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VIRTUAL MODELING OF A NUMERICAL CONTROL MACHINE TOOL USED FOR COMPLEX MACHINING OPERATIONS

Abstract: *This paper presents the 3D virtual model of the numerical control machine Modustar 100, in terms of machine elements. This is a CNC machine of modular construction, all components allowing the assembly in various configurations. The paper focused on the design of the subassemblies specific to the axes numerically controlled by means of CATIA v5, which contained different drive kinematic chains of different translation modules that ensures translation on X, Y and Z axis. Machine tool development for high speed and highly precise cutting demands employment of advanced simulation techniques witch it reflect on cost of total development of the machine.*

Key words: *numeric control axis, virtual machine design, machine tool, virtual product, computer aided design.*

1. INTRODUCTION

In the last recent years, a great progress has been made in precision machining. Nowadays, it is possible to make precision parts with submicron or even nanometer accuracy, which paves the way for many applications in biomedical, electronic or aerospace engineering. However, for the rest of problems into aeronautics and automotive industry a number of problems remain unsolved. For instance, the hardness of the cutting tools and workpiece pose a major limitation on the accuracy of the machined parts and tool life. To achieve high accuracy, ultra-precision machine tools are needed, which are very expensive. To improve the machining accuracy further without significant capital investment, real-time error compensation based on sensing and control techniques is needed. It is known that a machining process consists of four parts: (1) the machine tool structure including the motor and spindle; (2) tables of the machine tool and the driving systems; (3) workpiece; and (4) cutting process.

Machine tools are part of the working machines, designed to create surfaces of parts machined by cutting operation under certain conditions of productivity, accuracy, quality and cost [1].

The great variety of shapes and sizes of the parts used in technique, of the materials used to manufacture them, of their dimensional accuracy and the number of identical parts that must be executed in a certain time have led to a wide diversity of machine tools.

A machining centre is the machine tool provided with CNC numerical control equipment, with possibilities to perform numerous machining operations because the tools are automatically changed between the main spindle and a tool magazine. Two movements are required for cutting: cutting main movement (tool rotation movement) and feed movement – straight, circular or curvilinear movement of the workpiece or of the tool [2], [3].

In terms of construction, the numerically controlled axes of a machining centre can be equipped with linear motors or servo motors and leading screws – ball nuts; the functionality of the machine remains the same. Machine construction allows the use of long tools, rotation axes and other additional components [4], [5], [6].

2. CONSTRUCTION OF THE VIRTUAL MODEL

The bed of the machine is made of anodized aluminium profiles interconnected by means of screws. ISEL have used for many years aluminium as basic material for machine tool building. There is no rust or paint and such machines are suitable for different applications, like labs and food industry too [7], [8]. The bed allows the use of T slots profiles for the table. It also allows the use of various axes and it offers multiple possibilities of configuration. The sliding protective housing enables an easy access to machine table; it can be easily moved manually or can be equipped with motors for an automated opening/closing. The peculiarity of this construction is that the front part is sliding under the rear part and thus the access over the table is free from 3 directions.

Table 1

Technical specifications

Type of module	**ModuSTAR-MP100**
Travel distance on X/Y/Z (mm)	1.000 x 1.800 x 400
Table width-length (mm)	1.000 x 1.500
Opening (mm)	600 (max. 1.200)
Size: width-length-height	2.550 x 3.500 x 1.900
Travel speed on X/Y/Z axes (mm/s)	≤ 250 (max. 500)
Repeatability (mm)	≤ 0.02
Motor	Servo motors
Guiding elements	Adjustable ball screw assemblies
Command and control	

ModuStar machines use servomotors with ball screw drives. It is possible to use other types of motors that are compatible with the control systems [4], [5]. The pitch preferred for these screws is 5 mm but it can be also 10 or 20 mm optionally. ISEL linear motors have no return backlash and provide accurate positioning and high repeatability. The high travel speed of this alternative drive is adapted to the concept of the machine. The structural construction of ModuStar machine tool is presented in figure 1.

