# STATIC AND DYNAMIC ANALYSIS OF PORTAL MILLING MACHINE USING ANSYS WORKBENCH

Irina PETRESCU[1], Iuliana PISCAN[2], Mihai TICA[3]

**Rezumat.** *Precizia de aschiere a unei masini-unelte este direct influentata de comportamentul static si dinamic al acesteia. Aceasta lucrare trateaza comportarea statica si dinamica a masinii de frezat portal. Structura masinii de frezat portal a fost modelata folosind software-ul CATIA, dupa care a fost importata ca fisier neutru in software-ul de analiza cu elemente finite ANSYS WORKBENCH 11.0. Initial s-a realizat analiza statica a masinii de frezat portal sub actiunea fortelor de aschiere, prin simularea modelului in diferite pozitii ale cursei traversei. In continuare, s-a trecut la analiza modala in scopul de a evidentia intervalul de frecvente in care precizia masinii-unelte este obtinuta.*

**Abstract.** *The cutting accuracy of a machine tool is directly influenced by its static and dynamic behavior. This paper treats the static and dynamic behavior of portal milling machine. The portal milling machine structure was modeled using CATIA software then imported as a neutral file in the FEA software, ANSYS WORKBENCH 11.0. First was made the static analysis of portal milling machine under the action of the three cutting force components, by simulating the model in various positions of the cross-beam stroke. In the second simulation, was performed a modal analysis in order to underline the frequency range in which the machine tool is obtained.*

**Keywords:** FEA, static analysis, modal analysis, cutting, frequency.

## 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 [1].

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. 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

[1]PhD Student, affiliation: Faculty of Engineering and Management of Technological Systems, Department of Machine Tools and Manufacturing Systems, University “Politehnica”, Bucharest, Romania, (e-mail: irina_petresscu@yahoo.com).
[2]PhD Student, Faculty of Engineering and Management of Technological Systems, Department of Machine Tools and Manufacturing Systems, University “Politehnica”, Bucharest, Romania, (iuliana.piscan@yahoo.com).
[3]PhD Student, Faculty of Engineering and Management of Technological Systems, Department of Machine Tools and Manufacturing Systems, University “Politehnica”, Bucharest, Romania (ticamihai0@yahoo.co.uk).

the aircraft industry. These kinds of machine tools have a conceptual weak point due to the overhanging z-slider structure [2].

The majority of structures can be made to resonate, i.e. to vibrate with excessive oscillatory motion. Resonant vibration is mainly caused by an interaction between the inertial and elastic properties of the materials within a structure. Resonance is often the cause of, or at least a contributing factor to many of the vibration and noise related problems that occur in structures and operating machinery.

To better understand any structural vibration problem, the resonant frequencies of a structure need to be identified and quantified. Today, modal analysis has become a widespread means of finding the modes of vibration of a machine or structure.

Modes are inherent properties of a structure, and are determined by the material properties (mass, damping, and stiffness), and boundary conditions of the structure. Each mode is defined by a natural (modal or resonant) frequency, modal damping, and a mode shape (i.e. the so-called “modal parameters”). If either the material properties or the boundary conditions of a structure change, its modes will change. For instance, if mass is added to a structure, it will vibrate differently [3].

The Finite Element Method (FEM) is widely used to perform a Modal Analysis. FEM is extremely useful for complicated devices and structures with unusual geometric shapes.

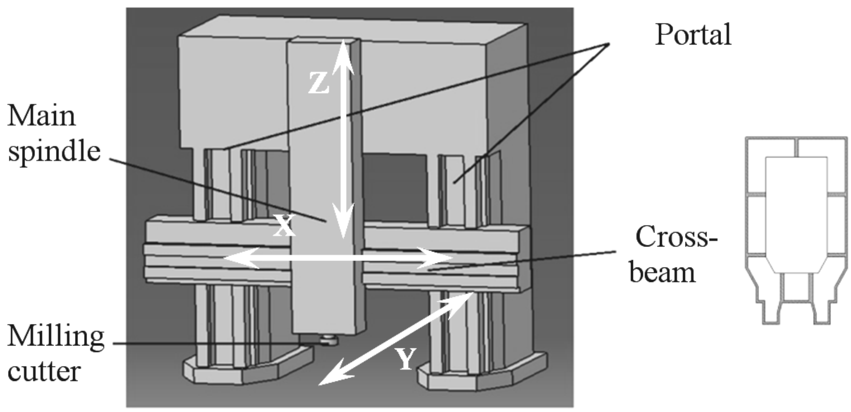
## 2. Model preparation

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 [4], 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 figure1.a. and imported in ANSYS WORKBENCH 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.




a) b)

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

## 3. Fem results

The portal milling machine simulations were carried out in order to study its static and dynamic behaviour under the actions of cutting loads. By using FEM programs we can calculate static or dynamic characteristics of the machine tool and also machine tool components.

### 3.1. Static analysis

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 a) minimum stroke, b) the second simulation at a distance of 200mm, c) the third one at 500mm and d) last at maximum stroke of 700mm. Total deformation resulted from loading the portal structure are represented in figure 2.

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 (fig.3.a).

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, showed in fig.3.b, c and d.

