MAGNETIC LEVITATION ACTUATOR TRACKING CONTROL FOR ELECTRICAL-DISCHARGE MACHINES

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ABSTRACT

This paper discusses the design and application of a controller that enables an actuator to have 5-degrees of freedom through the application of magnetic levitation. The authors propose a new type of magnetic levitation actuator for electrical-discharge machines (EDMs) and have designed a feed-forward and sensor compensator controller for the system. The practicality of the system was verified through experimentation, in which tracking error of ±1μm was proven. The gap controller designed consists of a conventional drive system and a local actuator module for EDMs. Its efficiency has been confirmed in experiments.

INTRODUCTION

Electrical-discharge machines (EDMs) provide precise machining of various types of conductive materials. A vital component of the machine is the actuator, which maintains the gap distance between the electrode and workpiece. The machining process commonly involves various stages in which machining conditions change: initially starting with a rough, fast high-voltage machining process followed by a slower process using low-voltage machining. The latter process involves changing the gap distance and requires planar motion to smoothen the side of the workpiece.

It has been reported that a high-response 1-degree of freedom (1-DOF) actuator increased machining speed. However, it was unable to machine a three-dimensional mold. The authors propose an EDM actuator that utilizes magnetic levitation to achieve 5-DOF while machining at gap distances of ±200μm. The architecture is identical to magnetic-bearing units, but operation is different—magnetic-bearing machines keep the electrode at the center of the gap, however, our actuator allows movement anywhere in the gap.

First, five controllers for each axis were designed; however, this was not effective for dynamic reference, and two problems were discovered: 1) Direction of the magnetic force. If the electrode is in the center of the gap, the direction of magnetic force is the same as the axes. Since our actuator moves the electrode everywhere, magnetic force direction changes as electrode position changes. 2) Error detection. Gap detection error is conducted by determining the difference between the electromagnet and the sensor mounting point.

Taking the above-mentioned circumstances into consideration, the authors undertook a study to develop a new type of magnetic levitation actuator for EDMs and have designed a feed-forward and sensor compensator controller for the system.

COMPOSITION

In order to maintain stable electrical discharging conditions, general electrical discharge machines use, for example, a gap control system that detects the average gap voltage for the purpose of adjusting the electrode position so that the detected value matches the desired value. To date, voice coil motors or piezoelectric elements have been utilized to improve processing speed, driving the electrode at high speed, but only in the Z-axis direction. However, there have been a number of problems with the quick-response electrode drive equipment proposed to date; for example, drive weight being limited to several tens of grams, difficulty of adding electrode rotation or automatic electrode exchange features, difficulty of making strokes several hundred microns long, and the difficulty of attaining quick response in all three (X, Y and Z) axis directions. We manufactured a prototype module to resolve these problems (FIGURE 1).

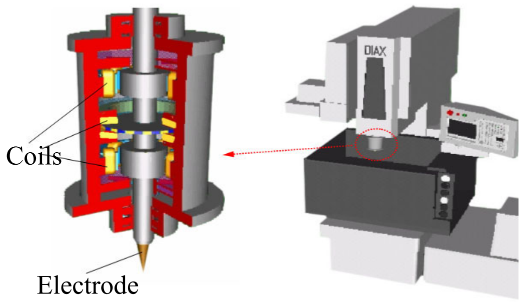


FIGURE 1: Composition

Two electromagnets are installed for the thrust direction, and moreover, a total of eight electromagnets (four each in the upper and lower sections) are installed for the radial direction. These ten electromagnets drive the electrode in the X, Y and Z-axis directions. Rotation is fixed using an adjustable joint.

CONTROLLER

First, five controllers for each axis were designed; however, this was not effective for dynamic reference, and two problems (FIGURE 2), were discovered: 1) Direction of magnetic force. If the electrode is in the center of the gap, the direction of magnetic force is the same as the axes. Since our actuator moves the electrode everywhere, magnetic force direction changes as electrode position changes. 2) Error detection. Gap detection error is conducted by determining the difference between the electromagnet and the sensor mounting point.

