Detection of Cutting Forces in Micro Machining Operations

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Abstract
The measurement of cutting forces is however problematic during micro machining operations, because the today's cutting force measuring devices have too low natural frequencies and are not qualified consequently for that. Therefore new force measurement systems with higher natural frequencies must be developed and assayed for their suitability. A solution of a piezoelectric force measurement system for the micro machining operations like micro milling is detailed presented and examined here. Results of first experiments show that with this new system more accurate force measurements are possible.

Introduction
The cutting force is one of the most representative process variable which allows a judgement and explanation of basic phenomenons in machining processes. Examples are the wear behaviour, the calculation of the energy quotas in tool, chip and workpiece, the setting of optimized input variables or the predicting of the workpiece quality. Also for the design of machine tools the knowledge of static and dynamic cutting forces is of major importance.

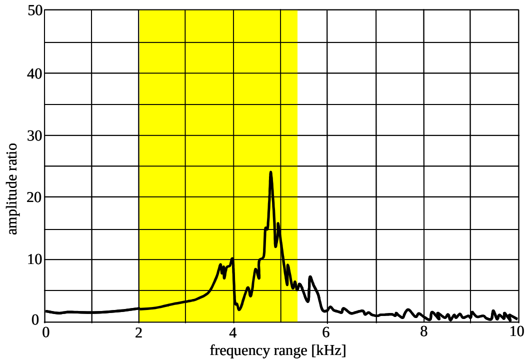

Fig. 1 Natural frequencies of the “MiniDyn Type 9256A2” in the x-axis [1] and excitation frequencies based on micro machining operations

However the accurate detection of the forces in micro machining processes is difficult today, because the exciting frequency caused by the single interactions between milling teeth and workpiece during machining is very close to the natural frequency of today's available cutting force measuring devices. This is the reason for a distortion of the force signal! So that it becomes clear figure 1 shows the natural frequencies of the conventional force dynamometer and the excitation frequencies (yellow range) based on micro machining operations (spindle speed up to 160.000 1/min). Consequently new sensors and force measurement systems have to be developed. The natural frequencies of these should lie clearly over the exciting frequencies, at least over 8kHz.

Experimental

At the Laboratory of Production Engineering of the Helmut-Schmidt-University (LaFT) prototypes of a new force measurement system for micro machining operations were developed. The present improved prototypes (Fig. 2) overcome the above mentioned disadvantages and enables an accurate detection of forces also under the high exciting frequencies which are typical for the cutting with a number of revolutions of the milling tool which can be up to 160.000 1/min. The new sensor is based on an axially working quartz sensor which is preloaded and which has a natural frequency of 27 kHz. The sensitivity of this sensor is -45pC/N. This is the reason for the capability of this sensor to measure especially the forces in micro machining operations, more precisely with very small cutting forces which are often less than 1N. The quartz force sensor was embedded horizontally (for measurements in x- and y-axis) and vertically (for measurement in z-axis) in a special jig. Radial causing forces are received through the membrane similar 0,1mm thin sheet steel. Thereby they take no influence on the axial forces. [2]

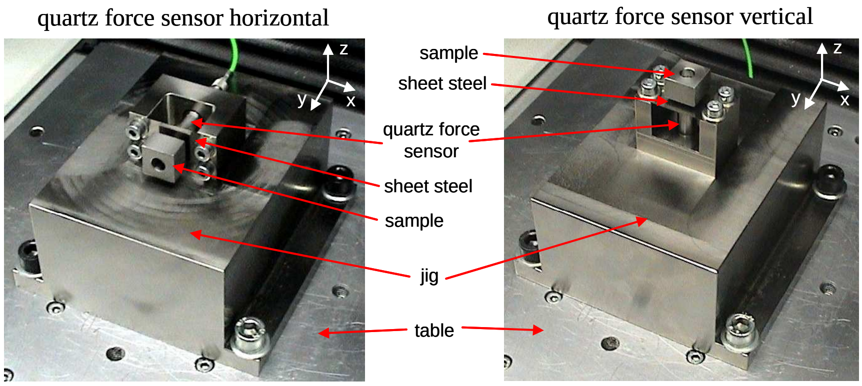

Fig. 2 Improved Prototypes of a force measurement system of the LaFT

The natural frequencies of this new force measurement system was detected by a modal analysis. First a transmission of force occurred by means of impulse hammer on the structure which has to be analysed. Whose effect is received by the piezoelectric accelerometer which is mounted at the structure. Both signals are boosted and fed to the FFT analyser. This calculates the transfer functions and indicates these graphically. The natural frequencies can be read off from the transfer functions. [3] [4] The available measuring instruments (impulse hammer, piezoelectric accelerometer, FFT analyser) permit an analysis in the frequency range to 8kHz. In order to avoid measuring errors the transmission of force occurred at the point of the actual excitation for example via a milling cutter and the piezoelectric accelerometer was mounted at 10 different places at the jig.

Further all attachment screws were tightened with a defined torque of 20Nm. The measurement was accomplished both for horizontally and vertically embedded quartz force sensor.

Results and Analysis

As a result it can be stated that the natural frequencies of the force measurement system with the horizontally embedded quartz force sensor are sufficiently far away from the exciting frequencies of the cutting process. No natural frequencies exist in frequency range up to 8kHz (left side in Fig. 3).

