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FUEL DETECTION SYSTEM USING OTDR WITH MULTIMODE FIBER

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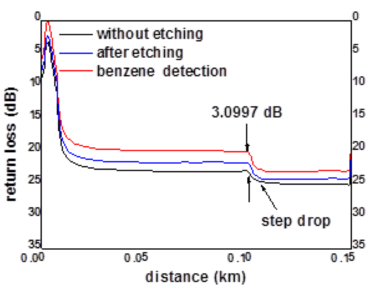
Graphical abstract



Abstract

This work presents an optical fiber based sensor for fuel detection adapted to an optical time domain Reflectometer (OTDR) as an analyzer. The sensing system consists of a portion of removal clad multimode fiber (MMF) as sensing part connected in between a receive and launch fibre. The sensing part was prepared by removing 1 cm of the MMF cladding layer using chemical etching technique. Both launch and receive fibres are using single mode fibre (SMF) where OTDR is connected to the Launch Fibre while Receive Fibre has one end with air interface.The sensor response is based on optical return loss recorded from OTDR trace when sensing part in contact with fuel where in this work diesel and benzene were tested. OTDR measurement revealed that the return loss recorded from OTDR increases when etching time of the MMF is increased. The highest return loss of 2.462 dB and 3.099 dB were recorded in diesel and benzene respectively with etching time of 20 minutes. The etching time up to 25 minutes however found to cause the fibre core become too thin and at the end the fiber core can completely dissolved. Further enhancement of detection sensitivity has achieved by using two point MMF sensing system.

Keywords: Fiber sensors, chemical liquid sensing, optical time domain reflectometer, multipoint optical fiber sensor

Abstrak

Kajian yang dijalankan adalah berkenaan penderia berasaskan gentian optik bagi pengesanan bahan api dengan mengadaptasi reflektometer optik domain masa (RODM) sebagai alat penganalis. Sistem pengesanan terdiri daripada gentian optik mod berbilang dengan sebahagian penyalutnya dibuang untuk bertindak sebagai bahagian penderia dan disambung di antara gentian optik pelancar dan penerima. Bahagian penderia telah dibuat dengan membuang sebahagian penyalut teras gentian optik dengan menggunakan kaedah kakisan asid. Kedua-dua fiber pelancar dan penerima merupakan gentian optik pembilang tunggal dimana RODM disambungkan kepada gentian optik pelancar manakal gentian optik penerima memiliki satu hujung yang terdedah kepada udara. Penderia berfungsi dengan cara mengukur jatuhan isyarat balikan yang diperolehi melalui analisis garisan dari RODM apabila penderia dalam keadaan bersentuhan dengan bahan api iaitu diesel dan benzene yang telah diuji dalam projek ini. Pengukuran RODM mendapati jatuhan isyarat balikan yang direkodkan oleh RODM bertambah apabila masa kakisan penderia bertambah. Jatuhan isyarat balikan yang tertinggi adalah 2.462 dB dan 3.099 dB telah direkodkan untuk masa kakisan 20 minit masing-masing bagi diesel dan benzene. Kakisan masa sehingga 25 minit didapati telah menyebabkan teras penderia semakin nipis dan mudah patah dan ini memberi had maksima bagi menentukan tahap kepekaan penderia. Peningkatan kepada kepekaan pengesanan telah dicapai menggunakan sistem dua titik penderia gentian optik mod berbilang.

Kata kunci: Gentian optik, Penderia bahan api, reflectometer optik domain masa, penderia gentian optik multi titik

1.0 INTRODUCTION

Fiber-optic sensors are devices that utilize or manipulate light-matter interaction and these can be used to develop many types of sensors such as fiber optic gyroscopes; sensors for temperature, pressure, vibration, and as chemical probes [1-4]. It also can be used to monitor fuel leakage [5], chemical spills that can cause fire, explosion [6] or suffocation due to the conversion of volatile liquid sample into a gas phase [1, 7].

The optical fibre-based monitoring techniques have certain advantages, such as simplicity, versatility, safety as light being used instead of electrical signal, low weight and reliability [1, 2, 13]. They are also considered immune to external electromagnetic sources that contributed to the detection of higher noise [14]. Optical fibres can carry light signals over long distances without appreciable loss of propagation [12]. These advantages offer a suitable sensor technology for numerous applications such as in aircraft fuel systems, industrial and chemical plants, oil pipelines, fuel station and tank storage [8-11].

