Experimentální Analýza Napětí 2009
Experimental Stress Analysis

OPINIONS WITH EVALUATION AND CATEGORIZATION OF MACHINES AND EQUIPMENTS INTO CATEGORIES IN THE CONTEXT OF THEIR FURTHER OPERATION

František Trebuňa [1] & František Šimčák [2]

Abstract: In the contribution is summarized knowledge from experimental analysis of vibration on non-moved parts of equipments with rotation and reversible movement. On the base of the analysis were stated conclusions that were supported by failures of equipments as a result of their further operation.

1. Introduction

Mechanical vibrations that arise during operation of machines consist of much useful information about their technical state and they reflect character of working process and intensity of machine loading. In the contrary to other diagnostic method the experimental analysis of vibration (vibrodiagnostics) allows to determine not only shortage in design or beginning of failure, but also their reasons. The point of departure is a processing of time-dependent signal of vibration emitted by Fast Fourier transformation (FFT). Common tutorials for measurement and evaluation of mechanical vibration of machine equipments on non-rotated (and if suitable also on non-reversibled) structural parts of machines are given by standard STN ISO 10816-1 [1]. Recommendations for measurement and evaluation criteria for individual type of machines are given in other parts of STN ISO 10816, while today is available only part STN ISO 10816-6 [2]. Evaluation criterions given by above-mentioned standard allow to categorize the machines and equipments into zones of evaluation and classes which according to measured magnitudes of vibration allows classification of their appropriateness for no limited long-lasting operation.

In the contribution is given knowledge gained during application of above-mentioned standard for classification of machines and equipments on the base of results from experimental analysis of vibration of machines with rotation and reverse movement [5,6].

2. Evaluation of machine vibration on non-moved parts according to standard STN ISO 10816

In common practice that is based on opinions is evaluated large-range vibration of rotated machine parts (frequency range from 2Hz to 1000Hz) by taking into account effective vibration velocity because it is in related to energy of vibration. However, instead of effective values can be preferred other quantities e.g. accelerations or amplitudes. In such a case are needed additional criteria that do not have necessarily simple relation to criteria based on effective value.

[1] Dr.h.c. mult. Prof. Ing. František Trebuňa, CSc.; Technical University in Košice, Department of Applied Mechanics and Mechatronics, Letná 9, 04082 Košice, Slovakia, frantisek.trebuna@tuke.sk
[2] Prof. Ing. František Šimčák, CSc.; Technical University in Košice, Department of Applied Mechanics and Mechatronics, Letná 9, 04082 Košice, Slovakia, frantisek.simcak@tuke.sk

It is confirmed that measurement of effective vibration velocity is very useful and suitable for characterization of vibration response of broad range of classified machines. For the simple time-dependent charts that consist of certain number of harmonic components of known amplitude and phase and that do not contain components of remarkable random vibrations or shakes, can be, by Fourier analysis with rigorously given mathematical relations stated relations between various base quantities (e.g. deflection, velocity, acceleration, effective value, average value and so on). These relationships are given in [3,4].

Frequently are the measurements accomplished on various measurement locations in one, two or three directions. Massiveness of machine vibration is defined as maximal value of magnitude of broadband vibration measured for given imposition and given operation conditions. For the majority of machines will one value of vibration massiveness characterize state of the machine. For some machines can be such a treatment inappropriate and vibration massiveness should be independently evaluated on various locations of measurement.

The measurements are accomplished in bearings on the body of bearing imposition or in other structural parts that have remarkable response to dynamic forces and characterize the whole vibration of machine. For the precise description of dynamic behavior of machine in every measured location is necessary to provide the measurements of vibration of neighborhood for the machine without operation. In such a way can be found out whether that vibration does not form significant contribution to the vibration in question. If the magnitude of neighborhood vibration exceeds one third of recommended border, in locations, where it is possible should be provided the measures to decreasing of such vibration.

