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

DYNAMIC BEHAVIORS OF A CHECKWEIGHER WITH ELECTROMAGNETIC FORCE COMPENSATION

Y. Yamakawa [1], T. Yamazaki [2], J. Tamura [3] and O. Tanaka [3]

[1] Univ. of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan, Yuji_Yamakawa@ipc.i.u-tokyo.ac.jp
[2] Oyama National College of Technology, Nakakuki 771, Oyama, Tochigi, Japan, yama@oyama-ct.ac.jp
[3] Anritsu Industrial Solutions Co., Ltd., Onna 5-1-1, Atsugi, Kanagawa, Japan

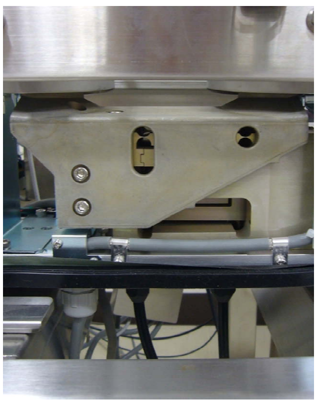
Abstract − This paper clarifies the dynamic behaviors of a high speed mass measurement system with conveyor belt (a checkweigher). The objective in this study is to construct the model of the measurement system. The checkweigher with electromagnetic force compensation can be approximated by the combined spring-mass-damper systems as the physical model, and the equations of motion are derived. The model parameters can be obtained from the experimental data. Finally, the validity of the proposed model can be confirmed by comparison of the simulation results with the realistic responses. The dynamic model obtained offers practical and useful information to examine control scheme.

Keywords mass measurement, checkweigher, electro-magnetic force compensation system, dynamic behavior

1. INTRODUCTION

In recently, a highly accurate mass measurement system of packages moving the conveyor belt operated at high speed, so-called the checkweigher, has been getting more important in the food and logistics industries etc. To achieve the high speed (continuous) measurement, packages should be moved in sequence. It means the measuring time for one package is very short. In the near future, the continuous mass measurement for 240 products per minute is required.

(a) Measurement system



(b) Roberval mechanism

Fig. 1. Photographs of checkweigher

In general, there are two types of the measurement system of the checkweigher, such as a load cell type and an electromagnetic force compensation (EMFC) type. In the load cell system, the mass can be measured by the deformation of Roberval mechanism when the mass to be measured is put on the weighing pan. Though this type is applicable to the wide range of mass, it makes this type difficult to achieve high accuracy. On the other hand, the EMFC system keeps a balance with the displacement of the lever linked Roberval mechanism with electromagnetic force.

Then, the mass of an object can be measured by the driving (or feedback) current for electromagnetic force. This type can be achievable for high accuracy by null method, but the wide range of measurement cannot be desirable.

For the dynamic behavior of the load cell system, Ono, W. G. Lee, and Kameoka have already cleared in detail [1]-[4]. But the dynamic behavior of the EMFC system has not still been presented. Our aim is that the performance of the checkweigher can be improved for high-speed and high-accuracy. To do this, it is highly necessary to develop the control scheme of the EMFC. Thus, in this paper, we examine the dynamic behaviors of the checkweigher with EMFC. Namely, the model of the measurement system will be constructed. Then, the validity of this model is confirmed by comparison between the simulation and experimental results.

2. MEASUREMENT SYSTEM

Fig. 1(a) shows the photograph of the checkweigher. Only a measuring conveyor appears in the photograph, actually, the feed conveyor is located in the left of the measuring conveyor and the sorter is located in the right. The products are moved by the feed conveyor, the mass of product measured by measuring conveyor and the product out of the measurable range is removed by a sorter.

The enlarged photograph of the mass measurement mechanism in the checkweigher is shown in Fig. 1(b). The mass measurement mechanism consists of weighing platform, the Roberval mechanism, the lever linked Roberval mechanism, the counter weight, the electromagnetic force actuator and the displacement sensor. By applying the Roberval mechanism to the measurement mechanism, the mass of the product can be measured even if the product locates in everywhere over the weighing platform.

