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EXPERIMENTAL SET-UP FOR STUDY OF CHIP FORMATION IN TURNING

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Abstract – This paper presents an experimental system for cutting research. System is based on high-speed laser light source, CCD camera and high-speed acquisition of acoustic emission (AE) signal. As a result, high-resolution images and AE signal are obtained simultaneously. This information can be used for cutting research and for research of AE sources.

Keywords: machining, acoustic emission, laser illumination.

1. INTRODUCTION

Cutting process and tool monitoring researches have traditionally been performed using on-line measurements of cutting forces, vibrations, temperature of cutting tool, and acoustic emission. Applicability of different type of inserts in cutting of steel alloys have been investigated by measuring the tool wear or the surface quality, which however is a slow and expensive way. On the other hand, the recent development of data processing has offered a good potentiality for effective data acquisition. High-speed data acquisition is becoming more important in tool monitoring and signal measurement in cutting research. [1,2,3,4]

How well-designed research system is, it is worthless if the measured signals can't be connected to their sources, the real mechanical phenomena. This paper presents an experimental system applied for cutting research. The system is based on high-speed diode laser light source (a stroboscope) and a CCD camera. They have been used to visualize chip formation in real cutting conditions when machining different steel alloys. A high-speed data acquisition of acoustic emission (AE) signals is simultaneously carried out along the visualization. As a result, high-resolution images of chip formation together with AE-signals are obtained. The main aim for the research is, to obtain new information about the sources of AE in turning process and to get images from chip formation. Synchronization of AE signal and high-resolution images will provide new fundamental information on cutting.

2. EXPERIMENTAL SET-UP ON A NC-LATHE

Tests were carried out with a nc-lathe (mfg. GF, max. spindle speed 4000 rpm, max. power 50 kW). Tool shank used was Sandvik PCLNL 2525 M16 and the insert used was Sandvik CNMG 160608 –PM 4035. The test parts were of machine steel S355J2C+C (Imatra 550 M or Imatra 550) and tempering steel 42CrMo4. The cutting speeds were 3,3…5,0 m/s, the cutting depths 2…3 mm and the feeds 0,15…0,50 mm/rev.

In the tests two sensors, one for acoustic emission and one for vibration detection, were attached on the tool holder. Both sensors were made by Kistler (8152B221 and 8141A121).

The data acquisition was organized through two cards. A High-speed card was used for acoustic emission. The sampling rate used was 20 million samples per second. This was fast enough for the frequency analysis of AE-signal. The other card sampled AE-RMS -signals and vibration signals at a lower frequency. The sampling rate was 38600 samples per second. A trigger signal was used for the synchronization of high-speed data acquisition and diode laser stroboscope.

Fig. 1 presents a schematic diagram of the experimental set-up.

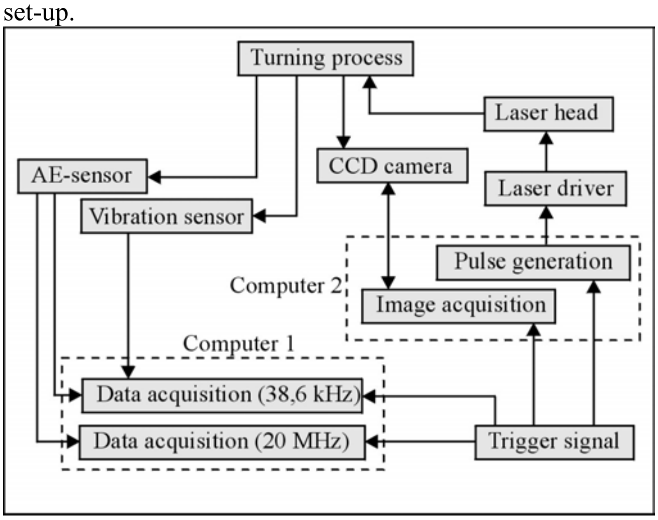


Fig. 1. Experimental set-up for diagnosis of the turning process. PC 1 was used for acquisition signals from AE and vibration sensors and PC 2 was operating the laser illumination unit and simultaneous image acquisition via CCD camera.

