

MODELING AND CONTROL FOR CHECKWEIGHER ON FLOOR VIBRATION

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Abstract – This paper discusses behaviors of a high speed mass measurement system. The goal of this paper is to propose a simple dynamic model of the system. The dynamics of the system with electro-magnetic force compensation is approximated by a mass-spring-damper system, and an equation of motion is derived. Model parameters are estimated from experimental data. Then, comparisons of the simulation results with the realistic responses are carried out. Finally, effects of floor vibration are explored.

Keywords: mass measurement, electromagnetic force compensation system, dynamic behavior, floor vibration.

1. INTRODUCTION

Recently a high-accuracy and high-speed 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 exist two types of the measurement system of the checkweigher, such as a load cell type [1-4] and an ElectroMagnetic Force Compensation (simply called EMFC) type. The load cell type is a displacement method, and this method can be considered to be a feedforward method in the control engineering. On the other hand, the EMFC type is a zero method and this method can be also considered to be a feedback method. In this research, because the measurement by the zero method is better in general, we

adopt the EMFC type in order to achieve the high-speed and high-accuracy mass measurement.

Until now, the dynamic behavior of the EMFC system has not still been discussed. Our goal is that the performance of the checkweigher can be improved for high-speed and high-accuracy. To do this, it is significantly necessary to develop the control scheme of the EMFC based on the dynamic model. Thus, we proposed the dynamic model of the checkweigher with EMFC in the previous paper [5]. In this paper, we confirm the validity of the proposed model for various situations such as step responses for open-loop and closed-loop system and floor vibration. At first, the step responses of the system will be shown in order to validate the effectiveness of the proposed model. Furthermore we will explore an effect of floor vibration occurred by surrounding machines motions and human walking. In particular, the EMFC system is the feedback type (zero method), and is more impressionable than the feed-forward type (displacement type) for the floor vibration. Therefore we will propose a model that can estimate effect of floor vibration and a compensation method of error in mass measurement for the floor vibration.

2. MEASUREMENT SYSTEM

Fig. 1(a) shows the figure of the checkweigher. 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 system consists of weighing platform, the Roberval mechanism, the lever linked Roberval mecha-

