

MESH QUALITY MONITORING IN EVOLVENTN TEETH IN GEARBOXES UNDER OPERATION – SIGNAL IDENTIFICATION

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Abstract – The work deals with the design and implementation of autonomy tensometric apparatus for measuring of gear mesh of wheels in large industrial gearboxes and with possibilities of processing and evaluation of the recorded data and results interpretation. The method is demonstrated on case studies showing development of loading distribution across the width of the teeth, limited stiffness of the tooth rim, repetitive artifact, and ovality of the paired wheel.

Keywords: gearbox, strain gauge, loading, stress, artifact, tensometric measurement, datalogger

1. INTRODUCTION

Large industrial gearboxes belong to principal machinery equipment in factories and engineering facilities, where their failure would mean radical functional limitation or even stoppage often without possibility of a possibility of back-up. Manufacturers of such transmissions have to perform series of measurements to detect possible defects before machines delivery to the customer. Testing is often performed directly on the supplied pieces. This fact however greatly complicates the measurement because the installation of a measurement apparatus must not affect in any way the gearbox ready for delivery. Thus, only indirect measurements able to detect possible defects can be applied to monitor phenomena accompanying the operation of the gearboxes, such as vibration or warming, which. The force-deformation characteristics of the gearing, from which the quality of the meshing can be directly deduced, can be collected nearly exclusively by strain gauge application. Because it is still very difficult to transmit reliably and with sufficient sampling frequency the signal from the strain gauges on rotating wheels to the recording devices wirelessly. The

experiment would not be so difficult if it was not planetary transmission (Fig.1).

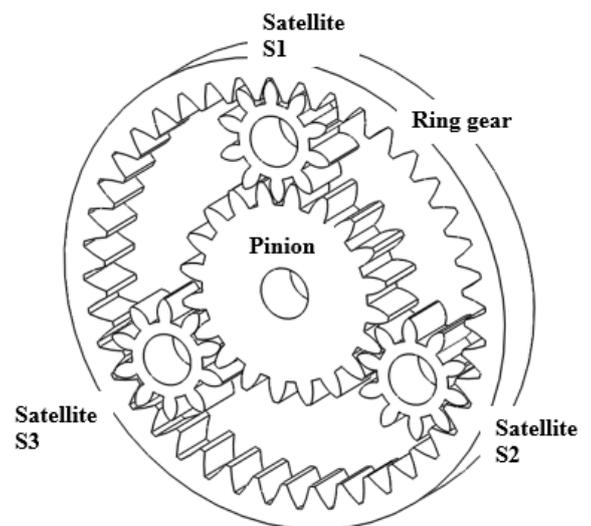


Fig. 1: Planetary transmission – 3 Satellites

It was necessary to determine the method of measurement on rotating parts. In case of determining the load on stationary gear, it is a common strain gauge measuring. For this measurement it is possible to use simple devices supplied by a number of manufacturers and implement data transfer over the standard wires. More complicated situation occurs if the gear is rotating around its own axis. In that event the wires can't be used for data transfer from strain gauge. There are used a Wi-Fi panels for instance. A satellite is the most complicated piece of transmission to be measured. The satellite is rotating around axis of other gear and at the same time around its own axis. Satellite performs compound movement composed of multiple rotations and moreover it is closed in gearbox often. Any kind of using Wi-Fi panel is very

hard for this gear. Therefore it was necessary to develop a special device.

Some autonomous recording units (data loggers) (Fig.2) appear a feasible solution. The data are downloaded to the computer after measurement completion. The data loggers usually communicate with the computer via a wireless connection that does not have to be so reliable and fast, because it serves only as information that the loggers are working.



Fig. 2: Recording device - „data logger“

2. METHODS

Due to the complexity of the measurement it is necessary to be very strictly adhere the following procedure.

1. Assignment
2. Determine the input parameters of experiment
3. Preparation of the experiment
4. Installation of measuring apparatus
5. Experimental measurement
6. Visual check after measurement
7. Evaluation of measurement

The fundamental starting point in terms of usability and validity of the recorded data is created by the strain gauges application, which must be very precise reconsidering the minimal space possibilities and the need to place them at the expected maxima of mechanical stress in the heels of the teeth (Fig. 3).

