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Metrological Investigation of an Actuator Device for Vibration Assisted Turning

Vibration assisted machining has the advantages of improved tool lifetime and chip breaking together with improved chip flushing and chip clearance. The basic principle of vibration assisted machining is the stimulation of either the cutting tool or the workpiece. Therefore the IFT developed a hydraulic based tool post actuator system making it possible to investigate the influence of superimposed frequencies on surface roughness and chip breaking. Frequencies of 0 to 30 Hz were applied while measuring the stroke of the tool post using laser interferometry. The results show that there is a significant dependency between the frequency of the tool post actuator system and the stroke value. Machining a specimen with vibration assistance showed better surface quality at higher frequencies and lower strokes. Moreover, vibration assisted machining had a significant influence on chip breaking causing eye shaped chips with comparably shorter length thus preventing continous chips completely.

Keyword: *vibration assisted machining, laser interferometry, chip breaking, tool lifetime, surface roughness.*

1. INTRODUCTION

The need to improve tool lifetime and optimize machining processes in production engineering is increasing constantly. Therefore, the Institute for Production Engineering and Laser Technology (IFT) sets a special focus on the issue of vibration assisted machining (VAM), which in recent times becomes a higher priority due to its special advantages. These advantages include an extension of tool lifetime as well as a targeted modulation of chip breaking which goes along with improvements for the chip flushing and clearance [1] [2] [3]. The basic principle of vibration assisted machining is the stimulation of the cutting tool, especially at its resonance frequency. This allows a positive supporting effect, especially for machining processes like drilling, milling and turning of brittle hard materials [4]. Generally speaking, stimulation of either the cutting tool or the workpiece is possible. VAM has been applied to a number of processes from turning to drilling to grinding [5]. The research on vibration assisted machining often focuses on ultrasonic assisted machining [6]. Thus products like DMG Mori Ultrasonic machine tools emerged on the market featuring ultra sonic actuated spindles [7].

In order to be able to provide vibration assistance during turning operations a special hydraulic based tool post device has been developed at the IFT. Hereby an oscillation is superimposed in axial direction on the helical movement during a longitudinal turning operation, which leads to an active chip breaking by recurrently reducing the chip cross section. The frequencies of the developed system can be varied up to 30 Hz and have an amplitude of about 0.5 mm.

This paper seeks to explore the developed actuator concept by measuring the realizable stroke using laser interferometry as well as assessing the resulting surface roughness using a tactile stylus instrument. During the experiments the steel materials C45E (1.1191) and X6CrNiMoTi17-12-2 (1.4571) are investigated.

2. VIBRATION ASSISTED TURNING

Vibration assisted turning, like all other vibration assisted manufacturing methods, bases on the principle of superimposing vibration on the actual manufacturing process. In this particular case a sine shaped vibration was superimposed along the z-axis causing a variation of the feed f at the tool center point (see Figure 1). Therefore the cutting force F_c as well as the passive force F_p and the feed force F_f cannot be considered constant during the operation.

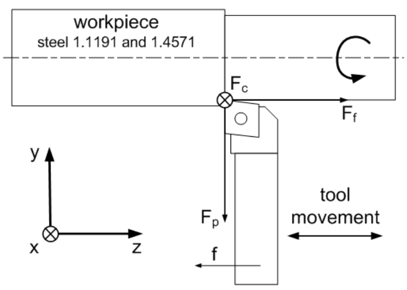

Figure 1. Tool movement and forces during vibration assisted turning

Figure 2 shows that the feed velocity v_f of the turning process and the stroke velocity v_S induced by the actuator device leads to a resulting velocity v_{res} with

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a certain amplitude A and an overall peak-to-peak value S (stroke) on which the sine vibration is superimposed.

Due to the superimposed vibration on the helical movement it is possible to achieve active chip breaking. This can be obtained by adjusting the frequency in such a matter that the peak in the current workpiece revolution aligns with a low from the previous workpiece revolution causing a chip cross section small enough to break immediately.

