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Research paper

Creation of an Integrated System for Monitoring the Technical Condition of High-Quality Helicopter Units based on Fiber-Optic Technology

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Abstract

This article discusses the problems of creating an integrated system for monitoring the technical condition of highly responsible helicopter units, and analyzed options for its creation. Fiber-optical technology is considered as a technology, on the basis of which it is possible to build an integrated system, since this technology makes it possible to measure various physical parameters such as vibration, deformation, temperature, acoustic emission and other parameters, and due to the miniature dimensions of the fiber-optic light guide. It can be built into the PCM design, which is a relevant factor due to the growth use of PCM in the design and manufacture of helicopters. The results of bench and flight tests of helicopter pilot and rotor blades with fasteners using fiber optic deformation sensors based on a Bragg fiber grille demonstrate the fundamental possibility of creating a system for monitoring the technical condition of helicopter rotors using fiber optic sensors .Also, there are examples of creating other elements of an integrated monitoring system based on the use of fiber-optic technology, such as a system for signaling the breakdown of air flow and flutter on the helicopter rotor blades, a system for measuring the weight and alignment of helicopter cargo and a system for monitoring the technical condition of the airframe.

Keywords: *Helicopter, HUMS, FBG, Fabry-peroit, Fiber-optic monitoring system, Rotor blade, Vibro-monitoring, Diagnostic, Composite material, Damage, Weight balance control, Acoustic emission.*

1. Introduction

At present, the main components of the aircraft are operated at a designated resource with a predetermined service interval, providing basically only a visual inspection. In this case, the same resource is assigned to the entire fleet of machines of the same type, which does not imply an individual approach to the maintenance of equipment. This approach to operation does not always allow timely detection of pre-failure states of the aircraft associated with the appearance of damage, including in hard-to-reach places of structures, which often leads to an unexpected failure (breakdown) of the entire unit. Moreover, due to the increasing requirements for flight safety and service, it becomes extremely necessary for the developer and manufacturer of aviation equipment to timely obtain objective information about the technical condition of the main units throughout the fleet, in order to reduce financial costs and better planning repair work with the supply accessories. In addition, the use for polymer composite materials (PCM) of similar methods and approaches to operation as for metals is impossible with regard to ensuring the required safety due to the massive use of PCM in aircraft engineering designs (not less than 60% for the Ka-62 helicopter, more than 30% for MS-21). This factor is primarily associated with a fundamentally different nature of the destruction and the formation of damage in the construction of PCM, rather than in metal. Thus, the most characteristic damage to the PCM is the internal delamination caused by the impact, which in turn is not detected by an external inspection of the equipment.

In the aggregate, to create a competitive, safe aviation equipment, it is necessary to have in the composition of the aircraft means of automatic objective monitoring of the technical condition of the units, timely warning the pilot and the operator of potential malfunctions and issuing recommendations for further maintenance of the equipment. In particular, HUMS (Health and Usage Monitoring Systems) technology for helicopters has existed and has been developing for more than 20 years, allowing to provide continuous monitoring of the technical condition of individual helicopter units. One of the representatives of this technology is the T-HUMS system, the developer of RSL, Israel, which is installed on helicopters such as AH-64 and CH-53, and is responsible for monitoring the operation of the engine, transmission, gearboxes, balancing and coaxial screws. As a rule, such systems are based on the principle of vibration monitoring, which allows to evaluate changes in the amplitude-frequency spectrum of moving elements of helicopter units, without the possibility of detecting hidden mechanical damage in such structures as steering and main rotor blades with their attachment elements and elements of a helicopter airframe.

To detect mechanical damage in highly responsible and heavily loaded structures, fundamentally different monitoring tools are needed to ensure maximum controlled coverage, which is relevant for extended PCM structures (airframe, rotor blades). One of the variants of such monitoring tools is the acoustic emission control method in conjunction with the measurement of deformations in structures [5, 6].

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This article discusses fiber-optic technology, as one of the possible basic technologies, on the basis of which a comprehensive system for monitoring the technical condition of all highly responsible helicopter units can be created.