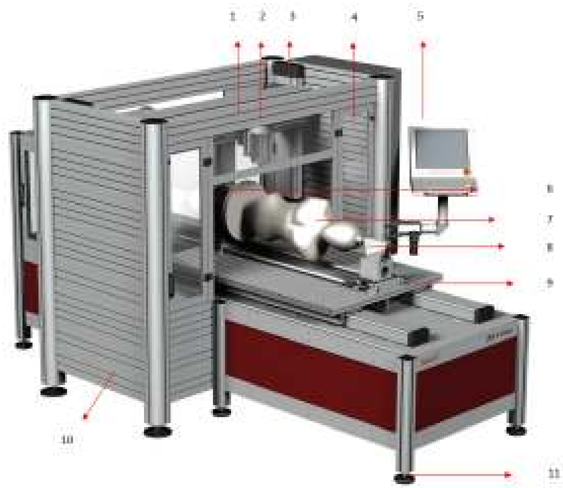

Fig. 1 CNC ModuSTAR MP 100d machine

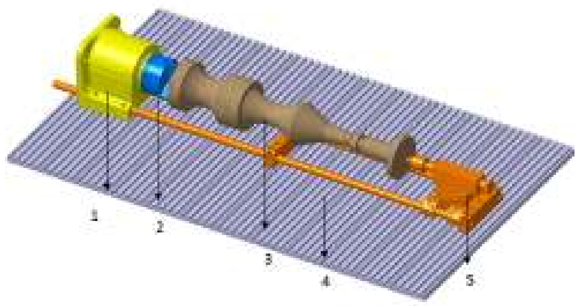

Fig. 2 Work piece clamped in the chuck of the machine

The components of the system that machines the workpieces are: 1 – rotary table RDH-M, 2 – chuck with 3 jaws Φ 125 mm RDH-M, 3 – workpiece, 4 – table of the machine, 5 – tailstock, as presented in figure 2.

Plates with T slots PT 25 type are used for the machine table. They have a standard size of 375 x 20 mm. Table dimensions are 1500x1000 mm. Thus there will be used 4 plates assembled on a connection support plate. These ones are ideal for determining the translational axes because they constitute a precise and stable support.

The machine is also equipped with three systems of translation to achieve the linear travels on X, Y and Z axes. These systems have modular configuration and can be used in different industrial applications.

These movement systems with linear travel are made of special profiles of aluminum alloy with high structural stiffness; they include ball screws, stepper motors or servomotors and also intermediate elements that provide the linear movement of the slider.

The components of the mobile unit, which define X axis, are highlighted in the following figures. Figure 3 shows the components included in the drive subassembly of the mobile unit. In figure 4 are highlighted the components that provide system operation, support of driving subassembly and the elements defining travel end (the damping elements situated at travel end and the limit stops).

Fig. 3 Organological structure of a translational axis

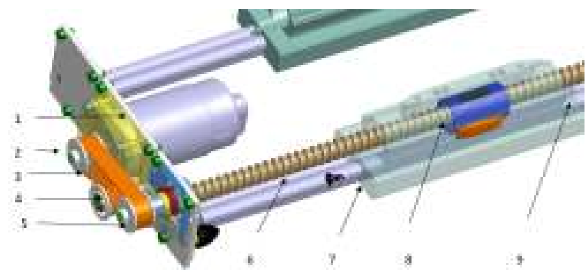

Fig. 4 Detailed representation of the drive for X axis

Thus the axis has the following functional structure shown in figure 4: driving servomotor 1 transmits the rotation movement by means of the transmission formed of the gear 2- clamped to servomotor shaft, toothed belt 3 and gear 5, ball screw 6.

Movement control is ensured by the pre-tensioning wheel 4 of the toothed belt. Rotation movement is transformed into translational movement by the assembly formed of the ball screw 6 and nut 7, located in the sliding shaft 8. This one is supported on the guiding bars 9 and serves to support the slide that moves on the mobile unit. The sliding shaft 8 is also providing the recirculation of the nut balls and is guiding inside the aluminum profile.

Figure 5 shows the system of clamping and supporting on bearings of the ball screw - nut system. The screw has a length of 1460 mm; it is supported at both ends by bearings represented by the flange provided with two bearings 1, located at the driven end, and by the flange from the undriven end 4. Flange 1 is fixed by the ball screw by means of the self-locking nut 2 and clamped to the covering plate 3 by means of hexagonal head screws.

If the length of the screw exceeds 1500 mm it is necessary to use a second pair of bearings to support the drive screw.

