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A newly developed rotary-linear motion platform with a giant magnetostrictive actuator

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ABSTRACT

Demands for machining and measuring three-dimensional geometries have recently increased in a variety of industries. In order to meet such demands, it is necessary to develop a compact versatile high performance spindle system. This paper presents a newly developed rotary motion platform combined with a linear motion mechanism driven by a giant magnetostrictive actuator. The developed platform can be characterized by a compact structure, a noncontact structure, and high accuracy. Performance evaluation results confirm that the developed platform provides precise linear motion during rotating.

1. Introduction

Demands for fabricating and measuring of high accurate three-dimensional (3D) patterns and geometries have recently increased in various industrial fields, because the functional surfaces which consist of periodic or nonperiodic fine 3D geometries create new remarkable characteristics such as water repellency and wear resistance [1,2]. For generating precise and fine geometric patterns on the workpiece surface, a piezoelectric actuator-driven tool is widely used [3]. In particular, many studies on fast tool servo (FTS) technique for turning process have been performed [4,5].

In order to achieve high performance machining and measuring the functional surfaces, it is useful to develop a new motion platform which can simultaneously achieve multi-degree-of-freedom motion, such as an *X*, *Y*, and *C* axis motion table system [6,7] and a rotary-axial motion spindle system [8]. These multi-degree-of-freedom systems make possible high efficient form generation and inspection of the structured surfaces.

This paper presents a newly developed rotary-linear motion platform. The developed rotary-linear motion platform employs a giant magnetostrictive material (GMM) as an actuator for driving linear motion and provides precise linear motion during rotating in a noncontact condition. Performance evaluation results confirm that the developed platform is capable of achieving accurate rotary-linear motion.

2. Concept of the proposed rotary-linear motion platform

2.1. Properties of giant magnetostrictive material

A conventional method for realizing simultaneously rotary and linear motion is to employ a stacked structure with a linear motion stage and a spindle unit such as a tool axis in a machine tool. In this structure, however, the moving mass is too large to achieve precise and quick motion for machining or measuring complex 3D geometries. Inversely, an FTS with a piezoelectric actuator for driving a cutting tool is available for turning process and provides high performance tool positioning which is short stroke but quick and precise. It is, however, difficult to apply the FTS technique to milling process with rotational tools because piezoelectric actuators require electric wiring to apply electric field for driving.

The GMM is one of the useful functional materials for actuator. The GMM has a unique characteristic which strain of material is generated by applied magnetic field to the element. In general, the GMMs have the following features in comparison with piezoelectric materials;

(1) large displacement,
(2) high Curie temperature,
(3) noncontact driving without electrodes,
(4) large generated stress (force), and
(5) Ease of fabricating various shape design.

Due to the above mentioned properties, the GMMs have been used for the tool positioning in an ultraprecision lathe [9] or the vibration polisher for ultraprecision finishing [10].

2.2. Design concept of the rotary-linear motion platform

Fig. 1 shows a design concept of a rotary-linear motion platform. The proposed platform employs a giant magnetostrictive actuator (GMA) for driving a moving part in the axial direction. In this concept, the GMA is installed on a rotating shaft, and coil units are fixed on a nonrotating part such as spindle housing. The expansion of the GMA can be controlled by magnetic flux generated in a noncontact condition without electric wiring to the actuator. Fig. 1(b) shows a driving principle of the platform. The magnetic flux generated by coil current passes though stationary and rotating parts made of magnetic material which are colored with blue. All magnetic flux is concentrated to the GMA located at the center of rotating part, and the expansion of the GMA

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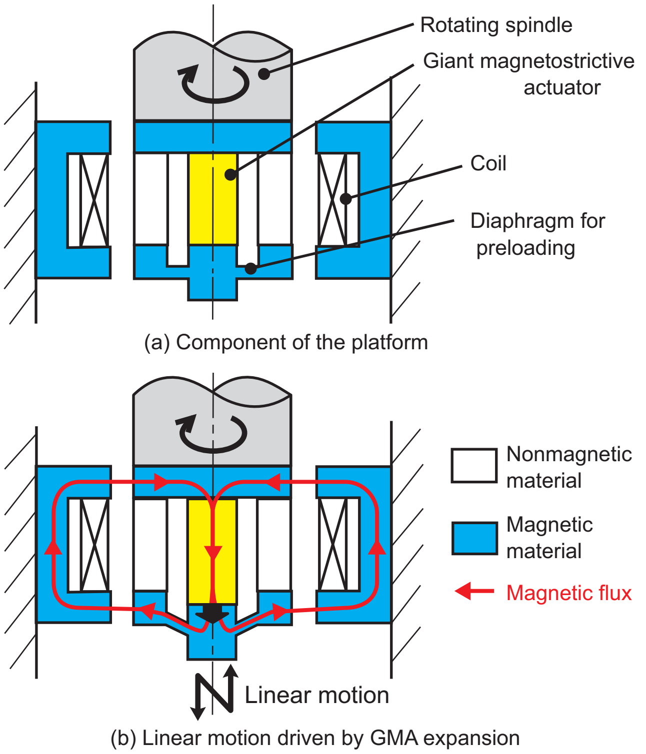

Fig. 1. Concept of the proposed rotary-linear motion platform.

