THE CORRELATION OF PARAMETERS MEASURED ON ROTARY MACHINE AFTER REPARATION OF DISREPAIR STATE

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The article describes the application of tools of technical diagnostics of bearings in device for the production of cellulose due to previous difficult disorder of device. Diagnostics of bearings is a very challenging area of operational diagnostics. Bearing damage may be caused by various factors such as the action of excessive forces, unsuitable lubricant, contamination of the lubricant, the lubricant oxidation, degradation of additives, etc. Such factors can significantly reduce the lifetime of technical device. The measurements and expertises that took place, as described in the article, were based on the requirement of operator's technical equipment to assess the trend of selected dynamic parameters, i.e. prediction of possibilities of risk of damage to the technical system in a short time. The measurement and subsequent identification of the real state of technical device has been performed in accordance with the recommendations of standard ISO 10816-3.

KEYWORDS

vibrodiagnostics, dynamic signal analysis, dynamic parameters, bearing, time record.

1 INTRODUCTION

The aim of technical diagnosis is an objective understanding of the technical state of the monitored object and determining its ability to perform a required function under stated conditions, not only now but also in the future. The system approach in the process of technical diagnostics represents a comprehensive assessment of diagnostic tasks that constitute security of diagnostic systems.Technical diagnostics represents a scientific branch, but at the same time as practical vocational dealing with the methods and means of finding the real technical condition of objects in real time without their disassembly, respectively destruction.Important for this area of technical activities is the replacement ofintuitive and individual approaches to identify the technical condition of an exact approach with maximum use of all available relevant information about diagnosed object or product[Panda 2016].
Division and interpretation of technical diagnostics may be different according to the different points of view, for example: in terms of completing the tasks, working engagement, on a time division in terms of the measured signal and the like.

In terms of the purpose technical diagnostics is divided into [Balog, 2003]:
- operational diagnostics,
- workshop diagnostics,
- research and testing diagnostics.

Operation diagnostics is part of the technical diagnostic designed to ensure reliable operation of the facility diagnosis of the user. The subject of review of operational diagnostics is an object (e.g. machining centre) as a whole. In the implementation of the diagnostic process are not excluded any components from the diagnosed object.Disassembling works are carried out only in exceptional cases, usually to ensure the accessibility of checkpoints [Jurko 2010].
Workshop diagnostics represents a part of service diagnostics at under review (diagnostic objects) structural parts or components removed from a technical object or intended for installation into them (e. g. a group or subcategories of vehicles; the diagnostic process is implemented regardless of the area from which they have been excluded or in which they built.The workshop diagnosticsis intended for practical need of repair and is used in process control.
Research and testing diagnostics is part of the technical diagnostics designed for security tasks related to research, development and testing of object. The various diagnostic methods or means of research and testing diagnosticsmay or may not be for the introduction of the object in normal use and used in the operational or workshop diagnostics.

From the perspective of the diagnostic resources technical diagnostics is divided into [Balog 2003]:
- internal (on-board) diagnostics,
- external diagnostics.

According to the method of implementation of the diagnostic process is technical diagnostics divided into [Balog 2003]:
- continuous diagnostics,
- diagnostics of operational inactivity.

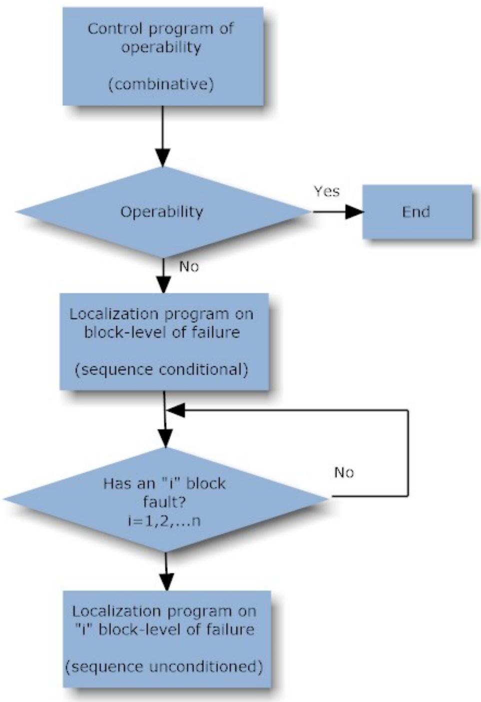

Figure 1. Detection of fault location

According to the character of the diagnostics object technical diagnostics is divided into [Balog 2003]:
- local diagnostics,
- total diagnostics.

