Consideration about determination of vibro-acoustic behaviour of the cycloid reducer

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Abstract. In order to achieve the favourable operating characteristics of the cycloidal reducer, it was conducted the necessary determination of the parameters which influence its vibro-acoustic behaviour and measurements of the vibrations of the cycloidal gears in initial stages of exploitation and after hours of exploitation. The conducted measurements presented in the paper allows to determine how the various deviations from the reference profile of the surfaces in contact cause different mechanical and acoustic vibrations, making possible assessments of the influence of deviations of the cycloid profile of the satellite wheels on the dynamic behaviour of the cycloidal reducers and the comparison of the results with the requirements of the standards in the field. In order to appreciate the effect of vibration on the mechanical system and the necessary measures for the attenuation of the phenomenon, the study is focus on the vibration content in frequency, which is done by the frequency analysis method.
Keywords: cycloid reducer, frequency of vibration, stand, measurement equipment

1. Introduction
In terms of constructive solutions, cycloid reducer ensures smooth and silent operation with extremely low vibrations, even under the most powerful loads, having aligned shafts and all the component machine parts are perfectly symmetrical, the centrifugal forces being compensated by the use of two satellite wheels disposed at 1800 or three satellite wheels disposed at 1200 [3].

To obtain these extremely particularly favourable operating characteristics of the cycloid reducer, it is necessary to obtain its machine parts with high precision involving more expensive manufacturing technology and cutting tools, especially for the profiled surface of cycloid satellite wheels.

The difficulty of dynamic behaviour modelling of cycloid gears imposes the need of vibrations measurements during the initial stages of research, design and exploitation.

Along with the development of vibration and noise measurement techniques, signal processing, the continuous test and control systems of the gears have also been improved. Research on gears demonstrates that the general maintenance of vibration characteristics, general level, peaks in the frequency domain and in noise measurements [2].

2. Parameters influencing the vibro-acoustic response of cycloid gears
The vibration behaviour of gears determines to a large extent the acoustic behaviour, between the vibration level and the sound pressure level is a qualitative and quantitative correspondence. Theoretical and experimental research on dynamics mechanism of the vibration and acoustic noise
generation have led to determining the main factors that decisively influence the vibro-acoustic behaviour of gears [4].

By analogy with the involute gear, in figure 1 we present the grouping of the parameters influencing the vibro-acoustic response of the cycloid gears [1].

![Diagram of parameters influencing vibro-acoustic behavior of cycloid gears]

**Figure 1. Parameters influencing the vibro-acoustic response of cycloid gears**

### 3. Vibro-acoustic determinations at cycloid reducer

It is proposed to study the vibro-acoustic behaviour of the cycloid reducer with bolts depending on the deviations of the cycloid profile, recognizing that they decisively influence the vibration and noise characteristics of the cycloid gears, raising the most important manufacturing technology issues.

Two series of acoustic pressure and mechanical vibration measurements were performed on a cycloid reducer with a transmission ratio $i = 17$, mounted on a test stand, over a large operating hours, period during which changes of deviations of the active cycloid profile occurred, as well as changes of the vibro-acoustic behaviour of the reducer.

We compare the levels of noise peaks and vibration peaks corresponding to the two measurement moments and correlate the obtained dates with the active profile changes that occurred during the reducer functioning between the two moments. Conclusions were drawn about the influence of the increases deviations of the profile of the planetary wheels on the vibro-acoustic behaviour of the cycloid reducer and comparison of the results with the requirements of industry standards has been made.

In order to appreciate the effect of vibration on the mechanical system and the measures that are necessary for the attenuation of the phenomenon, it is especially necessary to specify the content in frequency, which is done by the frequency analysis method. The frequency spectrums obtained are compared with the reference spectrum corresponding to the normal functioning of the reducer. In the
literature it is stated that the upper limit of the vibration level at which defects are to be searched is 2-3 times (6-10 dB) the acceptable vibration level.

3.1. Stand for vibro-acoustic measurements of cycloid gear

In figure 2 we present the stand used in vibration and noise measurements of the cycloid reducer. The essential components of the stand are: (1) the drive electric motor, (2) the cycloid reducer whose drive shaft is also the motor shaft, (3) the elastic coupling, (4) the EPM type magnetic brake.

![Figure 2. The stand for vibro-acoustic measurements of cycloid gear](image)

The measuring points: 1, 2, 2a, 3, 4, 5, 6, 7, 8, 8a, 9, 10 coincide with the mounting position of the vibration transducer and are located as close as possible to the moving parts: on the gear housing, on the bearing and on the fixed wheel body in its gearing planes with profiled wheels.

Points of measurement in two directions are used: radial measurements in horizontal direction (x) and vertical direction (y) and axial measurements at the front planes of the bearing in the vicinity of the planetary wheel. Mechanical vibration is characterized by its characteristics: displacement, velocity, acceleration, evolution over time, frequency spectrum and amplitude spectrum. Measurements made in the frequency spectrum are: (a) in the displacement range, with the amplitude expressed in $\mu m$, focuses on low vibration components; (b) vibration measurements in the velocity range, with amplitude expressed in $mm/s$, advantageous because machine vibrations have a spectrum of frequencies with relatively constant speed components over a wide range of frequencies up to 1kHz; (c) vibration measurements in the acceleration range, with the amplitude expressed in $\mu V$, focuses on high frequency components [5].

