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Cerce, L., Pusavec, F., Kopac, J.

SPATIAL CUTTING TOOL WEAR EVALUATION

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Abstract: *The tool wear evaluation has a very strong impact on the product quality as well as efficiency of the manufacturing process. This paper presents an innovative and reliable direct measuring procedure for measuring spatial cutting tool wear. The technique is specially characterized by its determination of profile deepness, so it has advantage comparing with currently used techniques.*

Key words: *Spatial cutting tool wear, Wear diagnostic, Optical triangulation*

Evaluacija volumskog habanja alata. *Evaluacija habanja alata ima veoma jak uticaj na kvalitet proizvoda, kao i na efikasnost proizvodnog procesa. Ovaj rad predstavlja inovativan i pouzdan direktan merni postupak za merenje volumskog habanja alata. Tehnika se posebno odlikuje po određivanju dubine profila, tako da ima prednost u odnosu na trenutno korištene tehnike.*

Ključne reči: *Volumsko habanje alata, Dijagnosticiranje habanja, Optička triangulacija*

1. INTRODUCTION

Machining performance of material is very important in terms of material processing and quality of final product. Based on the machining performance optimal machining parameters are determinate. The term machining performance refers to the ease with which a metal can be machined to an acceptable surface finish, and is hardly measured/evaluated. It is defined by the following criteria: cutting tool wear, cutting tool life, cutting forces, power consumption, chip formation, machined surface integrity and geometrical accuracy of the machined surface.

Criteria, such as cutting force, roughness, energy consumption, integrity and geometrical accuracy of the machined surface can be objectively determined by exact measurements, while cutting tool wear is in practice measured manually and on a subjective level. Most frequently, cutting tool wear is measured with the use of toolmakers microscopes to help determine the range of wear (flank face).

In addition to poor precision of this method, the problem is in three-dimensional nature of wear, which cannot be fully analyzed with 2D based measurements/measurement principles. It can be concluded that research on defining and analyzing tool wear in three dimensions is still of great significance.

Therefore, the developing of new wear evaluation methods on the field of computer vision and laser systems, are under the scope. More in detail the spatial tool wear measurement system is presented and upgraded with the case study experiments and result analyzes.

2. TOOL WEAR

The damages of a cutting tool are influenced by the stress state and thermal load on the tool surfaces, which in turn depend on the cutting mode, i.e. turning, milling or drilling, cutting parameters and the cooling/lubrication conditions.

In machining, the cutting tool wear mechanisms and the rate of it are very sensitive to changes in the cutting operation and the cutting conditions. To minimize machining cost, it is not necessary only to find the most suitable cutting tool and work material combination, for a given machining operation, but also to reliably predict the tool life.

Tool wear mainly occurs at rake and flank face. Flank wear is caused by friction between the flank face of the cutting tool and the machined workpiece surface and leads to loss of the cutting edge. Therefore, flank wear affects the dimensional accuracy and surface finish quality of the product.

In practice, flank wear is generally used as the cutting tool wear criterion. When critical value of tool wear criterion has been reached, cutting tool fails due to excessive stresses and thermal alterations. To avoid this, the cutting tool must be replaced before reaching its critical limit.

The preferred cutting tool life criteria is the tool flank wear upper limit, because the wear progresses gradually and can be easily monitored for tool-changing protocol in NC (numeric control) programs [1].

In practice, some directly measured dimensional characteristics and criteria of typical wear patterns, i.e. crater, flank wear, and depth-of-cut notch wear at the extremities, for HSS (high speed steels), carbide and ceramics tools, are standardized in ISO 3685, as shown in figure 1.

The process of cutting tool wear consists of three characteristic parts: the initial (running-in) period (I), the longest uniform (progressive) wear period (II) and accelerated wear period (III) leading often to catastrophic failure (figure 2).

