High Response Fast Tool Servo for Ultraprecision Turning

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Abstract

This abstract summarizes the work carried out in the design and development of high response Fast Tool Servo (FTS) addressed to manufacturing freeform microtexturing surfaces. The increase of complexity in mainly optical orientated pieces requires the use of drivers with a bandwidth higher than 1kHz with an effective stroke of around $50{\cdot}10^{-6}$m. With the aim of achieve of even overcome these features, it has been designed and developed a FTS.

The FTS has been designed with piezo-electrical driver, cooled with air to keep limited thermal dilatations generated by heat losses from pizoelectrical hysteresis. The driver acts trough a mechanism based on flexible joints, that for small displacements (maximum stroke $50{\cdot}10^{-6}$m) the system is linear. Cutting tool, usually a diamond tool, is clamped in the nose of the FTS. The movement of the tool is measured by a capacitive sensor, with a range of $250{\cdot}10^{-6}$m up to 15kHz and a resolution of $10{\cdot}10^{-9}$m, closing its control loop. These drivers are joined to the CNC of ultraprecision machine tools, such lathes as micromilling machines for turning/facing and fly cutting processes respectively.

The main specifications of the FTS are the maximum force 1000N, and the bandwidth 2000Hz, 25% of piezo-actuator's natural frequency 8KHz. The stroke of the tool is related with the working bandwidth, this way, for low frequencies (250Hz) the maximum stroke achieve $80{\cdot}10^{-6}$m, meanwhile at maximum operating frequency, 2000Hz, the stroke is limited to $10{\cdot}10^{-6}$m. For very high frequency operations, up to 2600Hz (a third part of piezo's natural frequency), the FTS will be able to reach $5{\cdot}10^{-6}$m of amplitude, however this case is not the most usual working condition due to the delay in the response. For the most usually cases, that require a frequency response around 1000Hz, the amplitude that achieve is between $20{\cdot}10^{-6}$m and $30{\cdot}10^{-6}$m, enough to cover all machining conditions of nowadays cases, [1] and [2].

1 Fast Tool Servo design and development

A Fast Tool Servo (FTS) has been designed to manufacture high precision surfaces and microtextures, usually used in the field of optics and tribology. The FTS presented in this paper has been designed in the Department of Microtechnology and Ultraprecision of Ideko IK4 Research Centre, where the maximum operating conditions of the mechanism are: frequency 2000 Hz at amplitude of $50 \cdot 10^{-6}$m.

In the Figure 1 the construction of the FTS can be seen:

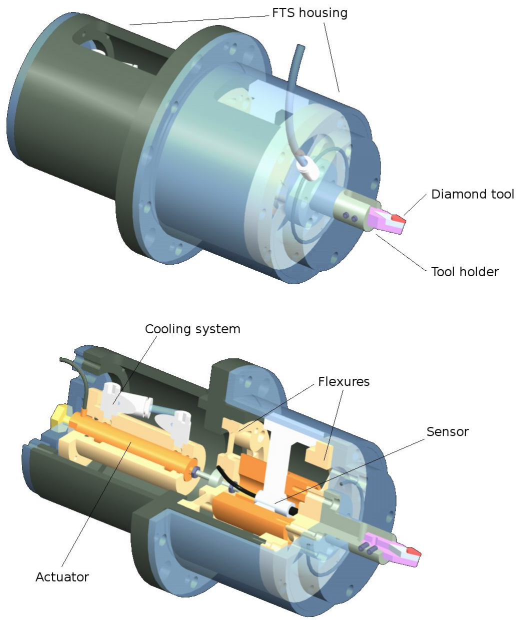

Figure 1: Fast Tool Servo design and internal parts view.

Very high hardness diamond tools are used in the manufacturing of optical components, tasks where tip's point radius is a key factor in final surface roughness. A piezoelectric actuator drives the tool through a flexible mechanism, and the flexures are manufactured from a monolithic structure. The actuator (Piezojena PA50/12 [3]) has a maximum amplitude of $50 \cdot 10^{-6}$m, with natural frequency of 8000 Hz, while the heat dissipation of the actuator at high frequency demands an air cooling system. Positioning control of the FTS is closed thanks to a capacitive sensor disposed between two flexure rings.

