PROPOSAL OF GEARBOX DESIGN METHOD WITH LOWERED VIBROACTIVITY

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Abstract

Research of vibroactivity of the means of transport, in particular of the gearbox, has become of significant importance in the recent years. Reducing of their environmental nuisance consists primarily of reducing the noise and vibration levels. Research of this type is currently conducted using simulation models, which is economically justified. The results of these studies may be a basis for the design of a gearbox with lowered vibroactivity.

The paper presents a proposal of the design method of a gearbox with lowered vibroactivity. The basis for the method consists of dynamic models of the gearbox in the transmission system and FEM models of different design solutions of ribbed housing, which are the main source of vibration and noise emitted by the gearbox.

It follows from previous research that the housing is excited to vibrate in bearing nodes by the dynamic load and vibration generated in meshing, that are transmitted through shafts to the bearings. Taking into account the mechanism described, it is assumed in the proposed method that a design of a gearbox with lowered vibroactivity is possible through a proper selection of the gears geometry, so as to assure a reduction of dynamic load of the gears, and of the location and dimensions of additional ribbing of the housing, with maintaining the lowest possible weigh of the housing. In the paper, the housing vibroactivity measure has been assumed and characterized, which is used in the evaluation of several engineering solutions of the gearbox housing.

Keywords: *gearbox, vibroactivity, simulation*

1. Introduction

Significant costs associated with acoustic testing of real objects of gearbox cause, very often, active research experiments substitution with simulation, that allow a complex analysis in accordance with the research assumptions. Conducting research studies using models allows the reduction of experimental studies to absolute minimum and is thus justified economically [1].

In the literature, there are descriptions of numerous models of gearbox and transmission system, by means of which it is possible to determine the influence of various factors on dynamic phenomena. Constantly increasing computer computational possibility allows developing further factors in already existing gearbox models and increasing their accuracy and usefulness in solving new or broader classes of problems [1].

In the design process of gearbox with lowered vibroactivity, a choice of dynamic model of gearbox in transmission system has a fundamental meaning. In current studies carried out in various research centres, there can be identified two main directions of research on optimizing the design of gearbox taking into account dynamic phenomena.

The first direction is studies of gearbox models describing dynamic phenomena occurring in meshing and bearing. New models of gearbox in transmission system are developing increasingly often, being a significant development of the previous modelling idea. This allows a more accurate description of dynamic phenomena in gearbox, caused by internal as well as external impact sources.

The second direction of research aims at determining the impact of gearbox housing shape on vibroactivity and possibility of improving general gearbox quieting. FEM and BEM methods are used inter alia to find optimal gearbox housing shape and the results of the real objects studies [1-3].

Vibroactivity of gearbox depends on the excitation of forces induced mainly in meshing and resonance gears, bearings and housing. The results of previous studies indicate, that gearbox housing produces noise mainly by excitation forces from vibration of shafts and bearings, not as a results of changes in the gearbox housing sound pressure. The energy carried by shafts and nodes of bearings is 90 to 95 % of the total vibration energy transmitted to the housing [4, 5].

Calculating the noise power spectrum of gearbox [6, 7] it can be assumed, that the excitation from different sources can be replaced by a single excitation force of the surface radiating sound. The spectrum depends on: the density of the surrounding medium „ρ_o" and the speed of sound in it „c", the radiation surface, the spectrum of excitation forces, filtering properties of transmittance and the coefficient of sound radiation η_r.

Assuming that the spectrum of excitation forces and filtering properties of transmittance can be replaced by the spectrum of vibration velocity, acoustic power emitted by the vibrating surface is calculated from the formula:

$$N_a = \rho_o \cdot c \cdot v_{avg}^2 \cdot S \cdot \eta_r \,. \tag{1}$$

Analyzing the formula (1) it can be seen that the value of gearbox sound power is proportional to the square of the mean value normal vibration velocity measurement points of the housing, assuming constant values of other volumes in the formula (1).