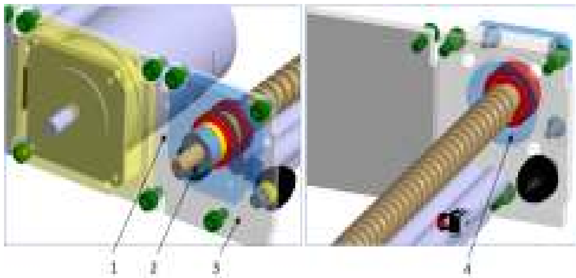

Fig. 5 System of clamping and supporting on bearings of ball screw-nut system for X axis

Figure 6 presents how are positioned the travel end dampers 1 and the protective limit stops 2. The cam 3 that actuates the limit stops is assembled on the sliding shaft that provides the translation movement. The limit stops are assembled inside the aluminum profile. They are positioned so they allow the slide to make a travel of 1000 mm such as shown in figure 7.

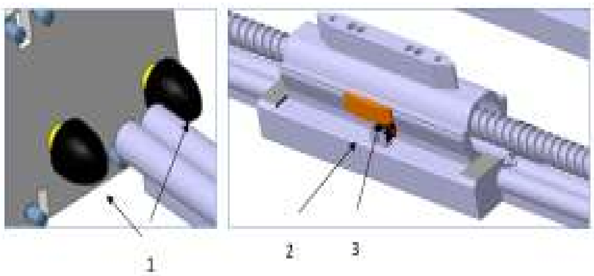

Fig. 6 Damping system at travel end and protective limit stops

Fig. 7 Example of maximum travel on X axis

Here in after we exemplify how the machine travels on Y axis. This is performed by means of a similar system, but, due to the problems that occur when driving a lead screw with a length superior to X axis, the driving system has been changed and it has been also introduced a supporting system for the ball screw.

Figure 8 shows the exploded view of the drive of this axis, with the following components: 1 - motor, 2 - coupling, 3 - support, 4 - screw, 5 - nut support, 6 - second support, 7 - support of motor, 8 - support flange, and 9 - second support of motor.

Figure 9 shows the drive kinematic chain of the module that ensures translation on Y axis.

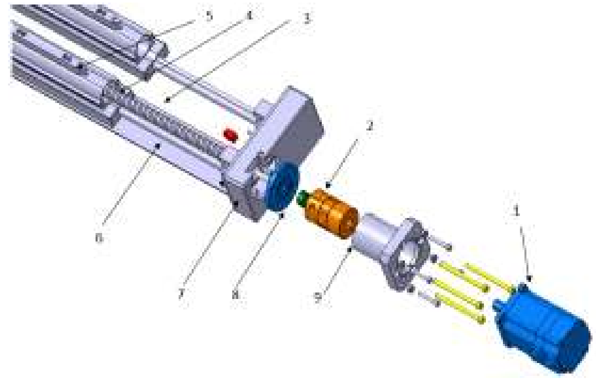

Fig. 8 Exploded view of Y axis drive solution

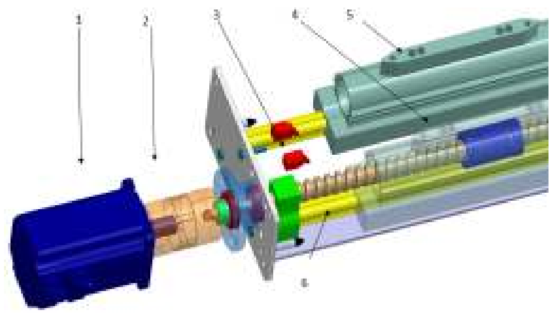

Fig. 9 Drive kinematic chain of the module that ensures translation on Y axis

Drive servomotor 1 transmits the rotational movement to screw 3 by means of coupling 2, fixed to servomotor shaft and to screw end. The rotation is transformed into translation movement by the assembly formed of ball screw 3 and nut 4, located in the sliding shaft 5. This one is supported by the guiding bars 6 and supports the slide that travels on the mobile unit. In the case of the designed machine there will be used two modular units of this type, with a considerable length. Due to the big length and the functional role of the two modules, in order to perform the translational movement of the machine table on Y axis there will be necessary 3 pairs of sliding axes – ball ways to support the table with dimensions of 1500mm x 1000mm.

