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An Impact-based Automatic Centering Actuator System for Ultra-Precision Turning

Seung-Kook Ro[1,#], Gyungho Khim[1] and Doo-Sun Choi[2]

1 Department of Ultra-Precision Machines and Systems, Korea Institute of Machinery and Materials, 156 Gajeongbuk-no Yuseong-gu Daejeon, 34103, Korea
2 Department of Nano-manufacturing Technology, Korea Institute of Machinery and Materials, 156 Gajeongbuk-no Yuseong-gu Daejeon, 34103, Korea
Corresponding Author / Email: cniz@kimm.re.kr, TEL: +82-42-8687115, FAX: +82-42-868-7180

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In this paper, we introduces an automatic workpiece centering system using an impact actuator for future use of automating centering process which is currently done bv time-consuming manual process. We were aimed to develop an actuator and automatic process to align workpiece center within 20 seconds. An impact actuator was designed to generate force to move work small displacement by continuously impacting during rotation. The proposed impact actuator has a voice coil motor for generating movements of two masses which are guided by miniature guides, and mass with smaller weight contacts workpiece. The measured eccentricity by a displacement was estimated on-line through LMS tracking method, and magnitude of excitation was calculated based on the tracked eccentricity. The proposed actuator was manufactured and integrated with a control system using low-cost micro-processor. The automatic centering actuator system was applied to a diamond turning machine for a micro lens core mold with continuous rotating speed of 60 rpm and 20 Hz of excitation frequency. It was demonstrated experimentally that centering workpiece was possible within 1 μm and no more than 20 seconds.

1. Introduction

Current expansion of mobile electronics and autonomous mobility increases demands of micro lens modules. The micro lens module has multiple lenses which are manufactured by injection molding or ultra-precision machining. For the injection molding, a number of core molds are required manufactured by ultra-precision turning for mass production. As the resolution of the image sensors are increasing, the requirements of the lens are also getting higher in accuracy and surface quality. Hence, the machining accuracy should be maintained very carefully during the ultra-precision turning of the core molds.

The workpiece centering process during ultra-precision turning of optical lens mold is inevitable for machining accuracy, but it is usually done by time-taking manual process which reduces productivity and prevents automatic work loading. From this reason, it is needed to develop method to center workpiece automatically. There are some method developed so far by sequential process using moving axis or additional actuator.[1, 2]

Hence, we developed an automatic centering actuator system using impact which was aimed for automatically aligning workpiece center within 20 seconds. An impact actuator was designed to generate force to move work small displacement by continuously impacting work during rotation, which are same mechanism of manual centering. The proposed impact actuator has a voice coil motor for generating movements of two masses which are guided by miniature guides, and mass with smaller weight contacts workpiece. The measured eccentricity by a displacement was estimated on-line through LMS tracking method, and magnitude of excitation varies with the tracked eccentricity. The proposed actuator was manufactured with control system using low-cost micro-processor. The proposed system was applied to a diamond turning machine for a micro lens core mold with rotating speed of 60 rpm and 20 Hz of excitation frequency. It was demonstrated that centering workpiece within 1 μm no more than 20 seconds experimentally.

2. Impact Actuator and Process for Centering

2.1 Design of Actuator and Process

An actuator for impact-based workpiece centering and process was designed as Fig. 1. The actuator has two moving mass and a voice coil motor between them to generate movement so that smaller reaction force of impact can be transferred to the frame compared to using only one moving mass. The required impact force was decided considering friction force between the vacuum chuck and mass of the worpiece, lens core molds. It was designed to have mass of impact part m_1 as 0.104 kg and mass of secondary moving part m_2 as 0.268

kg, and this was expected to generate higher velocity and movement of impact mass than secondary mass. Through the numerical simulation, it was verified up to 500 N of impact force could be expected with excitation force of 7.6 N, which was respectable for 1 A of current of the coil, and displacement of few micrometers were expected. Fig. 1 also explains automatic centering mechanism during continuous rotation of spindle. As the impacting time is very short, less than 1 ms, the spindle is not needed to stop during impacting. The eccentricity of the work was identified with tracking with LMS (least-mean-square) algorithm by filtering synchronous signal from the sensor. The amplitude of compensation output, a continuous square wave with 20 Hz, was modulated from the tracked signal and the amplitude for two cases; coarse impact over certain eccentricity and fine amplitude for minimal displacement. The impact and measurement is operating simultaneously, and the compensation ends when the eccentricity is reduced under desired value, 1 μm in this study.