ISBN 978-963-88410-0-1 © 2009 IMEKO

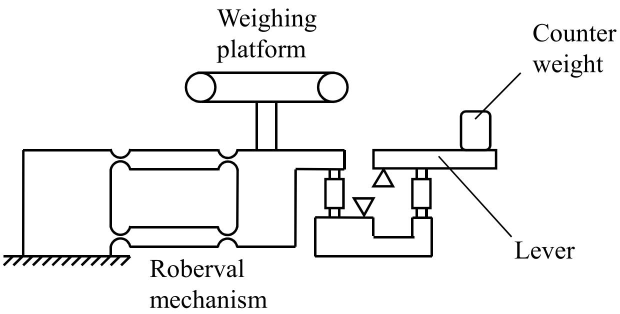


Fig. 2. Image of Roberval mechanism

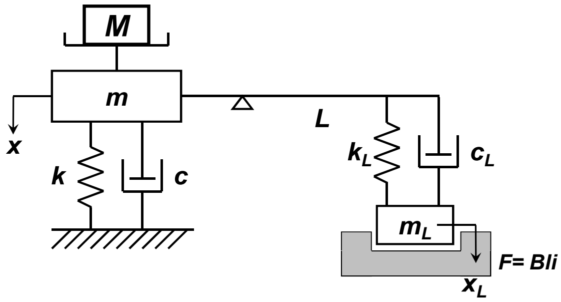


Fig. 3. Physical model of measurement system

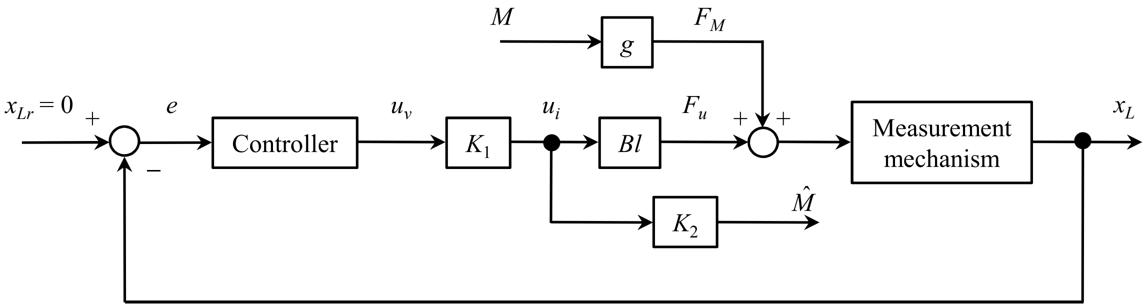


Fig. 4. Block diagram of the model

3. MODELING

Fig. 2 and Fig. 3 show the illustrations of the Roverval mechanism and the physical model of the measurement system including the Roverval mechanism, respectively. The measuring method of mass can be described as follows: First, when the mass is put on the measurement system, the displacement of the Roberval mechanism is caused. Then, the lever magnifies the displacement mechanically. And, the magnified displacement is measured by the photo sensor. Secondly, the current of electricity control is fed back so that the displacement can be maintained at zero. Finally, the current is measured. The current is converted to the estimated mass by using the linear function.

Considering the physical model as shown in Fig. 3, the equations of motion about mass m and mass m_L can be obtained as follows:

$$\begin{cases}(M+m)\ddot{x}+c\dot{x}+kx+k_L(x+\frac{1}{L}x_L)=Mg\\ m_L\ddot{x}_L+c_L\dot{x}_L+k_L(x_L+Lx)=F\end{cases} \quad (1)$$

where, m is mass of the Roberval mechanism, M mass of an product to be measured, c a damping coefficient, k a spring constant, g the acceleration of gravity, L (= 20 m/m) the lever ratio, and x the displacement of mass m. And, m_L mass of the lever, c_L a damping coefficient, k_L a spring constant, x_L the displacement of mass m_L, and F (= Bli, where B is a density of magnetic flux, l a length of the coil, and i a current.) an electromagnetic force which means the control input to control the position of the mass m_L. Finally, Fig. 4 depicts the block diagram of these systems.