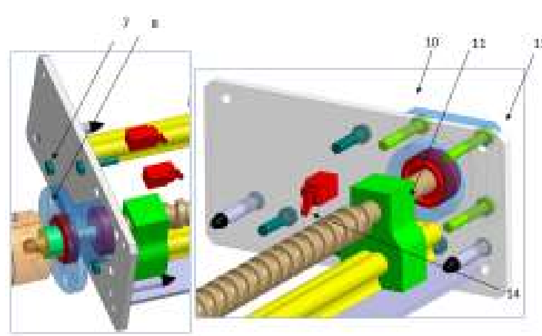

Fig. 10 Clamping and supporting on bearings the ball nut-screw system for Y axis

The screw has a length of 2890 mm. To avoid buckling, it needs an additional support (fig. 10). Same as in the case of the module shown above, the supporting on bearings is made at both ends of the screw. So, the flange with two bearings 7 is used to support the screw. Unlike the flange presented previously, at translation module on X axis, this flange is built especially for direct drive. The screw is locked on bearings by means of the nut 8. The free end of the screw is supported on the flange with bearing 10, fixed in the plate 13. The bearings 11 will be used additionally at each end (they are intended for screws with lengths superior to 1500mm).

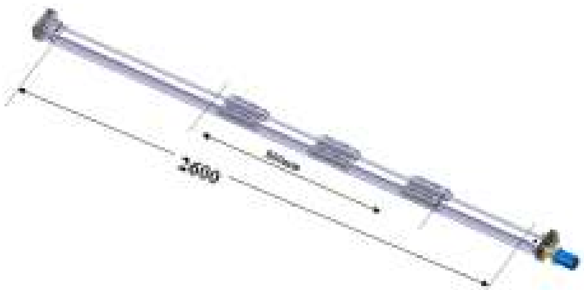

Fig. 11 Example of maximum travel on Y axis

Hereinafter in fig. 12 is shown the positioning of travel stop dampers 1 and mechanical limit stops 2. On the sliding shaft that performs the translational movement is assembled the cam 3 that actuates the mechanical limit stops fixed inside the aluminium profile. These ones are positioned so that to allow the slide to make a travel of 2600 mm.

Four travel limit stop dampers, provided with a spring, are clamped by means of hexagonal heads on the plates located at profile ends.

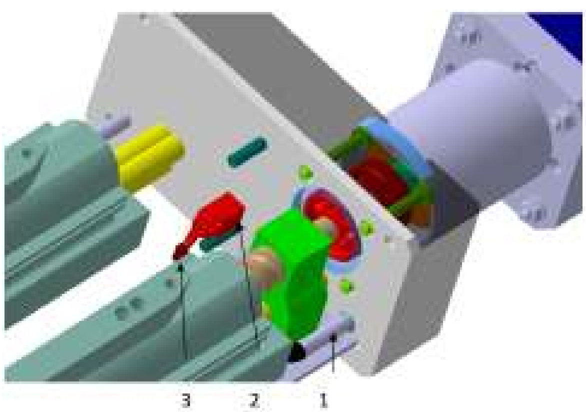

Fig. 12 Positioning of dampers and mechanical travel limit stops for Y axis

For the third axis of CNC machine, Z axis namely, there are used two driving systems similar to X axis, with a length of 490 mm, with the same features; that is why this topic has not been detailed anymore in the paper.

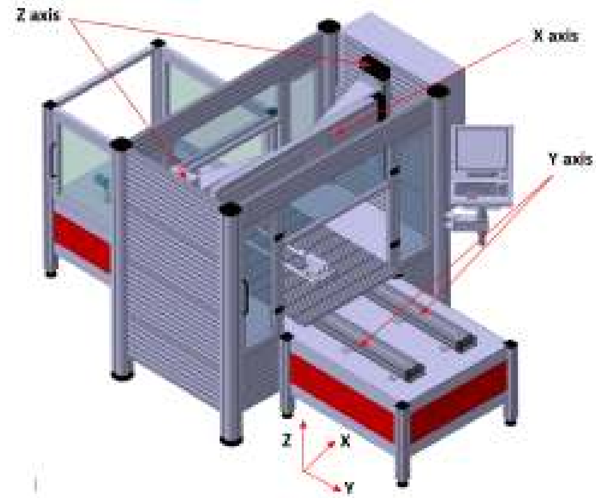

Fig. 13 Overview of the machine

Thus figure 13 shows the final organological structure of the machine. The X axis, located transversally, above the machine, is fixed by means of screws. As an option, it can be moved in height (gantry system). The peculiarity of X axis is that it makes possible the assembly of two Z axes which can be also moved independently.

Two translation modules are positioned on Y axis travel direction; they support the work table of the machining centre. So, the table moves during the operations of workpiece machining; the workpiece is clamped to the table by means of a clamping device with jaws.

In order to obtain bodies of revolution it is possible to implement a device meant to rotate the workpiece during machine operation.

