《高阶会员专属视频》-第27期

远端操作机器人使用的相对位置控制系统是什么？若不使用前馈，如何提升其位置控制性能？

《高階會員專屬-第27期》遠端操作機器人所使用的相對位置控制系統（relative position control）是什麼？
若不使用前饋，如何提升其位置控制性能？

Application of a Disturbance Observer for a Relative Position Control System

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《高階會員專屬-第27期》遠端操作機器人所使用的相對位置控制系統（relative position control）是什麼？
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***Abstract*—This paper presents an application of a disturbance observer for a relative position control system. In this system, since the prefixed motion profile is not defined *ex ante*, the acceleration state which is generated based on the profile is also not available. Therefore, feedforward acceleration controls cannot be used, and the position control performance is restricted solely by the bandwidth of the position controller. To enhance the control performance, disturbance observers can be utilized actively. The proposed method considers the position reference just as the result of a disturbance. Therefore, the relative position control can be performed by a disturbance observer as well as a position controller. As a result, the position control performance of the proposed method has been enhanced by up to 30% compared with that of the conventional method. The feasibility of the proposed method has been verified by experimental results using a high-precision linear motion control system as well as by analysis based on Bode plots.**

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【典型的位置運動控制系統】
來自位置命令產生器的前饋量

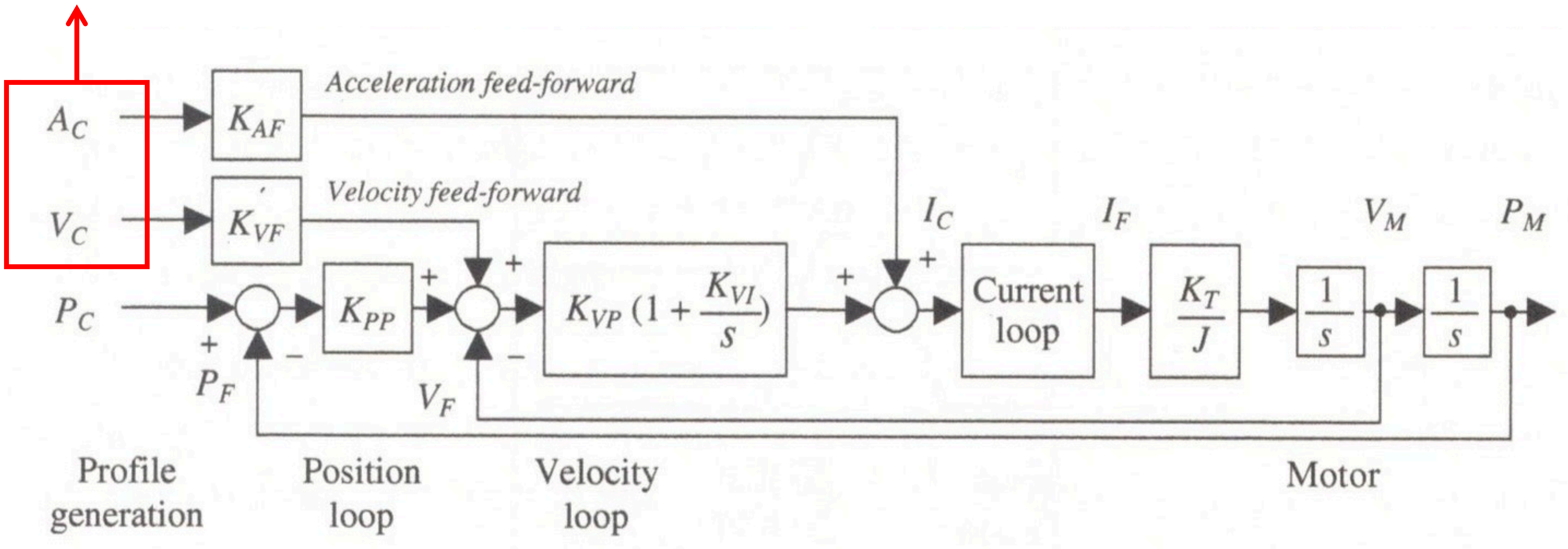

Figure 17.10:
Block diagram of P/PI loops with acceleration and velocity feed-forward.

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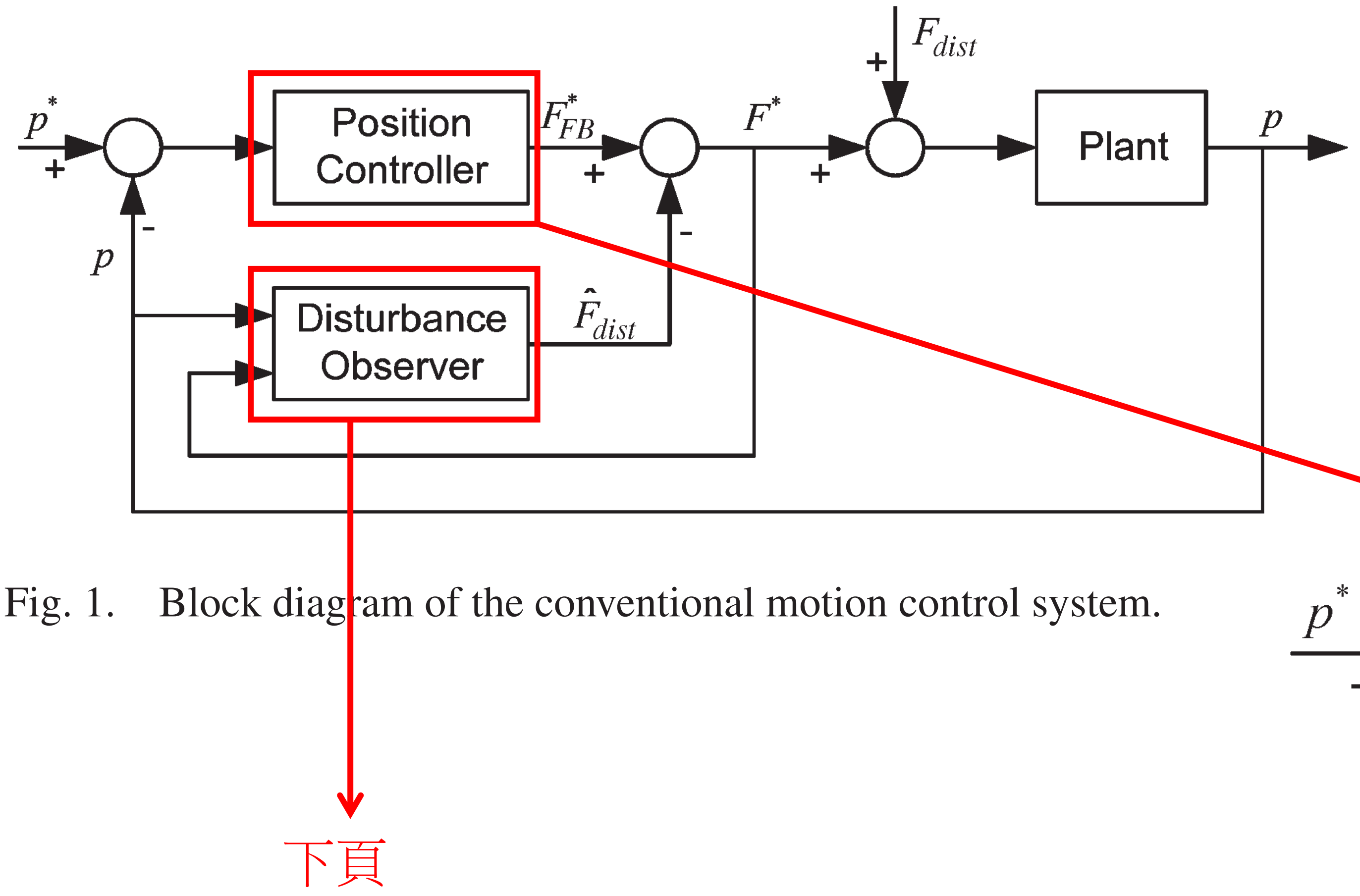

