

## 679. Cutting tool vibration in the metal cutting process

V. Gutakovskis<sup>1</sup>, G. Bunga<sup>2</sup>, G. Pikurs<sup>3</sup>

<sup>1,2,3</sup> Riga Technical University, Riga, Latvia

E-mail: <sup>1</sup>[Vgutakovskis@gmail.com](mailto:Vgutakovskis@gmail.com), <sup>2</sup>[Guntis.Bunga@rtu.lv](mailto:Guntis.Bunga@rtu.lv), <sup>3</sup>[Guntis.Pikurs@rtu.lv](mailto:Guntis.Pikurs@rtu.lv)

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**Abstract.** Research of machining dynamics have long history in manufacturing processes with consideration of cutting interruption, intermittency and coupled interaction between the tool and workpiece. It gives better understanding of the underlying physics of material removal. The complex motions in cutting dynamics are mainly caused by discontinuities, including chip and tool-workpiece seizure as well as complex stick–slip motion. Through the application of discontinuous system theory, a comprehensive understanding of the grazing phenomena is induced by the boundary of frictional-velocity and the loss of contact between the tool and workpiece are discussed. Significant insights are to control machine-tool vibration and to develop tool wear free machine-tool concept. The experiment on the stainless steel machining is presented in the paper and generation of machine tool vibrations and the associated cutting dynamics is considered.

**Keywords:** metal cutting, vibrations, cutting tool.

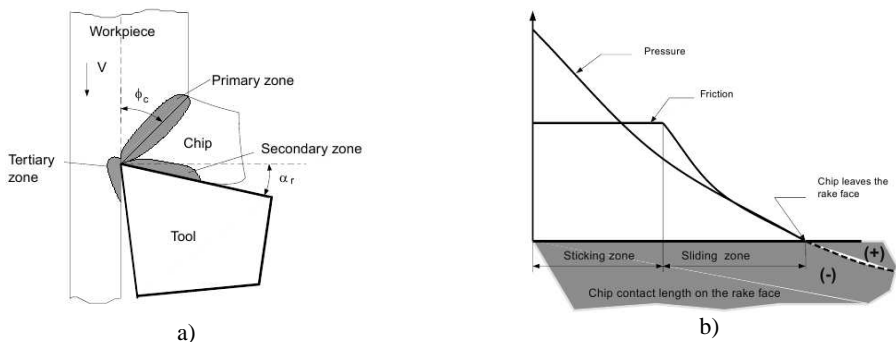
### Introduction

The final shapes of most mechanical parts are obtained by machining operations. Deformation processes such as forging and rolling are mostly followed by metal removing operations in order to achieve parts with desired shapes, dimensions and surface finish quality. The machining operations can be classified into cutting and grinding processes. The cutting operations are used to remove material from the blank. The subsequent grinding operations provide a good surface finish and precise part dimensions. The most common cutting operations are turning, milling, and drilling followed by special operations such as boring, broaching, honing and shaping. However, all cutting operations share the same principles of mechanics, but their geometry and kinematics may be different. The mechanics of cutting and the specific analysis for a variety of machining operations and tool geometries are not widely covered in this text [1].

### Mechanics of orthogonal cutting and vibrations in metal cutting

Although the most common cutting operations are three dimensional and geometrically complex, the simple case of two-dimensional orthogonal cutting is used to explain the general mechanics of metal removal. In orthogonal cutting, the material is removed by a cutting edge which is perpendicular to the direction of relative tool–workpiece motion. The mechanics of more complex three-dimensional oblique cutting operations are usually evaluated by geometrical and kinematic transformation models and applied to the orthogonal cutting process. The orthogonal cutting resembles a shaping process with a straight tool, whose cutting edge is perpendicular to the cutting velocity ( $V$ ). A metal chip with a width of cut ( $b$ ) and depth of cut ( $h$ ) is sheared away from the workpiece. In orthogonal cutting, the cutting is assumed to be uniform along the cutting edge; therefore it is a two-dimensional plane strain deformation process without side spreading of the material. Hence, the cutting forces are exerted only in the directions of velocity and uncut chip thickness, which are called tangential ( $F_t$ ) and feed forces ( $F_f$ ). However, in oblique cutting, the cutting edge is oriented with an inclination angle ( $i$ ) and the additional third force acts in the radial direction ( $F_r$ ). There are three deformation zones in

the cutting process as shown in the cross-sectional view of the orthogonal cutting (see Fig. 1. a). As the edge of the tool penetrates into the workpiece, the material ahead of the tool is sheared over the primary shear zone to form a chip. The sheared material, the chip, partially deforms and moves along the rake face of the tool, which is called the secondary deformation zone. The friction area (Fig. 1. b), where the flank of the tool rubs the newly machined surface, is called the tertiary zone. The chip initially sticks to the rake face of the tool, which is called the sticking region. The friction stress is approximately equal to the yield shear stress of the material at the sticking zone where the chip moves over a material stuck on the rake face of the tool. The chip stops sticking and starts sliding over the rake face with a constant sliding friction coefficient. The chip leaves the tool, losing contact with the rake face of the tool. The length of the contact zone depends on the cutting speed, tool geometry, and material properties. There are basically two types of assumptions in the analysis of the primary shear zone [2, 3].