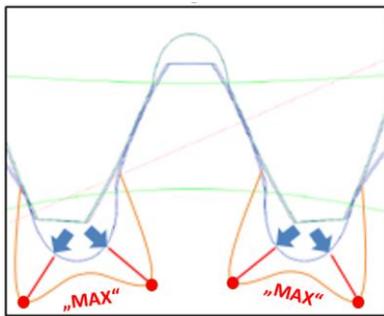


Fig. 3: The strain gauge placement with regards to tooth heel loading

To exclude artifacts and to attain reliable retrospective signal identification, the strain gauges are placed in two distant tooth gaps so that they are not loaded by the gear mesh at the same time. This approach also ensures that during a particular meshing, always one of the strain

gauges operates as the measuring one, while the second one is used for temperature compensation (Fig. 4).

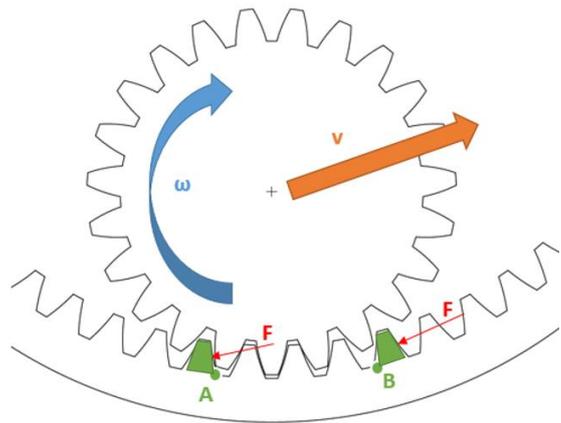


Fig. 4: The strain gauge placement into two tooth gaps (gap A – measuring strain gauge; gap B – compensating strain gauge)

Based on the Fig. 4, the theoretical meshing duration and appropriate sampling frequency can be calculated and implemented.

The position of strain gauges in toothings across a width on gears of transmission is evident from Fig.5. Measuring places on gears are intentional aligned. It is for comparing value between gears.

Ring gear	T1	T2				T6	T7
Planet gear	T1	T2	T3	T4	T5	T6	T7
Pinion	T1	T2				T6	T7

Fig. 5: Position of strain gauges on tooth of gears

Strain gauges are connecting to half bridge (Fig. 6). Strain gauge “A” measures loading of teeth. Strain gauge “B” compensates a temperature in gearbox. [1]

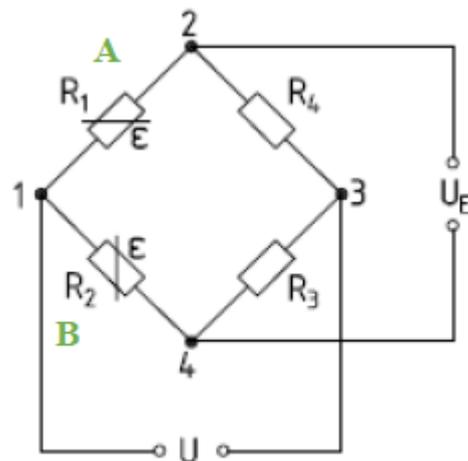


Fig. 6: Strain gauges connection

3. MEASUREMENT

The measurements were performed on planet gears of planetary gearboxes for heavy industry and wind power plants.

3.1. Apparatus installation

The measurements were performed by classic wire 350 Ohm strain gauges (Fig.7) placed in the gearing of the planets according to the principle shown in Fig. 4 All half-bridges were connected to separate amplifiers mounted in holes in the body of the planets. The data logger and battery unit were located in other separate holes. Necessary wiring was placed on front surfaces of the planets with minimal influence upon their outer dimensions and surfaces quality (Fig. 8).