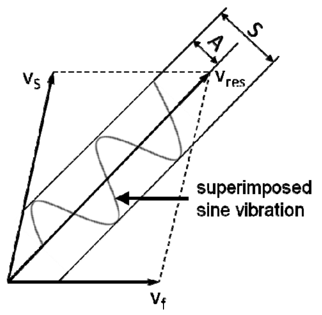

Figure 2. Velocities (v), amplitude (A), peak-to-peak value (S) and superimposed vibration

3. ACTUATOR DEVICE

The actuator device used for vibration assisted turning bases on a hydraulic cylinder. Additionally to a normal hydraulic cylinder the actuator was modified in terms of adding linear guides and the ability to be fitted into almost any machine tool via its HSK tool holder (see Figure 3).

Hydraulics was used to cope with the expected high feed force F_f which acts directly against the linear movement of the actuator. For applying the sine vibration on the system a servo valve was used which was controlled via LabVIEW. The servo valve alternately put pressure on the front side and the back side of the piston inside the actuator causing the slide, and therefore the tool, to vibrate in the predefined frequency.

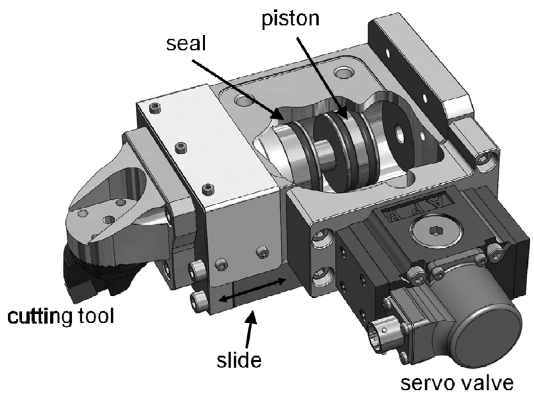

Figure 3. Actuator device (HSK tool holder not shown)

4. METHODS

The aim of the present study has been the investigation of an actuator system for intermittent machining, which enables a significant influence on chip breaking behavior during a turning operation. The actuator system was investigated by the use of a laser interferometer ML10 (Renishaw) to measure its stroke in dependence of the set frequency, which was varied between 0 Hz and 30 Hz. The measuring was done by focusing the laser interferometer to the front face of a tool post, which was headlong mounted on a table and stimulated by the given frequencies.

During the experiment, temperature and air pressure have been recorded with corresponding sensors in order to be able to take the environmental conditions into account [8]. Evaluation and controlling of the device and the sensors were done on a separate PC. To provide a stable fixation the actuator device was screwed upside down to a steel table. An overview of the experimental test stand set-up can be seen in Figure. 4.

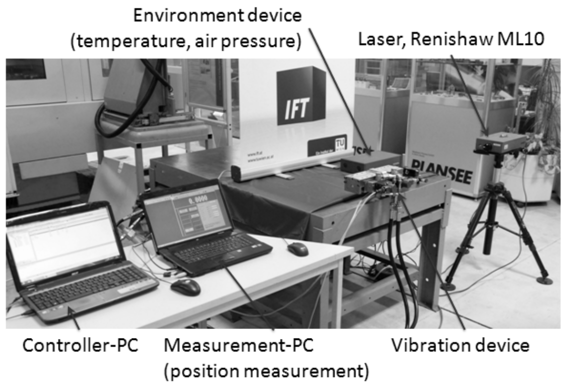

Figure 4. Experimental set-up for laser interferometer measurements

The setup contained a laser beam retroreflector which was screwed to the actuator device, an interferometer consisting of a beam splitter and an attached retroreflector and the laser source itself (see Figure 5).

Data recording was done by using Renishaw's QuickView software which provides an easy way to save up to 20 seconds of position data. For each investigated frequency a minimum of ten seconds of data was recorded. The output data were processed to find the minimum and maximum value of the recorded data and therefore calculating the peak-to-peak value (stroke) for each frequency.

Additionally a graph was plotted to determine the influence of the set frequency on the stroke of the actuator device. It was apparent that the actuator device cannot provide a sine vibration for frequencies below 15 Hz (see Figure 6). This is due to the fact that the stroke at these frequencies exceeds the mechanical limitations of the actuator device causing the piston to hit the end of the cylinder bore.

