«Сейфуллин оқулары – 18(2): «XXI ғасыр ғылымы – трансформация дәуірі» халықаралық ғылыми -практикалық конференция материалдары = Материалы международной научно-практической конференции «Сейфуллинские чтения – 18(2): «Наука XXI века - эпоха трансформации» - 2022 .- Т.I, Ч.IV. – Р.168-171

PROSPECTS OF USING FIBER OPTICAL SENSORS

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Fiber-optic sensors (VOD) are devices designed to record changes in the operating parameters of the system and broadcast a signal over a fiber–optic channel. Sensors can be used to monitor temperature and mechanical stress, and they are also used to monitor pressure, vibration and other indicators [1].

First of all, modern optical fiber consists of a core through which light propagates and a shell. It is covered from the outside with a polymer film. The core is a thread made of plastic or glass with certain additives (usually germanium) to increase the refractive index. The refractive index of the core is approximately 0.01...0.02 higher than the refractive index of the shell. Due to this, a beam of light directed into the core propagates through it, repeatedly reflecting from the "core-shell" interface.

The most important characteristic of optical fiber is the numerical aperture NA — the maximum possible angle at which light introduced into the fiber can propagate in it. The numerical aperture is determined by the refractive coefficients of the core and shell and is expressed as:

$$NA = \sin\Omega_m = \sqrt{n_1^2 - n_2^2} \quad (1)$$

If the angle of the light beam entering the core is less than NA, then it experiences a complete internal reflection and propagates only in it. If this condition is violated, part of the injected radiation is refracted and goes into the shell, and part is reflected inside the core [2].

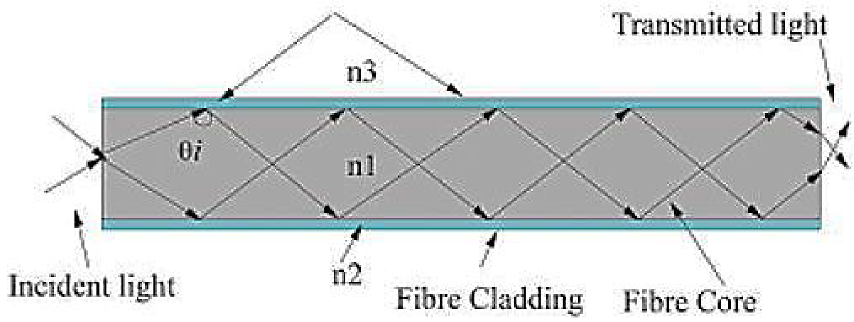

Figure 1 - Structured Light Fields in Optical Fibers

For optical fibers, there is a boundary value of the normalized frequency Fc. For the considered optical fiber with a stepwise change in the refractive index Fc = 2.045. If the calculated value of F exceeds this value, then a set of modes is propagated and the fiber is called multimode. Otherwise, one mode is propagated and the fiber is single-mode. Multimode optical fibers are technologically advanced, easily connected to radiation sources and detectors, as well as to other fibers. The disadvantage of multimode fiber is a violation of the coherence of the source, so it can be used to transmit information only about the intensity of the optical signal.

Single-mode fibers can use the polarization and phase of a coherent source, for example, a semiconductor laser, and on its basis it is possible to build sensors with fiber as a sensing element. The main disadvantage of a single—mode fiber is its high sensitivity to external mechanical influences and the relative complexity of coupling with other optical components. The outer diameter of multimode and single-mode fibers is the same and is equal to 125 microns. The core diameter of a multimode fiber is 50 microns at $\Delta \approx 1\%$, and that of a single—mode fiber is 10 microns at $\Delta \approx 0.3\%$.

Fiber-optic sensors can be divided into two groups: sensors with fiber as a transmission line and with single-mode fiber as a sensing element. Fiber-optic sensors of the first type are the most developed in theoretical and technological terms and are gradually being mastered in industrial production. They can be divided into sensors with an optical converter and sensors with an optical probe.

Sensors with an optical converter are a system that contains an optical element sensitive to the effects of the measured physical quantity, an emitter and a receiver. The optical element (converter) is placed between the ends of the transmitting and receiving multimode fiber. A low—noise LED is usually used as an emitter, and a p-i-n photodiode is used as a light detector. These semiconductor elements must be electro- and thermally stable.

In sensors with an optical probe, the probing light beam reflected or scattered by the measuring object enters the receiving optical system consisting of a lens and a fiber, the output end of which is connected to a p-i-n photodetector. Multimode or single-mode optical cables, as well as fiber-optic harnesses can be used in sensors of this type. LEDs or lasers are used as a light source, depending on the type of measured value (intensity, polarization, phase). Fiber-optic sensors based on this principle are highly sensitive and can be used for non-contact measurements.

Practical designs of fiber-optic sensors. Temperature sensor. The principle of operation of the sensor is based on the effect of fluorescence. A fluorescent substance is applied to the outer end of the optical fiber. Secondary radiation arising under the influence of a probing optical beam of the ultraviolet range is received by the same fiber. One of the components of fluorescent radiation ($\lambda 1$ = 510 nm) is characterized by a strong dependence on the temperature of the measured medium, and the other (λ2 = 630 nm) is very weak.

Pressure sensor**.** The pressure sensor is of the reflective type; it uses a change in the condition of light reflection by the membrane. Structurally, the sensor consists of a fiber-optic bundle, to one of the ends of which a membrane is connected through a small gap (~ 100 microns). Receiving optical fibers are placed in the center of the harness, and probing fibers are placed along the edges. The coupling coefficient between the probing and receiving fibers varies depending on the pressure exerted on the membrane. To increase the accuracy of pressure measurement, a photoluminescent material is applied to the membrane, providing the emission of a reference light signal, the intensity of which practically does not depend on the pressure value, and the sensor signal is processed using the two-wavelength method [3]. The temperature sensor is shown in Figure 2.