The equipments for the measurement have to be chosen such a way in order to work reliably in the environment in which it will be used, e.g. with respect to temperature, humidity an so on. Special attention have to be given to safe fastening of sensor of vibration and to the fact that sensor cannot influence properties of dynamic machine response.

For the evaluation of vibration massiveness of various machine classes the standard STN ISO10816-1 exploits two evaluation criteria. The first one takes into account magnitude of measured broadband vibrations, the second one the changes in magnitudes of vibration without respect whether it increases or decreases. Here we describe evaluation of vibration massiveness according to vibration magnitude.

According to this criterion are defined allowed (limit) values of absolute vibration that correspond to acceptable dynamic loading of bearings and acceptable transmission of vibration to the structure of support and to the foundation. Maximal value of vibration monitored in every bearing or pedestal is adjudicated by four categories of evaluation A,B,C,D determined on the base of international opinions. Maximal value of measured vibration is defined as massiveness of vibration. Standard STN ISO 10816-1 defines typical ranges of evaluation in the frame of general directives that allow qualitatively evaluate the vibration of machine shaft and it gives instructions for possible measures. For the specific types of machines that will be discussed in next parts of STN ISO10816 (to this time is available only part of STN ISO 10816-6) can be used different categorization and different number of ranges. Temporarily given values for range limits are shown in Table 1. These values are determined for upper limits of ranges A to C for machine classes given there.

Classification is the following.

Class I: Typical examples of machines in this class are electric drives to power 15 kW.

Class II: Machines of middle dimensions without special foundation, motor fixed or machines on special foundations.

Class III: Big drives and other machines with rotated masses fixed to stiff and heavy foundations that are relatively stiff in the direction of vibration.

Class IV: Big drives and other big machines with rotated masses fixed to foundations that are relatively weak in the direction of vibration.

For the individual ranges is valid:

Range A: In this range can be included values of vibration of new machines.

Range B: Machines which have magnitudes of vibration included in this range are built for unlimited operation.

Range C: Machines with magnitudes of vibration included in this range are considered to be not suitable for unlimited uninterrupted operation. These machines can generally operate in limited time interval to the suitable opportunity for reparation.

Range D: Magnitudes of vibration in this range are generally considered to be unallowable and they cause failure of machine.

Table 1: *Typical range limits according to STN ISO10816-1*

<table>
<tr><th>Effective values of vibration velocity [mm.s^{1}]</th><th>Class I</th><th>Class II</th><th>Class III</th><th>Class IV</th></tr>
<tr><td>0,28</td><td rowspan="3">A</td><td rowspan="4">A</td><td rowspan="5">A</td><td rowspan="6">A</td></tr>
<tr><td>0,45</td></tr>
<tr><td>0,71</td></tr>
<tr><td>1,12</td><td rowspan="2">B</td></tr>
<tr><td>1,8</td><td rowspan="2">B</td></tr>
<tr><td>2,8</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>4,5</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>7,1</td><td rowspan="5">D</td><td rowspan="2">C</td></tr>
<tr><td>11,2</td><td rowspan="4">D</td><td rowspan="2">C</td></tr>
<tr><td>18</td><td rowspan="3">D</td></tr>
<tr><td>28</td><td rowspan="2">D</td></tr>
<tr><td>45</td></tr>
</table>

Numerical values that correspond to range limits do not serve as acceptable technical conditions that have to be agreed by producer and customer. However, these values can serve as instructions for preventing coarse shortages or unreal demands.

As was mentioned above, standard STN ISO 10816-1 gives general instructions for evaluation of machine vibrations by measurements on non-rotated parts. Standard STN ISO 10816-6 is a document that prescribes procedure and instructions for measurement and classification of mechanical vibration of machines with reversible movement.

The machines with reversible movement can act as vibration generator so that it is necessary to use vibroisolation between machine and its foundation (carrying structure). Together with vibration response can have remarkable influence to vibration of machine itself. These vibration conditions depend also on vibration transmission from the environment of machines and accordingly they are not given by values of vibration of machine in question. Due this fact has the standard STN ISO 10861-6 only remedial position with relation to influence of machines with reversible movement to environment.

