Study of the contact forces between workpiece and fixture using dynamic analysis

V G Cioată, I Kiss, V Alexa and S A Rațiu

Politehnica University of Timisoara, Department of Engineering and Management, 5 Revolution Street, Hunedoara, 331128, Romania

E-mail: cioata.vasile@fih.upt.ro

Abstract. In the machining process, the workpieces are installed in machining devices in order to establish a strictly determined position with the cutting tool or its trajectory. During the cutting process, the weight of the workpiece, the forces and moments of inertia, cutting forces and moments, clamping forces, the heat released during the cutting process determine the contact forces between the locators and the workpiece. The magnitude of these forces is important because too large value can destroy the surface of the workpiece, and a too small value can cause the workpiece to slip on the locators or even the loss of the contact with the workpiece. Both situations must be avoided. In the paper is presented a study regarding the determination of the magnitude of the contact forces in dynamic condition using dynamic analysis realized with a CAE software.

1. Introduction

It is well known that within the technological system of machining by cutting, the fixture constitutes a basic component that defines, to a large extent, the main technical-economic coordinates of the obtained product - the cost and the quality [1], [2].

In the process of obtaining a part through a cutting process, the workpiece is installed directly on the machine table or in a fixture in a strictly determined position in relation to the trajectory of the cutting tool. The installation requires two phases, orientation and fixation, carried out simultaneously or successively.

Orientation means making contact between the surfaces of the part and the locators, and the fixation is achieved by applying clamping forces with the clamping mechanisms in order to maintain the orientation layout and to ensure maximum rigidity of the fixture – workpiece assembly.

In the practice of designing machining fixtures, the evaluation of the contact forces between the elements of the workpiece-fixture system (locators, workpiece, clamping elements) is very important because their size is not constant during the processing of the workpiece, depending on the cutting forces and moments, which have a variable feature and a position and direction which vary during the processing [3].

The maximum and minimum values of the contact forces are very important. The extreme values of the contact forces are determined according to [4] and [5].

The contact force must not exceed the maximum value fc_{max} as there is a risk of damage to the surfaces of the workpiece (indentation will appear) and the minimum contact force (fc_{min}) must prevent the loss of contact between the workpiece and the locators, and must also prevent the workpiece to slipping from the locators [6].

2. Model development

The paper studies the contact forces that appear between the workpiece and the locators, taking into account the material removal effect, using a CAD-CAE software.

The software of CAD-CAE type provides the user with working tools that enable designers to carry out design tasks in a specific environment, in a short time and with low costs. These are used in the most varied engineering situations [7-10].

The Ansys software is compatible with this simulation. Ansys Explicit Dynamics is a transient explicit dynamics workbench application that can perform a variety of engineering simulations, including the metal cutting simulation [11].

In order to study the contact forces between the elements of the assembly workpiece – locators - clamping elements, a model consisting of a workpiece, the cutting tool and machining fixture is proposed, as in Figure 1. The workpiece has a parallelepiped shape, with dimensions 30 x10 x10 mm, oriented on the 6 locators, according to the 3-2-1 orientation layout, and then fixed with the clamping elements, C1 and C2, the clamping forces being 250 N and 180 N.

It is processed by milling, with a milling cutter, with 10 mm diameter, a channel given by dimensions 1.5x2.25 mm, positioned according to Figure 1.
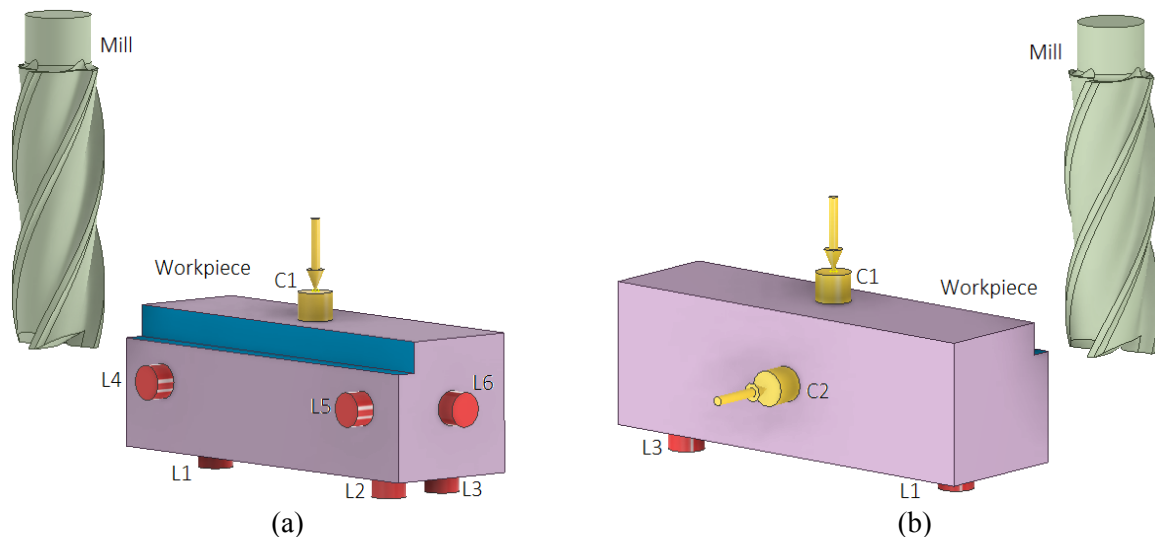
Figure 1. 3D model of the workpiece – fixture – cutting tool system

