Proceedings IRF2018: 6th International Conference Integrity-Reliability-Failure
Lisbon/Portugal 22-26 July 2018. Editors J.F. Silva Gomes and S.A. Meguid
Publ. INEGI/FEUP (2018); ISBN: 978-989-20-8313-1

PAPER REF: 7156

CONDITION MONITORING OF AN INDUSTRIAL BUCKET ELEVATOR FOR BULK MATERIALS

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ABSTRACT

The paper presents the results of diagnostic tests of the drive unit of a large bucket elevator in one of the Polish power plants. These studies included among others measurements of vibration velocity and acceleration of bearing units. On the basis of the results analysis it was shown that the tested power unit is in a good technical condition, which is acceptable for unrestricted long term operation.

Keywords: condition monitoring, bucket elevators, drive units, field research.

INTRODUCTION

Bucket elevators are used for transporting bulk materials in the chemical industry and in power plants for transporting solid fuel (coal, biomass, etc.) to boiler furnaces. Unlike in belt conveyors, the material transported by the bucket elevators does not form a continuous stream, but it is moved in a cyclic manner in buckets mounted to the chain or belt.

The basic advantages of bucket elevators include, among others: the ability to move materials vertically up to large heights of 30-40 meters (or more) as well as the possibility of transporting of dusty materials without risk of environmental pollution (thanks to the tight housing of elevators). Contemporary bucket elevators achieve a capacity of up to 1000 t/h.

The drive unit has a quite considerable influence on the operation of the bucket elevator and therefore monitoring its technical condition is particularly important. If it is necessary to assess the technical condition during operation of elevator without dismantling its components, then the research techniques based on the study of vibroacoustic residual processes, that is vibration and noise measurements, are particularly valuable and useful (Cempel, 1998; Sokolski, 2016).

This paper presents the results of vibroacoustic tests and diagnostic assessment of the drive unit of a bucket elevator installed in a supply system of boiler furnace with solid fuel in a Polish power station. Due to the confidentiality of the data, the name of the power plant and detailed technical data of the tested bucket elevator are not given in the paper.

OBJECT, PURPOSE AND RANGE OF RESEARCH

The research object was a bucket elevator in one of the Polish power plants. The tested driving unit consisted of 45 kW electric motor and a set of 3 gear transmissions (cylindrical and bevel).

The main goal of the research was to diagnose the technical condition of the driving units in terms of possibilities of further usage and safe operation in real working conditions in power plant.

The technical condition of the drive unit was evaluated basing on measurements of vibrations: velocity and acceleration on housings of bearings. The scheme of location of measuring points is shown in Figure 1.

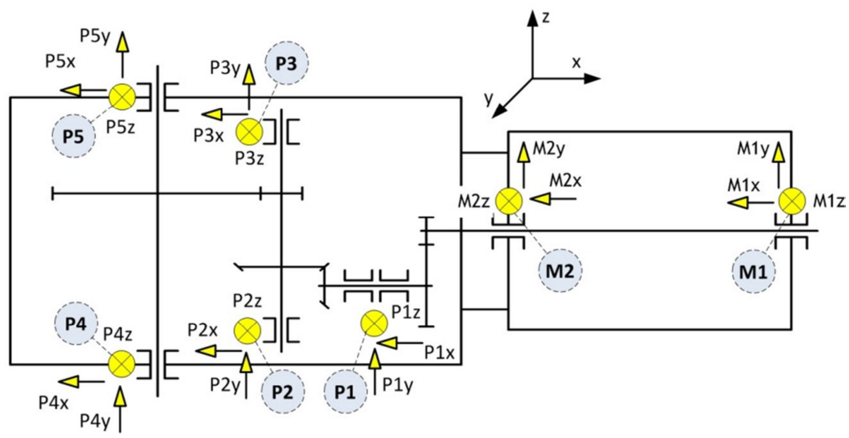

Fig. 1 - Measuring points on the tested drive unit

In the research, the following measuring apparatus were used:

- vibration level meter and analyzer type SVAN 954 with piezoelectric accelerometer type DYTRAN 3185D,
- noise level meter and analyzer type SVAN 945A with condenser microphone type 40AN.

