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STATIC ANALYSIS OF PORTAL MILLING MACHINE USING FEM

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Abstract: *This work presents a numeric simulation using finite element method to estimate the loss of accuracy of a portal milling machine when operating under static load. The mechanical structure of a portal milling machine was CAD modeled and numerically analyzed using ANSYS WORKBENCH software. In this analysis, three static loads which represent the components on X, Y, Z axes of cutting forces were imposed to the milling cutter of the machine and a deformation analysis revealed the deformed geometry.*

Key words: *machine tool, FEA, deformation, cutting forces*

1. INTRODUCTION

Machine tools are characterized by high precision, even at heavy-duty regimes (high magnitudes of cutting forces). During the machining process, the portal milling machine has to bear static and dynamic loads. The resulting displacements, especially at the tool centre point (TCP), should be as small as possible in order to ensure a high machining accuracy. Today's increasing requirements concerning productivity and capability of machine tools lead inevitably to machine concepts that allow higher velocity and acceleration while achieving higher machining quality. The structure mechanic behaviors of components that are in the force flux play a major role to fulfil these requirements. The static and dynamic behavior of portal machines was studied using coupled multibody simulation environment (C. Brecher et. al, 2008, C. Brecher et. al, 2010). Portal machine tool type have an important rate in establishing the relative displacement between parts and tool. Portal deformations are determined mainly by the columns bending (C. Ispas et. al, 1997). Portal machines, which enable up to five axes machining gain more and more significance in fields of mold and die production as well as in the aircraft industry. These kinds of machine tools have a conceptual weak point due to the overhanging z-slider structure (C. Brecher et. al, 2008).

2. MODEL PREPARATION

Portals are the basic structure elements, which have a much higher stiffness than horizontal frames. Portal machine tools consist of a horizontal frame or a support element which connects two columns, bounded together at the top with a stiffening beam to form a closed frame.

Usually, columns are made of ribs and diaphragms. Diaphragms (fig.1.b) have a considerable influence on the bending rigidity of the column, blocking the section frame deformation of the portal. The analyses were conducted with the help of FEM.

To analyze the portal milling machine under static load, the first step was to model its geometry on a CAD system. All parts, including columns, cross beam, milling cutter, main spindle were modeled based on real sizes of the machine. The 3D model was processesed in CATIA V.5. R 18, as shown in figure 1.a. and imported in ANSYS WORKBENCH 11.0 using a neutral file.

The restraints, as well as the materials of the machine parts were defined according to real conditions. In our model, the boundary conditions were applied on the lower side of the columns.

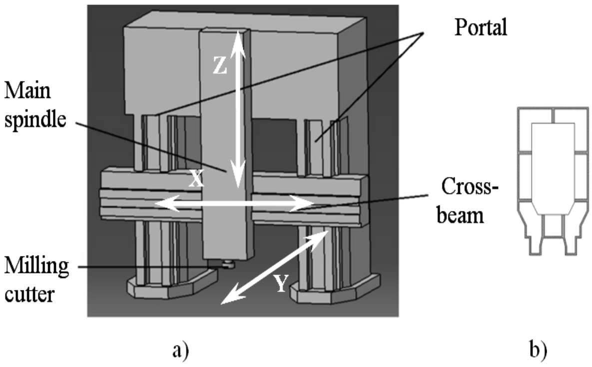

Fig.1. a) 3D model of the portal machine b) the diaphragme section of the columns

The forces were computed considering, in the case of machining a cast iron workpiece using cylindrical milling cutter. The forces were applied to the model on three directions which represents the tangential, radial and axial components of the cutting force. Cutting forces are computed using the formulas:

$$F_z = C_{F_1} \cdot t^{x_{F_z}} \cdot s_d^{y_{F_z}} \cdot D^{z_{F_z}} = 4883\ N \quad (1)$$
$$F_y = 0.7 \cdot F_z = 3418.1\ N \quad (2)$$
$$F_x = 0.5 \cdot F_z = 2441.5\ N \quad (3)$$

where: F_z - cutting force in Z direction, [mm];
F_y - cutting force in Y direction, [mm];
F_x - cutting force in X direction, [mm];
C_{F_1} - constant which depends on the milling condition, [mm];
$t^{x_{F_z}}$ - cutting depth, [mm];
$s_d^{y_{F_z}}$ - cutting feed, [mm];
$D^{z_{F_z}}$ - milling cutter diameter, [mm];
$x_{F_z}, y_{F_z}, z_{F_z}$ - exponents of cutting depth, feed and diameter.

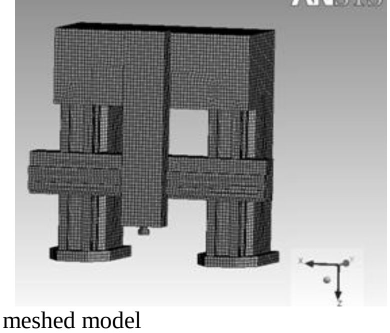

Fig. 2. The meshed model

Mesh size is very important in obtaining the accuracy of results; therefore our model was meshed using a Hex Dominant method and a size element of 50 mm in order to obtain a fine and good quality mesh. Finally the model had a number of total nodes of 434405 and a number of total elements of 122229. Fig. 2 shows the general mesh view of the portal milling machine.