The material used for the workpiece is an alloy of aluminum, Al 7039 and the cutting tool, Steel 4340, with the properties shown in Table 1.

Table 1. Properties of the materials

Properties	**Al7039**	**Steel4340**
Density [kg/m^3]	2770	7830
Specific heat [J/kg·C]	875	477
Bulk Modulus [MPa]	27600	$1,59 \cdot 10^5$
Shear Modulus [MPa]	-	81800

Because, in metal cutting, the materials will deform under high strains, high strain rates, and high temperatures conditions, for failure criterion is used the Johnson-Cook model. The metallic material relationships between stress and strain can be described by the Johnson-Cook model as follow:

$$\sigma = (A + B \cdot \varepsilon^n)\left[1 + C \cdot ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{ref}}\right)\right]\left[1 - \left(\frac{T - T_{ref}}{T_m - T_{ref}}\right)^m\right] \tag{1}$$

where σ is the equivalent stress, ε is the equivalent plastic strain, $\dot{\varepsilon}, \dot{\varepsilon}_{ref}$ are the strain rate and reference strain rate, T is the deformation temperature, T_m is the melting temperature of the material and T_{ref} is the reference temperature.

The material constants are A, B, n, C and m. A is the initial yield stress of the material under reference conditions, B is the hardening constant, n is the hardening exponent, C is the strain rate constant, and m is the thermal softening exponent. Values of these material constants are presented in Table 2, and Figure 2.

Table 2. Values of the materials constants

Material constant	Name	Al7039	Steel 4340
A	Initial yield stress, MPa	337	792
B	Hardening constant, MPa	343	510
n	Hardening exponent, -	0,41	0,26
C	Strain rate constant, -	0,01	0,014
m	Thermal softening exponent, -	1	1,03
$\dot{\varepsilon}_{ref}$	Reference strain rate, 1/s	1	1
T_{ref}	Reference temperature, ^{0}C	603,85	1519,9
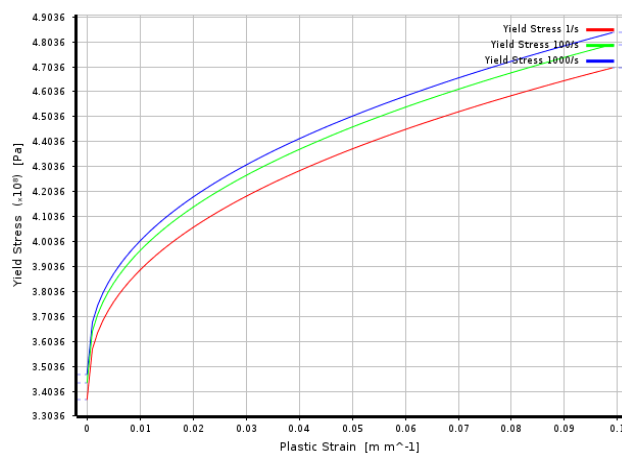
Figure 2. Dependency Yield Stress – Plastic Strain for Al 7039
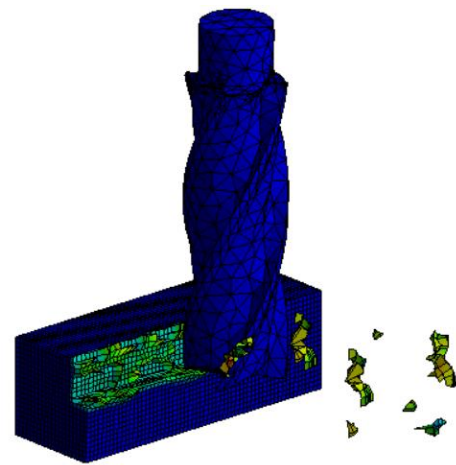
Figure 3. The sequence during the simulation

3. Analysis settings

For simulation, it must be activated the erosion control, that is the numerical mechanism for the automatic removal of elements during the simulation. There are a number of mechanisms available to initiate erosion of elements. The erosion options can be used in any combination. Elements will erode if any of the criteria are met [9].

