

Vibration Diagnostics of Electrical Machines by means of Optoelectronic Sensors

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Abstract: The proposed method allows determining the level of wear of the bearings of electric machines by means of rotor radial displacement during operation. Measurement is effected by non-contact method and optoelectronic sensor which converts the rotor mechanical motion into electric signal. Received informational signal is recorded and processed by computer system. Based on the processed input signal it is possible by means of mathematical algorithm to calculate the amplitude of rotor angular vibration. Then the revolution and the inherent vibration frequency of the rotor are compared followed by estimation the level of bearings wear. This evaluation can be used to forecast the residual operation margin of the machine.

Keywords: vibration, measurement, electrical machines, diagnostic, rotor, optoelectronic sensors

I. Introduction

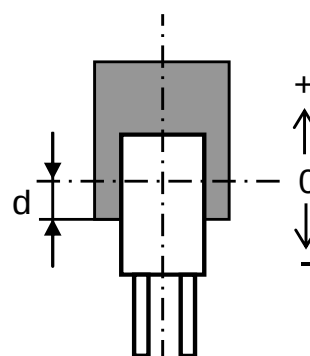
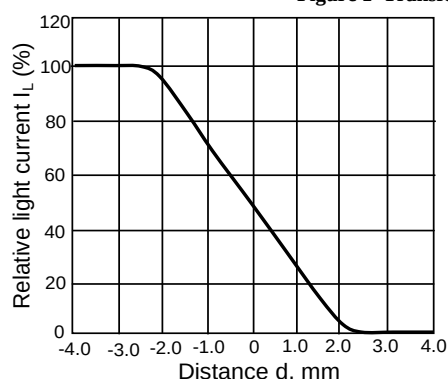
In various fields of industry in most cases electric drives are employed based on induction motors. One of the pressing problems nowadays appears to be reliability enhancement during their operation. The methods of vibration diagnostics are used as preventive maintenance to avoid failures. Piezoelectric accelerometers are usually used as primary transducers. They provide indirect information about the acceleration at the places where the bearings of the machine have been mounted but do not provide information about the absolute values of vibration amplitude. Another shortcoming of this type of sensors is that they cannot be mounted on mobile parts of electrical machines. In cases when there is relative vibration, i.e. electrical machine parts move towards each other, measurement data taken on the motor housing could be inaccurate. A method of contactless monitoring of the bearing clearances of electrical machines employing optoelectronic displacement sensors is described in this paper..

II. Optoelectronic sensors for measuring displacement

When measuring relative vibrations, displacement sensors are used, e.g. eddy-current sensors. They also have some deficiencies, for example: limited frequency band, they cannot operate in close proximity to one another, their readings depend on the type of metal (even on quality of steel), they cannot operate with non-conducting materials or with materials with thick non-metal coating. In this case as an alternative we propose a solution: these sensors to be substituted by optoelectronic sensors.

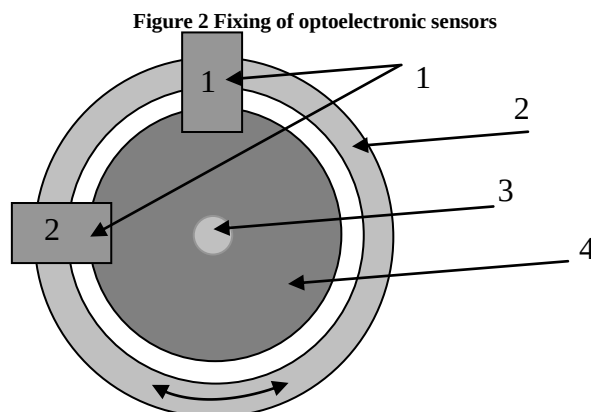
An optron with an air gap is used as a primary transducer[1]. Fig.1 shows a typical transfer characteristics of this class of optrons. With gradual closing of the optical channel, the collector current varies linearly within the -2mm to 2mm zone. If the closing element vibrates by a kinematic law, the collector current will be modulated in amplitude in the same way. The optron has been designed so that it does not transmit light onto the phototransistor.

