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OPTICAL FIBER AND ITS INDUSTRIAL APPLICATION

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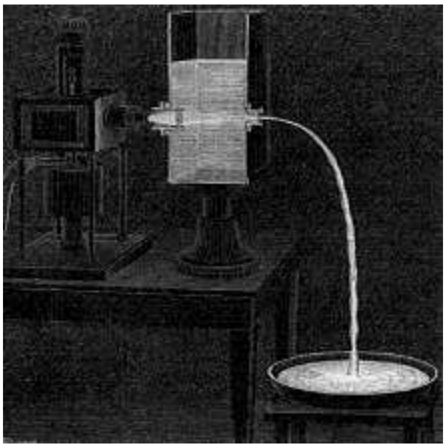
An **optical fiber** (or **optical fibre**) is a flexible, transparent fiber made of glass or plastic, slightly thicker than a human hair. It functions as a waveguide, or "light pipe", to transmit light between the two ends of the fiber. The field of applied science and engineering concerned with the design and application of optical fibers is known as **fiber optics**.

Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communication. Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference. Fibers are also used for illumination, and are wrapped in bundles so that they may be used to carry images, thus allowing viewing in confined spaces. Specially designed fibers are used for a variety of other applications,



including sensors and fiber lasers.

Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by total internal reflection. This causes the fiber to act as a waveguide. Fibers that support many propagation paths or transverse modes are called multi-mode fibers (MMF), while those that only support a single mode are called single-mode fibers (SMF). Multi-mode fibers generally have a wider core diameter, and are used for short-distance communication links and for applications where high power must be transmitted. Single-mode fibers are used for most communication links longer than 1,050 meters (3,440 ft).

Joining lengths of optical fiber is more complex than joining electrical wire or cable. The ends of the fibers must be carefully cleaved, and then spliced together, either mechanically or by fusing them with heat. Special optical fiber connectors for removable connections are also available.

Fiber is also immune to electrical interference; there is no cross-talk between signals in different cables, and no pickup of environmental noise. Non-armored fiber cables do not conduct electricity, which makes fiber a good solution for protecting communications equipment in high voltage environments, such as power generation facilities, or metal communication structures prone to lightning strikes. They can also be used in environments where explosive fumes are present, without danger of ignition.

Fiber optic sensors

Optical fibers can be used as sensors to measure strain, temperature, pressure and other quantities by modifying a fiber so that the property to measure modulates the intensity, phase, polarization, wavelength, or transit time of light in the fiber. Sensors that vary the intensity of light are the simplest, since only a simple source and detector are required. A particularly useful feature of such fiber optic sensors is that they can, if required, provide distributed sensing over distances of up to one meter.

Extrinsic fiber optic sensors use an optical fiber cable, normally a multi-mode one, to transmit modulated light from either a non-fiber optical sensor—or an electronic sensor connected to an optical transmitter. A major benefit of extrinsic sensors is their ability to reach otherwise inaccessible places. An example is the measurement of temperature inside aircraft jet engines by using a fiber to transmit radiation into a radiation pyrometer outside the engine. Extrinsic sensors can be used in the same way to measure the internal temperature of electrical transformers, where the extreme electromagnetic fields present make other measurement techniques impossible. Extrinsic sensors measure vibration, rotation, displacement, velocity, acceleration, torque, and twisting. A solid state version of the gyroscope, using the interference of light, has been developed. The *fiber optic*

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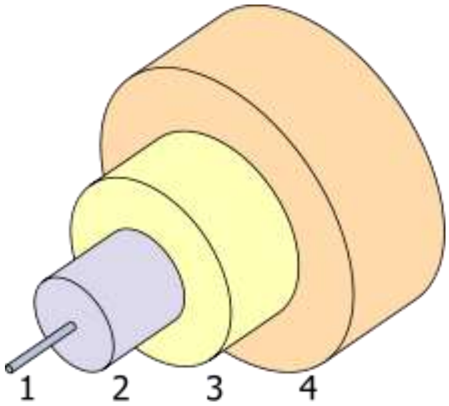
gyroscope (FOG) has no moving parts, and exploits the *Sagnac effect* to detect mechanical rotation.

Common uses for fiber optic sensors includes advanced intrusion detection security systems. The light is transmitted along a fiber optic sensor cable placed on a fence, pipeline, or communication cabling, and the returned signal is monitored and analysed for disturbances. This return signal is digitally processed to detect disturbances and trip an alarm if an intrusion has occurred.

