1. Vasile George CIOATA, 2. Imre KISS

THE MACHINING ERROR DUE TO CONTACT DEFORMATION OF WORKPIECE-FIXTURE SYSTEM

■ **Abstract:**

In this paper work there are described the error's sources due to workpiece-fixture compliance which appear while the workpieces are clamped, is presented the analytic models of calculus of the errors due to contact deformation between locators and workpiece and an example of using the finite element method in order to determine the contact deformation for a practical example. The differences between the results obtained using the finite element method and the results obtained using analytical relations are very small, which demonstrates that the finite element method can be used for determining the machining error due to contact deformation.

■ **Keywords:**
workpiece, fixture, deformation, machining error

■ INTRODUCTION

In the machining process the fixtures are used for the orientation and clamping, for the workpiece to be machined through various methods, assembling and controlling. Once the workpiece is orientated and clamped with locators and clamping devices the workpiece can be machined in order to accomplish the imposed accuracy conditions.

The errors due to fixtures are major ones and influence the workpiece's machining accuracy; the errors can amount to 20-60% of the overall machining error. Therefore, performance evaluations of the workpiece-fixture system constitute a significant task for fixture design optimization and control of the machining error before manufacturing and the application in production.

The errors due to the workpiece-fixture system can be classified in two categories: errors due to orientation of the workpiece in the fixture and errors due to deformations of the workpiece-fixture system during clamping and machining. During clamping and machining the workpiece, for a point P situated on the machined feature, the force assembly which acts on the workpiece-fixture system determines the appearance of three types of errors: errors due to contact deformation, errors due to locator's deformation and errors due to workpiece deformation.

■ ANALYTIC CALCULUS OF THE ERRORS DUE TO CONTACT DEFORMATION

In many different situations, in device design practice, the contact geometry between surfaces of workpieces and locators or clamping elements of fixture can be a point (sphere–sphere contact), a line (cylinder - plane contact) and a plane surface (plane – plane contact).

The contact deformation between workpiece and locators and clamping elements of fixtures can be characterized with Hertz's model of

contact stress. The hertzian theory of contact is based on the following simplifying assumptions [1]:

+ the materials in contact are homogeneous and the yield stress is not exceeded;
+ contact stress is caused by the load which is normal to the contact tangent plane which effectively means that there are no tangential forces acting between the solids;
+ the contact area is very small compared with the dimensions of the contacting solids;
+ the contacting solids are at rest and in equilibrium;
+ the effect of surface roughness is negligible.

■ CONTACT BETWEEN A SPHERE AND A PLANE SURFACE

The contact area between a sphere and a plane surface, as shown in Figure 1, is circular.
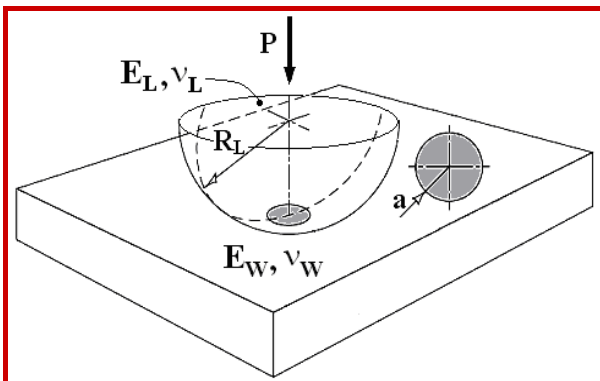

Figure 1. Contact between a sphere and a flat surface

The contact parameters for this configuration can be calculated according to the next formulae:

+ contact area dimensions: $a = \left(\dfrac{3PR'}{E'} \right)^{1/3}$ (1)

+ maximum contact pressure: $p_{max} = \dfrac{3P}{2\pi a^2}$ (2)

+ average contact pressure: $p_m = \dfrac{P}{\pi a^2}$ (3)

+ maximum contact deformation:
$$\delta = 1.0397 \left(\dfrac{P^2}{E'^2 \, R'} \right)^{1/3}$$ (4)

+ maximum shear stress: $\tau_{max} = \dfrac{1}{3} p_{max}$ at a

depth of $z = 0.638a$ (5)

where a is the radius of the contact area [m]; P is the normal load [N]; p is the contact pressure (Hertzian stress) [Pa]; δ is the contact

deformation (total deflection at the centre of the contact $\delta = \delta_A + \delta_B$, where δ_A and δ_B are the maximum deflections of body A and B respectively) [m]; τ_{max} is the shear stress [Pa]; z is the depth under the surface where the maximum shear stress acts [m]; E' is the reduced Young's modulus [Pa] and R' is the reduced radius of curvature [m] ($R'=R_L$).