Figure 1 Transfer characteristics of the optoelectronic sensor



The accuracy of conversion: displacement to collector current has been measured and it was higher than 5% of relative error, which is comparable with the accuracy of piezoelectric accelerometers. Fig. 2 shows

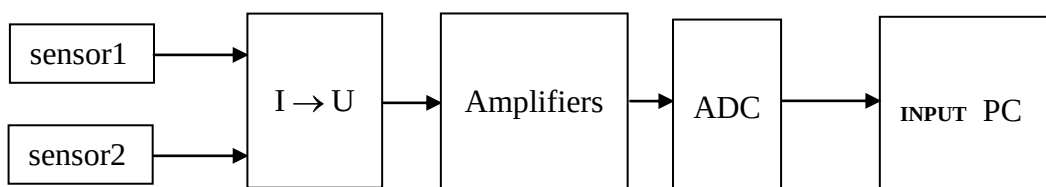
optoelectronic sensors 1, fixed on disk 2 at an angle of 90°. Measuring disk 4 made of non-transparent material, is placed on the rotor shaft.



Disk 2 and sensors 1 are fixed to the base on which the electrical machine is positioned so that the transfer of vibrations coming from the machine to the sensors is reduced to minimum. Disk 2 can rotate around its center so that the optoelectronic sensor can take measurements in all directions of vibrations of the measuring disk 4. The contactless measurement allows finding the direction in which the maximum value of vibrations is obtained by rotating disk 2. Before starting this experiment, optoelectronic sensors have been calibrated and a vibrating plate with vibration amplitude known in advance has been placed in the zone of measurement [2]. Calibration is necessary since the transmission coefficient of optoelectronic couples: light-emitting diode-phototransistor is temperature dependent and changes in the course of time due to aging of both active elements.

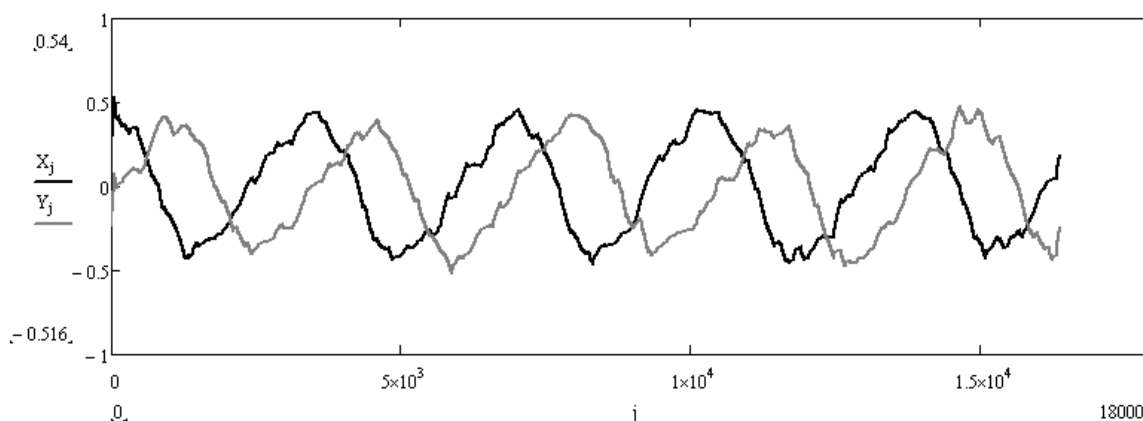
An electric block diagram is shown in Fig. 3. The photocurrents from the two optoelectronic sensors are converted into voltage owing to the linear relation: photocurrent-intensity of light flux. Presetting by a vibrating plate with known amplitude is performed by means of two amplifiers with variable amplification factor.

