Monitoring system with sensors networks: Architectural and functional design

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Abstract. This paper, a review of the considers the basis for constructing of the avionics faults monitoring system with hybrid electro-optic capacitive sensors for mechanical parameters measurement. The analysis of requirements for mechanical parameters of aircrafts, the change of which is characterized by mutual displacement of aircrafts structural elements was conducted. The use of hybrid fiber-optic sensors (HFOS) of aircraft mechanical parameters for constructing the measuring systems of avionics is proposed. It is shown that HFOS contain a fiber-optic for transmitting the measured information as well as traditional sensors as sensitive elements. This sensor combines the advantages of fiber optic and microelectronic technologies. Fiber optic it's key feature is that both the transmission data and power required for the embedded microelectronics are provided by optical fiber access. It is proposed to use capacitive sensors for HFOS, which provide high metrological characteristics and noise immunity.

1. Introduction

Along with the devices for direct crew information issuance (indicators of speed, altitude, fuel pressure, oil, etc.), a range of measuring transducers is used on board of the aircraft to obtain timely and accurate information about the processes taking place on board the aircraft. One way of obtaining measurement information is to use on-board digital measurement devices of certain parameters in the form of single blocks, each of which combines all the functional links from the measuring transducer with corresponding sensitive element to standardized output bus, through which the digital code corresponding to the measured value, is transmitted for further use - so-called "sensors with digital output" (SWDO). The information obtained from the sensors is used as input data for information measurement systems, or in automatic control systems and registration systems for flight conditions parameters.

Increasing the accuracy of measurement and the number of physical quantities that need to be monitored on board of the aircraft, the development and improvement of control objects (e.g. power plants), the growth of the dynamic characteristics of aircraft, the increase of safety requirements, etc., demand the development of new and improved existing SWDO that would meet the requirements for on-board SWDO. These requirements include the following: low energy consumption by primary measuring transducers; insignificant mass and dimensions; long service life; single calibration characteristic; the option of checking the efficiency without reinstallation from the aircraft; insignificant or completely lacking vulnerability to the action of powerful sources of electrical and magnetic impediments. The priority requirement is the complete unification of the sensors, that is, the possibility of constructing a SWDO of many non-electric quantities for different ranges of input parameters variation based on a single principle of operation and preferably a design that will dramatically simplify and cheapen the creation, manufacturing, adjustment, verification and operation of sensors.

Requirements for damage and error resistance of the sensors and communication lines demand the application of new methods and tools in the design and manufacturing process. These requirements are meet the hybrid fiber-optic sensors (HFOS). In this type of the sensor for data transmission and power delivery, fiber optic is used [1–3]. As primary sensors it is advisable to use specialized capacitive sensors, which allows to obtain fundamentally linear transmission characteristics. They have high precision, resolution, stability and error immunity. Achievement of such characteristics became possible due to successes in the field of precision measuring converters construction, which can be used for measuring small informative capacities against the background of large non-informative parasitic capacities [4-9].

Capacitive sensors are not influenced by electromagnetic, magnetic fields and temperature of grounded surface. Capacitive sensors are commonly used for reading the dielectric characteristics of materials – during checking the composite materials in aviation industry [10-12] or for measuring different kind of non-electrical quantities, such as geometrical dimensions of subjects, displacement and vibration of grounded surfaces, position of object, pressure, force and others mechanical parameters of aerospace equipment. Obtained information from sensors as SWDO can be used for measuring systems, or as information for the telemetry control and registration systems of flight mode parameters.

In this paper, we have described principles of developed HFOS of aircraft mechanical parameters controls for aircraft faults monitoring system. We also introduced the concept of hybrid HFOS that includes optical technologies for data transmission, and a photovoltaic energy converter for efficient power delivery to the capacitive primary sensor.

In the Department of Electrical and Magnetic Measurements of the Institute of Electrodynamics of the National Academy of Sciences of Ukraine, in recent years, meters have been created for distances to a grounded surface with a specified system of electrodes of various applications [13, 14]. Another section of your paper.

