Sensing Technologies using Optical Fibers and Metal Cables

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OKI Electric Cable is working on developing sensors that cover a wide range by utilizing features of optical fibers and metal cables. Particularly, sensor cables with high stress resistance are being developed considering the expanding use of sensors for such purposes as security and detecting abnormal vibrations for equipment maintenance. This article presents an overview and features of optical and metal type sensor cable technologies, as well as their anticipated applications and issues, and future prospects.

Oil Leak Sensor Cable

The optical fiber that OKI Electric Cable produces is referred to as HPCF (Hard Plastic Clad Fiber). The core of the fiber, which transmits light, is made of quartz glass, and the cladding that totally reflects the light and confines it within the core is made of fluororesin. HPCF has a larger core diameter than a conventional all-quartz fiber, and it is resistant to mechanical stresses and environmental changes. The oil leak sensor cable utilizes these features of the HPCF. Japan has multiple oil storage bases, and with both the government and the private sector combined, a total of approximately 80 million kiloliters (about 200 days' worth) of oil are stored. OKI Electric Cable's oil leak sensor cables are used in devices that monitor oil tanks for leaks caused by natural disasters, such as earthquakes, and aging (**Photo 1**).

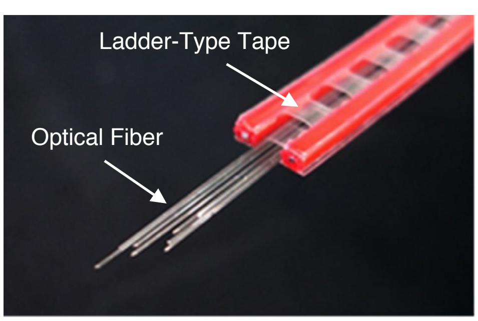

Photo 1. Oil Leak Sensor Cable

Optical fibers are used in these monitoring devices because of the danger involved with using electrical sensors to detect flammable oil, and also because optical fibers can maintain detection function over a long period of time without degrading or corroding.

The principle of oil leak sensing is explained below.

Since the cladding of the HPCF is made of fluororesin, portions of the cladding can be peeled away by hitting the surface of the desired areas with a strong laser beam (**Figure 1**). **Photo 2** shows an example of a HPCF that was actually processed.

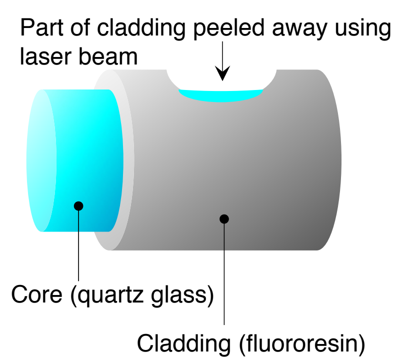

Figure 1. Structure of HPCF

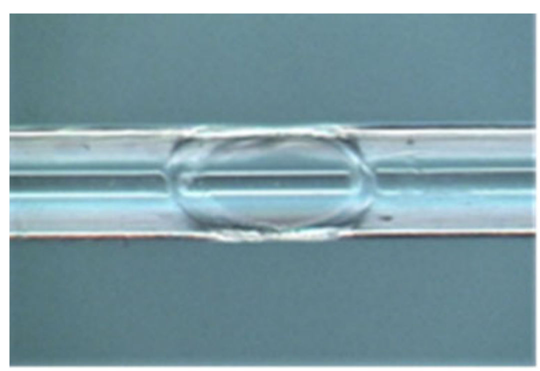

Photo 2. Laser Processed HCPF

When oil adheres to the exposed part of the core where the cladding has been peeled away, light transmitted inside the core escapes due to the difference in refractive index between air and oil. The resulting attenuation in light intensity allows detection of oil adhesion (**Figure 2**).