BASIS FOR DIAGNOSTIC ASSESSMENT OF TECHNICAL CONDITION IN DETERMINISTIC APPROACH

As the diagnostic criterion, the basic guidelines of ISO-10816-3 were adopted with respect to the drive units on the flexible support (Table 1). This criterion introduces 4 zones for vibration severity “A” ÷ “D”. The values of these zones boundaries are based on the maximum broad-band r.m.s vibration velocity measured on bearing housings in the frequency range at least from 10 Hz to 1000 Hz.

For long-term operated machines, such as, in particular, bucket elevators, it is additionally recommended the alarm values of vibration velocity to be defined. If the alarm value is exceeded, the operation may be conditionally continued for a certain period of time until the reasons for the increase in vibration are identified and corrective actions can be taken. According to recommendations of International Standard ISO-10816-3, the alarm value should not be higher than 1.25 times the upper limit of zone “B”.

However, according to some sources (e.g. Blake, 1972; Cempel, 1998; Zoltowski, 2004), the recommendations of ISO-10816-3 in some cases are too restrictive in relation to real vibration velocity, which can be accepted in the operation of drive unit with gears.

Table 1 - Numerical values used for a qualitative assessment of technical condition of the tested drive unit (according to ISO-10816-3)

Support conditions	**Upper limits of velocity RMS, mm/s**	**Evaluation zones/vibration severity**
flexible	2.3	Zone “A” - vibration severity for newly commissioned drive units
	4.5	Zone “B” - vibration severity considered acceptable for unrestricted long-term operation
	7.1	Zone “C” - vibration severity considered unsatisfactory for unrestricted long-term continuous operation and remedial action should be taken
	> 7.1	Zone “D” - vibration severity normally considered to be of limit to cause damage

The requirements of ISO-10816-3 refer rather to new drive units installed and tested on special test stands, where the influence of environmental vibrations on the level of diagnostic signals can be minimized.

However, in real conditions, drive units of industrial bucket conveyors are usually mounted on the housings of these conveyors. Under these conditions, diagnostic signals include components caused by vibration of other elements of bucket conveyor, e.g. especially from the housing structure and chain or belt on which the buckets are installed.

In this context, a more practical classification of technical condition of drive units with gears is proposed. This classification is based on vibration severity (see Table 2) and refers to the recommendations of ISO 8579-2.

Table 2 - Numerical values proposed as liberalized criteria for the assessment of technical condition of industrial drive units with gears (according to the recommendations of Zoltowski and Cempel 2004)

Velocity RMS, mm/s	**Technical condition**	**Required action**
$v_{RMS} \leq 8.0$	Condition acceptable for unrestricted long-term operation	No special action is required
$8.0 < v_{RMS} \leq 12.0$	condition considered as temporary acceptable	It should be stopped and inspected
$12 < v_{RMS} \leq 18.0$	condition considered as dangerous	It should be stopped and repaired within 24 hours
$v_{RMS} > 18.0$	condition considered as catastrophic	It should be immediately stopped

CONCEPT OF DIAGNOSTIC ASSESSMENT OF TECHNICAL CONDITION IN PROBABILISTIC APPROACH

However, it should be noted that in real conditions, the vibration severity at the bearing arrangements are random variables. For these reasons, the diagnosis of the technical condition should be carried out in a probabilistic approach.

Because of that, the authors propose that the Quantile Q_p (where p - confidence level) of velocity v_{RMS} should be taken as a measure of the vibration severity of the bearing arrangements.

According to this idea, if the Quantile Q_p of the vibration velocity does not exceed the upper level of zone "B":

$$Q_p \leq v_{RMS("B")}$$

then the bearing arrangements meet the requirements specified in the relevant standards (in particular in ISO-10816-3) and the drive unit is treated as acceptable for unrestricted long term operation.

RESULTS

The results of the research have shown that the highest vibration severity was occurring at the measuring point P4 located on the left bearing housing of the output shaft of the tested drive unit (see Figure 1).