Fig. 1. Block diagram of the conventional motion control system.

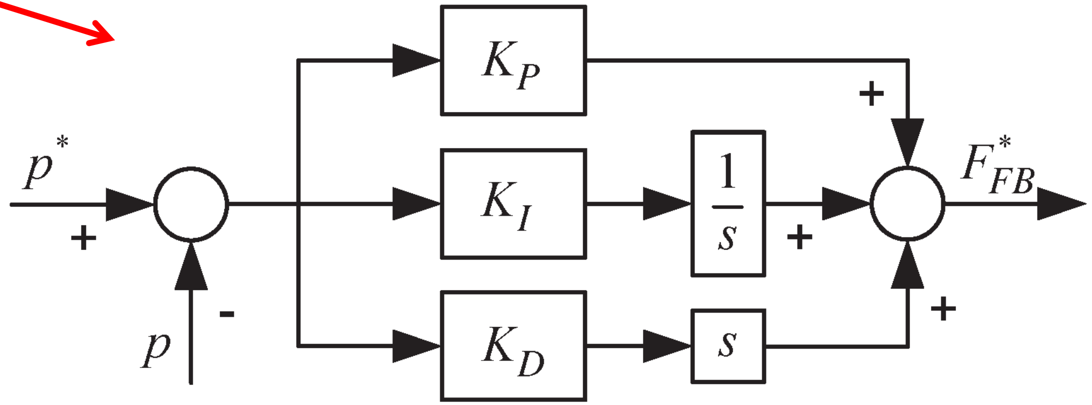

Fig. 2. Block diagram of the position controller.

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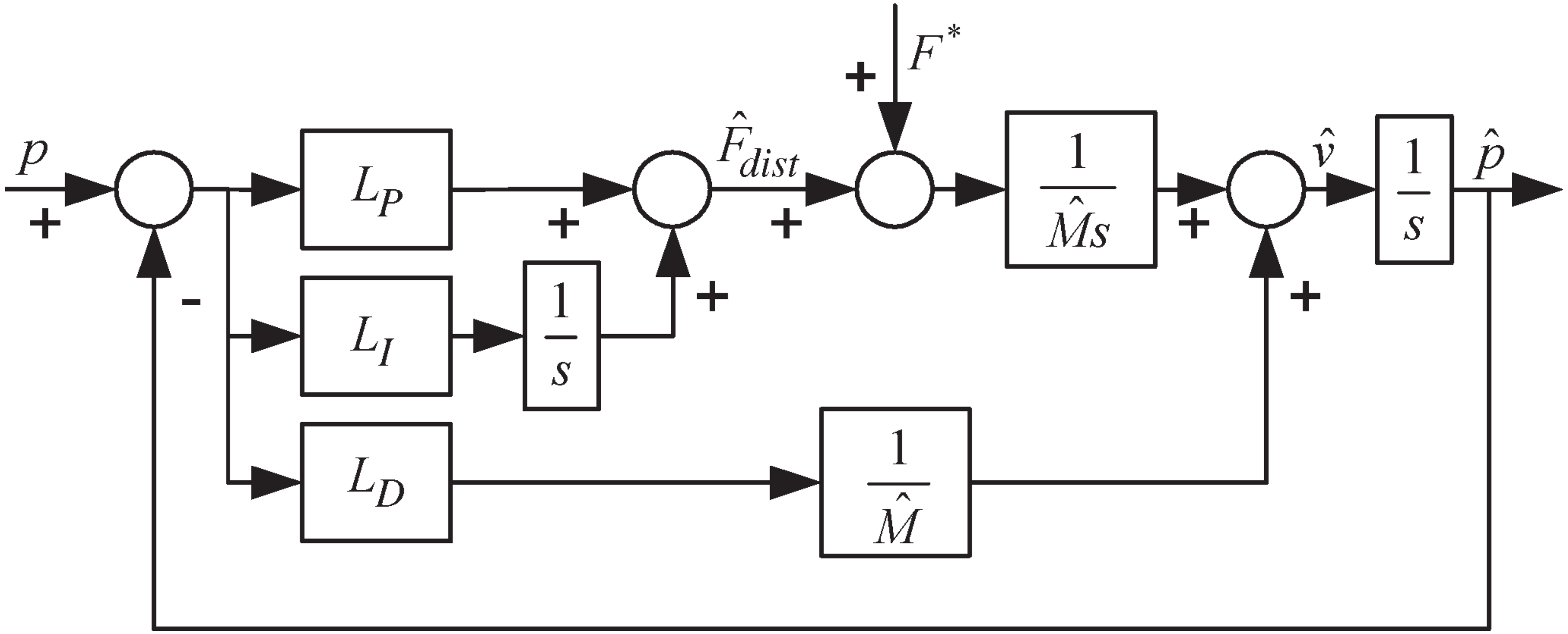

Fig. 3. Block diagram of the disturbance observer.

