

Investigation of the opportunities for experimental research of gear trains vibrations

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Abstract. The improvement of the dynamic and exploitation characteristics of power transmissions is a significant and important problem. The solution of this problem becomes possible through improving the methods in the area of machine design and the existing approaches in experimental investigations. The vibrations in different technical systems including driving systems and power transmissions increase the noise level and the dynamic load. Therefore, the frequency analysis of these systems is especially important. The theoretical analysis of the dynamic behaviour of gear trains indicates that the vibrations in the area of the resonance zone display non-linear character as a result of partial or complete loss of contact in the meshing. The objective of the research presented is to investigate the dynamic behaviour of gear trains. An experimental test device for measuring, processing and analysis of the gear train vibrations has been designed. The opportunities for data processing in an environment of LabVIEW and/or MATLAB aiming to obtain in an experimental way relationships demonstrating acceleration and resonant frequencies. Conclusions and recommendations have been summarized.

1 Introduction

The research problem concerning the improving of dynamic and exploitation parameters of power transmissions is a significant and interdisciplinary problem. Its solution becomes possible through improving the existing methods for creating theoretical models and applying contemporary approaches and tools.

In order to improve the research methods of planetary gear trains it is necessary to analyse and test certain scientific achievements of world-renowned scientists in this area. One of the annexes of ISO 6336 [1] considering the analytical determination of load distribution is based mainly on AGMA 927, [2].

In connection with the approach mentioned, some important additions have been made. The methodology of this annex has been adapted in [3] to the specific characteristics of the combination of the following components: shaft of the sun gear, carrier and planetary gears of planetary gear train. The author of [3] defines boundary values of the deformations and inaccuracies of the planetary gear train occurring as a result of bending and torsion of the shaft of the sun gear and of the system axle – bearing – planetary gear.

The idea of further development of AGMA 927 has been presented in another publication, [4]. The authors describe in details the inaccuracies in complex power transmissions which include such as planetary gear trains.

These inaccuracies occur as a result of variety of reasons. Some of the most important factors are: torsion and bending of the sun gear and of the ring gear; torsion of the planet carrier; bending of the planet pin relative to the planet carrier; current position of the planets (the position of the meshing point of the planet rotates with the carrier).

The authors' team of [5] claims that the outcomes of their research have led to ensuring the avoidance of interference, to reducing the influence of errors occurring as a result of displacements and deformations and finally: to a significant decrease of noise and vibrations.

An interesting analysis of the influence of the shape deviation and assembling errors upon the dynamic behaviour of the planetary gear components is carried out in [6]. The authors' team applies contact conditions for rigid and deformable solids in order to define the gear set excitation sources.

A relative original procedure is suggested for simultaneously solving the contact task between active flanks and the motion equations. The influence of linear profile modifications on spur and helical gears is discussed in details.

The analysis of the publications [5-9] implemented leads to the conclusion that, whether or not there are profile modifications, the vibrations of power transmissions have a non-linear character close to resonance zone as a result of partial or complete loss of contact in the meshing.

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Such loss of contact in the meshing involves the reduction of the overlap coefficient.

Based upon the studies described in the papers [7 - 10], upgrading investigations have been carried out in the field of dynamic behaviour of power transmissions, summarized in publications [11 - 13].

According to [11, 12] the theoretical model of the dynamic contact obligatory has to take into consideration the influence of the partial loss in the meshing. Based on computing procedures, the authors' teams of [6] and [13] emphasize, that inaccuracies in gears lead to partial loss of contact even under pure static load.

A significant difference is observed, however, in the analyses and conclusions outlined in [13] and [8]. The partial loss of contact in the meshing is due to specific inaccuracies according to the authors of [13]. On the other hand, the authors of [8] claim that this loss of contact arises as a result of the displacements, despite the fact that the gears are perfectly mounted in the planetary gear housing.

In conclusion, it can be deduced that most of the theoretical models discussed implement a discreet, parametric representation, which involves elements of the meshing such as solid bodies and combinations of elastic elements. The models analysed are characterized by a different level of complexity when considering meshing conditions, shafts, bearings and housing.

This short analysis of the state of the problem aims to outline the most important characteristics concerning the vibration research of power transmissions, including planetary gear trains.

