Comparison study between static and dynamic responses of optical fiber weight in motion sensor

D Hanto, R K Ula, A Setiono, P Puranto, H Adinanta, T B Waluyo and B Widiyatmoko

Research Center for Physics, Indonesian Institute of Sciences, South Tangerang, Indonesia

E-mail: dwi.hanto@lipi.go.id

Abstract. This research investigates responses of Optical Fiber Weight in Motion (WIM) sensors when static and dynamic weighing vehicle are applied. The vehicle used in the experiment was a replica of Mitsubishi FE 71 with weight of 23.01 kg. The WIM measurement system consisted of LED 1310 nm, optical fiber based WIM sensor, transimpedance amplified photodetector Ge PDA50 from Thorlabs, data acquisition DT translation 9816 S, speed sensors, and software program for WIM Evaluation. Static weighing was performed when the vehicle stopped. Besides performing static weighing on WIM sensor, measurement was also conducted on Kenko scale as validation. Meanwhile, measurement of dynamic weight was only conducted when the vehicle moved at a constant speed of about 1 km/h through WIM sensor. Experimental results showed two curves corresponded to the front axle load and the rear axle load. During static weighing, both WIM sensor and Kenko scales indicated similar output, which were flat curves. On the other hand, during dynamic weighing, WIM sensor had different output that was a pulse response. This preliminary study resulted in changes of amplitude and output shape. Unlike static weighing, moving vehicles contributed to the output of WIM sensor.

1. Introduction

Monitoring for structures and infrastructures on the transportation system should become government responsibility in order to support economic development. Indonesian government policy concerning transportation appears through Government Regulation or PP No. 43/1993, which regulates the classes of road and vehicle load restrictions [1]. This regulation itself is good, but it is weak in implementation. The reason is due to the lack of instrumentation such as vehicle weighing system.

In the modern countries, measurement of vehicle's weight can be performed by Weight In Motion (WIM) system. WIM is a moving vehicle’s weight measurement technology. This concept was introduced a few years ago [2]. The advantages of this technology include more efficient and time saving measurement, especially at a busy traffic [3]. Besides, this technology will support the intelligent transportation systems. Some of these systems have been applied at highways [3-4] which use many kind of WIM technologies.

In the market, there are various kind of sensors used in the WIM system such as load cell, strain gauge, bending plate, piezoelectric quartz sensors, and optical fibers [5, 6]. However, the optical fiber based sensor is a new technology development for WIM system. Optical fiber based sensors can be used as an alternative solution because it has several advantages such as high sensitivity, resistance to...
electromagnetic interference, high temperature resistance, and corrosion resistance. Thus, optical fiber is suitable for alternative to measure vehicle’s weight [2, 7, 8].

Recently, vehicle weight measurement can be predicted from the axle load [9, 10]. The advantage of this method is having small weighing area, which is not as big as the area of the vehicle. Data of vehicle weight is obtained from each wheel load of the vehicle called as axle load. Determination of the total weight of vehicle is calculated from total axle loads. This method can also be applied at WIM system in order to get additional advantages. Those advantages provide simple installation and maintenance.

Indonesia is one of the big countries in the world, which has large area of land and sea transportations. However, there are not many research and implementation of WIM system in Indonesia. So, it is important to start researching and developing WIM system. Moreover, this development will support the existing regulations [1]. The future expectation is to trigger further collaboration with other researchers and to support industry for the implementation.

In this article, authors describe about testing of WIM sensors developed by Research Center for Physics, Indonesian Institute of Sciences. Previous works on WIM sensor have been done by the same research group [11, 12]. The developed WIM Sensors are based on microbending optical fiber. A vehicle replica was used for testing the measurement in both static and dynamic weighing. The purpose of this testing is to compare the performances of static and dynamic weighing so that it can be applied for real vehicle.

