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Latest Machining Technologies of Hard-to-cut Materials by Ultrasonic Machine Tool

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Abstract

The application of advanced materials is continuously increasing in many fields of industry, primarily in the medical and aerospace. The utilization of traditional machining methods is commonly considered very challenging for advanced materials, such as ceramics, metallic super alloys, and fiber-reinforced materials. The machining of these advanced materials, by means of ultrasonic assistance has been already introduced in the past. In this paper, the flexible integration of state-of-the-art ultrasonic systems in machining centers is presented. Results of the latest machining test examples of advanced materials using ultrasonic-assisted machining are discussed.

Keywords: Ultrasonic; Grinding; Machining; CFRP

1. Introduction

Advanced materials are very demanding for machining technologies. The key requirements are productivity (large material removal rate), part quality (high machining precision and minimized surface roughness), and tool costs (reduced tool wear). Additionally, process stability and reliability are also of particular interest for high valued added parts manufactured in small series.

The application of high performance ceramics and glass in several fields of industry is based on specially designed properties like temperature stability and wear resistance. Manifold geometries with high levels of complexity require reliable machining processes. Vibration-assisted machining has been shown to be the best suited technology due to its lower process forces, improved surface quality, and reduced tool wear [1-3]. An exemplary example of ultrasonic's process enhancing potential can be found in deep hole drilling. Fig. 1 shows one instance of complex parts with very fine structures created for aerospace applications. Ultrasonic machining is a suitable technology for the production of such demanding components and increases the feasibility of thin-walled lightweight structures while achieving reduced machining times and improved part quality when compared to similar methods. Additionally, ultrasonic machining technology has been applied to trim the surfaces of other high valued added workpieces. High quality ceramics watch cases, for example, require high surface quality and are composed of complex shapes, as shown in Fig. 2. In general, ultrasonic machining technology has proven to be an efficient tool offering solutions to the challenges of advanced materials. Recently, this kind of hybrid machining has also been applied to metallic compounds like titanium-aluminum [4, 5]. These materials are increasingly applied in the aerospace industry, which is traditionally one of the leading drivers for innovation. Presently, the aerospace industry is increasingly focused on faster and lighter aircraft. Therefore advanced metal alloys are being employed to improve the efficiency and performance of engines. The ultrasonic-assisted machining of these materials has the potential to solve several challenges like large tool wear, high process forces and temperatures of tool cutting edges. Fiber-reinforced materials, as seen in Fig. 3 represent another material group of increased importance for lightweight structures in aerospace applications.

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Fig. 1 Mirror support with thin-walled light-weight structures made from Zerodur ® using ultrasonic machining

Fig. 2 Finishing of the outside contour of a watch housing made from ZrO_2 with Ra < 0.1 µm by ultrasonic machining

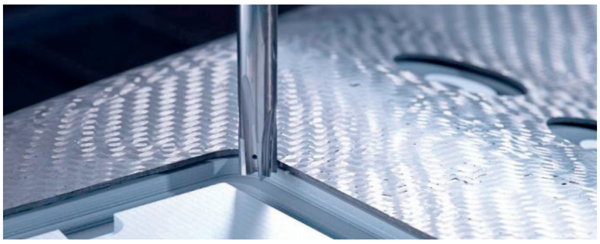

Fig. 3 Demo part for scarfing, drilling and machining of pockets in CFRP being improved by using ultrasonic-assisted grinding.

The main challenges in the machining of fiber-reinforced materials are fiber pull-out, delamination, and reduction of thermal stress to the work piece [6]. Moreover, the free particles generated by the milling process have to be extracted from the cutting zone in order to not build up on tooling surfaces. The aforementioned difficulties have been addressed through the use of tool vibration by the application of ultrasonic milling.

The flexible integration of ultrasonic machining and 5-axis milling in one machine tool is allowed by a specially developed spindle interface. This innovative concept covers a wide range of materials including conventional milling of e.g. aluminum and steel, ultrasonic grinding of hard and brittle materials such as glass and ceramics, as well as ultrasonic milling of composite materials and metal alloys.

This paper describes the integration, structure and effects of the ultrasonic technology for the machining of advanced and hard-to-machine materials.

2. Integration of the ultrasonic technology into 5-axis machine tools

Ultrasonic machine tools are characterized by two core elements. Firstly electronics; a frequency generator is integrated into the 5-axis milling center. Second, and most notability, is the ultrasonic actuator. This system is a special HSK-tool holder with a piezoelectric oscillator. Fig. 4 provides an overview of specialized ultrasonic components. By generating mechanical oscillations in the tool holder only, the machine tool can be used as both an ultrasonic and standard machine, due to the fact that non-ultrasonic HSK tool holders can be utilized as well. Concerning the actuator, the required electric energy is transmitted by a wear-free inductive system, enabling full compatibility to automatic tool changers. A schematic drawing of the ultrasonic actuator is shown in Fig. 5. The main component is the HSK-interface with a fixed inductive receiver system. In this manner power is provided to the piezoelectric transducer, generating mechanical oscillations according to the sine voltage applied. The system is in resonance at $\lambda/2$, and therefore the length of the oscillator (including tool) corresponds to half of the wavelength of the oscillation. To prevent any oscillation being transferred backwards to the spindle the connection between the transducer and the HSK tool holder is positioned in the knot plane / node, where the oscillation is zero.

Several tool interfaces for cylindrical tools (e.g. mills, drills), and for grinding discs are available. The HSK interface can be chosen between HSK32 and HSK100 according to the specific machine tool. Depending on the HSK size and the tool mounted in the actuator system, the operation frequency lies within a range of about 20 kHz to 60 kHz. The oscillation is driven along the tool axis due to the geometry of the piezoelectric transducer. At this point it should be mentioned that tools can be shaped specially to amplify other than the longitudinal oscillation mode. This can be advantageous, e.g. in grinding operations of large surfaces.

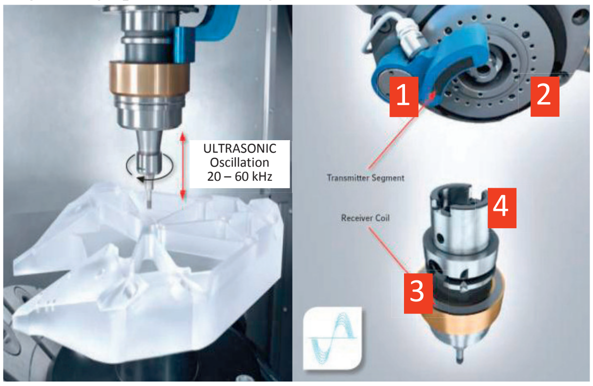

Fig. 4 Typical machining situation with a glass work piece (left). Ultrasonic tool holder integration into a 5-axis machine tool (right): Inductive input coil (1) is mounted at the spindle nose (2) for non-contact transmission of electric energy to the tool holder's receiving coil (3) fixed at the rotary actuator (4)

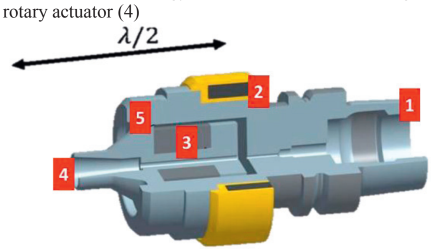

Fig. 5 ULTRASONIC actuator system consisting of HSK interface (1), inductive energy transmission system (2), piezoelectric transducer (3), tool interface (4), and vibration-free mounting flange (5).