Proceedings in MANUFACTURING SYSTEMS

Proceedings in Manufacturing Systems, Volume 6, Issue 4, 2011 ISSN 2067-9238

THEORETICAL AND EXPERIMENTAL RESEARCHES ON A MULTIFUNCTIONAL MACHINE TOOL MADE FROM COMPOSITE MATERIALS

Loredana PĂUN[1,*], Valeriu AVRAMESCU[2], Nicolae PREDINCEA[3], Constantin DOGARIU[4], Claudiu BÎȘU[5]

[1)] PhD. Eng., S.C. ICTCM S.A. – Mechanical Engineering and Research Institute, Bucharest, Romania
[2)] PhD. Eng., Head of DTPC, S.C. ICTCM S.A. – Mechanical Engineering and Research Institute, Bucharest, Romania
[3)] PhD, Prof., Machine and Production Systems Department, University Politehnica of Bucharest, Romania
[4)] PhD, Prof., Machine and Production Systems Department, University Politehnica of Bucharest, Romania
[5)] PhD, Lecturer, Machine and Production Systems Department, University Politehnica of Bucharest, Romania

***Abstract*:** *This paper is based on a CNC multifunctional machine tool for processing by turning, milling, boring, drilling. One of the news brought by this machine is that its structure is made mostly of composite materials. To see the dynamic behavior of this machine, theoretical and experimental researches have been achieved in order to determinate the proper frequencies. Some conclusions were drawn regarding the machine tool structure rigidity and some suggestions for improving the structure behavior were made.*

Key words: *multifunctional machine tool, composites, structure, FEM modeling, frequencies, modal analyses.*

1. INTRODUCTION

Traditional and natural materials, limited quantity or whose manufacture requires a high energy consumption, are becoming more and more replaced by composite materials, as a great alternative to energy and environmental problems caused by the production of the traditional materials.

The products made of composite materials have numerous applications in many fields such as ship building, automotive, aviation, transportation, medicine, electronics and energy, chemistry, consumer, sports equipment etc. Implementation of polymer matrix composite materials, particularly those reinforced with glass fiber, is determined, including the obvious availability of the used raw materials, and the variety of used materials for the matrix and for the reinforcement elements and also because of the combining possibilities in terms of quantitative and structural. These advantages of composite materials have the effect of substitution of traditional materials, whose reserves are increasingly scarce [1].

Starting from the current stage of researches regarding the utilization of composite materials in various fields, it is proposed an approach to a less development direction, namely the use of composite materials in building of some structure elements which are specific to machine tools.

In this way, the Mechanical Engineering and Research Institute has developed an experimental model of a multifunctional CNC machine tool for processing by turning, milling, drilling, boring, mortising, toothing and also plane, cylindrical and helicoidally rectification. In order to get a reduced weight of the multifunctional machine, the frame was made from pulltruded composite profiles reinforced with glass fiber which are bounded by metal straps [2].

The multifunctional machine tool [3], represented in Fig. 1, is based on a representative structure and it is designed modularized, with integration of composite materials. The concept of the multifunctional machine tool can provide multiple processing, the representative structure being equipped properly and specific to every processes [3].

On the cradle, which is made from pulltruded profiles, is mounted two longitudinal slides plate (SL1 and SL2), two transversal slides plate (ST1 and ST2) and two vertical slides (SV1 and SV2) to ensure the main movements for cutting.

The plates are designed in innovative options in terms of construction and operational point of view.

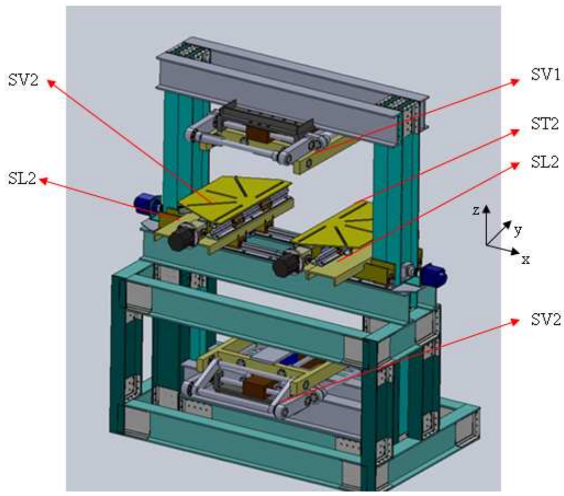

Fig. 1. The experimental model of the multifunctional machine tool.