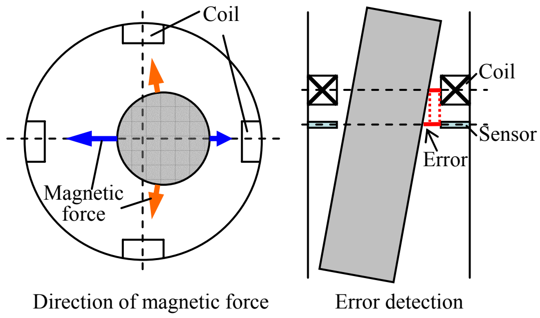


FIGURE 2: Problems

Taking the above-mentioned circumstances into consideration, our controller is equipped with two sensor detection compensators and two feed-forward compensators. The sensor detection compensators estimate the feedback position using the upper and lower sensors of each axis, while the feed-forward compensators estimate the current reference at the reference point using the references of the X and Y-axes on each side.

The feed-forward compensators were designed as follows. A compensation table of 10 μm units was created, and the optimal current for reference estimated. An integrator-equipped controller eliminated steady offset after sufficient time passed at the fixed reference. The steady current of the electromagnet was measured and defined as the optimal control output. One of these results is shown in FIGURE 3.

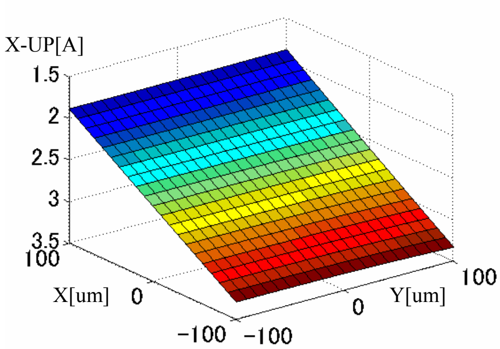


FIGURE 3: Compensation Table

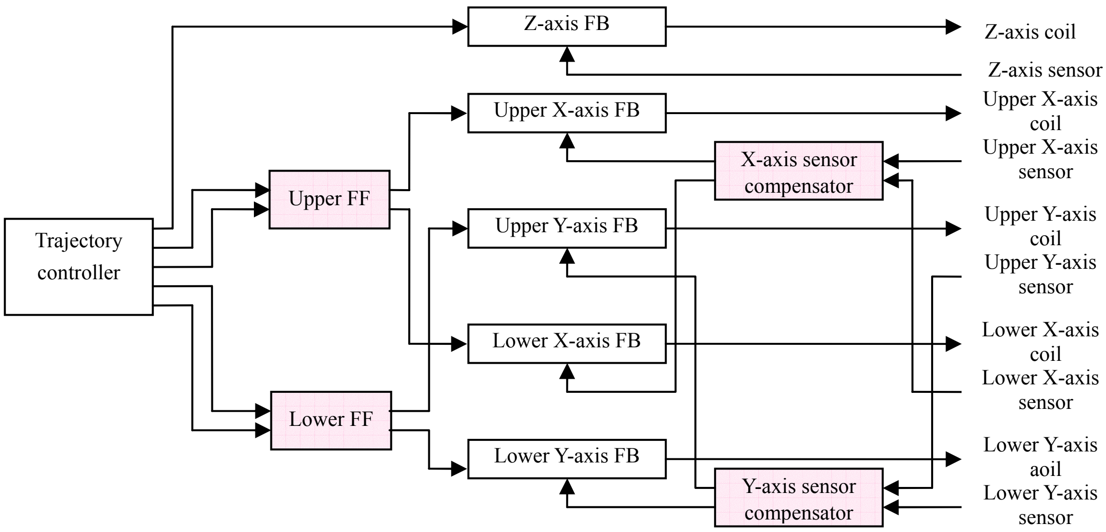


FIGURE4: Controller

It shows that the optimal control output of the X axis is changing as the reference of the X axis changes. Furthermore, even if the reference of the Y axis changing, the optimal output of the X axis changes only slightly. We designed a controller which has two feed-forward compensators and two sensor detection compensators (FIGURE 4).

