DEVELOPMENT OF ACTIVE MOUNTS FOR IMPROVED ACCURACY OF LARGE MACHINE TOOLS

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INTRODUCTION

Generally, in manufacturing of various precision parts of an ultraprecision machine tool, accuracy of a mother machine is not enough high and a tedious correction process by scraping is indispensable. However, such a correction processing needs a lot of time and cost. Moreover, a decrease of the number of skilled technicians who can operate scraping has become a serious problem. Therefore, to remove the scraping operations, it is necessary to establish a technology for producing the machine parts only by using a mother machine. So development of an ultraprecision mother machine is demanded, which can finish up various parts of an ultra-precision machine tool.

The mother machine should be able to machine the bed, the column, the table and so on of an ultraprecision machine tool with straightness better than 0.1 µm because it guarantee the motion accuracies of the ultraprecision machine tool. The ultraprecision mother machine involved was a double column type of surface grinding machine. The most important accuracy is straightness of table motion and the error is considered mainly due to a change of vertical deformation of the bed, which is induced by moving masses, for example, the table and work. Therefore, the bed and table should have high enough stiffness in vertical direction.

In preliminary study [1][2], the influences of thickness of the bed and table on machining accuracy were investigated by FEM analysis of two-dimensional model and it was found that even a bed thicker than 3000 mm caused machining error of around 200 nm in straightness depending on the table thickness and work size.

In previous study [3], to obtain a higher accuracy independent of bed thickness or work size, active mounts have been newly proposed which can support the bed foot by pushing up forces and actively control the deformations of bed while the table traverses, as illustrated in Fig. 1. There, a hydraulic active mount developed was composed of a hydraulic cylinder and a pair of electromagnetic solenoid valves characterized by high response and small delivery. However, it had a positioning resolution of about 1 µm, which was not enough high for the ultraprecision mother machine.

In this study, to improve the positioning resolution, two different types of active mount have been newly developed and their

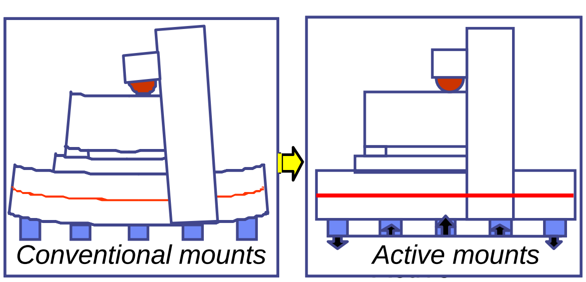


Fig. 1: Idea of active mounts

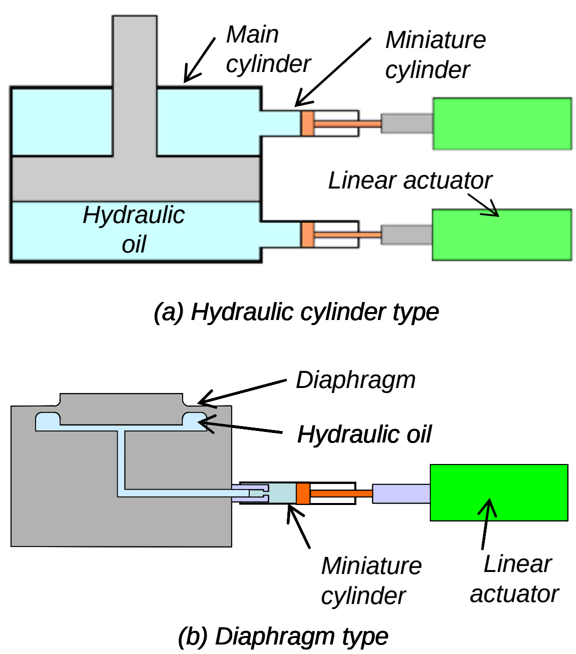


Fig. 2 Two different types of active mount

Table 1: Specifications of active mounts

	Cylinder/ Diaphragm	Miniature cylinder	Ratio
Diameter mm	*100*	*6*	*16.7*
Cross-sectional area mm^2	*7850*	*28*	*278*
Maximum force N	*10000*	*36*	*278*
Minimum displacement μm	*0.054*	*15*	*0.0036*

characteristics were investigated by experiments.

