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VIRTUAL PROTOTYPE APPLICATION TO HEAVY-DUTY VEHICLE GEARBOX CONCEPT

A. Prokop*, K. Řehák**

Abstract: *This paper deals with application of virtual prototype to the heavy-duty vehicle gearbox concept. First the methodology is developed and tested on the single-stage gearbox concept, where the sensitivity of input parameters is investigated and validated by the experiment. The methodology is applied to the heavy-duty vehicle gearbox concept, where all inputs parameters are calculated similarly as in case of single-stage gearbox. The virtual prototypes enable to investigate influence of different input parameters on the design parameters, which are necessary at design phase. The surface normal velocity, which is related to noise prediction, can be evaluated. An experimental approach to validate the application on such high level of gearbox has not been performed yet.*

Keywords: Surface normal velocity, Noise, Vibration, Harshness.

1. Introduction

The powertrain unit is continuously being developed to satisfy limits and requirements. The customer demands are related to the increase of power at continual stroke volume decreasing and fuel consumption decreasing. The harmful gas production is limited by legislation, which is getting stricter. At last but not at least, the legislation determines the noise limits for passenger and also for people around and also cities and locations where the traffic density is higher. The vibrations and related noise play an important role from the comfort point of view, thus they belong to one key factor of competitiveness between products in automotive industry. To decrease the overall noise level of the car, the dominant sources of noise have to be investigated.

Because of customer demands on low fuel consumption and also low price of the product acquisition, producers have to decrease both the development phase costs and material consumption. If the modification is performed, for example wall thickness is decreased in wrong area, the noise and related vibration could increase significantly. For that reason, these tasks cannot be performed without verification. This leads to a high number of prototype testing at the developing phase. Many manufacturers created their own methodology to predict behaviour of product without the necessity of creating numerous prototypes. On the other hand, all procedures should be validated by technical experiment. The noise, vibration and harshness (NVH) is very actual topic, because the new limits need to be met. Therefore, it is necessary to decrease the noise of the whole product by detecting potentially critical sub-products and decrease the noise of the most significant source. The gearbox belongs to the key components of almost every transport means, thus impacts on material saving and NVH parameters are taken into account. Moreover, when the other parts, as for example combustion engine, are not connected to the transmission, the dominant excitation is due to gear meshing phenomena (Tuma, 2014). In the end, vibrations of the external surface of the transmission due to inner processes are also accompanied by the noise emitting to the surroundings.

2. Methods

The numerical simulation is a frequently used approach in research and at developing phase of

* Ing. Aleš Prokop, PhD.: Institute of Automotive Engineering, Brno University of Technology, Technicka 2896/2; 61669, Brno; CZ, prokop.a@fme.vutbr.cz

** Ing. Kamil Řehák: Institute of Automotive Engineering, Brno University of Technology; Technicka 2896/2; 61669, Brno; CZ, rehak@fme.vutbr.cz

transmission (Kumar, 2014). In the presented paper the combination of multibody software ADAMS and finite element method (FEM) software ANSYS is used. Each part of the methodology is verified separately by an experimental approach on the single stage gearbox which was designed and manufactured for that purpose (Loutas, 2009). The parameters of the gearbox and validation with experiment measurement are thoroughly described in (Prokop, 2015). The software ADAMS is used to create parametrical open code to be used at different transmissions. It enables to include flexible bodies, bearings stiffness, gear mesh stiffness, backlash, variable input speed, and torque.

The FEM is used for Craig Bampton reduction which replaces real modal properties with the simplified approximation established from the two variants of degrees of freedom, multiplied by the special Craig-Bampton transform matrix, see Eq. (1):

$$\{\mathbf{u}_A\} = \begin{Bmatrix} \mathbf{u}_b \\ \mathbf{u}_L \end{Bmatrix} = \begin{bmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{\Phi}_R & \mathbf{\Phi}_L \end{bmatrix} \begin{Bmatrix} \mathbf{u}_b \\ \mathbf{q} \end{Bmatrix} = \mathbf{\Phi}_{CB} \begin{Bmatrix} \mathbf{u}_b \\ \mathbf{q} \end{Bmatrix}, \tag{1}$$

where $\boldsymbol{u}_A$ is the original vector of deformation, $\boldsymbol{u}_b$ are the boundary degrees of freedom (DOFs), $\boldsymbol{u}_L$ stands for interior DOFs, $\boldsymbol{q}$ represents modal DOFs, $\boldsymbol{I}$ is the identity matrix element, $\boldsymbol{\Phi}_R$ is rigid body matrix element and in the analogical way $\boldsymbol{\Phi L}$ are the fixed base mode shapes matrix element.

