Accuracy examination of an estimation method of axle weights for in-motion vehicles by using miniature experimental models

K. Imakura¹, K. Yoshida², K. Fukuda³, T. Kinugasa², and R. Hayashi²
¹Graduate school of Okayama University of Science, 1-1 Ridai-cho, Kita-ku, Okayama-city, Okayama 700-0005, JAPAN
²Department of Mechanical Systems Engineering, Okayama University of Science, 1-1 Ridai-cho, Kita-ku, Okayama-city, Okayama 700-0005, JAPAN
³Sohatsu Systems Laboratory Inc., 5-5-2 Minatojima-Minami, Chuo-ku, Kobe, Hyogo 650-0047, JAPAN
E-mail: k_yoshida@mech.ous.ac.jp

Abstract. Axle weighing system measures axle weights of in-motion vehicles. A method has been studied for estimating axle weights by processing the weight signal from the axle weighing system to improve the accuracy. The method has been applied to in-motion vehicles at the velocity of less than 15 km/h and axle weights have been obtained in high accuracy. However, the examination of the accuracy of estimated axle weights of in-motion vehicles with higher velocity has not yet completed. To examine and improve the accuracy of the estimated axle weight, a miniature instrumented vehicle and a miniature weighbridge have been developed. This paper presents the examination of the accuracy of the estimation method by using the miniature experimental models.

1. Introduction

Overloading a vehicle makes the vehicle less stable, difficult to steer and takes longer to stop. Also, that causes excessive wear and damage to roads, bridges, and pavements. Moreover, that causes noise and vibration pollution to the environment along roads and increases fuel consumption and air pollution. Then, in Japan, axle weighing system is often used to check the axle weights of heavy vehicles that are entering expressway and gives warnings to overloaded vehicles. The axle weighing system measures axle weights of in-motion vehicles. The weighbridge of the axle weighing system is detector part of the system and consists of weighing platform and loadcells. The platform has the length of 76 cm in vehicle traveling direction which is nearly equal to the diameter of a tire, to avoid measuring two axle weights at the same time[1]. (See figure 1.) The weighbridge is usually installed in front of a toll gate and used to detect axle weights of vehicles in low speed. One of the difficulties in estimating the axle weights of in-motion vehicles with using the axle weighing system would be that when vehicles are in-motion, vehicle bodies have vibrations which affect the weight signals when the vehicles go through on the weighbridge, i.e., the weight signal consists of a dynamic component and a static one. The static component would be the true value of axle weight. Moreover the signal segments which
are effective for estimation are extremely short, because the length of the platform is almost the same as that of the diameter of tire. Then, taking the vibration component into account, we have proposed and studied an estimation method for axle weighing by processing the weight signal from the weighbridge[2, 3]. Applying the proposed method to in-motion vehicles at the velocity of less than 15 km/h, we can obtain axle weights in high accuracy that has not been attained[3]. However the requirement for measuring axle weights of in-motion vehicles at higher velocity is increasing as ETC (Electronic Toll Collection) systems are widely used these days in Japan. Hence we have developed a miniature instrumented vehicle and a miniature weighbridge to examine the accuracy of estimated axle weights of in-motion vehicles with higher velocity[4, 5]. Through the experiments using these miniature models, we have obtained weight signals when the miniature instrumented vehicle passes on the weighbridge in various situations. Then, we show the results of the examination of the accuracy of the proposed method by using the miniature models in the paper.

2. Conventional method and a proposed method for determining axle weights

Each loadcell that supports the weighing platform detects the force $D_i(t)$ when the $i$-th axle is on the platform and converts it to the voltage signal. The calibrated output signals of all loadcells are summed up to be one signal. We call it “weight signal” from the weighbridge. Figure 2 shows a schematic picture of time behavior of the weight signal $f(t)$ and the force $D_i(t)$. $f(kT)$ and $D_i(kT)$ for $k \in \mathbb{Z}$ denote the discrete signals sampled from $f(t)$ and $D_i(t)$, respectively with sampling time $T$. The part of $f(kT)$ indicated with $S_i(kT)$ in figure 2 is the segment when the whole contacting areas of the tires of the $i$-th axle are on the platform. By processing $S_i(kT)$, we obtain measured weight for the $i$-th axle. We refer to $S_i(kT)$ as “effective part” and the time interval corresponding to effective part as “effective interval”. The force $D_i(kT)$ contains the vibration components caused by the vibration of vehicle body. Hence, as shown in figure 2, the effective part would not be flat but a curved line affected by the dynamic component. One of the typical conventional processing methods is the average of the effective part[1]. The conventional methods could give us an accurate value if the effective part is flat. As is clear from figure 2, if the period of the dynamic component is longer than the effective time, we cannot obtain accurate axle weight by using the conventional methods. Assuming that the dynamic component is a sine wave, we have proposed a method to get over the difficulty as follows. The details are in [2].