Considering the steady state of the second equation in Eq. (2) for $F = 0$ (open loop system), the following equation can be obtained,

$$x_L = -Lx\,. \quad (2)$$

Substituting Eq. (3) into the first equation in Eq. (2), the steady state of the Roberval mechanism becomes

$$x = \frac{Mg}{k}\,. \quad (3)$$

When the mass of the target is 0.1 kg on the basis that x_L = 0.24×10^{-3} m, and x = 0.012×10^{-3} m are measured, thus we can obtain as

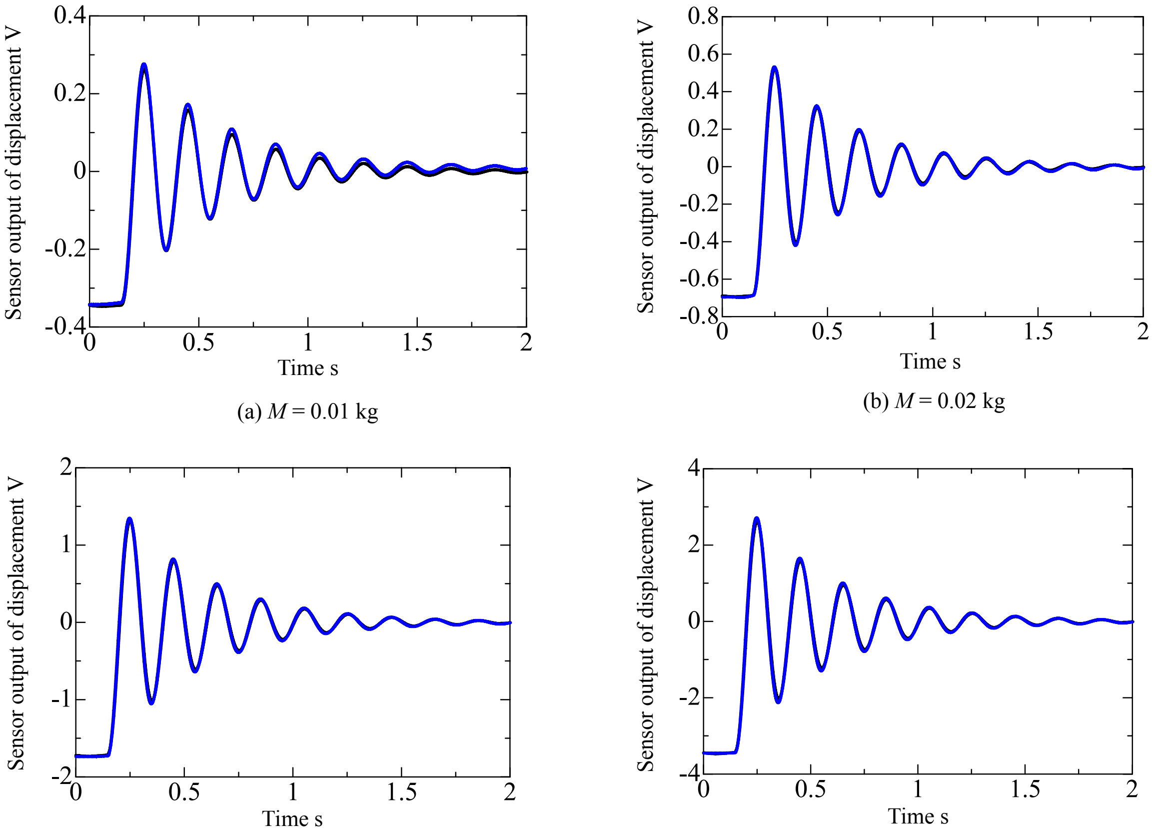
$$k = \frac{0.1\times9.8}{0.012\times10^{-3}} = 81.7\times10^{3} \quad (4)$$

From the second equation in Eq. (2), the natural frequency of the lever is

$$f_L = \frac{1}{2\pi}\sqrt{\frac{k_L}{m_L}}\,. \quad (5)$$

From the experimental result, the natural frequency of the lever is 5 Hz and the damping ratio is 0.08. Substituting f_L = 5 Hz and m_L = 0.215 kg into the above equation, the spring constant of the lever can be given as follows:

$$k_L = (2\pi\times5)^2\times0.215 = 212.2\,. \quad (6)$$



(a) $M = 0.01$ kg

(b) $M = 0.02$ kg

(c) $M = 0.05$ kg

(d) $M = 0.1$ kg

Fig. 5. Comparison between experimental result and simulation result (open loop)

4. EXPERIMENTAL AND SIMULATION RESUTLS

In this section, the validity of the proposed model is examined with comparison between the simulation result and the experimental result. In section 4.1, the comparison for open-loop system is performed. Moreover, the comparison for closed-loop system is discussed in section 4.2.