ACTIVE MOUNTS

The active mount must support a heavy weight and control a fine positioning. An application of Pascal's law seemed suitable to accomplish such performance. Two different prototypes of active mount were developed. One was composed of a hydraulic cylinder and a pair of miniature cylinder driven by linear actuators, as shown in Fig. 2(a). The hydraulic cylinder was certainly driven by push and pull mode. Another type of active mount was a combination of a hydraulic diaphragm and a miniature cylinder driven by a linear actuator as shown in Fig. 2(b).

Table 1 lists the specifications of the active mounts. To obtain a high positioning resolution and a large supporting force capacity, ratio of cross-sectional area of the cylinder/diaphragm to that of the miniature cylinder was designed as large as 278. The linear actuators used for both type of active mount were driven by ball screws and stepping motors. The maximum thrust force was 100N and the minimum displacement was 15μm. Therefore the active mount had a capacity of supporting force larger than 10000N and a positioning resolution finer than 0.1μm. The active mount could elongate as far as 10μm.

EXPERIMENTAL SETUP

To investigate the characteristics of active mount, a structural model was setup assuming a part of supporting system of machine tool. The active mount was assembled at the center between a pair of steel beams which were connected by four bolts at both ends, as illustrated in Fig. 3. The upper beam and lower beam correspond to the bed of mother machine

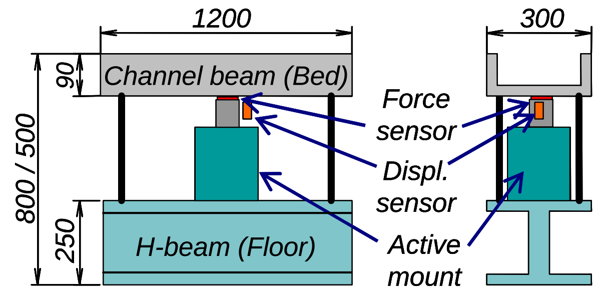
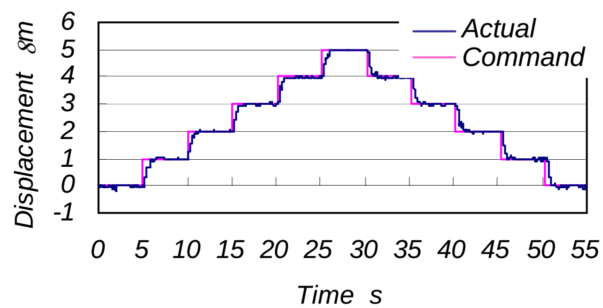


Fig. 3: Main structure of experimental apparatus

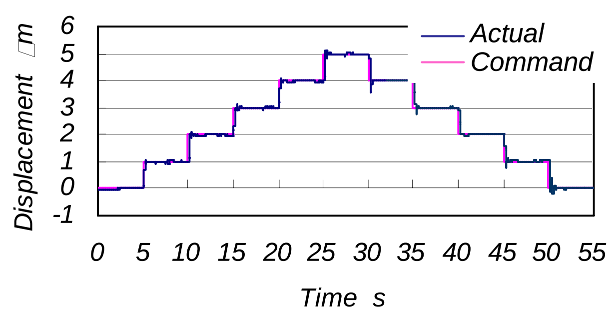
and the floor bearing the machine, respectively. The upper beam was less rigid than the lower one and pushed up by the active mount. A capacitive sensor measured the relative deflection between the beams and its output was used as feedback signal of control system. A force sensor measured the supporting load of the active mount. In the experiments, the active mount was preloaded at around 10000 N by screwing up the bolts at both ends of the steel beams.

