

VIBRATION DIAGNOSTICS OF SPIROID GEAR

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Abstract:

Spiroid gear is one of the progressive varieties of intersecting axis gears. It has a number of advantages: increased overlap coefficient, favourable contact conditions. Spiroid gears are notable for high loading and overloading ability, increased smooth running and less sensitivity to manufacturing and assembly errors, high reliability and durability. The analysis of the results of experiment on research of vibration of the spiroid gear PS-124 has shown, that the vibration level at frequency 200-300 Hz is reduced on 5 dB at increase of the resistance moment up to 1000 Nm at clockwise rotation of the reducer and at increase of the resistance moment up to 800 Nm at counter-clockwise rotation of the reducer. The vibration level at frequency 700-800 Hz is also increased on 5 dB at increase of the resistance moment up to 1000 Nm at clockwise rotation of the reducer and at increase of the resistance moment up to 800 Nm. If these vibration levels are exceeded, a defect is likely to occur. Economic efficiency of application of diagnostics systems is caused by increase of reliability and quality, reduction of accidents, decrease in defects, reduction of idle time of expensive equipment, reduction of expenses for maintenance and repair.

Key words: *spiroid gear, vibration, diagnostics*

INTRODUCTION

Spiroid gear is one of the progressive varieties of intersecting axis gears. Due to a number of advantages of geometry and kinematics of meshing – increased overlap coefficient, favourable contact conditions – spiroid gears are characterized by high load and overload capacity, increased smooth running and less sensitivity to manufacturing and assembly errors, high reliability and durability [1].

Spiroid gearboxes are used in various fields, including pipeline equipment and oil refineries. Failure of a gearbox leads to great economic losses and environmental disasters. Therefore, diagnostics of spiroids reducers both at the stage of acceptance tests and during operation is an urgent task. Nowadays the number of such researches has increased, which proves the relevance of works on gearbox diagnostics.

In the last twenty years much attention has been paid to research in the field of vibration diagnostics. Signals are received from vibration sensors installed on the gearbox housing.

LITERATURE REVIEW

One of the leading scientific schools in the world for design and manufacture of spiroid gearboxes is the school of professor Veniamin Goldfarb [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. The diagnostic technique consists in detecting signal changes caused by damage to gearbox parts [12, 13, 14, 15, 16, 17]. Vibration signal modulations occur in the gearbox, as gearboxes mainly operate under harsh operating conditions [17]. Their major components such as gears and bearings are subject to damage such as fatigue cracking, pitting, corrosion, and wear and tear [18]. Even a small failure can lead to a disaster, so condition monitoring and diagnostic systems must be installed for gearboxes to detect the appearance of defects in time to avoid accidents, repairs and replacement of equipment. Faults can be detected by statistical analysis of the vibration signal [19].

The technique of change in gearmesh stiffness is widely used to study the vibratory property of the gearbox in gear dynamic modeling and computer simulation. The vi-

bration response of the gearbox arrangement can be obtained analytically under various tooth fault conditions. It is also used to understanding the effect of the fault and system parameters on mesh stiffness in vibration diagnostic signal. To identify the condition of geared system a series of vibration signals can be generated through computer simulation analytically. Experiments can be conducted on single-stage and multistage gearboxes and vibration signals recorded for different levels of faults in gear tooth. The vibration response obtained from analytical model and experiments can be further analyzed by using different techniques available such as statistical and signal processing in the spectrum and its diagnostic performance is tested for comparative fault detection [20].

In [21] analysed methods for vibration diagnosis of electrical systems and gearboxes. In the case of gears, it can be noted that the oscillation of the gears is determined by the meshing frequency and harmonics due to the variable stiffness during meshing [22]. For a pair of damaged gears in gearboxes with fixed axles symmetrically around the meshing frequency and its harmonics, characteristic components and side bands appear in the frequency spectrum [23]. The vibration signal picked up by accelerometers mounted on the gearbox housing contains several types of vibrations from gears, shafts, bearings, etc. Informative vibration signals can easily be masked by strong background noise. Without noise reduction [24] it is therefore difficult to isolate faults in the low frequency range of the signal. Moreover, if a gearbox with several gearing pairs is involved, diagnosis becomes more difficult [25].

