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DETECTING GEAR DEFECTS USING VIBRATION ANALYSIS

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Abstract: *The article has as main objective the presentation and familiarization with the manifestation of gear fault vibration level. The paper presents and details how the theoretical expression of certain gear defects, also presented a practical study made to validate theoretical research. Theoretical research results are useful in vibrodiagnosis and can be successfully used in industrial processes for implementing and achieving predictive maintenance through vibration.*

Key words: *predictive maintenance, vibration analysis.*

1. INTRODUCTION

In accordance with 13306 European standard [1], maintenance refers to "the combination of all technical, administrative and managerial activities, in the life cycle of equipment to serve in the maintenance or to restore a state where the desired function can be performed ".

Based on the symptoms that a machine manifests during operation, we can estimate the technical state of functioning.

Vibrodiagnosis refers to a modern technology, of high performance, allowing appreciation of the operation of a machine using vibration measurements and knowledge of technological construction and operation parameters [2].

2. THEORETICAL MANIFESTATION OF THE GEAR IN VIBRATION

2.1. Normal range

A gear is a rotating device in whose spectrum are presented the rotation frequencies of the shaft and the driven wheel and gear natural frequency (GMF = number of toothed wheel teeth x RPM speed toothed wheel) with its lower harmonics, which are modulated in frequency (have sidebands). Under such a spectrum any resonant frequency is excited and existing frequencies have relatively small amplitudes. If the number of teeth is unknown the end tape frequency, F_{MAX} is recommended to be equal to 200 x RPM for each shaft, and if the number of teeth is known F_{MAX} is recommended to be at least 3.25 x GMF, fig. 1 [3].

Notations: $\#T_{a,p}$ - no. of shaft teeth / wheel driven;

$RPM_{a,p}$ - speed toothed wheel / wheel driven.

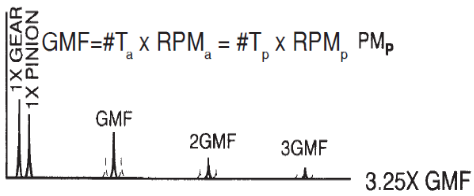

Fig. 1. Normal range of a gear [3]

2.2. Teeth wastes

Manifestations of the defect [4]:

- this defect is characterized by the appearance in the spectrum of the resonant frequency of the wheel with worn teeth. This frequency depends on the rotation frequency of the shaft;
- 2GMF and 3GMF amplitudes can be in some cases higher than GMF amplitude;
- around their own frequency of engagement and its harmonics sidebands appear with a large number of frequencies with large amplitudes. The appearance of

these sidebands is the best indicator of wear, fig. 2.

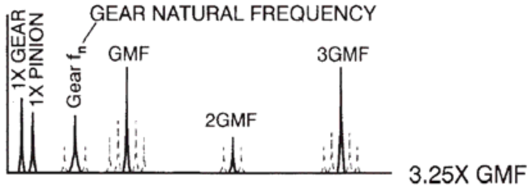

Fig. 2. Worn teeth [4]

2.3. Charged teeth

Manifestations of the defect:

• this defect is characterized by high amplitude of GMF's;
• no resonant frequency is excited;
• side bands remain at small amplitudes.

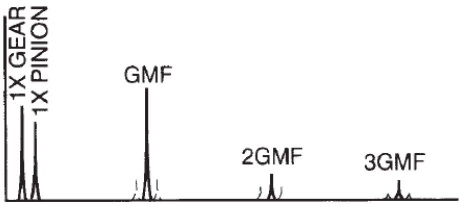

Fig. 3. Spectrum of a gear with charged teeth [4]

2.4. Eccentric and gaming gear

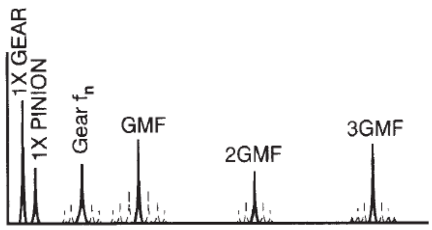

Fig. 4. Specific range of eccentric gear and gaming [4]

Manifestations of the defect [5]*:*

- this defect is characterized by high amplitude sidebands around GMF's;
- development of a frequency fn Gear of the resonance belonging to either GMF or frequency of rotation of one of the shafts, see fig. 4;
- 1x dominates the spectrum where eccentricity is the main issue;
- if the defect is movement of the gear GMF's amplitude will decrease with the increasing of the load.