EXPERIMENTAL RESULTS

By a series of experiments, the characteristics of the active mounts were investigated. Step response and sinusoidal response were

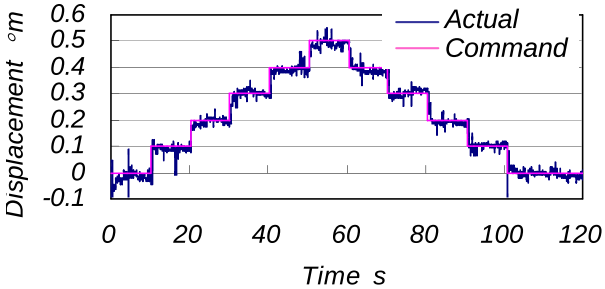


(a) Hydraulic cylinder type

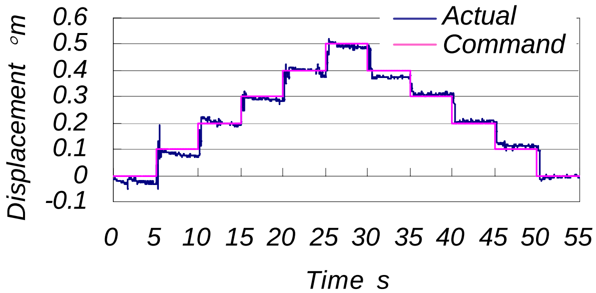


(b) Diaphragm type

Fig. 4: Step response of active mounts for 1 μm step



(a) Hydraulic cylinder type



(b) Diaphragm type

Fig. 5: Step response of active mounts for 0.1 μm step

measured for different conditions.

Step response

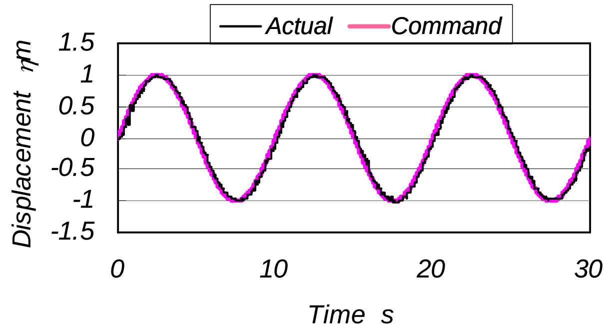
Figure 4 shows the results of step response for 1 μm steps. Both two types of active mount could certainly make positioning with 1 μm steps. The diaphragm type of active mount showed a more rapid response and a larger overshoot than those of the hydraulic cylinder type.

Figure 5 shows the results of step response for 0.1 μm steps. Both two types of active mount seemed to have a positioning resolution of 0.1 μm. The diaphragm type could make steadier positioning than the hydraulic cylinder type.

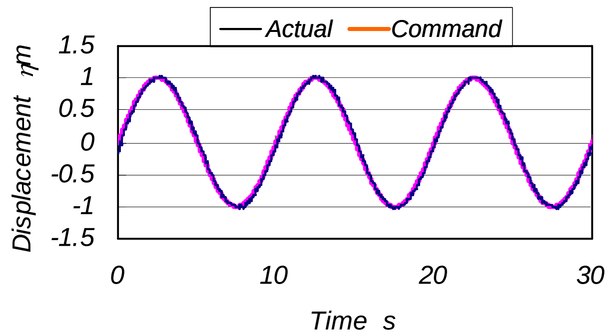
Sinusoidal response

Figure 6 shows the results of sinusoidal response for 1 μm amplitude. Both types of active mount show a good response though a small time lag occurs between the command and the actual response. Strictly, the diaphragm type has a little bit better response than the hydraulic cylinder type.

