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A Study on the Development of a Deformable Rubber Variable Preload Device

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One of the important element technologies for achieving high-precision in machine tool spindles is bearing preload technology. Recently, various preload methods have been used in machine tool spindles. However, there are some drawbacks for applying them to spindles. Also, all previously applied methods cause problems in applications due to complexity in its system, difficulty in precision control, high installation cost, processing error, and installation error. To reduce costs in its system by simplifying its structure, a variable preload device is proposed using rubber pressure. The operability in a preload device using rubber is the main focus of the work. Hyperelastic analysis is carried out for verifying the characteristics of the rubber in this study. An experimental system has been fabricated and tested, and the results of the tests are compared with the analytical results. For verifying the characteristics of the rubber used in this study, the rubber is selected from commercial products. It is shown that the variable preload device proposed in this study is applicable to machine tool spindles.

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1. Introduction

One of the important machine element technologies for achieving high-precision in machine tool spindles is bearing preload technology. Recently, the various preload methods have been used in machine tool spindles such as fixed position preload, constant pressure preload, convertible preload and variable preload methods. Harnoy[1] performed a study on the internal load applied to bearings, and improved the stiffness and rotational accuracy of bearings. Croft et al.[2] performed a study on the creep, hysteresis and vibration compensation for piezoactuator that is used as preload device, and demonstrated substantial improvements in positioning precision and operating speed. Park et al.[3] used active materials for machining processes. Jiang et al.[4] proposed an optimal preload based on the increase in bearing temperature at a low-speed range. Hwang et al. [5] performed a review on the preload technologies through classifying the preload technologies into three groups; a preload configuration technology, application technology and measurement technology.

However, there are several drawbacks for applying preload devices to spindles including complexity system, difficulty in precision control, high installation cost. Studies on the variable preload technology of spindle bearings have been carried out to solve these problems. The recent representative variable preload technologies are performed using electromagnetic systems, centrifugal force and hydraulic pressure systems. Kim et al.[6] performed studies on the variable preload structure based on centrifugal and eccentric mass forces. Kwak et al.[7] carried out an experimental and analytical investigation of the temperature effect on the displacement characteristics of a developed magnetostrictive actuator. Ro et al.[8] designed a novel surface motor stage supported by air bearings and driven by linear electromagnetic motors. Choi et al.[9] proposed new conceptual preloaded spindle bearings using various liquids.

And, research about defect free rolling element bearings is carried out.[10,11] Methods using hydraulic pressure and electromagnetics require additional external driving devices. Thus, these methods require high installation costs. The method using centrifugal force based mechanical systems has a drawback in decreasing its accuracy due to the processing and assembly errors of parts. In this study, a method using centrifugal force and rubber pressure is proposed. General elastic materials present an elastic recovery behavior in which the materials show a linear property as a load is applied and return to its original state as the load is removed. However, a rubber material shows a nonlinear property in its load-deformation characteristics, and is a hyperelastic within a large deformation range.[12-14] In the studies on the characteristics of rubber materials, uniaxial tensile, biaxial tensile, and shear tests are usually applied. It is important to determine nonlinear material constants based on the results of the studies on the characteristics of rubber and the equations obtained by using energy functions. In this study, a variable preload method that generates preloads to bearings using rubber is proposed.

The possibility of the operation of a preload device using rubber is presented, and an experiment as system is fabricated and tested. The results of the experiment are compared with analytical results. For verifying the characteristics of the rubber used in the analysis and experiment, the rubber is selected from commercial products.

2. Design of a Variable Preload Device

In general, springs are widely used to apply and release preloads in constant pressure preload, conversion preload, and variable preload applications. The preload device consists of spacer, lock nut including the spring. The bearing preload can be adjusted by controlling the fastening amount of the lock nut. The bearing preload can be determined by controlling the inner race dimension between the initial main and support bearings and the outer race spacer. As preloads are applied using springs, the same half-preload can be applied to both main and support bearings.

