XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6–11, 2009, Lisbon, Portugal

# A NEW WEIGHING METHOD FOR CHECKWEIGHERS BY USING SIGNAL PROCESSING

Kengo FUKUDA [1], Koji YOSHIDA [2], Tetsuya KINUGASA [3], Shinsaku FUJIMOTO [4], Morihito KAMON [5], Yoichiro KAGAWA [6], Toshiro ONO [7]

[1] Mechanical R&D Section, Oyo Measurement Co., Ltd, Osaka, Japan, k.fukuda@oyomm.co.jp
[2,3] Department of Mechanical Systems Engineering, Okayama University of Science, Okayama, Japan, {k_yoshida, kinugasa }@mech.ous.ac.jp
[4] Department of Intelligent Mechanical Engineering, Okayama University of Science, Okayama, Japan, fuji@are.ous.ac.jp
[5,6] Department of Automatic Machinery R&D, Yamato Scale Co., Ltd., Hyogo, Japan, {kamon-m, kagawa-y}@yamato-scale.co.jp
[7]Professor Emeritus of Osaka Prefecture University, Osaka, Japan, t-ono@s9.dion.ne.jp

**Abstract** – Checkweigher is usually equipped with an optical device. It is used to make a trigger to set time duration to allow a product to move on weigh belt completely for sampling the weight. In this paper, a new weighing method for checkweighers is proposed which uses just signal processing without the optical device. The effectiveness of the method is shown through experiments. Also a possibility of faster estimation of weight is shown.

**Keywords**: Checkweigher, Weighing method, Signal processing

## 1. INTRODUCTION

A checkweigher is an automatic machine to measure the weight of in-motion products. It is usually located around the end of product process and ensures the weight of a product within specified limits. Any products are taken out of line if the weight is out of the specified limits.

Fig. 1 Checkweigher

As shown in Fig. 1, a typical checkweigher consists of three conveyor belts: an infeed belt, a weigh belt, and a reject belt. The weigh belt is usually mounted on a weigh transducer such as a load cell. A typical checkweigher samples the weight signal of the transducer adequately and process it to form a weight. In most cases, a checkweigher is equipped with an optical device such as a photo-electric sensor to detect the passing of a product before loading on the weigh belt (See Fig. 2). The signal from the optical device is used as a trigger to set time duration to allow the product to move on weigh belt completely for sampling the weight. If we can make the trigger just by processing the weight signal from the transducer, we would be able to remove the optical device. This leads to bring about a reduction in costs. However, any general signal–processing method has not yet been achieved to make the trigger instead of the optical device, because the checkweigher needs to cope with various types of products and various conveyor speeds.

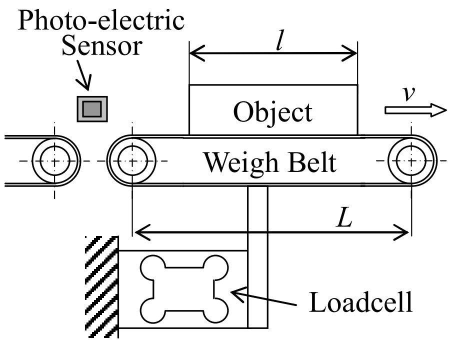


Fig. 2 Object on weigh belt

## 2. NEW WEIGHING METHOD FOR CHECKWEIGHERS

The purpose of this paper is to establish a general algorithm for processing the weight signal to determine the precise moment to begin and finish sampling the signal to provide the accurate weight of a product, that is to say, an accurate mass of the product.

In our researches on Axle Weighing System for In-motion Vehicles[1]-[5], we have proposed a simple method[1] to determine effective part (the part of weight signal to be processed for weighing) based on finding characteristic positions of a differentiated weight signal. The effective part of weight signal is the segment of the signal when the whole contacting areas of tires of in-motion vehicles are on weighbridge.

