Vibration Suppression using Filtered Velocity Reference for Flexible Structure *

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Abstract

With the flexible structure such as a stacker crane, vibration generates by the high acceleration of the driving axis in the load transportation part. For the improvement of the productivity, the vibration suppression is necessary. This paper proposes an experimental study on generation of the reference command for vibration suppression of a flexible structure. In the operation of the structure, residual vibration is generated. The important vibration frequency of the residual vibration to suppress is the first mode. But the phase of first mode is opposite to the phase of second mode. The reference command of suppression for the first mode vibration is excited the second mode. The reference command is generated by using a low pass filter for the suppression of the both mode. The desired effect is demonstrated experimentally.

Key words: mechatronics, flexible structure, vibration suppression, velocity reference, stacker crane

1. Introduction

In a stacker crane performing the handling of the automatic warehouse, a carriage is set up. The carriage goes both ways on the linear rail and works. A mast going up and down is installed on the carriage. So the going up and down mast has height more than 10m, it is the flexible structure. Because the mast is the flexible structure, at the time of stop of the high-speed operation of the carriage, the mast vibrates. Transportation work is not possible while this residual vibration is not settled. The work efficiency decreases. By the vibration suppression for the stacker crane, there are the following methods.

The linear motion velocity of the carriage at the time of a stop of the high-speed operation is changed by acceleration and deceleration, and the mast is moved to the opposite direction forcibly 1). The time of slowdown is set at the time of integral multiples more than the twice the natural frequency 2). The collision of object is reduced vibration 3).

In addition, there is the Input Shaping technique that the vibration suppression of the large-sized flexible robot arm is performed 4).

The structure of the stacker crane and the flexible robot arm has multiple vibration modes. Particularly, the first and the second vibration modes may become the opposite phase. Therefore the vibration suppressant effect is not provided enough to excite the second vibration mode even if the first vibration mode is targeted in improvement of the reference.

Dynamic damper is a method, therefore, to perform of vibration suppression, and the placement of the damper is decided in a tower-shaped structure by a vibration mode 5).

The technique to attach the dynamic damper to the appointed position is effective, but it is an effective remedy if it can be controlled vibration without attaching devices.

In this study, it is the purpose to suppress the residual vibration of the mast of the flexible structure by improvement of the operation reference of the linear motion axis.

The reference to the linear motion axis is given acceleration and deceleration velocity reference for vibration suppression to the first natural frequency of the mast.

The reference is set through a low-path filter so that the second natural frequency is not excited. The vibration suppression effect by the improvement is verified in the velocity reference by the experiment.

2. Experimental setup

The experimental setup is shown in figure 1. It is used a ball screw mechanism driven with an AC servomotor for the linear motion axis. The AC servomotor is 100W, the encoder resolution is 16 bits, and the lead of the ball screw is 4mm. On the table of the ball screw, a mast of the flexible structure is installed. The mast length is 1m, and the weight of the tip is designed so that the first natural frequency becomes 3Hz.

As for the motor of the ball screw drive, it is excited in a random wave, and the transfer function that the acceleration of the mast tip is measured is shown in figure 2. The natural frequencies are 3Hz, 20Hz, and 52Hz. The first vibration mode and the second vibration mode are opposite phase. Therefore the vibration suppressant effect is not enough to excite the second vibration mode even if the first vibration mode is targeted in improvement of the reference.

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Three vibration modes are shown in figure 3. All vibration modes vibrate in the tip of the mast. In this study, and vibration suppression of the tip is performed. The stacker crane has lifting mechanism to go up and down a load, and natural frequencies usually change. With this experimental device, a weight of the mast part is fixed, and experiments are carried out for the natural frequency as immutability. In addition, damping is extremely small because it is simple board structure.
3. Improvement of the velocity reference

The reference to apply the servomotor of the table drive is made. A motion of the mast part equation is equation (1).

\[ m\ddot{x}_m = -k(x_m - x_t) \]  

(1)

Where, \( m_m \): mast mass, \( k \): mast rigidity,
\( x_m \): displacement of mast,
\( x_t \): displacement of linear motion axis.