2. Comprehensive system for monitoring the technical condition of high-responsive helicopter units

2.1 Physical Principle of Base Technology

Achievements in the telecommunications industry are associated primarily with the rapid development of fiber-optic technology, which includes the development of new types of optoelectronic devices, differing in their small weight and size characteristics. In addition, at the present time, using a fiber-optic light guide, it is already possible to transmit not only information signals, but also to measure various physical quantities. This is achieved due to the presence of various physical phenomena during the passage of light inside fiberglass, such as the dispersion of Mandel'shtam-Brillouin, Raman and Relley, the appearance of interference patterns due to the application of periodic structures with different refractive index inside the fiber [9]. A fiber Bragg grating (FBG), which is a periodic structure inside an optical fiber, can be used to measure the deformation and temperature of an external object [1, pp.5-8]. To measure parameters such as vibration and acoustic emission in order to detect damage such as cracks and external influences on an impact type structure, it is possible to use fiber optic interferometric sensors, for example, based on a Fabry-Perot resonator [2, Section 2.4]. The Fabry-Perot resonator (or the Fabry-Perot interferometer) is a section of optical fiber with a length of 7–10 mm with mirrors applied on both sides with different reflectivity (Figure 1). The principle of operation is based on the following effect: when optical radiation passes through the optical fiber, light from the mirror No. 1 partially reflects the light in the opposite direction and hits the photodetector. The remaining part of the optical radiation, passing the length of the path from the mirror # 1 to the mirror # 2, is reflected from the latter and also falls on the same photodetector. As a result, an interference signal is recorded using a photodetector device, depending on the optical path length between mirror # 1 and mirror # 2, which in turn depends on external influences, including acoustic, on the sensitive part of the optical fiber.

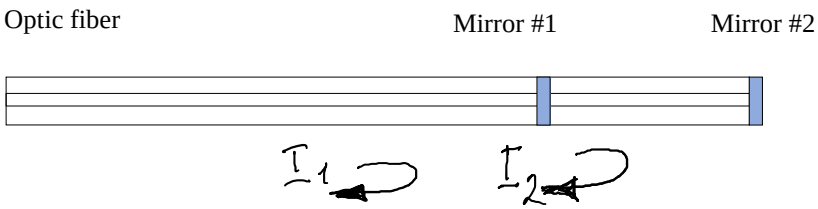


Figure 1: Fiber Optic Sensor Fabry-Perot

Based on the physical principles described above, it becomes possible to create a network of sensitive fiber sensors capable of measuring various quantities, such as temperature, vibration, deformation, acoustic emission, and others. Moreover, due to the miniature size of sensitive fiber-optic sensors (optical fiber diameter is 125 μm), the most effective solution for the installation of sensors is their integration into the PCM in the manufacture of the design of helicopter technology [3]. The effectiveness of the solution for the integration of fiber-optic sensors in the construction of PCM is due to the increased reliability of the built-in sensors by protecting the structure from external mechanical damage. Also, the good adhesion of the PCM binder to fiberglass is an additional factor in favor of the integration of fiber-optic sensors in the construction of PCM [7].

Thus, the creation of an integrated system for monitoring the technical condition of highly responsible helicopter units is reduced to the creation of PCM structures with fiber-optic sensors integrated at the production stage, which are analogous to the human nervous system (Figure 2).

Also, apart from a wide variety of physical principles that allow measuring various parameters using a fiber-optic light guide, there are also various schemes for registering an optical signal from sensors. Thus, a scheme with a broadband optical light source and a spectrum analyzer can be used to work with FBGs [1, Section 3.2]. Another way to record signals with FBG is a circuit using a tunable optical laser [10].

To control the technical condition of the blades of the steering and rotor helicopters with their fastening elements, it is necessary to solve the problem of removing useful signal from fiber-optic sensors mounted on rotating elements of the main and tail rotors. One of the solutions to this problem is to transfer data from sensors via a radio channel, for example, via Wi-fi. This approach is currently used during experimental flight tests of an Agusta-type helicopter in order to control the vibrations of the rotating elements of a helicopter [4]. In the case of data transmission from sensors via radio, it is necessary to have a miniature secondary converter from sensors installed as close as possible to the axis of rotation of the screw to reduce the centrifugal force acting on the device.