Depending on the degree of automation of the diagnostic process technical diagnostics is divided into [Balog 2003]:
- manual,
- automated,
- automatic.

In summary, it is possible the process leading to the detection of a fault (obtaining information about whether the object has a fault) and the fault localization (the process of obtaining information about which part of the object is broken) designated by the term diagnostic process (Fig. 1). The diagnostic process is generally intended for feeding multiple stimuli – inputs signals and multiple measurement and analysis of responses - the output signals of these stimuli [Straka 2014, Molnar 2015].

2 DIAGNOSTIC OF ROTATING MACHINES

Technical diagnostic is applying different methods to the needs of machine diagnostics.It often happens that measurements are not interpreted, resp. the interpretation is not correct.For example, during the vibration diagnostics,the factor of creation of forces and energies that create fatigue damage and shorten the lifespan of the machines and machine parts is often forgotten.It means e.g. that twice more force shortens the life of the bearings on 1/8 and product life is shortened from five to ten years to a few months [Valent 2010].
Diagnostic of bearings is a very difficult area.Bearing damage can be caused by unsuitable lubricant, contamination of lubricant, water, excessive force, oxidation of lubricants or by degradation of additives. In this case it is necessary to think about the influence of the human factor. The bearing may be installed with a larger overhang, or wasoverheated during the assembly process, greased, resp. non-greased.All these factors can shorten the life of the technical system for a few hours to several months [Valent 2010].
To ensure the quality of maintenance of rotating machines it is essential to interpret and evaluate the causes of the failures correctly. It happens quite often that cooperation between maintenance, technical diagnostic and functional information processing for evidence of repairs, lubrication plans and dates of technical diagnostics is missing.

2.1 Diagnostic of rolling bearings – Crest factor

Crest factor coefficient represents the basic methodology of diagnosis of rolling bearings.The method is based on measuring of effective and high vibration levels and on calculating their ratio PEAK/RMS (Fig. 2).Because the ratio is evaluated by two values, this method depends on the type of bearing and on the shaft speed.

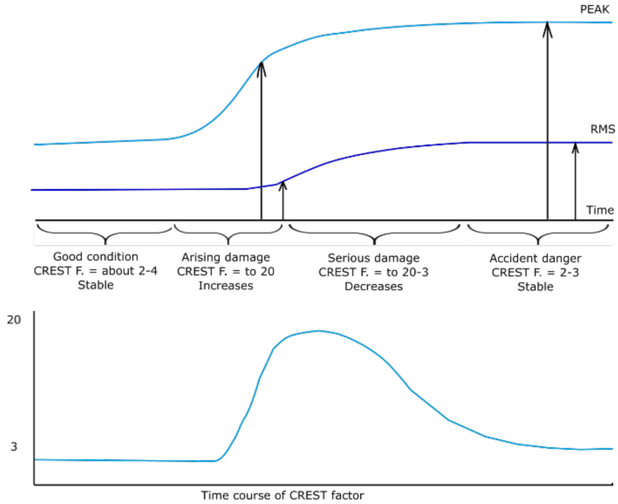

Figure 2. Crest factor

Crest factor is a sensitive parameter for causing a mechanical damage to the bearings which are already identified in the initial stages [Murcinkova 2015**]**.