The informative components of the gearbox vibration spectrum, consisting of gearbox speed, gearing frequency and their harmonics, are affected by faults. Fault identification is associated with the appearance of a characteristic frequency associated with that fault. Similarly, different frequencies associated with different gears can be equated [26].

Gearbox vibration signals measured by accelerometers are in the time domain. If a gearbox malfunctions, the energy variation can be seen in the signal. A statistical measurement of the energy of the vibration signal is carried out to detect a malfunction. The various diagnostic techniques used use the vibration amplitude and energy of the signal in the time domain [27].

Modern condition monitoring techniques employ advanced technologies to evaluate the machine health and predict when and where the machine is likely to fail, thereby maximizing the machine profitability. Generally, vibration sensors are adopted for condition monitoring of rotating machinery or manufacturing processes. It is generally accepted that vibration signals from a gearbox depend on the sensor location relative to the source and are often contaminated by structure-borne noises from other sources, leading to a low signal noise ratio [27].

Gearbox is the major component that leads to turbine downtime. Its failures are mainly caused by the gearbox bearings. Devising condition monitoring approaches for the gearbox bearings is an effective predictive maintenance measure that can reduce downtime and cut

maintenance cost. In [28] it is proposed a hybrid intelligent condition monitoring and fault warning system for wind turbine's gearbox.

The proposed framework encompasses the following:

- clustering filter – (based on power, rotor speed, blade pitch angle, and wind speed signals) – using the automatic clustering model and ant bee colony optimization algorithm (ABC),
- prediction of gearbox bearing temperature and lubrication oil temperature signals – using variational mode decomposition, group method of data handling network, and multi-verse optimization algorithm, and
- anomaly detection based on the Mahalanobis distances and wavelet transform denoising approach.

The proposed condition monitoring system was evaluated using 10 min average SCADA datasets of two 2 MW on-shore wind turbines located in the south of Sweden. The results showed that this strategy can diagnose potential anomalies prior to failure and inhibit reporting alarms in healthy operations [28].

METHODOLOGY OF THE RESEARCH

Experimental studies of highly loaded spiroid gear PS-124 were carried out at the scientific and production enterprise “Mekhanik” Ltd. of Kalashnikov Izhevsk State Technical University. Figure 1 shows the gearboxes produced by “Mekhanik” Ltd.

The tests were carried out on a test bench operating according to a closed circuit. The test bench consists of an electric drive with a gear reducer on the basis of a three-phase asynchronous motor AIR80V4U2 at 1.6 kW power and 1395 rpm speed, the studied spiroid gear PS-124, which has an input frequency of 45 rpm, a spuroid gear and a disk brake, which created the load torque, measured by a dynamometer DPU-0,2-2. A vibration sensor with a frequency range of 0-2000 Hz was fitted to the spiro gearbox via a magnet. The vibration data was fed into the LTR22 data acquisition system via the LE-41 charge amplifier and then displayed as a graph on the laptop screen.



Fig. 1 Gearboxes produced by “Mekhanik” Ltd

Gearbox vibration was measured as the load varies from 200 Nm to 1000 Nm, in steps of 200 Nm. Experiments were performed with the motor rotating in both directions. The spiroid gear PS-124 under investigation was subjected to 3000 running cycles: 2 revolutions, pause, 2 revolutions in the other direction and pause, which made

12 000 revolutions. The output speed of the spiroid gear was 21 rpm.

The structure of the test bench is shown in Fig. 2.