可以參考線上課程《交流電機控制回路設計》的**5.11**節內容

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- 如何設計位置控制PID參數？
- 可以參考：

《高阶会员专属-第26期》运动控制的三种主要的位置控制环的比较及其等效性

The gains of the position controller can be selected by various manners. In this paper, for analysis, the PID gains of the conventional position controller are selected as follows considering a damping factor:

$$K_P = K_{\text{pp}} K_{\text{pv}} + K_{\text{iv}} \quad K_I = K_{\text{pp}} K_{\text{iv}} \quad K_D = K_{\text{pv}}$$
$$K_{\text{pv}} = \hat{M} \cdot \omega_{\text{sc}} \quad K_{\text{iv}} = 0.2 \cdot K_{\text{pv}} \cdot \omega_{\text{sc}} \quad K_{\text{pp}} = \omega_{\text{sc}}/9 \tag{1}$$

where $\hat{M}$ is the estimated mass of the plant, K_{pv} and K_{iv} are the proportional and integral gains of the speed controller, K_{pp} is the proportional gain of the position controller, ω_{sc} is the bandwidth of the speed controller, and K_P, K_I, and K_D are the P, I, and D gains of the PID controller, respectively.

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- 如何設計擾動估測器參數？
- 可以參考線上課程：

《交流電機控制回路設計》的5.11節內容

The gains of the observer shown in Fig. 3 can also be selected by various alternative methods. By locating the poles of the observer as triple roots, the gains of the conventional observer are selected as

$$L_P = 3 \cdot \omega_{\mathrm{ob}}^2 \cdot \hat{M} \quad L_I = \omega_{\mathrm{ob}}^3 \cdot \hat{M} \quad L_D = 3 \cdot \omega_{\mathrm{ob}} \cdot \hat{M} \quad (2)$$

where L_P, L_I, and L_D are the P, I, and D gains of the observer and ω_{ob} is the pole of the observer.

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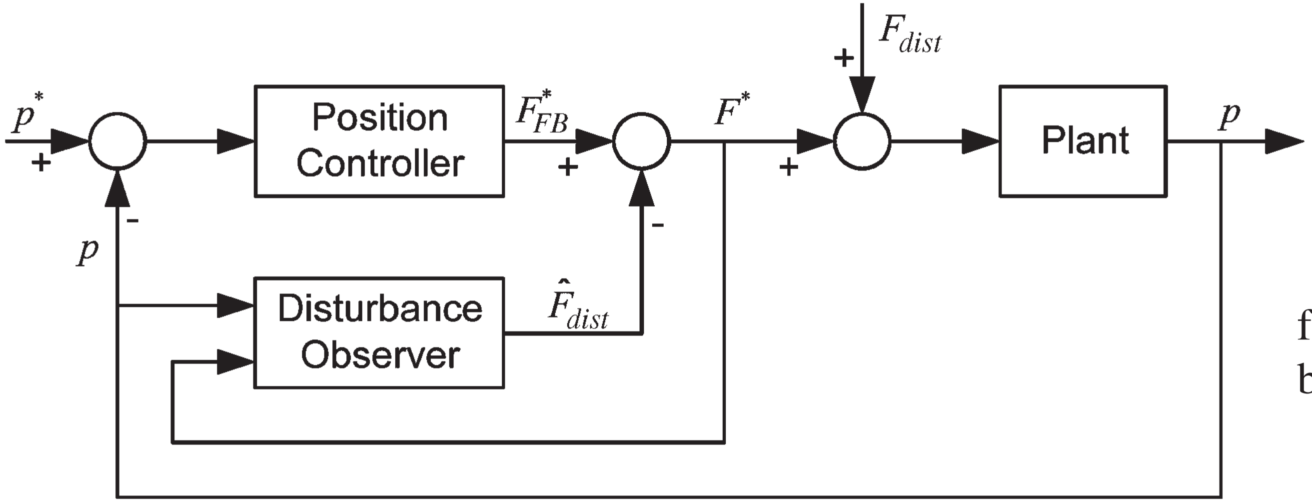

Fig. 1. Block diagram of the conventional motion control system.

Supposing that $\hat{M}$ is equal to M for simplicity, the transfer functions of the relative position control performance p/p^* can be described as

$$\frac{p}{p^*} = \frac{K_D s^2 + K_P s + K_I}{M s^3 + K_D s^2 + K_P s + K_I}. \quad (3)$$

As shown in (3), the disturbance observer does not affect the performance of the relative position control if the model of a plant is accurate. However, if there are some errors in the plant model, the disturbance observer can compensate them, and it is able to enhance the position control performance compared with the case where it is not adopted. Even in this case, however, the disturbance observer merely compensates the internal model error and does not affect the performance of the relative position control.

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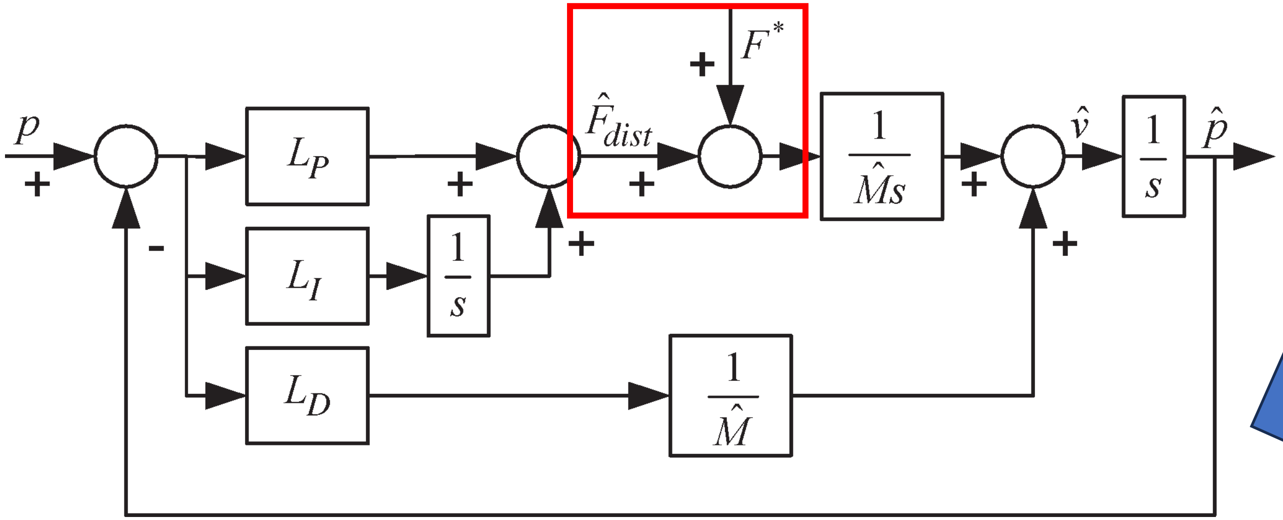