Figure 3 Block diagram



For analogue-to-digital conversion the computer sound card can be used, left and right channel, respectively. In this case the data obtained during the experiment are recorded in a file with *****.wav** extension. When a computer oscilloscope is employed for analogue-to-digital conversion, data are usually written in a text file. In this case, it is an advantage that the process can be observed immediately but data collected in this way are of small quantity. Fig. 4 shows part of the signals of both sensors recorded in format with **.wav** extension and opened by Mathcad software [3].

Figure 4 Signals from sensor 1 (Y) and sensor 2 (X)



Both signals have been normalized according to the preliminary calibration of the optoelectronic sensors and the noise has partially been deadened by direct and inverse wavelet transformation. Fig.5 shows the graphic

representation along X and Y, expressing the trajectory of motion of the rotor axis center. The relative motion of the rotor axis in relation to the motor housing is measured in μm along both axes. The result illustrated in Fig.5 has been obtained employing Mathcad software and the motor has $P_n=50\text{kW}$.

The specific trajectory described by the axis center of the motor being studied depends on the parameter deviations of both bearings and mostly at the side of coupling the machine to the mechanical load.

Figure 5 Trajectory described by the shaft central axis of a loaded electrical machine

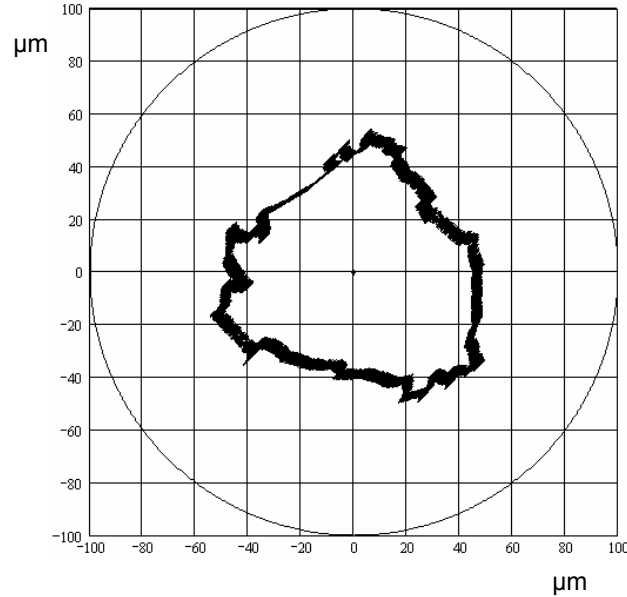
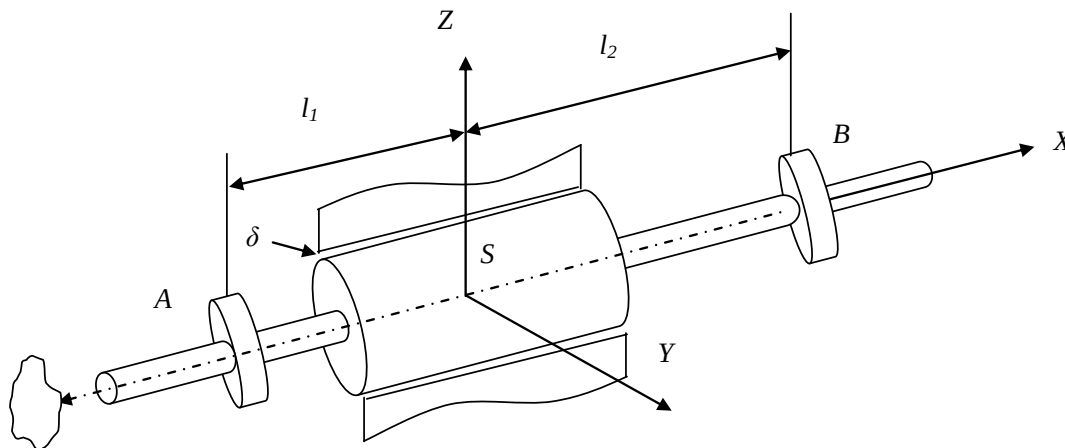


Fig. 6 shows a kinematic diagram of the rotor motion of the electrical machine. A and B point to the places where the bearings supporting the rotor axis are positioned, and S marks the mass center. The air gap between the rotor and stator is designated by δ .