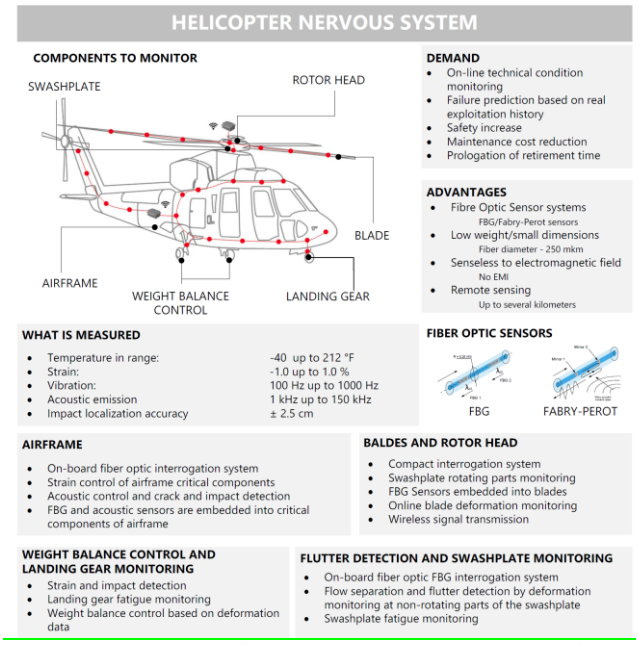


Figure 2: Integrated system for monitoring the technical condition of highly responsive helicopter units based on fiber-optic technology

2.2. Control of the state of the composite blades of the steering and rotor with their fastening elements

The second way to solve the problem of retrieving information from sensors from rotating elements of a helicopter rotor is to use special connectors with rotor and stator parts [8]. In this case, essential revisions of the rotating part of the propeller are necessary for their installation on the helicopter.

Based on the information described above, the most optimal scheme for building a system for monitoring the technical condition of the blades of the steering and rotor blades of a helicopter with their attachment elements is a circuit using a miniature recorder (secondary transducer). It is installed on the hub of the helicopter rotor, connected to fiber-optic strain and acoustic emission sensors installed on controlled rotating elements of the structure (or integrated inside the PCM) and transmitting the recorded data from the fiber-optic sensors to the onboard computer. At the same time, the creation of a miniature recorder for working with fiber-optic strain and acoustic emission sensors is possible using a registration circuit using a semiconductor laser source of optical radiation VCSEL [11].

2.3. Bench and flight tests of the monitoring system of the technical condition of the composite blades of the helmsman's steering and rotor propellers with their fastening elements

Experimental samples of the Ka-62 type helicopter rotor blades and the main rotor of the advanced laboratory of a high-speed helicopter (AL HSH) [12] with integrated fiber-optic strain sensors based on FBG and acoustic emission based on Fabry-Perot interferometers (Figure 3) were manufactured at the enterprise of the JSC "Helicopters of Russia" (JSC "Kamov" and JSC "MVZ named after ML Mil") to assess the possibility of creating a monitoring system for the technical condition of the composite blades of the helicopter's steering and rotor screws with elements of their attachment based on the use of fiber-optic strain and acoustic emission sensors. At the same time, more than 50 fiber-optic sensors were integrated into the rotor blade of the AL HSH.



Figure 3: Ka-62 type tail rotor blade with integrated fiber-optic sensors for static testing.

To assess the performance of embedded fiber-optic sensors, bench static and cyclic tests of samples of steering and main rotor blades were conducted, as well as flight tests developed by the company IRT Research and Development Company, Moscow, of a system for monitoring the technical condition of fastening elements (levers) Screw AL HSH. The system included: fiber-optic strain sensors glued on the surface of the blade turning levers; a miniature recorder (secondary converter) and on-board computer (Figures 6.7). Typical test results are shown in the form of graphs in Figures 4 and 5. Wi-fi was used as a method for transmitting data from fiber-optic sensors. At the same time, the electric power supply of the miniature registrar came from the accumulator unit installed in the immediate vicinity of the registrar unit. The purpose of these tests was to assess the fundamental possibility of removing data from fiber-optic sensors from rotating elements in actual operating conditions of the helicopter and to assess the metrological characteristics and durability parameters of the fiber-optic sensors embedded in the samples of composite blades of the carrier and steering screws.

According to the results of bench and flight tests, the following conclusions can be made:

1) The durability of fiber-optic sensors embedded in the construction of the PCM is comparable to the resource of the design itself and reaches more than 60 million loading cycles.