2. Method

2.1. WIM system design

Figure 1 shows general block diagram of optical fiber WIM System. The system consisted of a WIM sensor based on microbending of optical fiber, an LED with a wavelength of 1310 nm, a photodiode and amplifier Ge PDA50 for signal conditioning from Thorlabs Inc., an A/D converters data acquisition from DT Translation 9816 S with a sampling rate up to 750 kS/s per channel and 16 bit ADC resolution, and a PC equipped with WIM software evaluation as shown in figure 2. WIM software has some features, e.g. vehicle speed detector and vehicle load graph.

![Figure 1. Block diagram of optical fiber WIM system.](image1)

WIM sensor used for weighing was basically based on microbending optical fiber. When a vehicle passed on this sensor, the WIM sensor generated optical power losses due to microbending effect. The amount of the transmitted optical power after optical power losses was converted into electrical signal (voltage) by the photodiode and amplifier. Then, the voltage data acquired by the A/D converter DT9816-S was processed by WIM software and displayed in a graph as shown in figure 2. In this figure, two curves were appeared at the load graph which indicated that the sensor had been passed by axle loads from vehicle.

![Figure 2. WIM software evaluation.](image2)
2.2. Acquisition system for Kenko scales

Kenko scales was used in this experiment for validation. The Kenko scales had the ability to measure the mass of an object up to 250 kg. It was equipped with RS 232 so that the data can also be acquired by a PC as shown in figure 3. The software system was developed using Labview software based on serial devices.

![Figure 3. Block diagram of Kenko scales measurement.](image)

2.3. System test

The system test was conducted using replica of Mitsubishi FE 71 with 23.01 kg (empty). The experiment was done in three ways. First, vehicle replica was measured on Kenko scales at a static condition as shown in figure 4. Then the vehicle replica was measured on optical fiber WIM system in static condition as shown in figure 5. Finally, the vehicle replica was moved on the optical WIM sensor with low speed of approximately 1 km/h as shown figure 5.

![Figure 4. Measurement using Kenko Scales.](image)  ![Figure 5. Measurement using Optical Fiber WIM.](image)

The static and dynamic weighing described above were then conducted again by gradually adding 20 to 80 kg of payload into the vehicle replica. The methods on how to place the payloads on the vehicle replica was shown in table 1 and illustrated in figure 6. For instance, in the first experiment, the payload was placed on position 1 in the container of vehicle replica. In the second experiment, the payloads were placed on position 1 and 2, and so on. So, there were 4 experiments in total. The mass of the front and the rear axle load were measured by Kenko scales. The total mass of the vehicle replica was the result of front axle mass and rear axle mass.

| No | Payload placement | Mass of front axle (kg) | Mass of rear axle (kg) | Total mass (kg) |
|----|-------------------|-------------------------|------------------------|----------------|
| 1  | 1                 | 16.84                   | 26.23                  | 43.07          |
| 2  | 1 + 2             | 26.31                   | 36.54                  | 62.85          |
| 3  | 1 + 2 + 3         | 22.92                   | 60.09                  | 83.01          |
| 4  | 1 + 2 + 3 + 4     | 28.88                   | 74.61                  | 103.49         |
3. Result and discussion
The measurement results of a replica of vehicle using Kenko scales and WIM sensor are shown in figure 7-10. There are three kinds of graph on each figure. Graph (a) of each figure is a result of static weighing using Kenko scales. These graphs were used for measurement reference. The measurement output is showed in kilograms (kg) unit. Meanwhile, graph (b) and (c) of each figure show the performances of optical fiber WIM sensor when vehicle replica was used.

**Figure 7.** Results of the first experiment, (a) static weighing using Kenko scales, (b) static weighing using optical fiber WIM, (c) dynamic weighing using optical fiber WIM.

**Figure 8.** Results of the second experiment, (a) static weighing using Kenko scales, (b) static weighing using optical fiber WIM, (c) dynamic weighing using optical fiber WIM.