2.2 Diagnostics of roller bearings – HF (High Frequency Emission

Measuring of HF parameteris based on the recognition that the early damage increases the energy of vibration at all frequencies. This parameter is also very sensitive to lubrication failures.Emitted high frequency energy is evaluated in RMS value and expressed in units of grams (9,81 m/s^2).The values $g_{RMS}$are dependent on the rounds of the shaft.The evaluation of severity of the disorder is applied on the scheme of Fig. 3.HF parameter is highly sensitive to lubrication disturbances.It indicates insufficient lubrication, but also the presence of mechanical contamination of the oil [Murcinkova 2015].

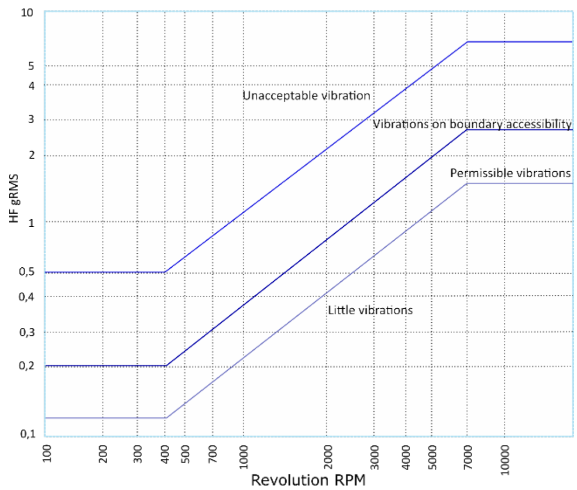

Figure 3. Assess the severity of the fault applying method HF

2.3 Roller bearing diagnosis – Kurtosis factor

Kurtosis parameter represents compared to other methods of analyzing the state of bearing a static approach. This is based on the premise, that the random vibration signal has normal Gaussian distribution, i.e.harmonic or periodic high frequency components are not represented.If it is necessary to determine whether the vibration signal meets this condition, it is possible to calculate two parameters by which it may be determined whether the distribution is represented by a Gaussian distribution.It is a skewness and kurtosis.For the purposes of vibration diagnostics is mainly used kurtosis.Skewness is affected by symmetry of dividing thesignal where this characteristic is not so important for the evaluation of the state. In practice, this parameter is called Kurtosis parameter [Murcinkova 2015].

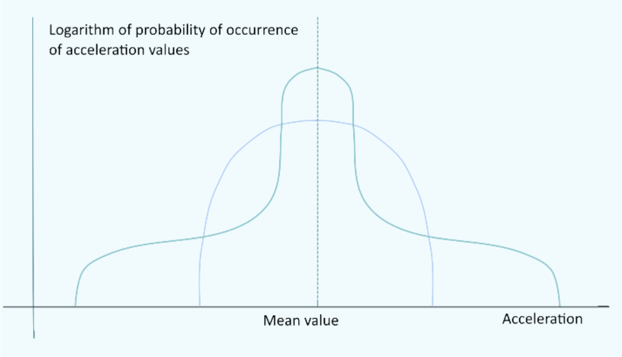

Figure 3. Comparison of the distribution of the signal for good and damage bearing

3 - 4	**Good condition**
5 -8	**Early damage**
9 – 13	**Serious damage**
> 13	**Potential accident**

Table 1. Kurtosis factor value and the corresponding bearing condition

2.4 Diagnostics of roller bearings – Envelope analysis

Envelope analysis is a method that not only indicates the damage of bearing but in conjunction with FFT allows you to specify which part of the bearing is damaged. Bearing for these purposes is divided into the outer and inner ring, rolling elements and cage of bearing.Because each from the following parts has a different relative speed, relative to the shaft, it is possible to identify the frequencies on which one can experience the problems.For the calculation of fault frequencies are used the following relations [Murcinkova 2015]:

Inner ring:

$$BPFI = RPM\ N_b(1 + \frac{B_d \cos\beta}{P_d})/2 \quad (1)$$

Outer ring:

$$BPFO = RPM\ N_b(1 - \frac{B_d \cos\beta}{P_d})/2 \quad (2)$$

Ball (roller):

$$BSF = RPM\ P_b(1 - \left(\frac{B_d \cos\beta}{P_d}\right)^2)/2B_d \quad (3)$$

Cage:

$$FTF = RPM\ (1 - \frac{B_d \cos\beta}{P_d})/2 \quad (4)$$

Where:
N_b–number of balls or rollers
B_d – ball or roller diameter
P_d – bearing pitch diameter
β – contact angle degrees