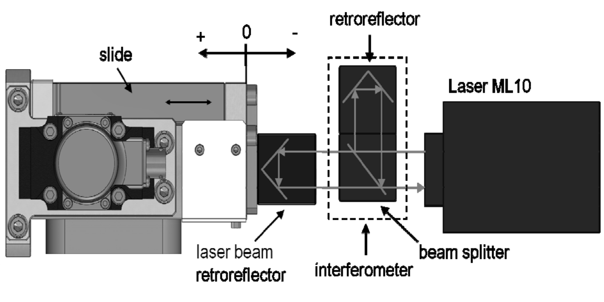

Figure 5. Measurement setup

5. SURFACE ROUGHNESS

For the investigation of the resulting surface quality machining experiments on an FS 300 (Heid) turning machine have been conducted. During these experiments the surface roughness was determined using a tactile roughness tester MarSurf PS1 (Mahr). A blank of C45E steel material (outside diameter of 105 mm and length of 150 mm) was treated by partly vibration assisted longitudinal turning operations. Thereby, the forced vibration was varied in the same frequency range as during the previous laser interferometer investigation. It has to be noted, that there was no possibility to measure the actual stroke of the actuator device during the turning operation but one can assume that the stroke was lower due to the present process forces.

In addition, three different inserts were used – Sandvik SNMG 12 04 08-QM, Sandvik SNMG 12 04 08-MM and Widia SNMG 120416 49. Both Sandvik inserts had a cutting edge radius of 0.8 mm whereas the Widia insert had a cutting edge radius of 1.6 mm. The expectation, that a bigger cutting edge radius will help improve the specimen surface quality, could not be found. In fact the Widia insert had the problem to run onto the existing machining grooves causing the tool to lift from the surface resulting in even worse surface quality. This effect is linked to the high variation of the present passive forces which deform the actuator system and its tool holder so it cannot be considered a general phenomenon.

After each turning operation three measurements were done to determine the average value of the material surface roughness.

6. RESULTS

The consideration of the vibration measured with the laser interferometer shows a significant dependency between the frequency of the tool post actuator system and the stroke value. As expected, the stroke magnitude decreases at higher frequencies. Furthermore, the amplitude of the stroke during the process was constant at lower frequencies but varied at higher frequencies. Hereby changing amplitude values occur at frequencies greater than 15 Hz (see Figure 6).

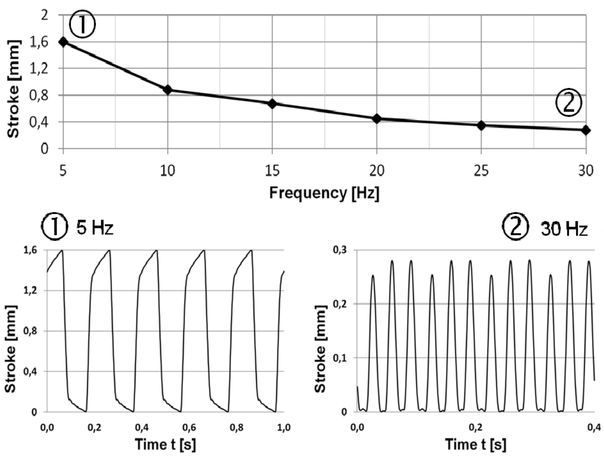

Figure 6. Dependency of stroke on frequency. Limitations of sine vibration.

Moreover, the vibration assisted processing showed high influence on the resulting chip form and chip length. The existence of vibration caused eye shaped chips with comparably shorter length. Thus, it could be shown that a distinct chip breaking was caused by the in feed direction forced vibration, which shows that the active influence on the chip cross section works properly. Compared to conventional longitudinal turning chip breaking was improved in all situations avoiding continuous chips completely. The theoretical chip length at a given workpiece diameter and constant revolutions per second was intermitted by the applied frequency of the cutting tool. Thus higher frequencies resulted in shorter chips (see Figure 7). It is apparent that there is no linear progression, most likely because the actuator device was not able to provide constant strokes at all frequencies.

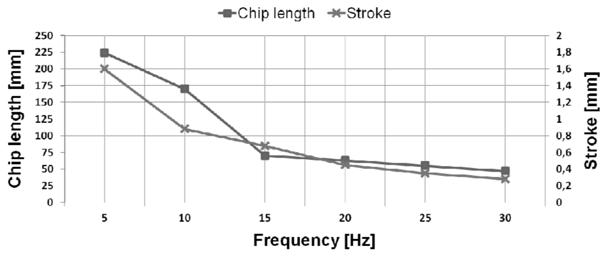

Figure7. Chip length in dependency on applied frequency and actuator stroke

The consideration of the resulting surface roughness further gives relevant information for the use of vibration assisted machining. Comparing the surface quality of conventional turned specimen and vibration assisted treated material it has to be noted, that the quality has been measurably and visibly worse. Thereby, a correlation between the surface roughness values and the used vibration frequency could be found. The higher the vibration frequency, the lower the surface roughness value was. Additionally varying the feed showed, that values of about f = 0.5 x S (stroke) resulted in comparably good surface qualities (see Figures 8 and 9).