The stiffness of bearings is calculated on one rolling segment and afterwards converted to the whole bearing. The gear mesh stiffness is calculated for one tooth, which repeats periodically. The stiffness corresponds to the results, which are mentioned in (Kiekbush, 2011).

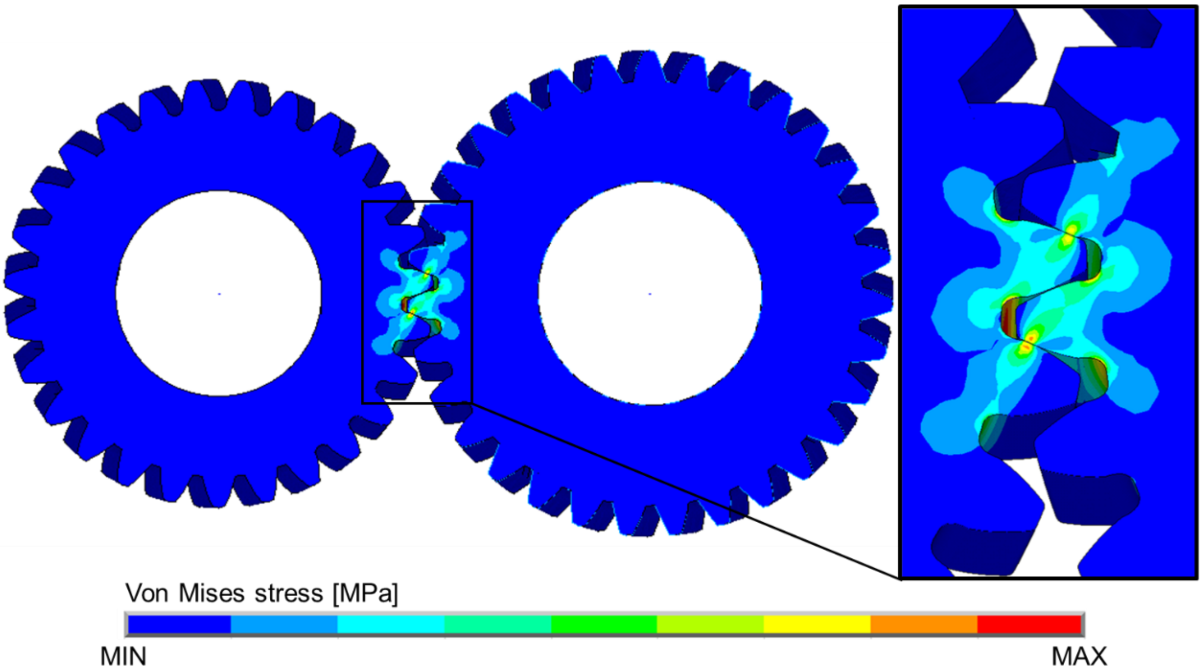

Fig. 1: Gear mesh Von Mises stress distribution.

2.1. Application to the heavy-duty vehicle gearbox concept

The heavy-duty gearbox concept is shown in Fig. 2. This virtual prototype enables to simulate dynamic properties of the transmission. On the input shaft variable speed is applied. Based on the functional principle of the combustion engine, output shaft is loaded by torque evaluated from traction forces. The gear mesh stiffness is calculated for each couple of gears at different torque up to designed maximal value. The bearing stiffness is calculated for proposed type and enables to confirm the lifetime of bearings. The backlash is taken from similar gearboxes.

3. Results

The virtual prototype enables to simulate steady state, as well as run up and run down for different selected gear. The surface normal velocity distribution is the most important result from the acoustic point of view, which is shown for run up simulation in Fig. 3. This velocity can be used as the input for another simulation to get sound pressure level acoustic map, which is important at the final phase of some product. Another possible virtual prototype outputs, which are important at design phase or when investigating some issue, are progress of axial distance between gears, deformation in bearings, reaction forces in bearings or reaction forces at the transmission housing handles, see Fig. 4.

