Design of Experiment for Load Gear Solution in Planetary Transmition

Ing. Ondřej Berka

Vedoucí práce: prof. Ing. Vojtěch Dynybyl, Ph.D. a Ing. František Lopot, Ph.D.

Abstrakt

Práce se zabývá návrhem experimentu pro měření zatížení ozubení v planetových převodovkách. V tomto typu převodovek určených pro přenášení velkých výkonů je zjišťováno mimo jiné rozložení zatížení po šířce ozubení. Vzhledem ke kinematice jednotlivých ozubených kol planetové převodovky, je zapotřebí vytvořit zařízení, které bude do jisté míry autonomní. Navíc bude odolávat vnějším vlivům ve skříni převodovky, jako je teplota a mazivo. Další komplikací jsou prostorové dispozice uvnitř skříně a rozměry samotného ozubení. Pro tento experiment byla sestavena metodika a následně i celý jeho průběh včetně potřebných komponent. S tím je spojené i vhodné zapojení tenzometrů umístěných na určených místech zubů jednotlivých kol.

Klíčová slova

Planetová převodovka, tenzometrie, rovnoměrnost záběru, napětí v patě zubu

1. Introduction

One of the examined place during testing the planetary transmission are gears. The tooth load of each individual component in planetary transmission is monitored. By large devices is also monitored load across the width of the tooth. It is coefficient $K_{h\beta}$.The actual experiment would not be so difficult if it was not planetary transmission. 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 planet is the most complicated piece of transmission to be measured. The planet is rotating around axis of other gear and at the same time around its own axis. Planet 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. Therefor it was necessary to develop a special device. It is an autonomous record device. This device can be placed inside or outside of gear, due to its small dimensions Moreover the device is supplemented by batteries and amplifiers for signal magnifying.

How it was implied before, this is the exacting strain gauge measurement. In the introduction the demandingness of measurement due to kinematic planetary transfers was mentioned. Another limiting parameter may for example be a space between teeth of gears during joint meshing, the temperature in the toothing under load–and aggression of lubricating oil. In compiling the experiment it must be all these boundary conditions taken into account. Space between gears tooth during joint meshing meanwhile the installation of strain gauge and wires on gears tooth must be respected. Toothing and lubrication oil temperature must be respected during choice of adhesive for strain gauge sticking, during choice of wires for strain gauge and

during choice of wires and strain gauges protection. Equally the temperature influence electronic device in gearbox. Furthermore all of components must be protected from aggression of lubrication oil. That includes strain gauges, wires and all electronic devices, which are coming into contact with lubrication oil.

Above several conditions were described, which must be complied during designing of experiment. Large limitation are dimensions of space in gearbox. For this purpose the recording device was created. It can be placed in small places in gearbox due to its size. Whereas, that the experimental measurement is done in gearbox, it is not possible to perform more design modifications of parts, because transmissions are distributing to the end customers. With this recording device is not required.

Next point of experiment is the placement and connection the strain gauges on tooth. Location must be such that it will be the maximum measured value of stress in the teeth. Further, temperature in toothing must be compensated. Last point of experiment is that the location and the connection must be for both directions of rotation. Thus meshing by first or second side of the teeth.

2. Method of measurement

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

Individual points will be commentated in follow chapters. In case of compliance of established method we prevent complications, which may come and which could result in unsuccessful experiment.

2.1 Assignment

During the measurement assignment requirements from client are determined. Everything must be sort out, because this measurement is very difficult. In requirements may be for example, which gears are measured, which load will be in transmission during experiment, how long will be the measurement in progress, and what kind of limitation factors are in measurement, etc.

2.2 Determine the input parameters of experiment

Determining input parameters for conducting an experiment is directly connected with the assignment. Parameters are revolutions of gears, space between top land and bottom land of tooth during joint meshing, temperature of toothing and lubrication oil, dimensions in gearbox, size of toothing, dimensions of parts, kinematic of planetary transmission, direction of gear rotation, expected stress in toothing.

2.3 Preparation of the experiment

After the determination of all requirements and parameters for experiment ~~is~~ follows preparation of experiment. It is a determination of a place for the strain gauges installation on tooth, choosing suitable strain gauges, adhesive, protecting of strain gauges and wires, setting

of an electronic parameters, determination of necessary constructing modification of gears and another parts, preparation of console for location of the measuring apparatus, etc.

