On-line Automatic Workpiece Centering Using an Impact Actuator for Ultra-Precision Turning

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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 less than 1 ㎛ 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 motion guides, and mass with smaller weight contacts workpiece. The measured eccentricity of the workpiece by a displacement was estimated on-line through LMS tracking method, and magnitude of excitation was calculated based on the tracked eccentricity. The actuator and control process were analyzed numerically considering dynamics. The proposed actuator was manufactured and integrated with a control system using low-cost micro-processor. Through simple test rig for impact force measurement, and it was shown enough impact force were generated. 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 ㎛ and no more than 20 seconds.

1. Introduction

The current expansion of mobile electronics and autonomous mobility has significantly increased the demand for micro lens modules. These modules, which consist of multiple lenses, are typically manufactured through injection molding or ultra-precision machining. For injection molding, numerous core molds are required, which are produced via ultra-precision turning to facilitate mass production. As the resolution of image sensors continues to rise, the lenses must meet increasingly stringent requirements for accuracy and surface quality. Consequently, maintaining high machining accuracy during the ultra-precision turning of core molds is crucial.

The workpiece centering process during the ultra-precision turning of optical lens molds is crucial for maintaining machining accuracy. However, this process is typically performed manually, which is time-consuming, reduces productivity, and hinders automatic work loading. Therefore, developing a method to automatically center the workpiece is essential.Several methods have been developed so far, often involving sequential processes using moving axes or additional actuators. [1, 2]

Hence, we developed an automatic centering actuator system using impact, aimed at automatically aligning the workpiece center within 20 seconds. The impact actuator was designed to generate force to move the workpiece by small displacements through continuous impacts during rotation, mimicking the manual centering mechanism.The proposed impact actuator features a voice coil motor that generates movements of two masses guided by miniature guides, with the smaller mass contacting the workpiece. The measured eccentricity was estimated online using the LMS tracking method, and the magnitude of excitation varied with the tracked eccentricity.The actuator was manufactured with a control system using a low-cost microprocessor. The system was applied to a diamond turning machine for a micro lens core mold, operating at a rotating speed of 60 rpm and an excitation frequency of 20 Hz. Experimentally, it was demonstrated that the workpiece could be centered within 1 µm in no more than 20 seconds.

2. Impact Actuator and Process for Centering

2.1 Design of Actuator and Compensation 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. 2).

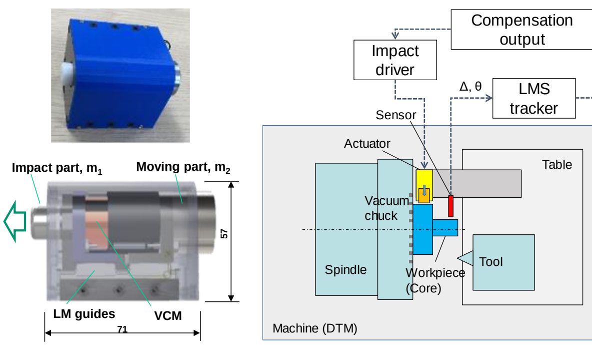

Fig. 1 The impact actuator and schematic diagram of automatic centering system

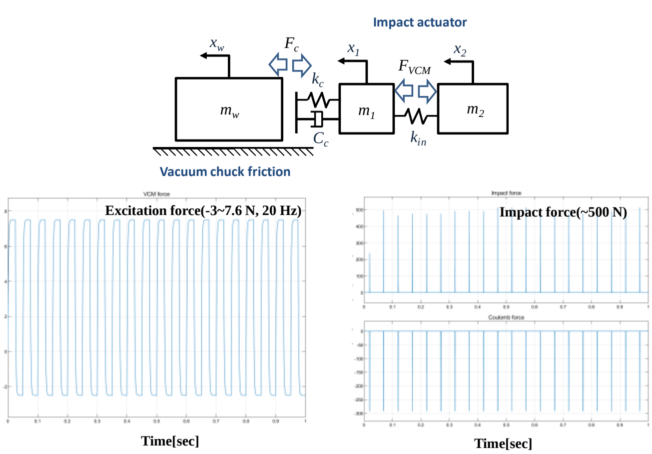

Fig. 2 Dynamic model of the impact actuator and simulation results of impact force

Figure 1 also illustrates the automatic centering mechanism during continuous spindle rotation. Since the impact duration is very short, less than 1 ms, the spindle does not need to stop during the impact. The eccentricity of the workpiece was identified using the LMS (least-mean-square) algorithm by filtering the synchronous signal from the sensor. The amplitude of the compensation output, a continuous square wave at 20 Hz, was modulated based on the tracked signal and adjusted for two scenarios: coarse impact for significant eccentricity and fine amplitude for minimal displacement. The impact and measurement operations occur simultaneously, and the compensation process concludes when the eccentricity is reduced to the desired value, which is 1 μm in this study.