The feed movement of the cutting tool assembled in the integrated shaft of the machine is performed in Z travel direction, formed of two translation modules.

These two axes can use two independent tool changers. The tool changers are accessible from the outside through the access doors, making them very easy to use.

Thus in figure 14 is shown the machine table that makes the translation movement on the two modules of translation that define Y axis. The rotation axis is positioned on the table; this axis includes also the workpiece clamping system. The gantry type structure, with two axes numerically controlled, is formed of 3 modules of translation.

For X axis – horizontal travel of the slide on which is fixed the integrated spindle that performs the milling-boring operations, a module with the length of 1490 mm is used - the necessary travel is 1000 mm. This module is positioned transversally.

For Z axis, the travel of the transverse module in vertical plane is performed by means of two modules of translation with a length of 490mm; the required travel is 400mm.

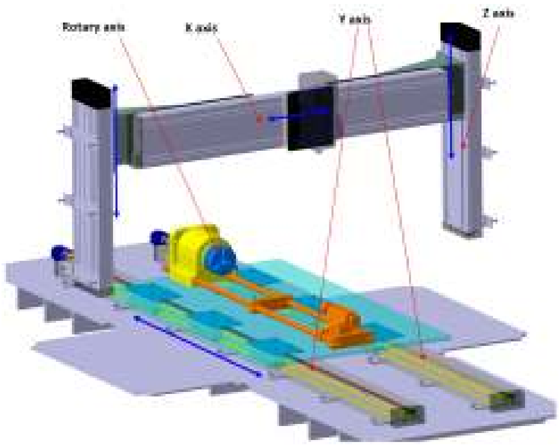

Fig. 14 Structure of numerically controlled axes of the machine

3. WORK PHASES

The main elements of the structure, correlated with the operations performed, are:

1. subassembly for travel on Y axis;
2. rotation subassembly;
3. subassembly for travel on Z axis;
4. subassembly for travel on X axis.

The work phases are as follows:

1. In the first work phase, the material to be machined is clamped on the rotation subassembly by means of a clamping system, as is show in figure 15.

2. The second work phase starts from the moment when the rotation subassembly which is fixed on the machining table is transported by the subassembly for travel on Y axis inside the structure. The table travels with a certain speed allowing the machining of the material.

3. In the third phase the two travel subassemblies (on Z and X axes) move in the two directions to perform the wanted shape of the workpiece. The milling operation itself is made inside the structure designed. The interior structure is isolated from the external environment during machining operations to protect the machine operator and to ensure cleanliness of the area around the machine tool. These two phases is presented both in figure 16.

Fig. 15 Phase 1 of machining cycle

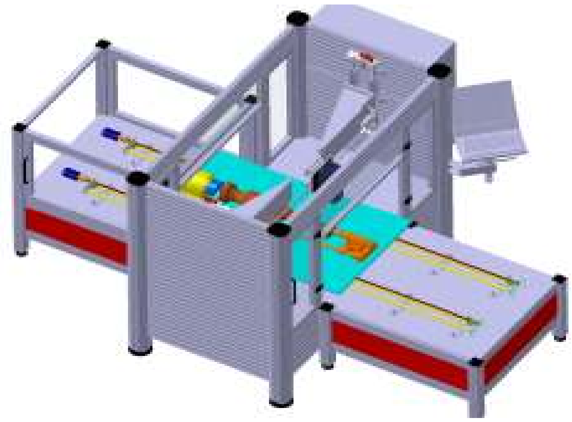

Fig. 16 Phases 2 and 3 of the machining cycle

4. Last phase – detailed in figure 17 - is when the machining table moves to the exit from the machine tool structure and the material machined is taken over from the driving system in rotational movement where it was fixed.

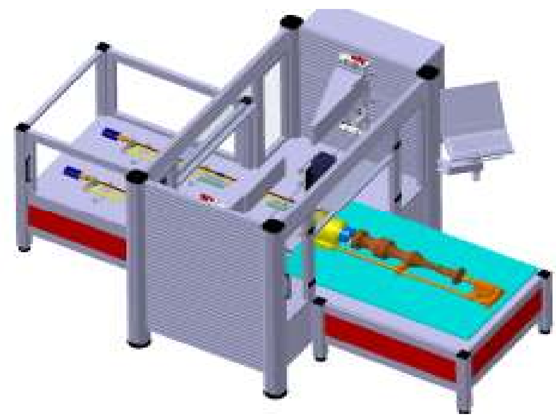

Fig. 17 Phase 4 of the machining centre

4. CONCLUSIONS

The virtual machine considers the interaction between the mechanics of the machine (including structural flexibility) and the control system. This paper exemplifies the usefulness of the virtual machine as a tool for product development.