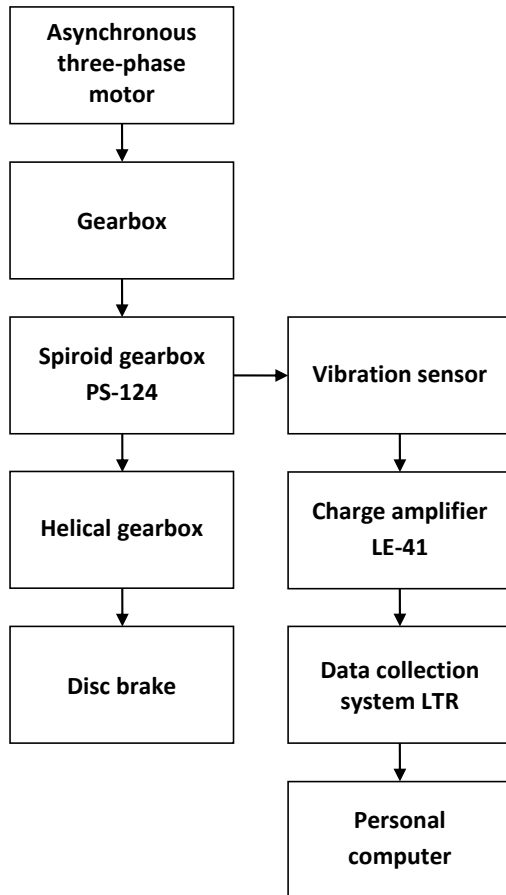


Fig. 2 Block diagram of the test bench

When carrying out an experimental vibration analysis, the type and technical characteristics of the sensors and their installation methods must be selected correctly. The way in which the sensors are mounted must not distort their specifications.

The locations for installing the vibration sensors (piezo accelerometers) should be selected so that the vibration sensor is as close to the gear zone as possible. Install the sensor in a location where the attenuation of the gear vibration is as low as possible. The distance between the vibration signals recorded from the gear zone and the vibration sensor should be as small as possible, especially in the case of gaps. The use of styli to mount the vibration sensors is not desirable, at least strong, rare-earth, permanent magnets should be used to mount the sensors on the gearbox.

The vibration sensor must be mounted in the direction of the line connecting the centres of the gearbox shafts or perpendicular to it.

For express diagnostics of gearboxes during acceptance tests it is reasonable to use magnetic fixing method with investigated frequency interval 0-2000 Hz, providing fast installation, for stationary diagnostics systems – pin connection with investigated frequency interval 0-10000 Hz, providing precise orientation at good machining.

The overall view of the stand is shown in Fig. 3.



Fig. 3 General view of the stand:

1 - gearbox; 2 - asynchronous three-phase motor AIR 80V4U2; 3 - spiroid gear; 4 - dynamometer DPU-0,2-2; 5 - spur gearbox; 6 - disc brake; 7 - vibration sensor; 8 - charge amplifier LE-41; 9 - laptop; 10 - modular data acquisition system LTR

Fig. 4 shows the locations of the vibration sensors.

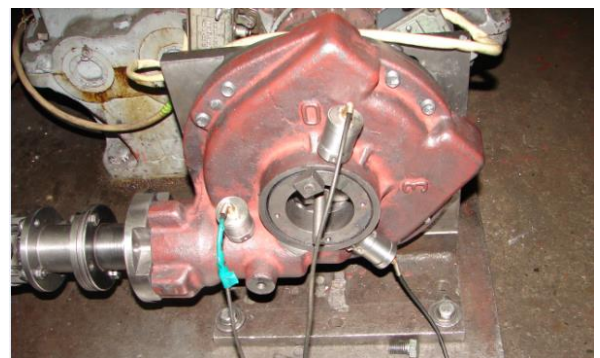


Fig. 4 Vibration sensor installation locations

RESULTS OF EXPERIMENT ON VIBRATION MEASUREMENT

Figures 5, 6 show examples of spiroid gear vibration measurements with a 4000 Nm load when the motor rotates in different directions.

Fig. 7 shows an example of 600 Nm spiroid gear vibration measurements on the LTR Modular Data Acquisition System.

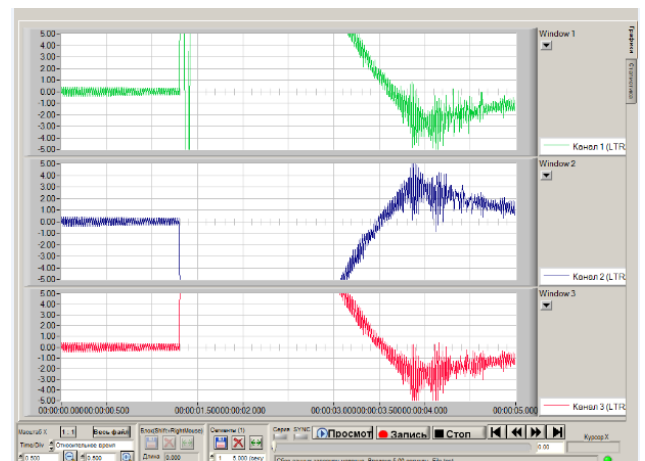


Fig. 5 Example oscilloscope of vibration for a spiroid gear with 4000 Nm load, clockwise rotation