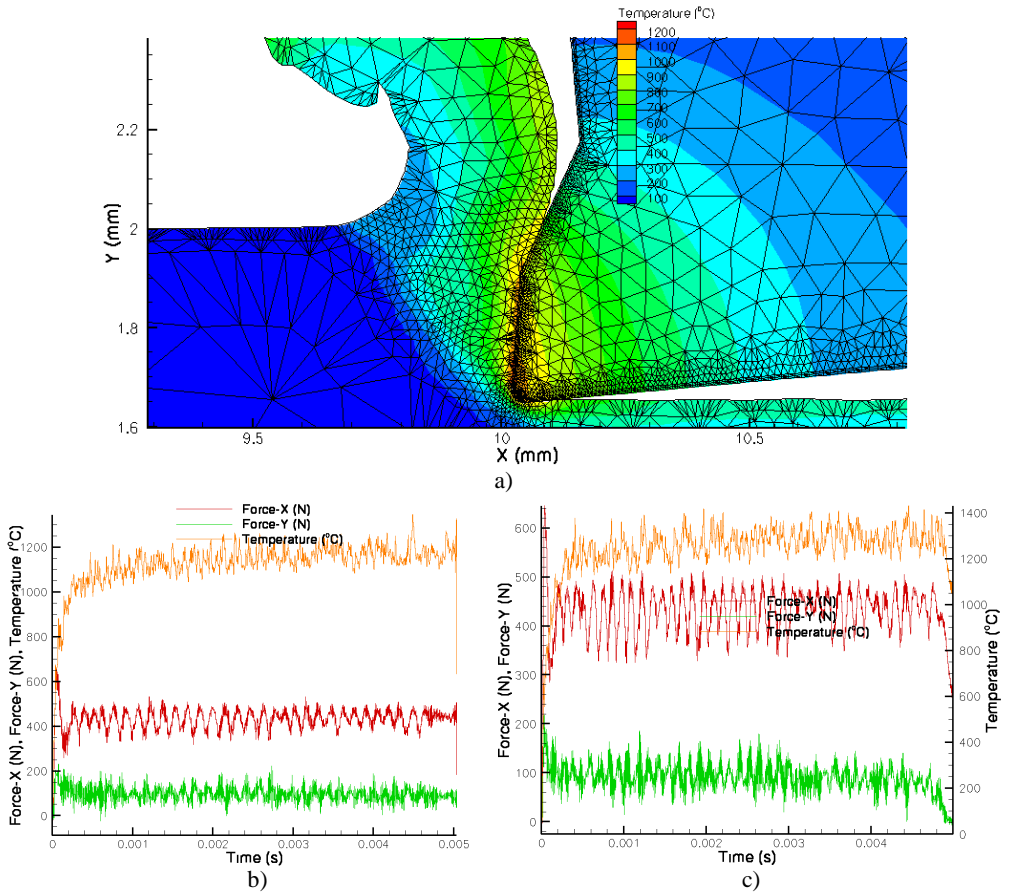
**Fig. 1.** a) Deformation zones and distribution of load on the rake face. b) The tool experiences compression stress under the chip contact zone (-) and tensile stresses (+) after the chip leaves the tool

The prediction of temperature distribution at the tool–chip interface is very important in determining the maximum speed that gives the most optimal material removal rate without excessive tool wear. The binding materials within the cutting tools may be weakened or diffused to the moving chip material at their critical diffusion or melting temperature limits. The fundamental machinability study requires the identification of a maximum cutting speed value that corresponds to the critical temperature limit where the tool wears rapidly. By using the approximate solutions summarized above, one can select a cutting speed that would correspond to a tool–chip interface temperature ( $T_{int}$ ) that lies just below the diffusion and melting limits of materials present in a specific cutting tool.