2) The error in measuring strain using fiber-optic sensors is not more than 5% in comparison with electrical strain gauges.

3) During the flight, it is possible to record data from fiber-optic sensors from the rotating elements of the helicopter rotor and transfer them to an onboard computer for subsequent analysis.

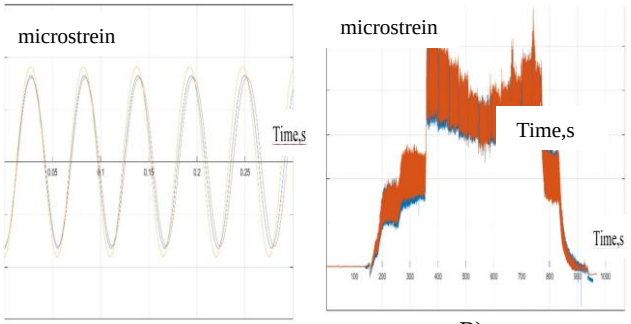


Figure 4: A) Graph of changes in deformations, measured using fiber-optic sensors embedded in the rotor blade when conducting bench cyclic tests, B) Graph of changes in the deformations of the arm turning the blade during the flight of the AL HSH, measured using fiber-optic sensors glued on the surface of the part

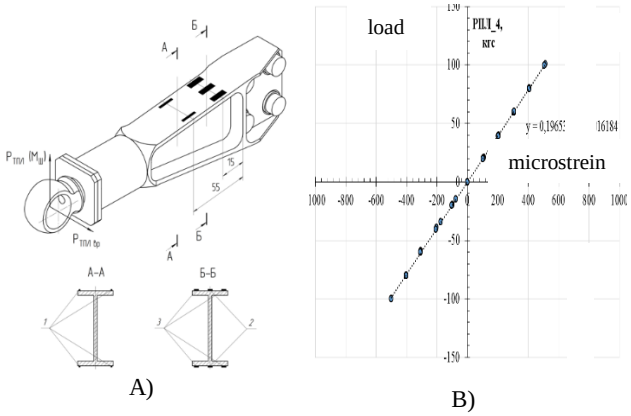


Figure 5: A) The labeling scheme of fiber-optic strain sensors on the lever of rotation of the rotor blade AL HSH;, B) the result of the calibration of fiber-optic sensors

Currently, the development of advanced aircraft (helicopters) for the possibility of reaching higher speeds is underway. Development and creation of an onboard complex to detect the stall of the air flow and flutter on the main rotor blades of the helicopter will ensure flight safety at high speeds, by timely notifying the pilot of the presence of stall, resulting in sharp increases in vibrations and loads both on the blades and on non-rotating parts of the swashplate, which can lead to a loss of the carrying capacity of the helicopter.



Figure 6: On-board computer

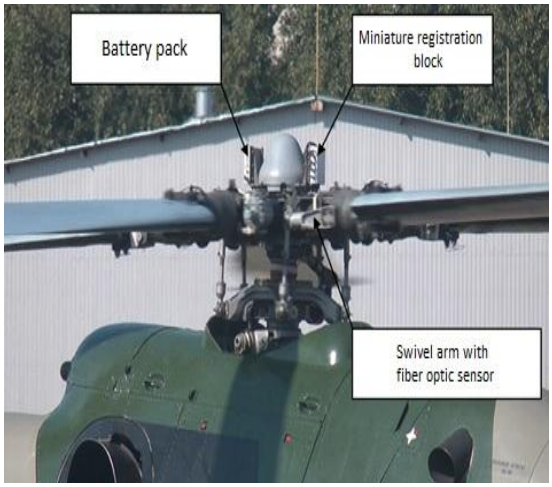


Figure 7: Installed on the helicopter elements of the monitoring system of the technical condition of rotating elements of the main rotor blade attachment.

3. Prospects for the application of the results

The results obtained during the bench and flight tests of the monitoring system of the technical condition of the blades of the helicopter's main and tail rotors with their fasteners show that it is possible in principle to create a comprehensive system for monitoring the technical condition of highly responsible helicopter units based on the use of fiber optic sensors.