[*] Corresponding author: Sos. Oltenitei, No. 103, Sector 4, Bucharest, Romania,
Tel.: 0213323770;
Fax: 0213320775
E-mail addresses: *loredana_theo@yahoo.com* (L. Paun), *vavramescu@ictcm.ro* (V. Avramescu), *cdogariu@gmail.com* (C. Dogariu), *cfbasu@gmail.co* (C. Basu), *nicolaeprednceа@yahoo.com* (N. Predincea)

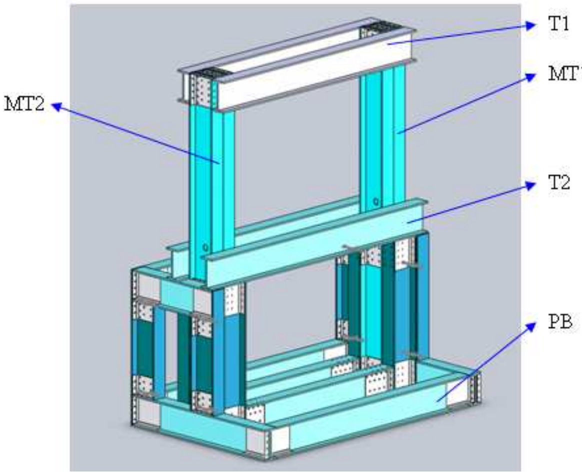

Fig. 2. Assembled bed.

The multifunctional machine tool can be equipped from simple to complex, depending on the prescribed processing. The devices used for attaching parts are designed modularized and intelligent functionality joining in CNC machine tools.

The cradle type is closed and is made of pulltruded composite profiles *I* 240. The main elements are:

- two double vertical beams (*MT*1 and *MT*2);
- one upper cross rail *T1*, for mounting the upper parallelogram slide;
- one horizontal beam *T*2, for mounting the longitudinal and transversal slides;
- the base plate *PB*, for mounting the inferior parallelogram slide and to support the entire system.

The machine structure, being done of six slides and two main spindles, the cradle has to be done as a special form, allowing cross paths these sleds and also easy access for installation and adjustment of operator tools and parts to be processed. Considering the conditions of machine tools cradles, the frame construction was made from profiled elements that allow a large stiffness during the movement of slides

In Fig. 2 was represented the assembled cradle that was done by the Mechanical Engineering and Research Institute [3]. The assembly was achieved by special angles stiffener, assembled by combining pulltruded profiles with screws. To increase the rigidity and safety assembly have used two pairs of nuts for each screw. Additionally, the contact areas of the profiles were fixed with a strong adhesive epoxy resin.

2. THEORETICAL AND EXPERIMENTAL REASERCHES

The determination of the frequencies and of the proper modes of vibration can be achieved by the modal analyses. The natural frequencies and the vibration modes are very important parameters for the designing phase because they provide information about the behavior of analyzed structures in dynamic regime [5].

Dynamic analyze of the machine-tool suppose the determination of the structure's proper frequencies, to which the structure of the machine can enter in resonance with important implications towards the work process. At the resonance frequency, the structure's deformations can be bigger than the static deformations, and this leads at large processing errors. There were determined ten proper frequencies, but there were enough 4, because these frequencies are increasing, and the work frequencies area is in the area of the first four proper frequencies. The proper modes of vibrations are shown in Fig. 3.

The feed motion on *Z* axis is carried out by a parallelogram mechanism. This mechanism and also the work plates were made of steel. The cradle and the longitudinal slides were made from composite materials.

In order to achieve the modal analysis, has been taken into account the mechanical characteristics of the steel and also of the composite material [5]. These characteristics were as follows:

- for the composite materials:
  - elasticity module $E = 5.2 \times 10^4$ MPa;
  - tangential elasticity module $G = 2.8 \times 10^4$ MPa;
  - Poisson coefficient: 0.23;
  - density – 1.655×10^{-3} Kg/m^3.
- for the steel:
  - elasticity module $E = 2 \div 2{,}1 \times 10^5$ MPa;
  - tangential elasticity module $G = 8 \div 8.1 \times 10^4$ MPa;
  - Poisson coefficient: 0.24÷0.28;
  - density 7.85×10^3 Kg/m^3.