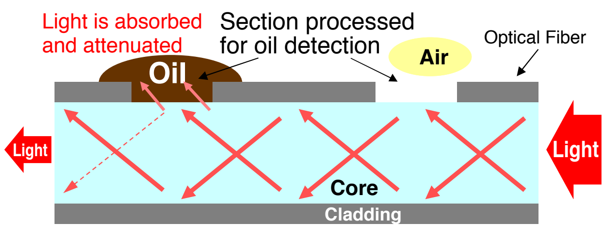

Figure 2. Principle of Oil Leak Sensing

Laser processing is performed on the HPCF at approximately 10mm intervals, and to further increase the detection sensitivity, multiple HPCF are bundled and housed in a cable with the structure shown in **Photo 1**. The cable consists of two support wires placed a certain distance apart, and transparent films that hold the support wires are fused from above and below. The transparent films have holes placed at regular intervals to allow oil to easily enter from the outside. The HPCF are held in a free state between the two support wires.

A reaction test was conducted in which a light source (LED, wavelength 880nm) and a light intensity meter were connected to the ends of this oil leak sensor cable (length approximately 50m). Then, a drop of heavy oil was dropped into the hole of the cable. The change in light output was measured, and the result is shown in **Table 1**. The moment the heavy oil came in contact with the optical fiber inside the sensor cable, the light intensity decreased indicating oil adhesion.

Table 1. Result of Oil Reaction Test

Before Test	After Oil Drop	Rate of Change
7.32μW	6.50μW	11.2%

In addition to oil storage tanks, the oil leak sensor is recently undergoing experimental use with offshore wind power generation devices (**Photo 3**).

Wind power generators are required to operate stably for long periods of time, and large amount of lubricating oil is used in a room called the nacelle that houses the main generator unit. If oil from the main unit leaks into the ocean, it will contaminate the surrounding area affecting the ecosystem and fisheries. The oil leak sensor was adopted to detect oil spills in advance.

Furthermore, oil spills are not limited to wind power generation devices installed offshore. Spills can also occur with generation devices installed on land. If oil spills, it can contaminate surrounding houses and crops, and even cause fires.

In such a way, the oil leak sensor with its ability to detect dangerous situations and prevent pollution is a product that contributes widely to society's security.

Photo 3. Offshore Wind Power Generation Device

Vibration Sensor Cable

Utilizing the "connect" technology cultivated over the years, OKI Electric Cable is working to develop sensor cables that can be used in a variety of environments. For instance, the use of metal cables for sensors not only saves space but also enables installation and detection over a wide area and over long distances. Additionally, through changes in the manufacturing process of the sensor cables, OKI Electric Cable is developing products

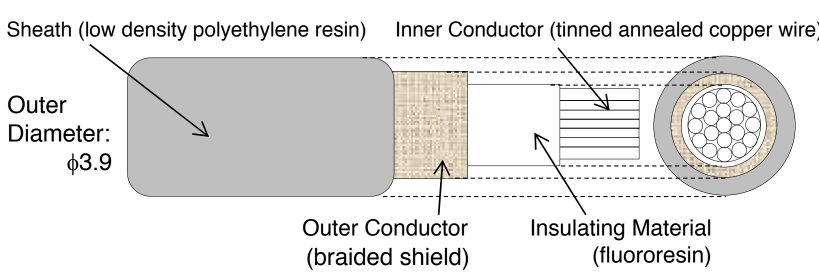

Figure 3. Structure of Vibration Sensor Cable

with higher sensitivity than other companies' sensor cables as well as products with smaller diameters and lighter weight. One of these products is the vibration sensor cable. The cable has a basic coaxial structure with an inner conductor covered in piezoelectric resin, which is in turn covered with an outer conductor and sheath (**Figure 3**). The cable is classified as a piezoelectric cable.

The detection principle uses the property of piezoelectric resin to convert mechanical energy such as vibrations and shocks into electrical energy. The occurrence of vibration is detected when the electrical signal generated by the piezoelectric resin propagates through the inner and outer conductors and reaches the receiver. Years of experience working with movable cables has led OKI Electric Cable to develop vibration sensor cables that resist breakage even when they are moved allowing the cables to be used for various purposes. So far, two types of vibration sensor cables composed of different materials, structure, and outer diameter have been prototyped and evaluated.

(1) ϕ3.9 Vibration Sensor Cable

The ϕ3.9 vibration sensor cable detects vibrations and shocks, and it is mainly used for security purposes. Simply installing the cable on a typical diamond-shaped or lattice-shaped fence turns the entire fence into a sensor. Although the actual coverage will vary depending on the installation condition and environment, the maximum installation length is 300m and taking advantage of the cable material's characteristics, detection is possible over long distances and wide areas.

