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Experimental Stress Analysis

# EXPERIMENTAL ANALYSES OF VIBRATION OF WORM GEAR BOXES

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**Abstract:** The article describes the experimental analysis method of worm gear boxes for specific products. The measuring station for the dynamic load worm reducers testing can simulate various extreme transition modes of operation. There are assessed low and high frequency vibration, temperature and ultrasonic emissions. The contribution is made in the framework of grant VEGA No. 1/3175/06 and 1/0292/08.

**Keywords:** reducer, worm gear, vibration, frequency spectrum.

## 1 Introduction

Gears are frequently used as drives of machines and devices. In connection with other parts of machine devices they present dynamical system where gears mean the element defining dynamical attributes of whole system. Dynamical behavior of gear mechanism is characterized by variety of factors. To inner factors belong basic gear parameters, material used, gear manufacturing technology, gear preciseness level, gear looseness, some dimensions deviations etc. Decisive factor from the view of reducers dynamics presents also production preciseness of all its components (shafts, bearings, reducer box), their deformations resulted from operational load, typical deformations of gear wheels, teeth deformation resulted from meshing forces proportion, wear, working environment, operation, assembly preciseness etc. As result of mentioned facts, gearing ratio becomes an variant value depending on swing angle. Above mentioned production deviations become the source of kinematical and dynamical inaccuracy of gearing and its noisiness, where periodical changes of instant meshing of gearing resulted from described facts are superimposed to angle frequency corresponding to rotation frequency of relevant shaft.

From the view of drive dynamics research, attention was paid mostly to drives with frontal gear wheels, where more analyzing methods for influence of kinematical inaccuracy to drive dynamics and consequential additional dynamical load were outlined. On the contrary, only marginal attention was given to dynamics of drives using cylindrical worm gearing.

Introduced contribution deals with problems of experimental analysis of worm reducers vibrations.

## 2 Measurement Characteristic

Subject of experimental analysis was realization of laboratory test of worm reducers. In first stage, the function of test station built on Department of Design of Machine Parts on Faculty of Manufacturing Technologies in Prešov [1] needed to be proved and its suitability for testing the gearings verified. Cylindrical worm gearboxes were tested in trial operation according to former planned operational mode [7]. Running conditions of *Operational Mode 1* (input spindle speed $n_1$ = 1400 turns/min, load: 5 weights in total of $m_{Z1}$ = 145 kg, running

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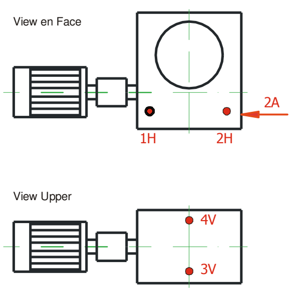
time $t_1$ = 3 hours) were designed in order to achieve 70 ÷ 80 % of nominal gearbox performance guaranteed by its producer and stable oil temperature under limitations. With *Operational Mode 2* (input spindle speed $n_1$ = 1400 turns/min, load: 2 weights in total of $m_{Z2}$ = 69 kg, running time $t_2$ = 3 hours) the load on gearbox was lower.

Dynamical values were monitored through the operation (temperature, vibrations, ultrasonic) in selected measure points of gearbox (*fig.1*).



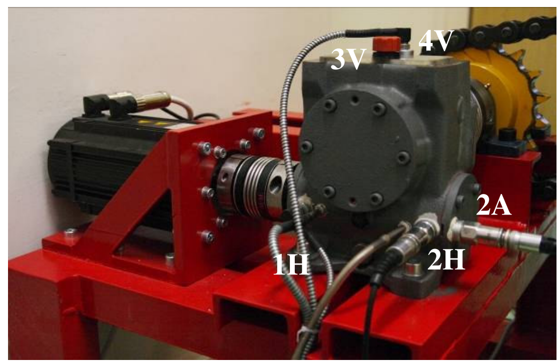




***Figure 1:*** *Placing the sensors on the surface of worm gearboxes*

In measure points 1H, 2H and 4V individual values (gearbox surface temperature and vibrations) were measured in online mode using double-channel online system Oktalon 2K from company Technická diagnostika, spol. s r.o. Prešov, based on the LWMONI2 module, through witch power supply of sensors and evaluating of vibrations were realized.