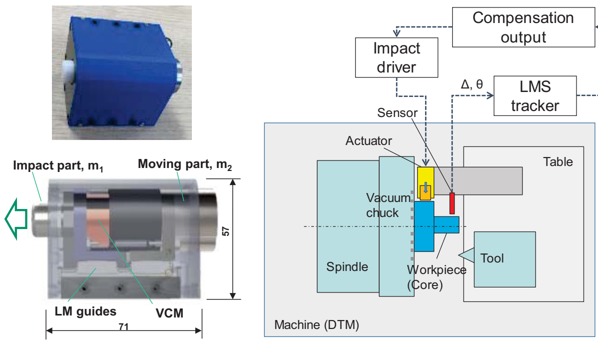

Fig. 1 The impact actuator and schematic diagram of automatic centering system

2.2 Experimental results

The proposed system was manufactured and assembled and tested in a testbed with force sensor and laser sensors to detect movements of both parts. The on-line tracking algorithm and calculation of compensation output were programed into a low cost ATmega128 micro-controller unit (MCU, Arduino), and current driver was connected D/A signal of the controller. The impact force in the test bed was measured up to 400 N for driving current of 0.15 A and excitation frequency of 20 Hz. We also measured required impact force of actual workpiece on the vacuum chuck by test with impact hammer, and it was shown that minimal force was 43 N and displacement with 0.14 mm per unit force over 1 μm.

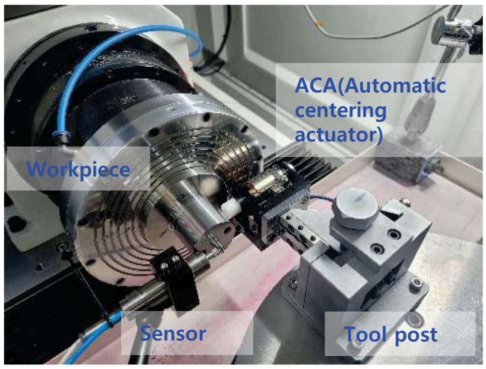

Fig. 2 Experimental set up for automatic centering

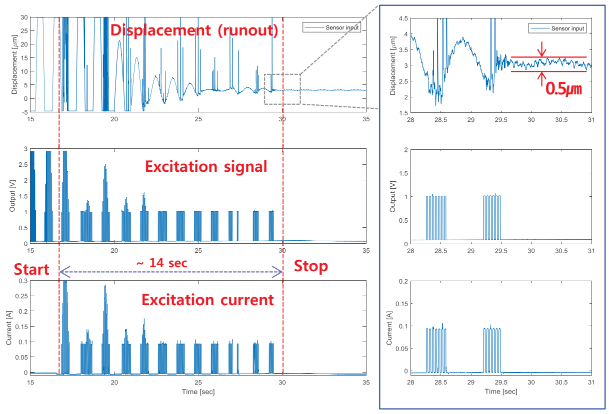

Fig. 3 Experimental results with automatic centering; measured displacement, excitation signal and currents

Fig. 2 shows experimental set-up for automatic centering. A capacitive LVDT sensor with resolution of 5 nm was installed to measure runout core mold where the automatic centering actuator was installed the body of workpiece in opposite side. The test was done done when spindle was rotating as 60 rpm continuously, and as the results shown in Fig. 3, it took about 14 seconds to runout under 1 μm.

3. Conclusions

In this paper, we proposed an impact actuator and control system for automatic centering of workpiece for micro lens core mold. The proposed system could align work to eccentricity of 1 μm within 20 seconds during rotation of the spindle. It is expected that set-up time can be reduced with this system for ultra-precision machining, and this will help for automatic change of workpiece in ultra-precision turning.

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