The sensor cable has been installed on a fence at OKI Electric Cable's Okaya factory and currently undergoing long-term tests to evaluate its sensitivity and weather resistance reliabilities. There are no general test conditions. Instead, an impact is applied to the fence under conditions that OKI Electric Cable has predetermined, and the sensitivity is checked at the receiver.

Photo 4. Installation Test

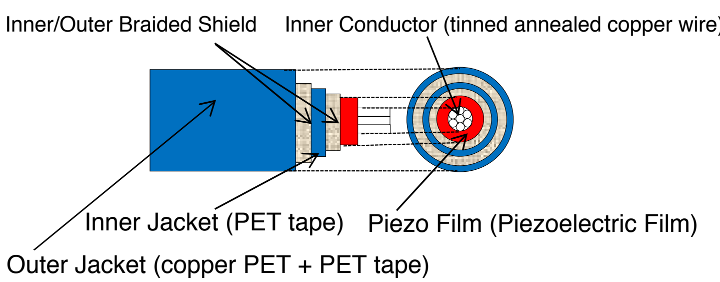

Figure 4. Structure of Ultra-Thin Vibration Sensor Cable

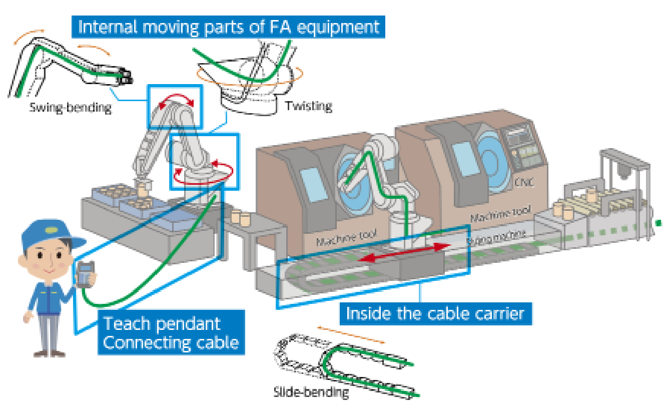

Figure 5. Usage Example

Since the sensor cable is to be used outdoors, the outermost layer is a weather-resistant polyethylene sheath that prevents deterioration from UV rays. The outer diameter of the cable is ϕ3.9, which provides thinness that makes the cable easy to handle and lay down during installation.

(2) ϕ0.7 Ultra-Thin Vibration Sensor Cable

A thin piezo film (thickness: 28μm = 0.028mm) is used instead of piezoelectric resin coating in the ϕ0.7 ultra-thin vibration sensor cable (**Figure 4**). As a result, the diameter of the sensor cable is a mere ϕ0.7, which is similar to the lead of a mechanical pencil making it ideal for wiring and vibration detection in narrow spaces.

Other than the conductor, the use of a PET tape (polyester / plastic) and copper-deposited PET tape (copper PET / plastic) in structuring the sensor cable also contributed to the thinness. The sensor cable is made by wrapping the thin tapes, which are no more than 50μm thick, in layers. However, the ultra-thin diameter also poses issues such as decrease in tensile strength and susceptibility to external noise. Therefore, taking strength and noise resistance into consideration, the sensor cable has been designed with a double shield structure.

A possible application is vibration detection in the arms, motors, bearings, etc. of industrial robots as shown in **Figure 5**. The ultra-thin structure makes it easy to wire the cable into narrow spaces. The technology is expected to be useful for predictive maintenance, which detects abnormal vibrations in motors and other equipment that are different from vibrations of a normal operation and provides warnings before actual failures or production line stoppages occur. OKI Electric Cable will continue with technical studies toward its commercialization.

Conclusion

People's lives are supported by various infrastructure facilities in operation around the world. Moreover, in the manufacturing industry, various machines are in operation and manufacturing goods every day. In order for these facilities and machinery to operate stably, maintenance activities are necessary. In particular, predictive maintenance, which detects early signs of trouble and enables maintenance to be performed before a failure occurs, is considered to play an important role in the future. Predictive maintenance requires the collection and analysis of facility data, and sensors are essential components for collecting data. Furthermore, appropriate sensors are required for each application. OKI Electric Cable will continue to develop unique sensing products and technologies that take advantage of cable features.

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