2.4 Installation of measuring apparatus

The prepared strain gauges and measuring apparatus now must be installed on the single parts of transmission. Technology of sticking again depends on parameters, which are temperature and aggression of the lubricant. Location of strain gauges on tooth must satisfy the following conditions. Strain gauges should be in place, where is stress maximum of teeth. Strain gauges must not come into contact with other gears. Strain gauges must be in same height of teeth for following smoothness of gear loading. The apparatus is locatied to avoid the contact with another parts of transmission.

2.5 Experimental measurement

In case, that the complete installation of measuring apparatus was made, the experimental measure can be performed. Measurement is based on the assignment. It is under way of the determine conditions, during different loading levels, etc. During the measurement it is possible to display the measured data online, for proving the accuracy of conducting experiment. At the same time the data are recorded for following evaluation.

2.6 Visual check after measurement

This point is very important, because during the experiment some parts of measuring apparatus may be damaged. Or some parts may be contaminated by lubrication oil. In this case the damaged parts and possible impacted measured data must be identified.

2.7 Evaluation of measurement

Based on the measured data an evaluation of the experiment is performed. The best solution is to use a created script from suitable software. From evaluated data are specified the results and evaluated the whole experiment.

3. Conducted experimental measurement

Measurement was conducted in testing room for transmission in producer factory. Measurement was made during running-in and testing of developed transmission for rubber industry. The purpose was monitoring of new construction effect for following smoothness of gear loading along the width of teeth during meshing with other gear. Measuring apparatus could not affect structure of transmission without arranged places of parts. For safety securing relevant applicable data the measurement was made synchronously with three autonomous systems on the ring gear (**Fig. 1**), planet (**Fig. 2**) and pinion (**Fig. 3**). For measurement on the ring gear was used four channel stable measuring apparatus National Instruments. For measurement on planet was developed unique self-sufficient measuring apparatus with own recording device (**Fig. 4**). Data from pinion was recorded by four channel apparatus National Instrument with Wi-Fi module for in-time data transfer to the computer (**Fig. 5**). Program for data recording and processing was created in software LabView. For final evaluation was used Matlab.

Fig. 1 *Ring gear with strain gauges and epoxide layer*

Fig. 2 *Pinion with strain gauges and epoxide layer*

Fig. 3 *Planet gear with strain gauges and epoxide layer*

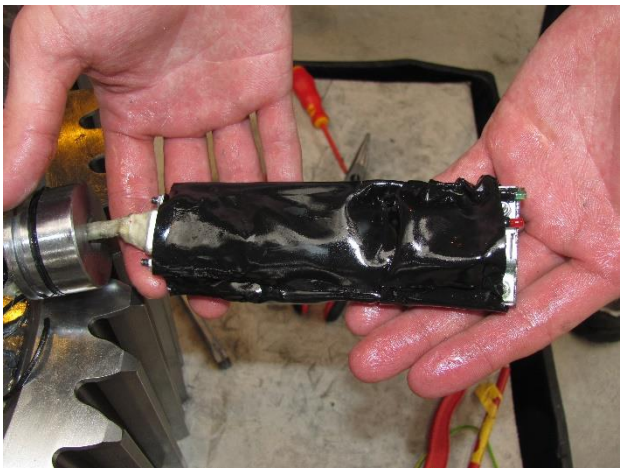

Fig. 4 *Recording device*

Fig. 5 *Systems for data recording*

3.1 Measurement realization

The position of strain gauges in toothing on gears of transmission is evident from Fig.6. Measuring places on gears are intentional aligned. It is for comparing value between gears.