According to STN ISO 10816-6 the machines with reversible movement should be classified by more than one sign in dependence by type, application, dimension, space distribution, elasticity or foundation stiffness as well as rotations. Todays are prepared recommendations for acceptable values of vibration massiveness for individual machine types. Now, the classification can be given by agreement between producer and customer on the base of opinions or results of machine operation.

3. Examples of classification of machines and equipments on the base of experimental vibration analysis

3.1. Experimental vibration analysis of fan (machine with rotation movement)

During operation of two identical radial fans one of them crashed [5,7]. In order to assess the reason of failure of the one fan as well as ensure further operation of the second one was on the bearing houses of operating fan realized vibration measurement. In Fig. 1 is a schema of positioning of supports for fixation of sensors.

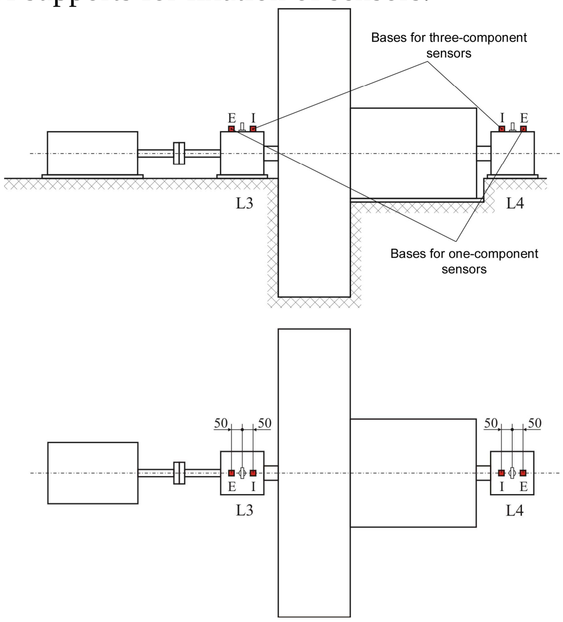


Figure 1: *Scheme of supports positioning for fixation of sensors on bearing houses of fan.*

Vibration measurement on bearing houses of the fan was realized by system PULSE 6.

Position of axes of sensors was the following:

- axis x axial direction of bearing,
- axis y radial (horizontal) direction of bearing,
- axis z radial (vertical) direction of bearing.

One-component sensors were oriented along axis z.

In Figure 2 are shown positions of sensors.

