Optical Fiber and Integrated Optics Accelerometers for Real Time Vibration Monitoring in Harsh Environments: In-Lab and in-Field Characterization

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Introduction

The reliability of rotating machines such as electrical generator is critical to the overall reliability and operation of electrical power plants. The very high cost of these machines, makes it necessary to improve the lifetime of a wide set of currently installed hydrogenerators around the world and avoid costly maintenance [1]. Vibration monitoring is essential in maintenance and protection programs [2]. However, due to the harsh environment (high electromagnetic fields and high temperature) and the very low frequency spectrum of the vibrations, the above mentioned machines cannot be appropriately monitored by piezoelectric sensors. Several approaches of optical sensors have been already developed either in fiber optics [3], or combination of optical fiber with silicon microstructures [4] or in integrated optics [5], but because of technical or economic reasons, up to now, these sensors are not fully suited for the above-mentioned applications.

In this paper both optical fiber and integrated optics accelerometers developed in order to satisfy specifications required for these applications are presented. Their developments were a part of a European project dedicated to real time defect detection and predict forthcoming failures of a generator group in an electric power plant in Spain. In- laboratory and in-field tests are reported.

Sensor System Description

The systems are basically composed of a transducer head and of an analogue electronic unit linked by optical fibers. Both sensors are based in the same modulation technique but the transducers are developed in fiber optic technology for low frequency vibrations (shaft bearing), and in integrated optics technology for the medium frequency range (winding).

They detect vibration levels by means of a moving fiber or of an integrated waveguide in cantilever configuration that modulates the transmitted light intensity through two output fibers or two integrated waveguides, according to the acceleration of the place where are located. After the corresponding modelisations [7, 5], the optical sensor heads were fabricated. The optical path and the seismic mass of the integrated transducer were made of the same silica material using the integrated optics LETI's technology. Three silica layers with different phosphorus

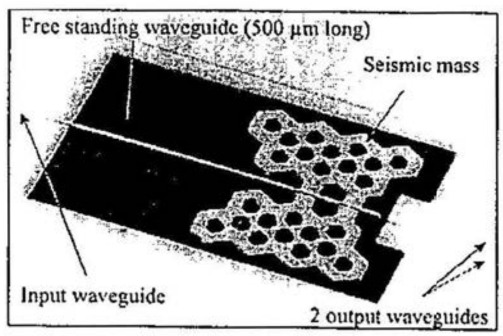


Figure 1. A SEM photograph of the optical transducer developed in integrated optic technology.

doping levels were used to define the waveguide structure. The device was fabricated in five main steps. The first step is the optical path fabrication. It is performed using PECVD and reactive ion etching technology. The second step is the mechanical structure fabrication.

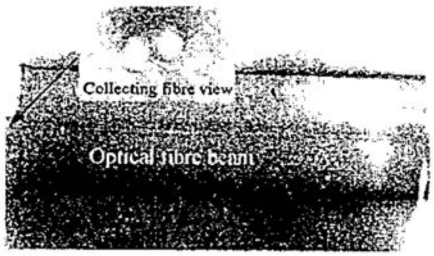


Fig.2.- Nomarski optical photograph of the optical fiber transducer head

This step is divided in two parts: RIE anisotropic etching of the three silica layers (about 15 microns thick) and anisotropicetching of silicon using an isotropic reactive ion etching. Groves for sturdy fiber connection were simultaneously etched in front of the input and output waveguides. A photograph of the sensitive part of the transducer (developed is shown in figure 1.

The main components of he optical fiber transducer head are the input optical fiber cantilever, the two receiving fibers and the housing, as is depicted in Fig. 2. The optical fiber transducer head has been fabricated using only insulated materials. The optical fibers (100/140 type) were positioned on an aluminum plate that had laser micromachined grooves suitably dimensioned and aligned, and they were led to their exact place with the help of a four-degree-of-freedom micropositioning system. They were fixed by means of a low shrinkage optical adhesive that meets U.S. Federal Specification Mil-A-3920. Apart from curing them with ultraviolet light, the optical heads were subject to temperature shocks in an *ACS* Hygros-15 climatic chamber, in order to reduce the infantile life period as much as possible.

The optoelectronic unit is the part of the sensor system that generates, receives and processes the optical signals occurring in the acceleration transduction. It communicates with the optical head by means of a fiber optic link so it can be located far away if the transducer operates in a harsh environment. The basic functions are: generation of the optical signal sent to the transducer, detection and pre-amplification of the return optical signals, differential processing, band-pass filtering, and conditioning of the output signal to its output scale. The light generation subsystem consists of a optical source and its driving electronics. An LED diode and a laser diode were chosen as the light sources for the optical fiber and the integrated optic sensor respectively.

Commercial low cost PIN photo-detectors, pre-amplifiers, processing, filter, and another electronic components were used for the implementation of the opto-electronic unit. Because of the differential nature of the processing carried out on the 2 optical intensities the output signal (voltage following the acceleration on the transducer) is compensated for environmental and other undesirable perturbations.

Fig. 3 . Photograph of one plug-in optoelectronic unit.

