

Ultrasonically assisted turning of NiTi based shape memory alloy

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Abstract

In this study, vibration cutting has been applied to machining of a novel material, NiTi based shape memory alloy (SMA), using a commercial ultrasonic piezoelectric transducer to vibrate an ISO insert CCMT geometry cutting tool. The effect of vibration in turning process was characterized by investigating the surface roughness of workpiece and surface quality assessment of machined surface using Light microscopy. Turning was conducted with ultrasonic vibration applied in the feed direction using autoresonant control software. The surface roughness of the ultrasonically and conventionally machined workpieces were measured and compared. The aim of the present research was to create an ultrasonic-assisted turning (UAT) facility to machining NiTi based SMA and to estimate the possible improvements in surface quality, using commercial transducers and ISO insert cutting tools. The results indicate that the application of ultrasonic vibration can significantly improve the surface quality of NiTi based alloy up to 30%.

Keywords: Ultrasonic assisted turning; NiTi based shape memory alloy; Surface characterization

1. Introduction

Shape memory alloy (SMA) based on NiTi shows the largest shape memory effect. SMAs are attractive for many high tech applications due to their superior properties. In order to establish new fields of application, the knowledge of machining these materials is essential and there is a crucial need for cost-effective machining processes applicable to this advanced material.

The continuous introduction of new or modified materials creates a new dispute to cutting technology. Ultrasonic cutting vibration and ultrasonic machining (USM) has been utilized with significant benefits for a variety of manufacturing and machining processes. The possibilities of applying ultrasonic vibration to a machining process were developed previously as follows:

The study on this method was firstly introduced about 50 years ago by Kumabe and Masuko [1]. They showed that the vibrating cutting force produces many advantages such as cutting force reduction enhancement of cutting heat conduction and increasing the tool life. Skelton in 1969 [2], used a magnetostrictive transducer to vibrate a carbide-tipped cutting tool while turning is taking place.

In addition Kumabe et al [3,4], examined that the precision machining of ceramics can be achieved using ultrasonic superposition vibration cutting of ultrasonically vibrated ceramics (USVC). They applied vibration cutting process not only to the machining of different metals like carbon steel, cast iron, stainless steel and hardened steel, but also to the final finishing and internal threading and their analysis has shown that vibration cutting is a suitable process for production of internal screw threads in thin stainless steel cylinders. Also they examined the feature of decreasing work displacement in their theoretical analysis of vibration cutting.

Elliptical vibration cutting was proposed by Shamoto and Moriwaki [5,6]. They proposed a novel vibration cutting method termed as "the elliptical vibration cutting (EVC)" in which a cutting tool attached to piezoelectric actuators circles along an elliptical path and penetrates into a workpiece when the cutting tool actuated by the piezoelectric actuators is brought into contact with a workpiece.

Astashev and Babitsky [7], showed that excitation of the vibro-impact mode of tool-workpiece interaction is the most effective way of using ultrasonic influence on dynamical characteristics of

machining, applied a non-linear analysis and discussed the advantages of ultrasonic cutting and possible ways of using it.

Lee et al [8], mounted a piezoelectric as a tuned vibration absorber on the turning tool and performed vibration experiments on a turning machine. They showed that tuned vibration absorber (piezoelectric mounted on tool) could optimize frequency response function therefore chatter can then be effectively suppressed leading to the increase of cutting stability.

Also, in order to realize high efficiency, low machining cost, high machining accuracy, noise reduction, tool wear, surface finish, and automatic machining, etc. by applying ultrasonic vibration during machining operations, many researchers have studied the mechanism of rotary ultrasonic machining (RUM), ultrasonic machining (USM) and ultrasonic assisted drilling (UAD) and many beneficial researches have been achieved [9-22]. RUM is regarded as one of the cost-effective machining methods for advanced materials. It is a hybrid machining process that combines the material removal mechanisms and ultrasonic machining [9].

When ultrasonic vibration applied to the machining of materials, there are two possibilities of using the ultrasonic vibration energy [23], i.e. (i) when an ultrasonic vibration is utilized indirectly to abrasive particles at the work surface and (ii) when the vibration is applied directly to a cutting tip. The advantages of using ultrasonic vibration energy when the vibration is applied directly to a cutting tip are not obvious, because normally machine tool vibration has to be vigorously suppressed in the most cases and the ultrasonic cutting is a strongly non-linear vibro-impact process [23]. The foundation of this theory and the principals of this method mainly for ultrasonic assisted turning (UAT), including experimental investigations and finite elements simulation was developed previously by Babitsky et al [23-32] for Inconel 718 modern aviation material.

However, few investigations on the ultrasonically assisted machining of modern aviation materials have been reported. In the focus of this study, there is a novel material; NiTi based shape memory alloy, suitable for engineering, robotic actuators, aerospace applications and medical applications. Because the high ductility and the high degree of work hardening of NiTi alloys during cutting, lead to difficult processing and poor workpiece quality [33-34], through this investigation, an ultrasonically assisted turning has been designed, fabricated and tested.