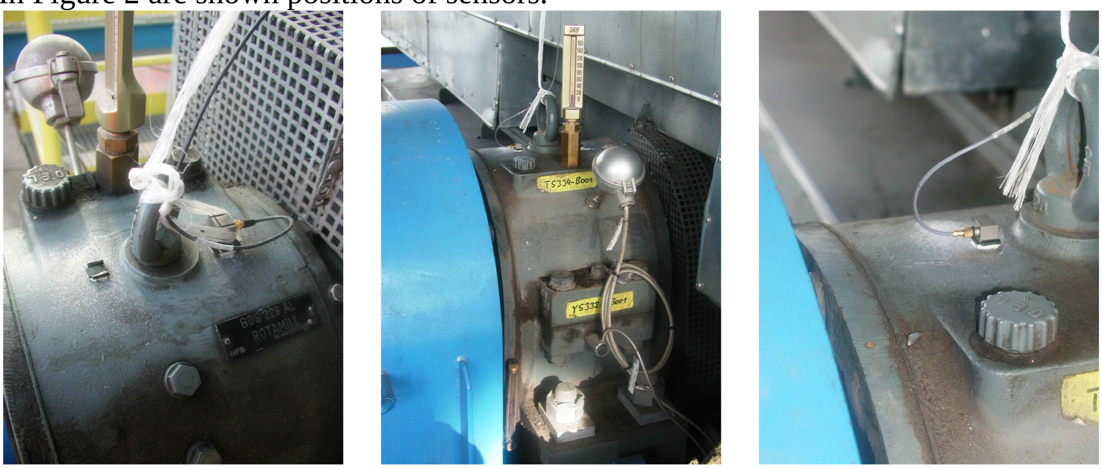


Figure 2: *Applied sensors.*

Measurements and frequency analyses were realized in the frequency range 2-800 Hz with rotations 600-1300 rpm (fan without loading), 1100 rpm during limited operation of fan (maximal allowable rotations with respect to crash of one fan) as well as with continual change of rotations 1100 to 1400 rpm during operation for one case allowed by operator.

On the base of analysis of time and frequency-dependent vibrations from two hundred measurements were the maximal values of velocities and accelerations identified on right bearing of fan (L4) with measuring by three-component sensor (location I) during operation of fan with 1100 rpm. In Fig.3 are time and frequency-dependent charts of acceleration from measurement in bearing L4.