Core of a single stand fiber.
1.Core:8 µmdiameter
3.Buffer:250 µmdia.



2.Cladding:125 µmdia.
4. Jacket: 400 µm dia

Applications

1. TELECOMMUNICATION

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Due to much lower attenuation and interference, optical fiber has large advantages over existing copper wire in long-distance and high-demand applications.

2. STREAMS

Integrated Intelligent Transport System is an enterprise traffic management system designed to operate in the Microsoft Windows environment. Like most traffic management systems, STREAMS is an array of institutional, human, hardware, and software components designed to monitor, control, and manage traffic on streets and highways.

Advanced traffic management systems come under the banner of ITS (intelligent transport systems). ITS is an umbrella term referring to the application of information and communications technology to transport operations in order to reduce operating costs, improve safety and maximise the capacity of existing infrastructure. STREAMS provides traffic signal management, incident management, motorway management, vehicle priority, traveller information and parking guidance within a single integrated system. STREAMS is developed by Transmax.

STREAMS employs a distributed computing software architecture. Intersection controllers, video cameras and speed detectors are connected to a central application server. Users connect to the application server via the workstation software, field communications are via Optical Fibre. The transport network data is set up via a GIS (Geographic Information System). The GIS allows for a graphical user interface displaying transport network data overlaid on street maps and updating in real-time.

3. POWER TRANSMISSION

Optical fiber can be used to transmit power using a photovoltaic cell to convert the light into electricity, it is especially useful in situations where it is desirable not to have a metallic conductor as in the case of use near MRI machines, which produce strong magnetic fields.

4. FIBER OPTIC STRAIN & TEMPERATURE SENSING FOR CIVIL ENGINEERING STRUCTURES

4.1 Introduction Structural health monitoring is certainly one of the most powerful management tools and is therefore gaining in importance in the civil engineering community. A typical health monitoring system is composed of a network of sensors that measure the parameters relevant to the state of the structure and its environment.

The additional value can include an improved quality of the measurements, a better reliability, the possibility of replacing manual readings and operator judgment with automatic measurements, an easier installation and maintenance or a lower lifetime cost. The successful industrial applications of fiber optic sensors to civil structural monitoring demonstrate that this technology is now sufficiently mature for a routine use and that it can compete as a peer with conventional instrumentation.

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From many points of view, fiber optic sensors are indeed the ideal transducers for civil structural monitoring. Being durable, stable and insensitive to external perturbations, they are particularly interesting for the long-term health assessment of civil engineering structures as of, long Dams and Bridges. Fiber optic sensors offer unique characteristics that are unparalleled by the conventional sensors.

4.2 DISTRIBUTED FIBER OPTIC SENSORS

Unlike electrical and localized fiber optic sensors, distributed sensor offer the unique characteristic of being able to measure physical and chemical parameters along their whole length, allowing the measurements of thousands of points using a single transducer. The most developed technologies of distributed fiber optic sensors are based on Raman and Brillouin scattering. Both systems make use of a non-linear interaction between the light and the silica material of which the fiber is made. If light at a known wavelength is launched into a fiber, a very small amount of it is scattered back every point along the fiber. The scattered light contains components at wavelengths that are different form the original signal. These shifted components contain information on the local properties of the fiber, in particular their strain and temperature

4.2.1 Raman Distributed Temperature Sensors

Raman scattering is the result of a non-linear interaction between the light traveling in a fiber and silica. When an intense light signal is shined into the fiber, two frequency-shifted components called respectively Raman Stokes and Raman anti-Stokes will appear in the back-scattered spectrum. The relative intensity of these two components depends on the local temperature of the fiber. If the light signal is pulsed and the back-scattered intensity is recorded as a function of the round-trip time, it becomes possible to obtain a temperature profile along the fiber.

4.2.2 Brillouin Distributed Temperature sensors

Brillouin scattering sensors show an interesting potential for distributed strain and temperature monitoring. Systems able to measure strain or temperature variations of fibers with length up to 50 km with spatial resolution down in the meter range are now demonstrating their potential in field applications. For temperature measurements, the Brillouin sensor is a strong competitor to systems based on Raman scattering, while for strain measurements it has practically no rivals.

Brillouin scattering is the result of the interaction between optical and sound waves in optical fibers. Thermally excited acoustic waves (phonons) produce a periodic modulation of the refractive index. Brillouin scattering occurs when light propagating in the fiber is diffracted backward by this moving grating, giving rise to a frequency-shifted component by a phenomenon similar to the Doppler shift. This process is called spontaneous Brillouin scattering.

