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# Fiber optics vibration sensor with selftest functionality

***Abstract**. Monitoring vibration level can provide a crucial information about condition of the electrical devices. In this work we describe the optical fiber, amplitude modulation -based vibration sensor scanning head combined with radio controlled vibration source powered with solar cell unit. This solution provides long-term ability to perform selftest feature. In this paper we provide the general description of implemented measurement system, with particular emphasis on the design of the scanning head. Also the preliminary test results are shown.*

***Streszczenie.** Monitorowanie drgań urządzenia może dostarczyć cennych informacji o stanie technicznym urządzeń elektrycznych. W niniejszej pracy opisano połączenie głowicy światłowodowego, amplitudowego, czujnika drgań, z kontrolowanym radiowo źródłem drgań zasilanym przez moduł fotowoltaiczny. To rozwiązanie pozwala na pracę urządzenia z możliwością realizacji auotestu. W pracy zawarto ogólny opis systemu pomiarowego ze szczególnym naciskiem na konstrukcję głowicy pomiarowej. Ponadto zaprezentowano wyniki wstępnych testów. (**Światłowodowy czujnik drań z funkcjonalnością autotestu**)*

**Keywords:** high voltage transmission network monitoring, vibration measurements, optical fiber sensors.
**Słowa kluczowe:** monitorowanie sieci przesyłowych wysokiego napięcia, pomiary drgań, czujniki światłowodowe.

## Introduction

Constant monitoring of the vibration level of electromechanical machines and devices is one of the essential sources of information about their condition. It also allows to predict the oncoming failure and enables preventing of sudden shutting down of major and essential energy transmission installations [1-3]. While both: vibration amplitude and spectra are analysed, one can point out specific patterns revealing significant deterioration of the machinery and immediate service need. Those patterns, while identified, can trigger repairing procedure.

However, it has to be underlined, that despite a common presence of very well established, standard piezoelectric sensors, one must keep in mind also the need of special type of monitoring systems, providing unique properties. While there are systems components at high voltage potential or exposed to strong magnetic fields, no electrical sensors are allowed, as both: safety and measurement quality can be seriously compromised. As the effective solution, one can utilize optical-fiber measurement heads. Their electromagnetic field immunity and dielectric properties enable measurement in such conditions without any functional disturbances. Recent development of optoelectronic devices opened a new areas of sensors implementation [4].

Among a variety of optical sensors, following major solutions are used: amplitude, interferometric [5], Bragg-grating (spectral analysis) [6,7] and also a significant group of MEOMS sensors [8-10]. Furthermore, also advanced concepts have been tested recently [11-13]. In terms of monitoring energy-distribution devices, also partial discharge was monitored using optical fiber acoustic sensor [14]. One has to keep in mind, that the piezoelectric sensors are concerned as the reference [15]. Concerning the optoelectronic solutions required in the implementation of such measurement systems, in particular the light sources and detectors properties, the amplitude-based sensors are

relatively easy to develop and provide reasonable price-performance ratio. Therefore we present approach to this particular concept, extended with the internal vibration source which provides the selftest feature, which may play important role, while the high-voltage transmission lines can't be disabled every time on needs to perform the verification of condition of scanning head itself. In this paper the small photovoltaic module provides sufficient energy necessary to charge internal battery of the module. Radio controlled vibration source can be activated remotely using 344 MHz bandwidth when necessary, with no physical contact to the device, as the operation safety is provided without compromise.

## Principles of the optical fiber amplitude vibration sensors

The simplified concept of the scanning head with amplitude modulation of transmitted light beam using freely moving cantilever made of optical fiber is shown in figure 1. This approach provides simplicity of the design, in particular in terms of the light source and the detector.

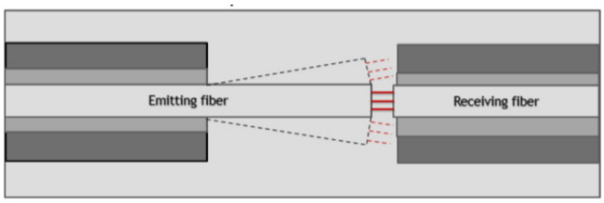


Fig.1. The idea of amplitude modulation-based optical fiber vibration sensor

However, as the cores of the multimode optical fibers vary in the range from 50 to 62,5 μm, very precise attaching/ positioning feature is desired. While we used silicon- etched microoptical structures providing desired fabrication accuracy and process repeatability [16], achieving approx. 7 dB signal's power loss between emitting and receiving fiber was possible.