Turning process was visualised using a CCD camera and a laser light source (Fig. 2.). The camera lens and the illumination were focused to the tool edge. Both of the camera and the light source were mounted to the moving turret in order to maintain free optical contact to the target during whole processing periods. The visualisation system was computer controlled. Illumination and the image acquisition as well as the simultaneous AE and vibration signal acquisition were synchronized according to external trigger.

The scientific grade CCD camera (SensiCam) had dynamic range of 12-bit and image resolution of 1280 by 1024 pixels. Wide dynamic range is an important property in visualising machining process since metallic targets often exhibit high local intensity variations.

The CCD camera was equipped with a telecentric lens (Melles Griot 59LGN702), which produced images with field of view of about 4 x 3 mm. The lens gives resolving power of approximately 10 μm when a 2/3-inch CCD array with pixel size of 6,7 μm was placed into the image plane. The depth of sharp focus was roughly 1 mm. The camera was mounted on two-axis precision adjustment stage in order to facilitate the focusing of the lens, which had a fixed working distance. Sensitive surfaces in the measurement system were protected against hot chips escaping from the cutting process with an aluminium foil or a piece of transparent window plate.

The diode laser light source offered precise temporal control over the studied phenomena. The operation of the laser light source was pulsed by arbitrary signal generator card, which was placed in the computer 2 (Fig. 1). The signal generator card was controlled by LabView based interface. The interface operator could adjust the number of light pulses between 1…10, temporal duration of each pulse in the range of 30 ns…3 μs, and the duration of delays between light pulses from 10 ns to several seconds. The temporal precision of light pulse and delay duration as well as the jitter of laser pulses was about 10 ns. Produced single or multiple pulses were transmitted as TTL-level signal to the laser driver unit, which amplified the incoming TTL-signal to high-current signal. The signal generator card and the laser diode driver had two channels so that two laser heads could be operated simultaneously and independently.

In order to freeze the movement of a processing target to a distance corresponding to the resolution of the imaging system (10 μm), maximum pulse duration of 2 μs is required. Light pulses of 1 μs duration were used in the measurements. The maximum resolving power of the imaging system was limited by the lens.

The measurement system was equipped with two laser heads in order to provide distributed illumination. The other laser head consisted of 288 laser emitters, which emitted monochromatic light at 808 nm. The other head was mounted by 144 lasers, which emitted light at visible 670 nm wavelength. Light was guided to the target using optical fibres. The optical output power of the laser system was adjustable up to max 700 W. Some tens of percents of the power were lost in fibre coupling and light conduction.

The advantages of spatially and dynamically high-quality images and the high temporal precision of the illumination were combined in this study. Moving targets were illuminated by a single or multiple light pulses during a single image acquisition. By doing so, quantitative information of kHz-level phenomena could be captured into individual high-resolution images.

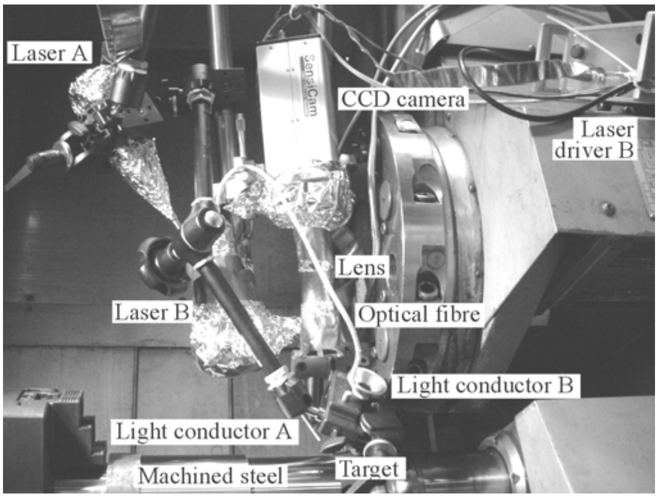


Fig. 2. Measurement system. Two laser heads and CCD camera were attached to the moving tool chunk.