The method is based on measuring the shock impulses generating from the breach of the trajectory along which rolled back the balls or rollers. Envelope analysis lies in the modification of the input signal through a high frequency filter and envelope detector.This signal is ready for use of FFT analysis and for determination of the fault frequency.The signal is further processed by envelope modulator for ensuring the positioning of repeated shock pulse [Asiri 2007].

When the modulated signal is processed into an FFT spectrum it appears in a recurring frequency shock pulse.Whereas the modulated shocks not having the character of harmonic signal it appears generally a series of harmonic signals.It is also common for the failure frequency that it is modulated as a carrier frequency, typically a rotational frequency.

3 THE CORRELATION OF PARAMETERS MEASURED ON ROTARY MACHINE AFTER REPARATION OF EQUIPMENT OF THE PULP PRODUCTION

Based on the cooperation with our workplace practices, showed the demand for real assessment of the technical condition of equipment of the pulp production (Fig. 4) due to previous severe accident on the device (a few week after the repair operation). It was also requested a trends assessment of selected dynamic parameters, e.g. the existence of the risk of damage to the technical system in a short time.

Figure 4. Sample of environment, operating conditions and ambient of technology workplace

The measurement and assessment of technical device was carried out in accordance with the recommendations of standard STN ISO 10816-3.

The basic parameters of the machine and the description of the operating characteristics:

- The rotor speed of mixer - 874 rpm (14,6 Hz).
- Nominal power Pn=140 kW.
- Medium: material of the pulp production - 90% water, 10% fiber.
- The abrasive medium is transported at relatively high speed, which entails high attrition of all contact surfaces. Aggressive environment represents a risk factor for corrosion of metal parts.
- For the belt pulley are used bearings of SKF 22315 with the impeller 22317.

In the context of bearing diagnostics was applied envelope analysis.

The following table (Table 2) shows the calculation of frequencies for the bearings of construction is CC and E.In addition to these types of designs SKF company also produces design C, CMA, ECC, EC and CY.During the diagnostic system it was not known that what kind of bearings (manufacturer, structural design) was used in the last repair of the machine.

DIMENSIONAL TYPE OF BEERING	MODI-FICATION	RPM	BPFO	BPFI	BSF	FTF
SKF 22315	**CC**	1	6,1779	8,8221	2,6772	0,4114
	CC	**14,56**	**89,95**	**128,45**	**38,98**	**5,99**
SKF 22315	**E**	1	6,0872	8,9128	2,4945	0,4059
	E	**14,56**	**88,63**	**129,77**	**36,32**	**5,91**
SKF 22317	**CC**	1	6,1449	8,8551	2,6140	0,4100
	CC	**14,56**	**89,47**	**128,93**	**38,06**	**5,97**
SKF 22317	**E**	1	6,5652	9,4348	2,6380	0,4107
	E	**14,56**	**95,59**	**137,37**	**38,41**	**5,98**

Table 2. Calculation of frequency for above noted types of bearings

3.1 Trend analyses of dynamic signals

Recommended levels of warnings - the alarm for rotating machines of a similar type and power are:

ALARM 1 – Warning	4,5 (mm/s g gE)
ALARM 2 – Danger	7,1 (mm/s g gE)

Table 3. Recommended alarm levels

Table 4 contains the measured summation values for each methods of measurement, bearing at 22315 with pulley, rotor bearing:

Measurement method of dynamic signal	January 2014	April 2014	**Evaluation of operating state of the rotor**
HFD 40 kHz (gHFD)	0,79	0,89	**Good**
Acceleration 10kHz (g)	3,61	3,59	**Satisfactory**
EnvAcc do 1kHz (gE)	2,64	2,43	**Satisfactory**
EnvAcc do 10kHz (gE)	3,91	4,48	**Satisfactory**
EnvAcc do 20 kHz (gE)	1,54	1,83	**Good**

Table 4. The resulting values for the trend analysis method

All measured data shows the value of dynamic signal below the recommended limit A1-warning.The measured values refer to the following fact:

- steady state, without any change in the frequency range to 1 kHz and above 10 kHz,

- in frequencies 1-10 kHz a slight increase of about 10%.