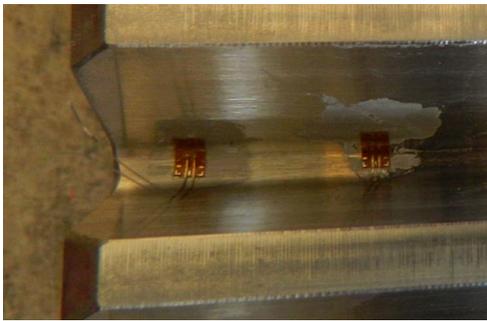


Fig. 7: 350 Ohm strain gauges



Fig. 8: Wiring of the installed apparatus after an epoxy protection

For wiring protection, sealing and closing of the hole covers of the strain gauges, an epoxy adhesive was used (Fig 9). With all this, the planet was finally installed in the gearbox. A sampling frequency of the data logger was adjusted on 2500 Hz.

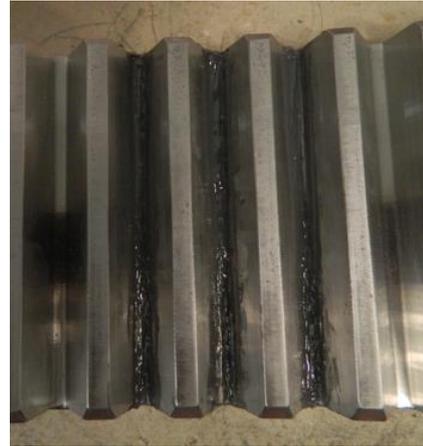


Fig. 9: Strain gauges after an epoxy protection

3.2. Measurement

For operating modes according to Tab. 1, measurements were performed using always two identical gearboxes on the stand in a back to back junction (Fig. 10).



Fig. 10: The testing stand

Tab. 1: Operating modes

Mode	RPM	Torque [kNm]	%
1	939	264	22
2	1271	488	42
3	1489	667	57
4	1660	822	70
5	1798	966	82
6	1798	1173	100
7	1798	1380	117
8	2000	1380	117

4. RESULTS

Comparing of the signals from strain gauges allows reliably exclude artifacts caused for instance by an immediate contact of some parts of the apparatus with the construction of the gearbox, or failure in data transfer, etc. (Fig. 11).

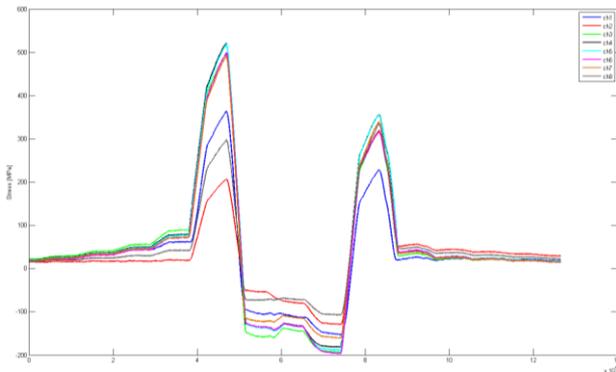


Fig. 11: The signal recorded from two strain gauges placed at two tooth gaps

The time difference of the maxima of both signals determines in fact the real meshing duration for given location and given operating mode. The first maximum is a signal from gap A and second maximum is a signal from gap B. For a following data processing data are dividing for gap A and gap B individually.

With successive arrangement of the records from strain gauges in one tooth gap according to their location, distribution of the loading on the tooth width can be visualized (Fig. 12). That is usable for verification with test with colour (Fig. 13).

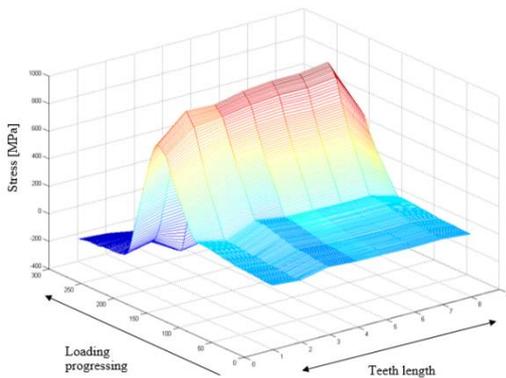


Fig. 12: The visualization of the distribution of the loading on the gear width



Fig. 13: Tooth with colour testing

By monitoring of signals over a longer time interval, limited stiffness of the tooth rim (if there are any apparent meshing impacts from distant teeth – see Fig. 14) and/or other disturbances such as incoaxiality or ovality of the paired wheels in gear (see Fig. 15) can be detected.