The proper modes of vibrations are shown in Fig. 3.

In Figs. 4–7 the results of the modal analyses were represented, showing the proper frequencies of the entire structure.

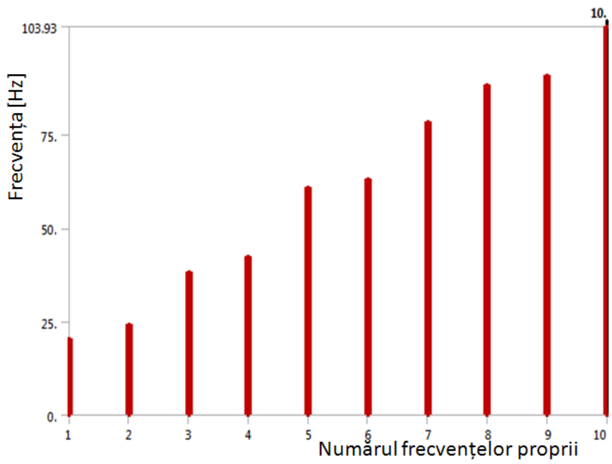

Fig. 3. The proper frequencies spectrum.

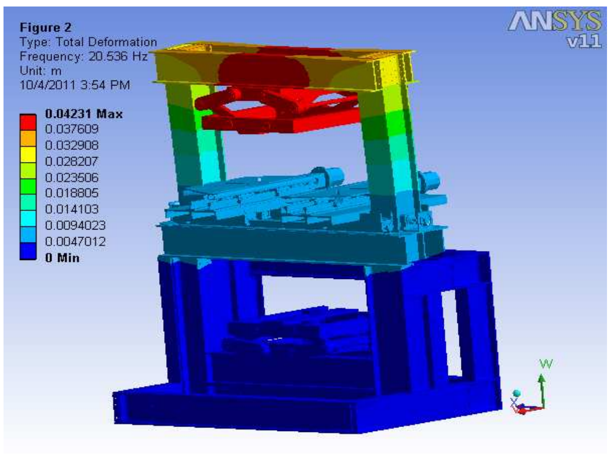

Fig. 4. The first vibration mode.

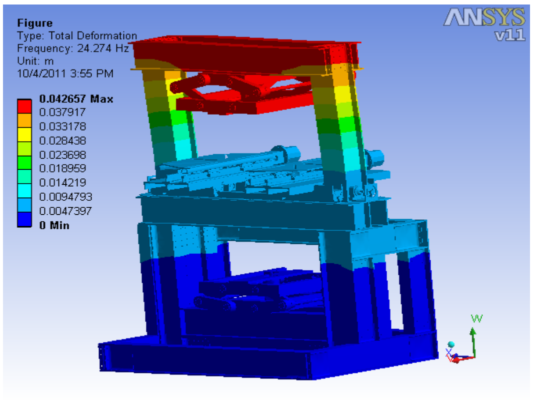

Fig. 5. The second vibration mode.

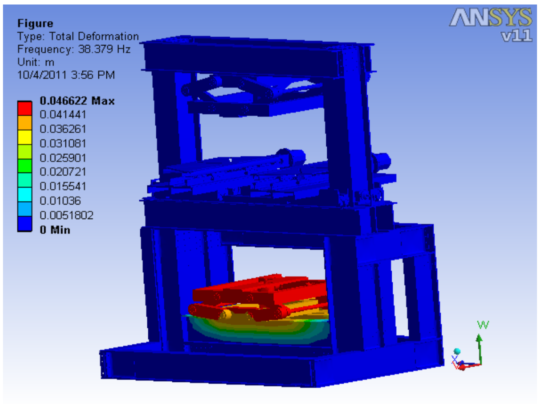

Fig. 6. The third vibration mode.

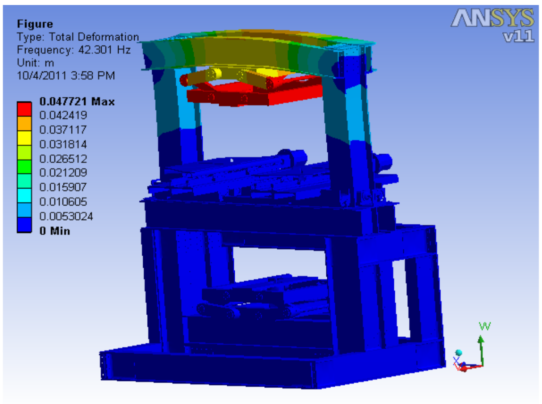

Fig. 7. The fourth vibration mode.