Fig. 3. Block diagram of the disturbance observer.

$$F^* = F^*_{\mathrm{FB}} - \widehat{F}_{\mathrm{dist}}. \qquad (6)$$

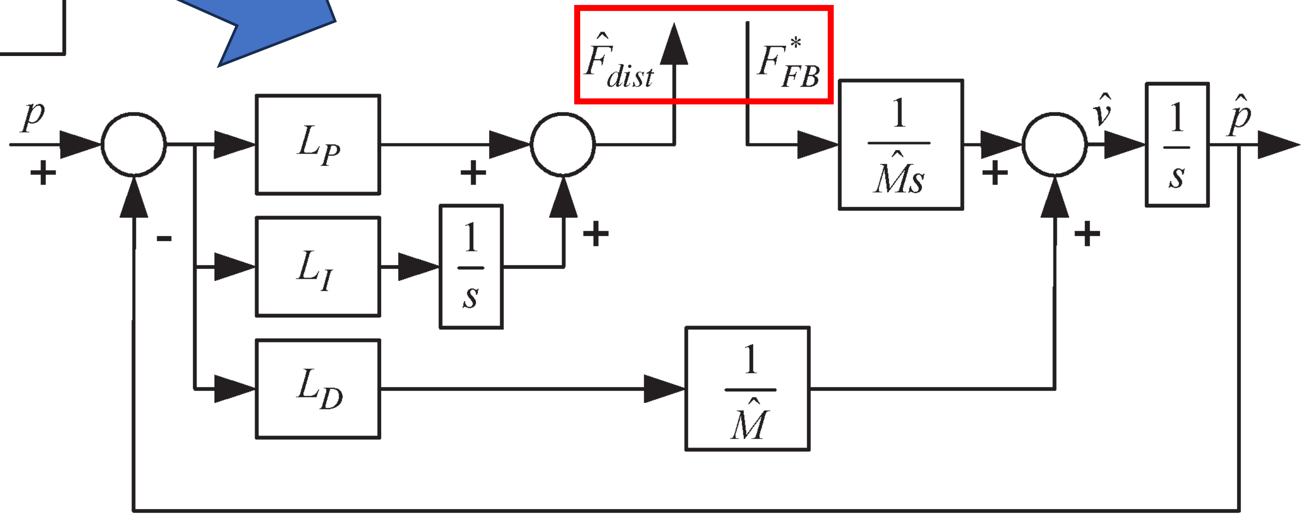

Fig. 6. Block diagram of the disturbance observer.

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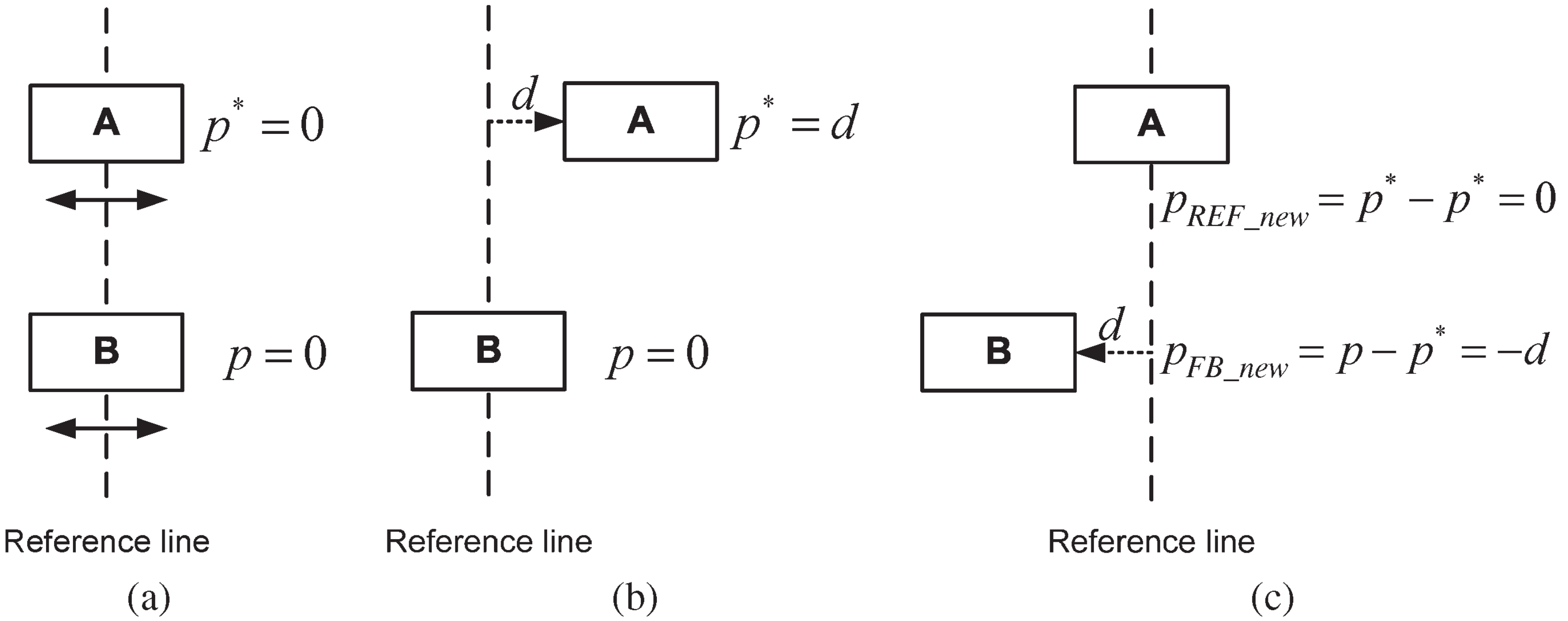

Fig. 4. Relative position control. (a) Steady state of the relative position control. (b) Transient state in the point of view of the conventional method and (c) transient state in the point of view of the proposed method.