For measuring temperatures it is sufficient to use a standard telecommunication cable. These cables are designed to shield the optical fibers from an elongation of the cable. The fiber will therefore remain in its unstrained state and the frequency shifts can be unambiguously assigned to temperature variations. If the frequency shift of the fiber is known at a reference temperature it will be possible to calculate the absolute temperature at any point along the fiber. Measuring distributed strains requires a specially designed sensor. A mechanical coupling between the sensor and the host structure along the whole length of the fiber has to be guaranteed. To resolve the crosssensitivity to temperature variations, it is also necessary to install a reference fiber along the strain sensor. Similarly to the temperature case, knowing the frequency shift of the unstrained fiber will allow an absolute strain measurement.

4.2.3 Sensing Cable Design

Traditional fiber optic cable design aims to the best possible protection of the fiber itself from any external influence. In particular it is necessary to shield the optical fiber form external humidity, side pressures, crushing and longitudinal strain applied to the cable. Design have proven very effective in guaranteeing the longevity of optical fibers used for communication and can be used as sensing elements for monitoring temperatures in the –20°C to +60°C range, in conjunction with Brillouin or Raman monitoring systems.

The strain sensitivity of Brillouin scattering prompts to the use of such systems for distributed strain sensing, in particular to monitor local deformations of large structures such as pipelines, landslides or dams. In these cases, the cable must faithfully transfer the structural strain to the optical fiber, a goal contradicting all experience form telecommunication cable design where the exact opposite is required.

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Finally when sensing distributed strain it is necessary to simultaneously measure temperature to separate the two components. This is usually obtained by installing a strain and a temperature sensing cables in parallel. It would be therefore desirable to combine the two functions into a single packaging.

4.2.4 Extreme temperature sensing cable

The extreme temperature sensing cables are designed for distributed temperature monitoring over long distances. They consist of up to four single mode or multimode optical fibers contained in a stainless steel loose tube, protected with stainless steel armoring wires and optionally a polymer sheath. These components can be differently combined in order to adapt the cable to the required performance and application. The use of appropriate optical fibre coating (polyimide or carbon/polyimide) allows the operation over large temperature ranges, the stainless steel protection provides high mechanical and additional chemical resistance while the polymer sheath guarantees corrosion protection. The carbon coating offers improved resistance to hydrogen darkening. The over-length of the optical fibers is selected in such a way that the fiber is never pulled or compressed, despite the difference in thermal expansion coefficients between glass and steel. The total cable diameter is only 3.8 mm. These cables can be used in a wide range of applications that require distributed temperature sensing, such as temperature monitoring of concrete in massive structures, waste disposal sites, onshore, off-shore and down hole sites in gas and oil industry, hot spots, cold spots and leakage detection of flow lines and reservoirs, fire detection in tunnels and mapping of cryogenic temperatures, just to name a few.

4.2.5 Strain sensing tape: SMART ape

When strain sensing is required, the optical fiber must be bonded to the host material over the whole length. The transfer of strain is to be complete, with no losses due to sliding. Therefore an excellent bonding between strain optical fiber and the host structure is to be guaranteed. To allow such a good bonding it has been recommended to integrate the optical fiber within a tape in the similar manner as the reinforcing fibers are integrated in composite materials. To produce such a tape, a glass fiber reinforced thermoplastic with PPS matrix is selected. This material has excellent mechanical and chemical resistance properties.The typical cross-section width of the thermoplastic composite tape that is used for manufacturing composite structures is in the range of ten to twenty millimeters, and therefore not critical for optical fiber integration. The thickness of the tape can be as low as 0.2 mm, and this dimension is more critical since the external diameter of polyimide-coated optical fiber is of 0.145 mm approximately. Hence, only less than 0.03 mm of tape material remains on top or bottom of the optical fiber, with the risk that the optical fiber will emerge from the tape. The use of such sensing tape (called SMARTape) is twofold: it can be used externally, attached to the structure, or embedded between the composite laminates, having also a structural role.