From the data obtained by finite elements was found that the structure is most solicited area from the entire structure is the upper beam of the cradle, and also the joints of the pulltruded profiles. On the top beam occur the lower proper frequencies that have a negative influence on the processing accuracy. It also notes that the bottom part of the cradle the frequencies have not registered with important implications because the stiffening of this area by the fourth inferior pillars.

In the experimental researches have determinate the proper frequencies of the structure and also the spectral response (amplitude spectrum-frequency). Determination of these data provides information in order to validate the theoretical researches.

The impulse by the hammer was applied on the structure, on the *Y* axis direction with the accelerometer mounted in 13 measuring points (Fig. 8). The points were distributed throughout the machine tool structure and then was performed the signal for determination the spectrum analyze on the three directions. For all measurements made in 13 points, it was taken into account the alignment of the three *XYZ* axes of the accelerometer with three axes of the tested machine tools.

The experimental researches were conducted on the directions of three coordinate axes by applying impulses on various areas of the structure. The accelerometer was mounted on the supporting structure, in different points, on *Y* and *Z* directions, and the direction of excitation was performed on *Y* axis of the machine [6].

The spectral analysis performed in the thirteen points, was found that the proper frequencies are different, although the structure is symmetric and the arrangement points was also symmetric.

Range of values for the proper frequencies of the structure is between 5.76 Hz and 694 Hz.

Analyzing the spectral response in the thirteen points, it appears that the more significant amplitudes recorded in P10 and P12 points, with values of 14.40 Hz, 149.75 Hz at 0.030 m/s^2, 0.045 m/s^2 amplitudes. The frequencies that were recorded at amplitudes below 0.001 m/s^2, probably accrue from the machine system as a whole. Points where were lowest vibration amplitudes were in P2 (Fig. 9) and P3 (Fig. 10). Most of proper frequencies were recorded in P13 (Fig. 11), and the fewest in P2, P3.

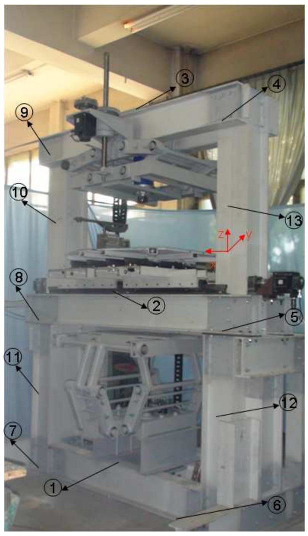

Fig. 8. The arrangement points of the accelerometer.

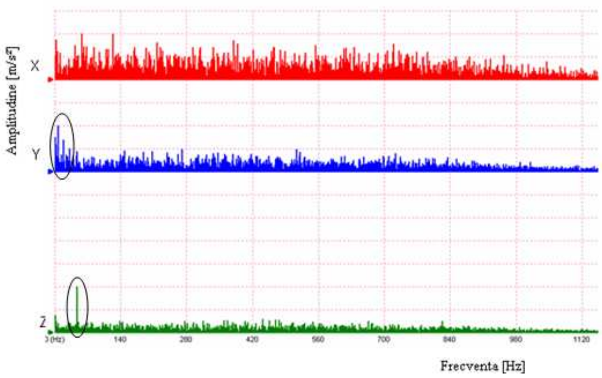

Fig. 9. Spectral response in P2.

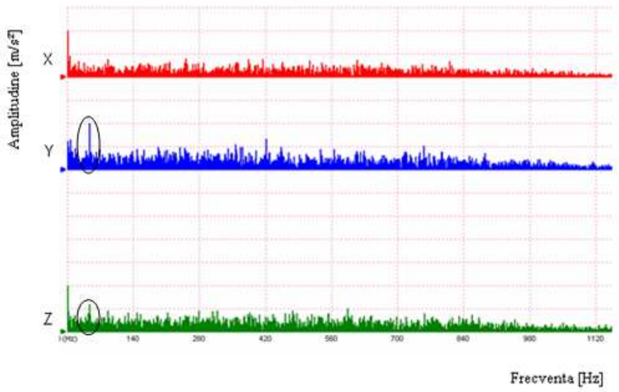

Fig. 10. Spectral response in P3.