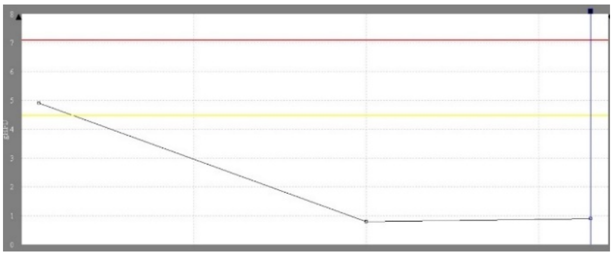

Figure 5. The progress of trend graph HFD

In the fig. 5 shows a record of trend graphs - Trend HFD, 3x measuring machine: emergency, after repair (January 2014) and repeated measurement of trend values (April 2014).After the repair there was a stable condition recorded, without increasing signal.

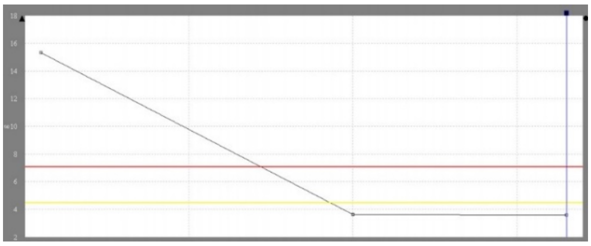

Figure 6. The progress of trend graph Acc

In the fig. 6 shows the record of trend graphs - Acc trend, 3x measuring machine: emergency, after repair (January 2014) and repeated measurement of trend values (April 2014).After the repair there was a stable condition recorded, without increasing signal.

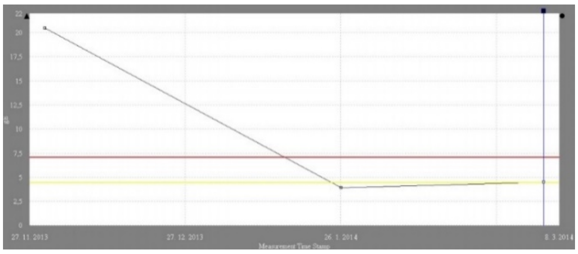

Figure 7. The progress of trend graph EnvAcc

In the Fig. 7 is a graph of the trend - the trend EnvAcc to 10kHz, 3 measuring machine: emergency, after repair (January 2014) and repeated measurement (April 2014).It is visible a slight increase in signal approx. 10%, on the border of recommendations A1 - warning.

The records of FFT spectrums for the frequency region to 1 kHz are presented in Figures 8 and 9.

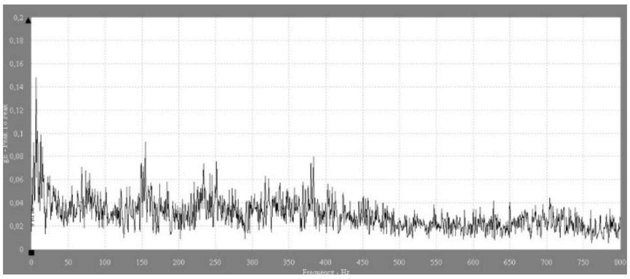

Figure 8. Record FFT spectrum, frequency range up to 1 kHz - January 2014

In the Fig. 8 can be observed low amplitude with the bearing frequency (73 Hz and 146 Hz BSF 6 Hz FTF) –a sign of running-storylines.

