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Vehicle Speed Calculation Using Weigh-in-Motion Sensor Based on Fiber Optic

Mefina Yulias Rofianingrum*, Bambang Widiyatmoko, Rini Khamimatul Ula
Research Center for Physics
Indonesian Institute of Sciences
Tangerang Selatan, Indonesia
*mefi001@lipi.go.id

***Abstract*—Weigh-in-Motion technology has been used to monitor the traffic load volume and prevent road damage. It has the potential to minimize problems of overloading practice. WIM technology has made it possible to measure a vehicle's weight without stopping. However, the vehicle speed is an important issue that should be considered in measuring a moving vehicle's weight. Therefore, the WIM system also has a speed sensor beside the load sensor. A proposed WIM sensor based on fiber optic made it possible to measure both the vehicle's weight and speed at once without speed sensor addition. This work proposed a method to calculate the speed of the vehicle from the fiber optic-based WIM sensor's output. The result shows that the proposed method proved to be reliable and close to the real speed. However, the high specification of detector and data processor are needed to avoid the high calculation error in measuring higher speed vehicle.**

Keywords—Weigh-in-Motion, fiber optic, speed, weight sensor, calculation method

I. Introduction

The increasing traffic load volume is one of the causal factors of road damage. The increasing traffic load volume is correlated with the traffic load deviations that occur when heavy vehicles carry loads beyond the allowable carrying capacity. An overloaded vehicle can cause its axle load in terms of ESAL (Equivalent Standard Axle Load) to increase rapidly. The overloaded vehicles decrease the performance of road pavement. The overloading phenomena can be controlled by monitoring the weight of the vehicle that passes the road. Weigh-in-Motion (WIM) is a technology that is capable to measure the weight of a vehicle without stopping the vehicle [1-7].

Generally, a WIM system consists of a load sensor, speed sensor, and computer interface. The speed sensor is usually placed before the load sensor to detect the vehicles and measure their speed. The computer interface monitors and stores the traffic data such as the data of axle spacing, vehicle weight, and vehicle speed [8]. There are two types of vehicle speed sensors. They are pavement invasive speed sensor and non-pavement invasive speed sensor. Generally, there are three types of pavement invasive speed sensors. They are inductive loop, magnetic, and magnetometer. Each of the sensors has advantages and problems. Most of their problems are related to the installment's problem, maintenance's issue, and the electromagnetic susceptibleness [9-10]. To simplify the WIM system, we can use the load sensor that has the capability in measuring both the vehicle's weight and the vehicle's speed.

WIM system often uses a bending plate, piezoelectric sensors, or load cell as load sensor. However, most of them have several problems in corrosion issue, electromagnetic susceptibility, and complex installment [3-7]. The fiber optic load sensor in this work is used to fulfill the requirement of accuracy at reduced costs, solve the conventional load sensor's problem and also simplify the WIM sensor requirements.

Research related to the fiber optic sensor has begun many years ago. Some of them used the Fiber Bragg Grating as the sensing component [11], birefringence effect in Sagnac loop interferometer setup [12], micro bend theory [13-14] and macro bend theory [15]. The fiber optic load sensor in this work used the macro bend theory as its principle of operation. Sensors based on bending losses have been used in temperature sensing [16], displacement detecting [17], and wearable sensing [18]. The work presented here proposes an approach to calculate the vehicle speed from the output signal of the fiber optic load sensor based on macro bend theory.

II. Design of Sensor and Principle of Operation

The sensing principle of the macro bend sensor relies on the detection of intensity losses when the fiber is bent. In this work, the proposed sensor detects the change of the loss that is caused by the change of macro bending diameter when the sensor is loaded. Figure 1 shows the sensor's principle of operation, where d is the initial macro bending diameter, d' is the final macro bending diameter and Δd is the change of macro bending diameter. The load sensor used in this work is fabricated by wrapping a single-mode silica fiber optic around a silicone rubber cylinder. Figure 2 shows the design of the fiber optic load sensor. The diameter of the silicone rubber cylinder equals the initial macro bending diameter (d). The diameter (d) and length (L) of the cylinder are 3.85 cm and 90 cm. The bending distance of the sensor (D) is 1.5 cm.