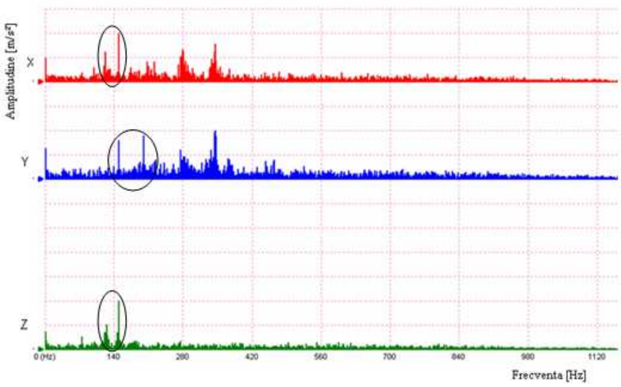

Fig. 11. Spectral response in P13.

Table 1

Comparative table

Frequencies obtained by FEM	Frequencies obtained by experimental reaserches
20.536	20.16
24.274	25.80
38.379	39.96
42.301	40.44
60.743	59.08
63.187	61.40
78.463	76.87
88.248	90.03
90.989	92.15
103.93	105.47

From this analysis, it notices that the machine is less stiffened on the side pillars than the upper and middle beams. These beams are rigid because of subassemblies both longitudinal and transversal slides and also of the upper parallelogram mechanism.

Analyzing the values from experimental researches and those obtained by finite elements method (FEM), has been found that the proper frequencies obtained by FEM can also be found in the spectrum obtained experimentally. These frequencies are shown in Table 1.

The differences between theoretical and experimental values are the result of the difference between the ideal structure used in finite elements analysis and the actual structure of the machine tool.

The comparative analysis between the two methods, it was performed the validation of the finite elements method.

Validation of the theoretical model with experimental research allows the static and also the dynamic behavior improved by appropriate constructive solutions and optimization of mechanical structure taking into account the other conditions of application of the structure.

3. CONCLUSIONS

From the theoretical and experimental data analyzing it was found that the most requested area is the upper beam of the cradle and also the joints of the pulltruded profiles.

In modal analysis, there were achieved the proper frequency modes, which if it coincides with the work frequencies may lead to the phenomenon of resonance, a phenomenon that leads to endless displacements for unredeemable structures and big displacements, for the redeemed structures. Desirable is that the proper frequencies do not overlap with work frequent field, for this purpose in pursuing the growth of these so that they will be working over frequency or lower than this [7]. If the resonance frequency cannot be avoided, it aims to increase the damping by introducing external damping [8].

After the study is seen as the proper frequencies of the structure are small, but the resonances effect can be reduced by increasing the external damps. However, the composite material that is made the cradle is a good damper vibration. The proper frequencies which cannot be modified can be removed by CNC and used software.

REFERENCES

[1] V. Vasiliev, E. Morozov, *Mechanics and analysis of composite materials*, Elsevier Science, First edition, 2001.

[2] *** www.fiberline.com.

[3] T. Maiwaki, *Multi-functional machine tool*, CIRP Annals – Manufacturing Technology, 57(2008), pp. 736–749.

[4] Project Multifunctional CNC machine for processing by turning, milling, drilling, boring, mortising, toothing and plane, cylindrical exterior and interior and helical rectification – Contract 45/2007 – developed between 2007-2009, within INNOVATION National Program – AMCSIT.

[5] M. Ginea, *Theoretical researches with FEM regarding the material which are used in modern manufacturing systems*, TechnoMarket, Bucharest, No. 12, 2009, pp. 18–22.

[6] E. Alămoreanu, R. Chiriţă, *Bars and plates made from composite materials*, Edit. Tehnică, Bucharest, 1997.

[7] E. Alămoreanu, C. Negruţ, *Calculation of composite structure*, Politehnica University Bucharest, 1993.

[8] D. Roşu, I. Goia, H. Teodorescu, *Static and dynamic behaviour of an extreme rigid and ultra lightweight sandwich structure*, The IVth International Conference of Machines dynamic CDM 2005, Braşov, 27–28 mai 2005, pp. 395–400.

.