Numerous works have been conducted in past decades using fibre optic sensors utilizing different light mechanism. Intensity, phase, and wavelength based fibre optic sensors are the most widely used in sensing techniques [15, 16]. Many optical sensors for chemical liquids detection have been proposed, including fibre grating sensors [3, 17, 18], surface plasmon resonance (SPR) sensors [19, 20], partially stripped cladding fibre sensor [21] and the OTDR technique [22, 23]. The chemical information may arise as a result of the samples and light interaction or from the physical characteristics of the optical fibre sensing system under investigation [24, 25].

The technique of optical time domain reflectometry was first demonstrated by Barnoski and Jensen [26]. The OTDR is a well-established technique for characterization of optical fibre networks or for the distributed sensing of physical parameters (strain, temperature, displacement) that detects information from every point along the sensing fibre by measuring from one end of the fibre [15]. In particular, a number of fibre optic chemical sensors have been investigated using OTDR technique [3, 27-29]. This technique has become a practical, useful tool in manufacturing, testing, and installing optical fibre cables. In this study, we performed a Multimode fiber chemical sensors for fuel detection using commercially OTDR as analysis system for return loss measurement.

2.0 METHODOLOGY

2.1 Principle of Optical Time Domain Reflectometer

OTDR is an instrument operating based on backscattered Light to find faults in optical fiber and loss [29,36]. OTDR is normally connected to one end of the fiber and the other end (far end) exposes to air as shown in Figure 1. The OTDR injects a series of laser beam pulses into the fiber under test. Then the pulses of beam propagated along the fibre until reach at the fibre end and is reflected back due to Fresnel reflection at interfaces of fiber – air. The pulses also reflected back due to disturbance inside the fibre because of fiber impurities or any physical change that causes a change in refractive index at the fiber core or cladding. This is known as backscattering. Figure 2 shows such examples of light backscattering inside the fiber and recorded as OTRD trace includes from connectors loss and splice loss.

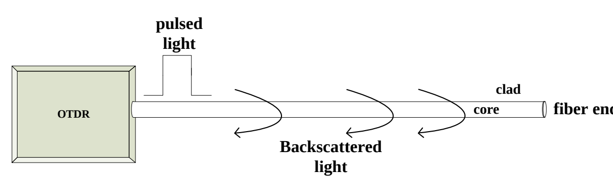


Figure 1 Optical time domain reflectometry principle

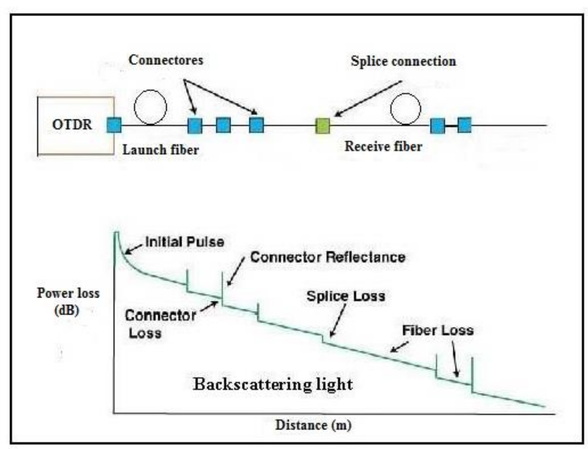


Figure 2 OTDR trace information includes the connecrtor loss and splice loss

Using OTDR, the fibre length can be determined using equation 1[30, 31]:

$$z = \frac{tc}{2n} \quad (1)$$

where c is the speed of light in vacuum, t is the time elapsed and n the refractive index of the core. The total backscattered power can be determined by equation 2 [31-33]:

$$P_{t(z)} = P_0\left(10^{\frac{-z\alpha}{10}}\right) \quad (2)$$

Where P_o is the input power, $P_{t(z)}$ is the output power and α is total losses in this study, The MW9070B (Anritsu) Optical Time Domain Reflectometer (OTDR) was used to record the return loss within the fibre. The OTDR trace can be used to measure total loss, interval loss, splice loss and length of fibre. It operates at wavelengths of 850 and 1300 nm with the pulse width range varied between 20 and 500 ns. The OTDR has maximum dynamic range up to 50 dB and the average scan speed of 150s, with a spatial resolution at the meter scale. The 1300 nm wavelength with a pulse width range of 20 ns were used in this work to measure the return loss during the fuel detection.