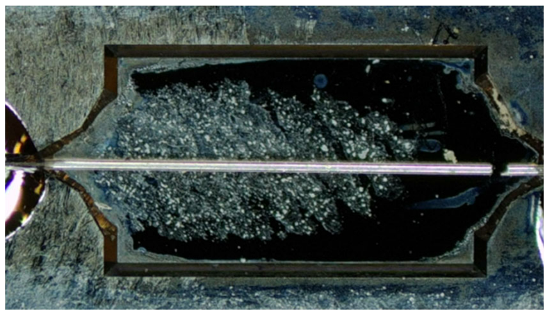

Fig.2. Assembled structure of optical fiber sensor. Emitting fiber (on the left) is directly forming the light beam into the receiving fiber (on the right).

As it can be seen, the vibration of the structure enable the light transmission modulation, therefore the detected signal is straightforward vibration related signal.

Having in mind that while in case of standard connector, optical coupling attenuation value may reach up to 1.5 dB, the outcome of implemented scanning heads meets our expectations.

As the vibrations occur and the emitting fiber is deflected appropriately 20 μm, the attenuation of the optical connection increases approx. 2 dB. Another 20 μm may increase the attenuation approx. 5 dB.

It also should be expressed, that normally, the length of freely moving opical fiber was designed to be in range of from 4 up to 7 mm, as it provides the detection frequency bandwidth from 17 to 5 kHz respectively. This solution covers the plateau detection range of the scanning head, enabling monitoring the vibration frequencies of majority of electrical machines. The view of assembled scanning head is shown in figure 2.

**Measurement setup description**

The general diagram revealing major components of developed system is presented in figure 3. Both: acquisition module and information panel are controlled by 32-bit microprocessors. Control panel can display measurement results graph, including minimum and maximum values obtained within last 24 hours, and in addition it can provide on-line reports as well as the data acquisition using non-volatile memory modules.

The acquisition module can work as stand-alone unit, while it can display the measurement results. It can't however provide the data storage features. The module consists both: the light source and detector, designed to work with 820 nm wavelength and ST- type optical fiber connectors (HFBR modules from Broadcom company). Implementation of standard connectors allows to utilize commercially available optical fiber cables, which are offered in large variety od length. This advantage makes the fabrication of the measurement system, and detection heads in particular, relatively easy, as the basic fabrication processes of the optical fiber connectors can be omitted.

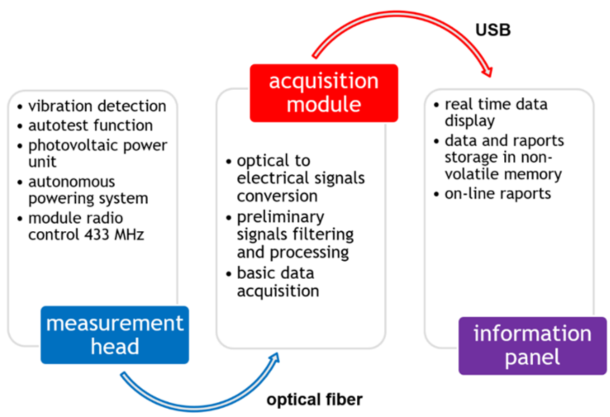


Fig.3. Block diagram showing the main components of measurement system and their functions

The scanning head, next to abovementioned optical fiber - based detection structure, consists of the radio-controlled DC motor with asymmetrically mounted vibration mass. This feature enables the performance tests of the measurement head, while no direct contact or access to the device is required at that time. This unique approach is necessary in order to verify if the response of the sensor is correct. This feature is essential in this particular group of sensors, while in case of the piezoresistive sensors no access limitation exists as no direct high voltage exposure is taken into account. Selftest feature provides three rotational speeds (excitation frequencies): 128 Hz, 144 Hz and 162 Hz, pulse mode and frequency sweep mode. This diversity enables various test protocols of the detection head. Presented device is also equipped with the solar cell unit, that provides charging the battery of the test module. Implemented feature can deliver enough energy to the test module, while there is natural or artificial light available within a reasonable time period. The limitations of the measurement head's size limited the power of the photovoltaic module. With its charging current of approx. 2 mA and output voltage 5 V, it can deliver approximately 10 mW, which is sufficient to acquire enough energy to perform 60 seconds tests every few days, while the internal LiPo battery of the device is capable to store 200 mAh.

The photography of the detection head is shown in figure 4. In order to provide its durability, the housing was made of stainless steel.