In this cutting simulation, we used two criteria for erosions: *on geometric strain limit* and *on material failure*. On geometric strain limit option allows removal of elements when the local element geometric strain exceeds the specified value. The value of 1.0 is used in this case. In material failure option, elements will automatically erode if a material failure property is defined in the material used in the elements, and the failure criteria has been reached.

The frictional type contact between the cutting tool and the workpiece was established, with friction coefficient 0,2 and damping coefficient 0,1. For body interactions, it is used Penalty formulation, with body self-contact and element self-contact.
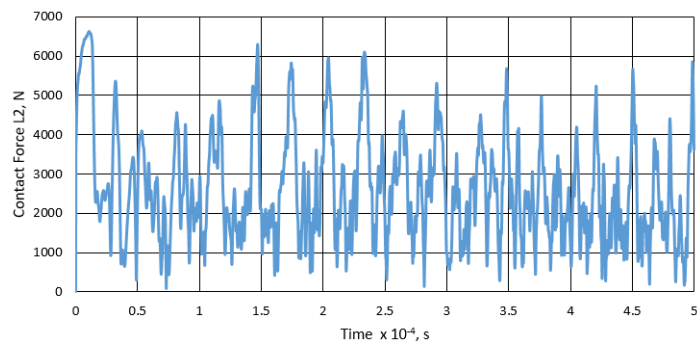
4. Results

A sequence during the simulation is presented in Figure 3. After the simulation, the results are presented in graphical form, in the following.
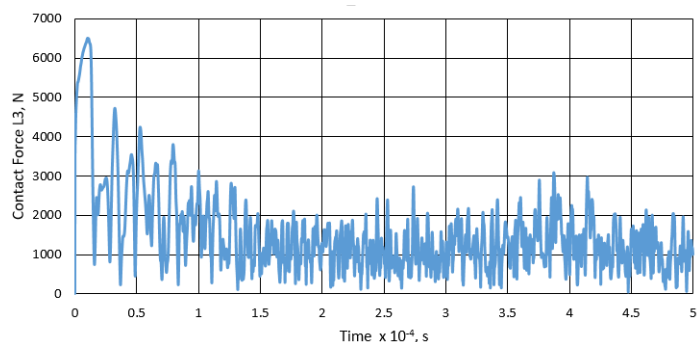
In Figures 4,…,9 the contact forces between the workpiece and the locators L1…L6 are shown.
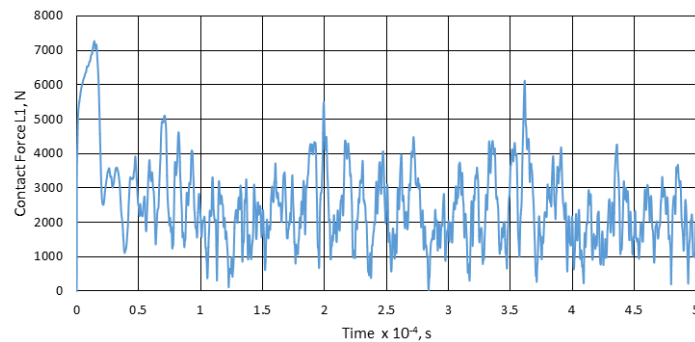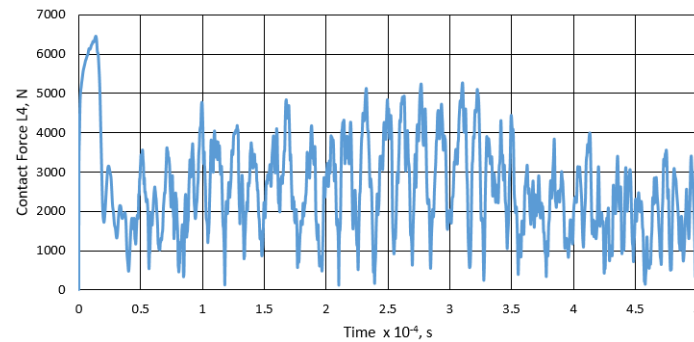