An exemplary velocity spectrum at the point P4 is shown in Figure 2. This bar chart shows that the maximum broad-band r.m.s vibration velocity does not exceed the upper threshold v_{RMS} = 4.5 mm/s of zone "B". This means that in deterministic approach this bearing arrangement and the whole of the tested gearbox meet the requirements of ISO 10816-3 and could be treated as acceptable for unrestricted long term operation.

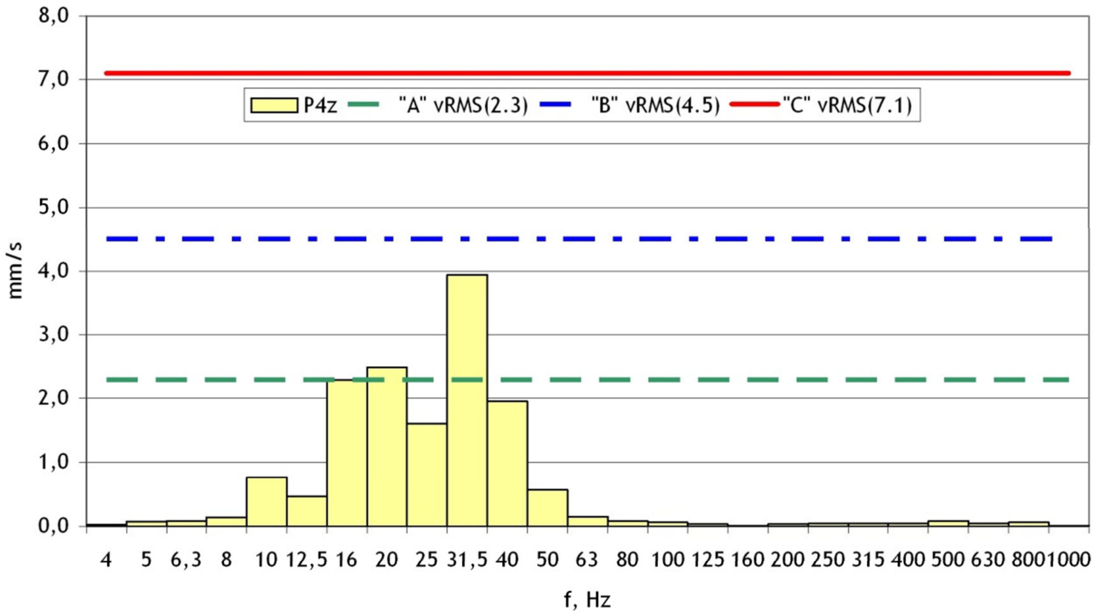

Fig. 2 - Typical spectrum of the root-square-mean values of vibration velocity in the vertical direction z measured at the point P4 on the gearbox housing

However, in accordance with the proposed diagnostic concept based on a probabilistic approach, the vibration severity of the bearing arrangements of the tested drive unit was also analyzed in order to evaluate the statistical distributions of vibration velocity values. Exemplary results in the form of histograms are shown in Figure 3.

