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Original Research Article

Improvement of cutting tool performance during machining process by using different shim

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ABSTRACT

Modern metal processing is characterized by high spindle speed machines causing high frequency vibrations. This significantly increases the requirements for stiffness and damping of cutting tool. The purpose of this study is to improve the quality of machined surface and the efficiency of hard turning using shim with high damping properties in the clamp set of insert. Five shims made of ceramic, epoxy granite, sandstone, granite and chlorite schist are proposed. Computer simulation and experimental investigation are provided to analysis the state of stress–strain in clamp set construction of insert. Static and dynamic characteristics of cutting tool with shim made of different materials are studied. In addition, the relationship between vibro-acoustic signal and material of the shim, wear of cutting edge, surface roughness and cutting conditions during hard turning are analyzed. It is concluded that using shim made of epoxy granite and sandstone improved damping capacity of the cutting tool and surface roughness by reducing vibration during machining process.

1. Introduction

In Machining process material is removed from the surface of a less-resistant body by tool, through relative movement and application of force [1]. In turning operation, vibrations occur and the cutting tool results in a wave on the surface of the workpiece, which magnifies the tool vibrations. Because of these vibrations the tool edge can be released from the workpiece. This unstable tool vibration so-called chatter was first understood by Tobias and Fishwick [2] and Tlusty and Polacek [3]. Chatter occurs at the frequency of the most dominant mode of the machine tool structure leading to an unstable cutting process affecting the surface quality, productivity, tool life, tool wear, dimensional accuracy of the machined workpiece and it is usually accompanied by considerable noise [4–7]. Avoidance of chatter has been a goal for many years. An appropriate choice of tool design and cutting conditions, stiffness damping improvement for the modes of vibration resulting in relative motion between tool and workpiece can reduce vibration [8]. Most of the researchers prefer vibration signals because they are very useful in the

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condition monitoring and dynamics of the cutting process. Cutting tool, in machining process, is considered the flexible element of the system, with the workpiece being rigid [9]. Passive and active methods are usually used to suppress the tool regenerative chatter. In active approaches the feedback monitoring of the cutting process are applied to adjust the cutting parameters or machining system accordingly, whereas in the passive methods passive control mechanical structure properties are improved or machining parameters are adjusted [10]. A simple method to reduce the dynamic displacement between cutting tool and workpiece is enhancing the stiffness of cutting tool. The principle of passive control is to convert vibrating energy into other forms by improving damping capability of the tool [11]. Materials used in cutting tool structures attracted a lot of attention due to their influence on the surface roughness in the machining process. These materials reduce vibration during machining by dissipating the vibrating energy. Hence, they must possess good material properties like high damping properties, stiffness, elastic modulus and thermal expansion coefficient. Nowadays, composite materials are typically used in substitution to conventionally used cast irons in structural applications for machine tools which require higher stiffness, strength and damping than can be achieved with cast irons [12]. Daghini [10] stated that by applying high damping viscoelastic materials in tooling structure the static stiffness of the tooling structure is reduced, however the stability limit was extended due to the higher damping property.

Recently many authors studied the optimization of cutting conditions to improve vibration level and surface roughness in a machining process, as well as the potential of composite materials for the development of precision machine structures. Zuo and Nayfeh [13] have proposed single tuned mass dampers with multiple degrees of freedom while Igusa and Xu [14] and Min et al. [15] developed multiple tuned mass dampers and a nonlinear tuned mass damper to suppress machine tool chatter, respectively. Ramesh and Alwarsamy [11] proposed new design of boring bar with impact dampers with different materials to enhance damping capability of the tool and suppress the chatter. Tunc and Budak [16] investigated the influence of cutting conditions, tool geometry and dynamic conditions on process damping in orthogonal cutting and end milling using the analytical method to identify and predict the process damping. Harms et al. [17] suppressed tool chatter using a piezo-electric actuator integrated into the tool holding structure for exerting a counteracting force against tooling vibration. Sisson and Kegg [18] stated that damping generated at the tool–workpiece interface causes high stability at low speed. They also reported that the most important factors, which affect the process damping are cutting speed, clearance angle and finite radius of the tool. A linear model was proposed by Altintas et al. [19], which verifies that the damping coefficient is approximately proportional to the ratio of vibration and cutting speeds. A new tool design including special elements made of damping materials presented by Devin and Osadchii [20] has reduced vibration amplitude and surface roughness by improving damping capability of the tool. Rama and Srinivas [21] pointed out that tool overhang and work cross-section are the main factors that affect the stability of machining process. An experimental study carried out by Sortino et al. [22] on the effect of the tool and workpiece material, tool geometry and cutting conditions on process stability in internal finish turning revealed the significant influence of the ratio of tool overhang to bar external diameter on the stability of the process. Nouari et al. [23] used the diamond as coating material in dry machining of aluminum alloys to improve the tool life. They also proved that the combination of the optimized cutting conditions and tool geometry leads to achieve high surface quality. A multiple degree of freedom model was proposed by Vela-Martinez et al. [24] to predict chatter in turning operation. Abouelatta and Madl [25] found a correlation between cutting vibrations and surface roughness in turning using a regression method. Baker and Rough [26] applied finite element method, which takes into account workpiece and cutting tool flexibility in the analysis. Wang et al. [27] proposed a theoretical physical model to describe and correlate the characteristic peaks in frequency domain with the behavior of tool-tip vibration in the steady-state cutting process. The proposed model captures the dominant factors affecting the surface roughness of the machined surfaces. Boden et al. [28] improved damping properties of the structure by applying high damping materials in critical joint interfaces (node regions where vibrational strain energy concentrates). Fu et al. [29] studied the influence of the tool clamping interface's normal pressure on the machining process stability to suppress tool chatter. Therefore, this discussion about turning operation indicates that it is a vital task to decrease vibration by improving damping of machine tool; and to select the optimum cutting condition to assure high surface quality of machined workpiece.

Therefore, in this paper, the effect of shims made of different materials on vibro-acoustic signal and surface roughness during hard turning is investigated. State of stress-strain in clamp set construction of insert is evaluated using photoelastic method and computer simulation. The static and dynamic behavior of cutting tools with different shim materials is analyzed. Performance of cutting tools during hard turning is analyzed in order to assess relationship between shim material, vibro-acoustic signal, surface roughness and cutting parameters.

2. Experimental details

2.1. *State of stress-strain in clamp set construction of insert*

The ratio of geometric parameters between the body and composite material gives the construction a certain dynamic quality. To solve this problem, the photoelastic method is applied, which is a polarization-optical method for stress investigation on transparent models design of the clamp set of insert. The experimental data are compared with the calculated data obtained by computer simulation using Solidworks.

To be able to predict the behavior of a component during vibration the energy concept is used, which is based on the accumulation of strain energy of the various elements in terms of their compliance. To determine the accumulated strain energy, the relation for identifying the potential energy of elastic deformation through the stress tensor is used [30]:

$$U_0 = KU_\Phi = ((1+\nu)/3)\,(\sigma_1 - \sigma_2)^2\,1.1 \quad (1)$$