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The new position reference and position feedback of the proposed method can be described as (4) and (5), respectively. They can be generated in the viewpoint of the target object A

$$p_{\mathrm{REF\_new}} = p^* - p^* = 0 \tag{4}$$

$$p_{\mathrm{FB\_new}} = p - p^* \tag{5}$$

where $p_{\mathrm{REF\_new}}$ and $p_{\mathrm{FB\_new}}$ are the new position reference and feedback of the proposed relative position controller, respectively.

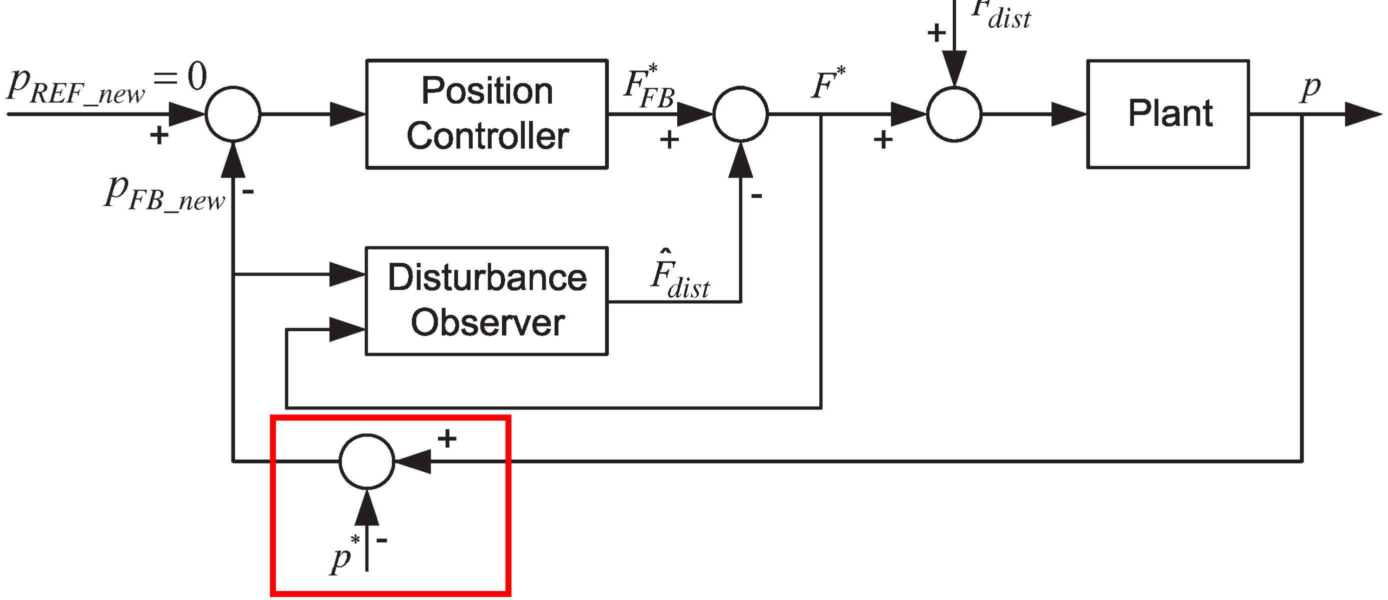

Fig. 5. Block diagram of the proposed method.

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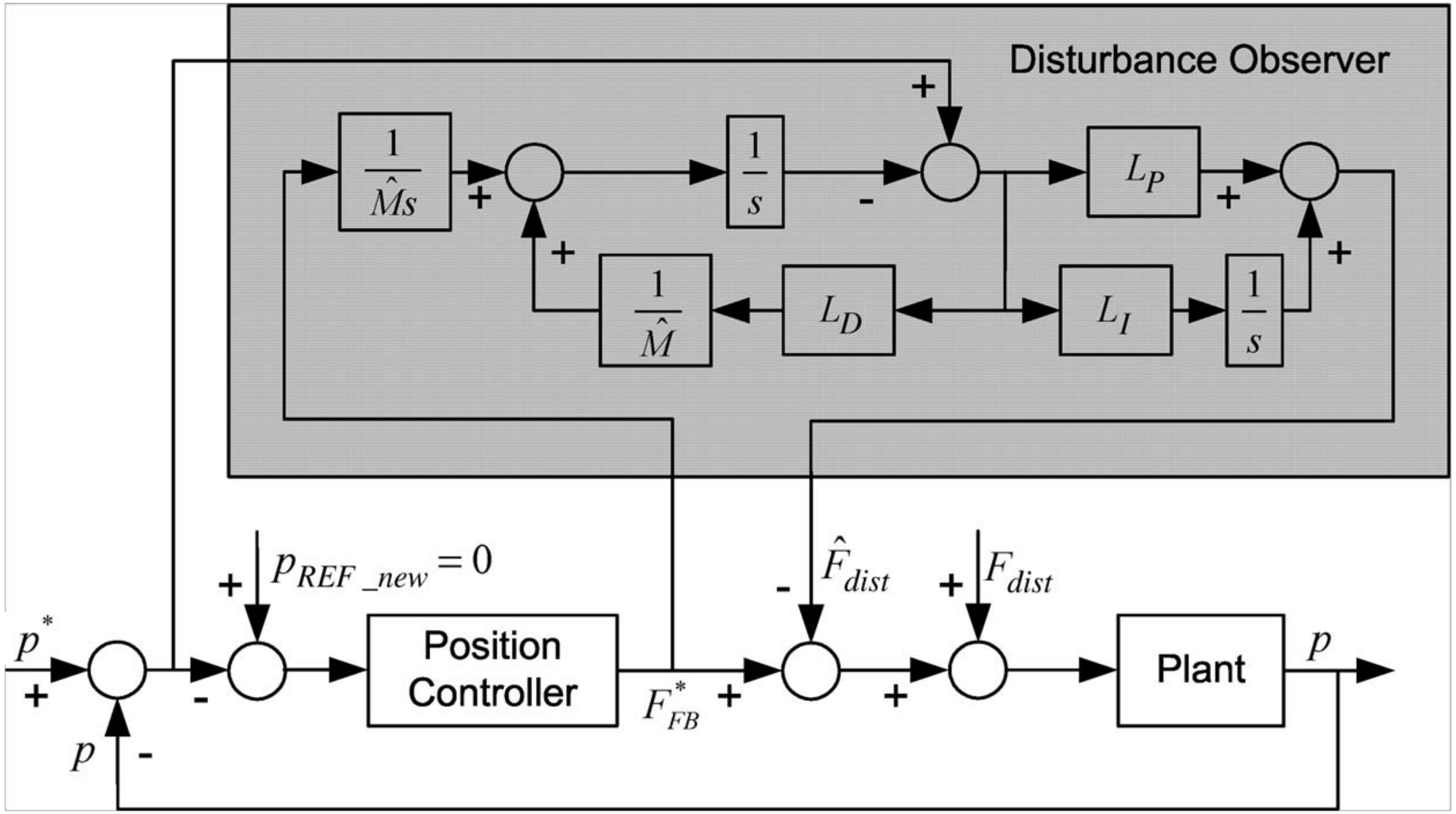