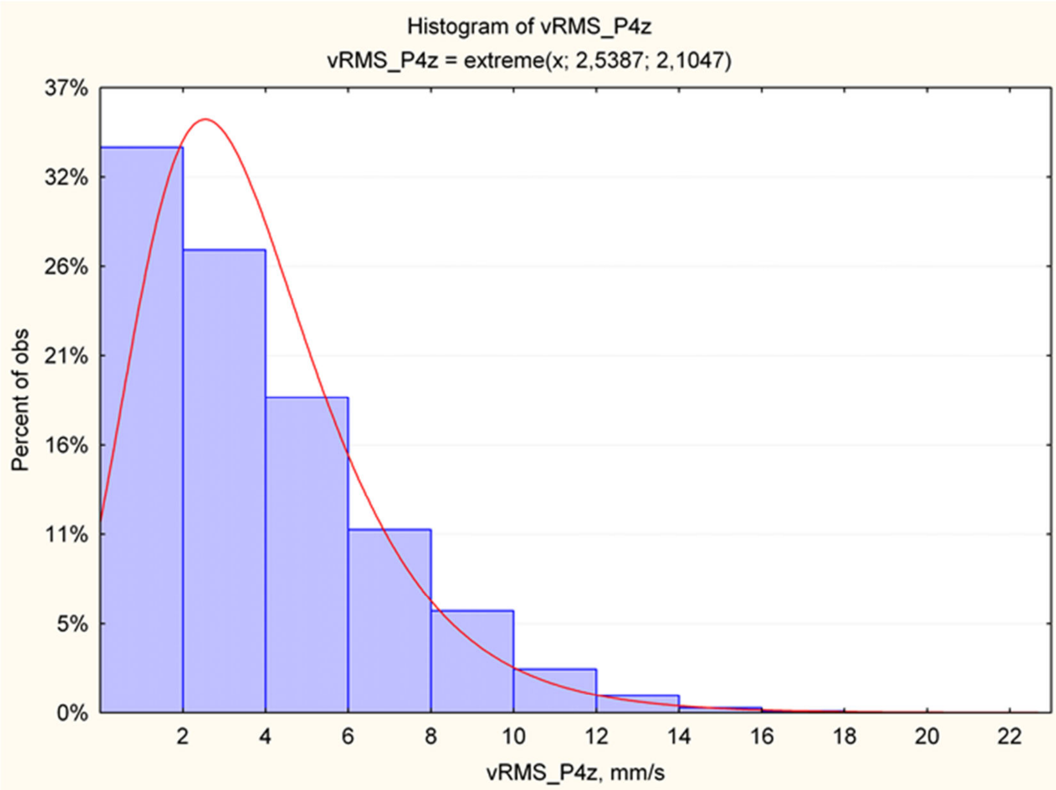

Fig. 3 - Histogram of velocity v_{RMS} at the point P4 in the z-direction

Then, the numerical values of the statistical distribution parameters of velocity v_{RMS} were estimated by using the Kolmogorov Smirnov test and the maximum likelihood method.

The best accordance with experimental data was obtained for the Gumbel Extreme Value

$$f_G(v_{RMS}) = \frac{1}{b} \exp\left\{ -\frac{v_{RMS} - a}{b} - \exp\left(-\frac{v_{RMS} - a}{b} \right) \right\}$$

where: b - the scale parameter Distribution expressed as:, a - the threshold parameter.

On this basis, the cumulative distribution functions CDF of vibration velocity v_{RMS} in each bearing arrangements of the tested drive unit was determined. Exemplary CDF diagrams and the limit values $v_{RMS\ (2.3)}$ = 2.3 mm/s, $v_{RMS\ (4.5)}$ = 4.5 mm/s and $v_{RMS\ (7.1)}$ = 7.1 mm/s of vibration severity zones “A”, “B” and “C” are shown in Figure 4.