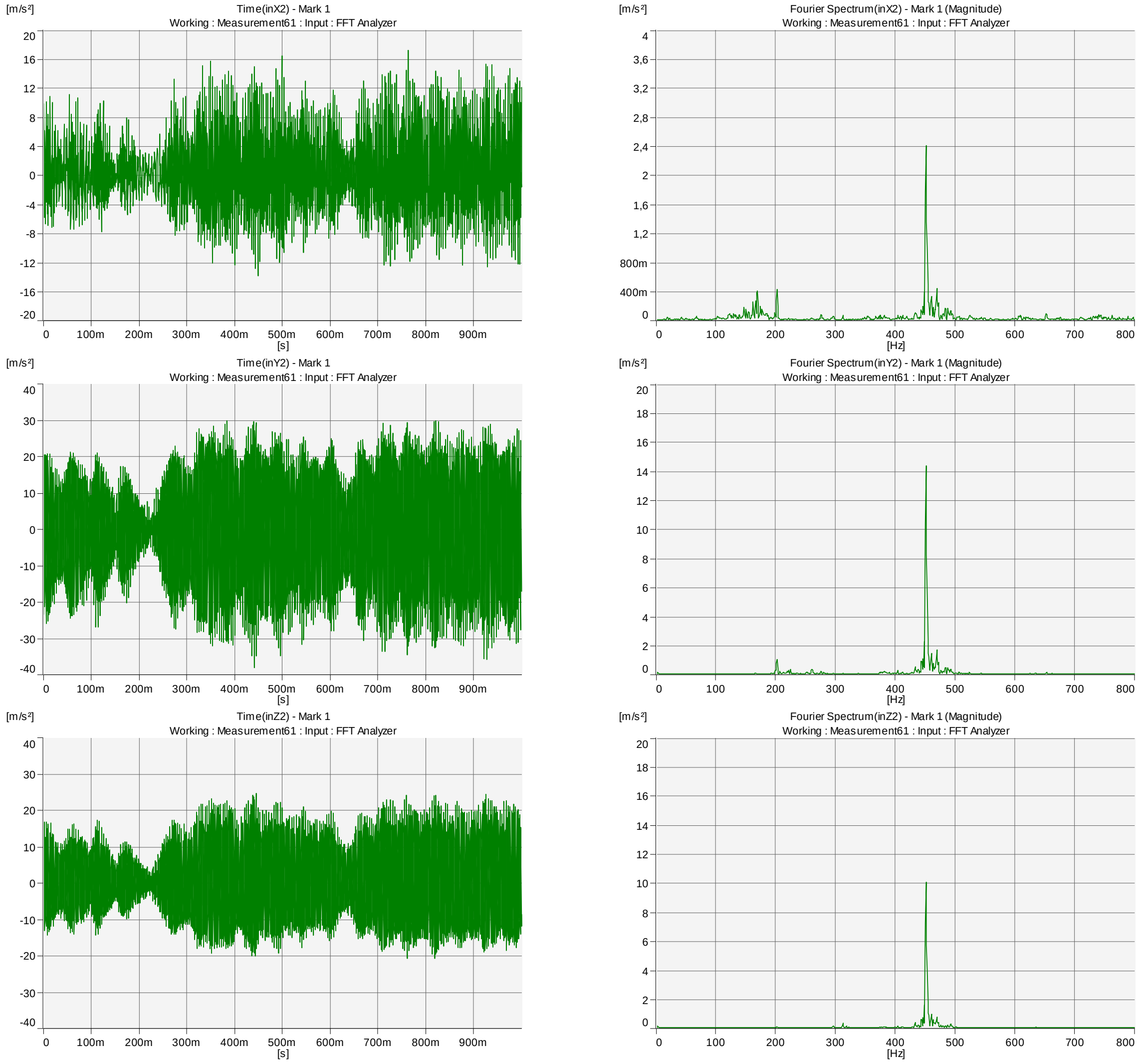


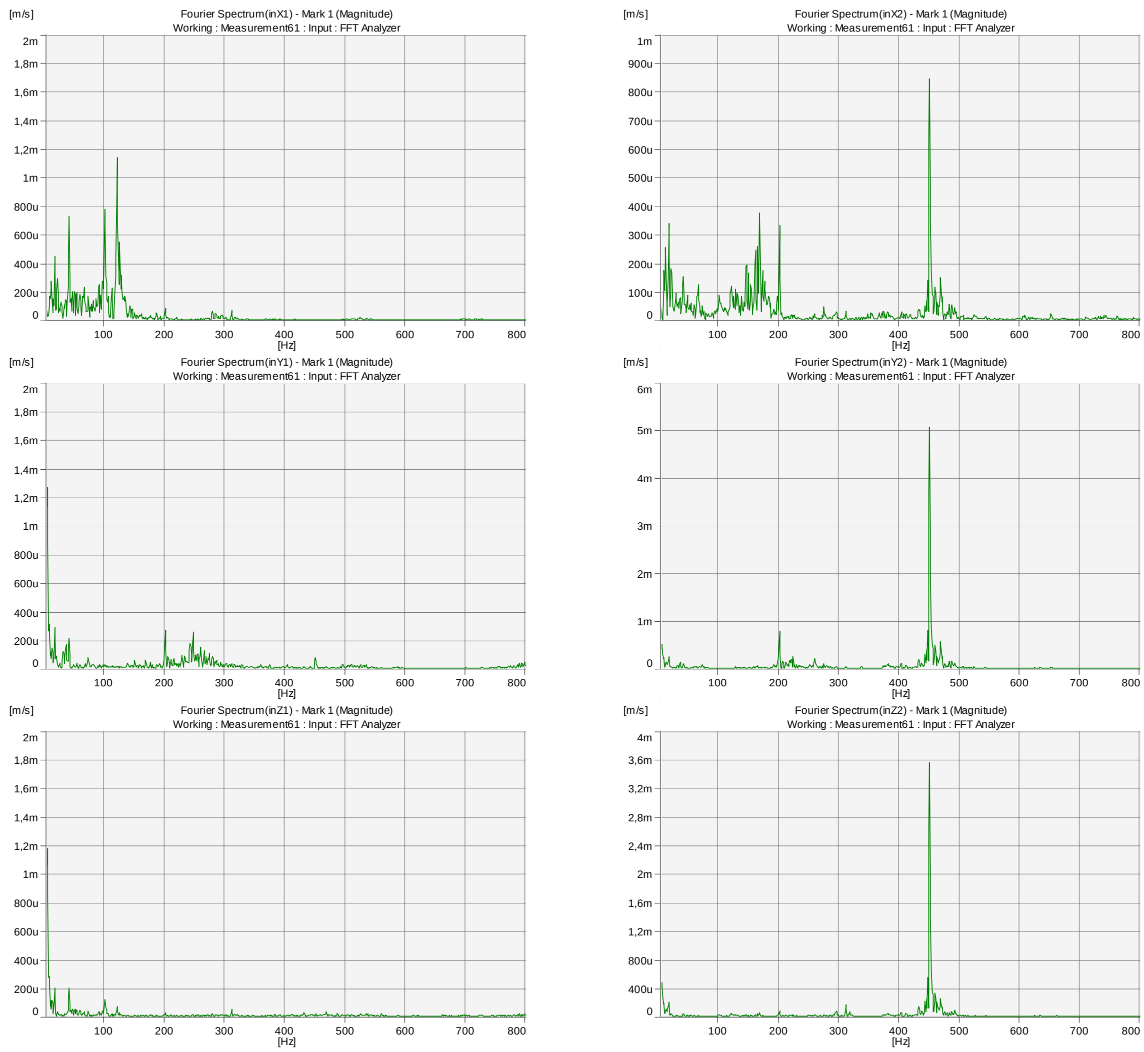
Figure 3: *Time and frequency dependencies of acceleration for maximal vibration (1100 rpm).*

