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Fibre Bragg grating-based sensing device for petrol leak detection

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Fibre Bragg gratings (FBGs) have emerged in recent years as important sensor elements for various applications. In this communication application of an FBG sensor using a surgical rubber as transducer element for petrol leak detection in pipelines and tanks is presented. The rubber, which is in tubular form and is bonded with the fibre containing FBG, reversibly swells in the presence of petrol thus resulting in Bragg wavelength shift. The shift is measured using an interrogator with a swept fibre laser source (1520–570 nm). The design aspects and experimental procedure along with analysis of results obtained and the potential for distributed sensing have been discussed.

Keywords: FBG sensor, petrol leak, transducer.

FIBRE Bragg gratings (FBGs) are simple intrinsic devices which are created in the fibre core by imaging an interference pattern through the side of the fibre[1]. They have all the advantages of an optical fibre, such as electrically passive operation, lightweight, high sensitivity and also some unique features of their own such as self-referencing and multiplexing capabilities, giving them a distinct edge over previously used devices. They are being used in structural health monitoring (SHM) of different types of civil structures, aircraft and aerospace vehicles[2–4]. In all such applications, FBGs are used as strain and temperature sensors because these two parameters have direct influence upon the Bragg wavelength and also because they are important for SHM studies. However, the application potential of FBG sensors can reach new horizons by introducing transducers in combination with the grating element. The purpose of the transducer is to produce strain or temperature variation due to the parameter to be detected. This variation in any sensing parameter is detected by monitoring Bragg wavelength shift. This communication discusses one such application of FBG sensors for petrol leak detection. Since petrol is a hazardous and precious commodity, it can be both dangerous as well as an economic loss if it leaks through pipelines and tanks. FBG sensors are functional in such situations because they are insulators, chemically inert and perform multipoint sensing within a single fibre. A fast detection system of petrol leak along with its location is possible using FBG sensors. The results obtained have been discussed and analysed.

When a light wave passing through the fibre core comes across refractive index variation (which acts as a grating plane), it gets scattered. Most of the scattered light becomes more and more out of phase after passing through subsequent grating planes, cancelling out each other eventually. However, one particular wavelength which satisfies the Bragg condition, and hence called Bragg wavelength, undergoes scattering from subsequent grating planes and is in phase resulting in a constructive interference. This wavelength element thus is missing from the transmission and results in reflection. It is a function of grating parameters and is given by

$$\lambda_B = 2n\Lambda, \tag{1}$$

where Λ is the pitch of the grating, n is the effective refractive index of the core and λ_B is the Bragg wavelength[5]. As evident from eq. (1), the Bragg wavelength is shifted if the effective refractive index or the grating periodicity is changed due to some perturbation; in fact both these parameters are directly influenced by strain and ambient temperature. At a constant temperature, the effect of strain on the wavelength is given as

$$\Delta\lambda_B = 2\left[\Lambda\frac{\partial n}{\partial l} + n\frac{\partial \Lambda}{\partial l}\right]\Delta l. \tag{2}$$

In eq. (2), the first term is for change in refractive index of the core, induced due to strain optic effect, while the

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second term represents change in grating spacing due to strain.

In most of the applications EBG sensors are used for point sensing of strain and temperature. The strain response arises due to both physical elongation of the sensor and the corresponding change in grating pitch and change in fibre index due to photoelastic effects. Thermal response arises due to inherent thermal expansion of the fibre material and temperature dependence of the refractive index. Typically, a wavelength resolution of ~ 1 pm (0.001 nm) is required (at λ_B ~ 1.3 μm) to resolve a temperature change of ~ 0.1°C or a strain change of ~ 1 μm strain. The basic principle of FBG sensor is to detect the shift in λ_B with the changes in the measurand.

To detect petrol leak, a rubber tube as a transducer is attached to an FBG. This rubber has the ability to swell by absorbing petrol without being dissolved in it and to shrink to its original state in the drying condition. This swelling and shrinking is converted into a mechanical force which acts on the FBG and is detected by measuring the Bragg wavelength shift[6]. Though FBG sensors have vast application potential in diverse areas; for detection of wavelength shift, a high resolution detection system is required because the shift as mentioned above is too small to be detected by the conventional spectrometers. For precise and dynamic Bragg wavelength shift demodulation, the interferometric scheme is used but it is not a convenient and practical method. For most of the applications, quasi-static[7] methods are employed and an interrogator falling in this category has been used in this study. This system takes advantage of tunable wavelength shift which is a typical tuning in and reading out system. In this system the reflected light from the grating is passed through a Fabry–Pérot (FP) tunable filter whose transmission bandwidth is similar to grating reflection bandwidth, while its free spectral range is much larger than the operating wavelength of the grating so as to accommodate a number of gratings with different Bragg wavelengths.

The FBG sensors in a single fibre are illuminated with a broadband swept fibre laser source (wavelength range = 1520–1570 nm) with a sweep frequency of 50 Hz through a fibre pigtail and the reflected light is returned via a coupler to a scanning FP filter and detector. The cavity length of the Fiber FP filter is tuned by a voltage signal via piezoelectric stacks to match transmission wavelength with the peak wavelength reflected from the grating. The locking voltage applied to PZT is a measure of that peak wavelength.