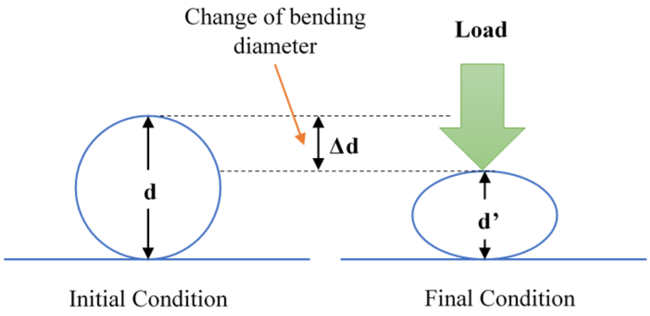

Fig. 1. Sensor's principle of operation.

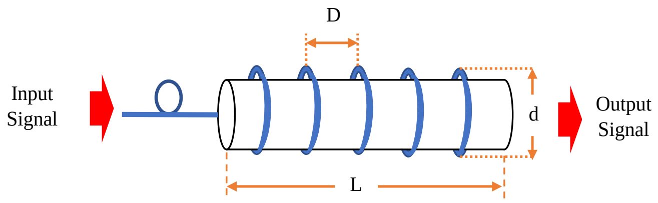

Fig. 2. Sensor's design.

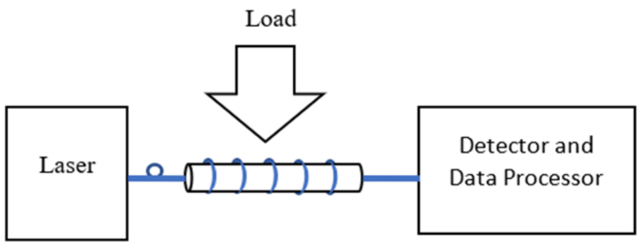

Fig. 3. Experimental setup.

III. Methods

A single-mode fiber optic is wrapped around a silicone rubber cylinder with a diameter of 3.85 cm as showed in Figure 2. Figure 3 shows the experimental setup of this work. The fabricated sensor is linked to an optical laser source and photodetector that is equipped with the data processor. The sensor is placed on the road while the optical laser source and the detector with the data processor are being located on the road's side or in the real environment, they will be placed in a station or guard room. The input wavelength is 1550 nm. To test the sensor, the dynamic load is applied with varied speed. The load that is applied to the sensor is a motorcycle with a driver and no passenger. To calculate the vehicle's load, the static loading data is needed as the calibration factor that will not be showed in this paper. To calculate the vehicle's speed, the data of vehicle axle distance is needed. The calculated vehicle speed is obtained by using the common formula below,

$$v = \frac{s}{\Delta T} \quad (1)$$

where s is the distance of the vehicle's front wheel and back wheel and ΔT is the period that is showed in sensor's response.

IV. Results and Discussion

The optical laser source transmits an optical wave with wavelength 1550 nm into the fiber optic sensor and then the transmitted wave is received and processed by the detector and data processor. When the vehicle passes the sensor, the transmitted wave that is received by the detector (received wave) will change. The received wave will be converted into voltage unit and then processed and calculated into vehicle's load and speed. Figure 4 shows the example of the sensor's response. The two peaks in the figure show the load from the two wheels of the motorcycle. V_0 shows the initial signal of received wave before and after the loading; V_f and, V_b show the sensor's response when the front and back wheel of the vehicle pass on the sensor, δ_{tf} and δ_{tb} show the time period of the front and back wheel; and ΔT shows the period of the vehicle to pass on the sensor.