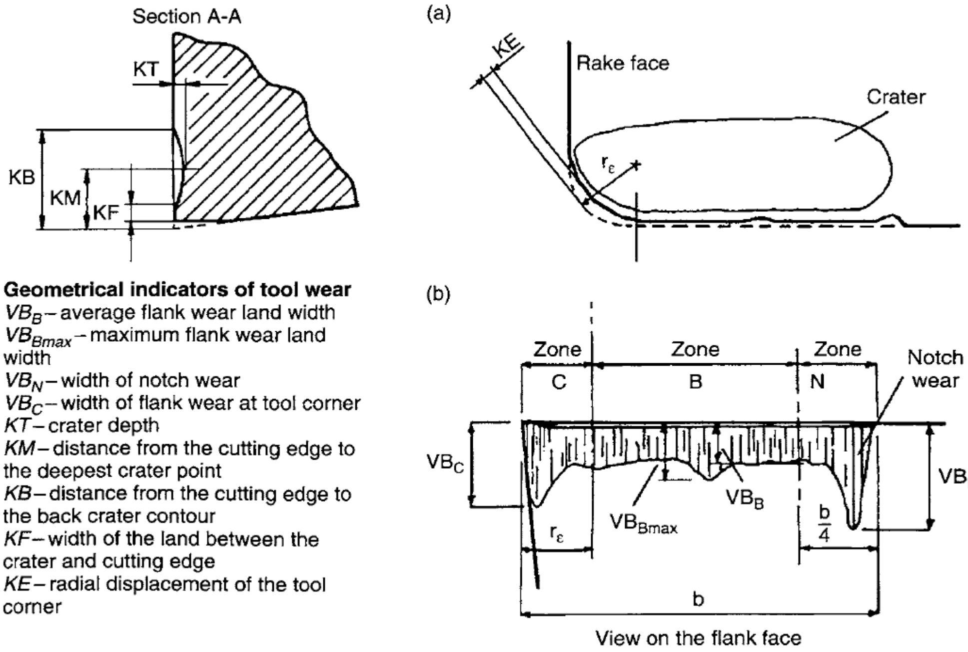


Fig.1. Typical wear pattern according to ISO 3685 [1].

The machining process needs to be stopped at the right time to prevent undesired consequences of the tool wear such as: increase of cutting forces, vibrations, noise, temperature in the cutting zone and deviation of part dimensions and surface quality from the view of respective tolerance values.

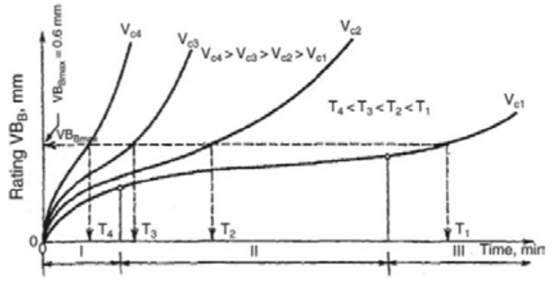


Fig. 2. Typical tool wear curve [1].

In reality several wear mechanisms occur simultaneously, whereby one of them may dominate the process. They can be qualitatively identified as mechanical, thermal and adhesive. Mechanical types of wear, which include abrasion, chipping, early gross fracture and mechanical fatigue, are basically independent of temperature. Thermal loads appear with plastic deformation, thermal diffusion and oxygen corrosion as their typical forms, increase drastically at high temperatures and can accelerate the tool failure by easier tool material removal (by abrasion or attrition) [1].

Figure 3 presents the dependence of the individual wear mechanisms and relative amounts of wear on the cutting temperature.

Adhesive and abrasive wear are the most significant types of wear at lower cutting speeds. At high cutting speed, temperature-activated wear mechanisms including diffusion (solution wear), chemical wear (oxidation and corrosion wear), and thermal wear (superficial plastic deformation due to thermal softening effect) occur.

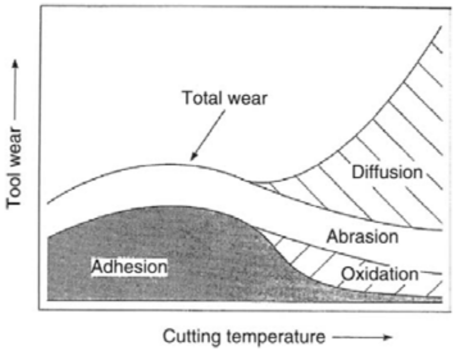


Fig. 3. Wear mechanism as a function of temperature in the cutting zone [1].