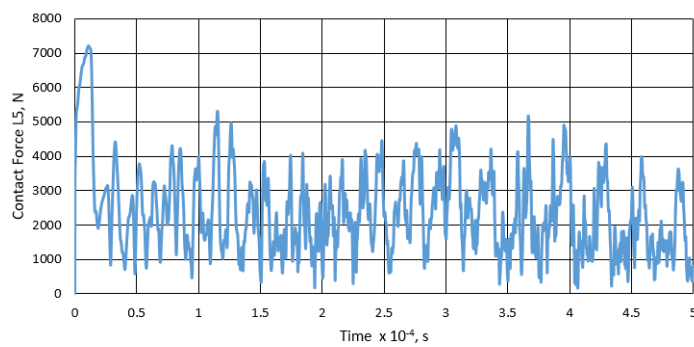**Figure 4.** Contact force between workpiece and locator L1

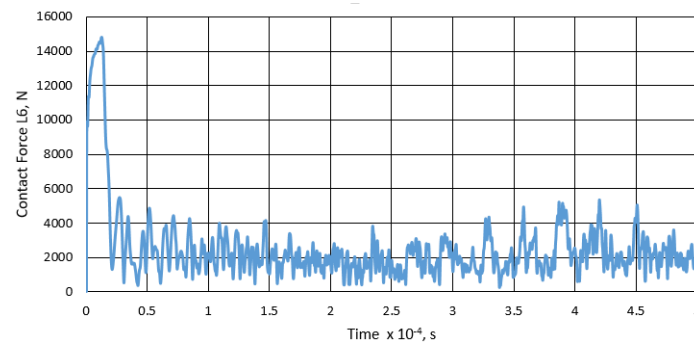**Figure 5.** Contact force between workpiece and locator L2

Figure 6. Contact force between workpiece and locator L3

**Figure 7.** Contact force between workpiece and locator L4

**Figure 8.** Contact force between workpiece and locator L5

Figure 9. Contact force between workpiece and locator L6

At the same time, the minimum and maximum equivalent stresses that appear during the simulation can be evaluated, as well as the temperature in the workpiece and the cutting tool that appears due to the heat generated during the cutting process. These are presented in the Figures 10 and 11.
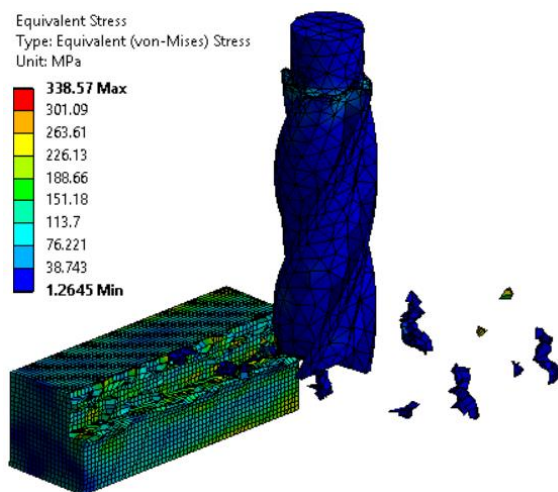
The equivalent stress in workpiece and cutting tool at the end of the simulation are shown in Figure 12 and the cutting temperature at the end of the simulation are presented in Figure 13.
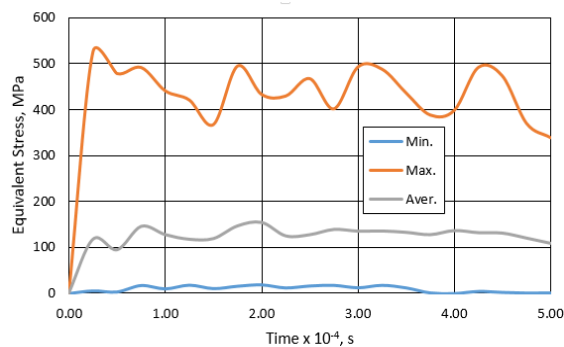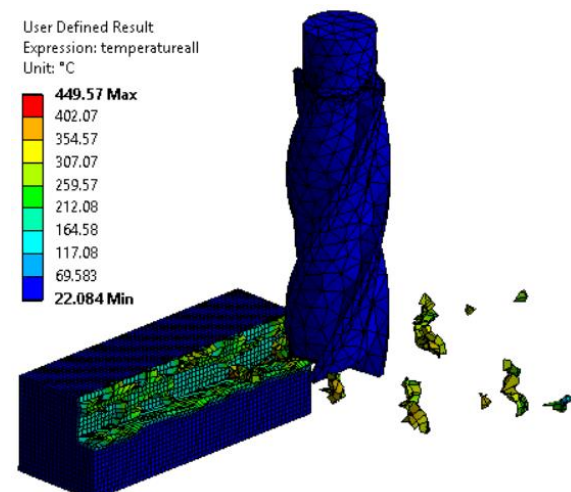
Figure 10. The Equivalent Stress evolution during simulation
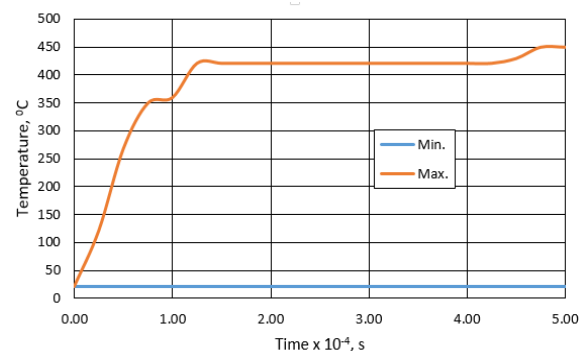
Figure 11. Cutting temperature evolution during simulation

