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INVESTIGATION OF SINGLE STAGE GEARBOX PARAMETERS INFLUENCING SURFACE NORMAL VELOCITY

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Abstract: *Presented paper examines the effect of the basic gearbox parameter on the surface normal velocity of the gearbox top cover. Firstly, in order to validate the inputs and results of the whole methodology a single stage gearbox was designed and manufactured. Secondly, a dynamic model is built for the single stage gearbox and each part of it is validated by an appropriate experiment. After the good correlation of the model and measurement, an additional simulation is performed to verify specified influences. The investigation focuses on finding the best conditions between thickness of gearbox housing top cover and dimensions of shafts, which are represented by the torsional stiffness. The method described is able to determine the impact of each modification, thus it can be useful at the design phase and also during measurement or investigation of an existent problem.*

Keywords: Single stage gearbox, Transmission, Noise, Vibration.

1. Introduction

Combustion engines, electric motors, compressors or transmissions are, nowadays, designed to have maximum possible efficiency, wide variety of running conditions, complexity and low production costs. The increasing number of such devices closely relates to the prevailing popular health issue topics. Moreover, the increasing global number of all the pollutants speeds up the development of electric car and accumulators. Since the combustion engines are absent in this regard, other noise components come into focus, mainly the transmissions. Currently, the gearboxes in the locomotive area are becoming a hot topic because trains are usually associated with densely inhabited district areas. In addition, transmissions in wind power plants, which are examined in papers by Feng et al. 2014 and Jin et al. 2016, as a renewable power source, are dealt with very often when the noise in surrounding areas is concerned, significantly influencing life quality there. Automobile industry with an extensive number of products is another part of this issue, where the transmission is one of the investigated topic (Kadmiri et al., 2012).

In cases where the transmission is expected to be the dominant noise source, usually it is the housing, which is responsible for more than 80% of the whole transmission emitted noise (Zubík et al., 2015). Housing NVH improvement is performed predominantly by a modal analysis, which can provide basic information about frequency and mode shape. This approach has some disadvantages, the frequency does not have to be, necessarily, excited by operation conditions or, on the other hand, the higher mode (over the operation mode) can be excited. Moreover, this approach does not provide any information about surface velocity, which is closely connected to the emitted noise. Modal analysis has an essential potential in a design phase when validating the differences between two possible options takes place (Yongxiang et al., 2014). The next level of gearbox investigation lies in using harmonic analysis, which can be performed

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by experimental or numerical approach. Harmonic analysis can provide information about surface normal velocity, but the exciting forces have to be known, which is sometimes difficult to obtain.

For that purpose, the Multibody dynamics system can be used. Inputs causing excitation here can be formulated in an easier form – input torque and rotational speed, which are transferred into related forces acting on each model part. The numerical simulation of transmission is frequently examined and also extensive topic, but all models have to be at the end verified by an experiment. The most advantageous variant of the transmission seems to be the single stage gearbox, because of easy modification to different gearwheels, bearings, shafts and covers. This kind of transmission is widely used for examination of oil behavior, the influence of contact behavior, unbalance, backlash, torque value and transmission error (Razpotnik et al., 2015; Ma et al., 2012; Loutas et al., 2012; Lei, 2010; Andersson & Vedmar, 2003; Ma et al., 2012). This paper deals with the examination of dynamic simulations of the single stage transmission, where the normal surface velocity on the top cover is mainly observed.

2. Methods

In order to examine the concept of gearbox dynamics, single-stage gearbox unit was chosen. It is due to a relative simplicity of the shape but still comparable behavior with the standard transmissions. First step of such a study should always take into consideration how to provide reliable experimental validations. Comparison with real the measurements is necessary for the evaluation of computational dynamic characteristics when compiling the methodology for the first time. Once the procedure on this simplified gearbox unit is complete, it can be extended and applied to any transmission with experimental validation at the end. The information about the used gears, gearbox housing, testing state and measuring are summarized in paper by Zubík et al., (2015).

