculated waterfall diagrams of crankcase surface velocities near the second cylinder and crankshaft axis

The noise produced by a powertrain can be estimated from crankcase surface velocities. Fig. 2 shows measured and calculated waterfall diagrams of crankcase surface velocities near the second cylinder and crankshaft axis. The value $v_0 = 5.10^{-8}$ ms^{-1} is used as a reference velocity. Measured results have been determined by POLYTEC Vibrometer OFV-5000. The calculation results have been obtained by virtual powertrain and incorporating modules defined in a chapter 2.6.

4. Conclusions

The results of the work show that the most complex computational models on the level of virtual prototypes are necessary to fully simulate noise and vibrations of powertrains. These large models also enable to understand interactions among different powertrain subsystems. The fact that all the results are computed by one computational model and stored in one result file is also an advantage.

The greatest disadvantage lies in high model complexity. The complex computational models require a high number of parameters to be inputted, which are often hard to find. Other disadvantages are: long solution times to solve the models numerically and sometimes a large storage place required for computed results.

Influences of other powertrain subsystems, gear timing drive or injection pump influences, on noise and vibrations are significant. All significant noise sources, as combustion pressure forces, meshing gear forces or injection pump torques, have to be also included into the powertrain computational model.

Acknowledgement

The research leading to these results has received funding from the Ministry of Education, Youth and Sports under the National Sustainability Programme I (Project LO1202).

References

Craig R. R. (1981) Structural Dynamics. First edition, John Wiley & Sons, 1981, ISBN 0-471-04499-7.

Novotný P. (2009) Virtual Engine – A Tool for Powertrain Development. Inaugural Dissertation, Brno University of Technology, Czech Republic.