Materials and Design 93 (2016) 311–323

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Analytical and experimental study of topography of surface texture in ultrasonic vibration assisted turning

S.A. Sajjady [a], H. Nouri Hossein Abadi [a], S. Amini [b,*], R. Nosouhi [c]

[a] Ultrasonic Lab., Manufacturing Department, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
[b] Manufacturing Department, Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
[c] Department of Mechanical Engineering, Faculty of Engineering, Najafabad branch, Islamic Azad University, Najafabad, Iran

ARTICLE INFO

Article history:
Received 14 October 2015
Received in revised form 20 December 2015
Accepted 21 December 2015
Available online 31 December 2015

Keywords:
Ultrasonic vibration assisted turning
Surface texturing
Ultra-precision surface
Face-turning, simulation modeling

ABSTRACT

Ultrasonic vibration assisted turning (UAT) is a machining method for creating precision surfaces that because of advantages such as increased tool life, decreased cutting force, high surface quality, and increasing the machinability of hard cutting materials is widely used. In this method, optimal choice of machining parameters has a significant effect on the obtained surface texture. This paper examines the parameters that influence surface texture in the UAT. Therefore, an algorithm was provided to simulate surface textures in the process of ultrasonic vibration assisted face-turning in three modes of one-dimensional, two-dimensional and three-dimensional. To validate this algorithm, experimental tests were performed on Al7075-T6. Comparing the results of the algorithm and experimental tests shows that the surface texture resulted from simulation algorithm is well-matched with the results of experimental tests. Finally, the effect of machining parameters of cutting speed and feed rate are investigated in a variety of vibration modes applied to the tool.

1. Introduction

In recent decades, with the development of industries such as microelectromechanical systems, (MEMS), biotechnology, nanotechnology and so forth, mass and precise production of small and light mechanical parts has been widely considered. In construction of such parts, traditional machining methods do not meet the needs of today's modern industries. In addition, non-traditional machining methods such as ECM, EDM, LBM, etc., because of increased costs, high energy consumption, restrictions in machining certain materials, creation of heat distortion on machined surface and so on, are used less. Therefore, to meet these needs, combining modern production methods with the traditional ones has been considered and investigated. Combining traditional machining with ultrasonic vibration is one of these methods. This process, through applying vibration components to the tool, results in the tool's periodic vibrations during the machining process and ultimately creates some textures on the surface of the workpiece (Fig. 1). Using these vibrations, high surface quality, high dimensional precision, and intermittent cutting conditions are achievable [1] and, thus, result in reduced machining force, reduced tool wear, temperature decrease during the machining process and increased tool life [2–9].

Ultrasonic vibration cutting is generally performed in two ways of one-dimensional vibration cutting and two-dimensional (elliptical) vibration cutting. For both methods, the path of the tool fluctuates in a few micrometers range and vibrational frequencies are in the ultrasonic range (usually above 20 kHz). Tool actuator is used through the tool's vibrational excitation in different directions. The first method is a resonance system which operates in natural frequency. Resonance actuators benefit a vibration structure to fluctuate the tool. The movement of the tool tip is obtained through assembling the tool to a designed acoustic structure. A transducer with a low amplitude and high frequency stimulates the acoustic structure in its natural frequency. This structure is designed in such a way to strengthen the transducer's vibrations and ultimately leads to the tool's vibration. Fig. 2a shows a 1D-VAT system. In this system, the ultrasonic generator, using a piezoelectric or limited magnetic actuator, results in a reciprocation harmonic motion with high frequency and low amplitude. The second method is a two-dimensional resonance system that is shown in Fig. 2b. In this method, the system is designed and made in such a way that the tool in resonance frequencies vibrates in two dimensions. Therefore, an elliptical path is created at the tip of the tool. The third method is a two-dimensional non-resonance system in which piezoelectric actuator is stimulated by sinusoidal voltage signals and causes them to expand and contract at a frequency lower than the first natural frequency of the system and, finally, using a mechanical lever, piezoelectric linear motion is converted into elliptical motion. Fig. 2c shows non-resonance 2D-VAM system [10].

