Experimental Measurement of Gears Impact in Transmission

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Abstract
The gears meshing in large industrial gearboxes is one of the most important factors specifying their user’s properties. The quality of gears meshing affects besides other things intended and real lifeness of gearing and its noise and vibration. In practice, the meshing quality is mostly observed by so called colour test (Figure 1).

Fig. 1: Final colour prints on teeth

However, the colour test has one huge disadvantage – it cannot provide colours and development of the gears meshing in time, it just displays the summarized result. This is why another more rewarding approach is needed [5].

1. Aim
The presented work deals with description of the method for continuous monitoring of meshing quality in gears of big industrial gearboxes. In terms of high clarity of outputs, the method works with generally respected $K_{\text{HB}}$ coefficient.

2. Background
$K_{\text{HB}}$ coefficient is introduced by respected technical standard ISO 6336-1 used for involute gearing proposal and check calculations. This coefficient is defined according to the next formula:
working with bending stress in teeth. This is an important fact, because bending loading can be relatively easy and reliably measured.

The concept of $K_{HB}$ coefficient is illustratively presented in Figure 2 on a simplified example of incorrect teeth meshing.

![Loading distribution across the tooth width](image)

Fig. 2: Loading distribution across the tooth width

In the figure, the typical course of the stress in the tooth heel is also seen and it must be highlighted here that the maximum value in each cross-section remains still in the same position.

3. Experiment

The experimental data acquisition is based on strain gauges application into the tooth heels (Figure 3).
Fig. 3: Applied strain gauges on tooth

Obtained data provide possibility to monitor actual loading distribution on teeth during gear operation. The $K_{\text{HP}}$ coefficient is then calculated directly from real data.

For the strain gauges installation, a special transparent plastic film is used (the film presence in Figure 2 is exhibited by black lines for easier work with). After strain gauges fixation using an appropriate glue, the film is removed. Practically, the only one limit here is the “size” of gearing defined by its modulus. Using standard commercially available strain gauges, the low limiting value of modulus is about 5 mm [2].

Due to as minimal encroachment in gearing construction as possible, the measurement can be performed directly on the customer supplied pieces also. The measuring apparatus is completely autonomous for certain time when it communicates with the main operator’s computer via a wireless connection.

So that the temperature will have minimal influence on the recorded data and the measuring apparatus will not require a specific orientation of revolution, the strain gauges are installed into two heels on opposite sides and wired in half bridge connection [1]. On the scheme in Figure 4, the “cick-cack” wiring used for performed measurements is presented.

![Strain gauges “CIKCAK” connection](https://doi.org/10.51202/9783181022948-1119)
This specific organization decreases a risk of complete loss of the signal from given measuring position when one of two there installed strain gauges fails.

The described apparatus is being used by collaborating producers of planet gearboxes for heavy industrial applications as oil platform movement, wind power station, etc. The gearboxes are tested in special stands usually in “back to back” connection from 0 to 100 – 120% of nominal transmitted power with step-wise manner in 6 steps à 20% (called working zone 1 up to 6).

4. Data processing

An example of data recording (here from annulus ring) is presented in Figure 5. The first and crucial step in data processing is to identify the signal from strain gauges correctly. In rows marked by T1, 2, 6 and 7, the data from strain gauges are presented. The first row combines these data in one graph. The colored rectangles marked by S1, 2 and 3 indicate regions of meshing the measuring tooth on annulus ring with satellite 1, 2 and 3.

After the identification, the corresponding data are organized into individual graphs for each measuring position in the tooth heel (Figure 6).

![Fig. 5: Signal identification](https://doi.org/10.51202/9783181022948-1119)
Fig. 6: Part of data for the satellite 1 from one of strain gauges

Fig. 7: Load distribution

The final phase of the data processing resulting in the graph displaying the loading distribution along the tooth width (Figure 7) is based on arithmetic mean of maximum values of signal for each measuring position displayed in the Figure 6 (red circled). The applicable validity of the arithmetic means is documented by the fact, that the corresponding standard deviations differ more over than two orders.

Following the text above, the values of loading of the tooth are arranged with respect to the ordinal number of the measuring position in the graph. Because the strain gauges are located in the tooth heel with equal mutual distance, the displayed courses are not deformed and can be used for final evaluation of the quality of teeth meshing. [3]
5. Results

In Figure 8, the data processing output is presented. Relatively big changes in $K_{H\beta}$ coefficient are seen depending on transmitted power (chap. Experiment – working zones).

![Graph of $K_{H\beta}$ coefficient in zones](image)

Fig. 8: Progress of coefficient $K_{H\beta}$ in zones

From the course of the described graph, various conclusions about the design both of the gearing and the gearbox can be done, e. g.:

- with respect to the first initial value which is much higher than the other ones, the dangerousness of operating around 20% of nominal loading of the gearbox is stated.

- the design of the gearing needs further treatments, because experimentally observed values stay higher than the expected ones (red line in the graph)

- increasing loading leads to better values of $K_{H\beta}$ coefficient, what can be interpreted as effect of limited stiffness of wheels and the casing of the gearbox also

In connection with other information from acquired signal, much more detailed information about the tested gearbox can be provided, e. g. about precision of manufacturing and/or about assembling. In the Figure 6, the oscillation of amplitudes in the acquired signal is observed. The frequency of this oscillation corresponds with RPM of the planets carrier. [4]

Considering the number of planets and signal from teeth of the sun, the problem of axial alignment of the annulus ring or its ovality is revealed.

Finally, combining loading (mechanical stress), location of the strain gauges and time course, an interesting 3D graph (Figure 9) which brings an illustrative representation of the progress of the gear meshing is obtained.
Fig. 9: 3D graph of representation of the gear meshing

6. Conclusion
The obtained results provide important information both for transmission design and its actual or following application using the demonstrative coefficient from respected standards. Considering other specifics in the acquired signal, other additional outputs can be realized. Based on these information, an important recommendation about gearbox design or identification of a potential problem can be effectively provided.

We believe that we have been successful by introducing the essential benefits and the huge possibilities of our method of continuous meshing quality monitoring presented above.
7. Bibliography


