

VIBRATION DIAGNOSTICS ON A HYDRAULIC ROTATOR

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DOI: 10.17973/MMSJ.2015_12_201557

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This article focuses on the philosophy of vibration diagnostics on an Indexator hydraulic rotator. Following the analysis of the construction and machine functions, defect frequencies are calculated. The vibration measurement system for the technical diagnosis of the rotator were then designed. According to the vibrations measured on the GV6 rotator, limits for a new machine are proposed (the boundary between zones A and B).

KEYWORDS

rotator, zones boundary, vibration diagnostics

1 INTRODUCTION

Current vibration diagnostics is seen as a multi-parametric method. Only the use of a sufficient number of vibration diagnostic methods enables the accurate and early detection and analysis of individual types of machine defects.

In technical practice, the measurement of vibrations on non-revolving components is often considered to be insufficient for the purpose of the assessment of the technical condition of a number of structures. It is common practice to measure and assess the total values of vibrations whereby significant changes are considered to be a relatively reliable indication of the technical condition of rotational parts resulting from imbalance, axial misalignment, mechanical backlash of bearings in a mounting, structure resonances, insufficiently rigid foundations, bent shafts, excessive wear of bearings, etc. The measurement of such vibrations must be generally broadband. It is understood that a specific frequency range will depend on the type of the considered machine and the distribution of the frequencies on the defects of its components.

The standard [CSN ISO 10816-1 + Amd. 1:1998] and other related literature ([Jankovych 2004], [Hammer 2009], [Berry 1997], [Hines 1999], [White 1997], etc.) define four typical zones (A, B, C and D) and vibration level assessment for the purpose of the assessment of the magnitude of vibrations of specific machines and to provide guidance for possible measures.

The practical application of the [ISO 10816-1] standard with regards to the conditions of operation of a specific machine, shows that the boundaries of the mentioned zones proposed by the standard are not adequately sensitive to changes in vibrations resulting from a change in the technical condition of a machine. Moreover, it is necessary to emphasize, that certain types of machines (e.g. low-speed hydraulic machines, etc.) are neither addressed in this standard nor in available literature. It is therefore necessary to search for procedures to determine all the required operating boundaries – the boundaries between zones A, B, C and D.

2 PROPOSED SYSTEM FOR VIBRATION MEASUREMENT

The conclusions set out in the previous chapter have been validated using the GV6 rotator Fig. 1, manufactured by the