Dynamical data (vibrations and ultrasonic) form measure points 2H and 2A were collected roundly in offline mode. Data collection was realized with measuring system NI PXI (measuring card type PXI 4472B, 8-channel simultaneous acquisition, 24 bit A/D converter, sampling frequency up to 102kHz, dynamical range 110 dB). Data analysis were realized with Lab View Professional Development System, including Sound and Vibration Toolset and Order Analysis Tools. Form measuring of ultrasonic emission Microlog GX a CMVA 55 - dataloger and frequency analyzer from SKF company were used.

Wear intensity on contact surfaces of teeth sides of worm gearing was monitored using more diagnostic methods.

## 3 Mechanical Vibrations Measuring

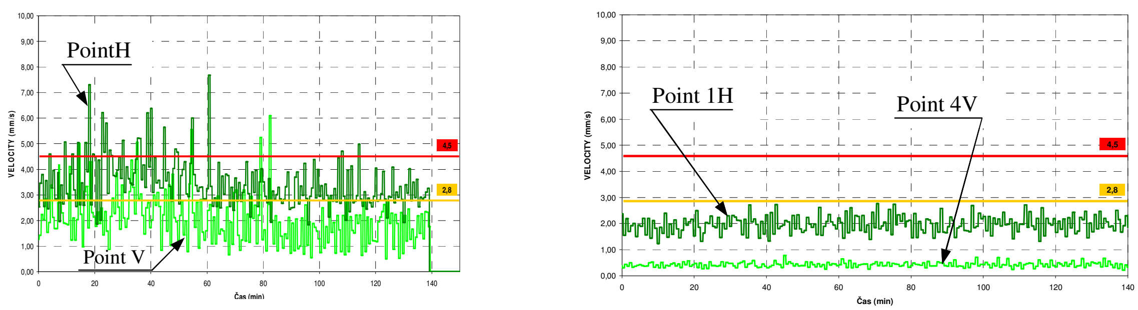
Concept of vibrations, or mechanical oscillation means readable and measurable oscillation of machine surfaces, constructional nodes, machines basements etc. Importance of measuring the mechanical oscillation of machine parts lies in its high information content. Mechanical oscillation indicates the machine condition, warns of dynamical stresses on machine, its basement and environment and provide the data for machine diagnostic. Low frequency vibrations and high frequency vibrations were measured on tested gearboxes.

### 3.1 Low frequency vibrations

As the result of resonance, on monitored mechanical system of entities (testing station) the low frequency vibrations were not stable. On *fig. 2* there is graphical record of measured values of mechanical vibrations for measuring points 1H and 4V in both operational modes. When running in *Operational mode 1* measured vibration values exceed limits for total level of mechanical vibrations VELOCITY, (mm/s, RMS), in range 10-1000 Hz recommended by norm STN ISO 10816-3. Measured device does not meet required criteria. In *Operational mode 2* vibration values taken in point 4V on output from gearbox are under the alert line.

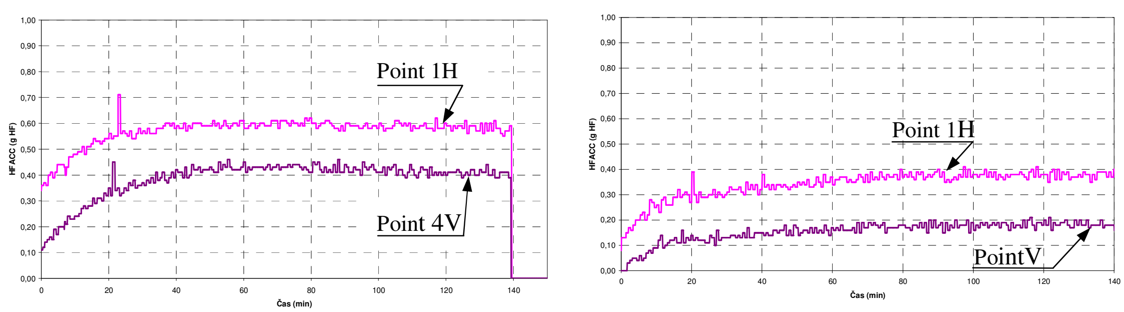
### 3.2 High frequency vibrations

High frequency vibrations are suitable for considering the gearing of teeth and also for considering operational status and running mode of voluble bearings.
*Fig. 2* brings value comparison of high frequency vibrations (HFACC in range 0,5-10kH) measured in points 1H and 4V, thus on input and output of gearbox.