Fig. 1 shows the proposed schematic of a variable preload device using rubber. As the spindle is rotated, a centrifugal force will be generated by the rotation of the assembled collar. The collar is split into 2 pieces. The bush is combined with the housing as sliding condition, and the flange is combined with the bush as fit condition. The centrifugal force pushes the rubber in its radial direction, which is deformed axially as it is constrained by the housing. The deformation of the rubber pushes the flange along its axial direction. Then, the flange can maintain a combined state to the housing by the bush. Therefore, the flange has a structure that is able to reduce the preload by pushing the inner race of the bearing.

Fig. 2 illustrates the method of applying the preload to the spindle bearing using rubber pressure. Fig. 2(a) and (b) show the variable preload device with the spindle stationary and the application of the force to the bearing inner raceway by the flange when the spindle is rotating, respectively. It is possible to verify the bearing displacement by the deformation of d+δd at a rubber length of d as presented in Fig. 2(a).

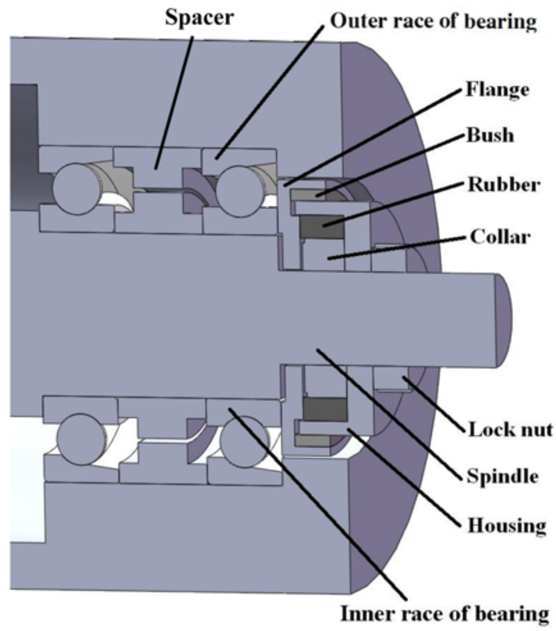

Fig. 1 Proposed deformable rubber variable preload device

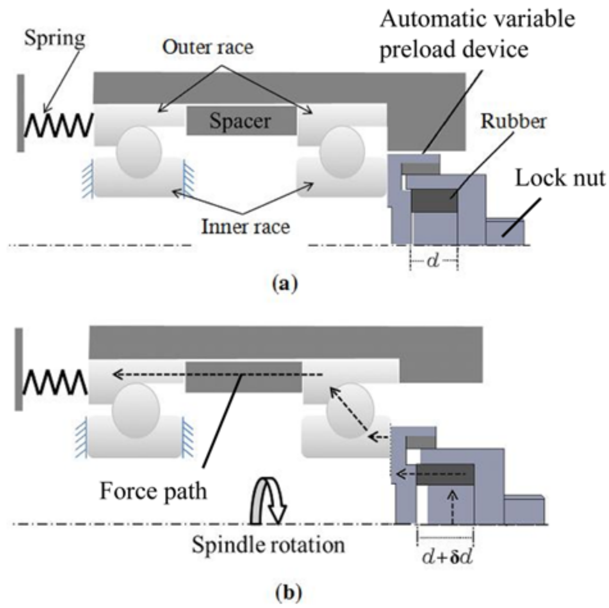

Fig. 2 Adjustment method of the variable preload: (a) when the spindle is not rotating, (b) when the spindle is rotating

3. Analysis of the Variable Preload Device

An analysis is performed to design a prototype device. In this study, a model is used to verify the deformation of rubber caused by the centrifugal force. The analysis is performed on the flange that is moved in its axial direction, collar, rubber, housing, all of which are influenced by the centrifugal force.

The boundary condition applied to the analysis of the deformation of the model. The analysis is performed by rotating the collar, rubber, and housing at different speeds. A frictionless support condition is applied to the connection between the bush and the housing to ensure smooth movements. In addition, a proper frictional condition is applied to each contact condition except for the bush and housing.