The reduced Young's modulus is defined as:

$$\frac{1}{E'} = \frac{1}{2} \left(\frac{1-\upsilon_L^2}{E_L} + \frac{1-\upsilon_W^2}{E_W} \right)$$ (6)

where v_L and v_W are the Poisson's ratios of the locator and workpiece, respectively and E_L and E_W are the Young's moduli of the locator and workpiece, respectively.

■ CONTACT BETWEEN A CYLINDER AND A PLANE SURFACE

According to the Hertz theory for the contact of cylindrical locator, when one of the contact bodies roughly takes the form of a rectangular block of thickness t, as shown in figure 2, then the deformation of the block through its thickness may be obtained with reasonable approximation, provided that the thickness of the block is large compared with the contact width (t>>a), then the deformation of the block through its thickness is

$$\delta = P \frac{1-v_L^2}{\pi E_L} \left[2\ln\left(\frac{2t}{a} \right) - \frac{v_L}{1-v_L} \right],$$ (7)

where t is the thickness of the block; v_L is Poisson's ratio of the cylindrical locator; E_L is Young's modulus of the cylindrical locator;

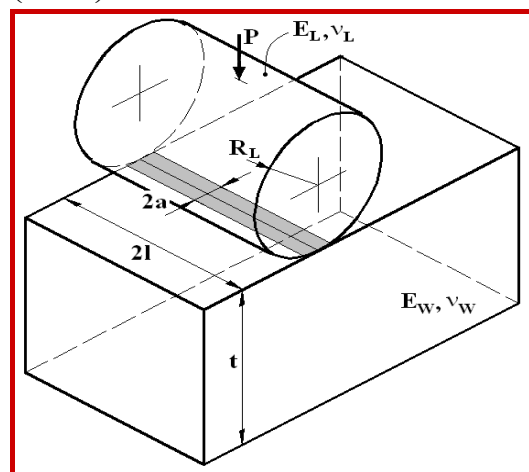$a = \left(\dfrac{4PR_L}{\pi E'} \right)^{1/2}$ (8) is the contact width.

Figure 2. Contact between a cylindrical locator and a rectangular workpiece

■ EVALUATION OF THE MACHINING ERROR DUE TO CONTACT DEFORMATION WITH THE FINITE ELEMENT METHOD

A quick and efficient evaluation of the machining errors due to contact deformation which appear during clamping of workpieces can be realized with the finite element method. Forwards it is presented an example of application of this method for contact between a cylindrical locator and a rectangular workpiece.
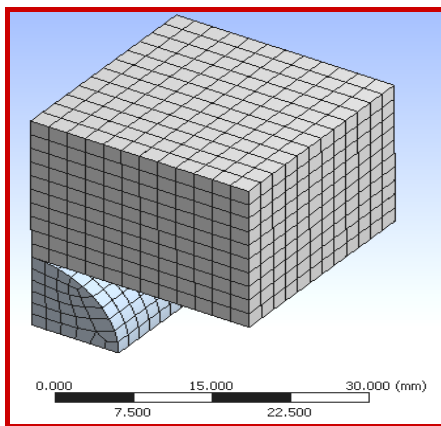

