Design of micro bending deformer for optical fiber weight sensor

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Abstract. The road damage due to excessive load is one of the causes of accidents on the road. A device to measure weight of the passing vehicles needs to be planted in the road structure. Thus, a weight sensor for the passing vehicles is required. In this study, we designed a weight sensor for a static load based on a power loss due to a micro bending on the optical fiber flanked on a board. The following main components are used i.e. LED 1310 nm as a light source, a multimode fiber optic as a transmission media and a power meter for measuring power loss. This works focuses on obtaining a suitable deformer design for weight sensor. Experimental results show that deformer design with 1.5 mm single side has level of accuracy as 4.32% while the design with 1.5 mm double side has level of accuracy as 98.77%. Increasing deformer length to 2.5 mm gives 71.18% level of accuracy for single side, and 76.94% level of accuracy for double side. Micro bending design with 1.5 mm double side has a high sensitivity and it is also capable of measuring load up to 100 kg. The sensor designed has been tested for measuring the weight of motor cycle, and it can be upgraded for measuring heavy vehicles.

1. Introduction

Many accidents in highway were caused by road damage due to overload vehicles. Although the government has provided weighbridge in some area, the drivers are generally reluctant to measure the weight of their vehicle. Most drivers said that it was time consuming and full of birocracy, so they tend to avoid such a measurement or to cheat whenever they have to get in the weighbridge. Therefore, we need a sensor that can detect a dynamic load with a high sensitivity/fast response so the drivers do not have to stop their vehicles, resistant to water and electromagnetic waves, low cost and capable to be planted in highway structure.

Currently, the weight sensor based optical fiber is one of the alternatives to measure load [1]. Micro bending fiber has been widely used for displacement sensor, pressure and temperature [2]. Such an optics-based sensor has a sufficiently small size, high sensitivity and not interference by electromagnetic waves [3]. Hence, the sensor is quite safe to be planted in highway structures so it will facilitate the process of measurement and avoid a chance for the driver to cheat. Setiono (2012) has developed a weight sensor with optical fiber models with dual side deformer made of wood and LASER 1310 nm as a light source to measure the weight of a motorbike [4]. However, this design has not been developed to a higher load.
Research Center for Physics has developed the weight sensor to detect the load up to 8 tons. In our previous studies, it was found that a 1310 nm LED as a light source has a high validity to be integrated with a weight sensor and resulted in measuring the load up to 100 kg with 99.1% accuracy\cite{5}. Some important points in the micro bending sensor were a design of deformer, bending period and the type of fiber\cite{6}. Therefore, in this study we used a multimode fiber optic with variation in the deformer i.e. single side and double side (sandwich). The purpose of this research was to get the design of deformer that was suitable to integrate with a weight sensor.

1.1. Optical Fiber and Weight Sensor by Micro bending

Optical fiber is a dielectric waveguide where the core material has a refractive index greater than the cladding. The optical fiber consists of a core to send signal optical data from the light source to the receiver, cladding which is a material surrounding the core that reflects the light into the core, and a buffer coating which is a plastic coating that protects the fiber from damage. Plastic coating around the core and cladding does not only strengthen the fiber core, but also helps the absorption and acts as an extra shield in bending the cable. When the incident angle of light is less than or equal to the acceptance angle, there will be a total reflection in the fiber core, where energy will be transmitted so that any losses larger than an optical power can be avoided.

Micro bending is the bending of an optical fiber in micro-size and affects the optical power loss. This bending is caused by mechanical stress on the optical fiber in the axial direction. If the optical fiber is bent in axial direction of the optical axis, the transmission coefficient of the light will change with a magnitude as the following equation\cite{7}:

\[
\Delta T = \frac{\Delta T}{\Delta \lambda} A_p k_f^{-1} \Delta P
\]  

(1)

with \(\frac{\Delta T}{\Delta \lambda}\) are coefficient which relates to the change in transmission of light in a deformed fiber, \(A_p\) is the deformer area, and \(\Delta P\) are the changes in pressure applied to the sensor.

Several factors which affect the change of transmission coefficient are the force applied by the vehicle load, bending the period and the characteristics of the optical fiber. Bending period in a step index optical fiber was determined by the equation\cite{1}:

\[
SI = \frac{\sqrt{2\pi R_{\text{core}} n_1}}{NA}
\]  

(2)

The change in the transmission coefficient of the optical wave due to bending period can be analyzed by equation:

\[
\Delta T = \frac{y \Delta F A \lambda^3}{3n Y R_{\text{core}} \eta}
\]  

(3)

with \(y\Delta T\) is the attenuation coefficient of fiber, \(\Delta F\) is the change in load, \(A\) is a cross-sectional area of fiber bent, \(\lambda\) is the bending period, \(Y\) is modulus Young of core material, \(R_{\text{core}}\) is radius core fiber, \(n_1\) is refractive index of core, \(\eta\) is the number of intervals bending, \(\Delta P\) is the change in pressure due to the load, \(NA\) is numerical aperture.

Transmission of light in an optical fiber would result in attenuation. It is caused weakening of energy so that the amplitude of wave would arrive at receiver smaller than those sent by the transmitter \cite{8}.