Tool wear can be measured using direct measuring techniques or estimated by indirect measuring techniques. In indirect measuring techniques, tool wear is estimated using other easily measurable cutting process variables such as cutting force, acoustic emission, accelerations, energy consumption, etc. A survey of the literature indicates that many different approaches have been applied for tool wear prediction [2-6], countrary direct measuring techniques make an assesment of tool wear by either evaluating the worn surface by optical methods (microscop), or measuring the tool material loss by radiometric techniques. Direct methods require to periodically interrupted the cutting process. Optical methods use optical equipment like the toolmaker's microscope, optical miscroscope, scanning electrical microscope, charged coupled devices (CCD cameras), white light interferometry etc [7-11]. Kurada et al. [7] have designed a system consisting of a fiber-optic light source to illuminate the tool and a CCD camera, which is used in combination with a high resolution of video zoom microscope. Identification of the tool wear area is based on the reflection from the

wear area of the light introduced via fiber optics, whereas the measuments are derived from this area.
The main disadvantages of mentioned methods are the inability of measuring crater depth KT (spatia geometry) and needs to preform them off line of the machining process. To perform the measurement with this methods the cutting insert should be removed from the machine tool. This cause time-loss and possible problems with the accuracy of subsequent processing.
The proposed novel method, which is described hereafter, belongs to direct methods of cutting tool wear measurements. The added value and advantage of this method is the measurement of spatial tool wear directly on the machine tool.

3. MEASURING SYSTEM

The measuring system consists of a high-accuracy 2D profile laser displacement sensor Keyence LJ-G015, controller Keyence LJ-G5001 and clamping device, as is seen on figure 4.

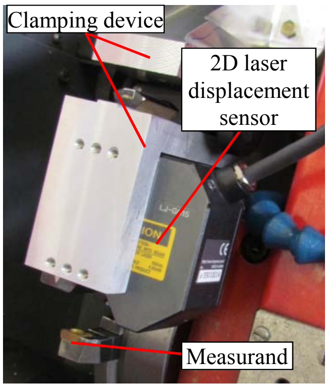


Fig. 4. Measuring system

With movement of profile sensor across the cutting tool and the support of developed software (Labview application), the data are grabbed and prepared in a matrix form for further evaluation/analyzes.

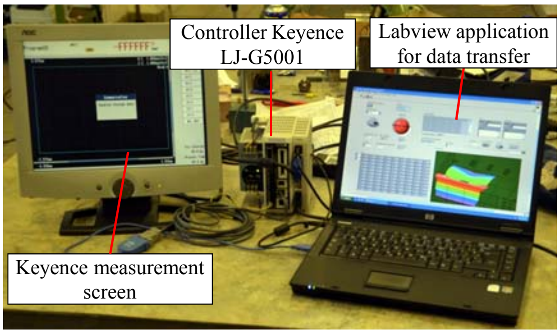


Fig. 5. Measuring interface and controller

Laser displacement sensor measure the distance to the points projected on the measured object (figure 6). In this way we measure Z-coordinate of point cloud. X-coordinate is defined by the specification of the laser displacement sensor [12], while Y-coordinate represents machine tool feed direction.

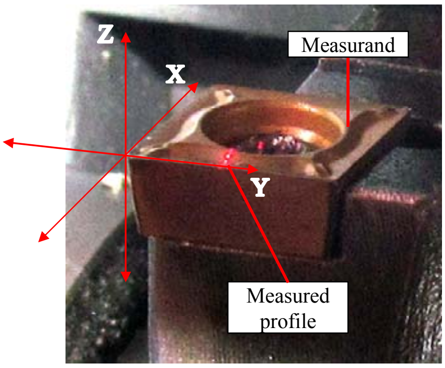


Fig. 6. Axis orientation and measured process

The measurement procedure is carried out in the following order:

1. Machine tool moves the cutting insert to the measuring area.
2. Laser displacement sensor captures the first profile.
3. The machine tool moves the cutting insert for predefined ΔY.
4. By repeating steps 2 and 3 gradually the system captured a large number of 2D profiles and stores it in internal memory of Keyence LJ-G5001 controller.
5. The system transfer data from the Keyence LJ-G5001 controller to PC.