EXPERIMENTAL RESULTS 1

The frequency response of the module is shown in FIGURE 5.

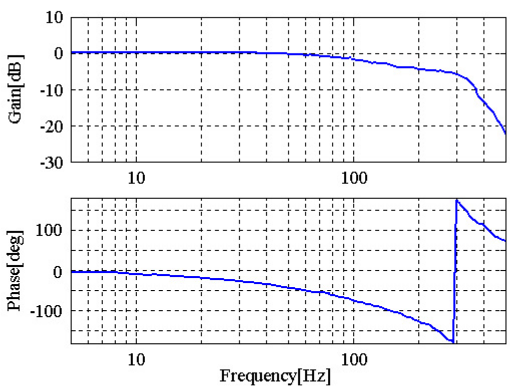


FIGURE 5: Frequency response of the module

Since the mass of each axis is too large, utilizing conventional mechanism, the response frequency is a at most 20-40Hz. However, utilizing proposed mechanism, a response frequency of 200Hz can be realized in each of the X, Y and Z-axis directions. FIGURE 6 and FIGURE 7 show examples of planetary motions, giving the results of trajectory control for a circle and a square. The big difference from the trajectory control of the conventional drive system is that since quick response is possible, high-speed trajectory motion is possible without reducing trajectory accuracy.

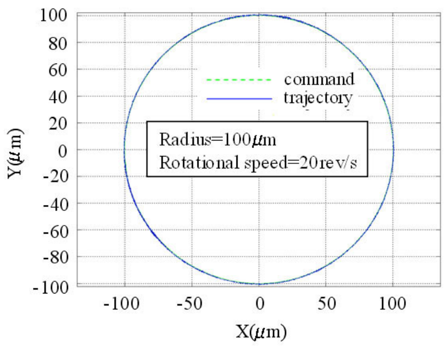


FIGURE 6: Circle motion

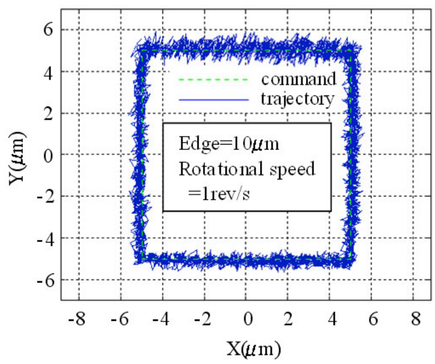


FIGURE 7: Square motion

The circle trajectory in the figure was created approximately 20 times faster than conventionally possible and with a trajectory accuracy within $\pm 1\mu m$. This trajectory accuracy is achieved by