As for the equation (1), it is done Laplace transform.

\[ X_m(s) = \frac{k}{m_s s^2 + k} X_t(s) \]

(2)

Here, \( \omega_n \) is the first natural frequency of the mast part.
\( X_m(s) \) that multiplied response \( X_t(s) \) of the linear motion axis by \( \omega_n^2/(s^2+\omega_n^2) \) becomes the response of the mast part.

\[ V_{imp}(s) = \frac{s^2 + \omega_n^2}{\omega_n^2} V_{ref}(s) = \frac{s^2}{\omega_n^2} V_{ref}(s) + V_{ref}(s) \]

(3)

The vibration of the mast part will be canceled by multiplying reference \( V_{ref}(s) \) by \((s^2+\omega_n^2)/\omega_n^2\) beforehand. Square wave reference having the size that divided jerk of original velocity reference \( V_{ref} \) by square of natural frequency \( \omega_n \) is added. Because it is \( f_m = 3 \) Hz of \( \omega_n = 2\pi f_m \), vibration suppression of the first vibration mode is performed.

The velocity reference of the original trapezoid wave is shown in figure 4. And the velocity reference which square wave is added, is shown in figure 5. The motor velocity reference is expressed in pulse/s. Because 16 bit encoders are installed, angle of rotation \( 2\pi/2^{16} \) is 1 pulse. It is confirmed in figure 5 that reference worked in acceleration and deceleration to the opposite direction is added.
4. Experiment

The velocity reference prepared in a foregoing chapter is integrated and is used as position reference to the AC servomotor, and the operation experiments are performed. The AC servomotor is driven by the proportional control of the position and proportional integral control of the velocity. It is worked the motor using trapezoid wave velocity reference shown in figure 4. The response of the result is shown in figure 6. The velocity response of the motor is shown in figure 6(a), and acceleration response of the mast tip is shown in figure 6(b).

The drive of the motor is finished in 1.3s, but as for the residual vibration of the mast, 0.1 m/s² continues until 16s. Frequency of the residual vibration is 3Hz. It is the first natural frequency of the mast.

The result that drives the motor using improved velocity reference of figure 5 is shown in figure 7. The velocity response of the motor, the acceleration responses of the mast tip are shown in figure 7(a), (b).

Frequency of the residual vibration of the acceleration response is 20Hz and coincides with the second natural frequency. As for the first vibration mode, it is done vibration suppression by improved velocity reference.

The amplitude at the time of 16s became 0.02 m/s², and it is decreased by 1/5. Because the phase of first mode and the phase of second mode become the opposite phase in transfer function of figure 2 and vibration mode of figure 3 at the mast tip, the first vibration mode is suppressed, but a second vibration mode is excited.

The velocity correction component used for improvement of the velocity reference is shown in figure 8. Square wave is used to suppress with the first vibration mode in this reference, and other vibration modes are excited by a rapid velocity change.

In this reference, the amplitude of the wave for suppression is maintained, and the velocity reference that high order frequency is not excited is generated. The reference that a low-path filter is put through is generated. Cut-off frequency of the filter is 7.5Hz.

The calculated velocity reference is shown in figure 9. The rectangle shapes get smooth, and it is the reference that vibration modes of high order frequency are not excited. This reference is added to trapezoid velocity reference of figure 4, and velocity reference is generated. The improved velocity reference is shown in figure 10.
Filtered velocity reference of figure 10 is used, and the response that the motor is driven is shown in figure 11. The velocity response of the motor, the acceleration responses of the mast tip are shown in figure 11(a), (b).

When the response given improved reference is compared with the response that original reference is given, as for the first vibration mode, it is suppressed, and the vibration suppression effect is obtained.

The amplitude at the time of 16s is reduced by 0.003m/s², and the second vibration mode is reduced 10s later, too.

5. Conclusions

As for the flexible structure represented by a stacker crane, it must be performed vibration suppression. The operation reference of the linear motion axis is improved, and the residual vibration of the mast of the flexible structure is controlled.

By experiment inspection, the following conclusions are obtained.

(1) The experimental device of the flexible structure has natural frequencies in 3Hz, 20Hz, 52Hz, and the first and the second vibration phase in the mast are opposite phase.

(2) Residual vibration occurs in the natural frequency of the mast of the flexible structure. The reference to the linear motion axis is given acceleration and deceleration velocity reference for vibration suppression harmonized by the first natural frequency of the mast, and the vibration suppression effect is obtained.

(3) The first vibration is reduced by acceleration and deceleration velocity reference, but the second vibration mode that is opposite phase is excited.

(4) The reference which the low-path filter is covered with not to excite second vibration mode is suggested, and the effect that first and both second are reduced at the same time is obtained.

References