2. Architecture of Control System With HFOS

The design of electric machines faults diagnostic system incorporates a wide range of mechanical sensors to control many technological parameters. However, in practice, during operation of the machine, external influences (electromagnetic fields, temperature, etc.) act on the measuring equipment. To reduce the effect of the listed external influences on the operation of sensors and systems of technical diagnostics, fiber-optic and other optical-electronic components are used in these structures [15, 16]. In this case, use of fiber-optic and other optical-electronic components in the control system with HFOS in the structure of technical diagnostic systems gives the latter qualitatively new properties, primarily due to the high level of galvanic isolation and isolation, using traditional sensing elements that are standardized or easily exposed certification, as well as the use of control system with HFOS avoids the difficulties associated with compensating for the action of vibrational accelerations in a wide range of frequencies and vibrations, as well as the effects associated with birefringence [17] in the fiber of the sensing element.

This configuration for measuring systems has been successfully used to implement a system for technical diagnostics of wind turbine blades with a capacity of 1.5MW [18]. For systems to ensure continuous monitoring of power losses in overhead power lines, the use of optoelectronic measuring transducers, which provides the required level of noise immunity to powerful magnetic fields of the monitored object[19]. System for monitoring the condition of hydrogenerators, developed by the Brazilian hydropower company Electronorte together with the Brazilian Center for Research and

Development in Telecommunication Systems Centro de Pesquisa e Desenvolvimento em Telecomunicacoes is based on fiber-optic sensors [20].

Embodiments implementing structures using HFOS composed information measuring technical diagnostics channels powerful electrical system shown in Figure 1.