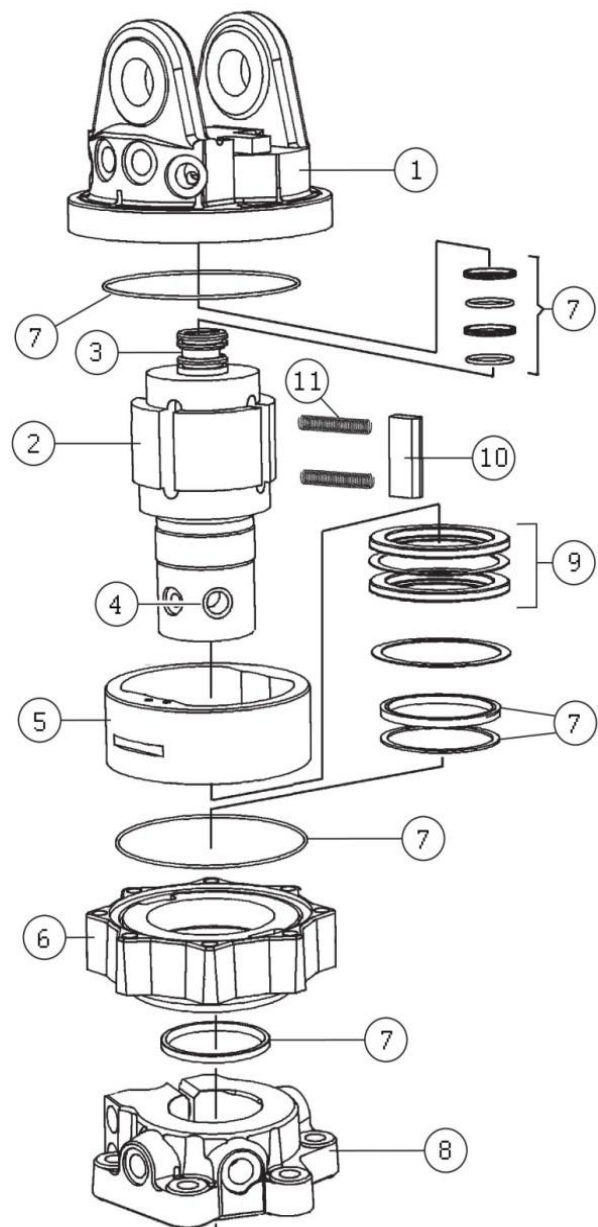


Figure 1. GV6 Rotator, adapted [Indexator 2015]

Swedish company Indexator. A rotator is a device that connects the main body of a grapple with the loader arm or with a machine to which it is attached. Fig. 2 demonstrates the use of the GV6 rotator on a forestry grab.

The rotator enables the grapple to be rotated with simultaneous closing or opening of the arms, claws or buckets. The maximum torque that can be produced by the rotator is 1400 Nm at a pressure of 20 MPa.

The rotator Fig.1 consists of a lamellar hydraulic motor with hydraulic rotation converter. The main parts are the top stator attachment flange (1), rotor with lamellae (2), hydraulic rotary converter (3) in the upper part of the rotor, outlets for hydraulic units on the grapple in the bottom part of the rotor (4), central part of the stator with internal double chamber design for lamellae (5), bottom stator flange (6) and sealing kit (7). Upon assembly of the drive part, the flange (8) which is used to attach the grapple is bolted to the shaft at the bottom part of the rotor.

The loading capacity of the rotator is 60 kN and any resulting axial force between the stator and the rotor is caught by axial bearing SKF 51115 (9).

The lamellar hydraulic motor contains four lamellae (10) and is of a double chamber design to enable high torque. Lamellae (10) are inserted in the rotor (2) and springs (11) push them into the interior of the central part of the stator (5). Pressurized fluid is always supplied to the location in front of the first and third lamella and took from the place behind the first and third lamella. As a result, pressure acts upon the surface of two lamellae which produces a force which is converted through the rotor (2) into the required output torque.



Figure 2. Forestry grabs with GV6 rotor, adapted [Hydraulika Petras 2015]

If we assume that the rotating speed of the rotor with lamellae (2) is known and mark it with the symbol f_i . Whereby, in the frequency spectra of the corresponding vibration parameters we always assume, or upon occurrence of a certain fault, the following frequencies - called the fault frequencies of the GV6 rotor:

- f_i - rotor rotation frequency,
- f_{Bi} - inner ring fault frequency (down ring),
- f_{Bo} - outer ring fault frequency (up ring),
- f_{Br} - roller elements fault frequency,
- f_{Bk} - cage fault frequency,
- f_S - stator fault frequency,
- f_L - lamella fault frequency.

The following table Tab. 1 presents the rotator fault frequencies for the measured rotor rotation frequency $f_i = 0.188$ Hz.

Fault frequency	Formula as function f_i	Fault frequency for $f_i = 0,188$ Hz
f_i	-	0.188 Hz
f_{Bi}	$11f_i$	2.068 Hz
f_{Bo}	$11f_i$	2.068 Hz
f_{Br}	$4.59f_i$	0.863 Hz
f_{Bk}	$0.5f_i$	0.094 Hz
f_S	$4f_i$	0.752 Hz
f_L	$2f_i$	0.376 Hz

Table 1. GV6 rotator fault frequencies

Based on the analysis of the design, function and fault frequencies of the above rotator, a suitable system for the measurement of vibrations was proposed, as specified in Tab. 2, to determine the boundaries for zones A and B. The vibration measurement system is viewed as a system that can be used to collect and process data on vibrations for the technical diagnosis of a rotator. In this case for technical

diagnosis by the manufacturer of the rotator, whereby the output control would include the measurement of vibrations for the manufactured rotator and the overall values would not be allowed to exceed the set value. This system generally consists of a summary of the selected vibration measurement methods, a summary of the means used for measurement and result processing methods and the selection and modification of the measurement points.

