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Measurement of Vibration of Honda Crv using Distributed Fibre Optic Sensor

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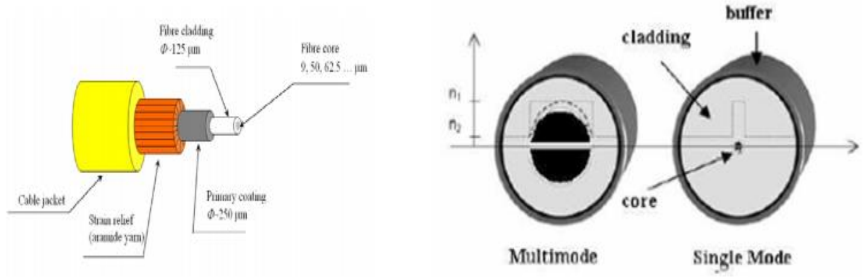
Abstract

Optical fibres are made of silicon glass or plastic for transmitting light signal over long and short distances. Technological advancement in photonics has led to its use in fibre optic sensor (FOS), which has gained popularity in present day sensing technology due to its immunity to electromagnetic interference, resistance to environmental toughness, remote sensing capabilities amongst others. Fibre optic vibration sensor converts vibration signal to light signal. A distributed fibre optic vibration measurement is employed to measure the frequency of vibration caused by controlled vehicular movement between Capitol and Energy Centre, in the University of Benin. Optical Time Domain Reflectometer (OTDR) is used to obtain the millisecond snapshots of the signal arising therefrom. An expression for forced vibration on the multi-mode fibre caused by external perturbation was derived to obtain the phase shift and change in propagation of the signal. MATLAB 7.3 software was used to transform the signal from space domain to frequency domain and hence carry out the spectral analysis. Data obtained from the Fiberizer cloud showed high attenuation contributed to low loss and low attenuation led to high loss. Vehicles movement were classified according to their speed. Comprehensive spectral analysis was carried out for Honda CRV at low and high speed. Frequency distribution at low speed gave 0.283Hz, 0.291Hz, 0.201Hz and 0.445Hz for Honda CRV.

1. Introduction

1.1 Optical Fibres

Optical fibres are optical waveguides usually made of glass, plastic or polymer with a diameter in the order of 0.1mm that enables the conveyance of light signals over long distances [1]. The **Fibre Optic Sensor** (FOS) has the ability to measure parameter such as strain, pressure, force, rotation, acceleration, electric and magnetic fields, acoustics, temperature, humidity, pH ,viscosity, chemicals, and biological elements such as Deoxyribonucleic acid (DNA), single viruses, and bacteria based on the end user requirement. The FOS is a sensing unit with a vibration sensor which can measures the vibration caused by vehicular movements [2].



(a) (b)

Figure 1: (a) Fibre Optic Cable [3] and (b) Types of Fibre Cables [1]

The advantages of optical fibres includes lightweight ,small size, passive composition, resistant to electromagnetic interference, high sensitivity ,large bandwidth, long range operation, multifunctional sensing possibility (distributed sensing), easy integration into a wide variety of structures, robust, more resistant to harsh environments, inherent safety and suitability for extreme vibration and explosive environments; and quick response in sensing different chemical and physical variables [4][5][6].
The principle of light propagation in optical fibre is based on total internal reflection which is the complete reflection of light rays within a medium from the surrounding surfaces as shown in figure 2 [7].

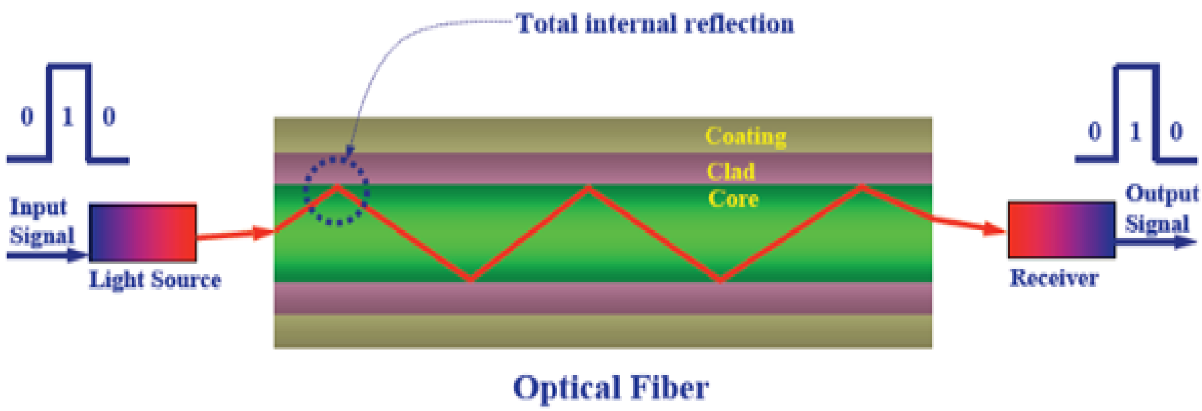


Figure 2: Propagation of light in an optical fibre [3]

Optical fibre as a vibration sensor can be classified based on its trait as well as on the measurement capabilities as shown in table 1.