2.2 Fabrication of Sensor Fiber

In the proposed system, the Multimode silica optical fibre (MMF) with length 60 m and RI 1.456 was used. the fiber consisting of core and cladding with diameters of 50 and 125 μm respectively. The MMF is used in sensor system used in this sensor system as it allows a larger amount of laser energy to propagate within the sensing region compared with using SMF thus increases backscatter signal and return loss[38].

The external buffer of the MMF was stripping up to 1cm. The fibre is then cleaned using acetone followed by drying with dust free tissues. The sensor preparation included in removing a small portion of clad layer of the fibre to allow physical contact between fiber core and the fuel during detection process. The removal of a small portion of cladding was performed using etching process. The etching process includes fixing the MMF on the plastic holder, then the MMF is placed in the HF acid bath with 49% concentration to remove 1 cm of cladding layer. Two plastic tubes were used to protect the MMF from damage during the etching process. After removing the cladding, the MMF subsequently rinsed with deioized water and methanol and followed by drying with dust free tissues. The purpose of etching is to allow interaction between propagating light and sample. A better contact between them will result in a better detection sensitivity and can be measured using standard OTDR.

2.3 Experimental Setup and Sensing System

Figure 3 shows the experimental setup of optical fiber sensor system based MMF sensor and OTDR for fuel detection.

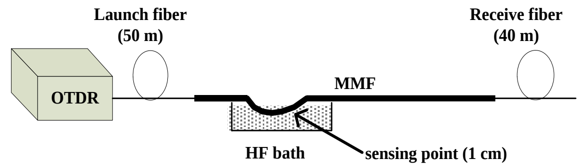


Figure 3 The instruments arrangement for system setup to remove the cladding of MMF

The OTDR was connected to a single mode fibre (launch fiber), Multimode fibre (MMF) and additional single mode fibre (receive fiber) from one end while the other end of the fibre left exposed to air. This configuration allows to locate the position of sensing region on recorded OTDR trace as it shows as a drop in the return loss signal similar to splice loss as shown in Figure 2. The launch fiber allows the OTDR to decrease the effect of dead zone where OTDR does not capable to resolve two adjacent points. A receive fiber is used to extend the pulse signal to travel at longer distance prior to reflected back through Fresnel reflection while avoiding detection on OTDR trace within the dead zone area. The fusion splicing method was used to join the MMF with SMF using splicing machine (Fujikura FSM 60S). The OTDR acts as both a light pulse transmitter and receiver. The light is emitted from OTDR source inside the optical fibre, and the backscattered and reflected light was measured at the same input end of the fiber in the form of attenuation or optical return loss. After recording the OTDR trace within the fibre in air, the fibre sensor immersed in diesel (RI 1.446) and benzene (RI 1.501) respectively. The refractive indices were measured using a refractometer, and the optical return loss was measured using OTDR trace.

3.0 RESULTS AND DISCUSSION

3.1 Single point Sensing System for Fuel Detection

Figure 4 shows the relationship between the time etching and removal cladding thickness of the MMF, where HF acid completely dissolved the thickness of cladding within 20 minutes. This leads to reduce the diameter of the fibre from the125 μm to 50 μm.

Moreover, if the time etching was more than the 30 minutes the whole fibre found to totally dissolve and this set the limit of detection sensitivity by means of etching.

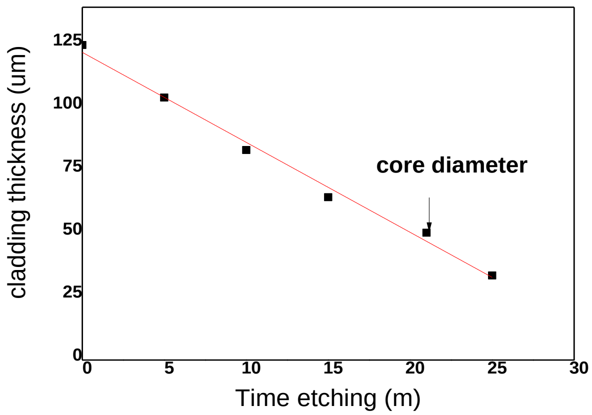


Figure 4 The relationship between the thickness of the clad layer of the MMF and the etching time

The image of MMF was obtained using Scanning Electron Microscope (SEM) before and after the etching process as shown in Figure 5. A significant reduction in the fiber diameter from 125 μm to 50 μm can be seen from Figure 5.