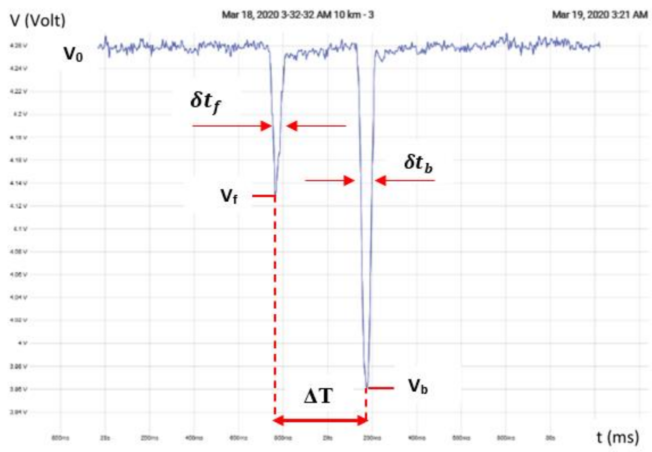

Fig. 4. Sensor's response.

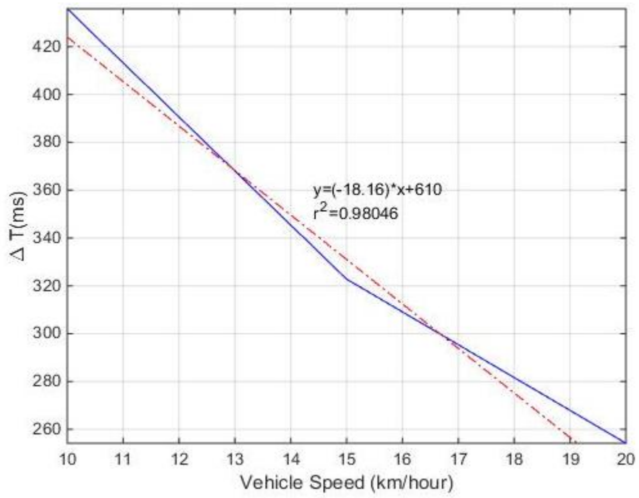

Fig. 5. Sensor's response.

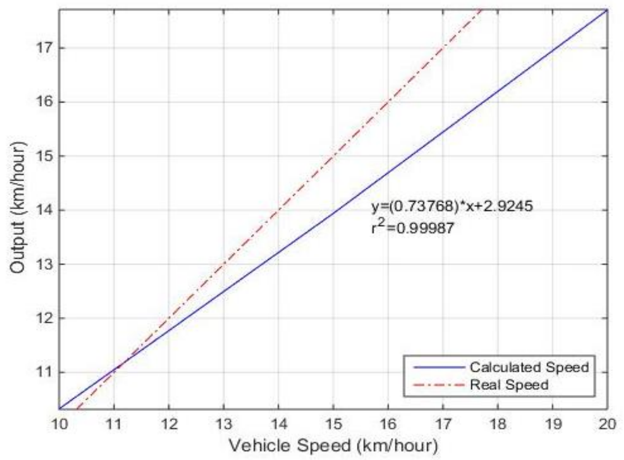

Fig. 6. Response comparison.

It has been explained before that the calculated vehicle's speed is depended to the axle distance and the period. Therefore, the database of axle distance is necessary in speed calculation. Figure 5 shows the sensor's response to the varied vehicle's speed. Figure 5 above shows that the proposed sensor's response will change around 18.16 ms when the vehicle speed changes 1 km/hour. By using the Equation 1 with the distance of the motorcycle wheel 1.25 m, the calculated vehicle speed is obtained.

Figure 6 shows the comparison of the calculated and real vehicle speed. Figure 6 shows that the proposed calculation method of the sensor has average calculation error around 7%. The result shows that the proposed calculation method is proved to be effective and reasonably reliable. By using this method, the speed sensor addition in WIM system is unnecessary. Therefore, the proposed sensor proves that it can be used to fulfill the requirement of accuracy at reduced costs, solve the conventional load sensor's problem and simplify the WIM sensor requirements.

However, from Figure 6, we also concluded that the calculated method tends to have higher error in higher speed. This higher error can be avoided by using the high specification photodetector and data processor. In addition, we also must ensure that the sensor is placed in fixed position and it will not move when a vehicle with high velocity pass through it.

V. CONCLUSION

The calculation method of vehicle speed from the output signal of the fiber optic load sensor has been proved to be effective and reasonably reliable. By using this approach, measuring the vehicle speed without adding the speed sensor in WIM system is possible. However, the high specification of detector and data processor are needed to avoid the high calculation error in measuring higher speed vehicle.

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