Fig. 3 shows a schematic of a weight signal, signals derived from it, and some important points on them indicated with symbols. $f(kT)$ for $k \in Z$ denotes the discrete signal sampled from a weight signal $f(t)$ with sampling time $T$. It should be noted that $f(kT)$ shown in Fig. 3 is a virtual signal which does not contain any vibratory component. $\Delta f(kT)$ is differentiated signal;

$$\Delta f(kT) = (z-1)f(kT). \tag{1}$$

It is smoothed to be a smooth signal

$$\Delta Hf(kT) = H(z)\Delta f(kT) \tag{2}$$

by applying a low pass filter $H(z)$. Here, the time delay of $\Delta Hf(kT)$ has been corrected.

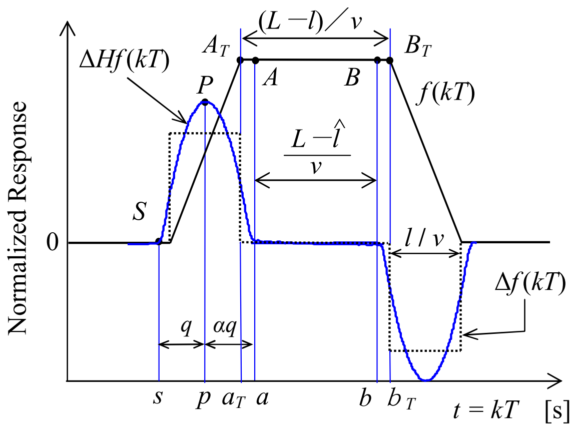


Fig. 3 $f(kT)$ and $\Delta Hf(kT)$

The weight signals of checkweighers have the same pattern as those of axle weighing systems, then we can apply the proposed simple method to the weight signals of checkweighers. The length of conveyor belt $L$ and conveyor speed $v$ are known when we use a checkweigher. Hence, we can determine the effective part $[a,b]$ of the weight signal by finding the points $S$ and $P$. In Fig. 3, $\alpha$ denotes a positive scalar. Let $l$ denote the length of an object (e.g., a product) on conveyor belt as shown in Fig. 2. In most cases, we should set $\alpha = 1$. If necessary, we can set $\alpha$ appropriately with considering the characteristics of the low pass filter $H(z)$. The obtained weight signal $f(kT)$ from the weight transducer of checkweighers contains vibratory components, then we have to use low pass filters. If the conveyor speed is low enough, we can use a higher-order filter which can smooth signals sufficiently. Using such filters, we can obtain $\Delta Hf(kT)$ sufficiently smooth and apply the simple method as shown in Fig. 3.

However, if the conveyor speed is high, we cannot use such high-order low pass filters. This is because the length of the effective time

$$b_T - a_T = (L-l)/v \tag{3}$$

is very short when the conveyor speed becomes very high. The time interval $[s,a]$, on which $\Delta Hf(kT)$ is non-zero, increases with the increase in the order of the filter. Hence if we apply the method shown in Fig. 3 to the weight signal $f(kT)$ in this case, we might determine the point $a$ at almost the end of the effective time $b_T$ or beyond it. Consequently, the obtained effective part $[a,b]$ would be useless for mass estimation. Then, we have to use lower-order filters. As a result, the point $P$ picked up from $\Delta Hf(kT)$, which is not smooth enough, would not be the appropriate point to determine the effective part (See Fig. 6). In this case, we use a new weighing method.

### <u>New weighing method</u>

We take the following steps:

**Step1**) Determination of a provisional effective part:
We determine the effective part $[a,b]$ of the weight signal by finding the points $S$ and $P$ in Fig. 3 even though the signal is not smooth enough. Then we take the $a$ as the beginning of the effective part provisionally.

**Step2**) Design of a FIR filter $G_k(z)$:
By using the least squares method, we design a 2nd order FIR filter whose coefficients are symmetric:

$$G_k(z) = 1 + \beta_1(k)z^{-1} + z^{-2}, \tag{4}$$

$$\min_{\beta_1(k)} \sum_{r=k}^{k+n-3} e^2(r), \tag{5}$$

$$\begin{aligned} e(r) &= f((r+2)T) + f(rT) + \beta_1(k)f((r+1)T) - C(k) \\ &= G_k(z)f((r+2)T) - C(k), \end{aligned} \tag{6}$$

where $k = a/T, a/T+1, \cdots, b/T-n+1, \quad n \geq 4$.