In Fig.4 are frequency dependencies of velocity for the same measurement on both bearings (left part - bearing L3, right part - bearing L4). As results from Fig.3 and 4, maximal values of accelerations and velocity were identified for frequency 458 Hz (25 multiple of rotation frequency). Maximal value of resulting effective velocity reaches 4,5 mms^{-1} .

According to standard STN ISO 10816-1 it is possible to include fan in question into class III., for which are the limits of ranges (see Table 1).

$$A - v_{ef} \leq 1{,}8\ mms^{-1},\ \ B - v_{ef} = 2{,}8 \div 4{,}5\ mms^{-1}\ ,\ \ c - v_{ef} = 7{,}1 \div 11{,}2\ mms^{-1},\ \ D - v_{ef} \geq 18\ mms^{-1}.$$

Maximal measured value of effective velocity $v_{ef} = 4{,}5\ mms^{-1}$ is on the border of ranges B and C. At the same time the range C is not suitable for long-time operation (limited operation).



L3 L4

Figure 4: *Frequence dependencies of velocity for 1100 rpm.*

3.2. Experimental analysis of sorter vibration (machine with reversible movement)

Equipment for sorting of rubble was fixed on operation container No. 28 by four feet and eleven springs (Fig.5). During operation of sorter the carrying structure undergo excessive dynamic loading. [6].

In order to determine of eigenfrequencies (for which the components of amplitudes of velocity and acceleration reach extreme magnitudes) was accomplished the measurement of time-dependent charts of acceleration by system PULSE 6. The sensors of acceleration were applied in locations given in Fig.6, on steel structure in locations to which the sorter is connected by helical cylindrical springs.

For the measurement were used 2 three-component sensors of acceleration that allow measurement of acceleration in three perpendicular directions according to Fig.6. Because the apparatus allows measurement with 6 channels, the measurement was accomplished such a way that the I. stage of measurements was realized in locations 1 and 2, the II: stage in locations 2 and 3 and the III. stage in locations 1 and 4. The measurements were realized for the following regimes – all conveyors on, but on the transportation belts was not any material; only empty conveyors on operational containers were on; sorter in operation without material; sorter in full operation – full operation regime.

