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MATHEMATICAL MODEL OF CHECKWEIGHER WITH ELECTROMAGNETIC FORCE COMPENSATION

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Abstract: In this research we develop a high speed mass measurement system with conveyor belt (a checkweigher). The objective in this paper is to propose a dynamic model of the measurement system. The checkweigher with electromagnetic force compensation can be approximated by the spring-mass-damper systems as the physical model, and an equation of motion is 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, electromagnetic 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 that the measuring time for one package is very short. In the near future, the continuous mass measurement for 300 products per minute will be required.

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 of an object can be measured by the deformation of Roberval mechanism when the mass to be measured is put on the weighing pan. Although 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 the 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, we proposed the dynamic model of the checkweigher with EMFC in the previous paper [5, 6]. However, the validity of the model for the closed-loop system cannot be confirmed. In this paper, the model of the measurement system is improved. Then, the validity of this model is confirmed by comparison between the simulation and experimental results.

2. MEASUREMENT SYSTEM

Fig. 1 shows the overall 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.

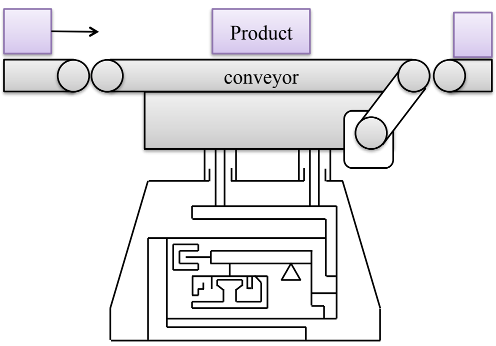

Fig. 1. Overall of checkweigher

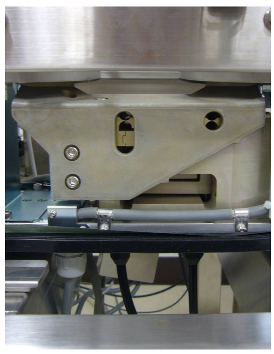

Fig. 2. Photograph of Roberval mechanism

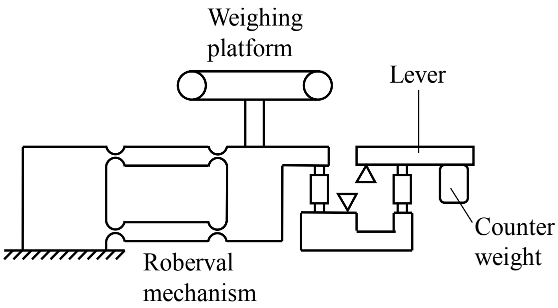

Fig. 3. Overall of measurement system

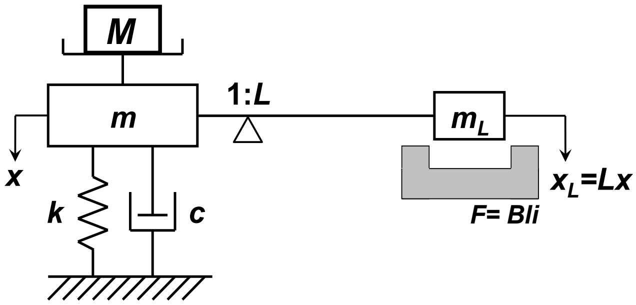

Fig. 4. Physical model of measurement system

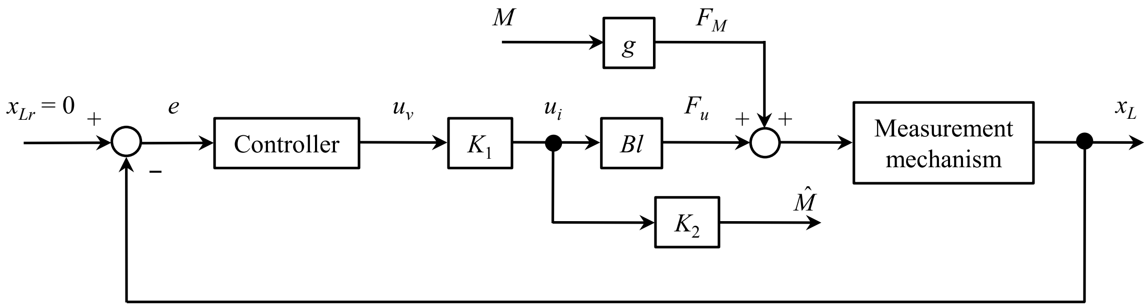

Fig. 5 Block diagram of measurement system

The enlarged photograph of the mass measurement mechanism in the checkweigher is shown in Fig. 2. The mass measurement system 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.