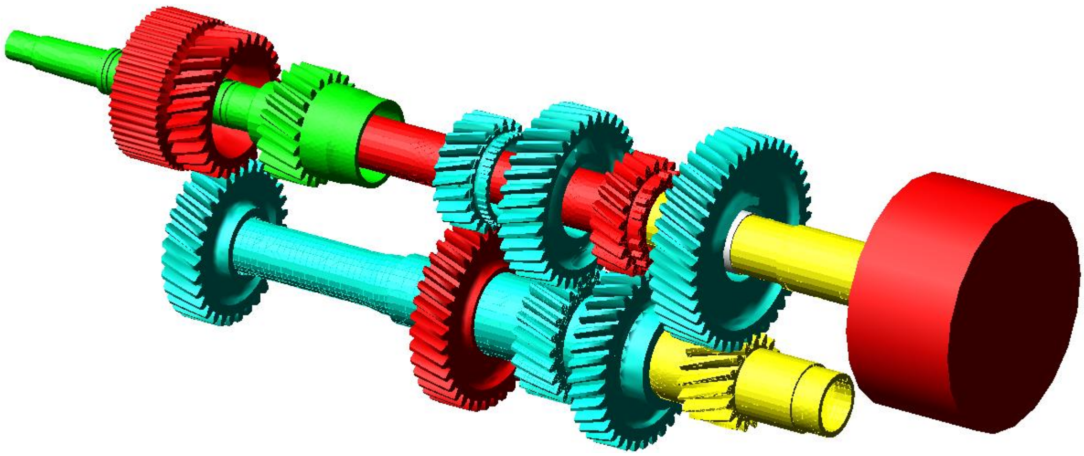

Fig. 2: Heavy-duty gearbox concept.

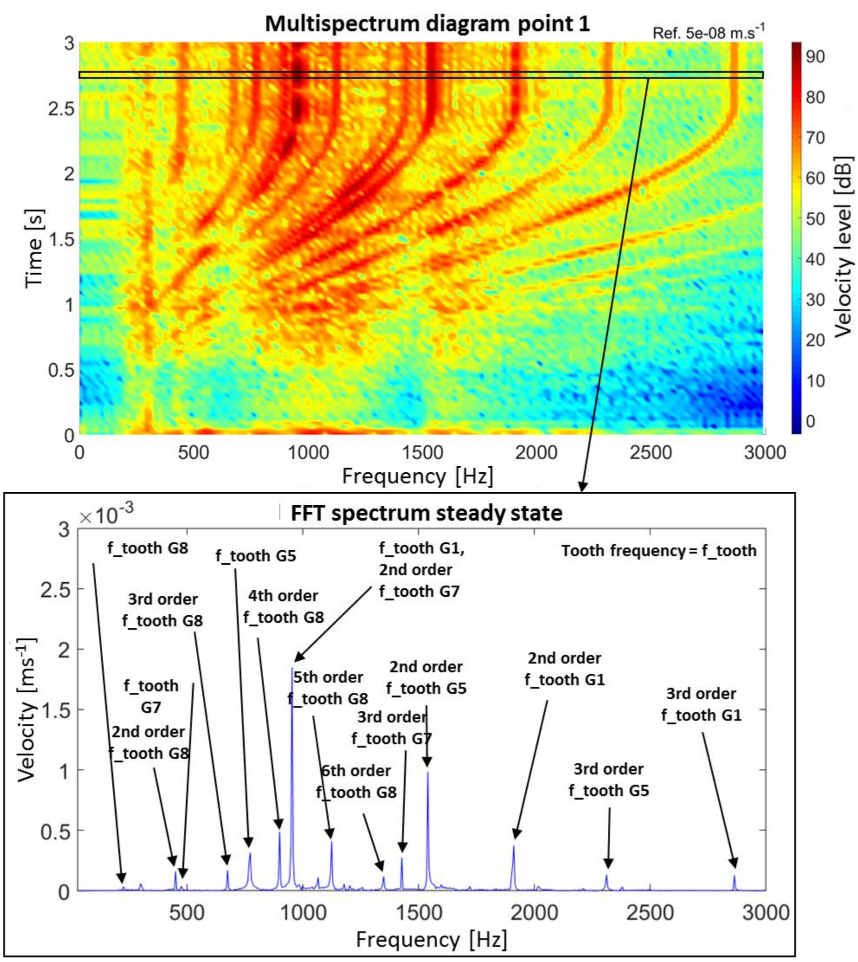

Fig. 3: Run up simulation for maximum rotational input speed 2160 rpm.