**Step3**) Estimation of the frequency of a dominant vibration component:
We calculate zeros $\sigma_1(k)$ and $\overline{\sigma_1(k)}$ of the filter:

$$G_k(z) = (1-\sigma_1(k)z^{-1})(1-\overline{\sigma_1(k)}z^{-1}), \tag{7}$$

where $\sigma_1(k)$ denotes the complex conjugate of $\sigma_1(k)$. Then, we can obtain dominant frequency $\omega_1(kT)$ by taking argument of the zero:

$$\omega_1(kT) = \angle\sigma_1(k)/T(>0)\ . \qquad (8)$$

**Step4)** Correction of $a$ in Fig.3:
We pick up a point $kT$ which satisfies the following inequality:

$$(\omega_0 - \Delta) \le \omega_1(kT) \le (\omega_0 + \Delta) \qquad (9)$$

and take it as the correct $a$ which would be denoted by $a_C$. Where, $\omega_0$ denotes the dominant frequency of the mechanical structure of a weighing system, and $\Delta$ denotes a tolerance value. In the strict sense, $a_C$ is not the point when the object is completely on the weigh belt, however the affection of transient vibration can be neglected.

**Step5)** Calculation of a mass $m(kT)$:
By estimating the coefficient in **Step3**, we can also obtain an estimated value of the mass $m(kT)$ at $f(kT)$ as follows

$$m(kT) = \frac{C(k)}{G_k(1)g}, \qquad (10)$$

where $g$ is the gravitational constant. Then, $m(a_C)$ would be the earliest mass estimated in high accuracy.

## 3. EXPERIMENTAL RESULTS

We introduce some results obtained by applying the new weighing method to the weight signals $f(kT)$ from the load cell of a checkweigher when an object moved through on weigh bed with low and high conveyor speeds. These speeds are 30m/min and 80m/min, respectively.

The objects used for weighing experiment have the same dimension: 95mm$\times$65mm, however, the statically measured weight of the object for the low speed weighing is 478.4 g and that for the high speed weighing is 486.7 g.

Fig. 4 shows amplitude properties of the filters used for experiments reported in the present paper. Their other characteristics are tabulated in Table 1. We designed two types of low pass FIR filters $H_L(z)$ and $H_S(z)$ as $H(z)$ of (2) using for smoothing $f(kT)$. Although a band pass filter $H_B(z)$ is not used in the new weighing method, it is additionally introduced in Fig. 4. This is because it is used for extracting the dominant vibratory component from $f(kT)$ in later discussions.

### 3.1. Example of low speed weighing

Fig. 5 shows weight signal $f(kT)$ when the conveyor speed is 30 m/min, its smoothed signal

$$H_L f(kT) = H_L(z) f(kT) \qquad (11)$$

and smooth differentiated signal $\Delta H_L f(kT)$ obtained by applying $H(z) = H_L(z)$, whose time delays are corrected, are also shown. Since the data length of the effective part available for measurement is sufficient enough, in this case we can select the higher order filter $H_L(z)$ as $H(z)$ in (2). $\Delta H_L f(kT)$ processed by a high order filter $H_L(z)$ is naturally smooth enough, hence we can apply the simple

Table 1. Descriptions of FIR filters for weight signals

| Notation | $H_L(z)$ | $H_S(z)$ | $H_B(z)$ |
|---|---|---|---|
| Tap number | 101 | 33 | 401 |
| Type | Lowpass | Lowpass | Bandpass |
| Desired cutoff freq. (-6dB) | 5 Hz | 5 Hz | 20Hz 30Hz |