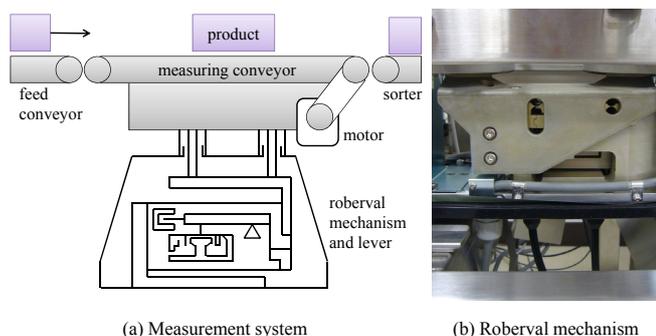


Fig. 1. Photographs of checkweigher

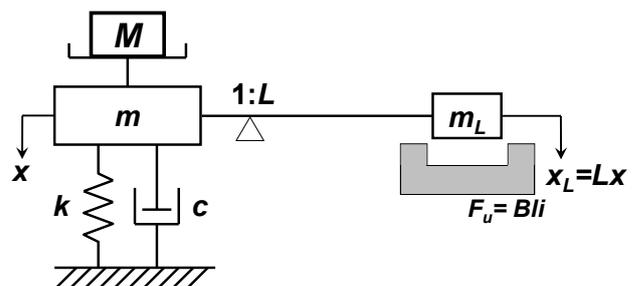


Fig. 2. Physical model of measurement system

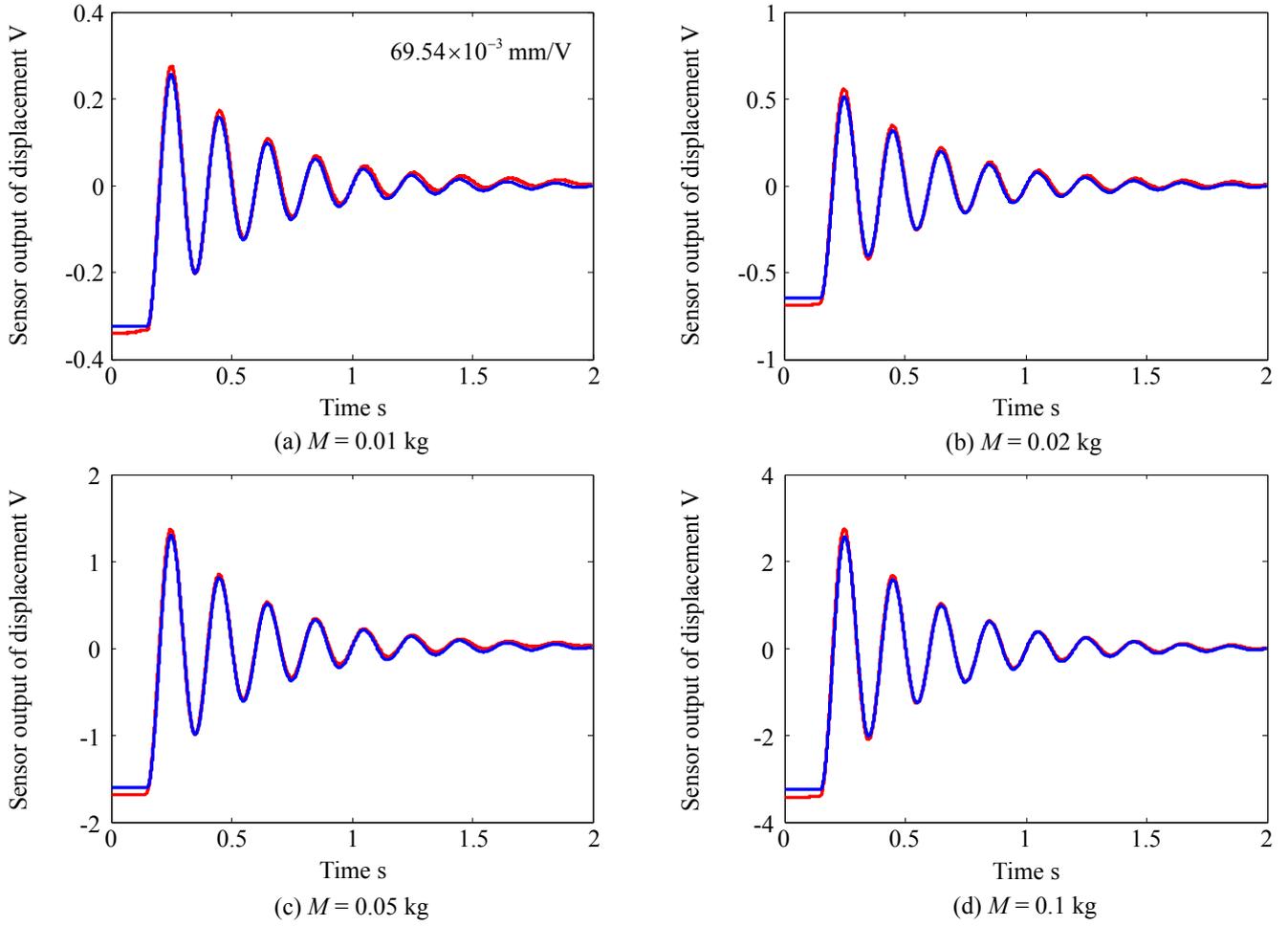


Fig. 3 Comparisons between experimental results and simulation results (open-loop)

nism, 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.

3. MODELING & STEP RESPONSES

Here we propose a dynamic model of mass measurement system and discuss step responses for open-loop and closed-loop system in order to validate the effectiveness of the proposed model.

3.1. System modeling

Fig. 2 shows a physical model of the measurement system. An equation of motion about mass m can be given by:

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

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 ($= 9.8 \text{ m/s}^2$) the acceleration of gravity, L ($= 20$ (

$= m/m_L$) the lever ratio, and x the displacement of mass m . And, m_L mass of the lever, x_L ($= -Lx$) the displacement of the lever, and F_u ($= Bli$, 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 in order to control the position x_L of the lever.

