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DIAGNOSIS OF THE OPERATIONAL STATUS OF ELECTROMECHANICAL DEVICES WITH AN OPTICAL FIBER VIBRATION SENSOR

In the presented paper a prototype of an optical fiber vibration sensor is described as a tool for diagnosis of machines and electromechanical devices. The application of the optical fiber as a sensor allowed a design of simple construction, where such advantages like electromagnetic noise immunity, galvanic isolation and spark-safety are crucial. Due to those advantages this sensor can be applied in places where installation of an electrical sensor is not possible. The results of preliminary tests and measurements performed on a high voltage transformer and electrical engine confirmed the effectiveness of the sensor.

Keywords: optoelectronics, microsystems, MEOMS, machine diagnostics, vibration measurement

1. INTRODUCTION

Monitoring of amplitude and frequency of machine's vibrations should be provided to allow evaluation of the condition of the machinery and predicting its malfunction or damage. Therefore one can plan a shutdown of the system at the most appropriate moment in order to perform the repair procedure and to minimize the costs of the whole operation. It should be emphasized that such approach allows avoiding serious damages and accidents as well as losses in machinery or in the whole system [1].

Utilization of optical fiber as the signal transmission medium and in some conditions also as a sensor, allows taking advantage of its properties such as: electromagnetic noise immunity, low signal loss, galvanic insulation, relatively low mass and dimensions [2, 3]. In the article we will present results of several tests which confirmed the possibility of machine's status evaluation with the presented device.

2. DESCRIPTION OF THE MEASUREMENT DEVICE

The design of the sensor and some achievements in research work were presented in several papers [4, 5, 6], where the development of the sensor and the whole measuring setup were described. The solution we present here is based on modulated optical coupling of two optical fibers. The mutual alignment of these fibers is modulated by the vibrations, thereby it can be used for detecting and measuring vibrations of a specific object (Figure 1).

Fig. 1. The idea of optical fiber vibration detection.

In order to achieve a precise optical alignment of optical fibers, a micromechanical structure with V-grooves was used. The microstructure was made of silicon using typical micromechanical processes. A view of the sensor during the assembly process is shown in Figure 2.

We have also designed and built a measuring module which, connected to the sensor with optical fibers, allows processing of signals. After initial tests, we could estimate the sensitivity of the measurement device [7]. The result of 21 mV/g was satisfying when referred to a commercial accelerometer ADXL311, which has a sensitivity of 174 mV/g (this unit is mostly used).

Fig. 2. A view of the assembly stands operational area through a magnifying glass (the dimension of the housing of the sensor: 42 mm × 23 mm × 13 mm).

The construction of the electronic measurement module allows sending the data to a personal computer, as well as working as a stand-alone device. All the crucial parameters of module configuration and measured value are shown on the front panel's LCD display. By changing the signal amplification one can adjust the detection sensitivity to specific conditions (device typical vibration amplitude).

The module can send averaged data of measured vibration amplitude to a PC (via RS232 with 115 kbaud transfer rate). The signal is converted with a sample rate of 15 s/s and a resolution of 12 bits. One can also acquire the signal with a high sampling rate (250 ks/s, 12 bits resolution) and save it in the nonvolatile memory of the module and upload it to the computer and analyze it afterwards. A simplified diagram of the device is shown in Figure 3.

Fig. 3. Block diagram of measurement module.

The optoelectronics module contains light emitting and detecting devices and all components necessary to provide appropriate powering and basic signal conversion. The signal conditioning module reduces signal bandwidth and allows to adjust the signal amplification, which determines the detector's sensitivity. This module is configured digitally by the configuration and control module, which, as a central unit, also controls the LCD display as well as the data conversion and acquisition module. The data conversion and acquisition module contains an analogue-digital converter and 1Mbit of NVRAM which can store 2 seconds of the sampled signal.