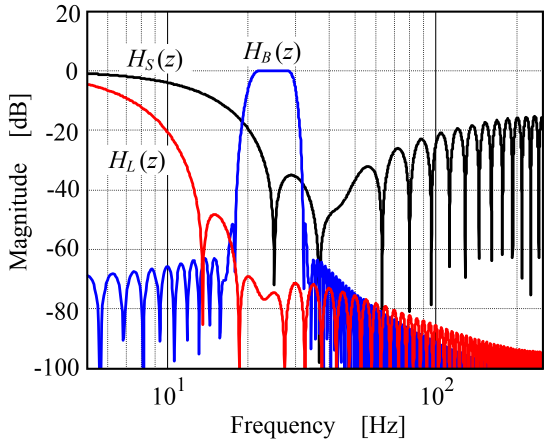


Fig. 4 Amplitude properties of $H_L(z)$, $H_S(z)$ and $H_B(z)$

method shown with Fig. 3. As the result, we have obtained $s = 0.978$ s, $p = 1.082$ s, then,

$$q = p - s = 0.104 \text{ s}, \qquad (12)$$

$$a = p + q = 1.186 \text{ s}, \qquad (13)$$

$$\hat{l} = 2qv = 0.104 \text{ m}, \qquad (14)$$

and

$$b = a + (L - l)/v = s + L/v$$
$$= 0.978 + 0.309/0.5 = 1.596 \text{ s}. \qquad (15)$$

In this case, since the data length of effective part is sufficient enough for averaging, we can simply obtain an accurate value by averaging: The average of the filtered weight signal $H_L f(kT)$ on the interval [1.186 s, 1.596 s] is 478.90 g, which is almost equal to the static value 478.4 g.

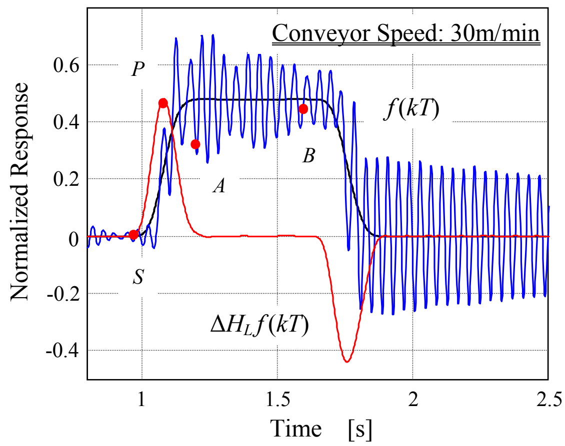


Fig. 5 Example of actual $f(kT)$, $H_L f(kT)$ and $\Delta H_L f(kT)$ in case that conveyor speed is 30 m/min

### 3.2. Example of high speed weighing

Here, we treat an actual $f(kT)$ when the conveyor speed is 80 m/min. This is the example of weight signals in high speed weighing that we cannot use a high order filter. Fig. 6 shows $f(kT)$, its smoothed signal $H_L f(kT)$ and smooth differentiated signal $\Delta H_L f(kT)$ by $H(z) = H_L(z)$ when the conveyor speed is 80 m/min, in the same manner as Fig. 5.

As mentioned before, Fig. 6 shows a typical example that the determined $a$ is beyond $b$. If we use a high order filters such as $H_L(z)$, the time delay of the differentiated signal would be so long that we cannot use the simple method illustrated in Fig. 3.

After all, it might be possible to determine the adequate effective time $[a, b]$ by means of adjusting coefficient $\alpha$ in Fig. 3, but it is not practical to find effective $\alpha$ for so many kinds of objects to be weighed with using trial-and-error approaches. Although useful $\alpha$ are obtained, we cannot measure weights by averaging. This is because $H_L f(kT)$ on $[a, b]$ in Fig. 6 does not contain the flat part as observed in Fig. 5.