Step 1: Applying a regression equation to the effective part $S_i(kT)$ with unknown coefficients $\alpha_i$ for $i = 1, 2, \ldots, N$ and an unknown constant $C$

Step 2: Estimating the coefficients and the constant in Step 1 by using the least square method

Figure 1. Weighbridge of the axle weighing system.
Step 3: Obtaining the axle weight as $W_i g = \hat{\hat{C}} / \sum_{j=1}^{N} \hat{\alpha}_j$, where $\hat{\hat{C}}$ and $\hat{\alpha}_i$ are the estimated values in Step 2

3. Miniature Models

We have developed the miniature models: a miniature instrumented vehicle and a miniature weighbridge of axle weighing system. The miniature instrumented vehicle is provided with the functions for accuracy examination. The outer dimensions and weight of finished miniature instrumented vehicle are width: 480 mm $\times$ length: 750 mm and 18.5 kg. The outer diameters of its tires are 240 mm. A shaker for giving an arbitrary vibratory component to the body is fixed on the centre of the load-carrying platform as shown in figure 3. We have conducted the driving experiments for the developed miniature instrumented vehicle in order to examine its functions[4]. Also, We have developed a miniature weighbridge which were designed according to the size of the miniature instrumented vehicle. figure 4 shows the developed weighbridge whose demensions are width:848 mm $\times$ length:88 mm. In the experiments, upper surface of the weighbridge must be in the same level of that of road, hence we have made metal lanes and set them both approach and departure sides of the weighbridge. We also have made wooden lanes and set them before the metal lane; the instrumented vehicle could pass through on the weighbridge smoothly.

4. Examination of the accuracy of the proposed method

In this section, we examine the accuracy of the proposed method described in Section 3 by applying the method to the weight signals which were obtained through experiments by using
the developed miniature models.

We have obtained various weight signals through experiments. Applying the proposed method and conventional method (which determine axle weight by just taking the mean values of an effective part) to the weight signals to obtain the axle weight, we calculated the relative errors of the obtained axle weights and classify them into several groups based on velocities (The group is called Speed zone.). Figure 5 shows the results. The velocities in the figure indicate the converted velocities of actual vehicle. Then we calculated the mean values and standard deviations of the relative errors in each Speed zone. In the figure, red circles indicate the mean values of the relative errors of the proposed method, blue circles the mean values of the conventional method, green horizontal line segments the standard deviations, black vertical line segments the ranges, i.e., maximum values and minimum ones of relative errors in the Speed zones, respectively. We can see that the proposed method is better than the conventional method in the accuracy when the miniature vehicle passes on the weighbridge with the velocities under 30 km/h.

![Figure 5. Averages and standard deviations of the relative errors](image)

5. Conclusions
We have developed a miniature instrumented vehicle and a miniature axle weighing system to examine the accuracy of the obtained axle weights by the proposed method. Through the experiments using these miniature models, we have obtained various weight signals when the miniature instrumented vehicle passes on the weighbridge in various situations. We have applied the proposed method to the weight signals. Then, we can see that the proposed method is better than the conventional method in the accuracy when the miniature vehicle passes on the weighbridge with the velocities under 30 km/h.

References
[1] Hanshin Expressway Management Technology Center 1985 Report on Investigation and Research on Improving the Measurement Accuracy of Axle Weighing System *Hanshin Expressway Public Corporation*
[2] Ono T, Fukuda K, Yoshida K, Uozumi H, and Tottori H 1999 Mass-estimation methods for in-motion vehicles using axle weighing system *Proc. IMEKO-XV* pp51–58
[3] Fukuda K, Tottori H, Kameoka K, Ono T, and Yoshida K 2002 Axle Weighing of In-motion Vehicles *Transactions of the Society of Instrument and Control Engineers* 38 pp653–659 (In Japanese)
[4] Sato T, Fukuda K, Kinugasa T, Fujimoto S, Yoshida K 2013 Experimental Study for the Improvement of Accuracy of the Estimated Axle Weights of In-Motion Vehicles - Development and Experiments of Miniature Models *CD Proc. SICE Annual Conference 2013 MoBT14.12*
[5] Yoshida K, Fukuda K, Ogawa K, Kinugasa T, Fujimoto S 2015 Development and Experiments of Miniature Models for the Study of estimation Method of Axle Weights for In-motion Vehicles *Proc. of XXI IMEKO*