2 Options for experimental research

Opportunities for experimental investigation of planetary and other transmissions are presented in a significant number of publications. The most widely used experimental methods [14, 15] are based on vibration detection. Modal analysis is a method based on vibration theory, and the main purpose is to get the inherent characteristics of structural system, such as natural frequencies and natural modes.

Quite often the mode analysis is conducted with the help of ANSYS, [16, 17]. Other scientists investigate planetary gear trains through modal analysis of gearbox housings [18, 19], taking in account some multilateral aspects of this approach.

A significant group of scientists investigated modal proprieties of planetary gear trains underlining the relationship between natural frequencies and parameters of such technical systems. The authors' team of [20] studied 3D modal deflection of a helical planetary gear and a double-helical planetary gear.

The authors Tanna and Lim [21] focused mainly on the modal frequencies of ring gears. Vibration modes of compound planetary gears have been investigated by Kiracofe and Parker [22] and Guo and Parker [23].

Kahraman and Vijayakar [24] studied the effect of internal gear flexibility of a planetary gear set. Ericson and Parker [25] used experimental modal analysis

procedures to analyse the dynamic behaviour of spur planetary gears.

The most commonly used devices for the experimental research of power transmissions are accelerometers. The location on the planetary gearbox of these devices is especially important, because planetary gears create similar vibrations passing through a fixed sensor [26].

3 Prerequisites for research implementing

Based upon the experience of the authors' team in the area of design theory, system approach and elaboration of new products, a significant improvement concerning the exploitation parameters of planetary gear components has been achieved.

Original theoretical models developed by S. Stoyanov, V. Dobrev and A. Dobreva for planetary gear trains are presented in [27-29]. The main purpose of these investigations in the field of power transmissions is to determine the conditions for reduction of noise and vibrations in planetary gears.

In [30] Dobreva and Stoyanov present a study of the internal meshing based upon the evaluation of the basic parameters of this type of engagement. Different methods for complex analysis of internal meshing and for the determination of the permissible and optimal values of its geometric parameters according to different sets of criteria have been examined, applied and discussed.

In [31-33], the authors perform optimization research of vehicle drive systems based on the frequency analysis of elements of these systems.

The requirement for clarity of the layout new design version of gear trains complies with the necessity for unambiguous executable production and assembly processes. Improved and refined procedures for evaluation and comparative analysis of different design solutions for a certain problem including several main stages is described in details in [34-36].

The main outcomes of these investigations described are the prerequisites created for conducting a simulation and experimental research of planetary gear trains and other power transmissions.

4 Design characteristics of the planetary gear train investigated

The kinematic scheme of the planetary gear reducer studied is shown on Fig. 1. The planetary gear train is designed and produced according to this scheme.

It consists of one central gear with external teeth, two sets of planetary gears and one central gear with internal teeth. The most important design feature of this two-stage planetary gear train is the significant value of the overall gear ratio, which is equal to 31.

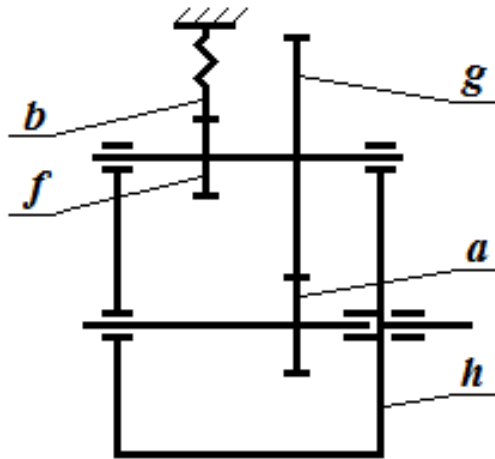


Fig. 1. Scheme of the planetary gear train investigated.

The driving shaft and the sun gear (a) are produced as one component. The driven shaft is connected with the planet carrier (h). The gear rim with internal teeth is fixed to the housing by means of an elastic component.

This specific design feature reduces the impact of the uneven distribution of the load between planet gear which is due to the inaccuracies occurring during the manufacturing and assembling of the different components of this reducer.

A picture of the gearbox disassembled is shown on Fig. 2.