Shamoto et al. [1,11], by applying linear ultrasonic vibrations to the tip of the cutting tool, concluded that this process, compared with traditional machining, has more capabilities and benefits including the creation of mirrored quality surface, the low rate of ablation threshold at clearance surface of the tool and so forth. Then, two-dimensional

* Corresponding author at: Kashan university, Kashan, Iran.
E-mail address: amini.s@kashanu.ac.ir (S. Amini).

http://dx.doi.org/10.1016/j.matdes.2015.12.119
0264-1275/

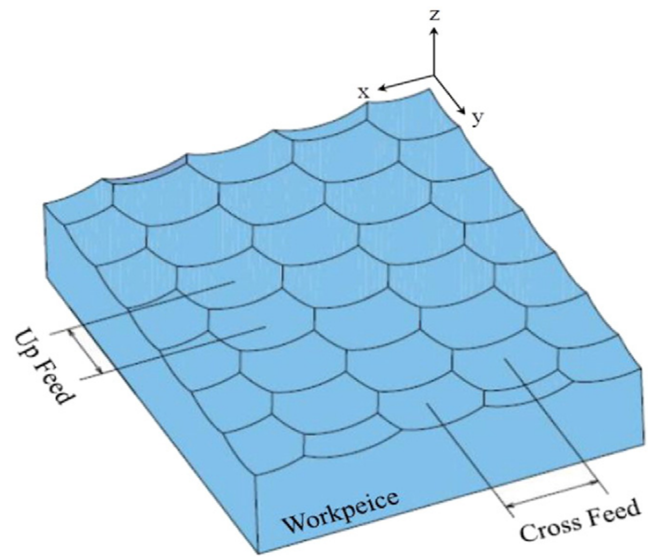

Fig. 1. Schematic form of surface texture obtained from ultrasonic vibration assisted machining operation.

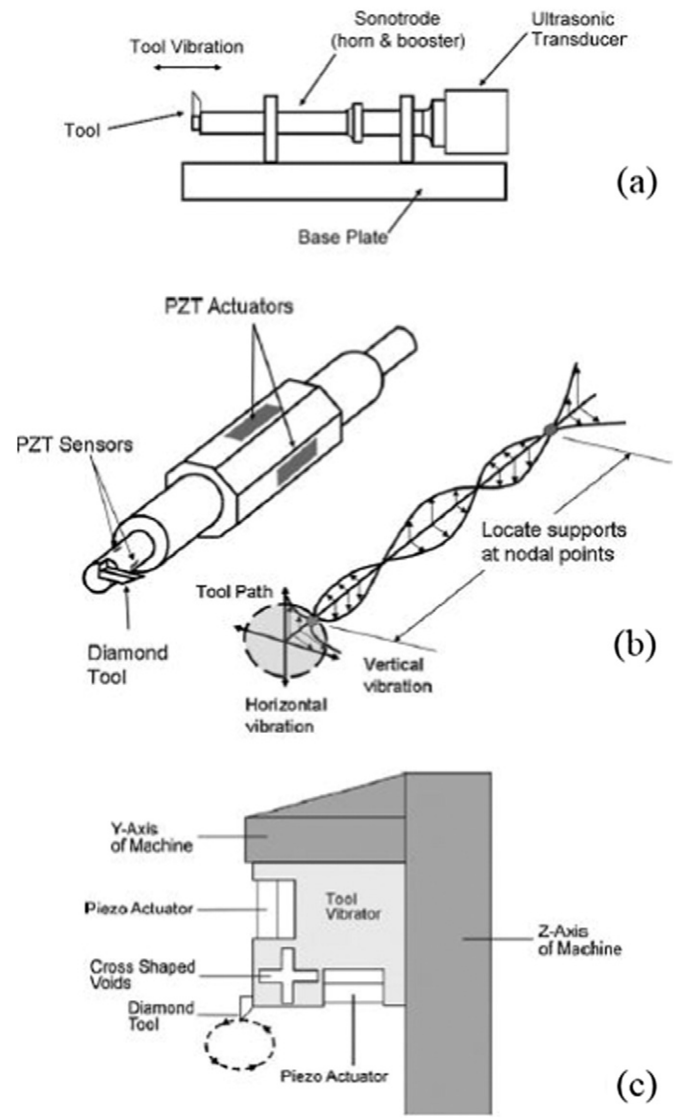

Fig. 2. Vibration actuators (a) the resonance 1D-VAT system using a ultrasonic generator, (b) the resonance 2D-VAT system, (c) the non-resonance 2D-VAT system [10].