2.1. Multi body simulation model

The multibody simulation is a very powerful tools for description of dynamic behavior. The gearbox is predominantly represented by information about the gear mesh contact, shafts, bearings and housing. To attain the most corresponding behavior, the most important is that housing should be considered as flexible by using Craig Bampton reduction principle. This procedure replaces real deformations included in the basic equation of motion form by the simplified approximation established from the two variants of degrees of freedom multiplied by the special Craig-Bampton transform matrix, see equation 1 (Craig 1968):

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

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, $\mathbf{q}$ represents modal DOFs, $\mathbf{I}$ 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. Deformation approximation is inserted into the equation of motion. The aim of this process is to model the assembly parts independently, where the internal dynamic behavior is represented by the natural vibration modes.

The whole model consists of gears mounted on the rigid shafts, where shaft torsional stiffness is defined by spring-damper coupler. Transmission housing is represented by the flexible body with the experimentally specified damping ratio. Parts connection is done through bearings specified by radial and axial stiffness. The whole model is loaded by the constant torque moment on the output side and rotation speed is going up to 6000 rpm on the input side.

2.2. Results

The main aim of this comparison is to find the best variant of cover thickness and shafts stiffness in operational range up to 500 Nm torque. Appropriate model with gear contact stiffness based on FE simulation is used, including the real gear geometry. Boundary conditions are set to cover the whole torque range. At first the cover thickness is optimized based on the torque and afterwards the best shaft variant is checked for previously chosen best variant of cover thickness. The highest value of surface normal velocity at three points on the top cover during run up to 6000 rpm is observed for each case from the graph, shown in figure 1.

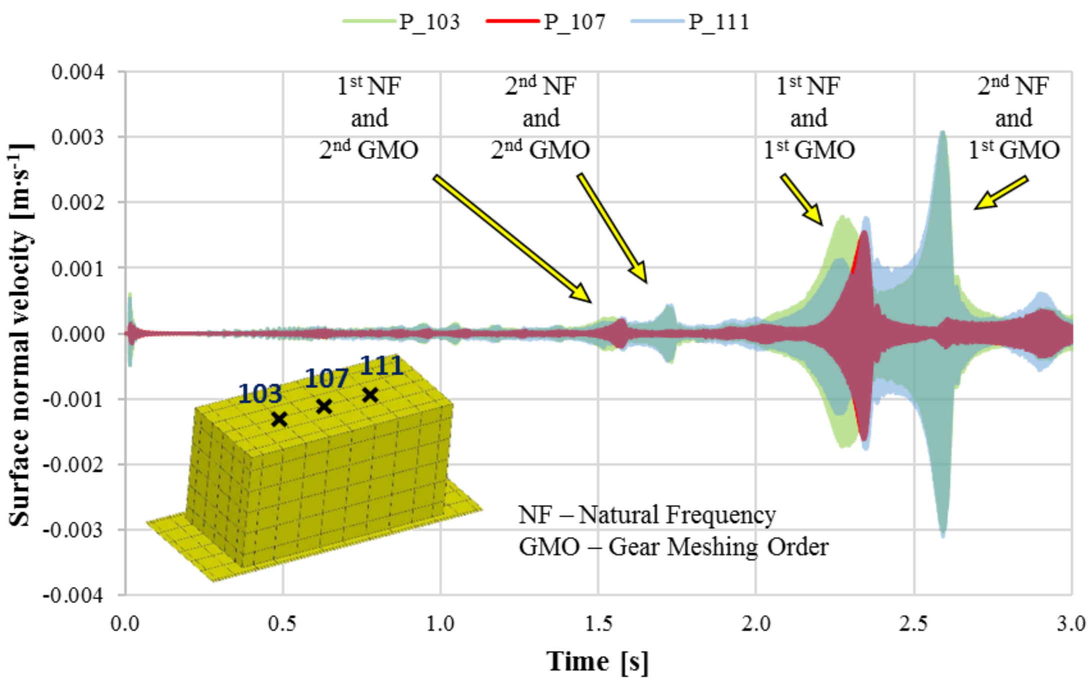

Fig. 1: Surface normal velocity amplitude identification on the top cover points.

