Operational limits in vibration diagnostics

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Abstract. The paper discusses some practical problems occurring at ISO 10816-1 application in technical practice. Technical diagnosticians find out frequently that the zone boundaries proposed by the standard are not sensitive adequately to the changes in vibrations during operation resulting from a change of technical condition of the machine. The principle of statistical determination of individual operational limits from the measured overall level of RMS vibration velocity (overall level) with utilization of statistical regulation of individual values is also described in the paper. The alarm limit for the overall level (boundary between the B and C zones) in the range 10 Hz to 1,000 Hz is specified in the paper on the basis of measuring of vibrations on the electric motor of Bosch Rexroth hydraulic unit.

Keywords: Operational limits; vibration diagnostics; zones boundary.

1 Introduction

It is assumed in technical practice that measuring of vibrations on the non-revolving components is very often suitable for the purpose of assessment of technical condition for a number of machineries. We most frequently measure and assess overall level the significant changes of which indicate progressive changes of technical condition of rotational parts resulting e.g. from imbalance, misalignment, mechanical backlash of bearings in mounting, structure resonances, insufficiently rigid foundations, bent shaft, excessive wear of bearings, etc. relatively reliably.

Four typical zones (A, B, C and D) for assessment of the level of vibrations are defined in the standard [1] and in other related references (such as [4], [5], [6], [8], [10], etc.) for the purpose of evaluation of intensity of vibrations of a given machine and provision of the guidance for potential maintenance measures. We mostly find out at practical application of the ISO 10816-1 standard to the conditions of operation of a specific machine that the boundaries of the mentioned zone proposed by this standard are not adequately sensitive to changes of vibrations resulting from a change of technical condition of the machine [3].

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2 Assessment of vibrations of the hydraulic unit electric motor

Verification of the above mentioned assumptions was carried out on HA 0070-120/008-050/050 hydraulic unit (hereinafter the hydraulic unit, Fig. 1) manufactured by Bosch Rexroth. The hydraulic unit is specified as a source of pressure oil for a didactic stand for lessons of hydraulics in our Institute for Production Machines, Systems and Robotics. The hydraulic unit (Fig. 1.) represents a set of hydraulic elements arranged functionally on an aluminium tank positioned in a valve table made of aluminium profiled components.

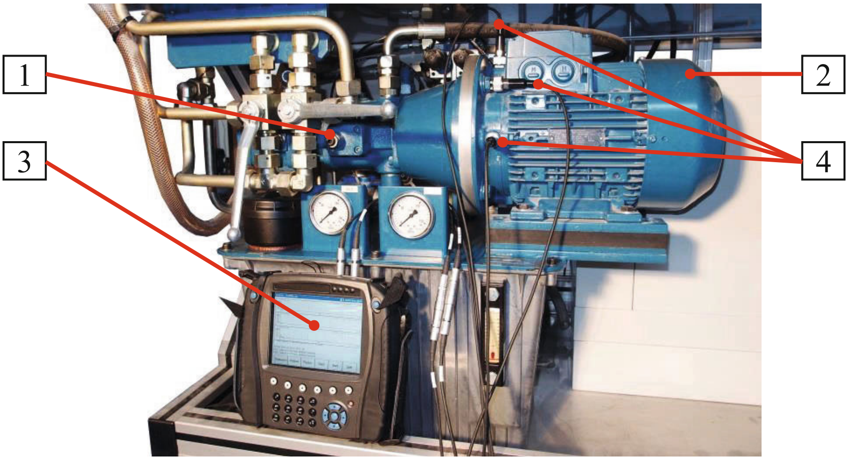

Fig. 1. Hydraulic unit with Microlog CMXA 48

The hydraulic circuit of the unit consists of two pressure circuits. A combination of two PV7 variable vane pumps produced by Bosch Rexroth (Fig. 1, item 1) with geometrical capacity of 12 and 7.5 cm^3/rev. controlled to a constant pressure and driven with Siemens 2.2 kW electric motor (Fig. 1, item 2) with synchronous speed of 1,000 rpm represents a source of pressure energy.

The Microlog CMXA 48 apparatus (Fig. 1, item 3) developed by SKF was used for evaluation of technical condition of the hydraulic unit. This portable vibration data collectors and analyzer has a good simultaneous triaxial or four-channel vibration measurement capabilities over a range of 0.16 Hz to 80 kHz.

Electric motor vibrations were measured using three CMSS 2111 accelerometers mounted to the flange of the electric motor with permanent magnets approximately in the horizontal direction (hereinafter H), in the vertical direction (hereinafter V) and in the axial direction (hereinafter A), see Fig. 1, item 4. The CMSS 2111 is a small footprint accelerometer that includes an integrated 2 m cable along with a magnetic mount (CMSS 908-LD).