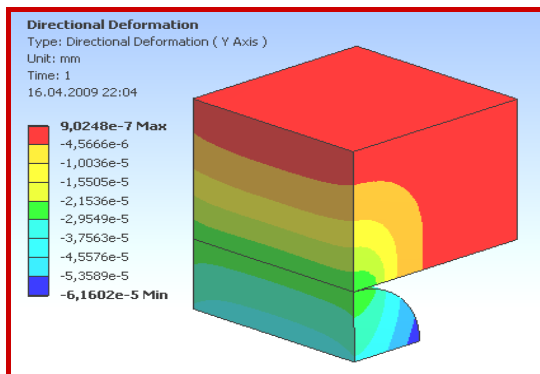Figure 3. a. FEA analysis of the workpiece-locator system

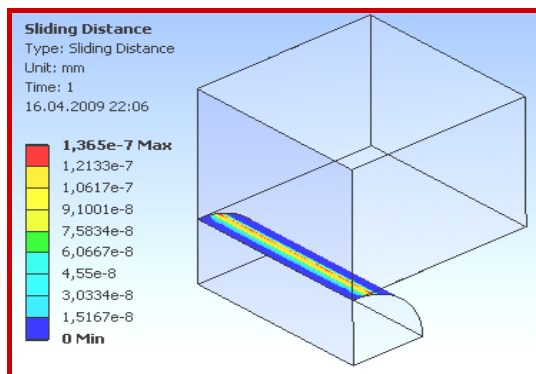Figure 3. b. FEA analysis of the workpiece-locator system.

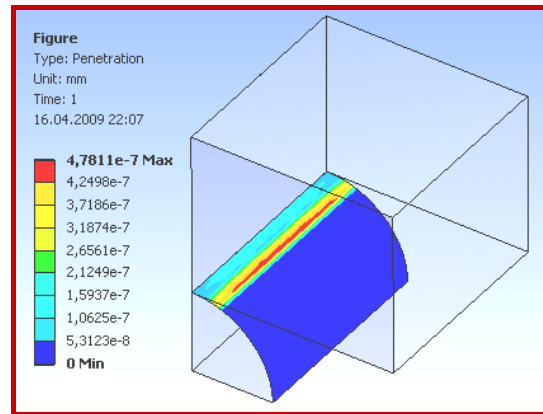Figure 3. c. FEA analysis of the workpiece-locator system.

Figure 3.d. FEA analysis of the workpiece-locator system

An elastic cylindrical locator of steel with a radius of R=10 mm pressed against a flat surface of a workpiece of the same material by a pressure P=0,20 MPa. Geometry of the rectangular workpiece: length 25 mm, width 25 mm and height 20 mm. Materials for cylindrical locator and rectangular workpiece: steel having Young's modulus E =205 GPa and Poisson's ratio ν =0.29. The clamp–workpiece contact was modeled using surface to surface contact elements.

The results are presented in figure 3. The contact deformation in contact zone are evaluated in figure 3, b.

■ CONCLUSION

The maximum contact deformation calculated with relation (7) is 0,388 μm. The contact deformation evaluated with the finite element method in middle point of contact line is 0,357 μm. These results demonstrate that the finite elements method permits a quick and efficient evaluation of the contact deformation due to workpiece-fixture system and the machining error due the contact deformation.

■ REFERENCES

[1] K.L. JOHNSON, Contact Mechanics, Cambridge University Press, Cambridge, 1985

[2] LI, B., MELKOTE, S. N., Fixture clamping force optimization and its impact on workpiece location accuracy. Int. J. Adv. Manuf. Technol., Vol. 17, No. 2, (January 2001), 104–113, ISSN 0268-3768, 2001

[3] RAGHU, A., MELKOTE, S. N., Modeling of workpiece location error due to fixture geometric error and

fixture-workpiece compliance. J. Manuf. Sci. Eng., Vol. 127, No. 1, 75–83, ISSN 1087-1357, 2005

[4] RONG, Y. M., ZHU, Y. X., Computer Aided Fixture Design, Marcel Dekker, ISBN 0-8247-9961-5, New York 1999

■ *AUTHORS & AFFILIATION*

[1.] VASILE GEORGE CIOATA
[2.] IMRE KISS

[1, 2.] DEPARTMENT OF ENGINEERING & MANAGEMENT, FACULTY OF ENGINEERING HUNEDOARA, UNIVERSITY "POLITEHNICA" TIMISOARA, ROMANIA