Options for methods of experimental investigation of planetary gear sets

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Abstract: *Planetary power transmission are characterized through more complex design and kinematics parameters compared to involute gear trains with parallel shafts. It has been established that their components should be measured and monitored more frequently in order to avoid intensive wear. The paper presents a design project of an advanced experimental device for measuring vibration and wear of planetary gear components. As it is well known, approaches to direct measuring of wear and vibration parameters are difficult to be implemented in these gear trains. The application possibilities of a measurement system that includes a micro-electro-mechanical system, a temperature sensor and wireless modules assembled in a planetary gear trains have been considered. The advantages of micro-electro-mechanical measurement systems have been analyzed precisely. The main characteristics of micro-electro-mechanical sensors are low power consumption, small size and good control and monitoring capabilities. A suitable advanced methodology for the experimental study of planetary gears has been created as well. Conclusions and recommendations have been deduced.*
Keywords*: PLANETARY GEAR SEYS, METHOD INVESITIGATION, THEORETICAL ANALYSIS, ELECTROMECHANICAL SYSTEMS*

1. Introduction

Planetary gears are used in power transmissions systems and in driving systems such as wind turbines, automobiles, helicopters. The specific design of the planetary gears allows the transmission of high torques within relative compact housings.

The possibilities of planetary gear research have been presented in a considerable number of publications and some of them are summarized in [1]. The most widely applied experimental methods [2, 3, 4, 5] are based on vibration diagnostics.

A significant group of scientists investigates the modal specific features properties of planetary gears, emphasizing the relationship between the natural frequencies and the parameters of the technical systems studied. Relatively often, the analysis of the mode of operation of planetary gears is carried out using ANSYS opportunities, [6, 7, 8, 9]. A significant group of scientists investigates the modal specific features properties of planetary gears, emphasizing the relationship between the natural frequencies and the parameters of the technical systems studied.

Significant experimental research on planetary gear trains has been done by several groups of world-renowned scientists. The authors of [10, 11, 12] mainly focus on the modal frequencies of gears. The vibration modes of complex planetary gear sets have been studied by the authors of [13, 14, 15, 16]. In one of these papers [16], experimental modal analysis procedures have been applied in order to analyze precisely the dynamic behavior of planetary gear trains.

2. Investigating the options for remote measuring of planetary gears trains

In order to select the most appropriate approach, it is necessary to analyze the most commonly used experimental instruments for remote, wireless research of planetary gears. During an experimental investigation with accelerometers, the location of these devices in the planetary gear set is extremely important due to the circumstance that the satellite gears create similar vibrations passing through the sensors assembled [17]. Besides, wireless sensors are known to offer more spatial advantages than wired ones.

The vibration research is planned to be carried out using two methods: using the Leonova Diamond - a multi-channel portable vibration analyzer for complex diagnostics and/or applying Airius - a wireless sensor for measuring and analyzing vibrations along three axes, [18].

The device “Leonova Diamond” is a multi-functional, portable analyzer for vibration measurement. The analyzer has a modular platform that allows step-by-step improvement and expansion with other additional functions, such as: detailed determination of damaged elements in the examined mechanical components, precise analysis of vibrations and establishment of various mechanical damages in planetary gears, reducers, electric motors, compression springs, pumps, fans. It also makes it possible to investigate resonance phenomena of rotating mechanical components.

Fig. 1 *Leonova Diamond for vibration and temperature measurement and Airius - wireless sensor for vibration measurement and analysis, [18]*

If there are tooth failures in the planetary gear trains, the device creates periodic pulses or serious modulating phenomena into the vibration signal.

According to [18], the corresponding characteristic frequency is related to the frequency of the damaged unit. In addition, the authors of [18] investigated vibration signal models for fault diagnosis in planetary gear sets.

The device Airius is a MEMS (micro-electro-mechanical) type sensor. The main characteristics of micro-electro-mechanical sensors are low power consumption, small size and good control and monitoring capabilities. The device a digital dynamic output signal (allows processing and analysis) and simultaneously measures vibration along 3 axes (horizontal, vertical and axial) as well as temperature. The sensor is offered in two versions: the first version realizes measuring in the frequency range 10-1000 Hz, the second version - between 2-5000 Hz. The sensor supports several different vibration measurement tasks, with a number of measurements de-fined by the researcher within a certain period of time. Characteristic frequencies, including gear rotation frequency and meshing frequency, are having a great importnce for gear fault detection.