From Eq. (1), the natural frequency f can be described by

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

From the experimental result, the natural frequency f of the system is 5 Hz and the damping ratio is 0.08. Thus, the spring constant k can be calculated as follows:

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

And the damper coefficient c can be adjusted so as to match the convergence rate in the realistic responses of the system.

3.2. Step responses for open-loop system

Fig. 3 shows experimental and simulation results in an open-loop system. The start-up operation is that a product of the mass M is put on the measuring conveyor. When the time is 0.2 s, the product is removed. At the same time, the displacement x_L is measured by the displacement sensor.

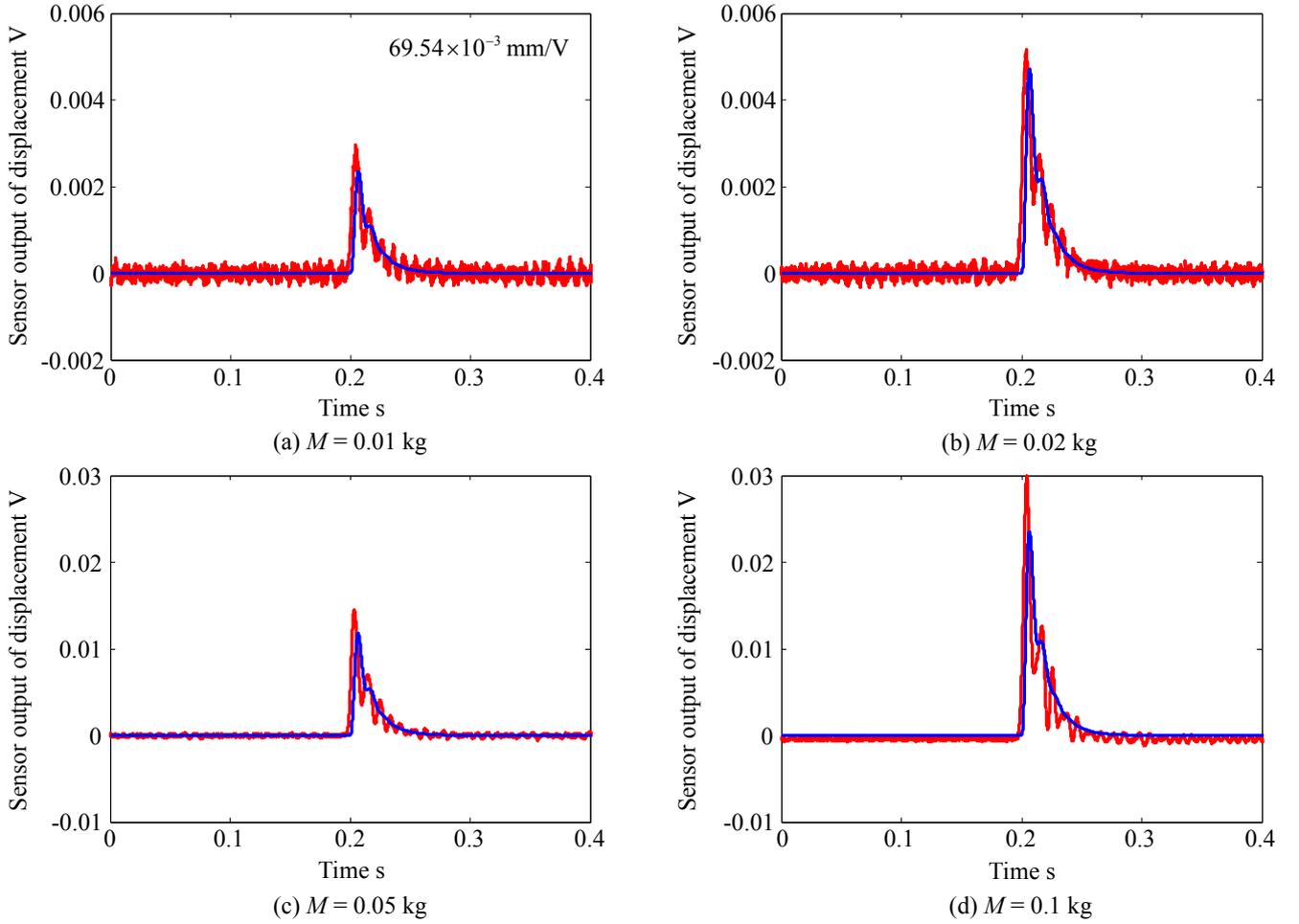


Fig. 4 Comparisons between experimental results and simulation results (closed-loop)

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 can be confirmed for the open-loop system.

