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Bearings vibration diagnosis based on hodograph XY

Abstract. *The article presents a method of bearings technical condition evaluate using XY vibration trajectory. Determination of trajectory is made with two transducers placed in the X and Y axes. The amplitude of vibration in the XY plane is always greater than the value recorded for each axle separately. Measuring only one axis does not reflect the maximum amplitude of the vibration of the machine. Reference image of the perfectly smooth bearing is a small diameter circle drawn on the XY plane. Practical application of vibration trajectory in the XY plane method is shown in the example of assessment of bearings with varying degrees of lubricant contamination. The results of tests presented in this paper were obtained during the test of induction 3-phase motor type Sg112M4 with P_N = 4 [kW]. Motor was placed on elastic foundation. Research consisted in measuring the vibration velocity v_e (RMS) and recording the instantaneous values of vibration acceleration, and drawn a function $a_X = f(a_Y)$. The measurements of instantaneous values of vibration acceleration were made with industrial accelerometers but vibration analyzer was made by authors.*

Streszczenie. *Artykuł przedstawia metodę oceny stanu technicznego łożysk bazującą na trajektorii xy drgań. Możliwość wykreślenia trajektorii uzyskuje się dzięki dwóm przetwornikom umieszczonym w osiach X i Y. Amplituda drgań w płaszczyźnie XY jest zawsze większa od wartości rejestrowanej dla każdej osi z osobna. Pomiar tylko jednej osi nie odzwierciedla maksymalnej amplitudy wibracji maszyny. Obraz dla łożyska nieuszkodzonego to okrąg o małej średnicy. Odstępstwo od tej zasady odpowiada konkretnemu uszkodzeniu łożyska. Praktyczne zastosowanie tej metody pokazano na przykładzie oceny łożysk o różnym stopniu zanieczyszczenia. Wyniki badań przedstawione w niniejszym artykule zostały uzyskane podczas badań silnika indukcyjnego 3-fazowy typu Sg112M4 P_N = 4 [kW]. Silnik do badań umieszczono na fundamencie sprężystym. Badania polegały na pomiarze v_e prędkości drgań (RMS) oraz rejestracji chwilowych wartości przyspieszenia drgań. Rejestracje wartości chwilowych przyspieszenia drgań zostały wykonane przy użyciu akcelerometrów przemysłowych, analizator wibracji został wykonany przez autorów* ***(Diagnostyka drganiowa węzłów łożyskowych w oparciu o hodograf xy)***

Keywords: electrical machine, motor protection, vibrations, bearings, measurement, diagnostic method.
Słowa kluczowe: maszyna elektryczna, ochrona silnika, drgania, łożyska, pomiary, metoda diagnostyczna.

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Introduction

In all rotating electrical machines, the main task of the bearings is concentric positioning of the rotor relative to the stator and allowing the rotary motion of the rotor, with a minimum of energy loss due to friction. Therefore, the bearings are very important part of the machine, which often fails.

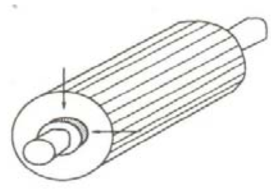
The symptoms of damaged bearings are:[6]

- noise,
- increased temperature around the bearing,
- increased level of vibrations.

Unusual sounds, which may occur during rotary motion of the defective bearing are easy to detect by an experienced operating personnel. If the work of bearing enables detection of its defect by the auscultation, in the most cases, the bearing is damaged and that qualifies the bearing for immediate replacement. Raised temperature of the bearing is the evidence of malfunction. This can cause an incorrect grease or incorrect quantity. This confirms the needs of measure the bearing temperature during operation of the machine. The temperature measurements can be done by installing temperature sensors, remote temperature measurement with laser equipment or infrared camera. Vibration of electrical machines increase in a natural way as bearing wear. Currently, the measurement of bearing vibration is widely used to assess its condition, and therefore diagnosis of rolling bearings is mainly based on the vibration diagnostics. Diagnosis is made by vibration measurements on the end shield, bearing pedestal or the machine frame in three axes: perpendicular to the shaft axis in the horizontal (X) and vertical (Y) direction and along the shaft axis (Z).

Vibration diagnosis

Currently, in each industrial plant, an electric drive that requires periodic vibration diagnostics can be found. Periodic testing of electrical machines are designed to prevent major accidents which generate high costs associated with the stopping of the machine (production costs) and repair costs. The aim of the bearings vibration diagnostic is to collect any information concerning the wear of these important elements. Depending on the aim of test and type of tested machines, it is very essential which waveform (displacements, velocities or accelerations) have to be recorded. The RMS value of the vibration velocity is dedicated for determination of overall assessment of the rotary machine. It reflects the destructive energy. However, if it is wanted to know the cause of the vibration it is necessary to conduct a detailed analysis of the vibration spectrum, which is transformation of the waveform in time domain to the frequency domain. Knowing the basic operating parameters of the machine and its construction, each component of vibration spectrum could be attributed to these elements or states.