Consequently, we must apply the lower order filter

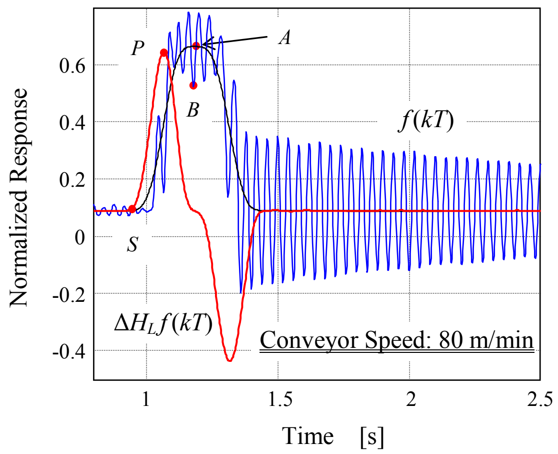


Fig. 6 Example of actual $f(kT)$, $H_L f(kT)$ and $\Delta H_L f(kT)$ in case that conveyor speed is 80 m/min

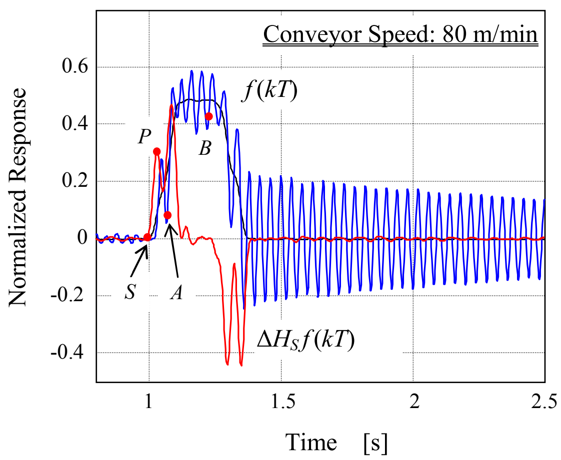


Fig. 7 Example of actual $f(kT)$, $H_S f(kT)$ and $\Delta H_S f(kT)$ in case that conveyor speed is 80 m/min

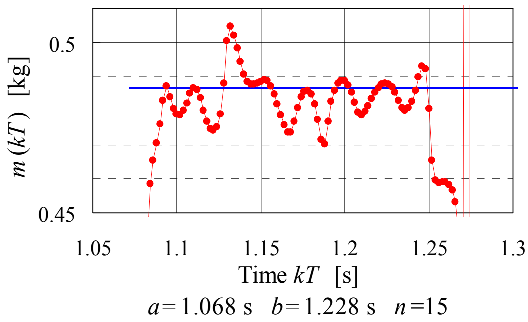


Fig. 8 Estimated mass of object by using $G_k(z)$ designed for $f(kT)$ in Fig. 7

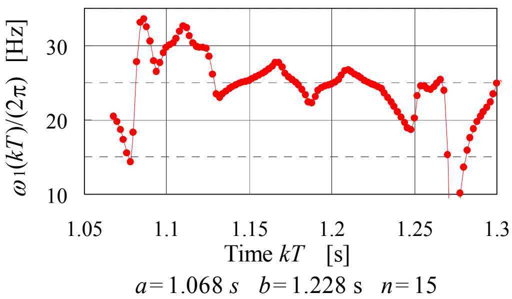


Fig. 9 Estimated frequency of dominant component by using $G_k(z)$ designed for $f(kT)$ in Fig. 7

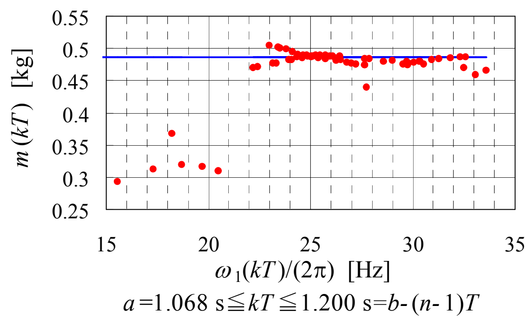


Fig. 10 Plot of Estimated frequency $\omega_1(kT)/(2\pi)$ and mass $m(kT)$

$H_S(z)$, ability to smooth of which is not enough, to $f(kT)$. As shown in Fig. 7, $H_S f(kT)$ and $\Delta H_S f(kT)$ would not be smooth enough. Hence we take **Steps** of the new weighing method described above.