![Figure 3. Measuring equipment used to determine the vibro-acoustic behaviour of the cycloid reducer](image)

Usage of specialized software allows performing some analysis functions: digital analysis in frequency or amplitude, spectral comparison, analysis and time mediation. The necessary measuring
equipment used is presented in figure 3. The frequency content of the signal received from the transducer gives indications of the machine's operating condition.

3.2. Experimental methodology

Frequency spectrum analysis for research, technological or monitoring purposes involves, as the first step, the determination of the frequencies through calculations. Not all calculated frequencies find significant correlation in the spectrum, some overlap, others have insignificant importance.

The coincidences between the measured frequencies and the obvious amplitude peaks and the calculated frequencies provide diagnostic data.

By reporting of all the values at the fundamental frequency, $f_1 = \frac{n_1}{60}$, $n_1$ - rotation of the driving shaft (rot/min), it is identified the order of the different spectral components.

3.2.1 Vibration displacement and vibration velocity measurements. In order to obtain quantitative and qualitative information, were carried out vibration displacement and vibration velocity measurements with the analyser IRD FAST TRACK/FS of IRD Mechanalysis, combining the data collection, data transfer and automated computer analysis software PMPower. The analyser IRD (full Spectrum) is a full spectrum data collector with the frequency range between 10Hz and 25kHz with 35 variable frequency ranges. It is a real-time analyser capable of performing a full FFT (Fast Fourier Transform) spectral analysis with the possibility of instantly providing a graphical representation of the spectrum.

In figures 4, 5, 6, 7 we present the representative spectrograms corresponding to the two process of measurements in point 9 of the cycloid reducer. On registered diagrams, figure 4, 5, the signification of notations are: RC - cycloid reducer at first set of measurements; RC1 - cycloid reducer at second set of measurements; n-the point of measurements (from 1 to 10 as figure 2); H,V or A represent the direction of measurements (horizontal, vertical or axial); mm/s the vibration characteristics measured (speed); μm the vibration characteristic measured (displacement).
3.2.2 Vibration acceleration measurements. To obtain accurate recordings in the field of vibration acceleration, the function of the transducer is provided by an accelerometer (piroelectric captor) fixed by gluing to the cycloid reducer measuring points.

The electrical signals are transmitted to an acquisition board that performs analogue-to-digital conversion including the sampling and coding of the analogue signals provided by the vibration captor.

The requirement for sampling is not to lose or distort the information contained in the analogous form of the signal. Therefore, in practice, the sampling theorem and the conditions regarding the choice of the number of static independent samples is respected. The recordings were made with a Sampling Frequency of 180284 Hz and with an acquisition time of 5.54 µs. From the Acquisition Plate, the values are taken in binary system by the computer and stored in the .txt file. It is used the computer and MatLab's specialized software to perform analysis functions: digital analysis in frequency or amplitude, spectral comparison, analysis and mediation in time. It is obtained a spectral vibration analyse using FFT algorithm, figure 8 and 9.

![Figure 8. Initial RC recording in the range 0÷5KHz](image1)

![Figure 9. Final RC1 recording in the range 0÷5KHz](image2)

To increase the resolution in spectral analysis, digital processing allowed the use of a window-type function, the use of spectrums zooming effect around the significant frequency, the division of spectra obtained in areas of interest in relation to the source, and the comparison of spectra, figure 10.

![Figure 10. Comparison by overlap of RC and RC1 and "Zoom" in the range 0÷300Hz](image3)

Appreciation and highlighting of changes and trends are favoured by comparing frequency spectra. The readings highlighted the coincidence of the frequency peaks with the harmonics of the fundamental frequency and with the harmonics of the gearing frequency, the maximum amplitude being located in the low frequencies and corresponding to the frequency $4f_1 = 44$Hz, being below
The next peak was identified at $12f_1 = 132\text{Hz}$ but is much lower, just over 20dB. When reading spectrogram, it can be concluded that the rest of the frequencies have amplitude below 10dB.

The results of the theoretical analysis are in good agreement with the experimental results, allowing the understanding the physical phenomenon and the adoption of qualitative measures to reduce the noise and vibrations.

4. Conclusions
Difficulties in modelling the structure properties or estimating the dynamic loads of the cycloid gears during normal operation impose the need to measure the noise and vibrations of the gears in the initial stages of research and design as well as in operation.

The different deviations from the reference profile of the contact surfaces determine different levels of mechanical and acoustic vibrations, thus making assessments of the influence of deviations of the cycloid profile of the satellite wheels on the dynamic behaviour of the cycloid reducers and comparing the results with the requirements of the industry standards.

Measurements in the deviation and vibration speed range recorded significant peaks at frequencies in the vicinity of the 5000 Hz area corresponding to the bearings operating frequencies. They also pointed to low frequency bands.

Acceleration measurements and computerized data processing have shown that the peaks correspond to the harmonics of the fundamental frequency with the maximum values in the low frequency range characteristic of the deviation in alignment, shaft inclination.

An uneven deviation of the profile of the cycloid satellite wheel causes the axle-box to lose its coaxiality with the output shaft. The effect in the vibro-acoustic behaviour is the presence of the peak frequencies in the low frequency band.

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