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Table 1: Optical Fibre Vibration Sensor Applications [1][6][8]

CLASSIFICATION	TRAIT	MEASUREMENT TECHNIQUES	MEASUREMENT PARAMETERS	WORKING PRINCIPLE
Point sensor	Discrete points at a sensitized tip in the measurand field	Interferometric: Fabry-Perot, Mach-Zehnder Michelson	Temperature, strain, pressure, displacement, refractive index etc.	Intensity/ phase
Quasi-Distributed sensors	Variable is measured at discrete points along an optical fibre	Interferometric: Sagnac	Optical gyroscopes, strain, pressure, twist	Intensity/ phase
		Fibre Bragg Gratings	Temperature, strain, pressure, displacement, acceleration, etc.	Wavelength
Distributed sensors	Measure along the length of the fibre itself	***RAYLEIGH SCATTERING***	Temperature, Strain, ***Vibration***	Intensity (OTDR)
		Raman scattering	Temperature	Intensity (OTDR)
		Brillouin Scattering	Temperature, strain	Intensity (BOTDR)

A vibration-based vehicle classification system using distributed optical sensing technology based on their axle type indicated optical fibre as a sensor can be used to classify vehicles [11]. The materials used include coupler, processor, photodetector, laser light, fibre optic cable and acquisition card. An embedded fibre optic cable was used as a distributed sensor to obtain vibration resulting from controlled vehicular traffic. A multi-step classifier was designed to categorize vehicles into different classes. The sampled data was used to estimate vehicles based on their axle configuration and vehicle categories. A review of Distributed Fibre-Optic Sensors for Vibration Detection with a Backscattering-Based Sensing Technology using OTDR [12] was done and it was discovered that the reflected backscattering power decreases exponentially with respect to time/distance along the fibre. A review of Distributed Fibre-Optic Vibration and Temperature Sensing Technology and did a comparative analysis on Rayleigh and Raman scattering using a Phase OTDR was carried out. The vibration frequency and temperature fluctuation in oil reserve was obtained and measured [13]. A research work on vibration measurement using a phase OTDR with fibre optic cable as sensor was carried out and the results shows that the signal-to-noise ratio and frequency response were measured [14].

2. Materials and Method

2.1 Theoretical Background

In order to achieve a valid result, the light intensity propagation in a multi-mode fibre was derived from Helmholtz equation which originated from Maxwell's equation to deduce the effect of forced vibration on the cable and hence the total light intensity after perturbation. Light in fibre optics are propagated in cylindrical coordinates which gives the general form of Bessel's equation after using differentiation by parts on the cylindrical coordinates.

To obtain the forced vibration and total light intensity, we have from Helmholtz equation [9][10],

$$E = A_m J_{n_m}(u_m r) cos n_m \theta e^{-i\beta_m z}; \quad B = A_l J_{n_l}(u_l r) cos n_l \theta e^{-i\beta_l z} \qquad (1)$$

From Poynting vector, light intensity in an optical fibre is given by

$$I(r,\phi) = \frac{1}{2}Y\sum_{m=0}^{N}\sum_{l=0}^{N} A_m A_l J_{n_m}(U_m r) J_{n_l}(U_l r).\cos(n_n\phi)\cos(n_l\phi)\, e^{[-i(\Delta\beta_{ml}z-\Delta\phi_{ml})]} \quad (2)$$

Equation (2) can be rearranged as follows:

$$I(r,\phi) = \frac{1}{2}Y\sum_{m=0}^{N}[A_m^2 J_{n_m}^2(u_m r)cos^2(n_m\phi) + 2\sum_{l=m+1}^{N} A_m A_l J_{n_m}(U_m r) J_{n_l}(U_l r).\cos(n_m\phi)\cos(n_l\phi)\cos(\Delta\beta_{ml}z - \Delta\phi_{ml})] \quad (3)$$

When forcing function, F(t) is applied, equation (3) becomes

$$I_i = A_i\{1 + B_i[cos\delta_i] - F(t)\theta_i \sin(\delta_i)]\} \quad (4)$$

If the force F(t) is not constant (vibration force), then the change in detected intensity is