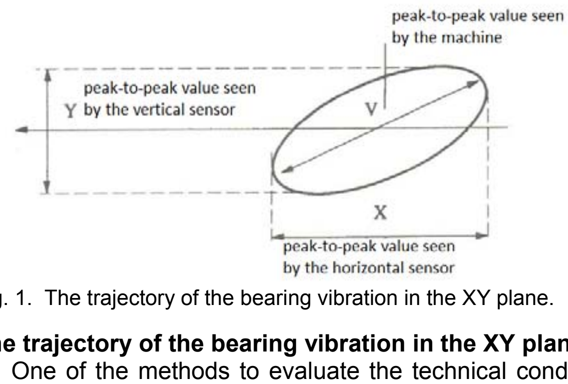


Fig. 1. The trajectory of the bearing vibration in the XY plane.

The trajectory of the bearing vibration in the XY plane

One of the methods to evaluate the technical condition of the rotating machines bearings based on the measurement of vibration is a method of the vibration trajectory analysis in the XY plane. Determination of vibration trajectory is made with two transducers placed in the X and Y axes, as shown in Figure 1 [3].

The amplitude of vibration in the XY plane is always greater than the value recorded for each axle separately. Measuring only one axis does not reflect the maximum amplitude of the vibration of the machine. Reference image of the perfectly smooth bearing is a small diameter circle drawn on the XY plane. Practical application of vibration trajectory in the XY plane method is shown in the example of assessment of bearings with varying degrees of lubricant contamination.

The objects of the research were electrical machines which has bearings with varying degrees of wear:

- intact (Table1, Fig.2.),
- with insufficient amount of grease (Table2, Fig.3.),
- with a slightly dirty grease (Table3, Fig.4.),

with a very dirty grease (Table4, Fig.5.).

Research consisted in measuring the vibration velocity v_e (RMS) and recording the instantaneous values of vibration acceleration, and drawn a function $a_Y = f(a_X)$. The measurements of instantaneous values of vibration acceleration were made with industrial accelerometers but vibration analyzer was made by authors. In order to avoid diagnostic signal distortion by digital processing, all results are based on the registration of instantaneous values of vibration acceleration.

The results of tests presented in this paper were obtained during the test of induction 3-phase motor type Sg112M4 with P_N = 4 [kW]. Motor was placed on elastic foundation. Vibration acceleration waveforms recorded at frequency of 100 kHz, taking into account the simultaneous sampling of signals in the x and y axes.

Undamaged bearing

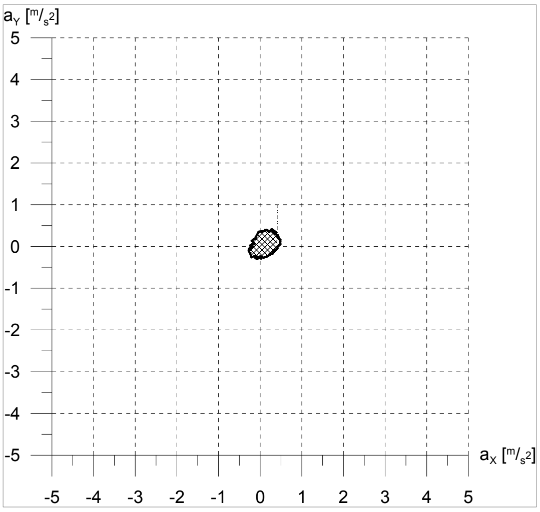
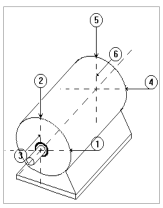


Fig. 2. The graph of $a_Y = f(a_X)$ function for measuring points X4, Y5.

Table 1. Vibration velocity measured on machine with undamaged bearing.

The measuring point	Vibration velocity v_e[mm/s]	
X1	2.34	
Y2	1.62	
Z3	1.95	
X4	1.45	
Y5	1.39	
Z6	1.51	

Bearing with a small amount of lubricant

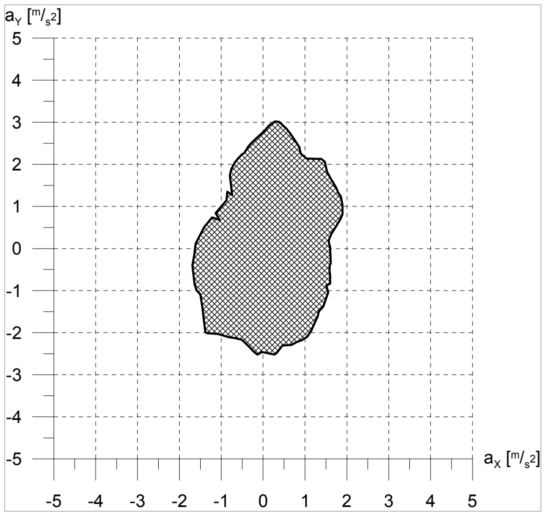
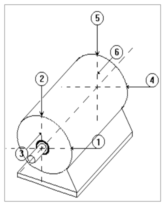


Fig. 3. The graph of $a_Y = f(a_X)$ function for measuring points X4, Y5.

