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Novel spatial cutting tool-wear measurement system development and its evaluation

Luka Cerce*, Franci Pusavec, Janez Kopac

Faculty of Mechanical Engineering, University of Ljubljana, Ljubljana, Slovenia

* Corresponding author. Tel.: +386 1 4771 712; fax: +386 1 4771 768. *E-mail address:* luka.cerce@fs.uni-lj.si

Abstract

The tool-wear of cutting tools has a very strong impact on the product quality as well as efficiency of the machining processes. Despite the nowadays high automation level in machining industry, tool-wear diagnostic that is measured of the machine tool, still prevent complete automation of the entire machining process. Therefore, its in-line characterization is crucial. Thus, the paper presents developed innovative, robust and reliable direct measuring procedure for measuring spatial cutting tool-wear in-line, with the usage of laser profile sensor. The technique provides possibility for determination of 3D wear profiles, as advantage to currently used 2D subjective techniques (microscopes, etc.). The use of proposed measurement system removes the subjective manual inspection and minimizes the time used for wear measurement. In the manuscript the system is experimentally tested on a case study, with further in-depth performed analyses of spatial cutting tool-wear.

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1. Introduction

Tool-wear and tool failure are critical problems in machining that not only raise the production cost but also degrade the product quality. Tool failure interrupts the machining process intermittently and substantially increases the preparation and cycle time. Tool-wear/failure can be directly indicated by two facts: one is that the work surface finish is inadequate, and the other is that the work dimension becomes outside tolerance [1]. However, this can be diagnosed when the failure has already appeared. Tool-wear can also be indirectly correlated with the analysis of machining dynamics, i.e. monitoring of cutting forces, energy power, torque, acceleration, etc. However, there is no robust, impartial and direct in-line measurement technique used in the industrial environment. Additionally, tool-wear/failure is a complicated issue, which has not been well clarified. Generally, tool-wear/failure depends not just on the workpiece material but also on tool material, its geometry, cutting parameters (cutting velocity, feed rate and depth of cut), cooling/lubrication condition, machine tool characteristics, etc. [2].

Criteria, such as cutting force, roughness, energy consumption, integrity and geometrical accuracy of the machined surface can be impartially determined by exact measurements, while cutting tool-wear is in practice measured manually, out of the machine tool and on a subjective level. Most frequently, cutting tool-wear is measured with the use of toolmakers microscopes, with the determination of the wear range/area (flank face or rake 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. Further, robust and automated tool-wear monitoring, on the machine tool itself and in-line, is sought by the industry.

Based on this state-of-the-art, the development of new cutting tool-wear evaluation methods, on the field of computer vision and laser systems, are under the scope of this research. More in detail, the spatial tool-wear measurement system is developed, analyzed and presented. For the proof of the concept, the case study experiments are performed and analyzed, and a new tool-life estimator is defined.

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Nomenclature

VB	flank wear land width
KT	crater wear depth
CNC	Computer Numerical Control
a_p	depth of cut
v_c	cutting speed
f	feed per rev
BUE	build up edge
V_{cut}	machined volume
A_{wear}	total tool-wear area
$V_{wear,t}$	total tool-wear volume
MRR	metal removal rate

2. Cutting tool-wear

Tool failure/wear can be typically grouped into two categories: premature tool failure and progressive tool-wear [1]. Premature tool failure takes place on various occasions and mostly occurs as sudden and unpredictable breakage of the cutting edge. The reason for edge breakage includes the rapid growth of the crater wear, preexisting potential cracks in the tool, inclusions in the workpiece material, or any other disturbances during in the machining process. Tool edge breakage leads to in-crease of cutting forces and further to complete tool failure, what usually results in damaged workpiece.