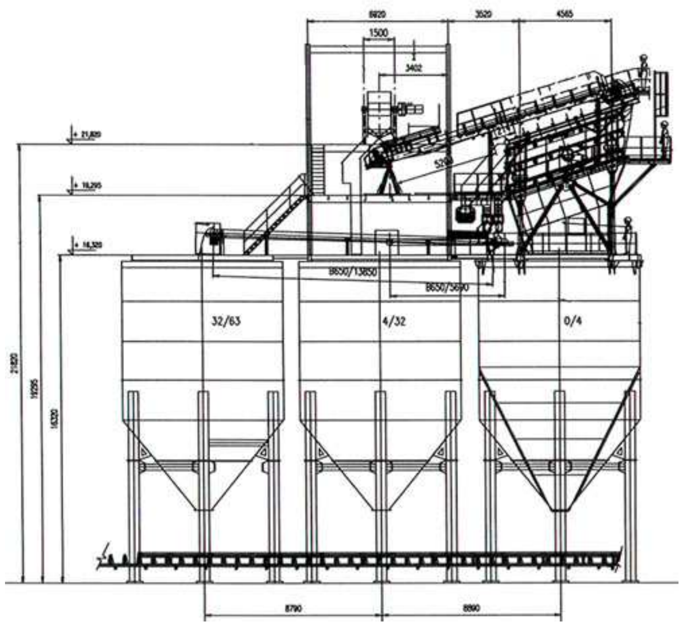


Figure 5: *Positioning of sorter on carrying structure.*

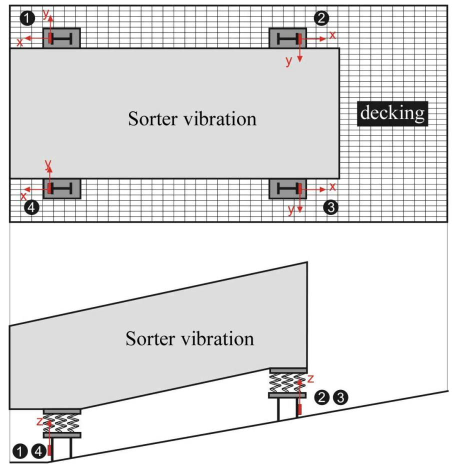


Figure 6: *Sensors of acceleration applied on steel structure.*

By the analysis of time and frequency-dependencies of acceleration and velocities during individual measurements was found out that the biggest amplitudes of accelerations and velocities are in location 4. In Fig.7 are time-dependent charts, frequency-dependencies of accelerations and velocities for maximal measured value of vibration velocity.