The mass of the product is estimated from the current of the electromagnetic force actuator to control the lever displacement.

The measuring method of mass can be explained as follows:

1. When the product of the mass M is put on the measurement system, the displacement of the Roberval mechanism is caused.
2. The displacement of the Roberval mechanism is magnified twenty times by the lever.
3. The magnified displacement can be measured by the displacement sensor.
4. The current is controlled so that the displacement of the lever can be maintained at zero.
5. The current is measured and the current is converted to the estimated mass by using the linear function.

3. MODELING

Fig. 3 and Fig. 4 show the physical model of the measurement system. An equation of motion about mass m can be obtained as follows:

$$(M+m)\ddot{x} + m_L L^2 \ddot{x} + c\dot{x} + kx = Mg + FL \tag{1}$$

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, 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 x_L of the mass m_L.

From Eq. (1), the natural frequency is

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{M+m+m_L L^2}}\ . \tag{2}$$

From the experimental result, the natural frequency of the lever is 5 Hz. Thus, the spring constant of the measurement system can be given as follows:

$$k = (2\pi f)^2 \times (M+m+m_L L^2) = 89.2\times 10^3\ . \tag{3}$$

The damper coefficient can be adjusted so as to match the convergence rate in the responses of the lever.

From Eq. (1), the Roverbal displacement at steady-state for the open-loop system ($F = 0$) can be described by:

$$x = \frac{Mg}{k}\ . \tag{4}$$

In addition, the lever displacement at steady state, that is magnified the Roverbal displacement by the lever, can be obtained by the following equation.

$$x_L = -Lx\ . \tag{5}$$

The simulation of the measurement system can be performed by using Eq. (1)-(5). Fig. 5 shows a block diagram of measurement system. In simulations and experiments, the validity of the model can be confirmed by comparing between the sensor outputs of the lever displacement (x_L).