We can obtain an estimated mass $m(kT)$ and an estimated frequency $\omega_1(kT)$ at each time $kT$ in **Steps** 3 and 5 (See Fig. 8 and Fig. 9), then, we make a pair ($\omega_1(kT)$, $m(kT)$) at $kT$. Fig. 10 shows the plots of the pairs; $\omega_1(kT)$ is measured along a horizontal axis and $m(kT)$ is measured along a vertical axis, when we set $n = 15$. A glance at Fig. 10 will reveal that $m(kT)$ is almost constant and close to the static value in the neighbourhood of $\omega_1(kT)/(2\pi) = 25$ Hz. We can therefore tentatively accept $\omega_0/(2\pi) = 25$ Hz and $\Delta/(2\pi) = 0.5$ Hz. Thus, we would obtain $kT = a_C = 1.142$ s which is the first moment (earliest time) that satisfies the inequality

$$24.5\ \text{Hz} \le \omega_1(kT)/(2\pi) \le 25.5\ \text{Hz}\,. \qquad (16)$$

At the same time, we can obtain $m(1.142) = 488.45$ g .

If we take an average, we can obtain more precise value $\overline{m}$ , namely,

$$\overline{m} = \frac{1}{n_E} \sum_{kT \in E} m(kT), \qquad (17)$$

$$E = \{kT \mid \omega_1(kT) \in [\omega_0 - \Delta, \omega_0 + \Delta], kT \in [a, b-(n-1)T]\}\,, \qquad (18)$$

where $n_E$ is the number of elements in *E*. In this case, $[a, b-(n-1)T] = [1.142\ s, 1.200\ s]$ , $\Delta/(2\pi)$ =0.5 Hz, and $n_E$ =12, then

$$\overline{m} = 487.60\ \text{g}. \qquad (19)$$

By taking advantage of the observation of Fig. 10, we can also check the estimated mass of the object whether it is accurate or not. For example, the estimated mass at $kT = 1.188$ s is $m(1.188) = 470.19$ g. It would not seem to be accurate, because $\omega_1(kT)/(2\pi)$ at $kT$ = 1.188 s is estimated to be 22.20 Hz and

$$\omega_1(1.188)/(2\pi) = 22.20\ \text{Hz} \ll 25\ \text{Hz}\,. \qquad (20)$$

Actually, $m(1.188) = 470.19$ g is far from the static value 486.7 g. This fact suggests that there exist the disturbances such as floor vibration, vibration due to unbalance of conveyor pulleys, and so on.

## 4. CONSIDERATIONS

### *4.1. Power spectral density of weight signals*

Fig. 11 shows the estimated power spectral density of the signals truncated by applying Hanning window to weight signals immediately after objects unload the weigh belt, which is calculated using a 1024 points FFT. The power spectral density of Fig. 11 is very smooth, because it is obtained by taking average of more than 40 FFTs of sample signals after weighing various kinds of objects against various conveyor speed settings.

We can observe two dominant spectral peaks at 10.3 Hz and 24.9 Hz. Since the conveyor speeds are not constant, the highest peak at 24.9 Hz probably indicates the natural vertical vibration due to the weighing structure (the loadcell with the weight belt) and another one at 10.3 Hz the disturbance due to the floor vibration.

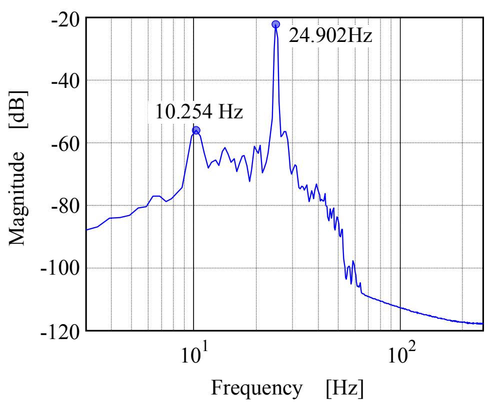


Fig. 11 Estimated power spectral density of weight signal immediately after weighing smoothed by averaging

### *4.2. Affection of disturbance*

The key point of our new weighing method is to design the FIR filter of order two $G_k(z)$ , which is the most simple structure, on the interval $[kT, (k+n-1)T]$ whose data length is $n$ . $G_k(z)$ can therefore eliminate only one vibratory component. For this example, the method is reduced to the design of the most simple filter that notches at around 25 Hz.