2.5. Gear misalignment

Manifestations of the defect [4]*:*

- this defect is characterized by the excitation frequency modulated 2GMF who is 2 x RPM;
- side bands around GMF's and its harmonics are not equal in amplitude, see fig. 5;
- 2GMF and 3GMF frequencies and amplitudes will be higher than the frequency of GMF.

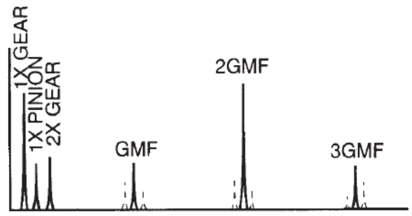

Fig. 5. Specific range of gear misalignment [3]

2.6. Cracked / broken teeth

Manifestations of the defect:

- this defect is best detected in the time domain where there is a pronounced peak whenever a tooth with problems is entering the gear [6], see fig. 6;
- high amplitude 1x RPM frequency;
- wheel natural frequency (fn) will be excited, and this will be accompanied by modulated sidebands with rotation frequency.

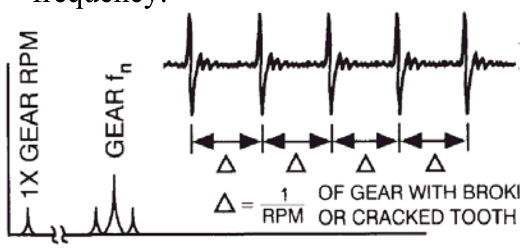

Fig. 6. Specific spectrum of a broken teeth gear [3]

2.7. Gears with weakening in camps

Manifestations of the defect:

- this defect is characterized by high amplitude frequencies GMF, 2GMF and / or 3GMF, fig. 7;
- occurrence of multiple harmonics of speed;
- this defect can lead to gear wear and / or damage to other component

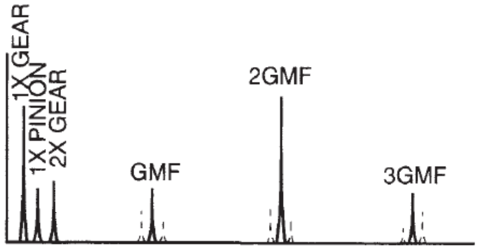

Fig. 7. Specific range of the gearing with weakening in the camps [3]

3. GEAR FAILURE ANALYSIS - CASE STUDY

The data obtained were conducted on a measurements booth, see figure 8 within Design and Robotics Engineering Department of the Mechanical Engineering Faculty, UTCN. This booth was build for pedagogical purpose as a support for the department, for a better understanding of the defects that occur within a dynamic machine, booth resembling a gearbox.

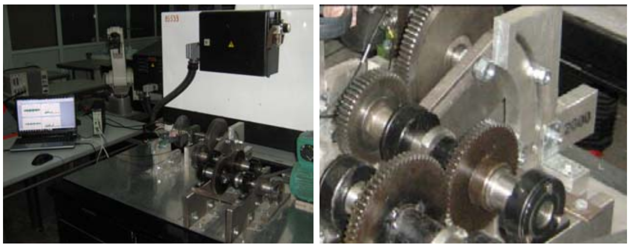
Fig. 8. Bench measurements

In the data acquisition process for fault detection gear, two measurements were made as follows:

- Restrained, at an engine speed of 560 RPM, resulting in a 668.08 RPM speed shaft, which equals 11.1346 Hz;
- Not restrained, at an engine speed of 560 RPM, resulting in a 668.08 RPM speed shaft, which equals 11.1346 Hz;

Like in the pursuit of the bearing defects case, in case of the vibration spectrum the fundamental frequency will be tracked, given by the shaft speed, the characteristic frequency of engagement, ie GMF, which is calculated as in the relationships 1, and also will track their harmonics, especially the second and third harmonic.

$$GMF = n \times z \qquad (1)$$

where: n = shaft speed;

z = number of teeth of the teeth wheel;

According to equation 1, we have the following common fault:

- *Fundamental frequency: 11.1345[Hz]*
- *Gear 3 (z = 51): 567.8595[Hz]*
- *Gear 4 (z = 89): 990.9705[Hz]*
- *Gear 5 (z = 51): 567.8595[Hz]*
- *First report: 6.38[Hz]*
- *Second report: 19.43[Hz].*

Data acquisition was performed with 3560B Bruel & Kjaer analyzer and the software used for signal acquisition and FFT processing is Lite Basic Pulse FFT. Software configuration was performed in accordance with the procurement rules found in the literature, namely:

- Maximum frequency for monitoring gear will be set at 3.25 x GMF. F_{max} chosen from the standard will become bigger, namely 2000 Hz;
- Number of sampling is 1.5 x Fmax. According to the standards it will become 3200.