The FBG is kept inside the swellable rubber tube of length 2.5 cm and diameter 0.1 cm, both ends of which are bonded with the fibre using a suitable epoxy. One end of this fibre is connected to the interrogator, while the other end is kept free. The FBG used in the present investigation has been manufactured and provided by IFAC, CNR, Firenze, Italy. With this FBG and the rubber tube as transducer along with interrogator put together, a sensor system is realised. The transducer is attached to a glass pipe of length 31 cm and diameter 0.7 cm with a small hole at the centre through which petrol is made to flow. The schematic of the experimental set-up implemented is depicted in Figure 1. The Bragg wavelength of this sensor system is observed on a laptop. Petrol is made to leak through the hole using a syringe. As soon as the rubber comes into contact with the leaked petrol, it starts swelling up. Since the rubber tube is bonded on both sides of the FBG, this swelling causes the FBG to stretch resulting in Bragg wavelength shift. This shift is monitored every minute for some time and then the sensor set-up is left for drying. The tube attains its original form, i.e. the Bragg wavelength attains its dry-state value typically after 4 h in the drying state. This complete wet–dry cycle was repeated after a gap of about 5 h. The behaviour of the Bragg wavelength observed for initial 18 min is shown in Figure 2.

The Bragg wavelength of the grating with the surgical rubber tube as transducer increases rapidly once the sensor comes in contact with the petrol, as shown in the Figure 2. The increase is not linear because the petrol was made to leak just for an instant and drying commences immedi-

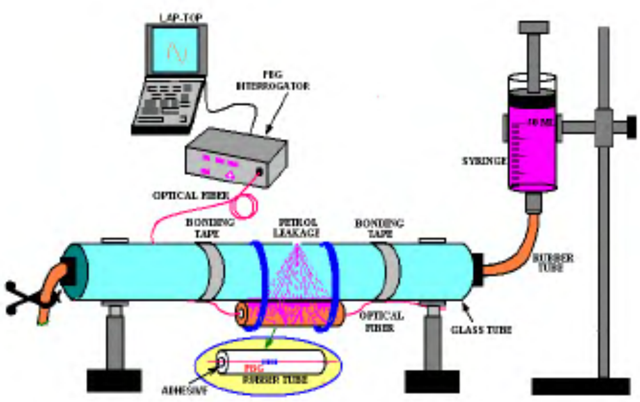

Figure 1. The experimental schematic for petrol leak detection.

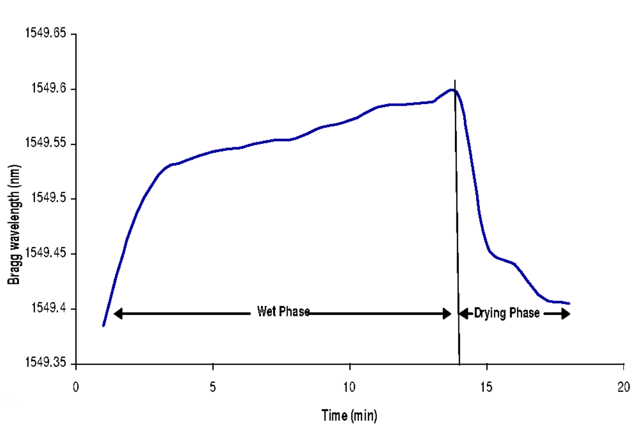

Figure 2. Response of Bragg wavelength to petrol.

Figure 3. Experimental set-up for petrol leak detection.

ately. A Bragg wavelength shift of 0.2 nm is recorded even for this short duration of petrol leak, which can be improved easily either by increasing the petrol contact time or by manipulating the size of the rubber tube. The experiment has been performed repeatedly in a controlled laboratory environment where the timing and extent of petrol leak is controlled manually, but this sensor should work equally well in actual field applications (Figure 3). The properties of transducer rubber tube do not change after repeated (up to ten times) use.

Since the sensed information, namely petrol leakage, is wavelength-encoded, it is independent of fluctuations in the light source, connector or fibre losses, etc. Another point which is crucial in hazardous environment is the feasibility of remote sensing. It is because the commercial fibres have low loss in the operating wavelength range used in this study and are able to transmit the sensed information to distant monitoring locations. Besides, the narrow bandwidth of FBG allows multiplexing of many sensing elements with known Bragg wavelengths and predetermined positions along the length of the pipeline or tank by design, which works independently without interfering with each other, thereby providing distributed sensing of both leakage and its locations. This study offers an efficient, fast, safe and inexpensive technique for applications involving remote monitoring of leakage and/or spillage along with its exact location in petrol pipelines and storage tanks and can be utilized as an alarm system for the same.

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Laser ablation-inductively coupled plasma mass spectrometry for 2D mapping of trace elements in soft tissues

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Metals are not homogeneously distributed in organ tissues. Although most mapping techniques, such as histologic staining methods, have been developed for element imaging on subcellular level, many suffer from either low precision or poor detection limits. Therefore, small variations in elemental distribution cannot be identified. We have developed a method using laser ablation-inductively coupled plasma mass spectrometry for the determination of elemental distribution in lamb liver using 2D mapping.

Keywords: Copper zonation, CRM pig liver paste, LA–ICP–MS, mapping, soft tissues.

LASER ablation has been used in the determination of trace elements in different non-biological solid samples like glass[1], geological materials[2], metal sheets[3], polymers[4], and even ice cores[5]. Although there have been a few studies on biological samples, all of them were hard tissues like tree rings[6–9], tree barks[10], teeth[11,12], leaves[13] and shells from bivalves[14–17]. Limited information is available about the applicability of a laser ablation system for fresh soft tissues like liver or brain.

In biological and clinical applications, it is often desirable to acquire knowledge about the distribution of a trace element in a soft tissue. Regional localization of trace elements in a thin section of lamb liver can be identified

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