Figure 7 shows the response of the vehicle replica when additional payload of 20 kg was given. Figure 7(a) shows the mass of vehicle replica in kg unit by Kenko scales. From this figure, it appeared that the contribution of weight from the front wheels was 16.84 kg and the rear wheels was 26.23 kg,
so the total mass became 43.07 kg. In a similar way, optical fiber WIM sensor was used to measure the load of the vehicle replica and the output is shown in figure 7(b). Figure 7(b) shows similar shape of curve to the Kenko scales output. It shows shorter amplitude of curve for front axle load in comparison to the amplitude of curve for the rear axle load. According to figure 7(a), front axle load was shorter than rear axle load. For static weighing using optical fiber WIM, the output appeared in two flat curves. The flat curve of front axle was at 0.021 V and the rear axle was at 0.031 V. The amplitude of the flat area was obtained from the difference between the voltage when flat area was reached and the voltage when there was no load. Figure 7(c) shows the response of the optical fiber WIM sensor when vehicle replica was moving on it with low speed. The resulted curves from this situation were no longer flat but spiky like pulses. Figure 7(c) shows that the amplitude of voltage for front axle and rear axle load were at 0.012 V and at 0.024 V, respectively. This amplitude in dynamic weighing was shorter than that in static weighing.

In the second experiment, another payload of 20 kg was added onto the vehicle replica with position in front of previous payload as shown as figure 6. The results of the second experiment are shown in figure 8. Figure 8(a) shows that the total mass measured by Kenko scales became 62.85 kg. The contribution of the axle loads were 26.31 kg for the front wheels and 36.54 kg for the rear wheels. On the other hand, the result of static weighing using WIM sensor can be seen in figure 8(b). The output of the front axle load was at 0.023 V and the rear axle load was at 0.028 V. When compared to the previous experiment, the amplitude of voltage was also proportional to the vehicle load. Like the dynamic weighing in the first experiment, it showed two pulse responses. The amplitudes of voltage were 0.020 V and 0.029 V. Similar to the first experiment, the responses in dynamic weighing were also shorter than in static weighing.

![Figure 9](image.png)

**Figure 9.** Results of the third experiment, (a) static weighing using Kenko scales, (b) static weighing using optical fiber WIM, (c) dynamic weighing using optical fiber WIM.

![Figure 10](image.png)

**Figure 10.** Results of the fourth experiment, (a) static weighing using Kenko scales, (b) static weighing using optical fiber WIM, (c) dynamic weighing using optical fiber WIM.
Figure 9 shows the results of the third experiment. According to figure 9(a), there were interesting results because front axle load was a bit lighter than the second experiment though 20 kg was added. However, the rear axle load got much bigger than the second experiment. This situation was caused by the placement of additional payload exactly above the rear wheels. The response for the static weighing using optical fiber WIM sensor is shown in figure 9(b) which looks similar to figure 9(a). In the case of front axle load, this result indicates that the amplitude of voltage in the third experiment was lighter than that in the second experiment. In the other hand, for rear axle load, the amplitude of voltage in the third experiment was much higher than in the second experiment. Then, figure 9(c) shows similar trends with the first and second experiments. Its shape also shows pulses response and its amplitude of voltage was shorter than the static weighing.

Lastly, the results of the fourth experiment is shown in figure 10. When static weighing on the Kenko scales was carried out, the contribution of mass for the front wheel increased insignificantly, which was from 22.92 kg to 28.88 kg. Otherwise, the mass contribution for the rear axle load increased significantly from 60.09 kg to 74.61 kg. When vehicle replica load was used on the optical fiber WIM sensor, the results was as shown in figure 10(b) for static weighing and in figure 10(c) for dynamic weighing. The results also showed similar trends as previous discussions.

4. Conclusion
This study compared static and dynamic weighing of optical fiber WIM sensor. Kenko scales was also used for performance comparison. Static weighing from vehicle replica using Kenko scales and optical fiber WIM sensor had the similar shape curves. From the experiments, the output of optical fiber WIM sensor was proportional to the mass distribution of axle load. Moreover, the response of dynamic weighing using optical fiber WIM sensor caused decrease in the amplitude of voltage. Study on the effect of speed variation to the WIM sensor is expected in the future research.

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