Fig. 3 shows the results of the deformation analysis in which the distribution of rubber deformation according to the rotation of collar is ascertained. Also, the movement of the flange according to rubber pressure can be ascertained. In the results of the analysis, the movement of the flange is 0.25 mm. In addition, it is ascertained that the force to the bearing inner raceway can be applied by the movement of the flange based on rubber pressure. An inner race is added to analyze the deformation and force reaction in order to obtain the force applied to the inner race of the bearing.

A virtual inner bearing race is added for the analysis model in order

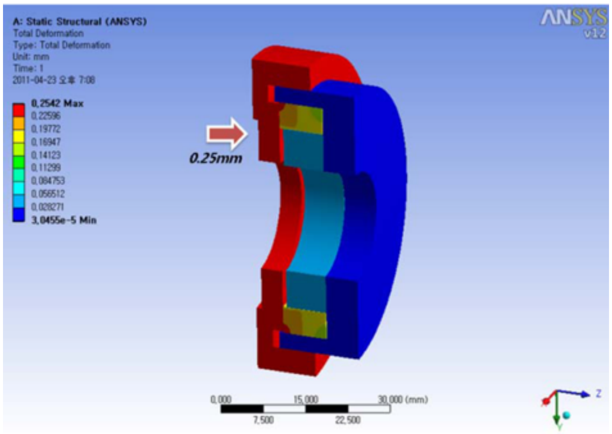

Fig. 3 Deformations distribution in the variable preload device

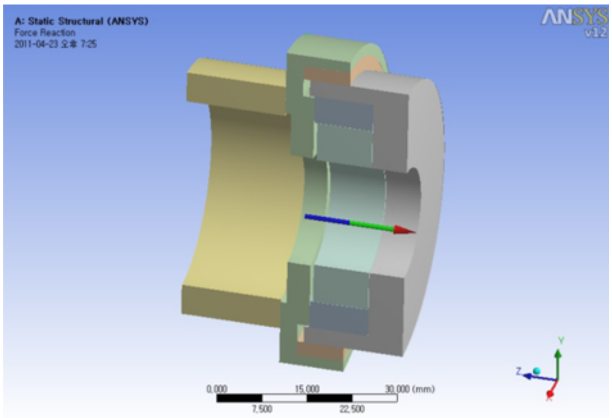

Fig. 4 Reaction force of the variable preload device

to obtain the force applied to the inner racer of the bearing. Fig. 4 shows the reaction force occurred at the flange and inner race of the bearing. The force reaction generates at the bearing inner raceway to the –Z direction is 7.76 N.

4. Experiment and Results

The variable preload device designed by referencing the results of the analysis. An experimental system is fabricated using the designed drawing. Fig. 5 shows the fabricated parts and assembled variable preload device. In the fabrication of these parts, the machining tolerances are controlled by grinding them for reducing its spindle assembly errors.

Fig. 6 illustrates the cross section of the spindle in which a loadcell and the variable preload device are installed.

The structure of the experimental system is designed for contacting the loadcell to the bearing in order to measure the force. The data of the force measured by using the loadcell is shown using a digital indicator. The measurement is performed using the data with a resolution of 1 N.

Fig. 7 represents the experimental system installed with the variable preload device used in the experiment. The spindle speed is measured by installing a rotation speed sensor. Rotational speeds of the experiment are set to be 2,000, 3,000, 4,000 and 5,000 rpms. Fig. 8 shows the