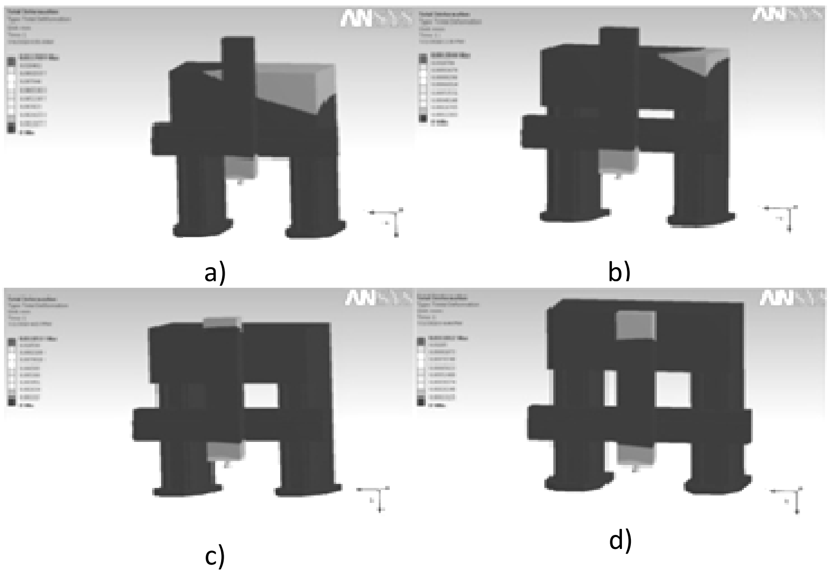



Fig.2. Path of the cross-beam along Z direction

a) at 0 mm b) at of 200mm, c) at 500mm and d) at 700mm.

b

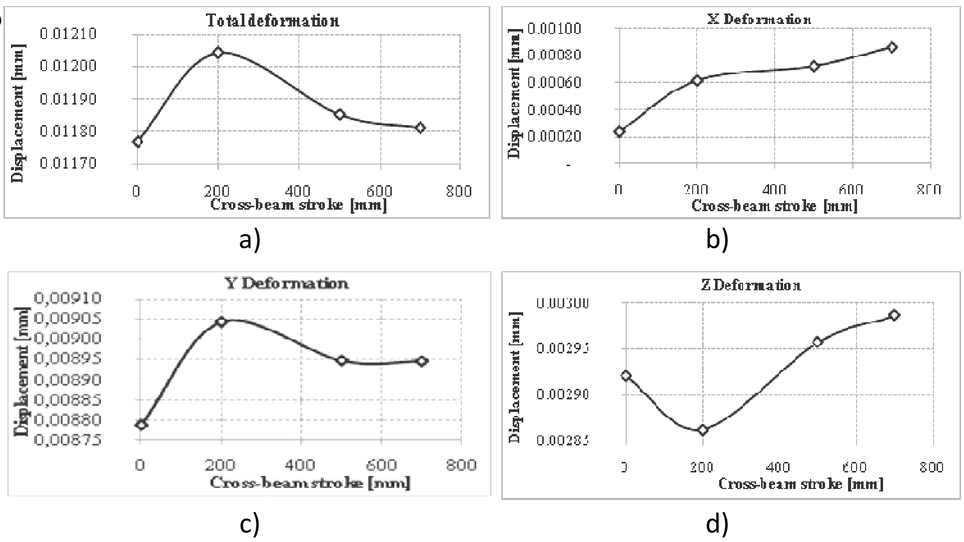



Fig.3. Graphics of the static analysis result: a) total deformation, b) X deformation, c) Y deformation, d) Z deformation

### 3.2. Modal analysis

A complete dynamic description of the machine requires the determination of the modal frequencies, mode shapes, and the system parameters: equivalent mass, stiffness, and damping ratio. The procedure determining this information of a system is called Modal Analysis [5].

Modal analysis studies the dynamic properties or structural characteristics of a mechanical structure under dynamic excitation: natural frequency, mode shapes and damping. The modal analysis has been performed on the model in order to determine the natural frequency and mode shapes of the portal milling machine structure and, also of its components (cross-beam, portal and main spindle).

It has been made a modal analysis for the three structural elements of the portal milling machine and it has been determined their frequencies and mode shapes. The frequencies that are calculated by the program are presented in table 1.

Table 1. Structural elements natural frequency.

| Modes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Cross-beam frequency [Hz] | 45.211 | 110.34 | 117.13 | 154.23 | 265.92 | 283.46 | | |
| Main spindle frequency [Hz] | 145.78 | 147.05 | | | | | | |
| Portal frequency [Hz] | 44.51 | 51.413 | 90.581 | 223.1 | 261.94 | 282 | 283.92 | 289.27 |

To find the critical speed range it has made a modal analysis of the whole portal milling machine. In figure 4 is showed the dependence of their frequencies and deformation. Between 60 and 80 frequency interval are highlighted the critical speed, in which is recommended to avoid using the machine during this interval due to its influence on manufacturing accuracy.

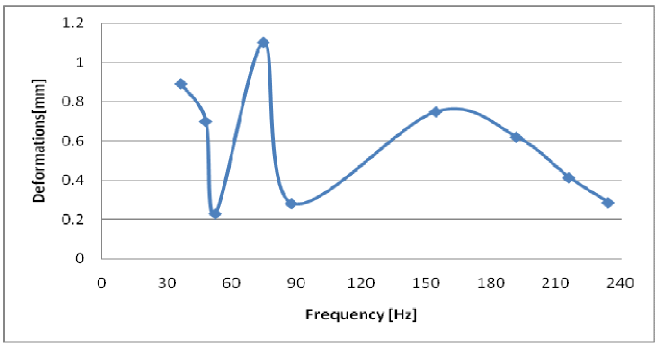



Fig. 4. The dependence between portal milling machine deformation and frecquency

## Conclusions

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 and dynamic characteristics in order to determine the natural frequency and mode shapes.

From the static analysis it can be concluded that the relative differences between the extreme deformations of cross-beam positions (0 and 200 mm) are very small (< 5%). Therefore the cross-beam position does not influence the cutting performance.

The modal analysis shows that the structure with the largest strains are found in the milling head. Between the speed range of 3600-4800 rpm, the portal milling machine is not working in normal parameters, and should be avoided this range.

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.

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