In the design process of gearbox with lowered vibroactivity, resonance structure of excitation and resonance structure of housing that is calculated in modal analysis have a significant meaning. Taking into account, in the designed model, the precise description of the gearbox dynamic phenomena broadens the possibility of impact analysis on vibroactivity of its housing, vibration generated in meshing and transmitted to bearing nodes.

The paper presents a proposal of gearbox design method with lowered vibroactivity that is the result of research conducted last year within the project "The impact of design and wear of component on vibroactivity of transmission systems with gearbox".

2. Proposal of gearbox design method with lowered vibroactivity

Taking into account the results of numerical and laboratory studies [1, 9-10] and using experience gained during the research project, there was proposed a method of computer-aided design of gearbox with lowered vibroactivity (Fig. 1).

The developed dynamic model of gearbox in transmission system, allows the optimal choice of geometric and technological features of gears and bearings ensure the minimization of dynamic load of teeth and bearing nodes of shafts. The calculated in the model dynamic forces at bearings nodes are taken as forcing in selected FEM models of housing.

In the case, when the designer does not have a gearbox dynamic model, it's possible to select the gears features by the guidelines given in the literature, and to load FEM models of housing use unit impulse, applied at the bearings nodes and then carry out the calculation using modal analysis.

Figure 2 presents usable models of gearbox. Fig. 2a presents an isolated model of palisade meshing of a pair of gears (L. Müller [7, 8]), and Fig. 2b a developed model of gearbox working in transmission system. Model presented in Fig. 2b shows a gearbox working in a power circulating system, as in the case on FZG laboratory stand [1].

Looking for a design solution of a housing of gearbox with lowered vibroactivity, it is necessary to consider different models of housing ribbing. In the selection process of ribbing variant and estimation its vibroactivity there were proposed different discrete models of FEM. Modal analysis of these models and also calculation of vibroactivity measure allow an optimal choice of the location and cross shape of additional ribbing of gearbox housing, taking into account its limited weight.

Table 1 presented FEM models of single-stage gearbox housing used in the study [1, 9,10].

