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Rotary-axial positioning system with giant magnetostrictive element

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Abstract

In this study, in order to fabricate micro structures on free-form surface with a Fast Tool Servo for milling process, a rotary-axial positioning system for a machine tool spindle was newly proposed. This positioning system developed is driven by a giant magnetostrictive element (GME) during rotation, and the GME is used not only as an actuator but also as a sensor simultaneously in order to estimate its displacement for the hysteresis compensation. The performance evaluation results confirmed that the developed positioning system achieves the rotary-axial positioning with a resolution of 0.25μm during rotational speed of 2500min^{-1} without additional displacement sensors.

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1. Introduction

The surfaces with micro-scale texture generated called as functional surface can control wettability, friction, optics of the substrates, and so on. The micro-scale texture can be generated by a photolithography, an energy beam or an ultra-precision machining process [1]. In recent years, demands for adaptation of the functional surface to the large free-form surface have increased in a variety of the industries. Therefore, the ultra-precision machining process, which has high flexibility and high precision, attracts a great deal of attention. However, it takes a lot of time to generate micro structures, hence the process costs high. Furthermore, the temperature fluctuation while machining causes reduction in the machining accuracy.

In order to reduce the lead time, a Fast Tool Servo (FTS) method has been proposed [2]. In the method, highly responsive and highly accurate actuators such as a piezoelectric actuator are widely employed. The conventional FTS is based on a single point turning, and thus this method has restriction of

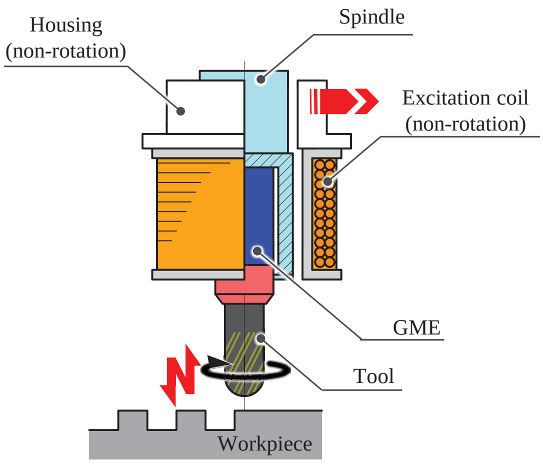

Fig.1 Fast tool servo for milling process

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machining form. Inversely, a milling machine equipped with the FTS system driven by piezoelectric actuator has been developed [3]. In this system, a slip ring inducing friction was employed so as to supply energy to the piezoelectric actuator. In contrast, a rotary-axial positioning system using Giant Magnetostrictive Element (GME), which can be driven without energy supply cable, has been already proposed by the authors, as shown in Fig.1 [4]. The GME supplies magnetostriction by a magnetic flux generated from an excitation coil aligned around the GME. This positioning system achieves linear motion during rotation with noncontact condition.

Meanwhile, in order to achieve accurate positioning, the feedback control using a displacement sensor is required due to the hysteresis with the magnetostriction. However, it is difficult to measure the displacement of the rotating milling tool accurately with satisfying the Abbe principle. Thus, in this paper the positioning system utilizes the GME as a sensor simultaneously in order to estimate its displacement for the hysteresis compensation. The performance evaluation results confirm that the developed rotary axial positioning system achieves the hysteresis compensation without any external displacement sensors.

2. Concept of the proposed rotary-axial positioning system

The GME has a feature generating magnetostriction by the magnetic flux change called Joule effect. On the other hand, under a ~~series~~ variation of stress, the GME changes its magnetic permeability. Due to this feature called Villari effect, the GME is adopted as a vibration sensor [5].

Fig.2 shows the principle of the proposed hysteresis compensation. In this study, in order to compensate the hysteresis between the applied magnetic field and the magnetostriction, the GME is applied to the positioning system not only as an actuator but also as a displacement sensor simultaneously using Villari effect. By using the estimated displacement for the feedback control, the proposed positioning system can be driven precisely.

In this paper, as an approach to a measurement of the magnetic permeability without contact, a method using inductance change of a detective coil was applied. This detective coil is concentric with the GME. An ~~following~~ inverse electromotive force occurs when high frequency small electric current is supplied to the detective coil.

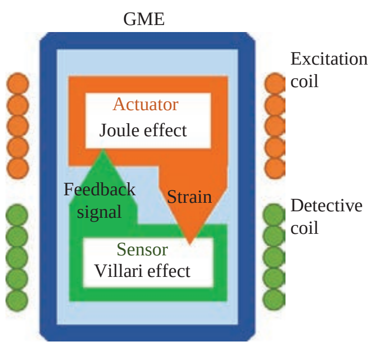

Fig.2 Principle of the hysteresis compensation

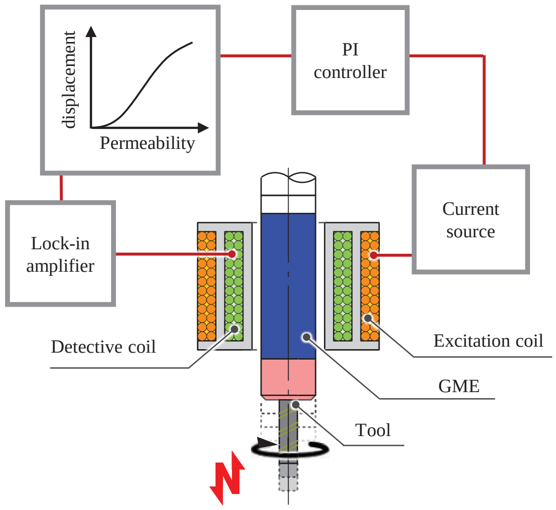

Fig.3 Concept of the rotary axial positioner

$$V = \mu n^2 l A \frac{dI}{dt} + RI - nI\frac{d\phi}{dt} \qquad (1)$$

Where, V : inverse electromotive force [V],
μ : magnetic permeability [H/m],
n : number of turns in a coil,
l : length of a coil [m],
A : cross section area [m^2],
I : supply current [A],
R : resistance of a coil [Ω],
ϕ : magnetic flux [Wb].

In Eq. (1), the second term of the right member is negligibly small because the supply current is quite small. Hence, the first term of the right member containing the magnetic permeability can be extracted using a lock-in amplifier.

Figure 3 shows a concept of a proposed positioning system. The GME generates magnetostriction toward the axial direction by the applied magnetic flux from the excitation coil. Simultaneously, the magnetic permeability in the GME varies with magnetostriction. Therefore, by means of measurement of the magnetic permeability using the detective coil, the

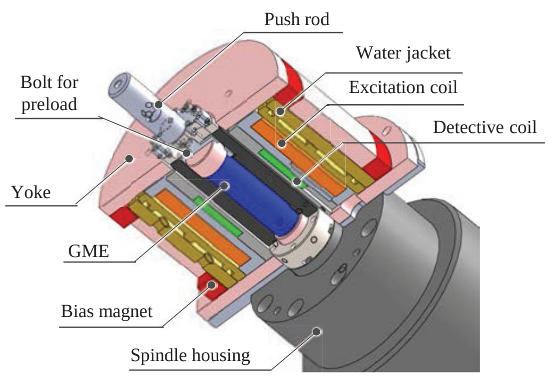

Fig.4 Structure of the rotary-axial positioner