4. Conclusions

The methodology, which is based on the combination of FEM and MBS, is developed on the single stage gearbox. One of the most important advantages of this methodology is the open code and an easy way of modification with aim to use it for wide range of transmissions. Also very useful is the possibility to use results as input from FEM, thus include own geometry modification. This article presents results and possibilities of using this methodology on the more complex transmission concepts. Nonetheless, this concept of gearbox is developed and the methodology is applied as another option to gain important information without the need to create high number of prototypes.

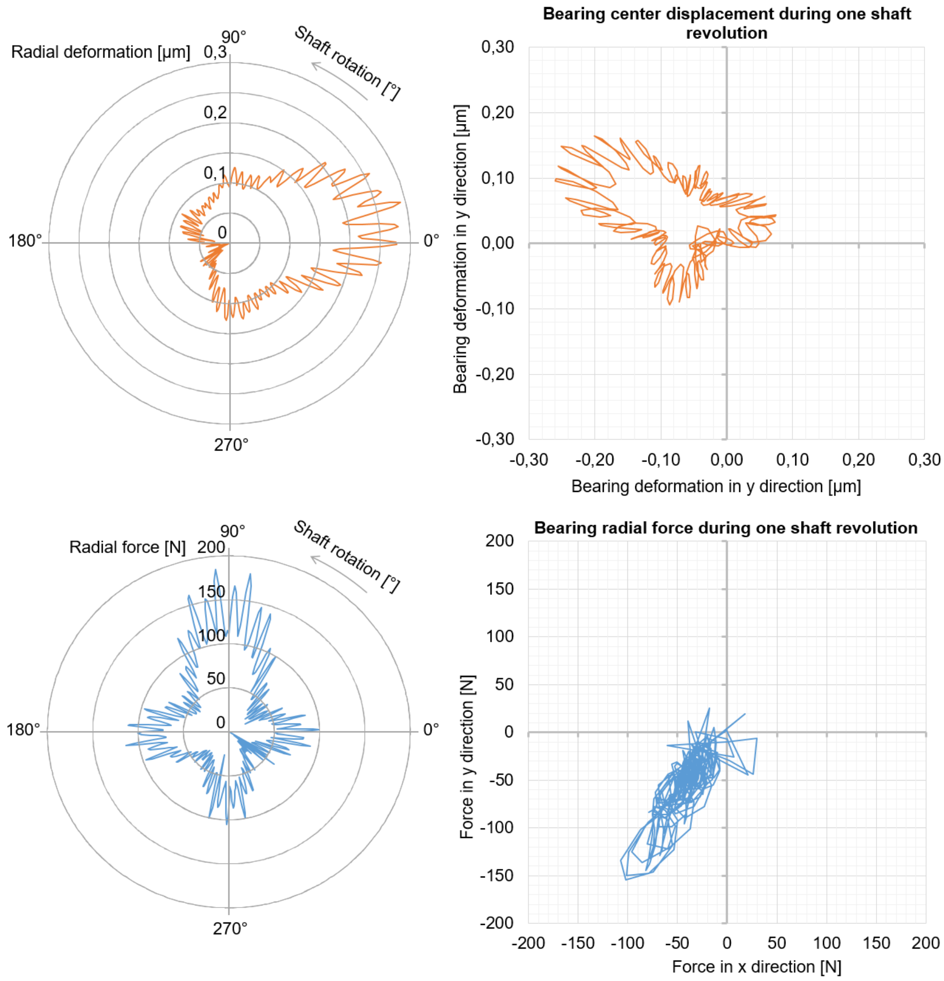

Fig. 4: Bearing radial displacement and force during one shaft rotation.

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