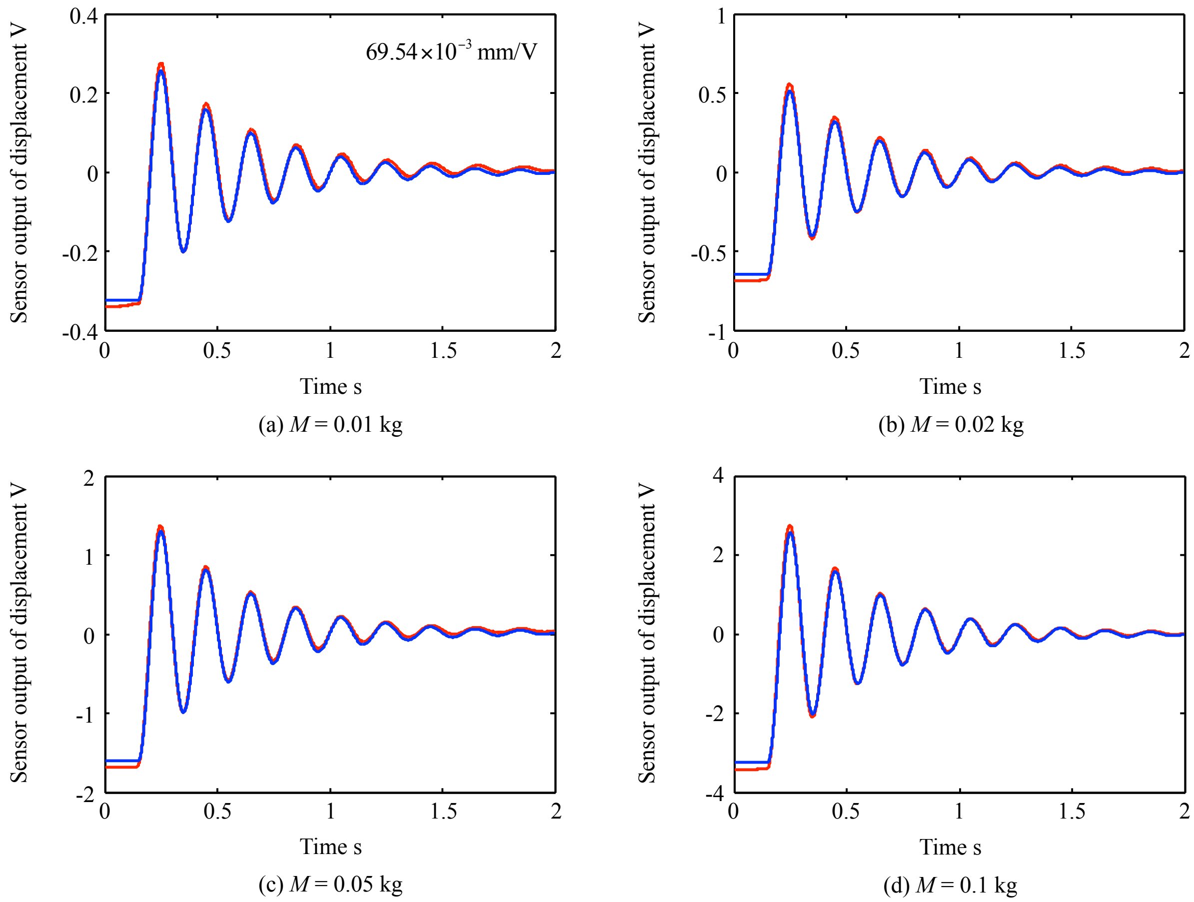

Fig. 6 Comparison between experimental result and simulation result (open loop)

4. EXPERIMENTAL AND SIMULATION RESULTS

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

4.1 Open-loop system

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

Fig. 6 depicts the experimental and simulation results for M = 0.01, 0.02, 0.05 and 0.1 kg. The red line and the blue line mean the experimental result and the simulation result, respectively. The start-up operation is the time when the product of the mass M is put on the measurement system. Then, when the time is 0.2 s, the product of the mass M is removed. At the same time, the displacement x_L is measured by the displacement sensor. In Fig. 6, the vertical axis shows the displacement 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,

$$C(s) = k_p + \frac{k_i}{s} + \frac{k_{dn}s}{k_{dd}s+1} \tag{6}$$

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 $U_v(s)$ (Laplace transform of $u_v(t)$) can be adjusted as follows.

$$U_v(s) = C(s)E(s) \tag{7}$$

where $E(s)$ is Laplace transform of $e(t)$ and $e(t)$ (= $x_{Lr} - x_L$) is the error between the reference x_{Lr} and the displacement sensor output of the lever x_L. The PID control can be performed by FPGA (Field Programmable Gate Array) at every 0.1 ms.