Measurement and analysis Detection Used sensor	Analysed area method of analysis	Detected faults (hypothesis)
Vibration velocity Rms Model 731A	0 Hz - 10 Hz - time waveform vibration and its overall value - frequency spectrum and overall value, 1600 lines - assessment according to the ČSN-ISO 13373 and ČSN ISO 10816-1 standards	- imbalance - axial misalignment - mechanical backlash - structural resonance - bent shaft - worn bearings - macroplastic deformation - total crack
Acceleration enveloping true peak to peak Model 731A	(5 Hz - 100 Hz) 50 Hz - 1,000 Hz 500 Hz - 10,000 Hz 5,000 Hz - 40,000 Hz - time waveform vibration and its overall value - frequency spectrum and overall value - 0 Hz – 10 Hz - frequency spectrum and overall value, 1600 lines - assessment of the condition according to the corporate documents of SKF on acceleration enveloping	- impact loading - bearing failures (2nd stage - pitting) - damage to lamellae and their chambers (2nd stage)
Acoustic Emission Enveloping (AEE/SEE) (Acoustic Emission Enveloping) true peak to peak CMSS 786M	100 kHz - 500 kHz - time waveform vibration and its overall value - frequency spectrum and overall value, 1600 lines - assessment of the condition according to the corporate documents of SKF on AEE/SEE	- improper lubrication - hard impurities in grease - corrosion - plastic deformation - growth of cracks - bearing failures (1st stage) - damage to lamellae (1st stage) - cavitation - etc.

Table 2. Vibration Measurement System for GV6 Rotator

Tab. 2 summarizes important information arising from the principle of individual vibration diagnostic methods which are capable of detecting the appearance and development of individual types of faults at various stages of appearance and development, and emphasises the importance of multi-parameter monitoring and the assessment of the technical condition of a rotator. Microlog CMXA 48 (measurement of oscillation rate and acceleration envelope) and Microlog MCVA 60 (measurement of Acoustic Emission Enveloping / Spectral Emitted Energy), developed by SKF, were used to assess the technical condition of the GV6 rotator using the method of vibration diagnostics. These portable vibration data collectors

and analysers have good simultaneous vibration measurement capabilities over a range of 0.16 Hz to 80 kHz.

As some of the fault frequencies in Table 1 are under the value of 1 Hz, it was necessary to use a Model 731A ultra-low frequency accelerometer with a Model P31 power amplifier [Wilcoxon 2015], see Fig. 3.

Acoustic Emission Enveloping was measured using a CMSS 786M sensor [SKF 2015]. This dual sensor was mounted on the same place. The paint was removed from the surface and a special AE couplant between the sensor and the surface was used.

For a new GV6 rotator we assume that only significant values will be measured for vibration velocity, corresponding to the design and function of this type of machine.



Figure 3. GV6 rotator with Model 731A accelerometer

3 EXPERIMENTAL RESULTS

The following figure shows the typical frequency spectrum of a new, fault-free GV6 rotator.

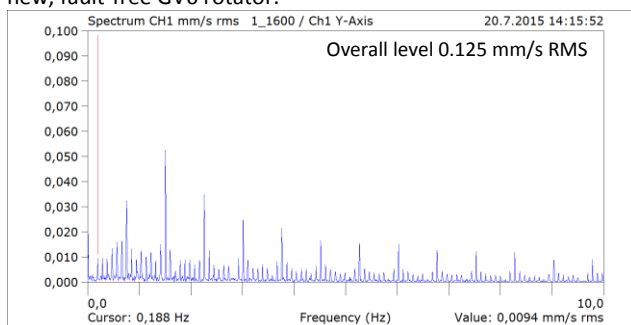


Figure 4. Characteristic rotator vibration spectrum

The overall level of vibrations was 0.125 mm/s (RMS).