4.2.6 Combined Strain and temperature sensing: SMARTprofile

The SMARTprofile sensor design combines strain and temperature sensors in a single package. This sensor consists of two bonded and two free single mode optical fibers embedded in a polyethylene thermoplastic profile. The bonded fibers are used for strain monitoring, while the free fibers are used for temperature measurements and to compensate temperature effects on the bonded fibers. For redundancy, two fibers are included for both strain and temperature monitoring. The profile itself provides good mechanical, chemical and temperature resistance. The size of the profile makes the sensor easy to transport and install by fusing, gluing or clamping. The SMARTprofile sensor is designed for use in environments often found in civil geotechnical and oil & gas applications. However, this sensor cannot be used in extreme temperature environments nor environments with high chemical pollution. It is not recommended for installation under permanent UV radiation (e.g. sunshine).

4.3 APPLICATION EXAMPLES

4.3.1Luzzone Dam Temperature monitoring

Distributed temperature measurements are highly interesting for the monitoring of large structures. . The raising was realized by successively concreting 3m thick blocks. The tests concentrated on the largest block to be poured, the one resting against the rock foundation on one end of the dam. An armored telecom cable installed in serpentine during concrete pouring constituted the Brillouin sensor.

The temperature measurements started immediately after pouring and extended over 6 months. The measurement system proved reliable even in the demanding environment present at the dam. It was possible to obtain a large number of measurement points with relatively simple sensors. The distributed nature of Brillouin sensing make it particularly adapted to the monitoring of large structures where the use of more conventional sensors would require extensive cabling.

4.3.2 Bitumen Joint Monitoring

In Palvinu Dam in Latvia a hydropower plant was built on clay-sand and sand-clay foundations with a maximum pressure limit. The HPP building is merged with a water spillway. The entire building complex is extremely compact. One of the dam inspection galleries coincides with a system of three bitumen joints that connects two separate blocks of the dam. Due to abrasion of water, the joints lose bitumen and the redistribution of loads in concrete arms appears. Since the structure is

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nearly 40 years old, the structural condition of the concrete can be compromised due to ageing. Thus, the redistribution of loads can provoke damage of concrete arm and as a consequence the inundation of the gallery. In order to increase the safety and enhance the management activities it was decided to monitor the average strain in the concrete arm next to the joints. The DiTeSt system with SMARTape deformation sensor and Temperature Sensing Cable is used for this purpose in order to send pre-warnings and warnings from the DiTeSt instrument to the Control Office.

4.3.3 Gas Pipeline Monitoring

About 500 meters of a buried, 35 years old gas pipeline, located near Rimini, Italy, lie in an unstable area. The landslide progress with time and could damage pipelines up to be put out of service. SMARTape sensor were installed over whole concerned length of the pipeline The lengths of segments were ranged from 71 m to 132 m. All the sensors were connected to a Central Measurement Point by means of extension optical cables and connection boxes. Since the landslide process is slow, the measurements sessions were performed manually once a month. The sensors have been measured for a period of two years, providing interesting information on the deformation induced by burying and by the landslide progression. A gas leakage simulation was also performed with success using the temperature sensing cable.

5 CONCLUSIONS

The use of distributed fiber optic sensors for the monitoring of civil structures and infrastructures opens new possibilities that have no equivalent in the conventional sensors system. Thanks to the use of a single optical fiber with a length of tens of kilometers has sensing elements; it becomes possible to obtain dense information on the structure’s strain and temperature distribution. This technology is therefore particularly suitable for applications to large or elongated structures; such has dams, large bridges and pipelines.

Biography

“**Sri Binod Chandra Padhi** is heading the technical committee to assist Shri Jaganath Temple Administration, Puri, Domain Specialist for Computerization of entire Works Depatment of Government of Odisha & Member Governing body of State Urban Development Agency(SUDA).He was the 1964 batch first class graduate of U C E, Burla , postgraduate of Highway Engineering from IIT Kharagpur, He is a Life fellow of Institution of Engineers(India), Institute of Bridge Engineers, Indian Roads Congress, INTACH, Orissa Environmental society & Red Cross. He has designed the first Box Bridge of the state on the State Highway connecting Khurda to Nayagarh, in the year 1977 effecting a lot of economy & around 800 bridges for Odisha including the first Road Over Bridge at Balasore & second one at Cuttack.He had topped the list of recruits of Public Service Commission & rose to the rank of Head of Works Department as Engineer- in- Chief of our state. His technical papers “Utilization of Waste Products of Rourkela Steel Plant”, “Should we start reusing MS Round Bars” have been awarded Gold medals. He has authored a book "Design of Culverts for Rural Roads" a useful handbook for all field engineers, now use in Odisha. For this Honble’ Governor of Odisha has awarded Gold Medal in 2004