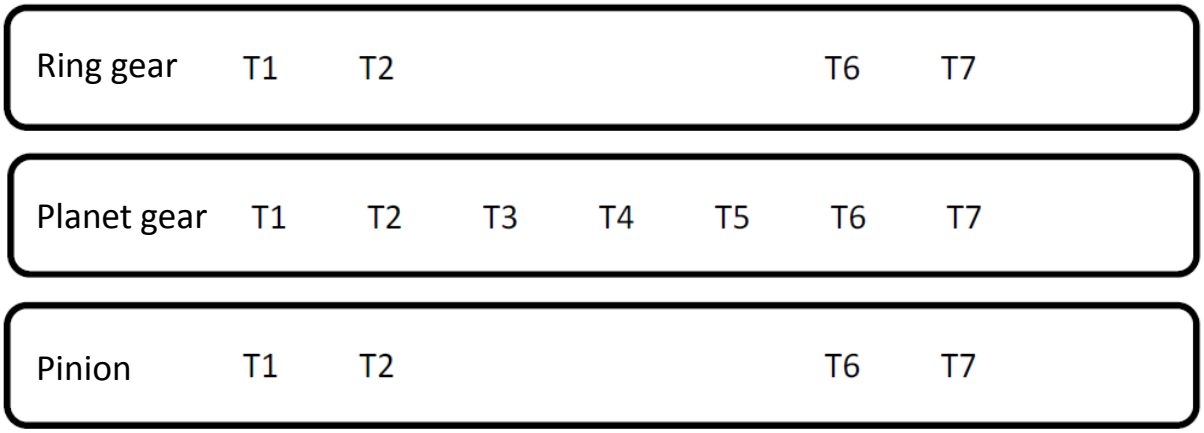

Fig. 6 *Position of strain gauges*

Transmit frequency of record was set on 2000Hz with respect to time of gears meshing.
Standard strain gauges was glued on tooth gap and connected to the bridge for following bending effect of loading in tooth bottom. Strain gauges and wires were protected from extraneous influence by layer of epoxide synthetic resin.

Temperature in toothing on ring gears and planet gears with sampling frequency 10 Hz was monitored in the same time with strain gauges measuring.

Measurement was realized in several phases (zones) wickedly **Fig. 7**. Phases were connected continuously. Load 100% in **Fig. 7** was the maximum loading during experimental measuring. It correspond to 30% of nominal loading. Data recording was under way continuously.

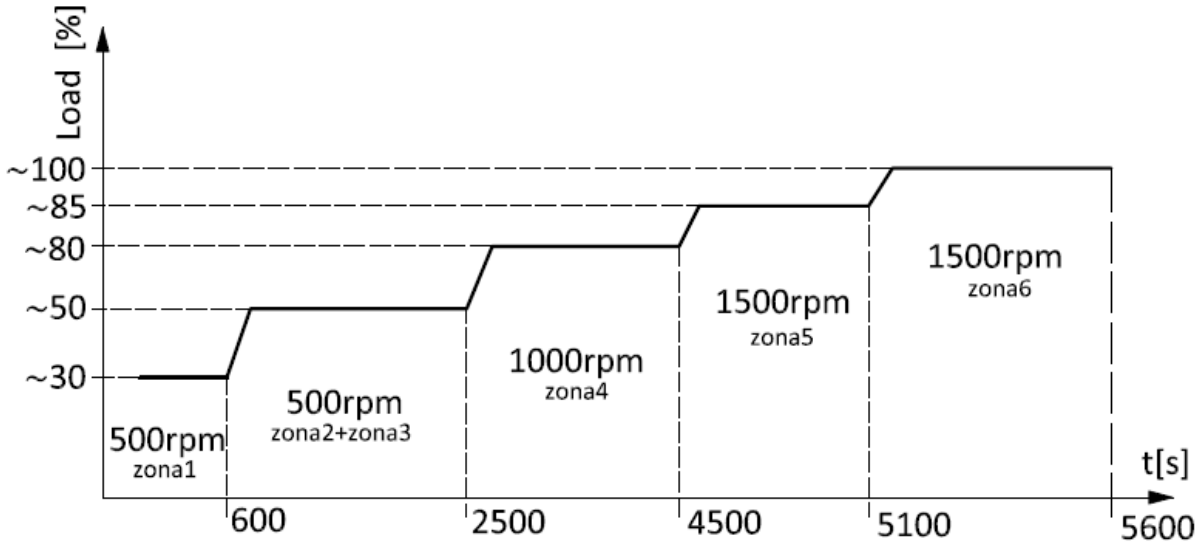

***Fig. 7** Phases of measuring*

3.2 Processing and evaluation data

Records form ring gear, planet gear and pinion are objects for processing. Fig. 8 purvey picture of strain gauges location on pinion with respect dimensions of pinion.