The frequency spectrum in Fig.4 shows that a new GV6 rotator generates frequencies that are multiples of the rotor rotation frequency 0.188 Hz. Additional characteristic frequencies are frequencies of $4nf_i$ ($n=1, 2, \dots$) with sidebands at $0.5f_i$.

The overall vibration levels can be used to assess the technical condition of the rotator. To determine the operating limits, in our case the boundaries between zones A and B, it is possible to apply a suitable statistical method [Jankovych 2004].

We will identify the overall level of RMS vibration velocity calculated from the i -th time record (hereinafter the overall level) with o_i whilst the \bar{o} mean value of all measured total values for the past monitored period will be identified by. In practice, this data would correspond to the measured vibrations for rotors manufactured in a particular batch.

The moving range of the overall level between two successive measurements is identified as R_{o_i} :

$$R_{o_i} = |o_i - o_{i-1}|. \quad (1)$$

The boundaries between zones A and B for the overall level can be calculated as follows:

$$UCL_{o_i} = \bar{o} + 2,66\bar{R}_o, \quad (2)$$

where \bar{R}_o represents the mean value of the moving ranges of total vibration values from all previous measurements.

The boundaries between zones A and B for the moving range of the overall level can be calculated as follows:

$$UCL_{R_{o_i}} = 3,267\bar{R}_o. \quad (3)$$

The formulae (2) and (3) only apply when the assumed risk of an unnecessary erroneous signal (first class error) equals 0.27 % [CSN ISO 8258:1994].

On the basis of the application of the aforementioned formulae to the completed vibration measurements, a boundary was determined between zones A and B for the GV6 hydraulic rotator. Zone A represents the vibration level of newly commissioned machines. Zone B represents the level of vibration machines that can be operated for unrestricted long-term period [CSN ISO 10816-1 + Amd. 1:1998]. Two new hydraulic rotators made in 2014 and 2015 were available. The measured rotators were never put into operation. For measurement purposes they were installed on a temporary stand. Both rotators were in good technical condition. The measurement of the overall levels can therefore be considered to be the assessment of the status of vibrations which corresponds to zone A in accordance with the standard [CSN ISO 10816-1 + Amd. 1:1998]. On the basis of the presented facts, we can consider the limit value calculated according to the formula (2) to be the boundary between zones A and B.

Tab. 3 lists the calculated boundaries between zones A and B for the overall level and the moving range for overall level.

Boundary between zones A and B:	[mm/s]
For the overall level (RMS):	0.223
For the moving range of overall level:	0.097

Table 3. Boundaries between zones A and B

4 CONCLUSIONS

The paper presents an original idea for the utilization of a method of statistical regulation based on the comparison of individual values and moving ranges for the determination of operational limits. The proposed procedure allows for a significant rise in the overall level over time. Beyond the scope of standards, the proposed method also offers an assessment of changes in vibrations with respect to the last measurement. The proposed statistical method used to determine the operating zones for vibrations was applied to vibration measurements on a GV6 hydraulic rotator. The measured data represent the status of vibrations which correspond to zone A in accordance with the standard [CSN ISO 10816-1 + Amd. 1:1998]. The calculated limit values are proposed as boundaries between zones A and B. When any of the calculated boundaries

(overall level or moving range) are exceeded it is possible to assume that the following is highly probable (99.73%):

- a) statistically significant increase in the overall level of vibrations, or
- b) statistically significant change in the overall level compared to the previous measurements.

The proposed method for the assessment of new rotators simultaneously introduces into practice both criteria for the assessment of the magnitude of vibrations according to the standard [CSN ISO 10816-1 + Amd. 1:1998]. The first criterion responds to the increase in the overall vibration level and the second is sensitive to the violation of the critical change of vibrations regardless of whether it is an increase or decrease. Improper assembly or the installation of a defective part would also result in the measurement of increased acceleration envelopes or acoustic emissions envelopes [SKF 2015]. Based on these experiments, whereby three different methods of rotator attachment to a test stand were tested, it can be said that for the proper assessment of the technical condition of a rotator it is necessary to propose a suitable test stand to adequately simulate operating conditions.

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