Figure 12. Equivalent Stress in workpiece and cutting tool at the end of the simulation

Figure 13. Cutting temperature in workpiece and cutting tool at the end of the simulation

5. Conclusions

During processing, due to the variable character of the forces and the moment of cutting, the contact forces between the workpiece and the locators have, in their turn, a variable character, sometimes varying within very wide limits.

In all the figures, very high values can be observed in the initial phase of the processing, at the entry into the cutting of the cutting tool, after which the values decrease. In practice, this can be avoided by using small feed rates at the cutting entry.

For the situation presented in the paper, the values of the contact forces were not less than zero, which indicates that the workpiece did not lose contact with the locators, so the orientation layout was not compromised.

The explicit dynamic analysis with the consideration of the material removal effect allows to study the behavior of the workpiece – fixture assembly more efficient and closer to reality. Important informations can be obtained that can be used to determine processing accuracy.

References

[1]   Ivanov V, Mital D, Karpus V, Dehtiarov I, Zajac J, Pavlenko I and Hatala M 2017 Numerical simulation of the system "fixture–workpiece" for lever machining, *Int J Adv Manuf Technol* **91**(1) 79-90

[2]   Ivanov V, Dehtiarov I, Pavlenko I, Kosovi I and Kosov M 2019 Technology for complex parts

machining in multiproduct manufacturing, *Management and Production Engineering Review* **10**(2) 25-36

[3] Cioată V G, Kiss I, Alexa V and Rațiu S A 2017 The optimization of the position and the magnitude of the clamping forces in machining fixtures, *IOP Conf. Ser.: Mater. Sci. Eng.* **200** 012015

[4] Jonhson K L 1987 *Contact mechanics*, Cambridge University Press, Cambridge, USA

[5] Sanchez H T, Estrems M and Faura F 2006 Fixturing analysis methods for calculating the contact load distribution and the valid clamping regions in machining processes, *Int J Adv Manuf Technol* **29**(5) 426-435

[6] Cioată V G, Kiss I, Alexa V, Rațiu S A and Rackov M 2017 Study of the influence of the cutting temperature on the magnitude of the contact forces in the machining fixtures, *IOP Conf. Ser.: Mater. Sci. Eng.* **294** 012072

[7] Ardelean M, Ardelean E, Heput T and Socalici A 2009 Simulation results regarding to cinematic parameters of mechanical systems, *Proceedings of the 13th WSEAS International Conference on Systems: Recent Advances in Systems: Mathematics and Computers in Science and Engineering*, pp 254-259

[8] Ardelean M, Ardelean E, Popa E, Josan A and Socalici A 2015 Research regarding to behavior on advanced plastic from rolling mills equipment, *IOP Conf. Ser.: Mater. Sci. Eng.* **106** 012035

[9] Tirian G O, Gheorghiu C A, Heput T and Chioncel C 2017 Control system of water flow and casting speed in continuous steel casting, *IOP Conf. Ser.: Mater. Sci. Eng.* **200** 012047

[10] Tirian G O, Prostean O and Filip I 2013 The control of a CNC metal plate cutting machine using a fuzzy algorithm, *IEEE 9th International Conference on Computational Cybernetics*, pp 247-250

[11] ***https://www.sharcnet.ca/Software/Ansys/15.0.7/en-us/help/wb_sim/exp_dyn_theory_erosion_cont.html (accesed on May, 2019)