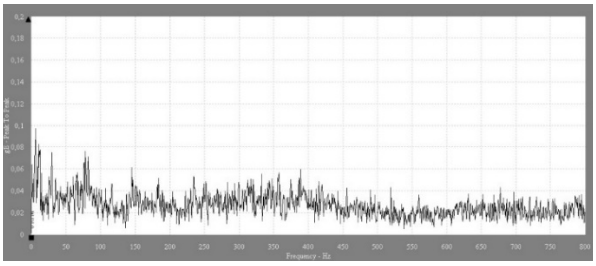

Figure 9. Record FFT spectrum, frequency range up to 1 kHz - April 2014

In April 2014 (Fig. 8), there is a slight improvement, e.g. the amplitudes corresponding decrease in the frequency of the bearing.

It may be stated a good deposit condition with no signs of damage and without degradation of the operational status of the contact surfaces.

Data for the FFT spectrum in the frequency region of 10 kHz is presented in Figures 10 and 11.

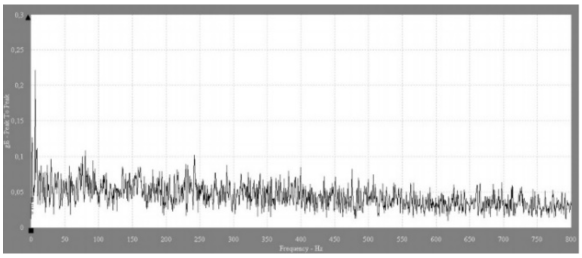

Figure 10. Record FFT spectrum, frequency range up to 10 kHz - January 2014

In January 2014, can be observed low amplitude with the bearing frequency (6 Hz FTF) –a sign of running-storylines (Fig. 10). Summation level in terms of high-frequency "noise" reaches the limit A1-warning.

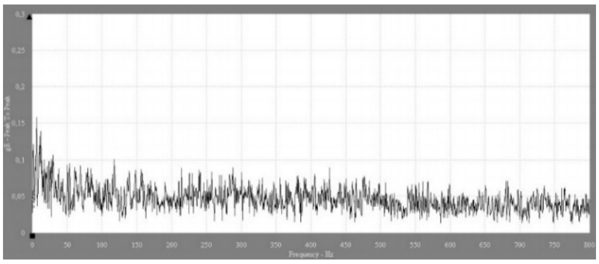

Figure 11. Record FFT spectrum, frequency range up to 10 kHz - April 2014

In April 2014, can be observed low amplitude with the bearing frequency FTF –a sign of running-storylines (Fig. 11).Summation level in terms of high-frequency "noise" reaches the limit A1-warning.

Good condition of the assembly, no signs of damage and no significant deterioration of the operating condition of contact surfaces.

4 CONCLUSIONS

Analysis of dynamic signal measurements across the frequency range points to the following facts:

- good correlation methods used in low frequency up to 1 kHz (velocity, EnvAcc),

- good correlation methods in the frequency range above 10 kHz (EnvAcc, HFD),

- slight discrepancy of 10% signal in the 1 - 10 kHz, may be caused by non-periodic variable signal that is associated with running-engine process (contact surfaces).

Summation values measured the dynamic parameters decreased after repair 4 to 5 times.The standard rule for basic setup of alarm levels of dynamic signal for rotating machines is:

- signal rise of 200% compared to the reference value (new status, condition after repairs), which means the alarm value (alarm 1 – warning),

- In case of further increase of the trend analysis beyond this limit, it is an A2-risk, then, preparatory to repair the measured node.

To verify the measurement method to set binding limits A1 and A2 it would be advisable to carry out repeated trend measurements with an interval of 1 month. In case of an increase in dynamic signal over 200% it is required to make a correction - exchange of bearings. Then implement the measurement of micro geometry contact surfaces (orbit of bearings), in particular: roughness, waviness, roundness and the cross profile.

For surface attrition over 1mm it is required to correlate the measured parameters:

- FFT and time of dynamic signal, especially in the 1-10 kHz,

- micro-geometry of contact surfaces.

In conclusion it can be said that the state of the monitored equipment – the pulp blender is after repair in good condition, resp. satisfactory.The measuring methods correlate well with each other; the values after repair are significantly lower and 3 months after repair are stable.

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