Design and Performance Testing of a Novel Three-Dimensional Elliptical Vibration Turning Device

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Editorial

A novel three-dimensional (3D) elliptical vibration turning device which is on the basis of the leaf-spring-flexure-hinges-based (LSFH-based) double parallel four-bar linkages (DPFLMs) has been proposed. In order to evaluate the performance of the developed 3D elliptical vibration cutting generator (EVCG), the off-line tests were carried out to investigate the stroke, dynamic performance, resolution, tracking accuracy and hysteresis along the three vibration axes. Experimental results indicate that the maximum stroke of three vibration axes can reach up to 26 μm. The working bandwidth can reach up to 1889 Hz. The resolution and hysteresis tests show that the developed 3D EVCG has a good tracking accuracy, relative high resolution and low hysteresis, which is appropriate for micro/nano machining. Kinematical modeling is carried out to investigate the tool vibration trajectory. Experimental results shown that the simulation results agree well with the experimental one, which indicate that the developed 3D EVCG can be used as an option for micro/nano machining. Freeform optics with complex geometric features has many advantages. In recent years, the requirement of applications for optical parts in aerospace and industrial production has increased year by year. However, the further application of optical parts is restricted due to high rates of tool wear, low efficiency of ultra-precision machining and high manufacturing costs. For optical elements manufacturing, generally, fast tool servo (FTS) or slow tool servo (STS) is usually adopted. Compared with traditional precision machining, FTS or STS do bring a lot of benefits especially for freeform optics manufacturing. However, the ability is limited when comes to the more complicated manufacturing requirements. Therefore, elliptical vibration cutting (EVC) is proposed and recognized as one of the promising ways, and its unique intermittent cutting and friction reversal characteristics caused large attention. In order to obtain ideal machining results, EVC generator (EVCG) always plays a key role in it. Thus, many studies have been carried out trying to achieve an effective design. The research of EVC apparatus has grown from two dimensional to three dimensional, and resonance to non-resonance. The two dimensional resonant EVC apparatus was first proposed by Shamoto and Moriwaki, which was actuated by two piezoelectric plates glued to the lateral surfaces and its resonant frequency is 20 kHz. However, this device has strict requirements when it is fixed, otherwise it is difficult to motivate ideal mode of the transducer. Shamoto improved the EVC device with 4 large piezoelectric plates subsequently and developed an ultrasonic elliptical vibration controller to compensate the vibration interfere in two perpendicular directions, then a 3 degree-of-freedom (DoF) ultrasonic vibration tool was developed for sculptured surfaces. Li and Zhang proposed an asymmetrical structural model of ultrasonic elliptical vibration transducer which was driven by single actuator with the longitudinal excitation. Kim and Loh proposed an ultrasonic EVC device for micro V-groove machining which was based on Cerniway's design. Guo and Ehmann developed a novel device which was composed of two bolt-clamped Langevin transducers [14]. The two bolt-clamped Langevin transducers work in the resonant mode of which the frequency are almost same and deliver an elliptical trajectory at this coupled resonant frequency. As is konwn, all these apparatus summarized above belong to the category of ultrasonic vibration cutting. The biggest advantage of resonant EVCG is the large working frequency. However, this is also a weakness of it due to the fixed working frequency. Therefore, non-resonant EVCG is proposed to increase the manufacturing flexibility during machining. Compared with resonant EVCG, non-resonant EVCG always have a lower frequency, but the working frequency is continuous, which make the processing process more flexible. The largest number of studies focused on 2D non-resonant EVCG. JH Ahn et al. developed a 2D vibration apparatus for micro-machining accuracy improvement which was actuated by two perpendicular piezoelectric actuators (PEAs), a cross-shaped voids are devised in order to remove cross-interference].

Cerniway and Negishi proposed a low-frequency and high-frequency EVC devices which can be operated at 200 Hz with vibration amplitudes of 20 μm × 4 μm and 4 kHz with vibration amplitudes of 18 μm × 3 μm, respectively. A 2D vibration cutting tool based on elastic hinges which can produce amplitude of 10 μm and maximum frequency of 500 Hz with no phase distortion was proposed by Ho-Sang Kim et al.. R Kurniawan and TJ Ko developed a non-resonant mode transducer tool holder inspired by Guo's and Kim's design proposal to fabricate micro-dimple and groove patterns. Zhou et al. proposed a double-frequency EVC apparatus for freeform surface by using two piezoelectric actuators perpendicularly each other which are both based on the leaf type flexure hinge. In order to obtain a compact design with high working bandwidth and low axis coupling, Lin et al. propose a parallel PEA actuated EVCG. Although these studies propose different method for different considerations to improve the machining performance, it is difficult to achieve a perfect result due to the inherent attribute, such as single vibration direction, mutual conflicting between high working bandwidth and large stroke. In order to obtain a more flexible vibration in space, a flexure-based 3D EVCG actuated by four PEAs are developed by Lin. In addition, a three PEAs actuated 3D EVCG is proposed by Zhu. However, the size is very large and the structure is relatively complicated. Then a novel rotary spatial vibration system is proposed by Zhu to impose tertiary motions with multiple DoFs on a rotating spindle for micro/nanomachining. This design uses three PEAs along three perpendicular directions to generate the 3D motion. The stroke is not very high, and the life of PEA is threatened by transverse force results from transverse motion. Moreover, the compound multibeam parallelogram mechanisms (CMPMs) are nonlinear according to the report of. And the non-linear behavior of the system is a common phenomenon due to the initial internal force, material non-linear and large deformations. However, for EVCG, the linear elastic material is often adopted and the deformation is only tens of microns which is relatively small. Therefore, it is appropriate to neglect the non-linear behavior of the system.

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