At figure 1, the deformer consists of two grooved plates and the optical fiber which is sandwiched between the plates. When the bend radius exceeds the critical angle, the light begins to leak out of the cladding resulted in intensity modulation. When a small bend is applied on the fiber, a certain portion of the propagation of light in the fiber core are lost and then incorporated in the radiation mode. A
Merger mode can be achieved by using a corrugated plate that changes the fiber shape into a series of bends. Therefore, micro bending causes the decrease in the light intensity.

Light emitting diode (LED) is a type of diode that can emit light. It is often used as a light source as well as an information carrier. In operation, the LED has a feature that does not require stabilizers for optical circuits and emits light with a little temporal and spatial coherence. That means LED light has a narrow frequency spectrum. LEDs have many advantages for its low power and long lasting.

2. Experimental

In this study, we used a step-index multimode optical fiber with a wavelength range of 850 - 2400 nm, with a radius core of 50μm, a refractive index core of 1.43 and a numerical aperture (NA) of 0.22. The light sensor was an 1310 nm LED. The length of the sensor was 50 cm and an optical power meter was used to detect the transmitted light from the fiber. Using equation (2), we can obtain the bending period of optical fiber. This study aimed to compare the performance of weight sensor with two types of a bending period i.e. (1.5 ± 1) and (2.5 ± 1) mm, both in the single side and the double side configuration as shown in figure 2. The thickness of the deformer plate was ± 1.5 cm.

In a typical experiment, the light from LED propagated on the optical fiber that micro-bended by the deformer, as shown in figure 3. The other end of the fiber was connected to an optical power meter. Initial optical power, $P_o$, was a power when the sensor in its initial condition with no load and the output optical power was the power when the sensor was being pressed by a load. The difference of both was the optical power loss that we were interested here.

![Figure 1. Microbending optical fiber.](image-url)

![Figure 2. Design of deformer with a bending period of 1.5 (a-b) and 2.5 mm (c-d). Both in the configuration deformer of single (a, c) and double side (b, d).](image-url)
Figure 3. Set up experiment design of micro-bending sensor.

3. Result and Discussion
According to Saleh et.al [9], the change of transmission coefficient can be represented by optical power loss. A good sensor required a linearity correlation between variable control and variable response [10]. As implied by equation (1) and (2), the changes of transmission coefficient for the sensor should be linear to load. Our experimental results for a load of 10 - 100 kg were shown in figure 4.

For the deformer with a bending period of 1.5 mm in the single side configuration, we found that response profile of the optical power loss was not linear but tends to be constant. With an accuracy of 4.3% and the standard error of 95.7%, this type of sensor was not fulfill the criteria as established by the equation (1) and (2), and hence it is not suitable for weight sensor design. In the other hand, for the deformer with a bending period of 1.5 mm in a double side configuration, the linearity was good and the accuracy 98.77% and a standard error of 1.23% were estimated.

Loss of optical power at the sensor with the bending period of 2.5 mm in single side configuration was shown in the graph C at figure 5 for a load of 10 - 100 kg. The linearity was only found when the sensor was pressed by a load of 10-60 kg, but not for a load of 70 - 100 kg. Overload pressure of 70-100 kg resulted in a decrease optical power loss. It might be because of the flattering of the optical fiber after pressed by a load of 10-60 kg. Flattered fiber optic made wave guidance in fiber not perfect, the leakage of optical power in fiber and hence, caused the signal attenuation. The level of accuracy and standard error measurement by were 71.18 and 28.82%, respectively. From these data, it can be stated that the type of weight sensor was only able to detect a load less than 60 kg, not for the load exceeds 60 kg.

Graph D at figure 4 shows the experimental results for the weight sensor using a deformer with a bending period of 2.5 mm in double side configuration. It is clear that the sensor was unstable to measure the load. Loading of 10 - 40 kg and 70 - 100 kg showed a linear increase in power loss, but when it was pressed by a load of 50 - 60 kg, the graph profile became volatile. Level measurement accuracy with double deformer side was 76.94% and the standard error was 23.06% standard error.

It can be concluded that the weight sensor using a deformer with a smaller bending period in a double side configuration was the best design in our case. The reason is that in a single side configuration, the optical fiber was bent only in one side and the produced arch disordered the fiber resulting in a disturbance of light propagation inside the fiber. Hence, only a weakened optical signal with a high power loss was measured. In the contrast, if the optical fiber was bent in a double side configuration, the series of arch were equally formed both side imitated a tooth pattern. In this kind of configuration, the optical signal was repeatedly weakened and strengthened many times during its propagation in the sensor, so the optical power loss due to load pressure was relatively significant. A smaller bending period was preferable, making sure a high number of arches produced in the fiber.
Optical fiber multimode has a mode dispersion more than a single mode optical fiber [8], so that the time needed by the light for going out of the fiber would be much longer than the one for a single mode. However, this work showed that the multimode fiber weight sensor with a standard error of 1.23% have been successfully developed to measure the load of 10 – 100 kg if using a deformer with a small bending period in a double side configuration. This design can be prospectively applied as a weight sensor for a two-wheeled motor vehicle with hundreds weight. This research will be developed further in order to measure loads up to 8 ton.

4. Conclusion
We have successfully developed a weight sensor that can measure a static load of 10-100 kg with the accuracy level of 98.77% using a deformer with a bending period of 1.5 mm in double side configuration. The light source used was a low-cost LED with a wavelength of 1310 nm. Further, it is significantly needed to do the next experiment to test the design with a load more than 100 kg.

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