Figure 7 shows the result of sinusoidal response for small amplitude of 0.1 μm. Both types of active mount could not response so exactly. In case of the hydraulic cylinder type, the curve of

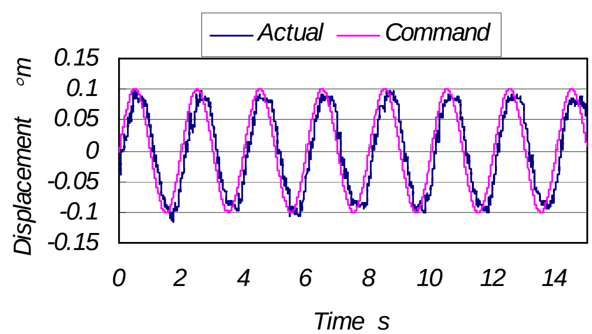


(a) Hydraulic cylinder type

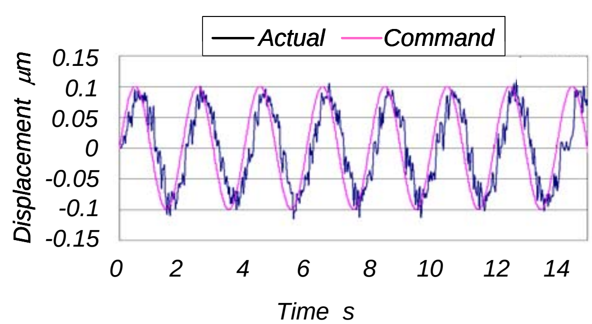


(b) Diaphragm type

Fig. 6: Sinusoidal response of active mounts for 1 μm amplitude



(a) Hydraulic cylinder type



(b) Diaphragm type

Fig. 7: Sinusoidal response of active mounts for 0.1 μm amplitude

actual response looks like a trapezoidal wave. In case of the diaphragm type, however, the response curve looks like a triangular wave.

Frequency response

A series of sinusoidal response experiments was performed under various frequencies. The amplitude commanded was 1 μm. Figure 8 shows the experimental result. A frequency where the gain becomes -3 dB was 1.4 Hz for the hydraulic cylinder type and 3.3 Hz for the diaphragm type.

CONSIDERATIONS

From the experimental results described in previous section, it was found that the both types of active mount had a capability of fine positioning with a resolution better than 0.1 μm but the responses were rather low, i.e. 1.4 Hz for the hydraulic cylinder type and 3.3 Hz for the diaphragm type.

In case of the hydraulic cylinder type, the piston was driven in push and pull mode and overshoot could be suppressed if the time difference between push and pull motion was small. However a friction between the piston and cylinder might deteriorate the dynamic characteristics, for example, the trapezoidal wave caused in sinusoidal response as shown in Fig. 7(a).

In case of the diaphragm type, there was not any friction in motion of the diaphragm. Moreover the volume of concerned hydraulic oil was much smaller than that of hydraulic cylinder type. Therefore the diaphragm type is considered to be able to obtain better characteristics than the hydraulic cylinder type.

CONCLUSIONS

In order to improve the machining accuracy of large machine tools, two different prototypes of active mount were developed. One was composed of a hydraulic cylinder and a pair of miniature cylinder driven by linear actuators. Another was a combination of a hydraulic diaphram and a miniature cylinder driven by a linear actuator.

By a series of experiments, it was found that the both types of active mount had a capability of fine positioning with a resolution better than 0.1 μm but the responses were rather low, i.e. 1-3 Hz. From this result, the active mounts were considered to be effective in improving the machining accuracy if the table moved slowly such as a large surface grinder.

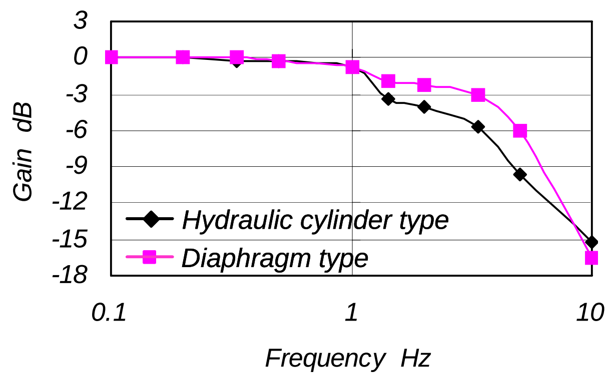


Fig. 8: Frequency response of active mounts for 1 μm amplitude

ACKNOWLEGEMENTS

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