Consequently, other vibratory disturbances whose the most dominant component is 10.3 Hz floor vibration are separated as the residue $e(r)$ through solving the normal equation. In other words, we observe the influence of the 10.3 Hz vibratory component by (16) instead of by evaluating the characteristics of the residue $e(r)$ . When $\omega_1(kT)$ satisfies (16), $m(kT)$ is adopted as a high accurate measurement value.

If the amplitudes of disturbances classified as $e(r)$ is relatively large in comparison with that of the 24.9 Hz component to be notched, there is a possibility that $\omega_1(kT)$ satisfies (16) does not exist, which means that we cannot obtain an aculeate $m(kT)$ . Let us observe the amplitudes of the disturbances of the weight signal in Fig. 7 by removing the 24.9 Hz natural vibration with a high order FIR filter.

The upper graph in Fig. 12 shows the output signal

$$H_B f(kT) = H_B(z) f(kT)\,, \qquad (21)$$

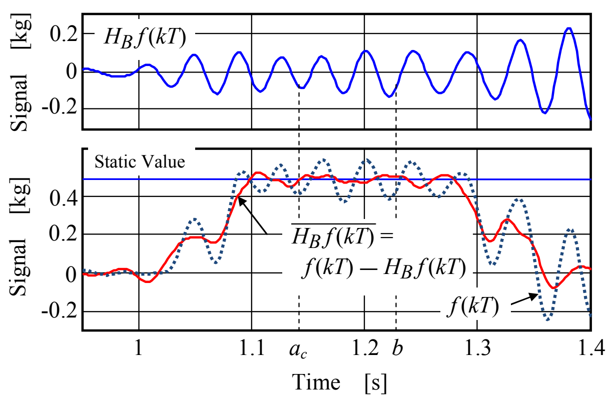


Fig. 12 Dominant vibration $H_B f(kT)$ and $\overline{H_B f(kT)} = f(kT) - H_B f(kT)$

Table 2. Index values of amplitudes of signals in Fig. 12

| | $f(kT)$ *1) | $H_B f(kT)$ | $\overline{H_B f(kT)}$ *1) |
|---|---|---|---|
| Maximum value | 0.10121 | 0.11706 | 0.02020 |
| Minimum value | -0.11970 | -0.12173 | -0.02067 |
| Peak to peak | 0.22092 | 0.23879 | 0.04087 |
| Root mean square*2) | 0.07400 | 0.07633 | 0.01490 |

Unit: kg

*1) Offsets of $f(kT)$ and $\overline{H_B f(kT)}$ are cancelled.
*2) Calculated by Rectangular method for numerical integration.

where $H_B(z)$ is a 401 taps band pass FIR filter whose pass band is [20 Hz, 30 Hz] as shown in Fig. 4. The lower one shows the original signal $f(kT)$ (a dashed line) and

$$\overline{H_B f(kT)} = f(kT) - H_B f(kT) \qquad (22)$$

which does not contain the 24.9 Hz component. Index values of the amplitudes of these signals on the effective time interval [1.142 s, 1.228 s] are tabulated in Table. 2. According to the table, if the amplitude of $\overline{H_B f(kT)}$ is about one-fifth times as large as that of $H_B f(kT)$ based on rms, the new weighing method is probably successful for high accuracy weighing at high speed.

Here, we cannot afford to refer to the frequencies of disturbances. The weighing method would be seriously affected by a vibratory disturbance whose frequency is smaller than the natural vibration frequency due to the weighing mechanism. We should add the remark that frequencies of disturbances would directly affect the selection rule for the data length $n$ that is important parameter in designing the 2nd order FIR filter $G_k(z)$ at $t = kT$ .