To ensure the reliability of the mechanism, a FEM analysis of flexible parts has been carried out. These flexures suffer severe stress level at quite high frequencies, so fatigue limit of the mechanism has to be high. In the Figure 2, displacement and stresses in the flexures are depicted for the maximum amplitude given by the driver, $50 \cdot 10^{-6}$ m. The maximal stress in the flexures for this case is 200 MPa (Figure 2), that is below than fatigue limit of flexures' material, springs' steel in this case 51CrV4, with a fatigue limit around 340MPa.

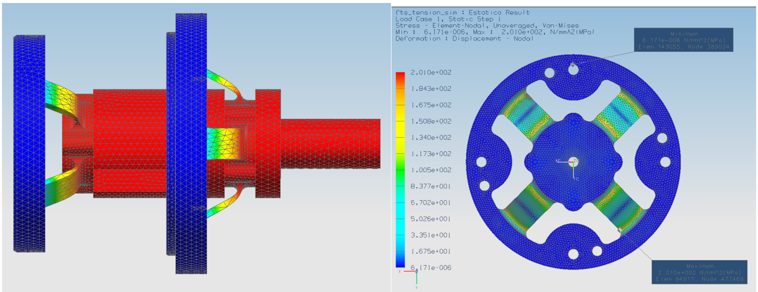

Figure 2: Flexures FEM analisys, displacement and stress.

The force required to maximum displacement of the driver ($50 \cdot 10^{-6}$ m) is 170 N, which diminishes the action of the actuator.

2 Microtextured Surface

One typical application of FTS's is turning and facing of cylinder pieces in ultraprecision lathes, although this equipment have been designed to be also used in micromilling machines to fly cutting operations.

An example of a microtextured surface in facing operation is presented below, with a workpiece of $50 \cdot 10^{-3}$m diameter and a sinusoidal surface with wavelength $70 \cdot 10^{-6}$ m and amplitude $5 \cdot 10^{-6}$ m. This surface can be realized by a 10^{-6} m/revolution feed rate, and cutting speed of 3.2 m/min. The desired structure is obtained by three movements: The spinning of the workpiece, feed rate of the tool and axial movement driven by the FTS. This sinusoidal surface and tool path are depicted in the Figure 3. The surface is simulated and represented in 3D graphs (left); and tool path and its frequency spectrum are shown in right side.

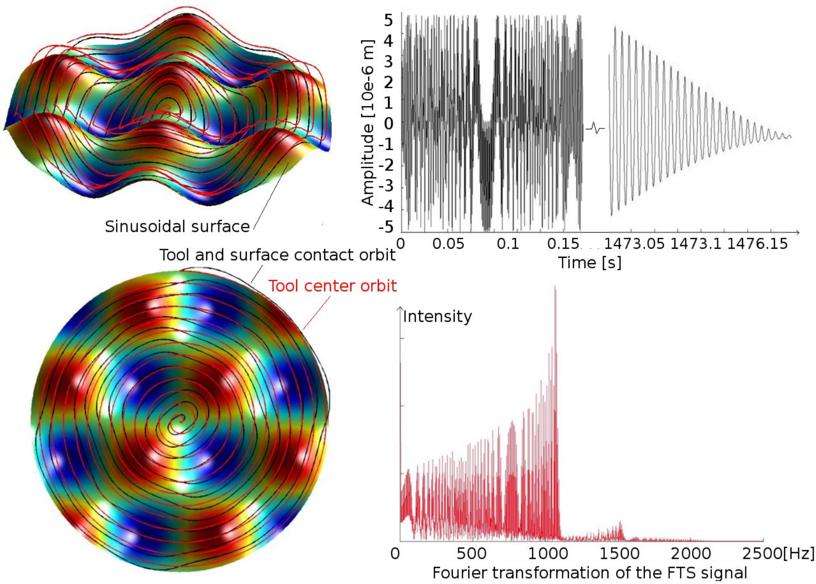

Figure 3: Sinusoidal surface and tool path signal analysis

After the Fourier transformation of the FTS actuator signal, the frequency maximum will be around 1500 Hz, which is below to the frequency limit of the actuator, 2000Hz, a quarter of its natural frequency.

3 Conclusion

The Microtechnology and Ultraprecision Department of IDEKO-IK4 Research Centre has designed and analyzed a FTS driver to be used in microtexturing tasks of ultraprecision and micromanufacturing processes.

References:

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