In the next section, we will also confirm the validity for the closed-loop system in the same experimental condition.

3.3. Step responses for closed-loop system

Fig. 4 shows experimental and simulation results in a closed-loop system (PID control). PID parameters are adjusted to be stable in the control system. The experimental condition is the same as before.

The electromagnetic force is controlled by PID control scheme. Taking the actual circuit of the D action into account, the ideal D action cannot be implemented. So, we use an approximated D action. Thus, the transfer function of the PID controller $C(s)$ can be described by,

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

where k_p is the proportional gain. k_i is the integral gain. k_{dn} and k_{ad} 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.

$$U_v(s) = C(s)E(s) \quad (7)$$

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 at every 0.1 ms.

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 can be confirmed for the closed-loop system. In addition, we also confirmed the validity for the open-loop system.

4. EFFECTS OF FLOOR VIBRATION

In this section we explore effects of floor vibration. Floor vibration is one of system disturbances to be considered. First we compare experimental results with simulation results for floor vibration and confirm the validity of the model. Then we propose a new method for decreasing effects of floor vibration to achieve high accuracy mass measurement.

Fig. 5 shows a block diagram of overall system in mass measurement. The upper and lower block diagrams show a compensation method for floor vibration and the proposed dynamic model of the system, respectively. In experiments, the floor vibrations are acted on the system by using a vibrator. In simulations, floor vibration inputs are applied to the system as the environmental disturbance, as shown in Fig. 5. And, displacement of the floor vibrations in the simu-

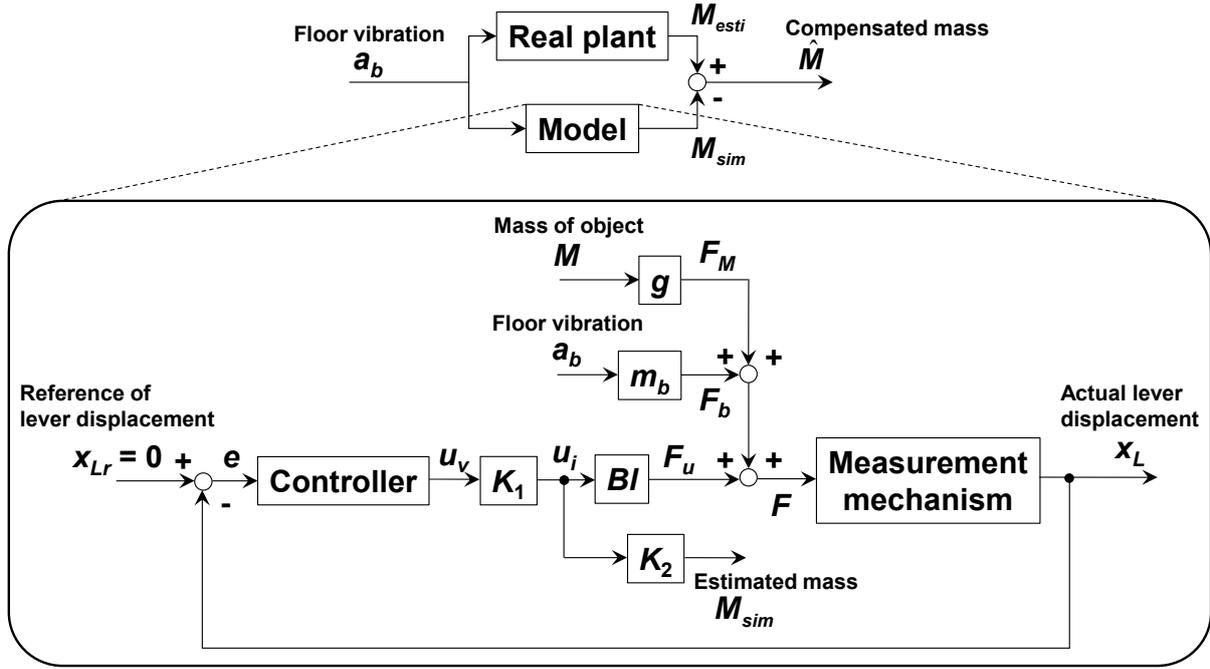


Fig. 5 Block diagram of mass measurement system including compensation method to floor vibration