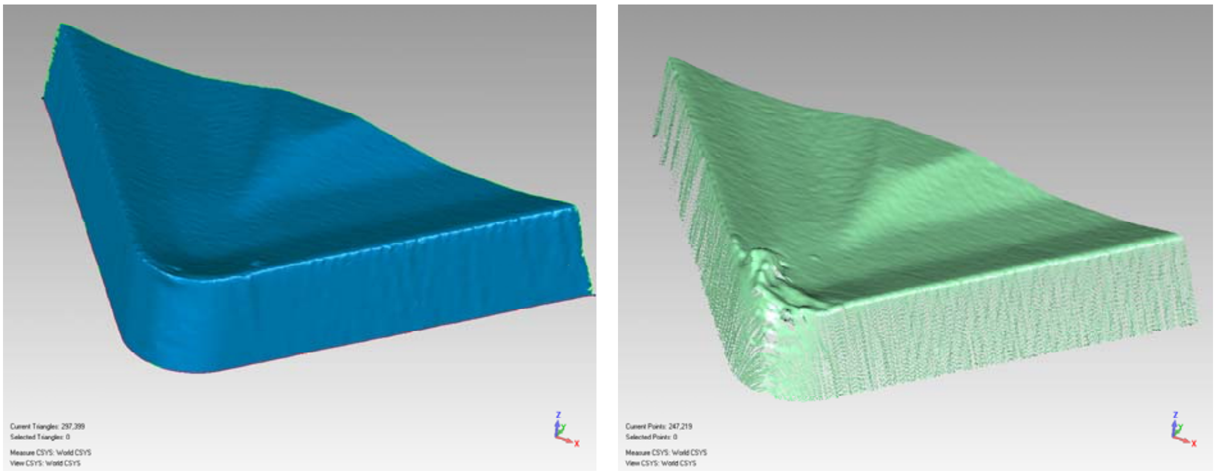
The measurements on case study are presented and analyzed in next chapter.

4. EXPERIMENTAL PROCEDURE

The presented measurement system was tested on longitudinal turning of Inconel 718. The initial workpiece diameter was 76 mm and length 237 mm. Experiment was performed on CNC lathe Mori Seiki SL-153 with the use of Sandvik CNMG 120408 SRM-1115 cutting insert. The experiment was performed with the use of flood cooling/lubrication fluids.
The cutting parameters have been defined according to the producer recommendations and were ap = 1 mm, vc = 70 m/min and f = 0.15 mm/rev. These parameters were defined based on maximizing the material removal rate with an industry acceptable tool life of 10-15 min.

(a) (b)

Fig. 7. Experimental measurement of tool wear (a-conventional, b-new)



(a) (b)

Fig. 8. Spatial measurements of new (a) and worn (b) cutting inserts

We machined the workpiece longitudinally at intervals over a length of 50 mm. After each operation, we measured the cutting insert wear in the following way (figure 7):

a) Conventional measurement of flank wear using toolmakers microscope.
b) New measurement of spatial wear with previously presented measurement system.

5. RESULTS AND DISCUSSION

Measurements of tool wear were performed with toolmakers microscope. The results are presented on figure 9. On the ordinate axis is flank wear VB while on abscise axis is cutting length. Cutting length is defined as spiral length that was made with cutting edge. In the picture is represented the state of cutting inserts after each experiment.

After 5th experiment (cutting length was 250 mm) flank wear VB was 0.43 mm which is the criterion to replace the cutting insert.

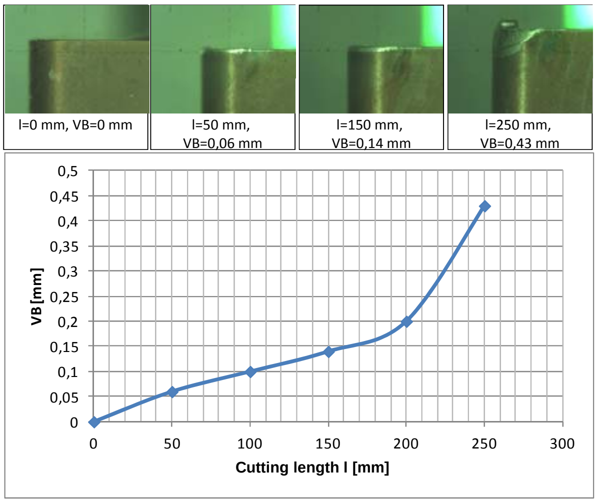


Fig. 9. Tool wear curve

In parallel, measurements of spatial wear were carried out with the use of developed measurement system. The measured values on a cutting length of 250 mm were compared and are showed in figure 8.

Spatial measurement of the worn cutting insert (figure 8b) was compared by measuring the new cutting inserts (figure 8a), which served as a reference.

On the measurement of worn cutting inserts (figure 8b), it is clearly visible signs of wear on flank and rake face. BUE (build up edge) is also evident on rake face.

Based on spatial measurements of new and worn cutting inserts spatial wear was calculated (figure 10). The deviations of measured points were calculated perpendicular to the surface of the reference model.