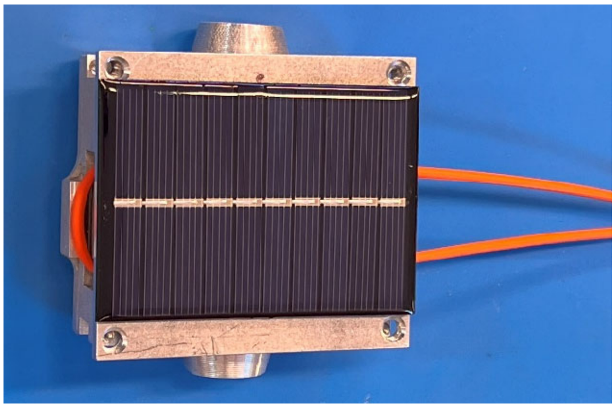

Fig.4. View of complete, detection head

**Test results**

Developed device was tested in several versions of the detection head, as various lengths of optical fiber were available. As the excitation source, the selftest motor, in frequency sweep mode was used. In order to confirm specific vibration frequencies detection correctness, additional sensor ADXL327 was used. Figure 5 shows: FFT spectra of both sensors, as well as the spectrogram of optical fiber sensor's response. Obtained results revealed that both sensors deliver fully coherent signals (basic frequency as well as the overtones). Also frequency sweeping mode provided the confirmation of accurate vibration detection (spectrogram).

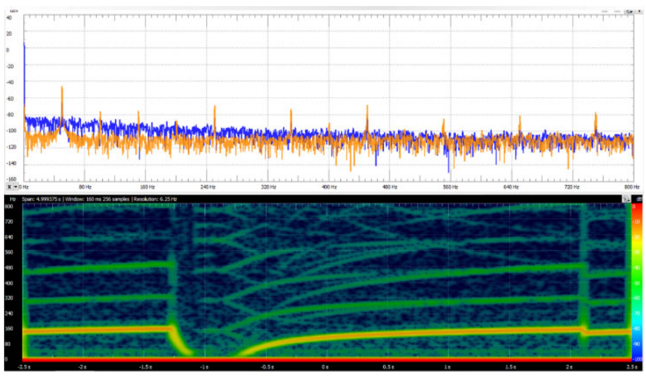

Fig.5. An example of a spectral analysis graph acquired during the test procedure

While the test procedure was performed, the rotation axis of the motor was adjusted both: parallelly and orthogonally to the axis of the optical fiber. It allowed to reveal much better detection sensitivity for the orthogonal alignment.

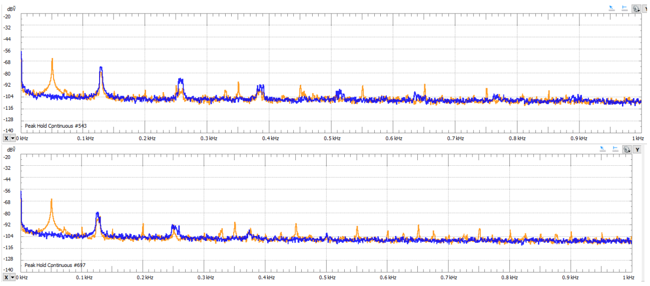

Fig.6. FFT graphs of acquired signals during the measurement head tests. Orthogonal alignment - top graph, parallel alignment – bottom graph. Yellow line – ADX327 signal, blue line – optical fiber signal.

This particular behaviour is very likely caused by the fact, that rotation of the mass on the motor rotor can cause circular movement of the transmitting optical fiber in respect to receiving fiber while parallel configuration is enabled. This, despite the response to the vibration excitation, causes limited light transmission modulation, therefore is harder to detect with optoelectronic device. As the result of the test, the orthogonal configuration was selected as the optimal for the selftest feature. The difference between orthogonal and parallel configuration is particularly visible in range of higher harmonic frequencies (figure 6). One also has to keep in mind, that it also can be noticed, due to the way the vibration of the fiber's structure causes the light modulation in the measurement head, causes the shift of the first harmonic frequency, and the rest as the result. This issue however can be easily resolved while the signals are processed by the microcontroller in the acquisition module.

**Summary and outlook**

Presented solution is an unique combination of optical fiber vibration sensor, radio controlled test module and photovoltaic powering unit. Such solution enables utilization of the sensor in the areas, where direct access on daily basis is impossible. Once the personnel is capable of verification of the measurement system without compromising the work safety rules, it can be installed in critical, high-voltage parts of the energy transmission system elements. On-board photovoltaic unit provides the energy necessary to enable selftest unit with certain time period.

Performed tests confirmed demanded signals detection properties, while additional sensor was used in order to perform the cross-reference verification. Available various test frequencies as well as the sweeping option can help in the distinguishing the response of the measurement system to test excitation from potential artifact signals.

Further tests of the measurement system are planned. It is expected that it will be assembled in one of the critical spots of the 50 MW electrical generator.

It is also planned to develop the data acquisition software in order to provide automatic verification of the acquired spectra while selftest unit is active. By refereeing obtained data do the reference signal or set of spectra peaks, the personnel will be effectively supported in decision-making processes, as one needs to operate with certain quantification protocols and follow specific criteria.

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