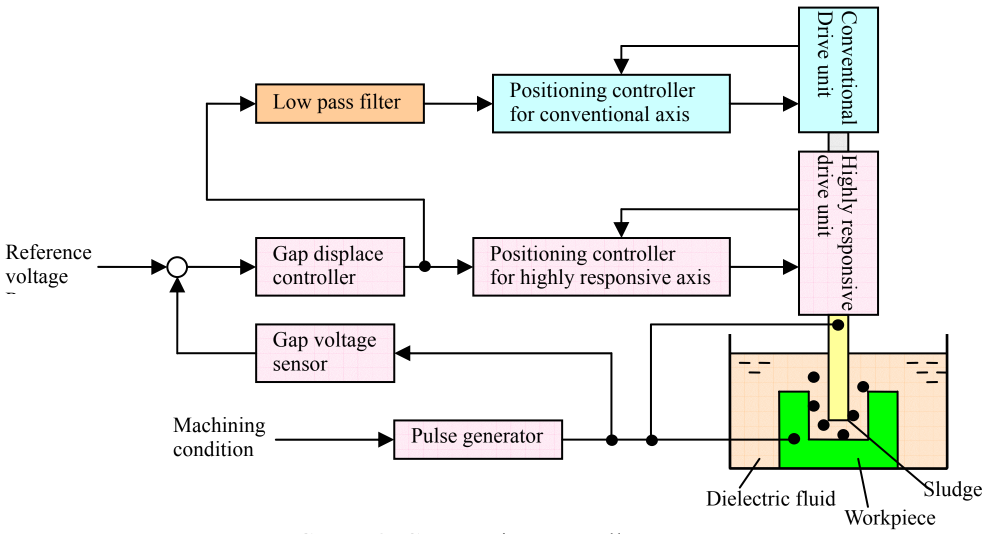


FIGURE 8: Cooperative controller

precise feed-forward compensation of a non-linear drive system that incorporates electromagnets. Furthermore, since the electrode is held in the air by electromagnetic force, the deterioration of circle locus accuracy at the point of change in coordinates often witnessed when using a ball-screw drive is prevented. The smaller square locus was also realized with an accuracy similar to that of the circle.

COOPERATIVE CONTROLLER

Utilizing the local actuator module makes the machining unit highly responsive, but the stroke range is only ±200μm. Therefore, for a possible construction of EDM, attaching the local actuator module to the conventional drive system was considered. FIGURE 8 shows a block diagram of a gap control system consisting of a conventional drive system and the local actuator module. This control system achieves moderate electrode feeding and continuous machining via the drive system, while the module ensures precise high-speed adjustment of the gap distance for stable machining conditions. Additionally, the module enables small stroke jumping, while the conventional drive system enables large stroke jumping.

EXPERIMENTAL RESULTS 2

FIGURE 9 shows the changes in actual electrode position, conventional drive system head position and electrode position controlled by the local actuator module when conducting micro-hole machining on a 1mm-thick SUS304 steel plate using a tungsten electrode with a diameter of 0.03mm. As can be obtained from reviewing the figure, in order to maintain stable machining conditions, the module performs precise high-speed adjustment of the gap distance, while the drive system feeds the electrode as machining progresses smoothly. Also shown are situations for avoiding unstable machining conditions, such as if the module stroke is not long enough, the drive system moves simultaneously, raising the electrode high.

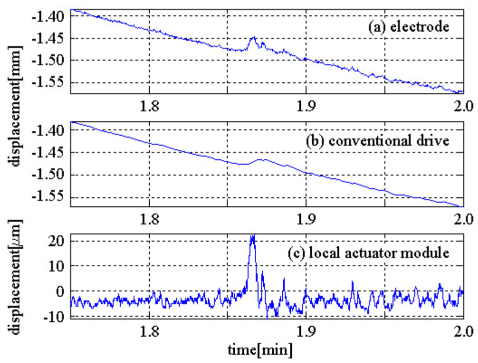
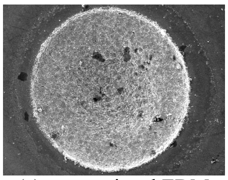
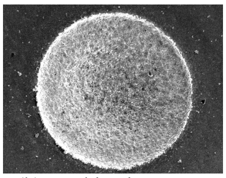


FIGURE 9: Cooperative control

FIGURE 10 shows a picture comparing the surface conditions of a workpiece machined using the conventional drive system and a combination of the drive system with the local actuator module. In the case of machining using only the conventional drive system, many black pits can be seen on the surface. However, in the case of machining using the module, there was no formation of pits observed. This means that the concentrated discharge and short-circuit conditions were effectively avoided owing to the quick response capability.



(a) conventional EDM



(b) combination EDM

FIGURE 10: Machined surface

CONCLUSIONS

In this study, we propose a new type of magnetic levitation actuator for EDMs and design a feed-forward and sensor compensator controller for the system. The practicality of the system has been verified through experimentation, in which a tracking error of ±1μm was proven. The gap controller designed consists of a conventional drive system and a local actuator module for EDMs. Its efficiency has been confirmed in experiments.

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