3. RESULTS

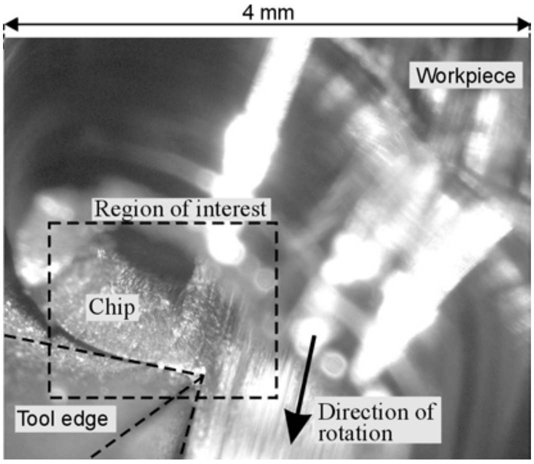
The tests were performed in three phases. First part included mainly the configuration of the experimental system. The main aim of the part was to get infallibility for primary tests. Test conditions were designed primarily for visualisation. This means that cutting parameters were lower than recommended and the insert was chosen with different grounds than in normal industrial production (direction of flying chips had to be strictly controlled).

The results of the second and the third part included high-resolution images and simultaneous AE signals of the cutting process. Examples of these results are shown in Fig. 3. and 4. The size of each image is about 4x3 mm. The moment of imaging (Fig. 4) is in the middle of AE-signal (below). The AE signal was printed in time domain (left) and in frequency domain (right). Whole frequency band was 50…1000 kHz, but in Fig. 4 band is 50…350 kHz. The reason for the narrow band was that a typical AE signal is in low frequency in cutting process. Images and simultaneous signals are used for studying signal sources and chip formation. Images are also serviceable material for teaching in and designing of tool monitoring systems.

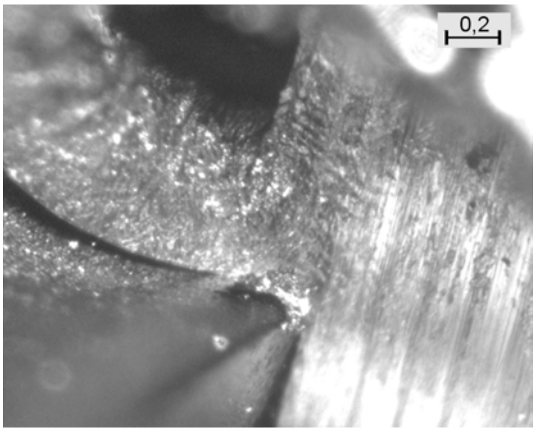
Further goal of the test program was to clear up phenomena in chip formation that explains the different characters in AE signal. The imaging equipment will be also used for study of hard turning.

3.1. Chip formation

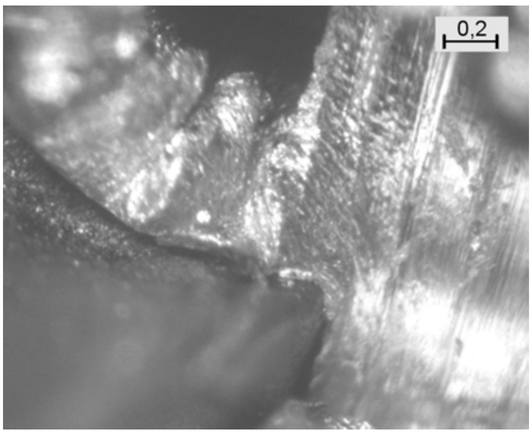
Images provide new information for the optimisation of cutting parameters, designing of chip breakers and research of machinability of steel alloys. Fig. 3 contains six example images of chip formation of three different steel alloys. Test parts in images a, b, c and d were of machine steel. M-steel is a steel alloy with calcium treatment, marked with M in fig. 3. Effect of the calcium treatment is distinct. The chip formation is sligtly smoother when cutting M-steel than with normal machine steel. Difference in chip formation between machine steel and tempering steel is also very clear. Chips of tempering steel are like saw teeth and bending of chip is much broader. Images in Fig. 3 are only examples. Total amount of analysed images was approximately 500. All tests were carried out with the same cutting parameters. Cutting speed was 4,17 m/s, depth of cut was 2 mm and feed 0,3 mm/rev. The insert was suitable for all material used.