Data interpretation was done according to the "stas" Extras of the specialist and depending on the author's experience. Below you can see the FFT spectra results and in the right side there are the first 20 frequencies, which have the highest amplitude of the spectrum:

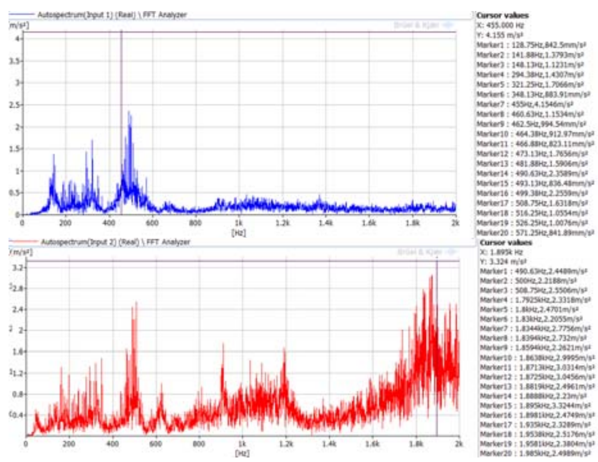
Fig. 9. FFT signal - 560 RPM – restrained: a) vertical axis; b) horizontal axis

Based on spectrum analysis, namely the horizontal axis, it was concluded that the toothed wheel teeth are worn. After analyzing the teeth it was observed that vibrations come from toothed wheel number two in the kinematic chain.

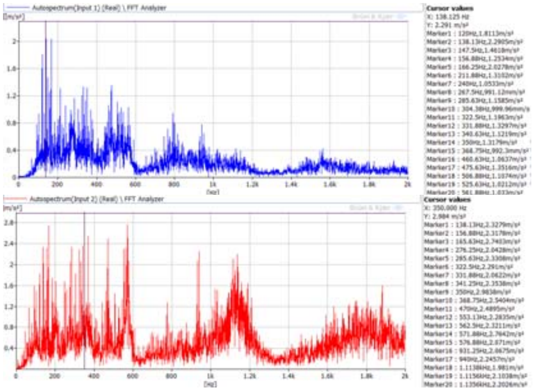

Fig. 10. FFT signal - 560 RPM – not restrained
a) vertical axis; b) horizontal axis

Based on the spectrum analysis it was concluded that the maximum amplitudes that characterize vibration does not occur at frequencies that indicate gear faults.

4. CONCLUSIONS

Once gathered knowledge on maintenance, here we refer to the setting operating condition through vibration knowledge with respect to severity of vibration, especially knowledge of field data acquisition it can be said that the conditions necessary for a vibrodiagnosis are accomplished. It goes without saying that with the accumulation of experience vibrodiagnosis process becomes a lot easier.

For vibration interpreting is absolutely necessary to know the exact axle speed, in the vicinity of whom the data collection is done, because even the smallest deviations can lead to incorrect decisions.

After investigating two acquired signals, where only the load was the "variable" element, it can be concluded that some defects can be hidden if the machine operates empty, so it is imperative that the acquisition is done with restrained equipment.

5. ACKNOWLEDGEMENTS

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Detectarea defectelor de angrenaj cu ajutorul analizei vibratiilor

***Rezumat**: Articolul are drept principal obiectiv prezentarea si familiarizarea cu modul de manifestare a defectelor de angrenaj la nivel vibratoriu. In cadrul articolului se prezinta si se detaliaza modul de manifestare teoretica a anumitor defecte de angrenaj, totodata este prezentat si un studiu practic realizat in validalea cercetarilor teoretice. Rezultatele cercetărilor teoretice sunt foarte utile în domeniul vibrodiagnozei acestea putand fi utilizate cu succes în cadrul proceselor industriale de implementare si realizare a mentenantei predictive prin vibratii.*

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