We understand the value of the measured variable proportional to the total vibration energy (strength or intensity of vibrations) related to a considered time record as overall level of mechanical vibration *o*. The overall level can be calculated from the time record according to the following formula:

$$o = \frac{\sqrt{\sum_{i=1}^{m}(y_i)^2}}{\sqrt{m}}, \qquad (1)$$

where y_i is an amplitude of the determining quantity of mechanical vibration in the time t_i and m is a number of discrete points in the corresponding time record (in which the y value is ascertained).

By ascertaining of the value of overall level o and its comparison with the normal level, we will obtain some of possible information on the condition of the machine or any of its parts. When comparing the measured values, it should be verified whether the measurements of both values (the original one which represents information on the normal status and the new one through which current technical condition of the machine is assessed) have been made in the same frequency range (e.g. 10-1,000 Hz) and expressed in the same way (e.g. the peak value). If the value of total vibrations is higher than the normal level, we can assume that there is a problem which caused these higher values.

Such method of assessment of technical condition is recommended also by ISO 10816-1 standard. In this standard, individual types of machines are classified either in the group of "small machines" such as electric motors up to power of 15 kW or in the group of "bigger machines".

In our case, an asynchronous motor (2.2 kW) drives a pair of pumps. The first pump with a geometric capacity of 12 cm3/rev. was loaded using a throttle valve to a constant value of flow rate of 7 l/min at pressure of 5 MPa during vibration measuring. The other pump was hydraulically alleviated. It results from these loading parameters that the electric motor is loaded with approximately 0.6 kW, i.e. at about 30% of its nominal power. And that is why the machine is classified in the group of "small machines".

Values of measuring in accordance with ISO 10816-1 standard were set on Microlog CMXA 48 the lower frequency limit was set to 10 Hz while the upper one to 1,000 Hz. Number 10 was selected for averaging process, overlapping was 0% and measurements were repeated 30 times in order to obtain a sufficiently representative statistical sample of vibration values.

As the power of an electric motor was lower than 15 kW, it results from the standard that overall level for the zone boundary of the A/B zones can be specified to the value of 0.71 mm/s. Similarly, the value 1.8 mm/s is recommended for the alarm limit (boundary of B/C zones) while the value of 4.5 mm/s for the trip limit.

Fig. 2 shows the measured values of vibrations in all three directions (H, V, A) with the illustrated zone boundaries in accordance with the standard [1]. It is possible to say on the basis of Fig. 2 that the alarm and operation shutdown limits are very probably too far from the measured values. The alarm value specified using this method would not probably allow timely warning of the operator in case of a significant rise of vibrations.

It means that it is necessary to define new substantiated operational limits, e.g. using suitable statistical tools, in practice when establishing a system of predictive maintenance.

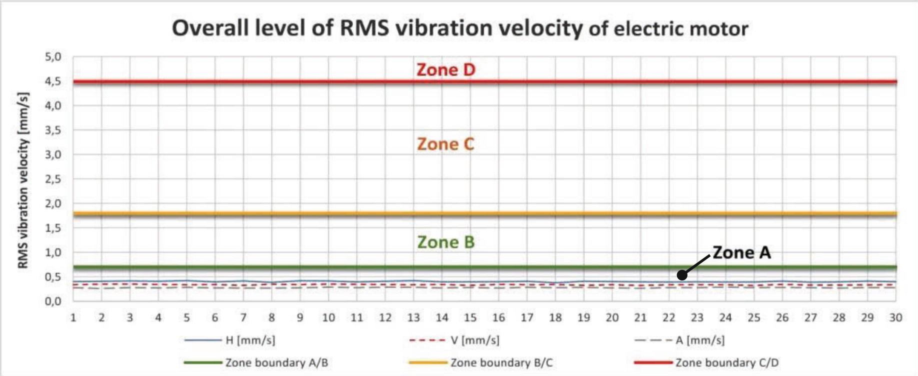

Fig. 2. Measured overall levels and zones for their assessment

3 Statistical determination of operational limits

We will identify overall level calculated from i-th time record with o_i symbol while the mean value of all measured overall levels for the past monitored period will be identified with $\bar{o}$ symbol. Moving range of overall levels between two successive measurements will be identified with R_{O_i} symbol:

$$R_{o_i} = \left| o_i - o_{i-1} \right| , \tag{2}$$

The alarm limit for overall level which should not be exceeded is given by the following formula:

$$UCL_{o_i} = \bar{o} + 2.66 \bar{R}_o , \tag{3}$$

where R_{O_i} represents the mean value of the moving ranges of overall levels from all previous measurements.

The alarm limit for moving range of overall levels can be calculated according to the formula:

$$UCL_{R_{o_i}} = 3.267 \bar{R}_o . \tag{4}$$

The formulas (3) and (4) apply only when the assumed risk of unnecessary error signal (risk α, type I error) equals to 0.27 % (for more details please see [2]).

Both limit values are in the distance of 3 sample standard deviations from the mean values $\bar{o}$ of overall levels and mean values $\bar{R}_O$ of their moving ranges.