By contrast using inserts with different cutting edge radii showed low divergent results in case of surface roughness and chip breaking behavior.

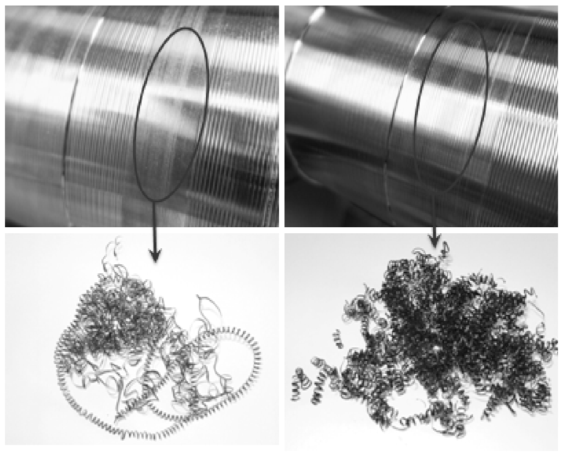

Figure 8. Surface and shape of C45E steel material chips: without (left) and with (right) vibration-assistance

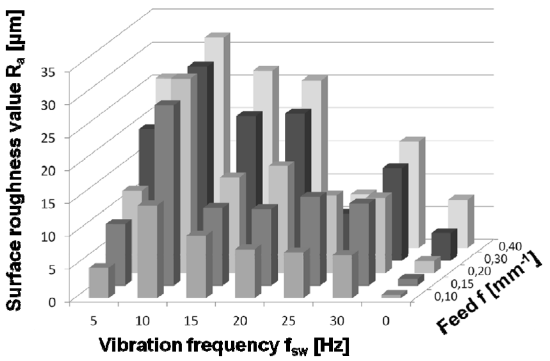

Figure 9. Surface roughness value R_a

7. CONCLUSION

As part of the present investigation the influence of vibration-assistance on turning operations could be shown. Using the developed actuator system the formation of continuous chips could be completely prevented for machining the steel material C45E (1.1191). Also a significant reduction of a continuous chip formation has been investigated in the case of the stainless steel X6CrNiMoTi17-12-2 (1.4571).

By performing metrological investigations the frequency influence on the actuator stroke as well as on the resulting surface topography could be shown. Analyzing the results it is apparent that the achieved stroke of the actuator system is highly dependent on the frequency. Furthermore the superimposed frequency influences the surface quality in such a matter that low frequencies lead to rough surfaces whereas high frequencies result in surface qualities comparable to conventional turning.

Therefore one can assume that applying frequencies above 30 Hz combined with actuator amplitudes in the order of the 2 x the feed will improve the surface quality and also provide sufficient active chip breaking.

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МЕТРОЛОШКО ИСПИТИВАЊЕ АКТУАТОРА КОД СТРУГАЊА УЗ ПОМОЋ ВИБРАЦИЈА

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Предности машинске обраде потпомогнуте вибрацијама су побољшана постојаност алата и ломљење струготине, као и побољшано испирање и уклањање струготине. Основни принцип машинске обраде уз помоћ вибрација јесте боља искоришћеност резног алата и обратка. Сходно томе, Институт за производно машинство и ласерску технологију је развио алат на бази хидраулике, тј. систем актуатора који се накнадно активира, што омогућава истраживање утицаја суперимпонираних фреквенција на површинске неравнине и ломљење струготине. При мерењу хода алата после примене ласерске интерферометрије коришћене су фреквенције од 0 до 30 Hz. Резултати показују да постоји значајна зависност између актуаторског система и вредности хода алата. Бољи квалитет завршне обраде при већим фреквеницјама и мањем ходу алата показала је обрада узорка уз помоћ вибрација. Осим тога, обрада потпомогнута вибрацијама имала је значајног утицаја на ломљење струготине, при чему је настајала струготина у облику ока, релативно мале дужине, што је у потпуности спречавало настајање струготине која се не ломи.