Fig. 4 shows the block diagram of the model. When the electromagnetic force F_u is equal to zero, the measurement system is open-loop system. On the other hand, when the force F_u acts to the measurement mechanism, the closed-loop system is constructed.

4.1. Open-loop system

In this section, the validity of the proposed model is examined with comparison between the simulation result and the experimental result for the open-loop system.

Fig. 5 shows the experimental and simulation results for $M = 0.01$, 0.02, 0.05 and 0.1 kg. The start-up operation is the time when the mass M is put on the measurement system. Then, when the time is 0.2 s, the mass M is removed. At the same time, the displacement x_L is measured by the photo sensor. In Fig. 5, the vertical axis shows the photo sensor output of the lever displacement.

It can be seen from these figures that the responses of the simulation made a good agreement with the experimental results perfectly. Thus, the validity of the proposed model is confirmed for the open-loop system. Although the amplifier of the response is changed depending on the mass, the convergence time is not changed. Thus, this measurement system can be assumed to be the linear system. Namely, even if the controller is added to the measurement system, the response does not depend on the mass.

In the next section, the validity of the proposed model for the closed-loop system will be confirmed.

4.2. Closed-loop system

This section explains the experimental and simulation results with EMFC. The electromagnetic force is controlled by proportional-integral-differential (PID) control scheme. Taking the actual circuit of the D action into account, the ideal D action cannot be implemented. So, it is assumed that the D action is the approximated differential action. Namely, the transfer function of the PID controller $C(s)$ can be described by,

$$C(s) = k_p + \frac{k_i}{s} + \frac{k_{dn} s}{k_{dd} s + 1} \qquad (5)$$

where, k_p is the proportional gain. k_i is the integral gain. k_{dn} and k_{dd} are the numerator and denominator coefficients of the differential gains, respectively. And, the control voltage $u_v(t)$ can be adjusted as follows.