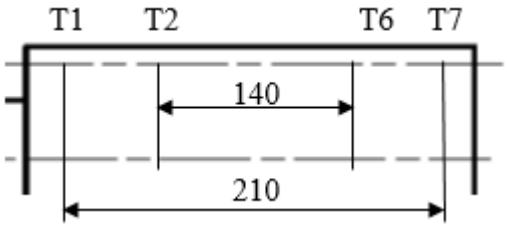

***Fig. 8** Strain gauges location on pinion*

Partial results are represented graphically for better illustration and with relevant comments. Identification of meshing with individual planet gears is set up for better orientation in diagrams. Planet gears are symbolized by symbols S1, S2 and S3 (**Fig. 9**)

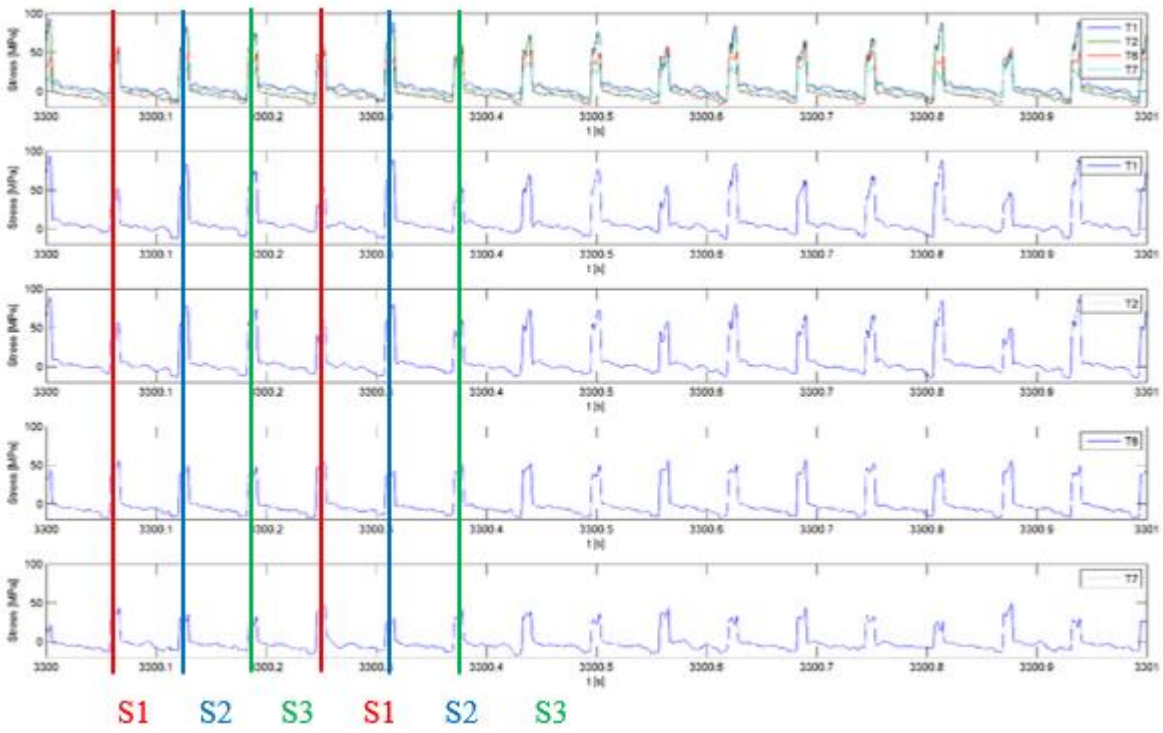

Fig. 9 *Identification meshing with individual planet gears*

Identified images of meshing individual planet gears were arranged to time line for individual measuring channels without section, which were under way meshing with another planet gears. Changing value of stress in tooth bottom is emphasized by this method (**Fig. 10**).