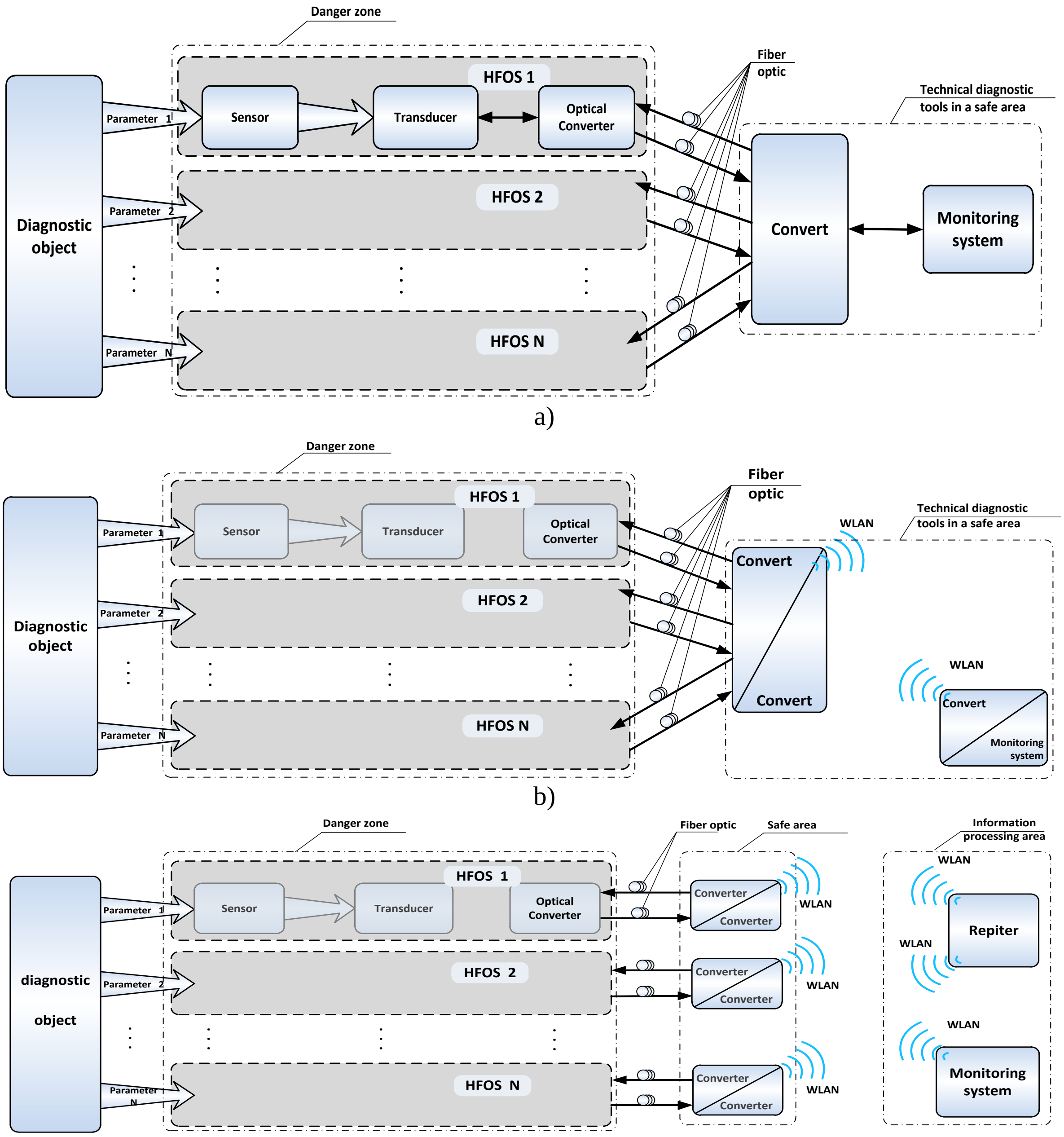

Figure 1. The use of hybrid fiber-optic meters in the structure of technical diagnostic systems for powerful electrical equipment with: a) use of a wire link between system components and the diagnostic object; b) the use of wireless communication with the location of the means of treatment at a short distance from the object of diagnosis; c) the use of wireless communication and the location of the means of processing at a considerable distance from the object of diagnosis

In figure 1.a shows the option of using wireless communication (for example: WLAN) when transmitting data from the monitoring system to the technical diagnostic system. The scheme additionally uses WLAN - a wireless local area network built using Wi-Fi or WiMax technology and PAC - code-converter.

In this case, voltage-modulated output signal from the hybrid fiber-optic meter sensor is converted into a modulated optical signal, which is then transmitted from a region with high electromagnetic potential (Zone of control or danger zone of mechanical parameters, Figure 1) through a fiber-optic channel to a region with low electromagnetic potential (Safe Zone, Figure 1) for further secondary processing in the control unit and registration of information. The information on the controlled mechanical control and diagnostic parameters from the means of secondary processing, located in the control unit and registration of information is transmitted to the technical diagnostic system, located in the information processing area (Figure 1).

The structure in Figure 2 contains a sensitive element, such as a primary measuring transducer, a microcontroller secondary measuring transducer of physical quantity into digital code with appropriate software and mathematical software, an optical interface with a light-code / code-light converter and a power supply.

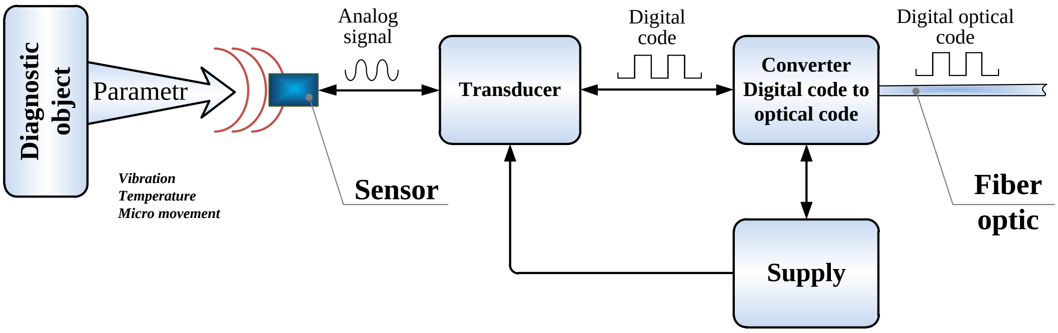

Figure 2. Structure of hybrid fiber-optic sensors

The hybrid fiber-optic converter of mechanical defects parameters works as follows. Sensor - converts the value *d* (micro-movement of structural nodes of the controlled node) in the value of capacity *C*. Capacitive C sensors made in the shape of flat capacitor geometry do have high values of sensitivity. In this case, the electrical C capacitance sensor depends on the size of the air gap d and can be written as [13, 21, 22]:

$$C=f(d) \quad (1)$$

The distance *d* in equations (1) is the distance between the electrodes of the capacitance sensor.

Theoretical determination of response characteristic of the sensitive elements of hybrid fiber-optic sensors for metering air gap defects is detail described in works [11, 13, 22]. Then the value of the capacity is converted into the corresponding digital code using Transducer. Transducer includes a capacitor-code converter, a microcontroller and the corresponding software and mathematical software designed to control the operation of the capacitor-code converter and interaction with the subsystem of the diagnostic system. The power supply of the sensor can be summed up by the ways described in [3, 23-29].