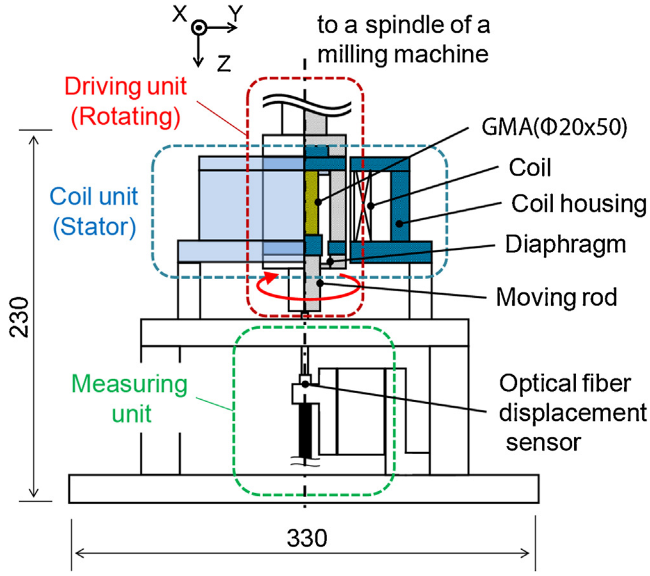

Fig. 2. Structural configuration of the developed platform.

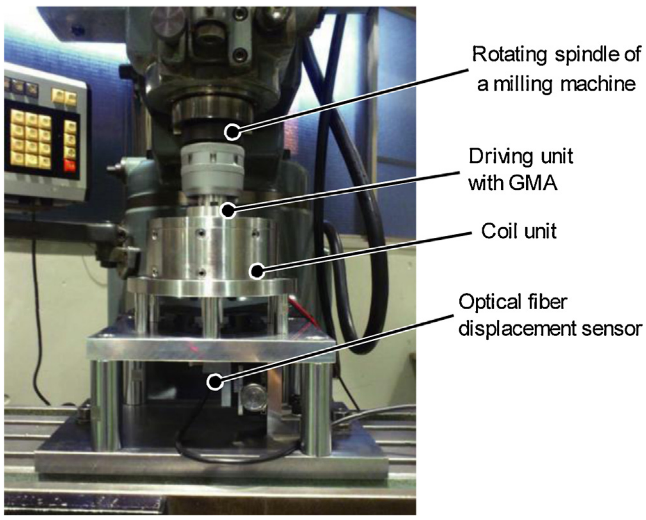

Fig. 3. Appearance of the developed platform.

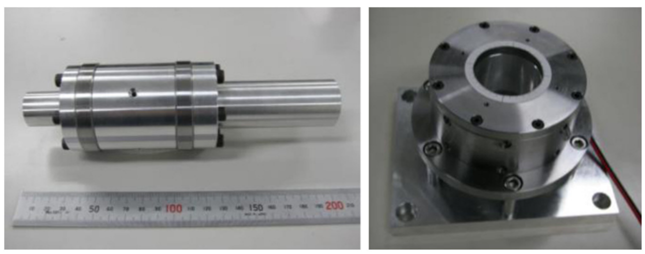

Fig. 4. The driving and the coil units.

pushes an end face. In consequence, the GMA in the rotational spindle provides precise linear motion during rotating.

A similar rotary-linear motion mechanism driven by a magnetic actuator [8] has been proposed for actuating a rotating shaft in the axial direction. The mechanism proposed can be also applied to conventional machining spindles because it is enough to install an additional driving unit with GMA on the end face of the rotary spindle. Furthermore, this linear actuation during rotation provides quick response and accurate positioning, so that it can be applied to FTS for milling process and ultrasonic vibration milling.

3. Prototype development of the platform

3.1. Structural configuration of the prototype platform

Fig. 2 shows the structural configuration of the prototype platform based on the above mentioned concept. The prototype consists of three principal units: a driving unit, a coil unit, and a measuring unit.

The driving unit with a GMA was coaxially arranged with the rotating axis. The GMM used in the driving unit was Terfenol-D ($Tb_{0.27}Dy_{0.73}Fe_{1.9}$) of a cylindrical form with a diameter of 20 mm and a length of 50 mm. The GMA was preloaded by a diaphragm element. The coil unit had a solenoid coil of 1260 turns inside the steel housing and the coil was arranged coaxially with the driving unit. In addition the coil unit was fixed on a base in this prototype, and the coil was connected with an electric amplifier. The measuring unit employed an optical fiber displacement sensor in order to minimize noise due to the coil current for driving. The sensor measured linear motion of the end face of driving unit from underneath. In actual applications, however, it is difficult to adapt such a configuration due to the interference with tool. Therefore, for example, a displacement sensor can be installed into the coil housing and axial displacement of the flange face is measured.

The appearance of the prototype platform is shown in Fig. 3. The driving unit was set to a rotational spindle of a milling machine. The coil unit and the measuring unit were fixed on a work table of the machine. Fig. 4 shows the developed driving unit and the coil unit. In the prototype, rotation of the driving unit was provided by the spindle of the milling machine, and the output of the displacement sensor was recorded with a data logger.

3.2. Basic characteristic of the platform

Fig. 5 shows the magnetic flux density distribution measured on the inner side in the coil unit before assembling the driving unit. A gaussmeter was used for measuring the magnetic flux density. The magnetic flux density generated by the coil was almost constant at 100 mT along the circumferential direction. Therefore, magnetic flux applied to the driving unit is independent from rotational angle and the eddy current loss between the coil and the driving units is negligibly small.

After assembling the driving unit, the measurement of GMA expansion was performed. In this evaluation, the displacement of