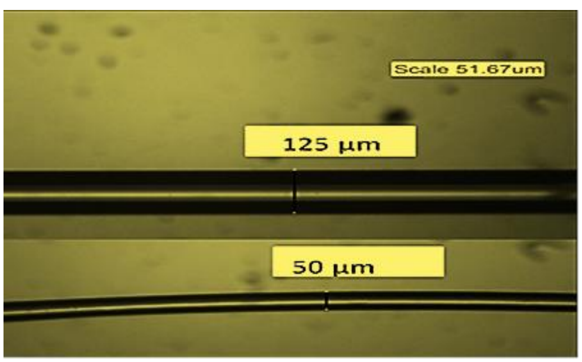


Figure 5 Electron Microscopic image of MMF before and after over cladding removal

Figure 6 and 7 show typical OTDR traces when the sensing point of MMF is exposed to diesel and benzene respectively. In the presence of diesel and benzene, the step drop measured from OTDR trace found to have the biggest drop (highest return loss) compared with without any sample in contact with the etching MMF and without etching. The highest loss of optical signal when the sample in contact with the MMF sensor is due to the increase in the radiation mode. More light escapes in radiation mode as the different between refractive index of fiber core and sample no longer effective for total internal reflection to guide the light propagate within the fibre core-cladding interface [29, 34, 35]. This is different when the fiber is not etching as total internal reflection still govern the light to propagate as no contact between fiber core and sample. The drop in the loss as observed in the OTDR trace is only contributed by splicing loss. The return loss of increased to about 2.462 dB and 3.099 dB measured for the diesel and benzene respectively taking without etching OTDR trace as the reference point. It can be seen that the return loss of benzene is larger than the loss of diesel about 0.5484 dB. This is due to the refractive index of benzene is greater than the refractive index of diesel thus more light escapes in the case of benzene than diesel.

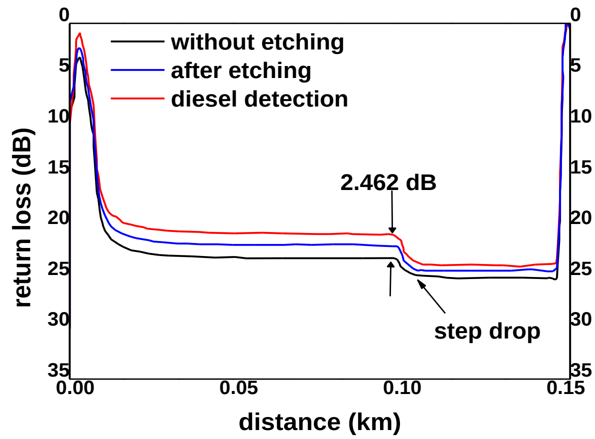


Figure 6 OTDR traces of sensor response in diesel condition, step drop indicates the position of contact

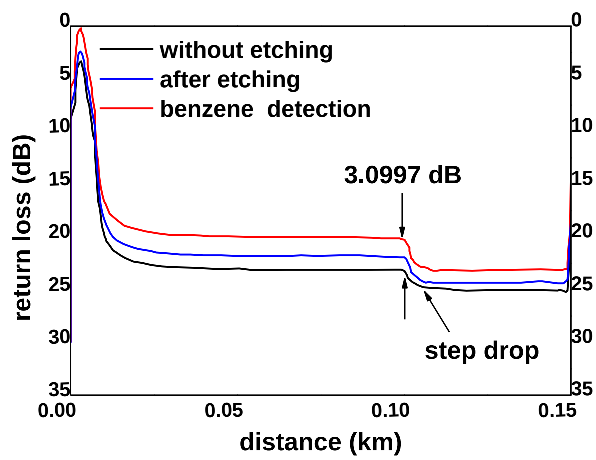


Figure 7 OTDR traces of sensor response in benzene condition, step drop indicates the position of contact

3.2 Tow point Sensing System for Fuel Detection

The efficiency of this sensor can be enhanced by using a two point or more sensing point as shown in Figure 8. Experiments were conducted as previous with two sensing points of the MMF. The results show that the detection of diesel and benzene produce a higher in the return loss as shown in Figure 9 and Figure 10.