The alternative idea for coping with disturbances is to increase the order of $G_k(z)$ . For this example, we regard the 10.3Hz floor vibration as the dominant vibratory component to be notched as well as the natural vibration. That is to say, we replace (4) with

$$G_k(z) = 1 + \beta_1(k)z^{-1} + \beta_2(k)z^{-2} + \beta_1(k)z^{-3} + z^{-4} \quad . \qquad (4)'$$

Nevertheless, at the present time, it is almost impossible to implement (4)' in commercially available checkweighers with considering the calculation load on its CPU system. Although the order of $G_k(z)$ increases, it is also noticed that the evaluation of the disturbance is still indispensable for the new weighing method in practical use. At least, we must clarify the condition that guarantees the existence of $\omega_1(kT)$ of $G_k(z)$ which satisfies (9).

## 5. CONCLUSIONS

i) In case that a conveyor speed is lower, we have shown the effectiveness of an algorithm to determine the effective part in weight signals from a checkweigher. The algorithm consists of smoothing the weight signals and finding characteristic points on differentiated weight signals.

ii) In case that a conveyor speed is higher, we have proposed a new method which consist of three phases, namely; 1)designing a 2nd order FIR filter whose coefficients are symmetry, 2)applying it to many local parts of a weight signal in order to estimate the frequency of dominant vibration component and the weight in each local part of them, 3)determining the first local part whose estimated frequency is acceptable in comparison with preset value such as the natural frequency of the weighing mechanism. The first point of that part is the beginning point for weighing and the estimated weight in that part would be accurate.

iii) The methods mentioned above have been shown effective through experiments.

Consequently, we have shown the possibility to remove the optical device from checkweighers and to achieve fast weighing method for them.

## APPENDIX

Equations in **Step2** of Section 2 are concretely expressed using matrixes and vectors as follows:

$$y = X\beta + \varepsilon \ ,$$

$$y = \begin{bmatrix} f((k+2)T) + f(kT) \\ \vdots \\ f((k+n-1)T) + f((k+n-3)T) \end{bmatrix},$$

$$X = \begin{bmatrix} -f((k+1)T) & 1 \\ \vdots & \vdots \\ -f((k+n-2)T) & 1 \end{bmatrix}, \quad \beta = \begin{bmatrix} \beta_1(k) \\ C(k) \end{bmatrix}. \qquad (A1)$$

Where $\varepsilon$ denotes error vector. If the normal equation for

$$X^T X\beta = X^T y \qquad (A2)$$

is solved, then the residue $e(r)$ at $t = kT$ is nearly equal to zero and the 2nd order filter $G_k(z)$ is obtained. Since the linear regression model is a linear function, we could effectively calculate $C(k)$ and $\beta_1(k)$ at every time when the newest $(k+n-1)$ th data point is stored.

## REFERENCES


[1] K. Fukuda, K Yoshida, T Kinugasa, K Kanazawa and T Ono, "A Dynamic Model for the Weighbridge of an Axle Weighing System for In-motion Vehicles with High Velocity", *APMF 2007 International Symposium*, Sydney, Australia, CD-ROM, Oct. 2007.

[2] K. Fukuda, K. Yoshida, T. Ono, K. Kameoka, T. Hirata: "An Advanced Algorithm for Estimating Axle Weights of In-motion Vehicles", *19th International Conference on Force, Mass & Torque, IMEKO TC3*, 20.pdf, Cairo, Egypt, CD-ROM, 2005.

[3] K. Fukuda, K. Kameoka, T. Ono and K. Yoshida: "Evaluation of a New Mass-estimation Method for Axle Weights of In-motion Vehicles Using Vehicle Models", *17th International Conference on Force, Mass, Torque and Pressure Measurements, IMEKO TC3,* pp.219-229, Istanbul, Turkey, 2001.

[4] K. Fukuda, H. Tottori, K. Kameoka, T. Ono and K. Yoshida, " A Method for Estimating Axle Weights of In-motion Vehicles and Its Evaluation", *SICE Annual Conference Osaka*, pp.71-75, Osaka, Japan, 2002.

[5] T. Ono, K. Fukuda, K. Yoshida, H. Uozumi and H. Tottori: "Mass-Estimation Methods for In-motion Vehicles Using Axle Weighing System", *IMEKO-XV, Vol. III, IMEKO*, pp.51-58, Osaka, Japan, 1999.