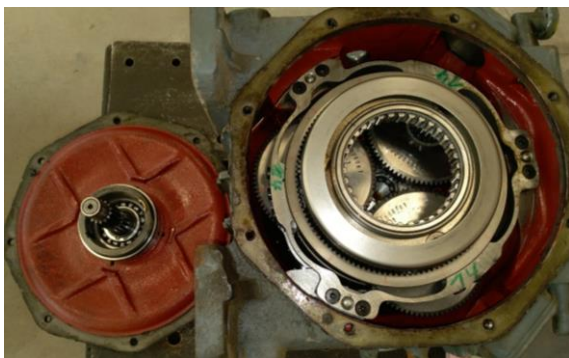


Fig. 2. Picture of the planetary gear train.

The components of this planetary gear train are characterized with the teeth numbers listed in Table 1.

Table 1. Parameters of the reducer.

| Component | Teeth number |
|-----------|--------------|
| z_a | 15 |
| z_b | 117 |
| z_f | 21 |
| z_g | 80 |

5 Design of the experimental test machine

A schematic layout of the experimental test machine is presented on Fig. 3. This test machine layout is done based upon the theoretical and practical experience of the authors' team.

The design of this test machine is also taking into consideration the main options for experimental investigation of planetary and other transmissions which are presented in part 2 of this paper.

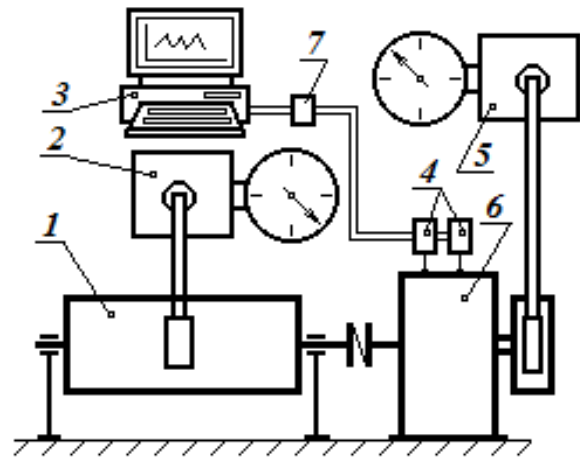


Fig. 3. Design of the experimental test machine.

The experimental test machine contains the following components: 1 - electric motor; 2 - scales; 3 - computer; 4 - sensors (accelerometers); 5 - scales; 6 - gearbox tested; 7 - converter.

The following components of the experimental test machine are already available: electric motor; scales; computer; gearbox tested; converter.

Appropriate sensors (accelerometers) and amplifiers possessing certain technical parameters appropriate to the purposes of the study are to be purchased.

6 Methodology for the experimental research

The methodology suggested is taking into account the most important characteristics concerning the vibration research of power transmissions, including planetary gear trains. Besides, some previous important outcomes of the authors' team investigations are used as prerequisites for implementing an experimental research of planetary gear trains.

The methodology includes the following stages:

1. A theoretical FEM model for the presented planetary gear box has been created in accordance with the methodology suggested in [29].

The necessary assumptions, constrains and specific features of the gear train studied are taken into consideration. The model created is suitable tool for simulation research of the dynamic behaviour of planetary gear train.

2. The input and output torques of the planetary gear trains are to be measured for 3 different values of the rotational speed: 750 rpm; 1000 rpm and 1400 rpm.

3. The efficiency of the gearbox is to be estimated based upon the experimental data obtained.

4. The vibrations of the planetary gear box are to be measured for 3 different values of the rotational speed: 750 rpm; 1000 rpm and 1400 rpm. The location of the sensors will be on the housing of the planetary gearbox.

5. The results obtained are to be analysed with the help of an appropriate software product, which is effective enough for the processing the experimental data.

7 Conclusions

Based upon the investigation implemented, the following conclusions can be deduced:

1. An analysis has been made concerning the opportunities for the experimental research of vibrations of planetary and other power transmissions.

2. A test machine for experimental research of vibrations in planetary gear trains is designed. This test machine layout is carried out mainly based upon the practical experience of the authors' team and the design options for experimental investigation suggested in the publications discussed.

3. A methodology is suggested which corresponds with the research objectives determined. This methodology is considering the most important characteristics concerning the vibration research of power transmissions, including planetary gear trains.

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