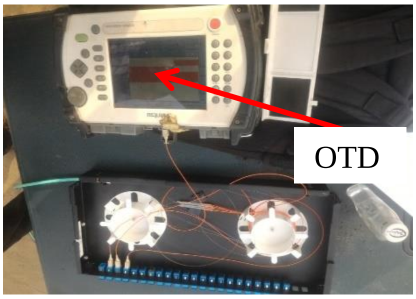
$$\Delta I_T = [\sum_{i=0}^{N}|C_i sin(\delta_i)|]\left|\frac{dF_{(T)}}{dt}\right| \quad (5)$$

2.2 Experiment

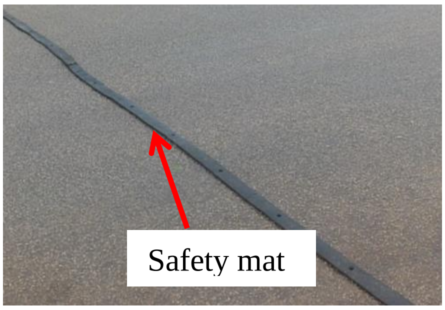
Materials used

- ✓ OTDR (Anritsu MT9083AI Access Meter),
- ✓ Multimode Fibre Cable (about 61 meters),
- ✓ Patch Panel [comprises of pigtail, patch cord (Fibre LAN)]
- ✓ Safety Mat (Insulated material)

A multi-mode fibre cable was attached to a patch panel and mounted across the road at Ikpoba River Road by The Capitol with a safety mat on it as an insulating material to protect the fibre cable from damage for the controlled analyses. The Capitol area was best chosen because of low vehicular movement at that location so there can be proper control of vehicles around.



(a) OTDR and patch panel connect



(b) Fibre cable covered with safety mat

Figure 3: Experimental setup

The plate below shows the Honda CRV used in the experiment on the fibre cable with the specifications of the vehicle beside it

Honda CRV Specifications:
Model: September 2003
Length: 279cm
Tyre: 215/70 R16
Width of tyre: 19cm
GVWR: 1959.51kg
GAWR Front: 980kg
GAWR Rear: 1021kg
(Source: Vehicle label by drivers' seat)

Figure 4: Honda CRV's front tyres on the fibre

The connector is connected at the fibre end attached to the OTDR, while the OTDR records as a reflective event as shown in figure