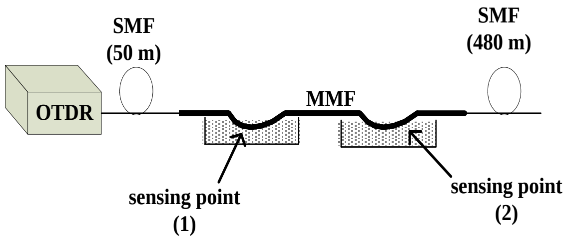


Figure 8 Experimental setup of the optical fiber sensor system for two sensing points

The return loss of diesel and benzene for the two point MMF sensor found to be 3.736 and 5.711 respectively. Using two point sensing system allows more light to escape resulted from radiation mode at each point. The light interaction with fuel at the sensing points reaches a value where decreasing the amount of light in the fibre, leads to increasing the return loss along the fibre and decrease in the fibre transmittance. This indicated the possibility of construction of multipoint sensor system (distribution sensor) for fuel detection along of fiber detection. However, the use of multipoint is subjected to the capability of the OTDR to deliver the laser pulses until reach at the far end of the fibre and receive the reflected light at its detector. This is because the multipoint of MMF meaning that more light will escape as radiation mode and light will has less power when it reach at the far end and the reflected light might not strong enough when detect by the detector.

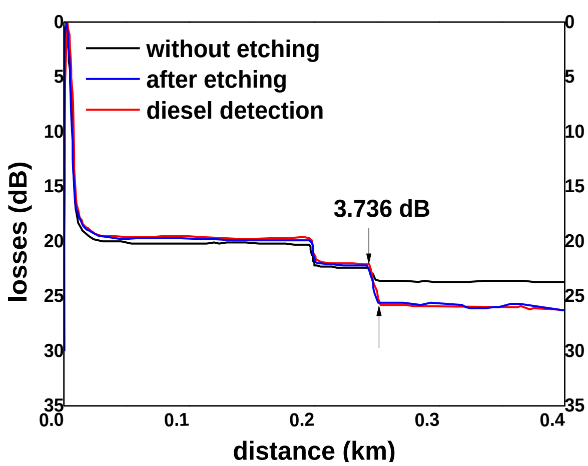


Figure 9 OTDR traces of MMF with multipoint sensing in diesel condition

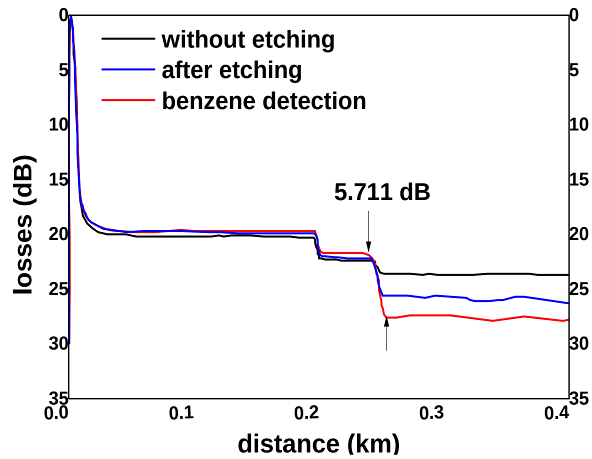


Figure 10 OTDR traces of MMF with multipoint sensing in benzene condition

4.0 CONCLUSION

In this paper the Multimode optical fibre sensing system for fuel leakage monitoring was used, and the optical losses were measured by the OTDR device. The results show the high single step drop in the OTDR trace at sensing point (uncladding region), with losses 2.462 dB and 3.099 dB for the diesel and benzene respectively. Also this study includes the distribution sensing system along the MMF for fuel leakage detection. The single step drop was observed in the OTDR trace and the losses of diesel and benzene were 3.736 and 5.711 respectively. All collected results show a clear single step drop in the OTDR traces with a good response of MMF. Additionally, This work shows the possibility of constructing a multipoint sensing for fuel detection.

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