$$u_v(t) = C(s)e(t) \qquad (6)$$

where, $e(t)$ ($=x_{Lr} - x_L$) is the error between the reference x_{Lr}

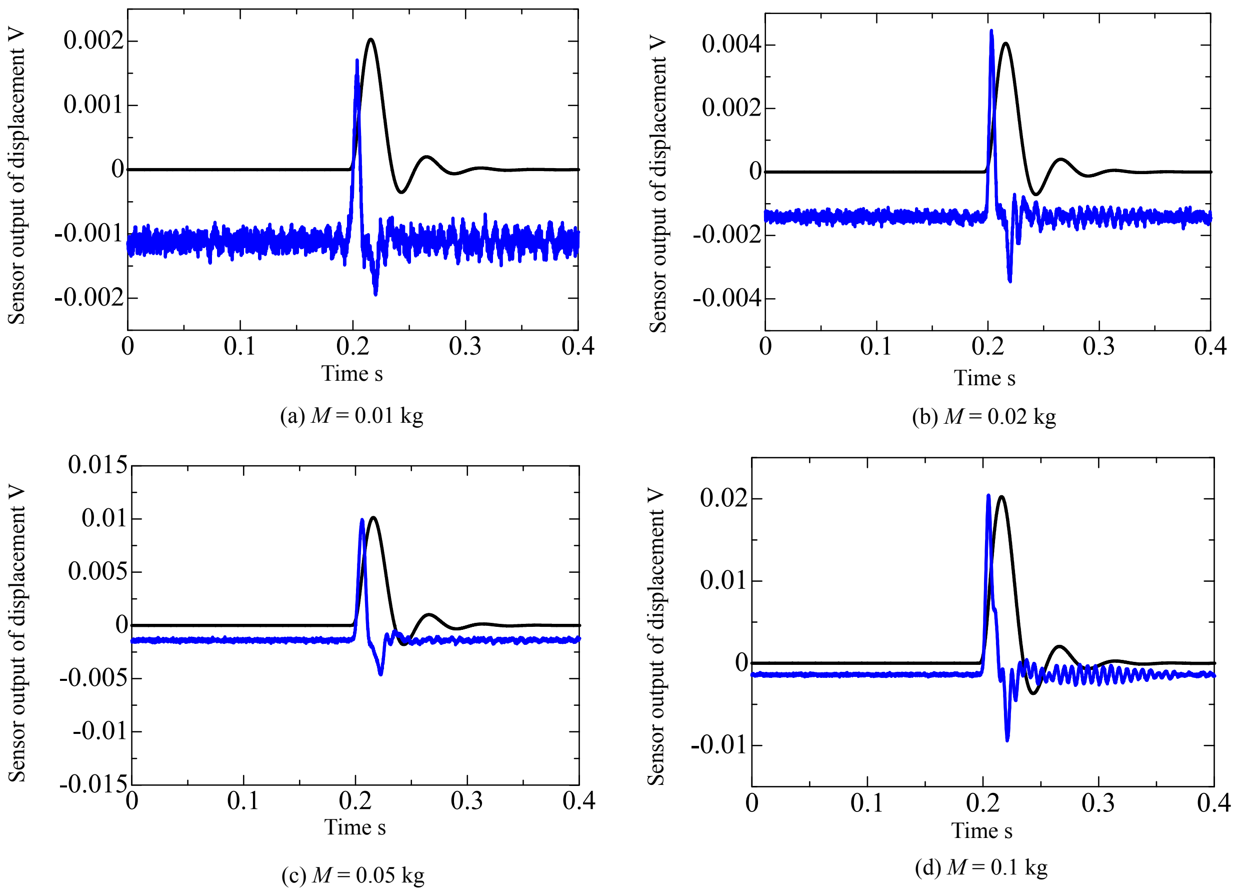


Fig. 6. Comparison between experimental result and simulation result (closed loop)

and the photo sensor output of the lever x_L.

Fig. 6 shows the experimental and simulation results for M = 0.01, 0.02, 0.05 and 0.1 kg. The blue line and the black line mean the experimental result and the simulation result, respectively. The simulation and experimental conditions are the same as the open-loop.

From these figures, the validity of the EMFC model is confirmed. However, the convergence time, the rise time and the settling time between the simulation and experimental results are slightly different. In the future, the factors of the differences between the simulation and experimental results will be considered and this problem will be solved.

5. CONCLUSIONS

In this paper, the dynamic model of the electromagnetic force compensation (EMFC) system is constructed. The measurement system is composed of the Roberval mechanism and the lever. Thus, the model consists of the dynamics of the Roberval mechanism and the lever. Each model is approximated by a spring-mass-damper system. The model parameters are identified by the experimental data for open-loop. Then, the validation of the proposed model is examined for the open-loop system and the closed-loop system. As a result, the validity of the model is confirmed. In particular, the responses between the simulation and experimental results for the open-loop system are the perfectly same.

However, there exist a few differences of the responses for the closed-loop system. Thus, this problem should be solved.

In the future, an entirely new control scheme for the electromagnetic force compensation will be proposed by using the proposed model. Then, the high-speed and high-accuracy mass measurement system will be applicable to many industrial fields.

REFERENCES

[1] T. Ono, Basic point of dynamic mass measurement, Proceedings of SICE, pp. 43–44, 1999.

[2] T. Ono, Dynamic weighing of mass, Instrumentation and Automation, Vol. 12, No. 2, pp. 35, 1984.

[3] W.G. Lee, et al., Development of speed and accuracy for mass measurements in checkweighers and conveyor belt scales, Proceedings of ISMFM, pp. 23–28, 1994.

[4] K. Kameoka, et al., Signal processing for checkweigher, Proceedings of APMF, pp. 122–128, 1996.