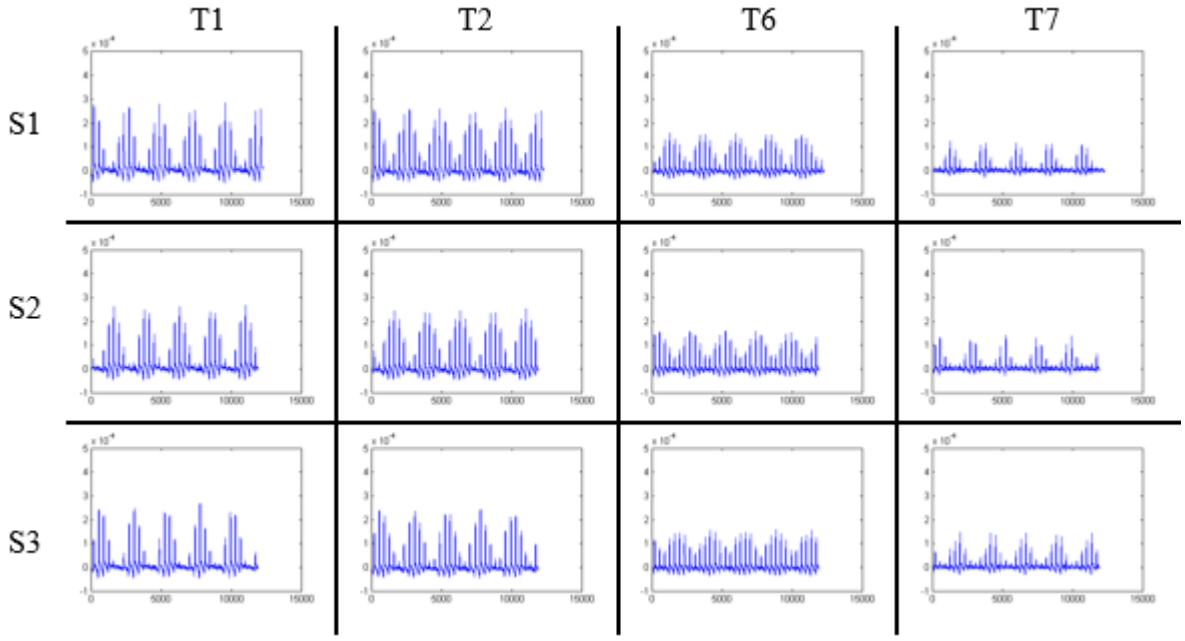

Fig. 10 *Identification of individual planet gears meshing*

Strain gauges were connected to half bridge (**Fig. 11**). Strain gauge "A" measures loading of teeth. Strain gauge "B" compensates a temperature in gearbox and "B" is located near recording device.

