THE VIBRODIAGNOSTICS OF DAMAGED GEARS OF PLANETARY GEARBOXES

This article deals with description of a diagnostic device used at the Department of Design and Machine Elements at the University of Zilina which has been built in order to measure, diagnose and evaluate gearbox faults by vibrodiagnostics. The article describes methods and damage creation process for tested gearboxes. Evaluation of different faults is also processed in this article as well as description of comparative measurements between real and artificially created pitting. Comparison of all measured data with SPM methods is also included.

Keywords: Vibrodiagnostics, frequency, spectrum, damage.

1. Introduction

The Vibrodiagnostics is considered to be one of most progressive maintenance methods. It offers possibilities to diagnose status and conditions of devices while they are fully operational [1]. The testing device has been constructed at the Department of Design and Machine Elements in order to measure and evaluate faults of components by analysing frequency spectra of gearboxes (Fig. 1). Laboratory research primarily aims at diagnostics of damaged gears of planetary gearboxes.

The testing device consists of one 15 kW electromotor controlled by a phase shifter, two planetary gearboxes type A2000 mounted in series and also one dynamometer. Components are coupled together by cardan shafts. The testing device is supplemented with noncontact sensors HBM T10F for RMP and torque measurement. Gearbox A2000 is a planetary gearbox with two planetary gearings with involute spur gears [2].

The diagnostic apparatus was purchased from SKF and it contains six acceleration sensors with sensitivity of 100 mV/g, on-line diagnostic unit type IMx-S and one PC equipped with @ptitude analyst software. Both frequency analysis and envelope method for signal processing are used to determine gearbox faults.

Gearbox A2000 was tested for fault response at 1470±10 RPM. Input shaft can rotate both clockwise and anticlockwise according to current needs.

Fig. 1 The testing device used at the Department of Design and Machine Elements for diagnostics of planetary gearboxes´ faults (left) and placement of vibration sensors (right)
Preliminary measurements of undamaged gearboxes needed to be done first in order to indicate key frequencies in spectrum of undamaged gearbox. Some components of gearboxes were artificially damaged later.

2. Measurements of gears with teeth damaged by pitting

The sun gear of the first planetary gearing was first to be damaged. First type of damage is represented by the notch on face area of one tooth. This damage was done with assumption of significant response within frequency spectrum. The damage can be seen in vibrations velocity spectrum by analysing sideband of gear mesh frequency of the first planetary gearing, because first amplitudes significantly surpassed magnitude of gear mesh frequency. Its effect was even more significant in enveloped accelerations spectrum filter 3 (Fig. 2). Frequency 55 Hz of damaged sun gear dominated throughout spectrum and its harmonic frequencies showed up (marked as red). Sideband was created around gear frequency with the delta equal to RPM frequency 24.69 Hz of damaged gear (marked as blue). Sideband can be clearly seen in vicinity of its harmonic frequency [3].

Small pitting was created on the opposite side of already damaged tooth after first fault simulated by the notch was evaluated. This type of fault showed similar effect when compared to tooth damaged by the notch in vibrations velocity spectrum, however amplitudes of sideband were not as significant. Fault effect in enveloped accelerations spectrum filter 3 also showed similar results as before and once again amplitude of the gear frequency of the damaged gear was significant, but values were lower when compared to those of tooth damaged by single notch [4] - [7]. Its harmonic frequencies were not as significant; however 2nd, 3rd and 4th harmonic frequency is clearly visible.

Fig. 2 The frequency spectrum of enveloped accelerations filter 3 for tooth of the sun gear damaged by the notch on its face area

Fig. 3 Sun gear of planetary gearing damaged by artificially created pitting (left) and sun gear damaged by real pitting (right)
Pitting was created on every single tooth of the sun gear as experiments continued. Significant change occurred in vibrations velocity spectrum where one more sideband appeared with the delta equal to gear mesh frequency of damaged gear alongside regular gear mesh frequency of first planetary gearing. 2nd and 3rd harmonic frequency of gear mesh frequency also showed up (Fig. 4). Fault effect in enveloped accelerations spectrum filter 3 was similar to previous faults. Values of amplitude however increased greatly and amplitude of gear mesh frequency of the gear damaged by pitting on every tooth rose by 2100% when compared to the gear damaged by pitting only on one tooth.

In order to compare all measured data, another experiment with artificially created pitting on half of gear’s teeth (on the same face area as damaged by the notch) took place (Fig. 3 left). Artificially damaged sun gear was replaced by another sun gear damaged by real pitting on half of gear’s teeth (Fig. 3 right). After both spectra were measured and frequency spectra were compared, we came to the conclusion that artificially created pitting has very similar effect when compared to real pitting (Fig. 4). This comparison confirmed that measured data match reality and test method was suitable for this application as well [8] and [9].

Vibrations velocity frequency spectra with different pitting affected area of the sun gear of the first planetary gearing can be seen in Fig. 5. The upper part of spectra represents only one tooth damaged by pitting, middle part corresponds to all teeth damaged by pitting and lower part represents the gear damaged on half

*Fig. 4 The comparison of frequency spectra of gearbox with sun gear damaged by artificially created pitting on half of gear’s teeth (blue) and sun gear damaged by real pitting (violet)*

*Fig. 5 Frequency spectrum of velocity of vibrations with differently damaged sun gears of first planetary gearing by pitting*
of its teeth by real pitting. Straight lines between measurements reflect time when the testing device was offline.

3. Measurements of gears with teeth damaged by breaking

Another phase involved sun gear with one tooth partially broken and later with whole missing tooth. Measurements were made on gears which were previously damaged by pitting on half of their teeth (Fig. 6).