In figure 3, a view of one plugging optoelectronic module is shown. For its installation in the power plant, six optical fiber sensor heads for low frequency shaft-bearing and three integrated optics sensor heads for winding vibration monitoring were fabricated and their associated electronic boards, including their power supply, were integrated in a 19'' rack. A custom optical channel that meets the requirements of international specifications such as B56724 and VDE-0207 was built to link the 19'' rack with the optical distribution boxes at each turbine level, and to connect the sensor heads to these boxes.

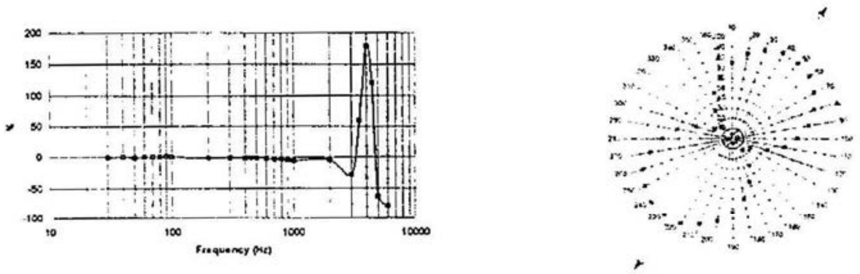


Fig. 4 Examples of in-lab Characterization: frequency response and transverse sensitivity of the integrated optic transducer

The system was fully tested and calibrated in the laboratory prior to its installation in the plant. The frequency response and the transverse sensitivity of the integrated sensor head are shown in figure 4.

Field Operation

The system was installed and fixed for its operation in the hydroelectric plant for more than one year, and, since that time, it has been working continuously. Figure 5 shows a view of accelerometer for winding monitoring.

The signal generation and detection unit for the optical sensors was located 40 meters away from the turbine, where the intensity of the electromagnetic field is no more significant.

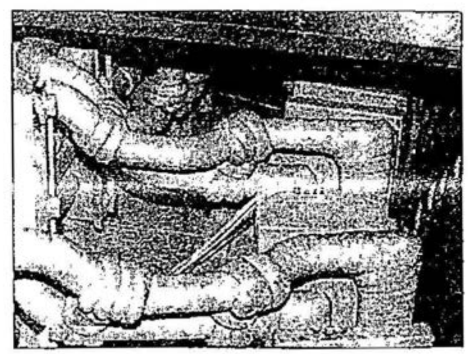
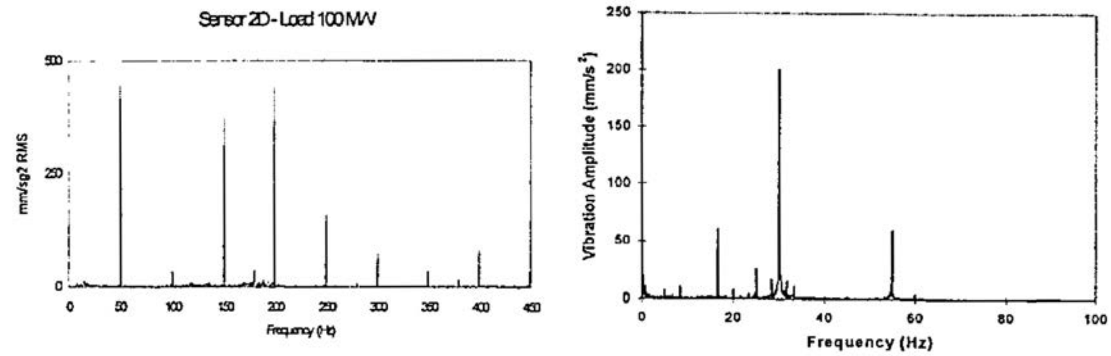


Fig.5. Integrated sensor head installed on the winding of a hydrogenerator.

Figs. 6a and 6b, show a picture of the vibration spectrum of both accelerometers in the same working generator machine conditions. Improvements of some parts of the optical accelerometers were done according with the field obtained data. At last the technical characteristics of the developed and validated sensor systems are summarized in table I.



Fig, 6. Winding (a) and shaft bearing (b) vibration spectral features obtained in one field test

Characteristics	Integrated optic	Fiber optic
Frequency range	30-2000 Hz	0.2-140 Hz
Frequency response	<±5%	<±5%
Amplitude range	0.5-600 m/s^2	0.025-10m/s^2
Amplitude linearity	<1%	0.04% (0...1G)
Resolution	0.5 m/s^2	0.02m/s^2
Transverse sensitivity	<5%	<4%

Table I. Summary of the final behaviors of both sensor systems developed.

Conclusions

An optical accelerometer system composed of six fiber low frequency, and three integrated optics medium frequency transducer heads has been fully developed and tested, both in-lab and in-field conditions with very good agreement with their specifications.

The long-term stability of the system was surveyed. The signals from the optical sensors were analyzed for a long period in which the generator group operated in actual production conditions, and no significant time drift has been found, what validates the system for real time field operation in a harsh environments.

At last, many potential similar applications could be considered such as pressure sensor, microphone.... for applications to electrical power nuclear or chemical plants.

Two patents related to this work are pending.

Acknowledgement

This work has been partly funded by the European Economic Community and the Spanish CICYT Commission through the Brite Euram 7289 and the TIC95-0631-c0401 projects respectively. The authors are grateful to the European partners. The industrial power is managed by Iberdrola (Spain).

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