The identification of faults is related to the occurrence of the characteristic frequencies that can be referred to a certain damage [19]. Studies and comparisons in this topic have been made with the different types of teeth damages in the planetary gear trains, [20]. Data processing is performed through a virtual processor. Additional hardware is not required. Results have been monitored via specialized software or a mobile phone, computer or tablet application, [20].

3. Specific design features of the planetary gear train tested

The design of the planetary gear train to be investigated experimentally is as follows: 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 is the large value of the total gear ratio, which is 31. The driving shaft and the sun gear have been manufactured as one component. The driven shaft is connected to the carrier. The ring gear with internal teeth is fixed to the housing with the help of an elastic component. This specific design features reduce the influence of uneven load distribution be-tween the planetary gears, which is due to inaccuracies occurring during the manufacture and assembly of the various components of this gearbox.

4. Methods for experimental investigation

As it is well known, planetary gear trains are characterized by a more complex de-sign and more complicated motions compared to cylindrical involute gear trains with fixed shafts. This feature of planetary gears makes it difficult to observe and diagnose the occurring failures.

A possible diagnostic option is to check the gear elements frequently in order to avoid excessive wear. The author's team offers an advanced methodology for the experimental study of planetary gears, including the following five stages:

The first stage envisages the improvement of an existing experimental machine, described in [21].

The second methodology stage involves the assembling of wireless external sensors that can register vibration and temperature signals. In accordance with the study of [22], a micro-electro-mechanical measurement system (MEMS) will be implemented according to the preliminary conceptual design, which includes a three-axis MEMS accelerometer, a temperature sensor and wireless modules integrated in the planetary gear train.

The third stage envisages the development of a virtual software tool based on LabVIEW, with the help of which it is possible to obtain and display data for different frequency domains in order to detect planetary gear faults in a certain period of time.

The fourth stage includes experimental investigations of the planetary gear train at different rotational speeds and loadings.

Within the framework of the final stage, an analysis of the results obtained is to be carried out.

5. Conclusions

Through the investigation presented it has been established that the components of planetary gear trains are to be measured and monitored more frequently in order to avoid intensive wear.

The paper summarizes the options for remote measuring of planetary gear sets through advanced experimental devices for measuring vibration and temperature of planetary gear components.

The application possibilities of a measurement system that includes micro-electro-mechanical components, a temperature sensor and wireless modules assembled in planetary gear trains have been considered. The advantages of micro-electro-mechanical measurement systems have been analysed precisely.

A suitable advanced methodology for the experimental study of planetary gear sets has been created as well.