There was no significant change in vibrations velocity spectrum (Fig. 7) compared to the sun gear damaged by pitting on half of its teeth [10]. Enveloped accelerations spectrum filter 3 - from 5 Hz to 1kHz (Fig. 8) also had similar characteristic compared to same sun gear with no missing teeth, but amplitude of gear mesh frequency and its harmonic frequencies had higher values compared to pitting damaged sun gear.

4. Comparative measurements of two different methods

Comparative measurements were made in cooperation with vibrodiagnostic specialists from SPM Instrument s.r.o. SPM HD and SPM Spectrum methods were used to examine current status of the gearbox. The gearbox was damaged by missing tooth and pitting on the sun gear and notch type damage was made on the satellite gear.

Frequency spectrum measured by SPM HD method is shown in Fig. 9. Teeth frequency of damaged gear (54.976 Hz) and its harmonic frequencies within spectrum are marked by numbers. Figure 10 contains data measured by enveloped accelerations method filter 3 where teeth frequency (55 Hz) and its harmonic frequencies of damaged gear are also marked by numbers. Spectra...
in both figures are very similar with small difference of amplitude magnitude for 6th, 7th and 8th harmonic frequency because these harmonic frequencies have much lower amplitudes with enveloped accelerations method.

Vibrations velocity frequency spectrum obtained by SPM Spectrum method can be seen in Fig. 11. Spectrum’s shape is very similar to SKF methods in direct comparison (Fig. 12), difference is in amplitude magnitudes. Spectra in both figures highlighted amplitudes of sideband with the spacing of teeth frequency of damaged sun gear (55 Hz) and amplitude of sideband of gear mesh frequency of the first planetary gearing which has high value of amplitude dominating through whole spectrum.
It is necessary to mention that influence of damaged planet gear has not been detected either in vibrations velocity spectrum or in enveloped accelerations spectrum [11], [12] and [13].

5. Conclusion

Measurements we made so far clearly show artificially developed faults of the sun gear in high frequency vibrations velocity spectrum and enveloped accelerations spectrum for given gearbox correspond to vibration responses of faults developed under real conditions for same gearbox and, therefore, confirm used methods of measurements. Similarity of SKF and SPM methods was proved by comparing both results. Effects of faults are also similar although technology for signal processing differs significantly between these two methods.

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References

[1] PRODAJ, J.: Applications and Diagnosis of Selected Nodes of Stationary and Mobile Gear System (in Slovak), Dissertation thesis, Zilina, 2012.
[2] GAJDOSIK, T., BUCALA, J., KOVALICEK, M.: Vibrodiagnostic of Gearboxes, Proc. of intern. conference Transcom 2013, Zilina, 2013.
[3] KUCERA, L., GAJDOSIK, T.: The Vibrodiagnostic of Gears, 54th Intern. conference of machine design departments, September 2013, Hejnice: Liberec: Technical university, 93-98, 2013. ISBN 978-80-7372-986-8.
[4] SAPIETA, M., STEVKA, O., DEKYS, V.: Localization Luders Band in Infrared Spectrum, *Applied Mechanics and Materials*, vol. 420, 2013, 194-201, ISSN 1660-9336.

[5] DEKYS, V., DVOULETY, O.: A Contribution to the Condition Monitoring of Fans, *Zeszyty naukowe Politechniki Slaskiej: Transport*, z. 76, No. 1865, 2012, 49-56. ISSN 0209-3324.

[6] DEKYS, V., SAGA, M., ZMINDAK, M.: Damage Detection Based on Dynamic Measurements, New methods of damage and failure analysis of structural parts, September, 2012. Ostrava: Technicka univerzita, 41-49. ISBN 978-80-248-2802-2.

[7] VASKO, M., SAGA, M., DEKYS, V.: Contribution to Numerical Analysis of Uncertain Mechanical Systems Using Probability and Possibility Theory, Advances in mechanisms design, Proc. of TMM 2012, Dordrecht: Springer Science+Business Media, ISBN 978-94-007-5124-8, (Mechanisms and machine science, vol. 8, 263-269. ISSN 2211-0984).

[8] KOPAS, P., SAGA, M., UHRICIK, M.: Contribution to Multiaxial Damage Calculation Using FEM, *Applied Mechanics and Materials*, vol. 420, 2013, 318-324. ISSN 1660-9336.

[9] NEMECEK, M., DEJL, Z.: Geometric Calculations of the Chamfered Tip and the Protuberance Undercut of a Tooth Profile (Conference Paper), ASME 2011 Intern. Design Engineering Technical Conferences on Computers and Information in Engineering Conference, IDETC/CIE 2011, Washington: DC, August 2011; Code 91020.

[10] NEMECEK, M.: Problems with the Design of Internal Gearing with Extreme Parameters (Conference Paper), 2007, Proc. of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC2007, vol. 7, 2008, 199-206, 10th Intern. Power Transmission and Gearing Conference, presented at 2007 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, IDETC/CIE2007; Las Vegas, NV, September 2007, Code 72172.

[11] KOHAR, R., HRCEK, S.: Dynamic Analysis of Rolling Bearings with Elastic Cage, Proc. of 54th intern. Conference of Machine Design Departments, 211-216, September 2013, Hejnice: Liberec: Technical university, 2013. ISBN 978-80-7372-986-8.

[12] KOHAR, R., HRCEK, S., MEDVECKY, S.: Usage of Dynamic Analysis to Determine Force Interactions between Components of Rolling Bearings, *Communications - Scientific Letters of the University of Zilina*, vol. 14, No. 3, 2012, 62-67. ISSN 1335-4205.

[13] HRCEK, S., KOHAR, R., MEDVECKY, S.: Determination of the Maximum Roller bearing Load with Regards to Durability thereof using FEM Analysis, *Communications - Scientific Letters of the University of Zilina*, vol. 14, No. 3, 2012, 55-61. ISSN 1335-4205.