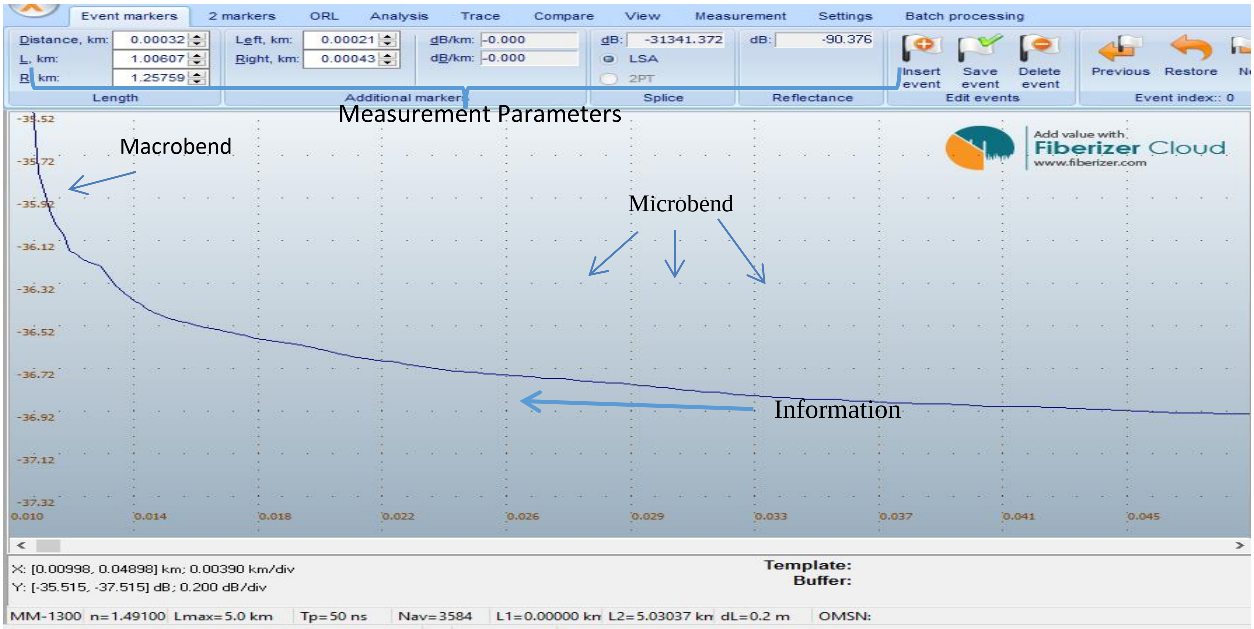


Figure 5: Fibreizer Cloud Trace for controlled vehicular movement of Honda CRV

3. Results and Discussion

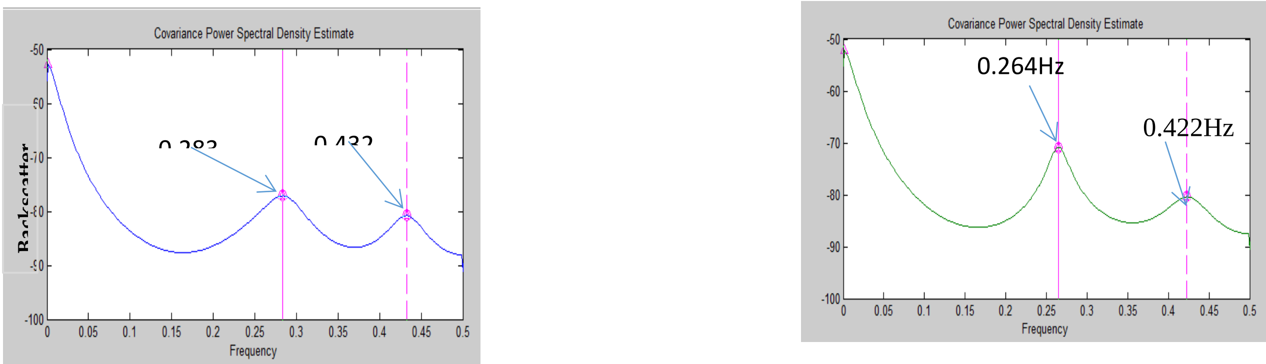
The first analysis was to drive the vehicle at low speed (about 10km/hr) over the sensing fibre. Thereafter, the Honda CRV's momentum was increased to a higher speed (about 80km/hr) and the results obtained are shown in table 1.1

Table 1.1: OTDR trace result for Honda CRV at low and high speeds respectively

DISTANCE (km)	QUIET TRACE (dB)	HONDA CRV (dB)	
		Low Speed	High Speed
0.01207	-36.081	-36.114	-36.132
0.01227	-36.110	-36.132	-36.143
0.01247	-36.123	-36.154	-36.161
0.01268	-36.135	-36.167	-36.177
0.01288	-36.143	-36.174	-36.225
0.01308	-36.185	-36.219	-36.232
0.01328	-36.222	-36.256	-36.269
0.01348	-36.253	-36.286	-36.299
0.02978	-36.658	-36.737	-36.763
0.02998	-36.662	-36.741	-36.766
0.03018	-36.665	-36.744	-36.767
0.03038	-36.668	-36.747	-36.770
0.03058	-36.671	-36.751	-36.774

0.03078	-36.675	-36.752	-36.777
0.03099	-36.678	-36.756	-36.780

The quiet trace has to do with when the vehicle did not pass on the fibre cable otherwise known as the rest point. The vehicle was not driven over the cable but light signals and pulses were sent to obtain the readings for the quiet trace as shown on table 1.1 above.
The values from table 1.1 above gave rise to carry out a comprehensive spectral analysis at both low and high speed as shown below



(a) (b)

Figure 6: Power Spectral Density Analysis of Honda CRV at (a) low Speed (b) high speed

Low Speed: The CRV was accelerated from a distance and as it moves close to the fibre, light pulse of 50ns was sent from the OTDR into the fibre. The vibration created excitations on the fibre which generated the spectra as seen in in figure 5(a). The speed was calculated using Zhao's method [11] by measuring the distance between the front and rear axles and recording the time it took both axles to cross the sensing fibre. The OTDR recorded an attenuation of 0.224dB with resulting spectra showing two broad peaks of 0.283Hz and 0.432Hz at backscatter levels of -77.13dB and -80.79dB respectively.
High Speed: The speed of the CRV was increased. The front and the rear axle cross the sensing fibre after 1 second. The vibration caused by the CRV created excitations on the fibre. The OTDR recorded an attenuation of 0.073dB with resulting spectra showing one dominant frequency peak of 0.264Hz at a backscatter level of -70.82dB and a broad peak of 0.422Hz at a backscatter level of -80.39dB. The dominant peak is due to increase in the speed.

5. Conclusion

This work is focused on measurement of vibration for controlled vehicular movement using distributed fibre optic sensor (DFOS). The Φ-OTDR was used to send 50ns light pulses into the fibre to measure the Rayleigh scattering caused by external perturbation. The backscattered light result in weight-in-motion were measured and analyzed. A distributed fibre optic sensor is used to measure vibration signal caused by controlled vehicular movements (Honda CRV) at Ikpoba River Road by The Capitol, University of Benin.

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