Fig. 7. Rearranged block diagram of the proposed method.

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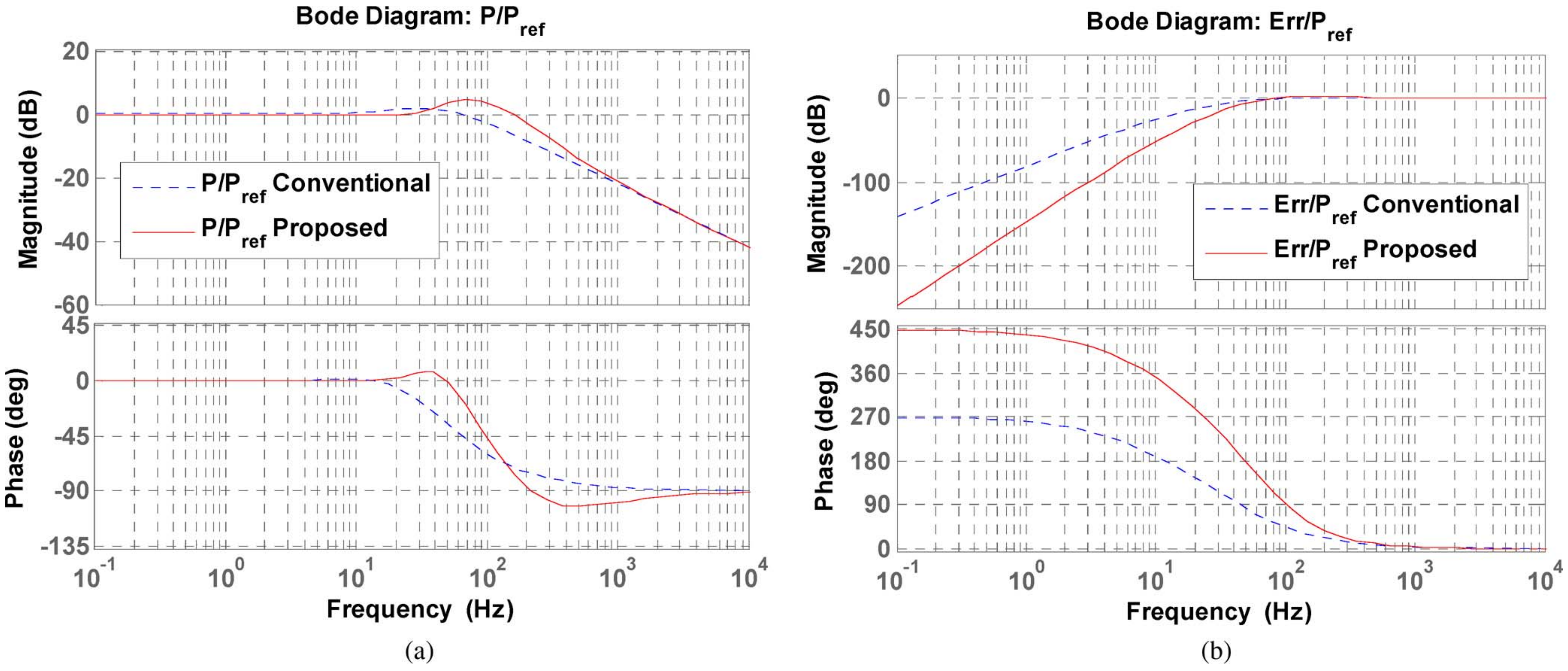

Fig. 8. Comparison of the position control performance. (a) p/p^* and (b) Err/p^*.