lations can be given by

$$x_b(t) = A \sin \omega t \quad (8)$$

where $x_b(t)$ is the displacement of floor vibration, A [mm] is an amplitude of the floor vibration, ω [rad/s] ($= 2\pi f$, f is a frequency) is an angular frequency of the floor vibration, and t is the time. Therefore an acceleration $a_b(t)$ of the floor vibration can be described as follows:

$$a_b(t) = -A\omega^2 \sin \omega t \quad (9)$$

And an input of floor vibration to the system can be obtained by multiplier of the acceleration $a_b(t)$ and the mass m_b of the part of the Roverbal mechanism. The input of the floor vibration is added to the right side in Eq. (1) as $m_b a_b$.

The conditions about the floor vibration for experiments and simulations are the followings:

- (a) $A = 1$ mm, $f = 10$ Hz
- (b) $A = 1$ mm, $f = 15$ Hz
- (c) $A = 1.25$ mm, $f = 10$ Hz

4.1. Effects of floor vibration

At first we compare experimental results with simulation results about effects of floor vibration. Then we will confirm the validity of the proposed model for several floor vibrations.

The figures on the left side in Fig. 6 show experimental results (red lines) and simulation results (blue lines) about floor vibrations. From these results, we confirmed that almost the same responses between the simulations and the experiments can be obtained. Thus we confirmed the effectiveness of the model for floor vibrations.

However, the error between the simulation result and the experimental result in the condition ($A = 1$ mm, $f = 15$ Hz) as shown in Fig. 6(b). This reason is that the mass value in the experiment becomes smaller by suppressing the lever dis-

placement with the mechanical limitation.

4.2. Method for decreasing floor vibration effects

Since the same responses for floor vibrations can be obtained using the model, we can compensate the effect of floor vibration in terms of mass measurement by subtraction. Namely, we compensate the estimated error using the following equation,

$$\hat{M} = M_{esti} - M_{sim} \quad (10)$$

where \hat{M} , M_{esti} and M_{sim} means a compensated mass value, mass value obtained by the system and mass value obtained by the simulation with the proposed model, respectively.

The figures on the right side in Fig. 6 show compensated mass values about floor vibrations which are the same condition as before. It can be seen from these results, the errors of the mass measurements by the floor vibration can be decreased more than half of the original errors.

Proposal of actual compensation method for floor vibration

Actual compensation methods for mass measurement error due to the floor vibration can be considered as follows:

- 1) An acceleration of floor vibration is measured using an acceleration sensor. The measured acceleration is used as the input of the floor vibration in the proposed model. The compensation for mass measurement is performed by the proposed method.
- 2) At first we develop the dummy mechanism that has the same characteristics as the actual measurement system. The lever displacement for the floor vibration can be measured using the dummy mechanism. Then the simulation for the floor vibration using the model is executed and the compensation is carried out.

Here we discussed the effectiveness of the proposed method 1). In case that the frequency of the floor vibration is low, the proposed method 2) can be considered to be effective.