Using the formulas mentioned above, the alarm limits for the hydraulic unit electric motor were determined on the basis of completed measurements of vibrations; these alarm limits are listed in Table 1. The mentioned electric motor has been used in non-demanding operation for about 10 years. It is in a good technical condition so that measuring of overall levels can be considered to be the assessment of the status of vibrations which correspond to the zone B in accordance with the standard [1]. On the basis of the above mentioned facts, we can consider the limit value calculated according to the formula (3) to be the boundary between the B and C zones (alarm limit).

We can conclude on the basis of assessment of the measurements that the maximum vibration values were measured in the horizontal direction as expected and for that reason, we will use them for illustration of the proposed procedure of determination of the alarm limit.

Fig. 3 illustrates the measured overall levels in the horizontal direction from which the alarm limit for this direction was calculated (0.438 mm/s).

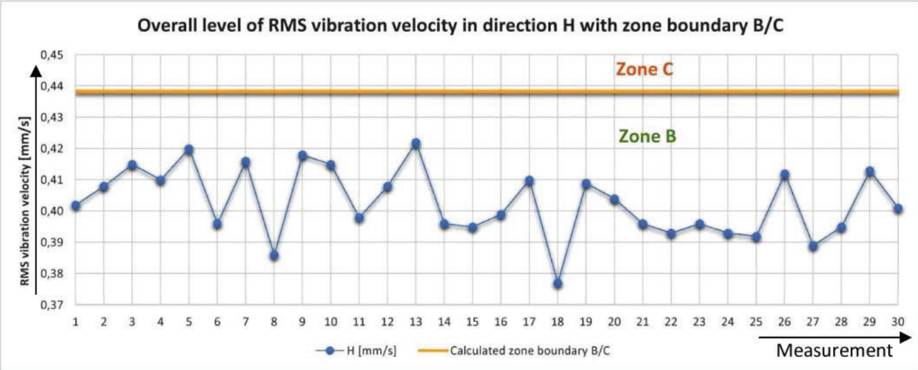

Fig. 3. Overall level of RMS vibration velocity in direction H

Fig. 4 illustrates the corresponding moving ranges of overall levels and the calculated alarm limit of moving range for the horizontal direction (0.044 mm/s).

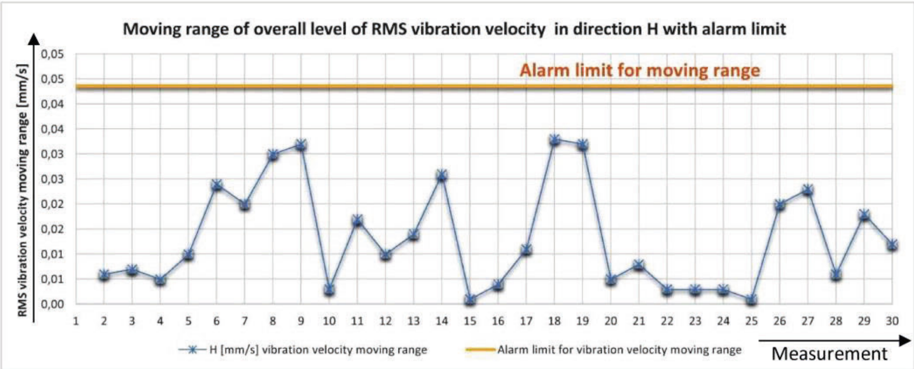

Fig. 4. Moving range of overall level of RMS vibration velocity in direction H

Table 1 contains the calculated alarm limits for overall level all three measured directions.

Tab. 1. Calculated alarm limits for overall level and moving range

Alarm limits:	H [mm/s]	V [mm/s]	A [mm/s]
For overall levels:	0.438	0.361	0.299
For a moving range of overall levels:	0.044	0.029	0.027

4 Conclusion

It happens very frequently in practice that the general standards for assessment of vibrations of machines and equipment during operation provide only approximate setting of an alarm limit and an operation shutdown limit (trip limit) which must be made more accurate progressively on the basis of experience and evaluation of the real course of measurements of vibrations.

The paper presents an original idea of utilization of the method of statistical regulation based on comparison of individual values and moving ranges for determination of the operational limits. The proposed procedure allows to respond to significant rise of overall levels in time. Beyond the scope of the standard, the proposed method offers also assessment of change of vibrations with respect to the last measurement.

The proposed statistical method of determination of the operational limits of vibrations was applied to measuring of vibrations of a hydraulic unit electric motor for three directions (horizontal-H, vertical-V and axial-A). The measured data represent the status of vibrations which correspond to the B zone according to the standard [1]. The calculated limit values are proposed as the boundary between B and C zone (alarm limit). When at least one of the calculated limits is exceeded (overall level or moving range), it is necessary to arrange for a suitable maintenance intervention immediately.

Identical method can be used for determination of the substantiated value of the boundaries between the A and B or C and D zones according to the standard [1].

The authors of the paper offer cooperation to all persons from the industry interested in verification of this procedure also for other types of machines.

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