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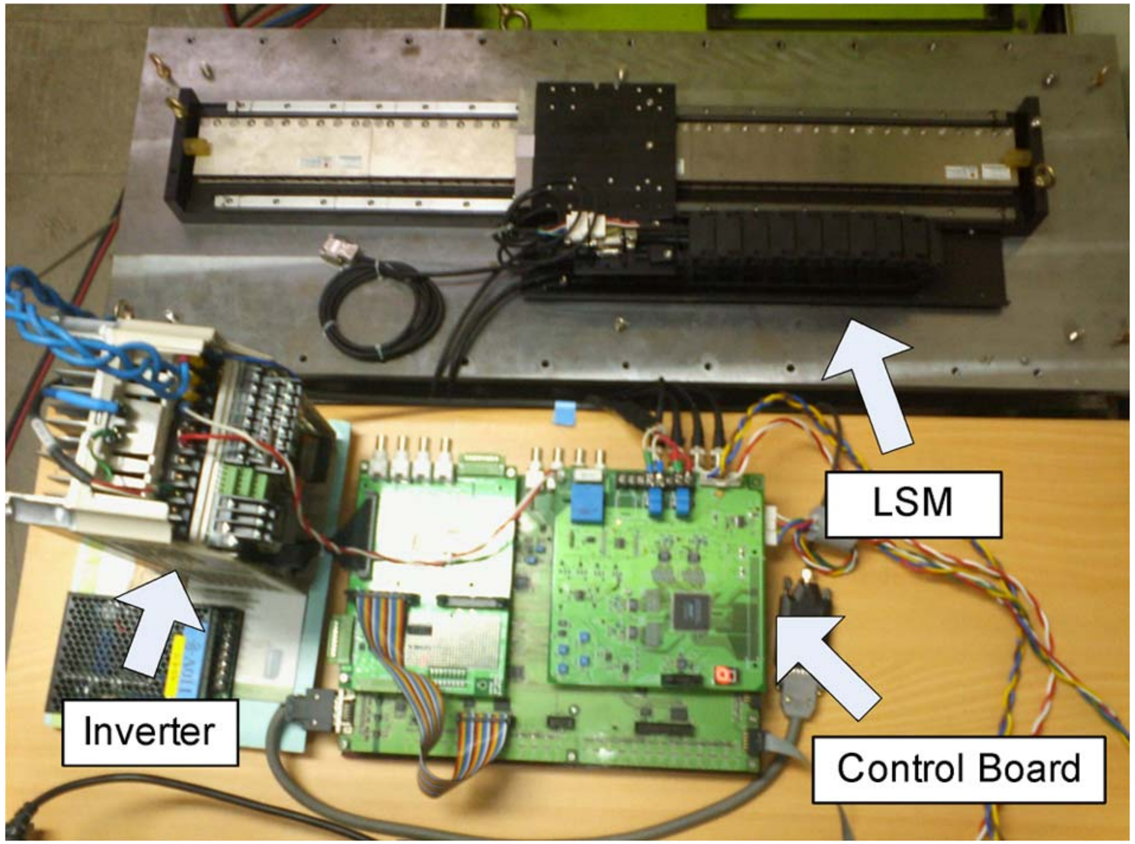

Fig. 9. Experimental setup.

IV. Experimental Results

Experiments using a high-precision motion stage comprising a permanent-magnet LSM and a linear encoder were performed. Fig. 9 shows the experimental setup. The parameters of the LSM under test are listed in Table I. The resolution of

the linear encoder is 40 nm, and a commercial inverter has been used. The nominal parameters of the inverter are listed in Table II. The switching frequency was set to 10 kHz, and the current control bandwidth was 2 kHz using a high-bandwidth

current controller [15]. To implement a high-bandwidth current controller, the control board used a 32-b floating-point DSP, namely, TMS320VC33, and a 12-b 20-MHz sampling analog-to-digital converter, ADS805.

be reduced to make the system stable. For the plant in this paper, both ω_{sc} and ω_{ob} were set to 80 Hz to avoid such a mechanical resonance. The control performance was found out to be underdamped when the bandwidth was higher.

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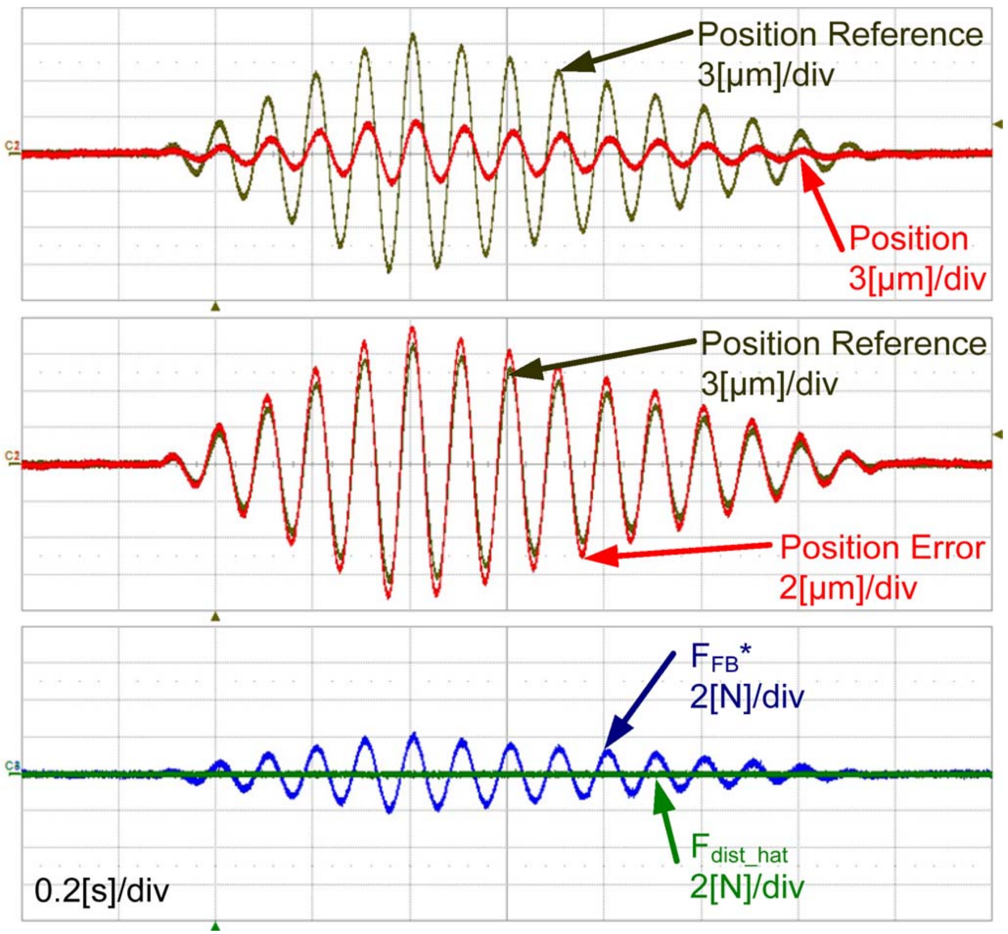

Fig. 10. Relative position control performance of the conventional method without the disturbance observer; the frequency of the position reference is 10 Hz.