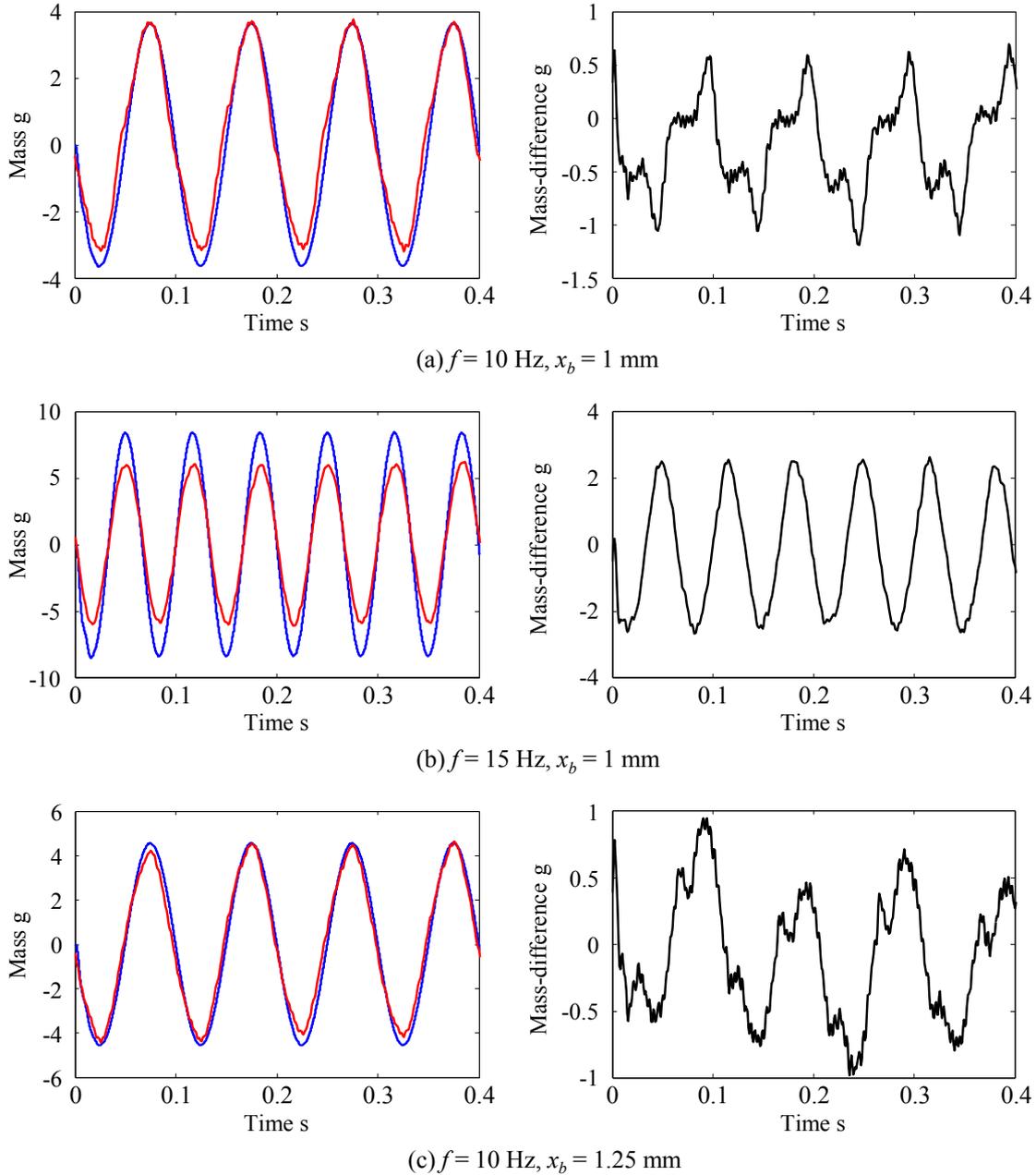


Fig. 6 Comparisons between experimental results and simulation results (closed-loop)

5. CONCLUSIONS

In this paper, the dynamic model of the measurement system with EMFC was proposed. The model was approximated by a mass-spring-damper system. The model parameters were estimated by the experimental data. Then, the validations of the proposed model were examined for the open-loop and the closed-loop systems. Comparing the experimental results with the simulation result, the same responses can be obtained by using the proposed dynamic model.

Furthermore we discussed the effect of the floor vibrations to the mass measurement system. And we can duplicate the effects with the proposed model. And we suggested the method for decreasing the error about the mass measurement which is generated by the floor vibrations.

In the future, we will implement the proposed method to

the system and explore the effectiveness of the proposed method in actual environment. In addition, we will verify the effectiveness of the proposed method for floor vibrations.

6. REFERENCES

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