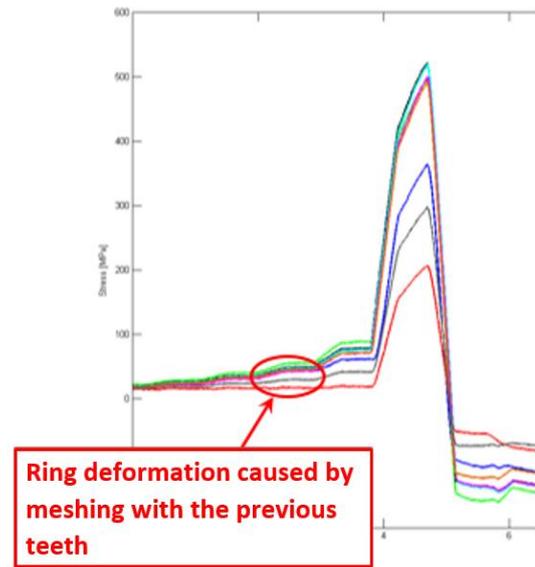


Fig. 14: Limited stiffness of the tooth rim

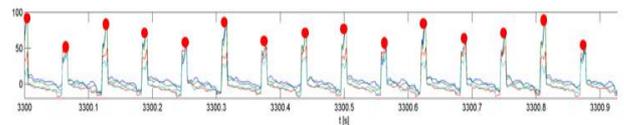


Fig. 15: Cyclic fluctuation of the signal - manifestation of the ovality of the paired wheel

Progress of teeth loading is represented at Fig. 16 for illustration. It is record form strain gauges placed on the one teeth. Main teeth loading is zone II. It is a tensile load of teeth during meshing with other gear. In zone I there is the tensile load of teeth too. But this load is produced by meshing previous tooth before investigated teeth with other gears. It is total deformation of gears. After meshing investigated teeth with other gears come up to unloading of teeth and teeth is changing over to pressure load. It is caused by meshing with the following tooth of the gear. This phenomenon is in zone III. It is total deformation of the gears again.

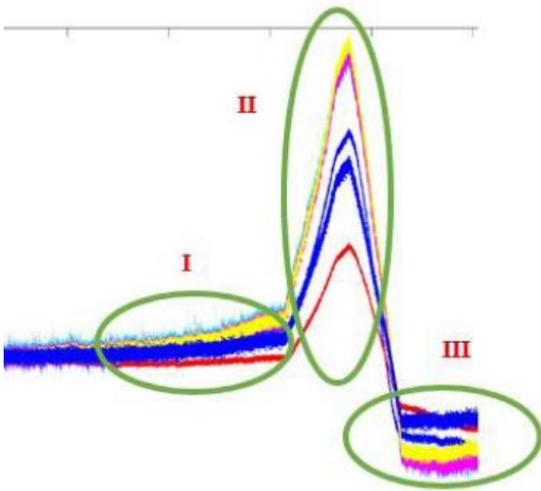


Fig. 16: Progress of recording value from strain gauges

5. CONCLUSIONS

Because the proposed method has been tested repeatedly and successfully and because the outputs correlate well with the results of measurements of vibrations and geometry performed in parallel by the gearbox manufacturers, we can confirm our approach as being an universal and reliable method for the direct monitoring of the above mentioned parameters and for research operation of the involute gearing.

Moreover, because the method is economically not too demanding process and it offers enough relevant outputs to describe and quantify the quality of tooth meshing, we believe that it can be offered to the industrial commercial sector, too.

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REFERENCES

- [1] O. Berka, F. Lopot, and M. Dub, Experimental Analysis of Gear Loading in Planetary Transmission, *Applied Mechanics and Materials*, 732, pp. 231-234, Feb. 2015, 10.4028/www.scientific.net/AMM.732.231