Another element of this complex system can be an onboard alarm system for disrupting the air flow and flutter on the rotor blades of the helicopter using fiber-optic deformation sensors mounted on non-rotating elements of the helicopter skew autometer [13]. The need to create such a system is determined by the following factors: The main limitation for many modern helicopters is the disruption of flow on the lagging blade, leading at high flight speeds to a sharp increase in loads on the rotor and control system and the growth of helicopter vibrations. As a result, the estimated cruising speed of a helicopter without auxiliary propulsion at the current level of technological development is in the range of 280-370 km / h. An improvement in the aerodynamics of the rotor and fuselage, or a significant change in the configuration of the helicopter is required to achieve higher speeds.

The transition to the operation of the swashplate of the helicopter on the actual state, and not on the designated resource. It is worth noting that IRT Research and Development Center is developing an onboard alarm system for disrupting airflow and flutter on the rotor blades of the helicopter and monitoring the technical condition of the swashplate as part of the project with the Russian Ministry of Education (agreement No. 14.579.21.0150, identification number RFMEFI57917X0150). Within the framework of this project, bench and flight tests of an experimental model of the system were carried out, confirming the possibility of detecting stalling phenomena on the rotor blades of the helicopter by measuring loads using fiber-optic sensors mounted on non-rotating elements of the swashplate.

Another element of the integrated system can be a system for measuring the weight and centering of the helicopter's cargo through the use of fiber-optic deformation sensors installed on the helicopter landing gear. Unlike electrical strain gauges, which are trying to use to create such a system, fiber-optic sensors have several advantages, such as:

- Lack of electromagnetic pickup,
- High sensitivity to the measured value,
- No restrictions on the length of the signal supply fiber-optic cable,
- Miniature sizes,
- Lack of electrical power to fiber optic sensors.

Thanks to the results obtained in the implementation of a project to develop a system for early detection of damage to structures from PCM advanced aircraft [14] based on fiber-optic technology, it is possible to create a system for monitoring the technical condition of a helicopter airframe, which is part of an integrated system for monitoring the technical condition of highly responsible helicopter units. The system includes fiber-optic strain sensors and fiber-optic acoustic emission sensors embedded in airframe components made of PCM, or installed on the surface of its metal elements. The principle of operation of the system is based on the following: during operation of the helicopter, the system is recorded using fiber-optic load sensors acting on the monitored structure, and acoustic signals arising in the structure when mechanical damage occurs due to the load and / or abnormal external impact, for example, the fall of the tool when servicing a helicopter. In this case, the system registers the fact of the presence of this impact, determines its location and energy. Later, in a ground analysis of the data recorded by the system, a detailed inspection of the site of structural damage is carried out and a conclusion is made about the nature and admissibility of the damage. In addition, it is possible to monitor the development of the structure life and timely determine its pre-failure condition when reaching accumulation of damage threshold value, registering in real time the load parameters acting on the structure and the accumulation of acoustic emission signals, which is primarily related to the formation and development of latent internal damage to the structure.

It is also worth noting that, due to the advantages described above, in the future it is possible to use fiber optic vibration sensors (accelerometers) to replace existing piezoelectric sensors used in the construction of vibrodiagnostics systems and monitoring engine performance, gearboxes and transmissions.

Thus, the cumulative application of all the above systems will allow to create a comprehensive system for monitoring the technical condition of highly responsible helicopter units.

4. Conclusion

The article examined the problems of creating an integrated system for monitoring the technical condition of highly responsible helicopter units, and analyzed options for its creation. It is advisable to consider fiber-optic technology as a technology on the basis of which it is possible to build an integrated system. Since it can be used to measure various physical parameters such as vibration, deformation, temperature, acoustic emission and other parameters, and due to the miniature dimensions of the fiber-optic light guide, it can be built into the PCM design, which is a relevant factor due to use of PCM in the design and manufacture of helicopters.

In addition, the results of bench and flight tests of samples of the blades of the steering and rotor blades of the helicopter with their fastening elements using fiber-optical deformation sensors based on FBG were considered. The test results showed the fundamental possibility of creating a system for monitoring the technical condition of rotating elements of the helicopter main and tail rotor using fiber optic sensors.

In addition, there are examples of creating other elements of a comprehensive monitoring system based on the use of fiber-optic technology, such as a system for signaling the stall of air flow and flutter on the rotor blades of a helicopter, a system for measuring the weight and alignment of helicopter cargo and a system for monitoring the technical condition of the airframe.

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