a) *Operational mode 1* b) *Operational mode 2*

***Figure 2:*** *Low frequency vibrations of mechanical system*




a) *Operational mode 1* b) *Operational mode 2*

***Figure 3:*** *High frequency vibrations measured online in points 1H and 4V*

## 4 Measuring of Gearbox Temperature and Evaluation of Temperature Gradient

For correct detection of gearing wear, the temperature is measured together with vibrations. Connections between temperature and vibrations of gearbox give us valuable information about condition of reducer.

With worm reducers it often comes to fast gearings overheat, that is why continual monitoring of temperature enhancement of oil, or reducer gearbox was important part of the tests. After setting the reducer to running, its surface became warmer, until its surface temperature got stable. Durin *Operational mode 1* temperature got stable after around 90 minutes of running at value 80,7 °C in point 1H and with value 77°C in point 2H. Heat source presents bearing of worm shaft near clutch on reducer input – point 1H. During *Operational mode 2* temperature became stable slower. After around 140 minutes of running it got close to 47 °C, but was not stable yet.

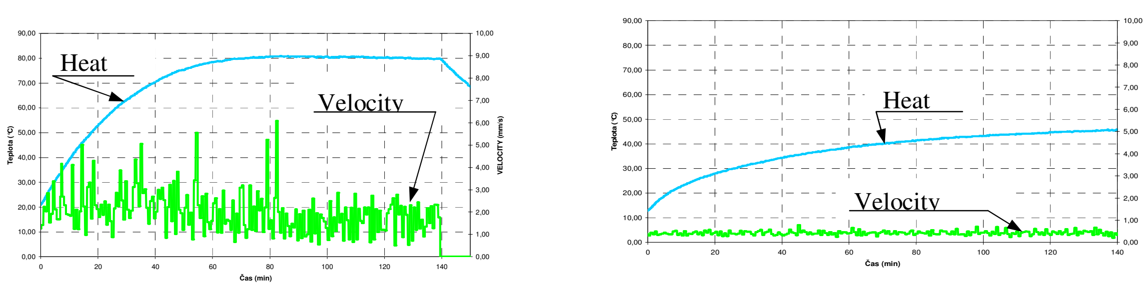
Temperature gradient indicates the grades of changes in temperature value in last minute. For *Operational mode 1* the maximal temperature gradient in first minutes of running was 2,2°C/min. For *Operational mode 2* the maximal temperature gradient in first minutes of running was 1,5°C/min. With increasing time the values of temperature gradient for both operational modes got stable close to 0.

From comparison of graphical behaviours of temperature and low frequency vibrations (*fig. 4*) it can be seen that in *Operational mode 1* after stabilizing the temperature, mechanical vibrations got stable as well. During running in *Operational mode 2* the mechanical vibrations of monitored mechanical system are stable even in spite of changing temperature.

Measurements of high frequency vibrations proofed that with gradual increasing of gearbox temperature while running in defined operational mode, also the total level of high frequency vibrations got higher until the stable state. From behavior of measured values on *fig. 5* their mutual relation is obvious, while temperature and total high frequency vibrations are related to the load (5 or 2 weights).