The highest amplitudes are checked by applying partial FFT decomposition of the signal and comparison with the natural frequencies of the appropriate variant of housing. It has to be taken into account, that modal analysis in free boundary conditions used for the flexible body reduction does not include all of the natural frequencies and shapes. Some of them are a result of the bonded attachment of the gearbox housing, but still can be excited in the real operating conditions. To gain further knowledge, separate coupled modal analysis should be performed together with the uncoupled one.

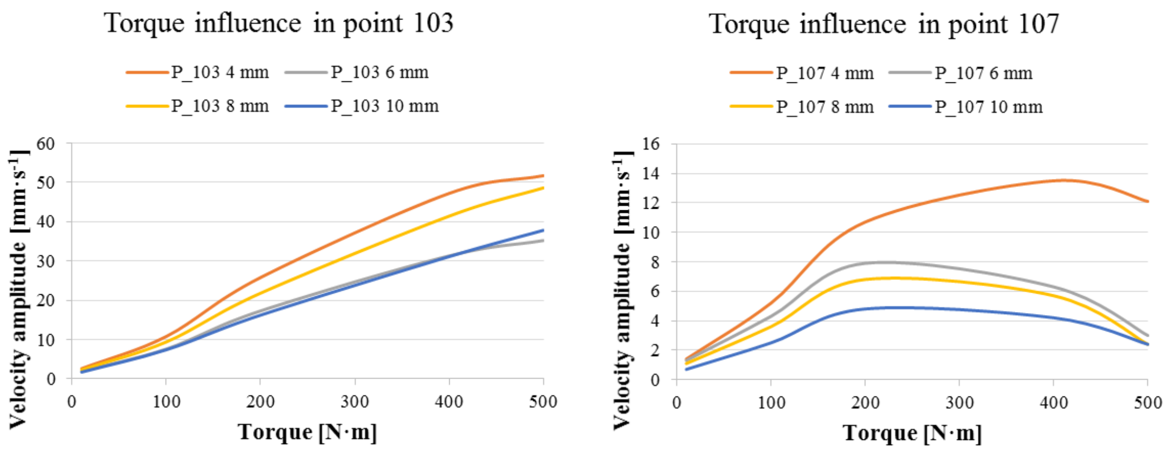

Fig. 2: Surface normal velocity amplitudes related to applied torque and gearbox housing cover thickness in two separate points 103 and 107.

Figure 2 shows the tendencies in the progress of surface normal velocity amplitudes when changing the housing cover thickness. From both result points, 103 and 107, can be assessed that the value 6 mm of thickness is the best option when considering material costs and the final level of velocities. Result data from point 111 are not presented because of very similar tendencies regarding the point 103. Engineering approach usually improves surface vibrations by adding stiffening ribs to the structure. Additional ribs on the cover would definitely change the results to have possibly even thinner cover with lower velocities, but this is not primarily the intention of the study. Presented solution is primarily chosen to maintain gearbox simple construction and not to achieve best cost effectivity.

The impact of shaft torsional stiffness is observed, where by 10 times increased and decreased value of stiffness is used, but without any significant change in the final surface velocities. In smooth operating conditions (with constant loading torque) is no need to consider torsional deformations of the shafts because they are hardly transferred further into the gearbox housing.

3. Conclusions

The method described in this paper can predict the gearbox dynamic behavior of a gear set before the manufacture. This phase predominantly focuses on the fast but still valid solution for finding the best components parameters. The thickness of cover or wall generally, is one of the most important factor for noise emission. The optimal value of cover thickness was found based on the increasing speed with constant loading by torque. The next step was based on the influence of shaft diameter, which was represented by the shaft torsional stiffness. There is no significant effect of torsional stiffness on normal surface velocity. Another case with varying input torque or speed could be more appropriate for this investigation. With some modifications, the methodology and experience gained from the experimental gearbox examinations can be easily used for common heavier single stage or two stage locomotive gearbox.

In the future step, a model of each component on a higher level of will be tested and it will undergo same testing of parameters afterwards.

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