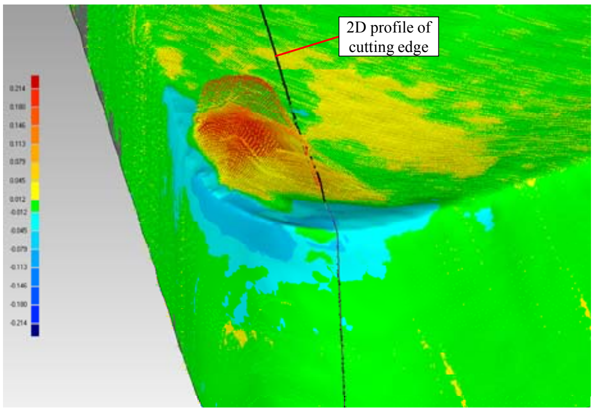
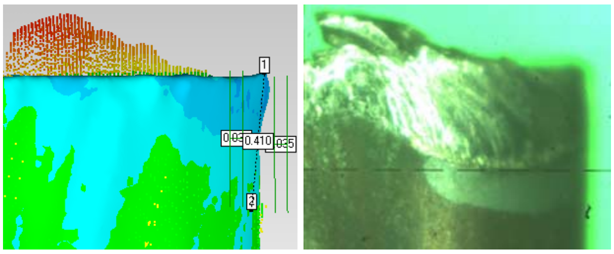


Fig. 10. Spatial wear of cutting insert (rake face with crater ware and BUE)

The picture (figure 10) is showing the wear on flank and rake face, BUE and chipping of cutting edge. Crater wear depth KT is evident and is in a range between 0.041 mm and 0.136 mm. Maximum height of BUE on rake face is 0.199 mm.

Additionally figure 11a represent measurement of flank wear with spatial measurement system. From these measurements it is evident that after 250 mm length of cut VB is 0.410 mm. With the use of toolmakers microscope (figure 11b) VB was 0.43 mm.

Variations in measurements may be attributed to the subjective nature of measuring with toolmakers microscope. This error may also occur due to the precision of determining the lower limit of the wear formation, since the microscope image does not reveal the depth of flank wear.



a b

Fig.11.Comparison of flank wear measured with spatial measurement system (a) and the toolmakers microscope (b)

Whit the use of spatial measurement system, the limit of the wear formation can be accurately determined. Depth of flank wear can be seen from the comparison of cutting inserts cross-sections, 0.5 mm from the secondary cutting edge (figure 12). This represents half of the cutting depth, where the cutting edge is in contact. From the figure becomes clear that the depth of flank wear is in the area from 0 to 0.1 mm. This means that the work pieces produced with such cutting tool would have 0.2 mm bigger diameters.

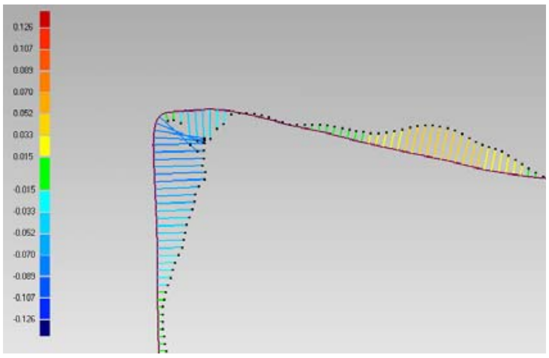


Fig. 12. 2D comparison of cutting edges cross section.

6. CONCLUSIONS

In this work newly developed spatial tool wear evalvation is presented. The proposed spatial tool wear measurement system offers high resolution and accuracy 3D dimensional deviation measurement. It outperforms traditional 1D deviation methods both in accuracy, efficiency and reliability. Another huge benefit of the developed method is the fact that the measurement can be performed very qickly, without removing the cutting tool from the machine tool.

Future work will be focused on developing computational procedures for the analysis of 3D deviation data provided. The objective is automatic diagnostics and early alert pointing to possible tool damage, excessive local tool wear, tool misalignment and other possible causes for tool breakage and stop of the process.

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Authors: **MS.c Luka Cerce, Assist. Prof. Dr. Franci Pusavec, Prof. Dr. Janez Kopac**, University of Ljubljana, Faculty of Mechanical Engineering, Laboratory for Machining, Askerceva 6, 1000 Ljubljana, Slovenia, Phone.: +386 1 4771-712, Fax: +386 1 4771-768.

E-mail: luka.cerce@fs.uni-lj.si
franci.pusavec@fs.uni-lj.si
janez.kopac@fs.uni-lj.si