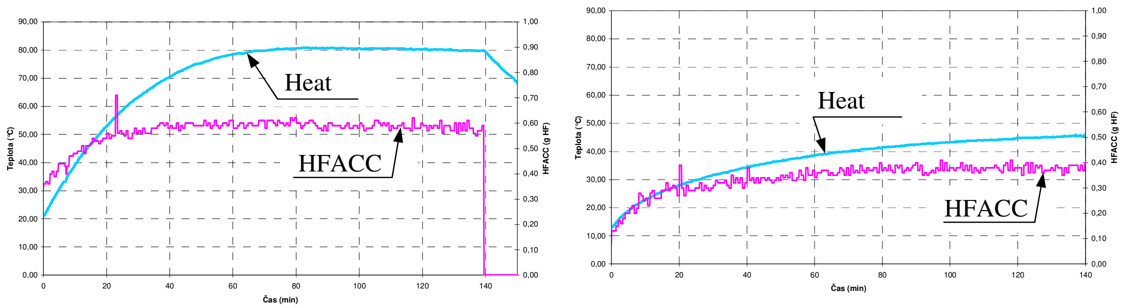
## 5 Ultrasonic Emission Measurement

Technical condition of mechanical system is generally given by amplitude of ultrasonic emission and by its location on time line. On *fig. 6* there is record of amplitude acquired in point 2H for both *operational modes*. *Fig. 6a)* shows dependence of amplitude value on time, recorded while pulling up the weight. Dominant source of ultrasonic emission on reducer was in point 2H with frequency of 6,8Hz. In this interval it comes to actuating the ultrasonic emission, gradual amplitude enhancement and exasperation of mechanical system condition (lower carrying capacity of oil filter – higher scraping of contact surfaces). *Fig. 6b)* brings the record of amplitude while dropping the weight.




*a) Operational mode 1* *b) Operational mode 2*

***Figure 4:*** *Comparison of temperature and mechanical vibrations in measuring point 1H*




a) *Operational mode 1* b) *Operational mode 2*

***Figure 5:*** *Temperature and high frequency vibrations in measuring point 1H*

In interval of 6,8 Hz recorded signal becomes smoother, amplitude value gets lower and condition of mechanical system is better.

After processing particular signals in their entire time line using frequency analysis (FFT) dominant frequencies of mechanical system were determined (*fig. 7).*

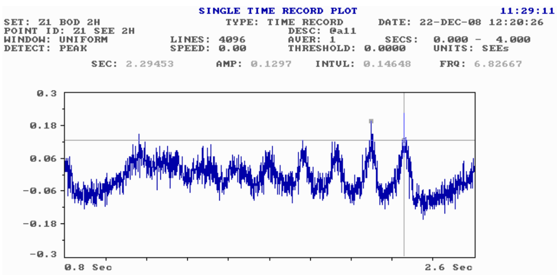
## 6 Free Frequencies of Mechanical System

Free frequencies of mechanical system (critical spindle speed) were determined by swing test while mechanical system was inactive. Swing test on vertical frame provided dominant frequencies 6,7Hz and 10,3Hz and on horizontal beam under the chain wheel 34Hz, 45Hz and 89Hz.

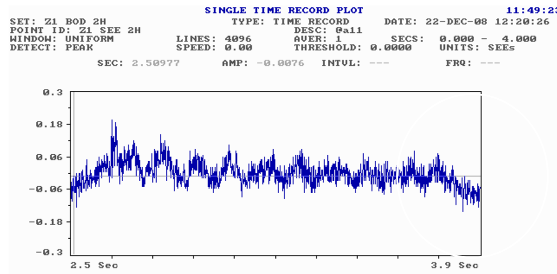
## 7 Total Evaluation of Laboratory Testing Results

In relation with wear in contact points of teeth sides and after all used diagnostic methods (measuring of ultrasonic emission, low frequency and high frequency vibrations, temperature of reducer gearbox, measuring of teeth width and analysis of oil) similar wear behaviors were obtained. Based on this fact, the testing station was after little constructional changes evaluated as an suitable one for testing of worm gearboxes.

In relation with objective evaluation of technical condition of worm reducer it can be said, that there was noticeable wear of worm wheel after six hours of operation in contact points with worm. Strong exasperation of gearing ratios was caused by significant resonant actions, high mechanical vibrations over the recommended limit values according to *ISO 10816-3 Recommended vibrations limits* especially for vertical beam (6,8Hz and 10,3Hz) and horizontal frame under the chain wheel (33Hz), and transmission of these vibrations onto gearbox. Operational conditions were negative also for start and rundown of machine (gearbox), especially with higher loads (oscillation and bad chain leading), again the vibrations were transmitted onto gearbox. With these situation, objective evaluation of technical condition of tested reducer could not be done. It is proposed, that the results of monitoring of technical condition of worm reducers will be acceptable after optimization of bearing frame construction. After that, the laboratory testing of worm reducers can continue. After evaluation of results from all planned tests in extent necessary for complex experimental analysis of vibrations of worm reducers, it will be possible to provide such experimental testing for gearings producers.