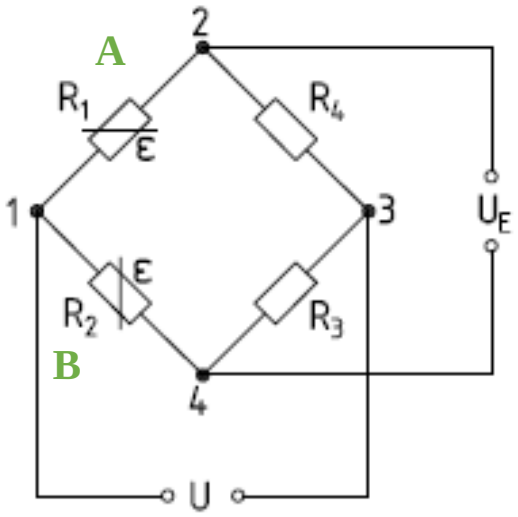

Fig. 11 *Strain gauge connection*

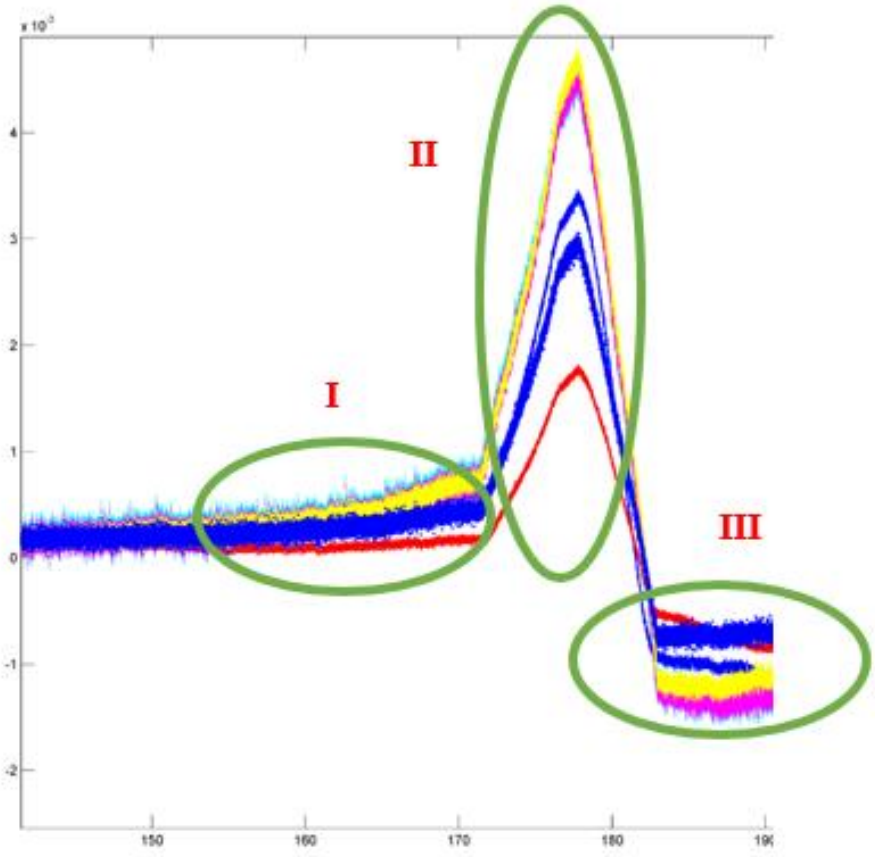

Fig. 12 *Progress of recording value from strain gauges*

Progress of teeth loading is represented at **Fig. 12**. 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.

For verification the measurement it is compared with a gear-testing using colour. Tooth are painted by colour along their whole length. Colour is wipe off after contact with another tooth. Positioning of loading along length of teeth is evaluated by this test. 3D diagram is made for comparing. Diagram describes measured loading along length teeth (**Fig. 13**). Verification is done by visual comparing **Fig. 13** and **Fig. 14**.