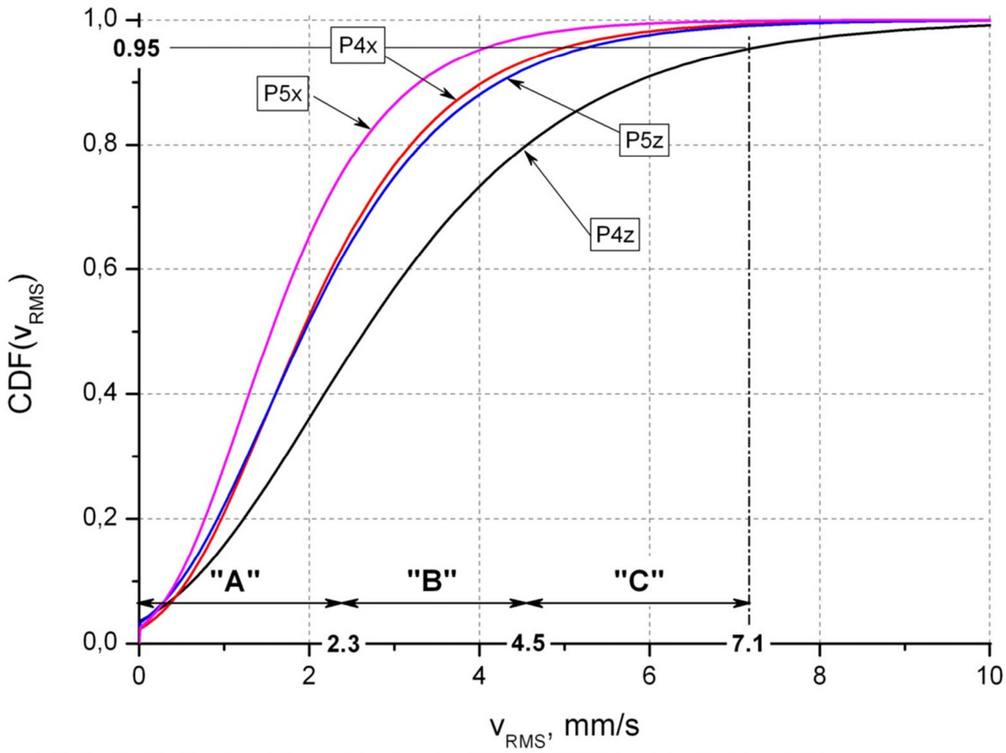

Fig. 4 - Cumulative Distribution Functions of vibration velocity v_{RMS} at the test points P4 and P5 (x, z denotes the vibration directions, and symbols “A”, “B”, “C” denotes the zones of vibration severity)

The research have shown that the tested drive unit of the bucket elevator meets in general the requirements for the vibration severity zone “B” that is normally considered acceptable for unrestricted long term operation. The probability that the vibration velocity v_{RMS} at the measuring points will exceed the alarm value $v_{RMS(B;alarm)} = 1.25 \cdot 4.5 = 5.6$ mm/s for the zone “B” is not greater than 0.05. The exception is the point P4, in which the probability that the vibration velocity exceeds the alarm value of $v_{RMS\,(B;\,alarm)} = 5.6$ mm/s in the vertical direction (along the z-axis) is slightly higher and amounts to approximately about 0.11.

However, if liberalized criteria for the assessment of the technical condition of industrial drive units with gear transmissions (Table 2) are taken into account, then it can be found that the tested drive unit may be treated as acceptable for unrestricted long term operation.

The probability that the vibration severity in the tested dive unit will exceed the acceptable level of $v_{RMS(B;8.0)} = 8$ mm/s is very small and amounts to $P(v_{RMS} > 8.0) < 0.03$.

In addition, the research of acoustic climate in the environment of the tested drive unit was carried out. The results of this research show that the noise level reaches the value of $L_{Aeq} = 73 \div 75$ dB(A), so it does not exceed the value of $L_{Aeq} = 85$ dB(A) which is a permissible level for the stands of physical work. This conclusion means that there are no acoustic hazards in the area of the tested drive unit of bucket elevator.

CONCLUSION

The research results of the drive unit of an industrial bucket elevator installed in a Polish power plant were presented.

The purpose of this research was to diagnose the technical condition of the drive unit and to assess the acoustic climate in the environment of this object.

The tests included measurements of vibration velocity of the bearing arrangements of the drive unit and noise measurements as well.

Based on the analysis of the research results, it was shown that the tested drive unit can be treated as acceptable for unrestricted long term operation and there are no acoustic hazards in its environment.

Among methods of reduction of vibrations in gear transmissions one can list application of dampers in which stiffness and damping play a key role in their operation. Study on influence of such structures is analyzed by among others (Stosiak, 2015, Firouzi, 2017). One of the most recent materials used as dampers are shape memory alloys (Naresh, 2016). Integral squeeze film damper supports are also highly advantageous in terms of reducing vibrations level in gear mechanisms while being integral bearing dampers (Lu, 2017). Utilization of such solutions results in lowering of vibrations level in modern gear transmissions.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by Ministry of Science and Higher Education of Poland within designated subsidy for research for the development of young scientists. Project number 0402/0060/17.

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