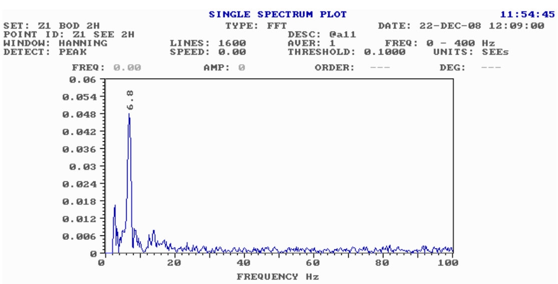



*a) Mode with pulling the weight up*

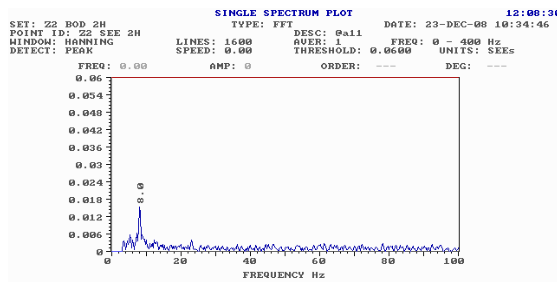



*b) Mode with dropping the weight*

***Figure 6:*** *Ultrasonic emission, Time See point 2H*




*a) Operational mode 1*




*b) Operational mode 2*

***Figure 7:*** *Ultrasonic emission, See FFT spectrum point 2H*

Following figures (*fig. 8 and fig. 9*) show behavior of current in servomotor using frequency transformer of voltage on PC and analysis of current behavior with two weights.

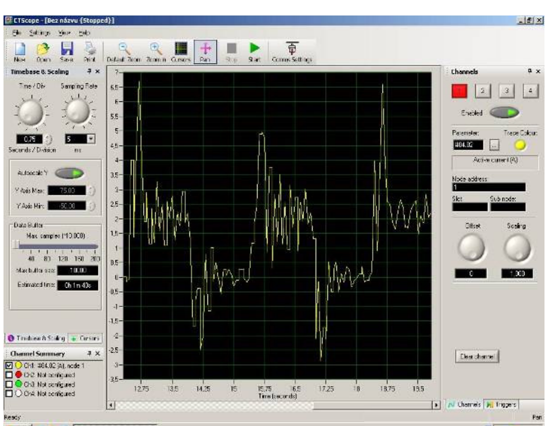


***Figure 8:*** Current behavior on servomotor

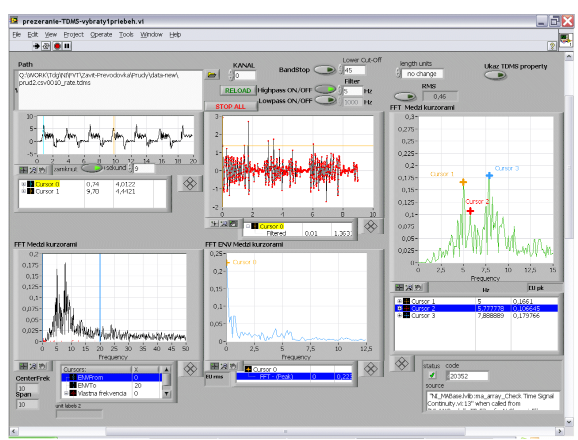


***Figure 9:*** FFT analysis of current behavior

## 8 Conclusion

From test results the producers of worm reducers can obtain many information about influence of technological parameters of production to drives dynamics, about achieved performance parameters, about carrying capacity of reducers especially in extreme transitional modes, effectiveness of gearing etc. On the base of these facts, it will be possible to realize optimization of influence of technological parameters to dynamical load of worm reducers.

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