Magneto-optical magnetic field and current sensor. For non-contact measurements of strong magnetic fields (over 10 E) and corresponding currents, a fiber-optic sensor based on the magneto-optical Faraday effect is used. The magneto-optical effect consists in the rotation of the plane of linearly polarized light propagating in a substance along the magnetic field lines passing through this substance. This discovery of Faraday was the first proof of the existence of a direct connection between magnetism and light. The linearly polarized radiation passing through the medium can always be formally represented as a superposition of two waves polarized in the right and left circles with the opposite direction of rotation. In general, an optically transparent substance magnetized by an external field cannot be characterized by a single refractive index n. The refractive indices n+ and n– for the radiation of the right and left circular polarizations become different (magnetic anisotropy).

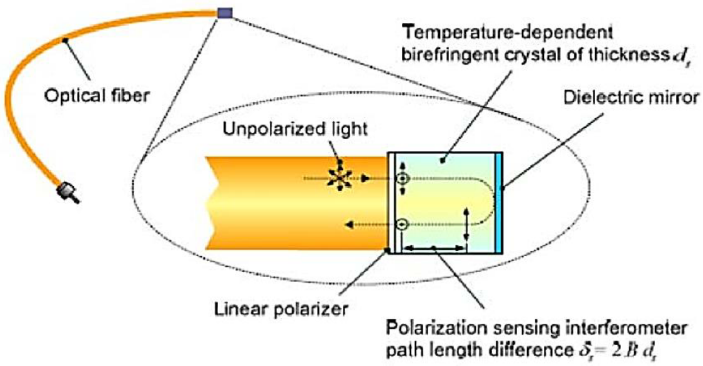

Figure 2 - The temperature sensor

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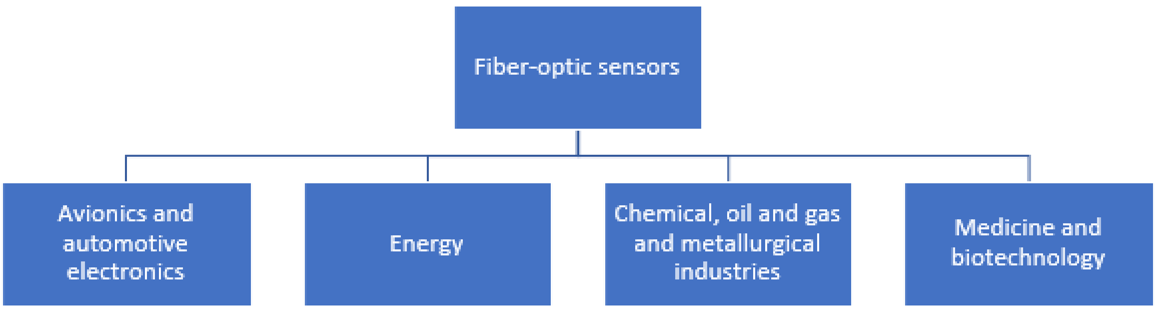
Fiber-optic gyroscope. The gyroscope is a key element of the inertial control and navigation system, which performs the function of measuring angular velocity. Quite high requirements are imposed on aviation and space gyroscopes: minimum launch time, high resolution, zero drift no worse than 0.01 degrees /hour, dynamic range of angular velocity measurement — 6 orders of magnitude, high noise immunity from spontaneous and regular electromagnetic interference. In many aviation and robotic systems, mechanical gyroscopes are still used, the principle of operation of which is based on the law of conservation of the moment of the amount of motion — holding the axis of rotation of the body in a certain direction of space. In the manufacture of these devices, high accuracy of the shape of the body of rotation is required, ensuring the minimum possible friction of the mechanical elements of the gyroscope, an automatic control system that provides a high degree of stabilization of the rotation of the gyromotor shaft.

The figure 3 shows the fields of using of fiber-optic sensors.

Avionics and automotive electronics. In these areas, there are advantages of resistance to electron-magnetic interference, the ability to work in conditions of reduced (up to -70 ° C) and elevated (up to 150 ° C) temperatures, small dimensions and weight. In avionics and automotive electronics, optical sensors of temperature, linear and angular position, accelerometers are used. Optical gyroscopes based on a ring interferometer using the Sagnac effect have become widespread in military and civil aviation.



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Energy. The advantage of using fiber-optic sensors in this area is provided by their stable thermal and electrical insulation characteristics, noise immunity and inertia-free. Fiber-optic voltage transformers (the Pockels effect), current transformers (magneto-optical sensors based on the Faraday effect), temperature sensors can be used here. Such sensors can be used to create a diagnostic system for high-voltage transformers without their decommissioning.

Chemical and oil and gas industry, metallurgy. In these industries, there is a demand for devices with non-contact measurement methods (beam thermometers, image beam drives, optical sensors for measuring gas flow, acceleration and displacement sensors) that can function stably in aggressive and explosive environments, high temperatures, intense electromagnetic interference.

Medicine and biotechnology. In this specific area, the advantages of fiber-optic sensors are particularly evident, such as flexibility and small diameter of the fiber, chemical and biological resistance, high spatial resolution.

Conclusion. The main directions of development of fiber-optic sensors are currently integrated optical technologies that will allow combining electronic processing circuits and micro-optical components in a single crystal or micromodule. This will significantly reduce the cost of fiber sensors and increase their operational characteristics.

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