vibrations with small amplitude and high frequency were added to cutting movement of the tool to create elliptical ultrasonic vibration assisted machining process. In order to generate elliptical vibration motion, many efforts have been so far conducted to create and develop high-performance transducers. Shamoto and Moriwaki [3] used a new vibrator to create elliptical vibration with ultrasonic frequency in cutting tool. Lee et al. [12], used an asymmetrical structural model of ultrasonic elliptical vibration transducer driven by single actuator, which had only a linear excitation, to create an elliptical vibratory motion.

Shamoto et al. [13] offered an elliptical ultrasonic vibrator with a number of piezoelectric (PZT) which were orthogonal to each other. In this model, when driving voltages are applied, longitudinal and bending vibrations are generated in the second and fifth resonance modes. Then, combining these two resonance vibrations, the vibrator fluctuates elliptically with an ultrasonic frequency in a very limited range.

Kurosawa et al. [14] designed a transducer consisted of two sandwich-type vibrators which intersected each other orthogonally at their end. This transducer is used to create two symmetrical and asymmetrical vibrations.

Zhang et al. [15], based on the concept of Kurosawa's work, developed a transducer consisted of two Langevin vibrators with π/2 angle to each other to create elliptical vibration motion.

Asumi et al. [16] miniaturized a V-shaped transducer of ultrasonic motor (VSM). The size of their miniaturized VSM was significantly less than the former one, while its speed and precision was desirable compared with the former VSM.

Gua et al. [17], based on Kurosawa's works, offered a new design that added vibrations to the tip of tool both in cutting and feed directions. In this design, a third vibration motion in radial direction is added to the tip of the tool in the elliptical vibration cutting process that, by changing the direction of the tip of the tool, can be easily adapted for various elliptical vibrations.

Kim and Loh [18] designed a piezoelectric actuator for ultrasonic elliptical vibration cutting process which consisted of two parallel piezoelectric actuators. When these actuators are stimulated by sinusoidal voltages, they expand and contract alternately. Moreover, controlling the phase difference between the applied sinusoidal voltages permits the tool to transfer or rotate in the determined elliptical path.

Surface texturing is an essence of the surface which is determined by three parameters of topography, roughness, and waviness. In other words, surface texturing consists of very minor local asperities compared with an ideal flat surface, and is one of the influential factors in the control of friction and displacement of layer structure during wear operation. Thus, according to the studies conducted so far, it can be concluded that surface texture is fundamentally important in the study of tribological properties (wear and friction) [19]. In fact, surface texture is studied in order to evaluate its effect on wear and friction properties during the sliding condition as the most important feature of this type of surface.

The process of creating surface texture by using elliptical ultrasonic vibration has been inspired by the surface-shaping system proposed by Hong and Ehmann [20]. This process, by adding a tertiary motion component as a higher-order motion to cutting and feed movements, creates a controllable and predictable vibration between the tool and workpiece. In this case, cutting conditions are chosen in such a way that the ratio of cutting speed (the ratio of cutting speed to vibration speed) is less than one. As illustrated in Fig. 3, cutting begins in t_b moment; then, at t_0 moment, the tool reaches to the lowest point of its elliptical path and, finally, the contact ends at t_e moment. Therefore, the tool and workpiece in each cycle of vibration cutting are in contact with each other at t_e–t_b moment, and then at t_e–t_0 moment, the chip formed during the tool movement is drawn up in the direction of chip flow. During T- (t_e–t_b), the tool, without removal, is returned to the cutting point in each vibrational cycle [21,22].