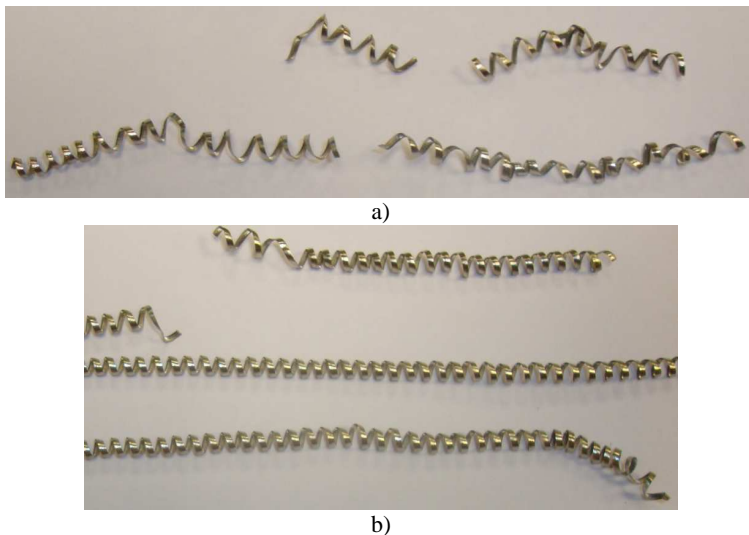
Machine tool vibrations play an important role on machining performance. Excessive vibrations increase tool wear, are cause of poor surface finish, and may damage the spindle bearings. The workpiece, cutting tool and machine form are sophisticated system with complicated dynamic characteristics. The reactive forces from the workpiece are transmitted to the machine. The cutting tool receives its cutting forces from the machine. Under certain operating conditions, the structural system may pass through heightened vibrations. The presence of vibrations results in poor surface finish, cutting-edge damage and irritating noise. It is, therefore, very important to study the causes and control all types of free and forced vibrations due to interaction between the cutting process and the machine tool structure.

Machine tools are complex structures consisting of mass points and therefore infinite degrees of freedom. The cutting forces can be resolved into steady or constant component and time-dependent dynamic component. The steady component of cutting forces along with dead loads can cause static deflections in the elastic workpiece tool-machine system. These deflections disturb orientation and motion of tool relative to workpiece. Cutting load in the





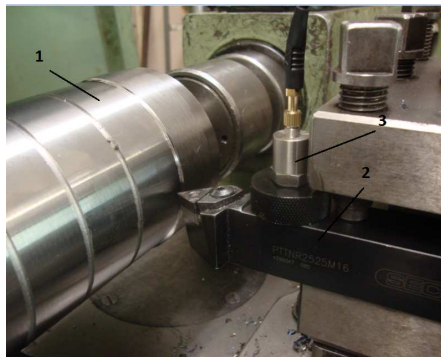
**Fig. 2.** FEM temperature fields distribution (a) modeling results of the 420 stainless steel cutting process. Cutting temperature and cutting forces graphs on cutting speed 273 m/min (b) and 341 (c)



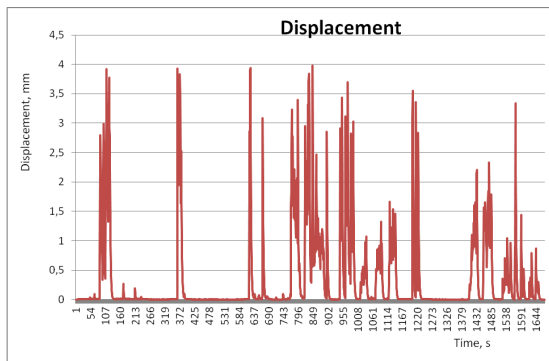
**Fig. 3.** Experimentally received chips

**Table 2.** Machining parameter combinations

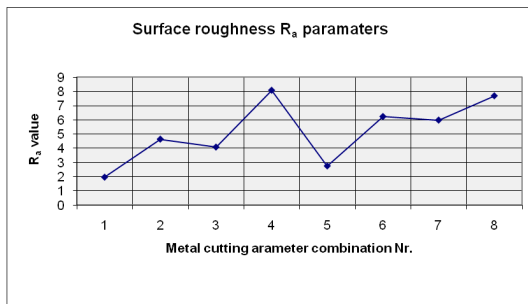
Machining parameter combination Nr.	Cutting speed, m/min.	Feeding, mm/rev.	Cutting edge angle
1	341	0,1	60
2	341	0,35	60
3	273	0,1	60
4	273	0,35	60
5	341	0,1	90
6	341	0,35	90
7	273	0,1	90
8	273	0,35	90



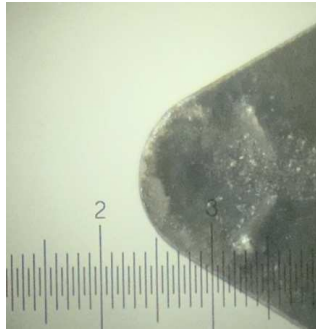
**Fig. 4.** Experimental test rig, 1- 420 Stainless Steel machined part, 2- cutting tool holder with the cutting insert, 3 – vibration accelerometer



**Fig. 5.** Measured values of the cutting tool displacement obtained during testing



**Fig. 6.** Measured surface roughness values



**Fig. 7.** Cutting tool wear

## Conclusions

Obtained results of experiments demonstrate variation of surface roughness as a function of actual cutting parameters as well as variation of displacement of the cutting tool during combination type machining process. By using of increased cutting speed became known, that the cutting tool, that we use can give higher wear and toughness characteristics, as a result we checked and it is more than recommended from manufacturer. Although, the experiments revealed high values of tool wear, this does not leave affected the machining process, as we can see in the vibration of fixation and in the surface roughness results.

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