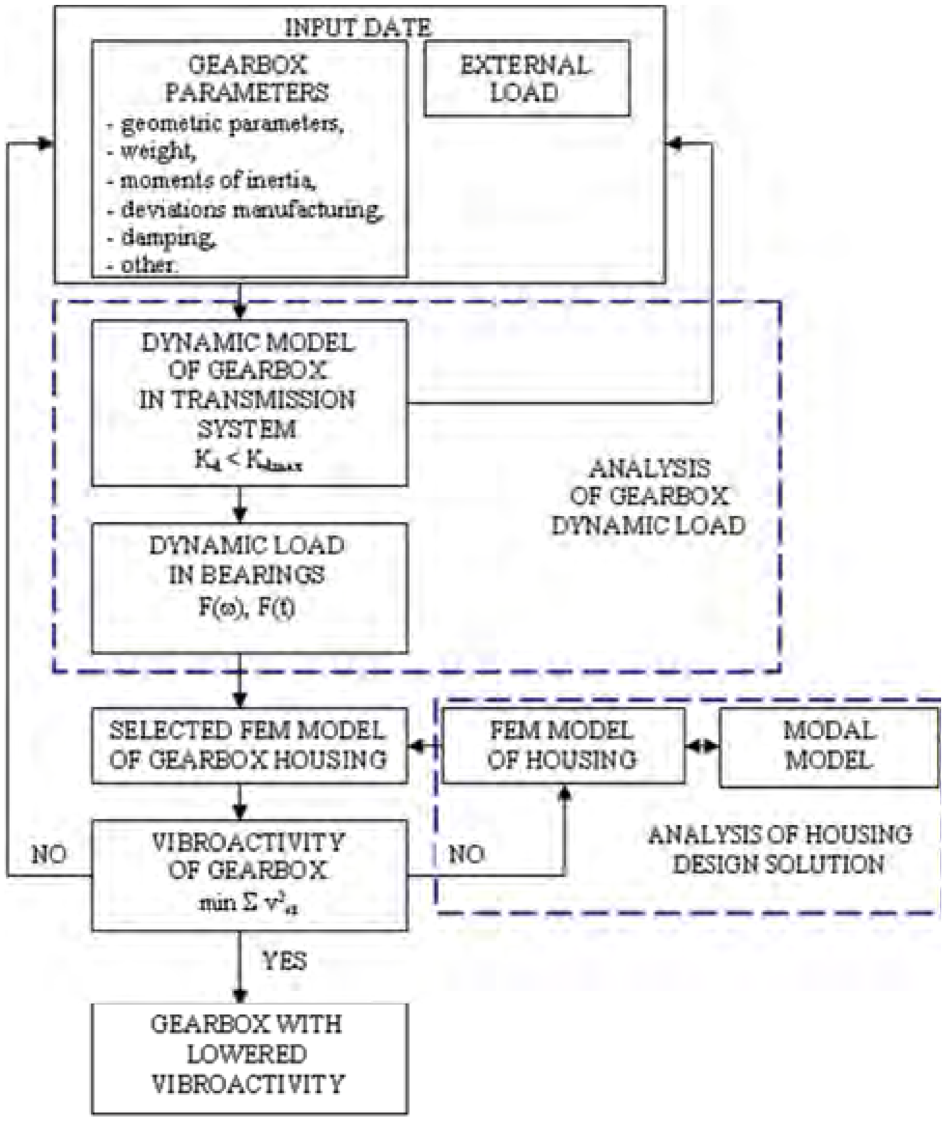


Fig. 1. Proposal of gearbox design method with lowered vibroactivity [1]

a) b)