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

The useful life time of a cutting tool can be defined in terms of the progressive wear. Progressive tool-wear mainly includes the wear on the tool rake face (crater wear) and that on the flank face (flank wear), as shown on Fig. 1. Of these two, maximum flank wear is often used as criteria to define the end of effective tool-life. As the flank wear land width (VB) grows to a certain thresh-old level, it influences the dimensional accuracy and surface finish of the machined part/workpiece, as well as the stability of the machining process. The tool failure due to flank wear can be estimated by the maximum value of VB_B (VB_{Bmax}) and predicted by a function of time. Flank wear is also commonly used for cutting tool condition monitoring [2, 3].

In machining, the cutting tool-wear mechanisms and their rate 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 workpiece material combination, for a given machining operation, but also to reliably predict the tool-life.

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 Fig. 1.

These types of tool-wear are difficult to be determined in machining with grooved tools. Jawahir et. al. [3] found that the tool-wear pattern on a worn grooved tool insert is influenced by the three-dimensional chip-flow and by the complex chip-groove configurations. They also found that quite often some grooved tools fail long be-fore the major flank wear (VB_B) reaches its failure criterion. It is also shown, that grooved tools demonstrate tool-failure as a result from concurrent multiple tool-wear parameters. This confirms that the tool-wear/tool-life is significantly affected by the combined effects of cutting conditions and the chip-groove configuration. For this purpose several new measurable parameters have been proposed for tool-wear in machining with grooved tools [3].

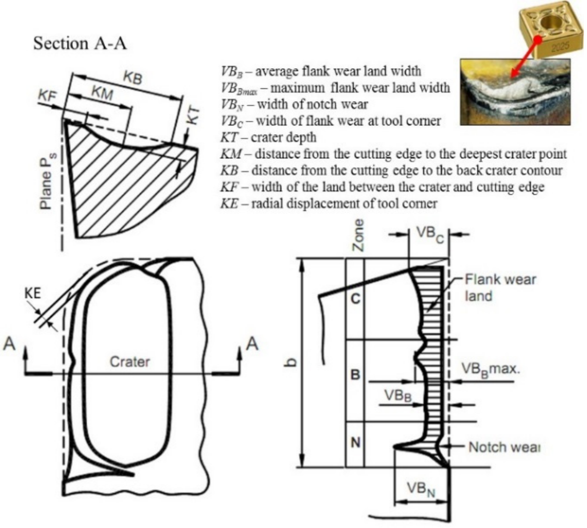

Fig. 1: Typical wear patterns according to ISO 3685 [2].

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 more measurable machining pro-cess variables such as cutting force, acoustic emission, acceleration, energy consumption, etc. A survey of the literature indicates that many different approaches have been applied for tool-wear prediction [4-6]. Contrary, direct measuring techniques offer assessment of tool-wear by either evaluating the worn surface by optical methods (microscope). Direct methods require periodical machining process interruption, when the worn tool is replaced by new one. Optical methods present optical equipment like the toolmaker's microscope, optical microscope, scanning electrical microscope (SEM), charged coupled devices (CCD cameras), white light interferometry, phase shifting method, etc... [7-15]. The main disadvantages of mentioned methods are the inability of measuring wear profiles in depth (spatial geometry of crater wear – KT, etc.) and that they are preformed off line of the machining process. This cause time loss and possible problems with the accuracy of subsequent processing.

The advantage of proposed novel method, which is described hereafter, is the possibility of spatial tool-wear measurement directly on the machine tool, without the need of removing cutting tools from the tool holder.

3. New developed measurement system

The new developed measuring system (Fig. 2) consists of a high-accuracy 2D laser displacement sensor Keyence LJ-G015 with a proper controller Keyence LJ-G5001, motorized linear translation stage Standa 8MT173-DCE2 and of developed LabVIEW application for process controlling.

The measurement range of 2D laser displacement sensor Keyence LJ-G015 is in Z-axis (height) ±2.6 mm and 7.0 mm in X-axis at the reference distance (15 mm). The repeatability in Z-axis is 0.2 µm and 2.5 µm in X-axis [16]. For linear positioning of the measurement head motorized linear