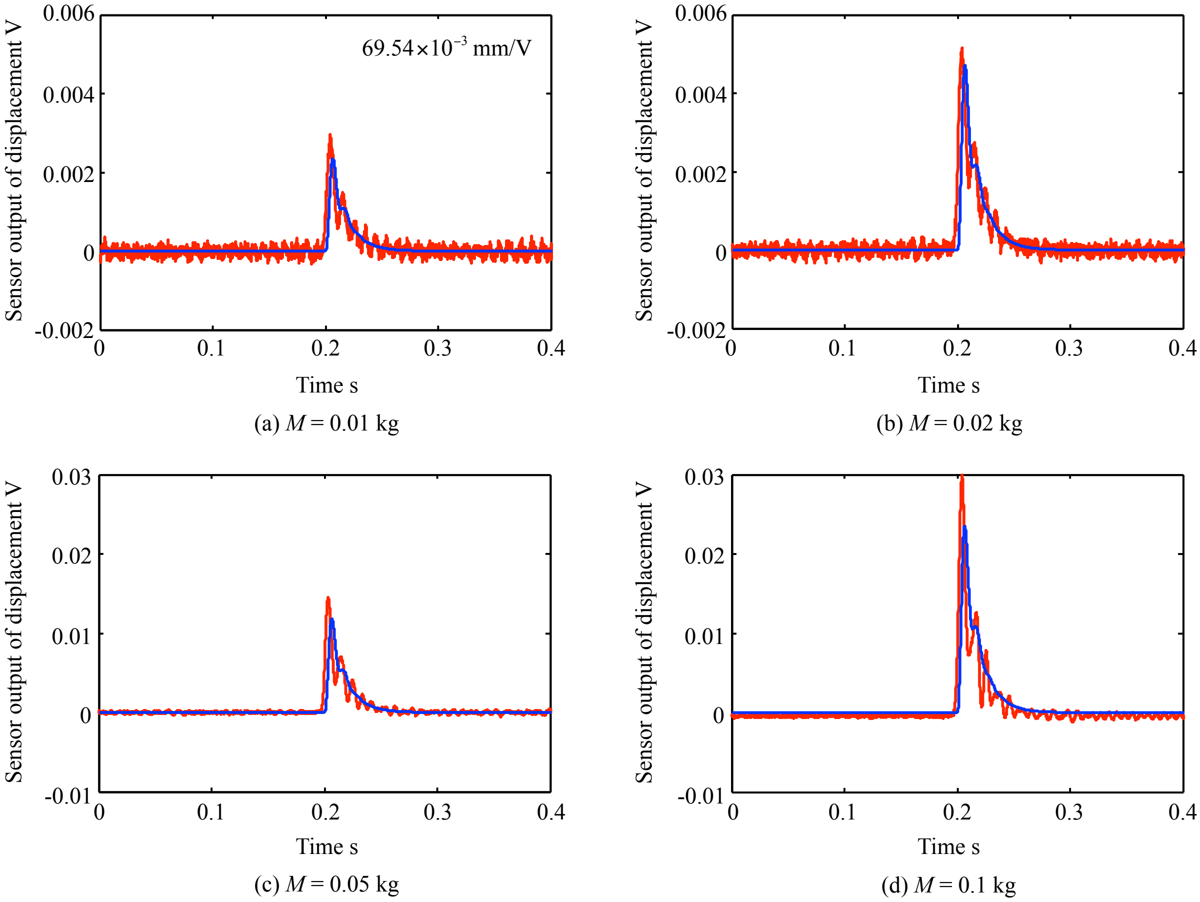

Fig. 7 Comparison between experimental result and simulation result (open loop)

Fig. 7 depicts the experimental and simulation results for M = 0.01, 0.02, 0.05 and 0.1 kg. The red line and the blue line mean the experimental result and the simulation result, respectively. The simulation and experimental conditions are the same as the open-loop system.

The response such as the convergence time, the rise time and the settling time between the simulation and experimental results are almost the same. Thus, the validity of the proposed EMFC model is confirmed. We consider that the reasons of modeling error are the friction force in small displacement and the magnification mechanism of the lever. However, the peak value of the simulation result for M = 0.1 kg is different on that of the experimental result. Moreover, the high-frequency response occurs in the experiments due to the system noise.

5. CONCLUSIONS

In this paper, the dynamic model of the electromagnetic force compensation (EMFC) system is constructed. The model is approximated by a spring-mass-damper system. The model parameters are identified by the experimental data for open-loop response.

Then, the validation of the proposed model is examined for the open-loop system and the closed-loop system. In particular, the responses between the simulation and experimental results for the open-loop system are the exactly same. And, both responses for the closed-loop system are the almost same. As a result, the validity of the proposed EMFC model can be confirmed.

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.

6. REFERENCES

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