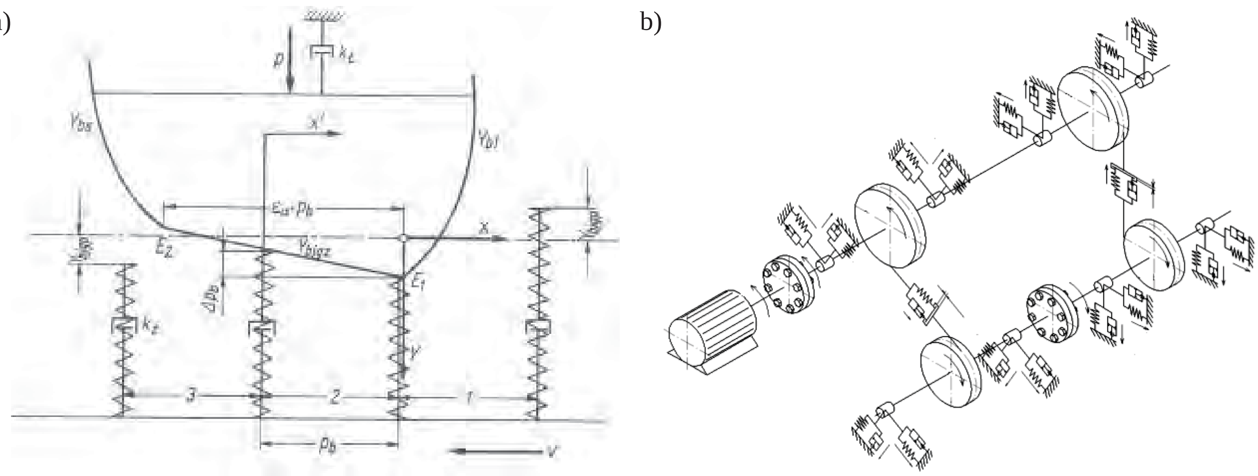
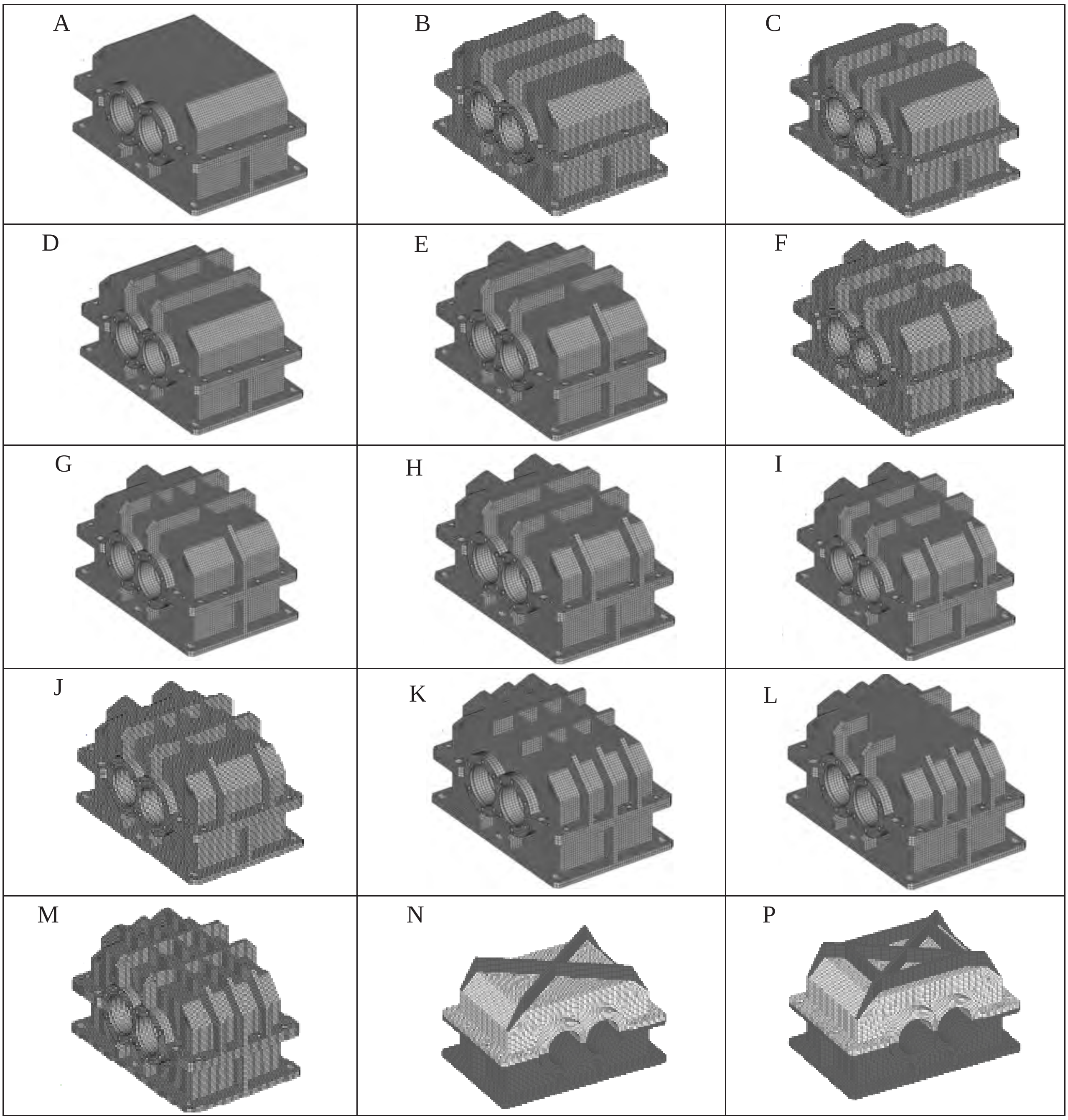


Fig. 2. a) L. Müller gearbox model [7, 8], b) model of gearbox working in a power circulating system [1]

The estimation of vibroactivity of the assumed solutions of gearbox construction may be conducted using modal analysis, assuming load of bearing nodes of the FEM model of housing with unit impulse or loading forces variable in time, calculated in dynamic model of gearbox.

Tab. 1. The developed FEM models of gearbox housing [1]



The basis of vibroactivity estimation of gearbox is the analysis of distribution of a FEM model normal vibration velocity of calculation nodes and determined on its basis measure according with formula [1, 7]:

$$v_{avg}^2 = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=k}^{l} (v_i\ (f_j))^2 , \tag{2}$$

where:
n - number of measurement points,
k - lower range of analysis frequency,
l - upper range of analysis frequency,
v_i - velocity of normal vibration,
f_i - frequency of vibration.