Table 2. Vibration velocity measured on machine with a small amount of lubricant.

The measuring point	Vibration velocity v_e[mm/s]	
X1	2.19	
Y2	2.02	
Z3	1.26	
X4	1.55	
Y5	1.41	
Z6	1.38	

Bearing dirty in a small extent

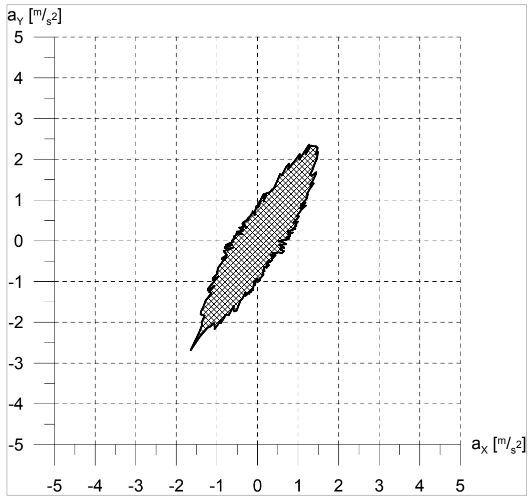
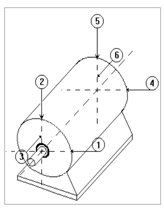


Fig. 4. The graph of $a_Y = f(a_X)$ function for measuring points X4, Y5.

Table 3. Vibration velocity measured on machine with bearing dirty in a small extent.

The measuring point	Vibration velocity v_e[mm/s]	
X1	2.14	
Y2	1.95	
Z3	1.11	
X4	1.55	
Y5	1.41	
Z6	1.16	

Bearing dirty in a large extent

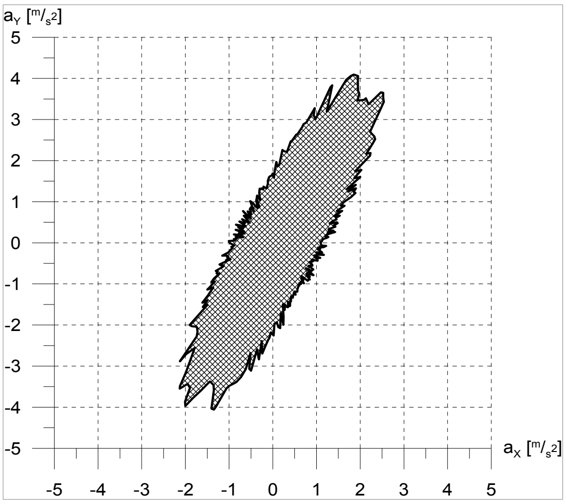
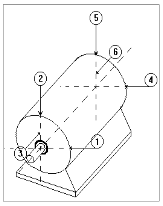


Fig. 5. The graph of a_Y = f (a_X) function for measuring points X4, Y5.

Table 4. Vibration velocity measured on machine with bearing dirty in a large extent.

The measuring point	Vibration velocity v_e[mm/s]	
X1	2.45	
Y2	2.21	
Z3	1.36	
X4	1.88	
Y5	1.46	
Z6	1.46	

Conclusions

According to the literature [1, 4, 5], results of research show that abnormal bearing work is reflected in the electric machine vibration. Its effects can be seen in the RMS value of vibration velocity, spectral analysis acceleration and as a function of: a_Y = f (a_X). The traditional measurement of RMS value of vibration velocity leads to the conclusion that there is a malfunction of the electrical machine. Sometimes, changes in vibration velocity are small and difficult to observe, and the bearing may already be damaged. This is shown in Table 5.

This article does not describe a new method. There are a number of scientific publications [2,3,7] that describes hodographs theme for the measurement of vibration. However, authors did not found any publication, that clearly describes the changes of trajectory XY with respect to the degradation of the bearing. The authors, basing on their own research conclude that it is possible in a relatively simple way to diagnose the technical condition of the bearings of electrical machines by defining the boundary of the resulting image. In the case of the bearing in very good technical condition the boundary is similar to a circle of small diameter, as shown in Figure 4. The deficit of lubricant increases diameter of the boundary and makes it irregular (Fig. 5). When the bearing is contaminated, the shape becomes an ellipse which axis ratio depends on the degree of contamination. This situation is illustrated in Figures 6 and 7. Note that the shape and the position of hodograph depends on imbalance of the rotor. The authors intend to research this issue in future.

Table 5 Vibration velocity measured on machine with varying degrees of bearing damage measured at points X4, Y5.

	v_X[mm/s]	v_Y[mm/s]
Undamaged bearing	1.45	1.39
Small amount of lubricant	1.55	1.41
Dirty in a small extent	1.55	1.41
Dirty in a large extent	1.88	1.46

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