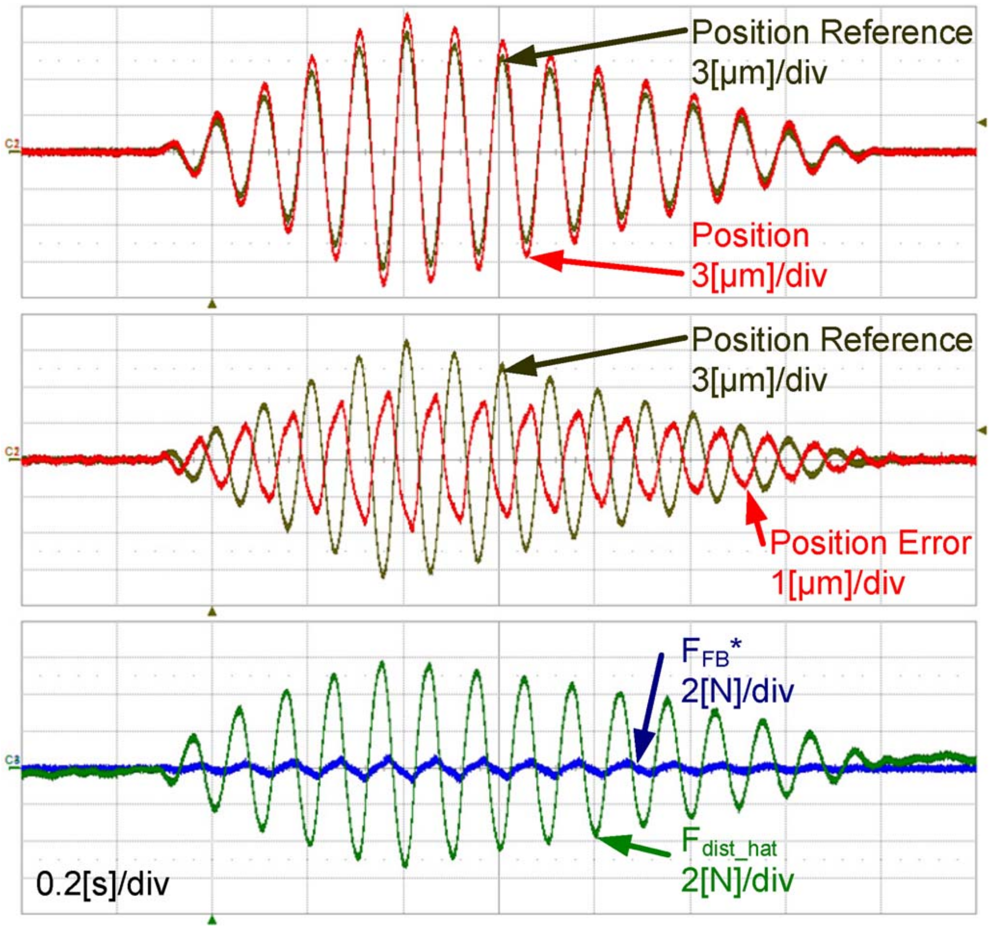

Fig. 11. Relative position control performance of the conventional method with the disturbance observer; the frequency of the position reference is 10 Hz.

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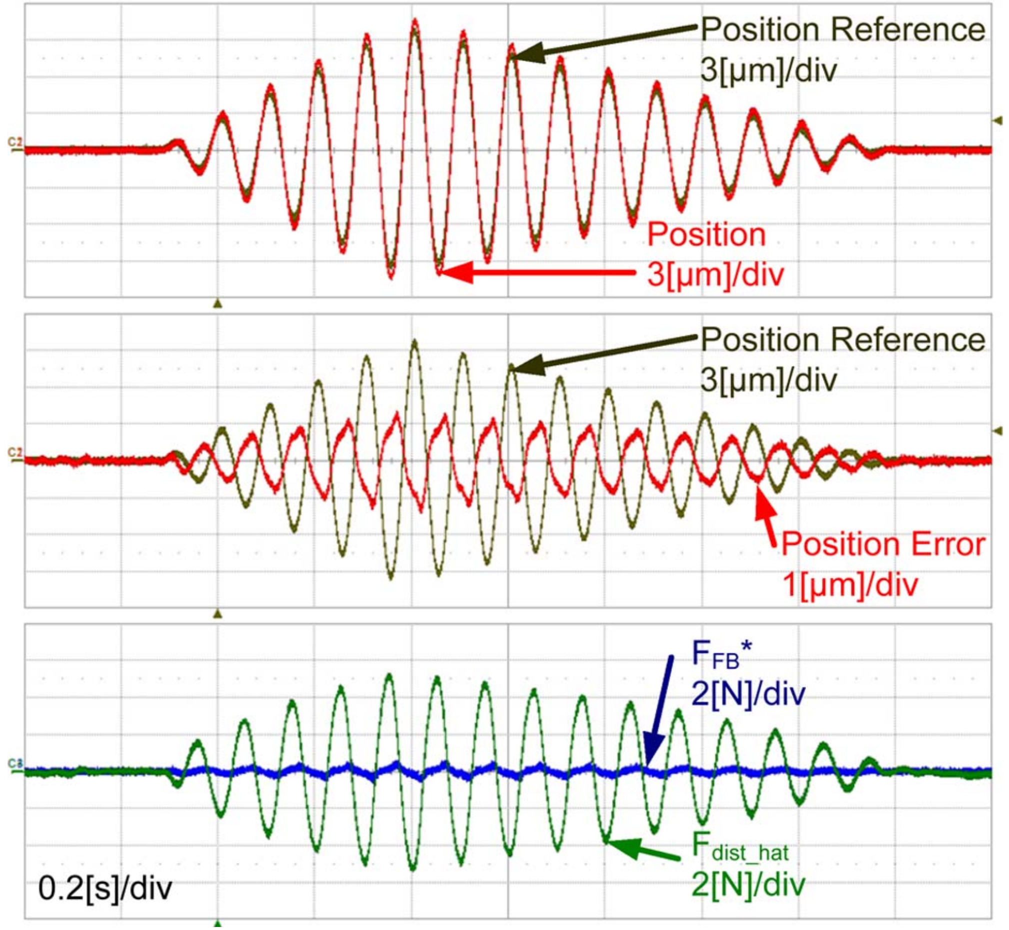

Fig. 12. Relative position control performance of the proposed method; the frequency of the position reference is 10 Hz.

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V. Conclusion

This paper has presented an application of a disturbance observer for a relative position control system. The proposed method provides a different viewpoint for the relative motion control, in which the position command has been considered as the result of a disturbance. Therefore, the relative position control has been performed by the disturbance observer as well as by the position controller. As a result, with the simple modification, the relative position control performance was enhanced by up to about 30% compared with that of the conventional method with the disturbance observer.

The feasibility of the proposed method has been verified by the experimental results using a high-precision linear motion stage as well as by the analysis based on Bode plots.