In the case of research carried out in time domain, measure of vibroactivity can be determined out of the following formula:

$$v_{avg}^2 = \frac{1}{n}\sum_{i=1}^{n} \left(\frac{1}{k}\sum_{j=1}^{k} (v_{ij}\ (t_i))^2\right), \tag{3}$$

where:
$v_{ij}(t)$ -vibration velocity in time t_i j-node point of FEM model,
n - number of samples of time analysis,
k - number of node points of FEM model.

Using the proposed method of simulation study in design of gearbox allows optimal choice of features of gears and bearings ensuring the minimization of dynamic load of gears and bearing nodes of shafts and allowing the choice of the location and shape of additional ribbing of gearbox housing, which meets the criterion of gearbox housing vibroactivity minimizing.

Figure 3 presents example results of housing vibroactivity calculations, assuming load of unit impulse in bearings nodes.

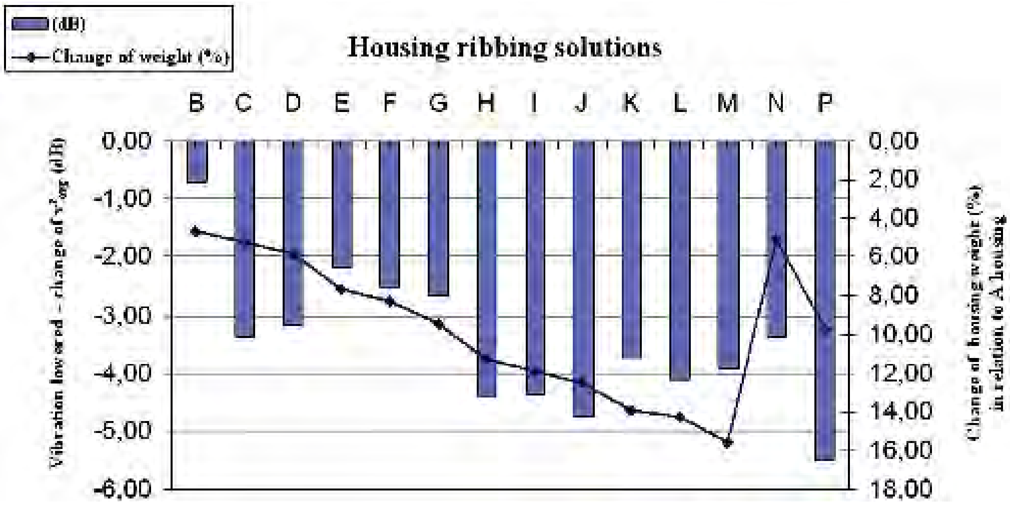


Fig. 3. Value of vibroactivity measure v^2_{avg} depending on ribbing gearbox solution in relation to A housing (without ribbing) in dB [1]

The calculation results confirm the significant impact of additional ribbing of gearbox housing on the generated vibration. It is possible to select the ribbing shape which allows to lower vibroactivity, considerably, (3-4 dB) with a simultaneous increase of housing weight only by a few percent. The details of these experiments are given in [1].

3. Summary

The results of numerical and experimental studies indicate usefulness of using the developed method in design of gearbox. The use of original dynamic models of meshing and housing in this research makes it possible to select a design solution of gearbox with lowered vibroactivity.

On the basis of the carried out research it can be concluded, that lowering gearbox vibroactivity is possible mainly by:

- appropriate selection of gears, bearing and other moving elements features ensures the minimization of dynamic forces in meshing and bearings, and by reduction of outside overload of gearbox in transmission system
- appropriate choice of design solution of gearbox housing ribbing.

In the gearbox design process, it is useful to carry out a modal analysis of selected solutions of ribbing housing and calculated characteristics of resonance frequencies. Choosing a solution of ribbing must include the requirement, that characteristic resonant frequencies of housing, are not close to the basis meshing frequencies that result from the number of teeth and speed of gearbox. This also has an impact on lowering vibroactivity of the design gearbox.

In designing gearbox housing the location and shape of additional ribs can be chosen the way to significantly reduce the vibroactivity level, with constant or only slightly increased weigh.

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