Fig. 13 *Toothing with testing colour*

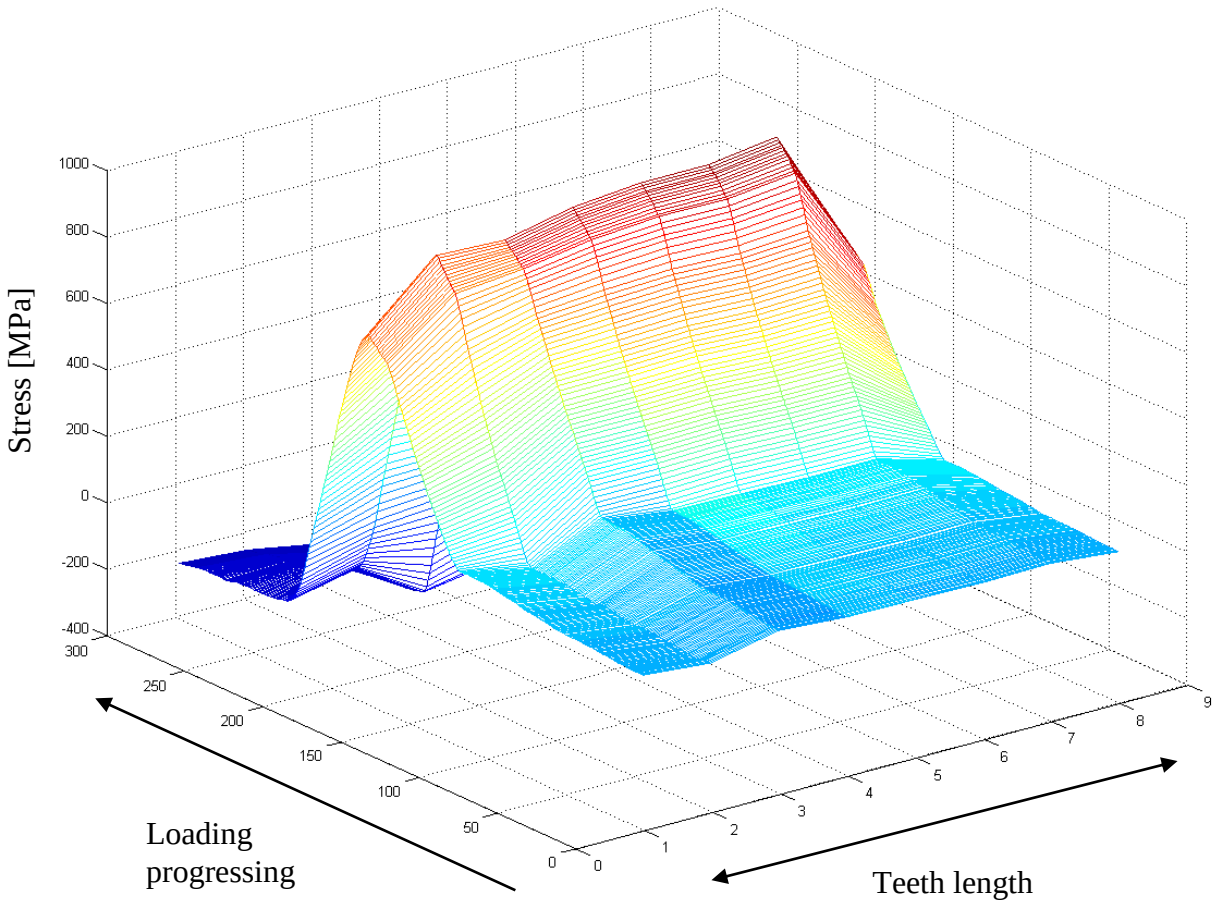

Fig. 14 *Loading processing along teeth length*

Coefficient $K_{h\beta}$ is calculated by norma - *ISO6336 method A.*

$$K_{h\beta} = \frac{max(max\overline{T_i})}{\overline{(maxT_i)}} \tag{1}$$

$$K_{h\beta} \in < 1; \infty) \qquad K_{h\beta}^{\ opt} = 1 \tag{2}$$

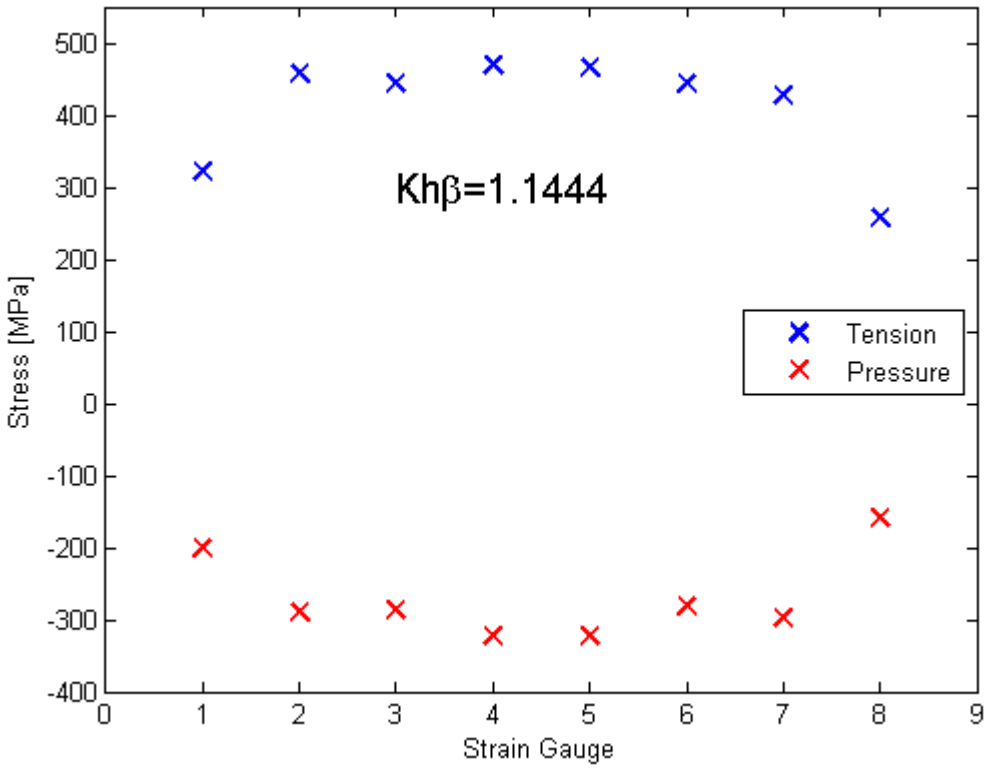

Fig. 15 Loading processing along tooth length

4. Conclusion

Designed method was used for this experiment. Measurement brought several additional piece of knowledge. These are information how to make better the next measurement. For example using another adhesive and epoxide, better location of strain gauge, etc. Results were compared with impression of teeth which were coloured. Resulting values agree. Experiment and measurement can be declared as successful.

List of symbols

$K_{h\beta}$	Coefficient	(1)
T_i	Stress from strain gauge *i*	(MPa)
$\overline{T_i}$	Average stress from strain gauge *i*	(MPa)

References

[1] ŠALAMOUN, Čestmír, Miloš SUCHÝ a Jiří SVOBODA. *Mechanické a hydraulické převody*. Praha: ČVUT, 1984.