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7. References

1. D. Bonev, A. Dobreva: Analysis of Planetary Gear Trains Applied in Vehicles. Interna-tional Scientific Journal "Trans MOTAUTO World", ISSN: 2367-8399; 2534-8493, pp. 5-8 (2023)
2. T. Lin, Z. He, F. Geng: Prediction and Experimental study on Structure and Radiation Noise of Subway Gearbox, J. of Vibroeng., 15 (4), pp. 1838 - 1846, (2013)
3. Z. He, T. Lin, J. Song: Analytical Computational Method of Structure-borne Noise and Shock Resistance of Gear System, J. of Measurement in Eng., 2 (4), pp. 215 - 224, (2014)
4. S. Tarulescu, R. Tarulescu: Researches on Combustion Quality for a Single Cylinder Die-sel Engine, International Congress of Automotive and Transport Engineering, doi: 10.1007/978-3-319-45447-4_48, pp. 1-9, (2016)
5. N. Crăciunoiu, A. Oprica, C. Pascu: Aspects about Deployment of Lean Principles for Improving the Production Process Quality in Automotive Industry. RoJAE, vol. 27 no. 2, pp. 45 – 88, http://siar.ro/wp-content/uploads/2021/08/RoJAE-27_2.pdf#page=5, (2021)
6. Z. Wang, T. Lin, Z. He, X. Yang: Vibration Characteristics Analysis of Vertical Mill Reducer. In. Conf. on Automation, Mechanical Control and Computational Engineering, AMCCE, (2015)
7. C. Korka, C. Miclosina: Shape Improvement of a Gearbox Housing Using Modal Analy-sis, RJAV, 15 (1), (2018)
8. S. Stoyanov: An experimental setup for determination of the resonant frequencies of a mechanical frame structure. Fund. Sciences and Applications, Journal of the TU – Sofia, Bulgaria, 24, pp.67-71, (2018).
9. S. Stoyanov: Software tools for mechanical structures resonant frequencies determination: Vibration signal processing for modal analysis. CompSysTech'18: Proceedings of the 19th International Conference on Computer Systems and Technologies, pp. 120–123, https://doi.org/10.1145/3274005.3274037, (2018)
10. R. Tanna, T. Lim: Modal Frequency Deviations in Stimating Ring Gear Modes Using Smooth Ring Solutions, J. of Sound and Vib., 269099-1110, (2004)
11. A. Dumitru, S. Rosca, N. Dumitru, N. Craciunoiu, D. Tarnita: Theoretical and experi-mental models for the dynamic response analysis of the mechanisms with deformable ele-ments applied to automobiles. Annals of DAAAM and Proceedings of the International DAAAM Symposium, pp. 1407–1408, (2009)
12. D. Dumitru, E. Dragut, N. Craciunoiu, L. Geonea: Experimental bench for spur gears effi-ciency measurement. Mechanisms & Machine Science, 57, pp. 477–485, (2018)
13. D. Kiracofe, R. Parker: Structured Vibration Modes of General Compound Planetary Gear Systems, J. of Vib. and Acous., 129, pp 1-16, (2007)
14. Y. Guo, R. Parker: Purely Rotational Model and Vibration Modes of Compound Planetary Gears, Mech. and Mach. Theory, 45, pp 365-377, (2010)
15. R. Tarulescu, S. Tarulescu: Measurement methods for the path deviation of mobile robots. Proceedings of the 7th International Conference on Electronics, Computers and Artificial Intelligence, ECAI 2015, pp. P91–P94, 7301259, (2015)
16. T. Ericson, R. Parker: Planetary Gear Modal Vibration Experiments and Correlation against Lumped-parameter and Finite Element Models, J. of Sound and Vib., 332, pp. 2350-2375, (2013)
17. N. Feki, M. Khabou, F. Chaari, M. Haddar: Frequency Analysis of a Two-stage Planetary Gearbox Using Two Different Methodologies. Comptes Rendus - Mecanique, 345 (12), pp. 832–843, (2017)
18. Z. Feng, M. Zuo: Vibration signal models for fault diagnosis of planetary gearboxes Vol. 331, pp. 4919–4939, Journal of Mechanical Science and Technology, (2016)
19. L. Yaguo, J. Lin, M. Zuo, Z. He: Condition monitoring and fault diagnosis of planetary gearboxes, Journal of Mechanical Design and Vibration, Vol. 7, No. 1, pp. 21-26, DOI:10.12691/jmdv-7-1-3, (2019)
20. Y. Yang, N. Hu, Y. Li, Z. Cheng, G. Shen: Dynamic modeling and analysis of planetary gear system for tooth fault diagnosis, Mechanical Systems and Signal Processing 207:110946, DOI:10.1016/j.ymssp.2023.110946, (2024)
21. S. Stoyanov, V. Dobrev, A. Dobreva: Investigation of the Opportunities for Experimental Research of Gear Train Vibrations, MATEC Web of Conferences, 6th International BAPT Conference "Power Transmissions 2019", ISBN: 978-619-7383-12-6, pp. 1-5, (2019)
22. L. Huang, J. Chang: Vibration Characterization and Fault Diagnosis of a Planetary Gearbox with a Wireless Embedded Sensor. Appl. Sci. 2023, 13, 729. https:// doi.org/10.3390/app13020729 (2023)