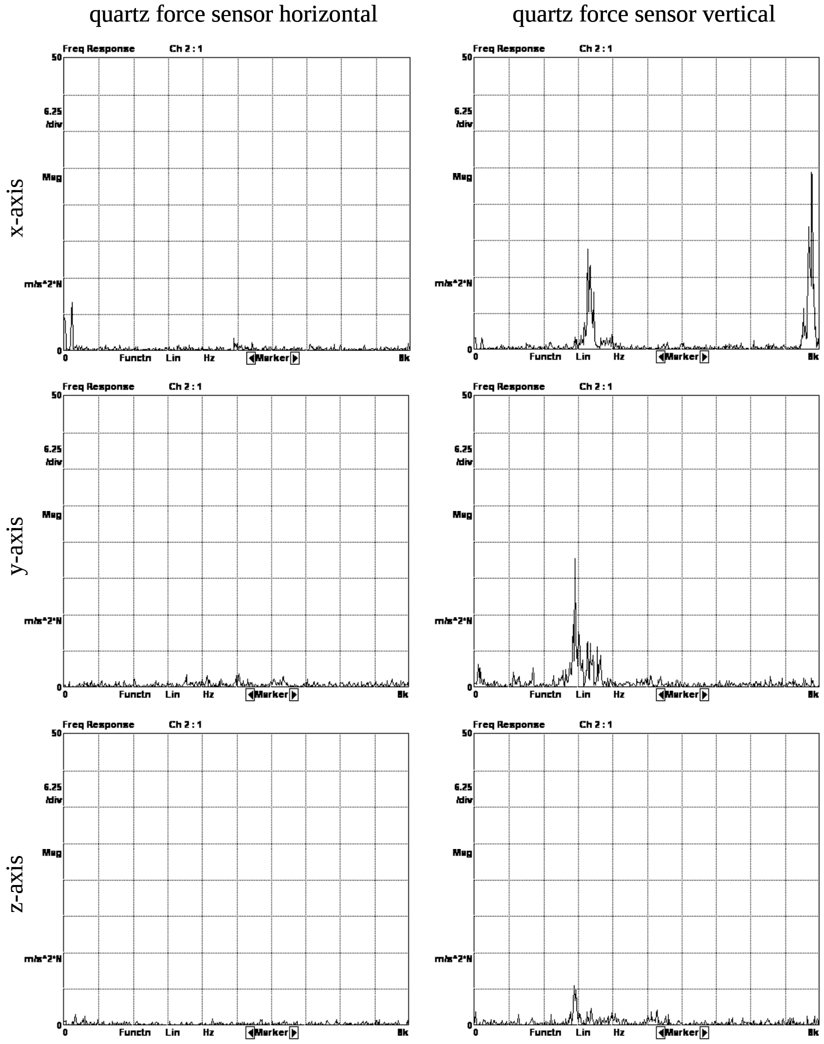

Fig. 3 Transfer functions in the x-, y- and z-axis

The natural frequencies of the new force measurement system with the vertically embedded quartz force sensor exist by 2,4kHz and 7,8kHz (right side in Fig. 3). The first natural frequency exist far below, the second natural frequency far above the exciting frequencies of the above described micro machining operations thus enough for precise measurements. The next version of the force measurement system with the vertically embedded quartz force sensor is developed, whose natural frequencies should lie also above 8kHz.
First experiments have shown that with this new force measurement system more accurate force measurements and subsequently more accurate calculations of power and energy which are describing the cutting process are possible. Figure 4 shows a force progression during milling (spindle speed n=110.000 min^{-1}; feed speed v_f=20mm/min; width of cut a_e=0,01mm; depth of cut a_p=0,3mm) which was measured and indicated with the new force measurement system.

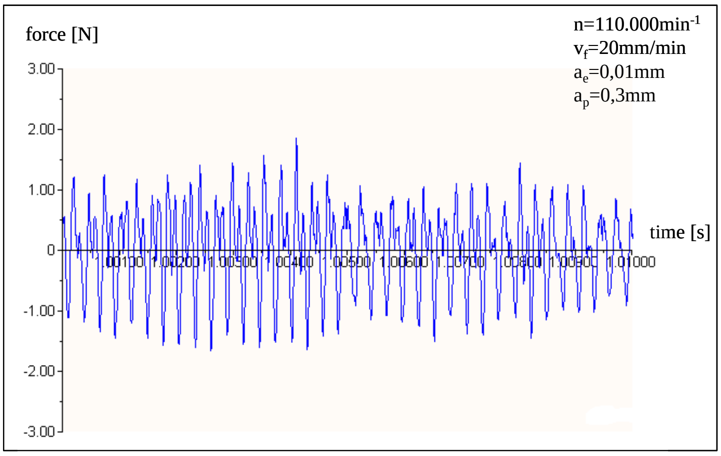

Fig. 4 Force progression in the y-axis for 10ms during milling

Conclusion

We presented a new piezoelectric force measurement system for micro machining operations. This was developed completely at the LaFT and assayed for their suitability. The natural frequencies of this new force measurement system are sufficiently far away from the exciting frequencies of the cutting process. First experiments have shown that most exact force measurements are possible. In next time the further development of this force measurement system will be pushed.

References

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(2) Kistler Instrumente AG Wintertur – data specifikation, quartz force sensor Type 9203
(3) D.J. Ewins, *Modal Testing – Theory and Practice* (1995)
(4) Zhi-Fang Fu, Jimin He, *Modal Analysis* (2001)