Figure 3 shows an example of simulated results with initial 100 μm eccentricity of the workpiece. The limit for the coarse impact was 5 μm. Approximately over 2 μm was moved by the coarse impact, and it can be observed that fine impacts occurred when eccentricity was less than 5 μm**.** Total number of the rotation was less than 20 revolutions which means centering was finished within 20 seconds considering rotation speed was 60 rpm. The bigger impact force, the bigger movement can be expected. So, adjusting amount of coarse and fine impact force is if reduction of centering time is required.

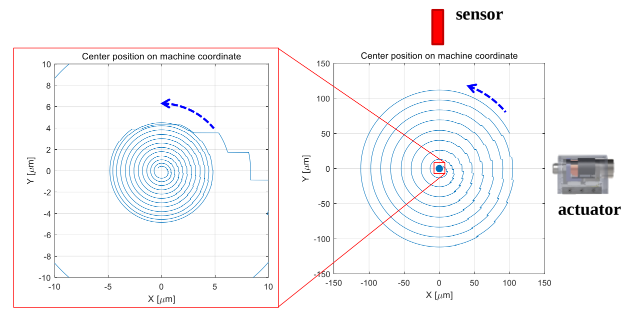

Fig. 3 The impact actuator and schematic diagram of automatic centering system

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 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. 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.

Fig. 4 Manufactured control box for the impact actuator

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.

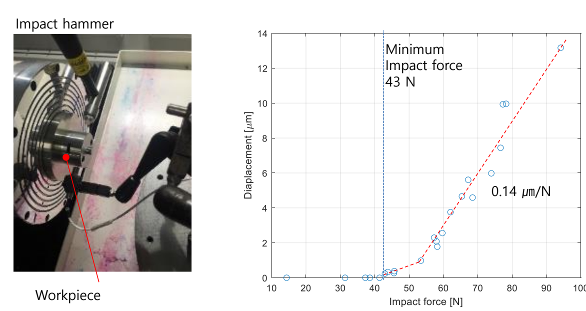

Fig. 5 Test for measuring actual impact force required to move workpiece

From the results, we adjusted coarse impact current as 0.2 A and fine impact current as 0.1 A. The limits for the coarse impact wad decided as 10 μm. Fig. 6 shows experimental set-up for automatic centering on a ultra-precision diamond turning machine. 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 when spindle was rotating as 60 rpm continuously, and as the results shown in Fig. 7, it took about 14 seconds to runout under 1 μm after amplifier was on.

The sensor signal was exceeded input range of the controller A/D converter, and there were transient displacement of the worpiece by impact, but it was not affected for generating impact signals because it was only affected by tracked eccentricity by LMS algorithm. It was proven this on-line compensating method was stable and robust with enough speed of centering.

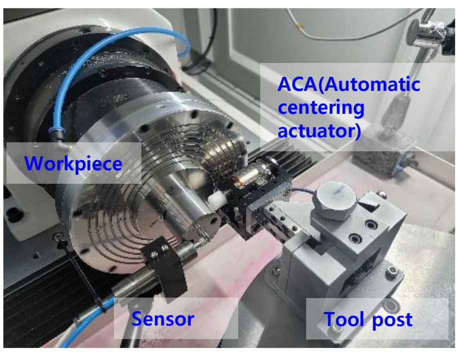

Fig. 6 Experimental set up for automatic centering

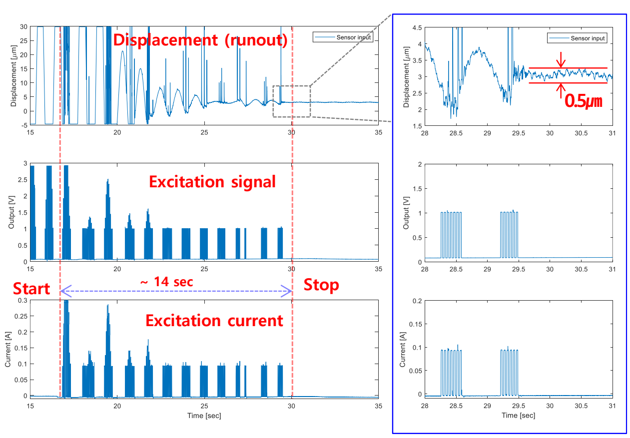

Fig. 7 Experimental results with automatic centering; measured displacement, excitation signal and currents

3. Conclusions

In this paper, we propose an impact actuator and control system for the automatic centering of workpieces in micro lens core mold manufacturing. The proposed system with impact actuator and compensation algorithm with LMS tracker can align the workpiece to an eccentricity of 1 μm within 20 seconds during spindle rotation. This system is expected to reduce setup time in ultra-precision machining and facilitate the automatic change of workpieces in ultra-precision turning.

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