Figure 6 Kinematic diagram of rotor motion



Displacement ΔS and angular deviation Ψ_S of the rotor mass center depending on the displacement of supporting points A and B on which the rotor bearings are positioned, is represented in Fig. 7. The clearances of the respective bearings are designated by ΔA and

ΔB , and their angular deviations by Ψ_A and Ψ_B . Considering the projections of the sides of quadrangle BSB_0S_0 , along the vertical and horizontal axes [4], the following equations can be written:

$$B_0S_0 + \Delta S \cos \Psi_S - BS \sin \theta - \Delta B \cos \Psi_B = 0 \quad (1)$$

$$\Delta B \sin \Psi_B - BS \cos \theta - \Delta S \sin \Psi_S = 0 \quad (2)$$

Taking into account the equality:

$$\frac{B_0 S_0}{S_0 A_0} = \frac{BS}{SA} = \frac{l_2}{l_1} \quad (3)$$

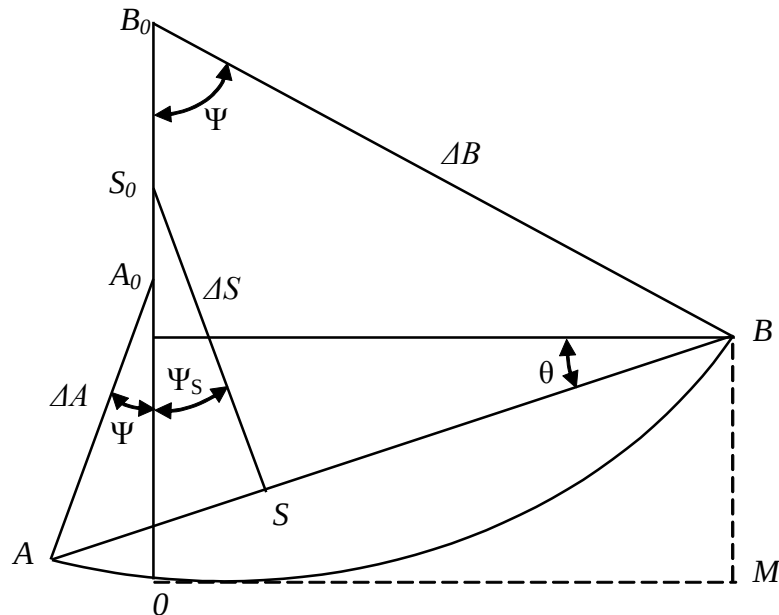
the size of displacement ΔS is determined:

$$\Delta S = \sqrt{A^2 + B^2 + 2AB \cos(\psi_B - \psi_A)} \quad (4)$$

where,

$$A = \Delta_A \frac{l_2}{l_1 + l_2}; B = \Delta_B \frac{l_1}{l_1 + l_2} \quad (5)$$

Figure 7 Displacement of the rotor center of gravity



The trajectory described by the rotor center and shown in Fig. 5 corresponds to the size of displacement ΔS , determined by (4). Thus ΔS can be compared to the size of air gap δ and in this way to predict the residual resource of normal operation of the electrical machine being studied.

III. Conclusions

The linear relation between the output signal and the degree of closing the optical channel of the optoelectronic sensor allows through suitable mathematical transformations and by applying the potentialities of Mathcad software, to propose new methods of vibration diagnostics for electrical machines. The methods have been experimented in laboratory conditions and make possible the diagnostics of electrical machines of medium and low power. This is possible because optoelectronic sensors do not influence each other when positioned at close proximity. The methods described allow comparison of the kinematic characteristics of rotor motion to the air gap size in order to reduce the risk of breakdowns.

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