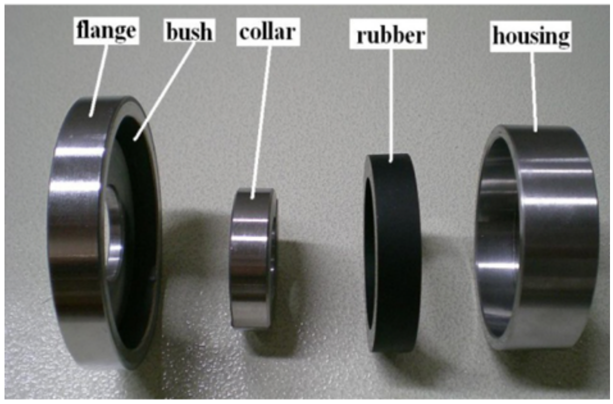

Fig. 5 Fabricated parts of the variable preload device

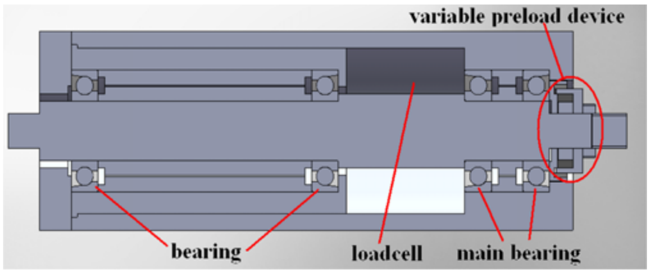

Fig. 6 The cross section of the experimental system with the loadcell and the variable preload device

Fig. 7 The experimental system with the variable preload device

comparison of the results between the experiment and that of FEM. The preload is measured by varying speeds. The preload sequentially increased according to the increase in spindle speeds. The change in the force at 5,000 rpm is verified by comparing it with that of the stopped state and the change is 8 N. It is natural that the preload is not linear output of whole range of revolution because the centrifugal force is non-linear with respect to spindle revolution. Even though the preload 7.76 N at 5,000 rpm is obtained, the preload will be increased to 279 N at 30,000 rpm and 497 N at 40,000 rpm, because of centrifugal force increase. The preload is sufficient to maintain the variable preload device. It is thus shown that there is good agreement between the preload obtained in the deformation analysis and that of the experimental results. Based on these results, it is considered that the variable preload

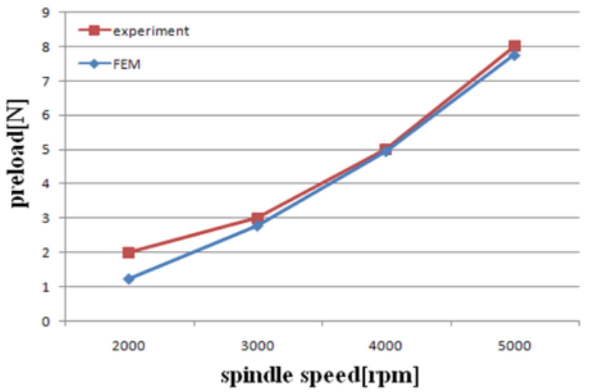

Fig. 8 Results between the experiment and FEM analysis

device using the rubber pressure can be applied to a spindle system.

5. Conclusion

In this study, a variable preload method is proposed using rubber pressure. It is verified that the proposed method can be used as a method for reducing complexity caused by mechanical structures, assembly errors and high costs. The following results are obtained through developing the variable preload device:

(1) A new preload device using rubber pressure that can be applied to the spindle bearings is proposed. Improvement of the drawbacks presented in the existing variable preload devices is expected.

(2) The movement of the flange that can reduce preload is verified based on the results of the deformation analysis performed by using the proposed analysis method. It is identified that the movement of the flange according to the rubber deformation is 0.25 mm.

(3) Base on the results of the proposed analysis, the force applied to the inner race of the bearing is 7.76 N. The design and fabrication for the proposed variable preload device are carried out and the fabricated device is installed to the spindle used in this experiment. In the results of the experiment, the force at 5,000 rpm applied to the bearing is 8 N. It is thus shown that there is good agreement between the preload obtained in the deformation analysis and that of the experimental results.

In this study, the new variable preload device is proposed and verified. However, it is necessary to ensure more data under various conditions through experiments in order to apply the proposed device to spindles. The possibility of the operation of a deformable rubber preload device is studied. The future studies should be continued to increase the preload using an amplification device of the centrifugal force.

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