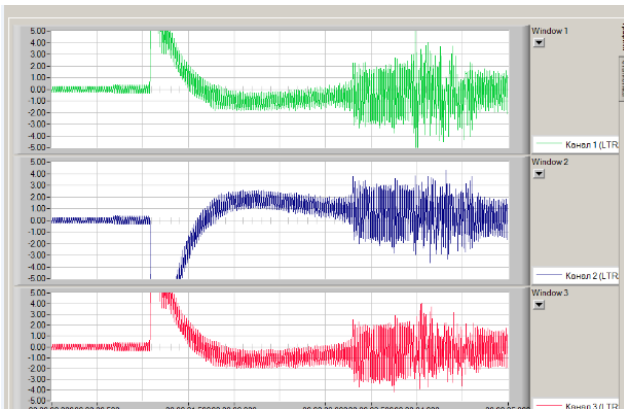


Fig. 6 Example oscilloscope of vibration for a spiroid gear with 4000 Nm load, anti-clockwise rotation

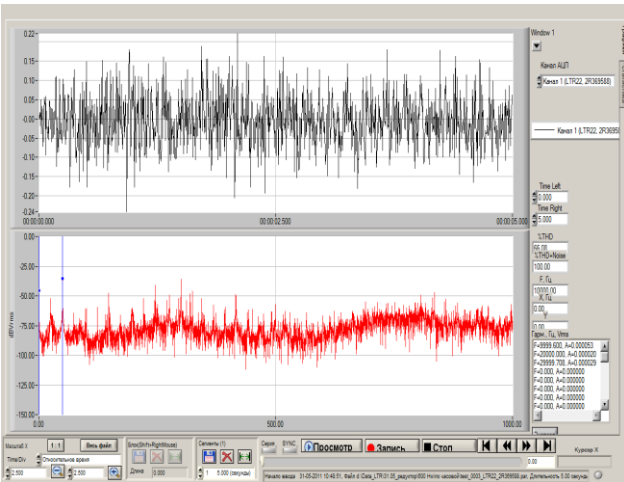


Fig. 7 Example of oscillogram and vibration spectrum for spiroid gear with 600 Nm load torque

Table 1 shows the experimental results for the low frequency vibration of the spiroid gear PS-124.

Table 1
Results of experiment on measurement of low-frequency vibration (200-300 Hz) of the spiroid gear PS-124

Load torque, Nm	200	400	600	800	1000
Amplitude of low-frequency vibration 200-300 Hz with clockwise rotation of the gearbox, dB	-60	-60	-60	-60	-65
Amplitude of low-frequency vibration 200-300 Hz with counter-clockwise rotation of the gearbox, dB	-60	-60	-60	-70	-70

Table 2 shows the experimental results for the medium frequency vibration of the spiroid gear PS-124.

Table 2
Results of experiment to measure mid-frequency vibration (700-800 Hz) of the spiroid gear PS-124

Load torque, Nm	200	400	600	800	1000
Amplitude of mid-frequency vibration 700-800 Hz with clockwise rotation of the gearbox, dB	-70	-60	-60	-60	-55
Amplitude of mid-frequency vibration 700-800 Hz with counter-clockwise rotation of the gearbox, dB	-60	-60	-60	-55	-55

CONCLUSIONS

Spiroid gears are notable for high loading and overloading ability, increased smooth running and less sensitivity to manufacturing and assembly errors, high reliability and durability.

The analysis of results of the experiment on investigation of vibration of the spiro gearbox PS-124 shows that the vibration level at frequency 200-300 Hz is reduced by 5 dB with an increase of the resistance moment up to 1000 Nm by clockwise rotation of the gearbox and an increase of the resistance moment up to 800 Nm by counter-clockwise rotation of the gearbox.

The vibration level at frequency 700-800 Hz is increased by 5 dB with an increase of the resistance moment up to 1000 Nm by clockwise rotation of the gearbox and an increase of the resistance moment up to 800 Nm by clockwise rotation of the gearbox. At excess of the given vibration levels the probability of occurrence of defect is high. Economic efficiency of application of diagnostic systems is conditioned by increase of reliability and quality, reduction of accidents, decrease in defects, reduction of downtime of expensive equipment, reduction of maintenance and repair costs.

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