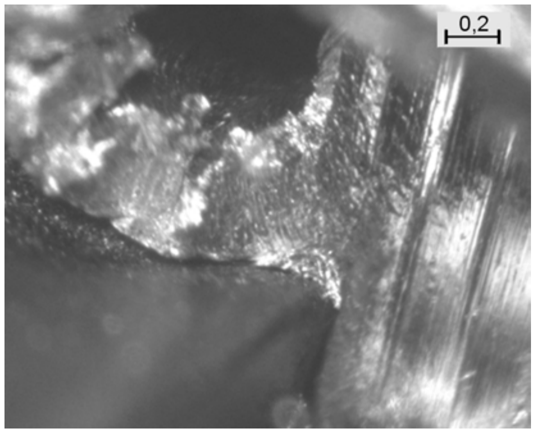
a) Imatra 550 M



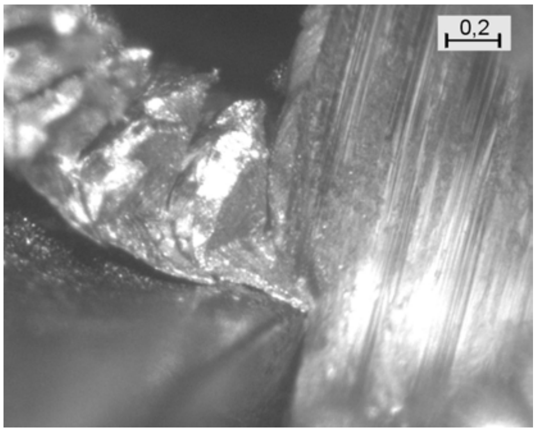
b) Imatra 550 M



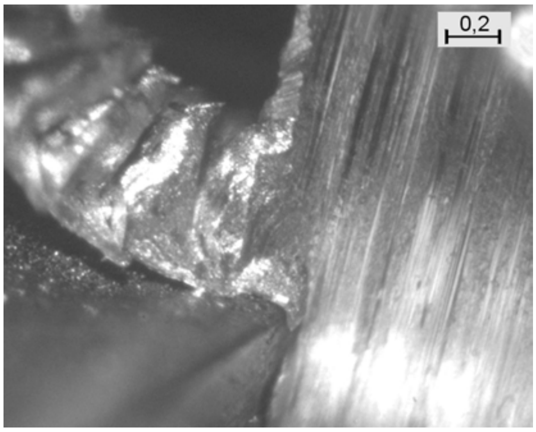
c) Imatra 550



d) Imatra 550



e) 42 CrMo 4

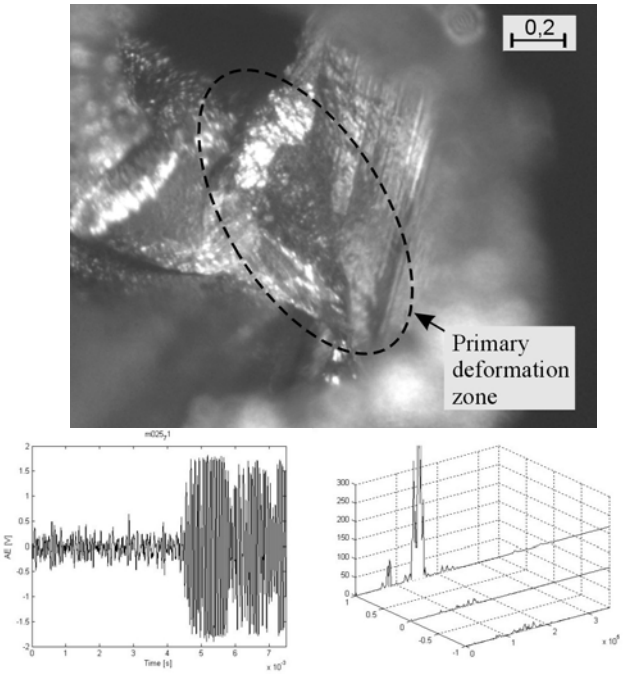


f) 42 CrMo 4

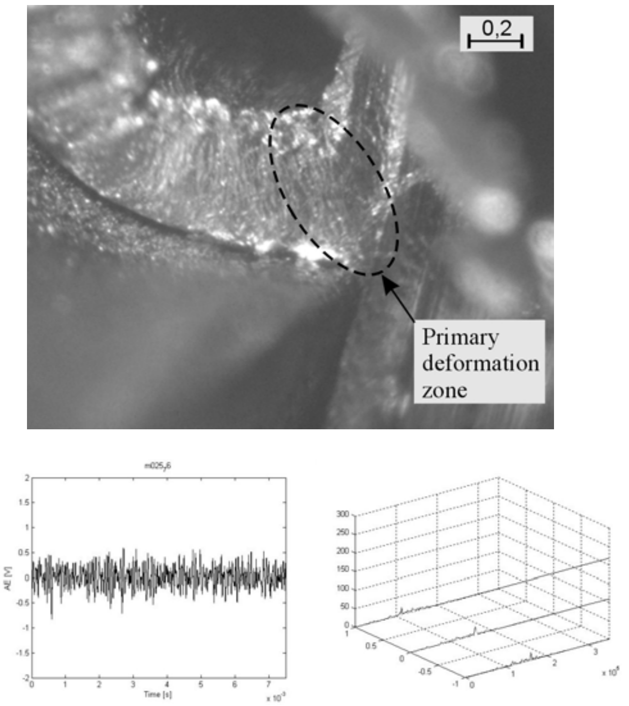
Fig 3. High-resolution images of chip formation. The field of view in the image a) is 4x3 mm and 2x1,6 mm in b)…f). Image a) shows an overall view to the chip formation. The detailed view of the images b)…f) is marked by quadrangle with dashed borders in the image a). Materials of test parts: Imatra 550 M (a, b), Imatra 550 (c, d) and 42CrMo4 (e, f).

3.2. Images and simultaneous AE signal

Main source of acoustic emission in turning is primary deformation zone [5, 6]. Effect of sudden increase of primary deformation zone can be noticed in Fig. 4. The zone has increased in image a). Below the image is a simultaneous AE signal, in time domain (left) and in frequency domain (right). The moment of imaging is at the middle of the curve (left). Image b) is reference for image a). A comparison of the images demonstrates that the size of the primary deformation zone has an obvious impact on the level of AE signal. Total number of analysed images and the corresponding signals was approximately 3500.



a) Large primary deformation zone



b) Normal size primary deformation zone

Fig. 4. Images of chip formation and the simultaneous AE signal.

4. CONCLUSIONS