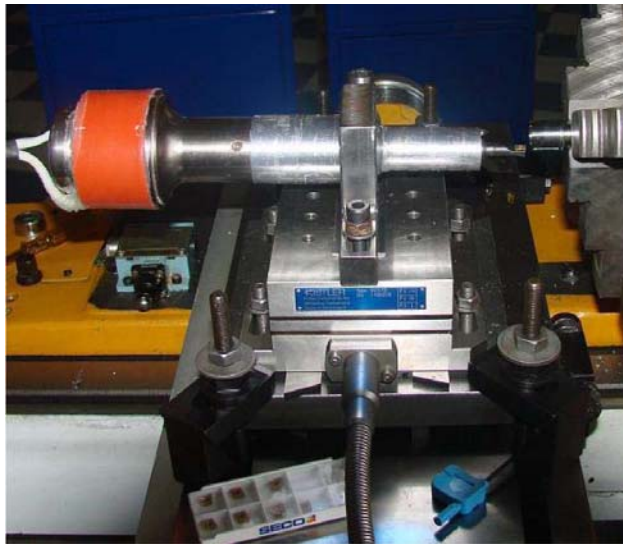


Fig. 1. Experimental set-up for autoresonant UAT

2. Experimental setup

2.1. System specification and arrangements

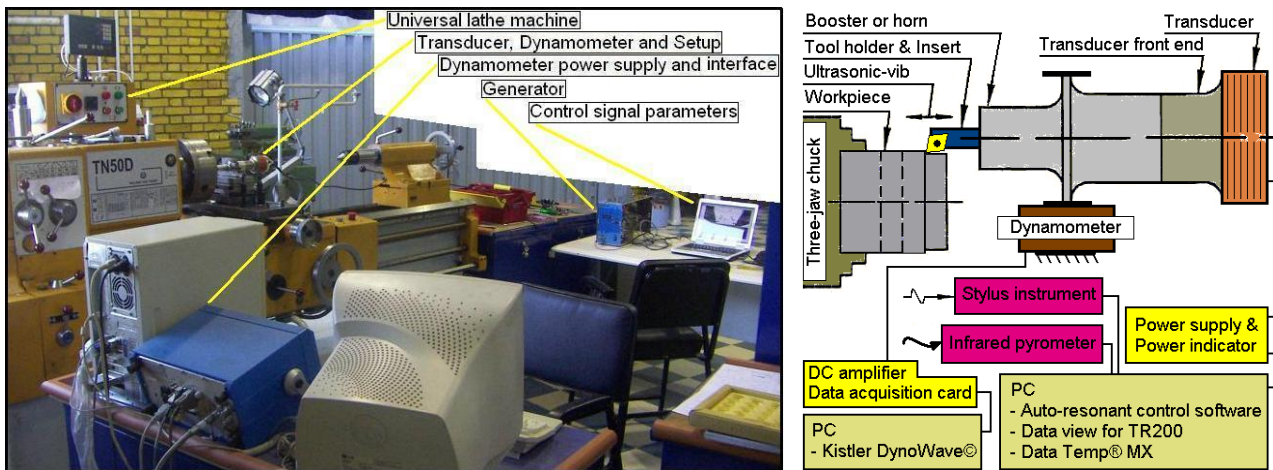


Fig. 2. Experimental setup arrangement and Schematic diagram of autoresonant ultrasonic cutting system of the experimental system.

2.2. Horn (Booster) design

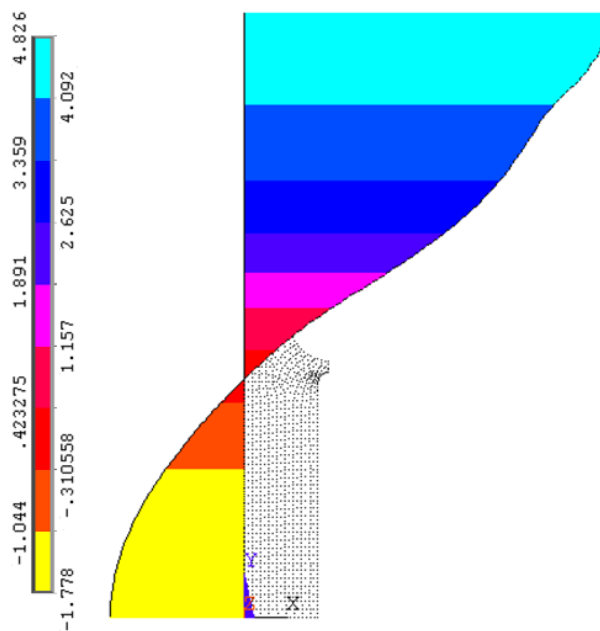


Fig. 3. FE-simulation (modal analysis) of movement distribution for calculating amplification factor (2.7), nodal point and Horn dimensions