3. FEM RESULTS

The simplified model simulations were carried out in order to study the portal deformation under the action of the three cutting force components.The deformation analysis was performed with the cross-beam stroke at several positions of the working area in order to evaluate the path of the cross beam in Z direction; the first simulation was performed at minimum stroke, the second simulation at a distance of 200mm, the third one at 500mm and last at maximum stroke of 700mm. Total deformation resulted from loading the portal structure are represented in figure 3.

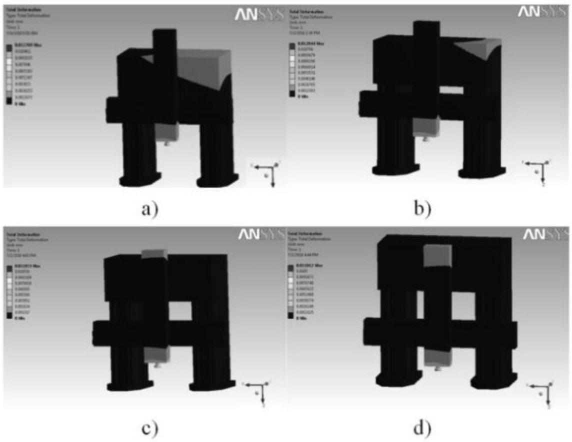

Fig. 3. Path of the cross-beam along Z direction

The maximum total deformation appears in the cutting tool with different values for each position of the cross-beam, these values are close and it can be seen that at the stroke distance of 200 mm is the major deformation, showed in fig. 4.

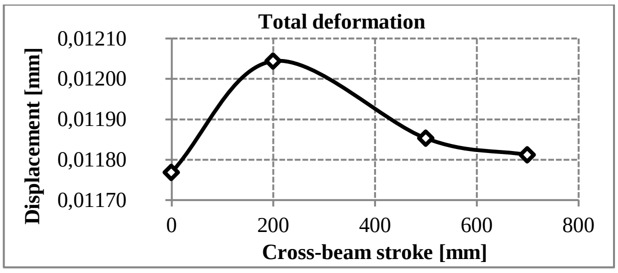

Fig. 4. Total deformation dependence of cross-beam stroke

Figures 5, 6, and 7 show the results of finite element analysis for the three components of cutting force.

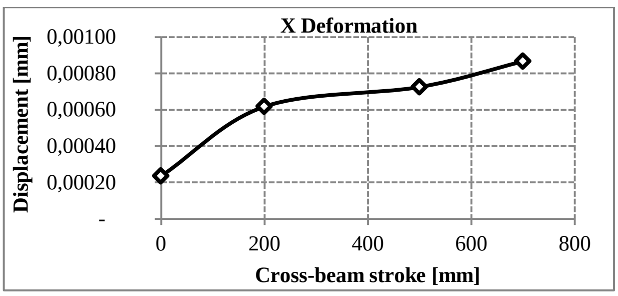

Fig. 5. X deformation dependence of cross-beam stroke

After analyzing the four position of the cross-beam stroke, the three directions of portal machine deformation are relatively close, and it can be seen an increase displacements on the y direction.

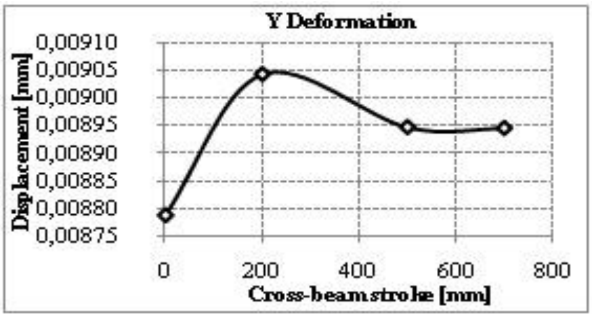

Fig. 6. Y deformation dependence of cross-beam stroke

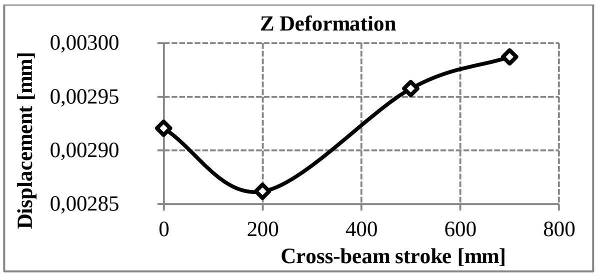

Fig. 7. Z deformation dependence of cross-beam stroke

4. CONCLUSION

The objective of this paper was to analyse the portal milling machine behavior under static load that occurs during the cutting process in different positions of the cross-beam stroke.

These graphics show that the relative differences between the extreme deformations of cross-beam positions (0 and 200 mm) are very small (< 5%). It can be concluded that the cross-beam position does not influence the cutting performance. The application of numerical analysis in evaluating the machine deformations can be a powerful tool to verify the influence of some design variables that affects its accuracy.

The analysis of all structure parts of the portal machine, regarding their influence and rates on portal deformation will be part of future research.

5. ACKNOWLEDGEMENTS

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