The presented experiment set-up has shown to be a useful method for research the chip formation and AE sources. In future, the results will be used for comparing earlier studies [1,7] and latest information on cutting. The test system will also be used for study of hard turning.

REFERENCES

[1] T. Väisänen. Chip formation, modeling of cutting and formation of oxide layer in steel cutting. In Finnish. TKK Konepajatekniikan laboratorio. p 45. 2001.

[2] D.F. Micheletti, W. Koenig & H.R. Victor In Process Tool Wear Sensors for Cutting Operations. *Annals of CIRP*. Vol. 29. pp. 483…496. 1976 .

[3] I. Inasaki. & S. Yonetsu. In.Process Detection of Cutting Tool Damage by Acoustic emission Measurement. *Proceeding of the 22nd International Machine Tool Design and Research Conference*. Pp 261…268. 1981.

[4] I. Inasaki, S. Aida & S. Fukuoka. Monitoring System for Cutting Tool Failure Using an Acoustic Emission sensor. *JSME, International Journal. No. 261. vol 30*. pp 523…528. 1987.

[5] I. Inasaki, S. Yonetsu. In-Process Detection of Cutting Tool Damage by Acoustic Emission measurement. *Proceedings of the 22nd International Machine Tool Design and Research Conference*. pp. 261…268. 1981

[6] E.Kannatey-Asibu, D.A. Dornfeld. Quantitative Relationship for Acoustic Emission from Orthogonal Metal Cutting. *ASME, Journal of Engineering for Industry*. pp. 330…340. 1981.

[7] G.T. Smith. Advanced-Machining-The handbook of cutting technology. Bedford. 1989

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