3. EXPERIMENTAL RESULTS

One of the application areas for the optical fiber vibration sensor can be monitoring of transformer operating status. To perform the test, a high voltage CWOM transformer was used (U=220/40000, I=4,55/0,025, S=1,0 kVA). Vibration as a function of the primary voltage was observed. No load was connected. The obtained results are presented in Figures 4 and 5.

Fig. 4. Oscilloscope traces with FFT analysis – the signals acquired during CWOM transformer operation: no voltage applied (left hand side) and 70V applied (right hand side).

Fig. 5. Oscilloscope traces with FFT analysis – the signals acquired during CWOM transformer operation: 100V applied (left hand side) and 140V applied (right hand side).

Fast Fourier Transformation (FFT) of the obtained signals reveals visible differences between vibrations for different primary voltage levels. The 50Hz component has a linear correlation with the input voltage, therefore one can easily diagnose this device using such a sensor. Due to dielectric properties of the sensor, the measurement procedure is safe even if a voltage appears on the chassis of the device.

Another object which we used for tests, was a motive unit of total power 9 kW consisting of devices listed in Table 1.

Table 1. Set of electrical machine parameters of the motive unit.

Motor SZIe 44a	Power generator PZOb 54a	Power generator PZBb 22b
P=5.5 kW	P=3.5 kW	P=0.4 kW
U=220 V/380 V	U=230 V	U=230 V
I=19.5/11.5 Δ/	I=15.2 A	I=1.74 A
cosφ=0.86	I_W=0.79 A	I_W=0.42 A
speed=1440 rpm	speed=1450 rpm	speed=1450 rpm

The SZIe 44a motor was powered properly and failure of one phase was simulated. The results are presented in Figure 6.

Fig. 6. Oscilloscope traces with FFT analysis – the signals acquired during electrical machine diagnostics: no operation situation (left hand side), appropriate powering (center) and asymmetrical powering (right hand side).

The presented signal traces and their FFT graphs show clearly the difference between proper work and a failure state of the motive unit. The increase in signal amplitude (from 34.8 to 23 mV) as well as new components in signal spectra appearance, allow recognition of these different states.

Another failure situation, which can occur in such devices, is displacement of rotor's gravity centre. It can lead to quick damage or destruction of the machinery, therefore it also should be considered as a source of potential danger for the personnel. The sources of this phenomenon can be events such as: wear of rotor, bearing, as well as gear boxes or clutches.

In order to simulate such failure, a special 35 mm holder was mounted on the rotor and different mass objects were mounted onto the holder (105, 167, 178 and 237 grams). The correlation between the unbalanced rotor work and the signals obtained with the measurement system was investigated. The results are shown in Figures 7 and 8.

Fig. 7. Oscilloscope traces with FFT analysis – the signals acquired during electrical machine diagnostics (different rotor center's of gravity displacement).

Fig. 8. Oscilloscope traces with FFT analysis – the signals acquired during electrical machine diagnostics (different rotor center's of gravity displacement).

The signals and the FFT analysis were shown in the order of increasing mass. The first signal was obtained without any additional mass, however some unbalance can be already seen. An increase of the additional mass caused changes in the vibration spectrum. The appearance of higher frequencies can be seen. Large forces acting on the rotor made the whole motive unit vibrating, therefore also low frequency harmonics appeared as well. The changes of the signal were clear and easy to resolve, which proved that the measuring device can be used for device state evaluation.

4. SUMMARY

The obtained results confirmed the possibility of machine's monitoring with the designed measurement device. The acquired signals allow evaluation of the condition of a machine or device. Moreover, optical fibers can guarantee safety of the maintenance and test crew, by full isolation from the object. Also the electromagnetic noise immunity of this sensor is an advantage.

The construction of the sensor is relatively simple but effective. The possibility of applying such solutions in increased-risk areas like a device under high voltage (generators or high voltage lines) as well explosion risk areas (mines) can be very attractive.

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