The information on the controlled mechanical control and diagnostic parameters from the means of secondary processing, located in the control unit and registration of information is transmitted to the technical diagnostic system, located in the information processing area (Figure 1).

In this case, a fiber-optic channel is used as a backbone, which allows to achieve high noise immunity of the meter, and as a communication line between the information-measuring channel and the microcontroller module, standard shielded twisted pairs are used to organize the optimal cost and metrological characteristics network of the measuring complex on control of mechanical parameters of object of diagnosing.

To ensure the operation of the system it is necessary to develop special software and hardware, including: user interface, control module and data processing module. Modules of software and hardware are designed to ensure the interaction of the data acquisition device, sensors and data processing module of the technical diagnostics system, organization of information flows in the system, implementation of data processing algorithms, display of the obtained results.

Figure 1.c shows a variant of using wireless communication in the case of the location of the output optical interface hydride fiber-optic meter of mechanical defects in the area with a safe level of electromagnetic and other radiation. This area may be the outer part of the stator of the turbogenerator or hydrogenerator, where conditions are provided for the transmission of information using wireless communication. A feature of this scheme is the ability to place the processing means at a considerable distance from the object of diagnosis.

The transmission of measuring information in the above structures is digital with the help of code-pulse modulation. In this case, when constructing each hydride fiber-optic meter for the parameters of mechanical defects, separate measuring channels are used, each with its own analog-to-digital converter contained in the secondary measuring converter. The integration of the hydride fiber-optic meter of mechanical defects into a single network is carried out using a digital interface that forms a local distributed network.

Distributed networks, in turn, in accordance with the IEEE-802 standard, are structurally divided into switched (IEEE-802.3), with a marker ring (IEEE-802.5) and with a marker bus (IEEE-802.4).

Each of these structures of the network organization has its advantages and disadvantages, which are described in detail in [30, 31].

For switched networks, the main advantage is the operation at significant distances between the hydride fiber-optic meter of mechanical defects and the microcontroller, and the main disadvantage is the low speed of the survey, due to the number of meters (K1 ... Km) and channel bandwidth.

For networks with a marker ring, the speed and the possibility of simultaneous polling of many meters is an advantage over the previous topology. However, the lower density of measuring channels and the complexity of the implementation of a significant number of meters is their significant disadvantage.

The advantage of networks with a marker bus, compared to switched, is the ability to increase the number of meters without significant losses in speed and bandwidth of data transmission.

Given the advantages and disadvantages of each of the structures according to the IEEE-802 standard for the construction of an economical information and measurement system and its easy scaling, it is advisable to use a switched network and a marker bus. In the proposed functional structure, each of the hydride fiber-optic meters included in the network has its own unique number (marker), connected to ensure cost-effectiveness of construction to a digital switch. Digital switches K1 ... Km are connected to a microcontroller, which performs the functions of pre-processing of digital signals and transmitting them to the monitoring system, i.e. formation of data packets with their information required by the technical diagnostic system, polling hydride fiber-optic meter and mechanical defects. Receiving measurement information from them, as well as transmission of control signals from the monitoring system to each of the hybrid fiber-optic meter parameters of mechanical defects.

3. Practical realization

The theoretical results obtained were used to create an experimental sample of HFOS. The result of the experimental studies of the primary capacitive sensor for its HFOS detail described in the [8] with the described principle of their use in [2]. All the top-level software for prototype developed in the LabVIEW [32].

The result of the experimental studies of the HFOS detail described in the next works [2, 33-36] without a description of the construction structure and the principles of its work in the fault diagnostic system structure.

Figure 3. Experimental research of the HFOS with measuring and data analysis system:
1 – sensor with measuring transducer; 2,4 – transducer electrical digital code to optical digital code and optical digital code to electrical digital code with digital controller; 3 – optical fiber; 5 – operation control systems of control mechanical parameters of the aircraft unit.

Conclusion

In this paper present, the electro-optic capacitive mechanical sensors for aircraft fault monitoring system. Hybrid capacitive sensor has few benefits of fiber optic and microelectronic technologies. Hybrid sensor has specifically designed as sensor for electric machines monitoring application. The use fiber optic for data transmission is able to provide simple and economic solutions for monitoring, control and metering problems which are immune to electromagnetic interference, have low thermal and mechanical inertia, electrical noise, corrosive, explosive, high-voltage, high-current or high-temperature environment.

The purposed architectures hybrid sensor can be easily adapted for measurement of various mechanical parameters of control aircraft equipment.

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