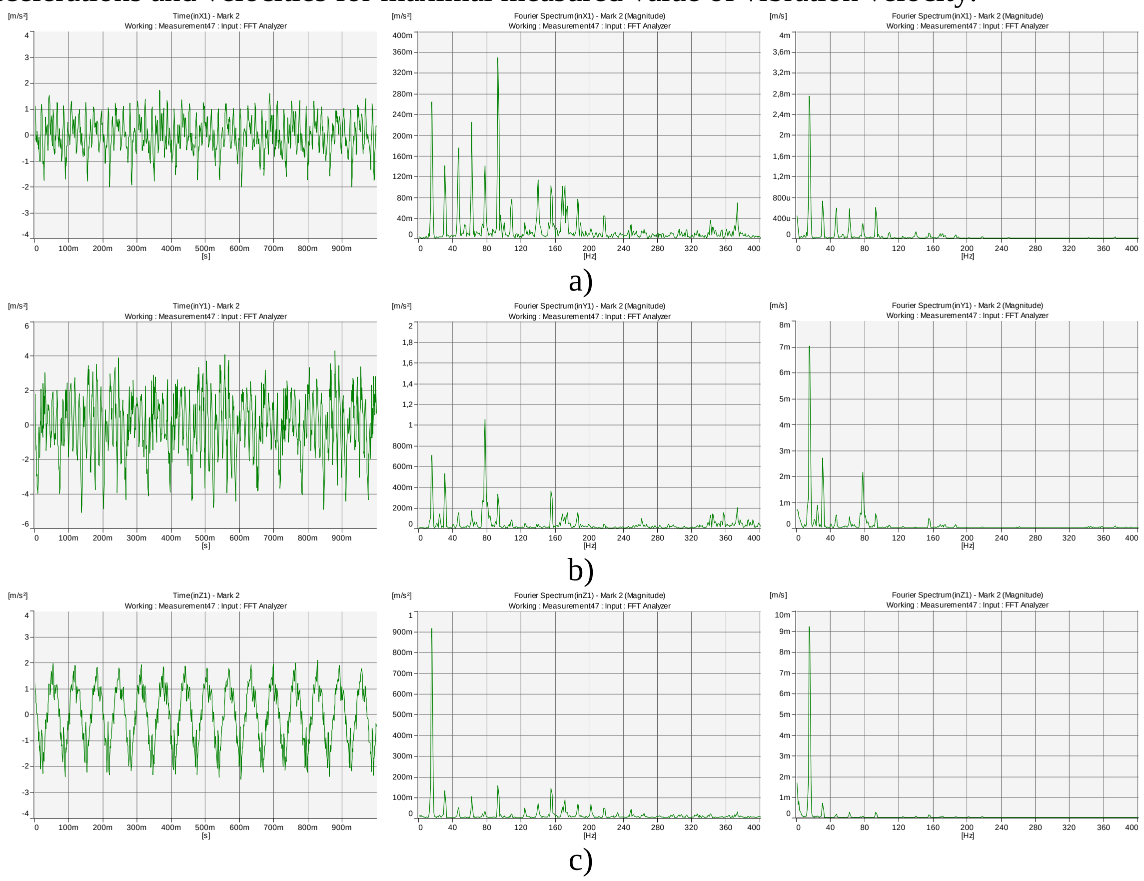


Figure 7: *Maximal measured value of vibration. a) time-dependent charts of acceleration, b) frequency-dependent charts of acceleration, c) frequency-dependent charts of acceleration.*

As result from Fig.7 the maximal values of vibration velocity were identified for frequency 16 Hz. Maximal effective velocity reached value 8,5 mms^{-1} that predicts according to above-mentioned standards limited operation of equipment.

4. Conclusion

In the contribution is presented on two practical examples of application of experimental analysis the treatment to evaluation of equipments in the context of problems during their operation. Measurements clearly documented that categorization of equipment according to the standards is reliable and it allows with sufficient precision the statement about prospective failure beginning of equipment.

Acknowledgement

The contribution was elaborated with the support of grant agency VEGA, projects No.1/0004/08 and 1/4163/07.

References

[1.] Norma STN ISO 10816-1 Mechanické kmitanie. Hodnotenie kmitania strojov meraním na nerotujúcich častiach. Časť 1: Všeobecné pokyny. SÚTN, Bratislava, júl 1999
[2.] Norma STN ISO 10816-6 Mechanické kmitanie. Hodnotenie kmitania strojov meraním na nerotujúcich častiach. Časť 6: Stroje s vratným pohybom menovitého výkonu nad 100 kW. Úrad pre normalizáciu, metrológiu a skúšobníctvo SR, Bratislava, apríl 2000
[3.] Trebuňa, F., Šimčák, F.: *Príručka experimentálnej mechaniky*. TypoPress, Košice, 2007.
[4.] McConnell, K.G.: *Vibration Testing. Theory and Practice*. John Wiley&Sons, Inc. New York, 1995.
[5.] Trebuňa, F. et al.: Expertíza havárie ventilátora K4 a posúdenie ventilátora K5 vrátane kontroly ich kotvenia : Záverečná správa. Košice : TU, SjF, 2008. 320 s.
[6.] Trebuňa, F. et al.: Určenie zložiek zrýchlenia, rýchlostí a klasifikácia zariadenia triediča na medzizásobníkoch na základe merania mechanického kmitania na nerotujúcich častiach. Košice : TU, SjF, máj 2008. 56 s.
[7.] Trebuňa, F. et al.: Assesment of ventilator failure on exhausting of converter. In: Experimental Stress Analysis 2008 : 46th international conference, Horní Bečva, Czech Republic, June 2-5, 2008 : Book of contributions. Ostrava : VŠB TU, 2008. 4 p. ISBN 978-80-248-1774-3.