The machining centres are used this way to obtain a wide range of parts in different technological configurations with high accuracy such as required by the respective application. Their design using a virtual model is very helpful in terms of costs reduction because it allows to make and view the machine before its physical manufacture. This fact is really useful in the case of special purpose machine tools or the machines that must perform complex operations or work in special environments such as the industrial environments where product packaging is done in a protective atmosphere.

The optimization of the virtual product (the future real product) can easily be made without any kind of risks (financial, functional, technological, human etc).

Theoretically, all the aspects presented in figure 1 can be simulated and studied with high performance CAD-CAM-CAE software. Today computer aided design is a usually step in product conception. The other aspects just began to be applied in the civil industry (machine tools, automotive etc.), but the performances of new products are obviously better than before.

REFERENCES

[1] Paraschiv, M. D., Bîșu, C. F., Zapciu, M. (2014). *Contributions to positioning accuracy during linear motion of cnc machine tool table,* Proceedings in Manufacturing Systems, Volume 9, Issue 1, pp 53−58, ISSN 2067-9238, Bucharest.

[2] Enciu, G. (2006). *Electromagnetic fields of RFID technology applications in AS/RS structures of industrial logistics*, Proceedings of the 15th International Conference on Manufacturing Systems, Published by Editura Academiei Române, pp. 197-200, ISSN 1842-3183, Romania, 26 – 27 October, 2006, Bucharest.

[3] Enciu, G. (2006). *About some elements for design of AS/RS shelves in industrial logistics*, Proceedings of the 15th International Conference on Manufacturing Systems, www.icmas.eu, Published by Editura Academiei Române, pp. 201-204, ISSN 1842-3183, Romania, 26 – 27 October, 2006, Bucharest.

[4] Enciu, G., Popescu, A. (2011). *Researching and achievement of a sensor testing stand*, Proceedings in Manufacturing Systems, Vol. 6, ISSUE 4, 20-th International Conference on Manufacturing Systems, Published by Editura Academiei Române, pp 29-36, ISSN 2067-9238, Romania, 10-11 November, 2011, Bucharest.

[5] Ispas, C., Mohora, C., Anania, F. D., Paraschiv, M. D. (2007). *Virtual Design Methods for the New Products,* Proceedings of the 16th International Conference on Manufacturing Systems – ICMaS 2007, ISSN 1842-3183, Romania, 14-15 November, 2007, Bucharest.

[6] Enciu, G., Nicolescu, A. F., Dobrescu, T. G., Popescu, C. A. (2012). *Industrial sensors testing*, Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium, Editor B. Katalinic, Published by DAAAM International, ISSN 2304-1382, ISBN 978-3-901509-91-9, Croatia, 24-27 October, 2012, Zadar.

[7] Enciu, G., Nicolescu, A. F., Ivan, A. M., Briceag, C. (2009). *CAM software package and light jig boring and milling machine tool*, Proceedings of the 2nd WSEAS International Conference on Environmental and Geological Science and Engineering (EG '09), September 24-26, 2009, Brasov, Romania, ISBN 978-960-474-119-9, ISSN 1790-2769.

[8] Nicolescu, A.F., Enciu, G., Stanciu, C., Stanciu, M.D. (2008). *Engraving, Drilling and Milling Application Software Developed for 2 ½ Milling Machine Tool MGC 450*, Oproteh 08 – constructive and technological design optimization in the machine building field, November 01-03, 2008, Faculty of Engineering, University of Bacau.

[9] Zaeh, M. F., Hennauer, M., Poehler, A. (2007). *The Machine Tool of Tomorrow: An Optimised, Complete System*, in: Sixth International Conference on High Speed Machining 2007, San Sebastian, March 21 – 22.

[10] Fredin, J., Wall, J., Jönsson, A. & Broman, G. (2007). *A robust motor and servo drive model for real-time machine tool simulation*, Proceedings of the 19th European Modeling and Simulation Symposium (EMSS 2007), Bergeggi, 4-6 October 2007.

[11] Installation and Maintenance Manual, available at: https://www.isel.com/germany/?lang=en, *Accessed*: 2015-08-10.

[12] Automatization catalog: https://industrial.omron.ro/ro/products/catalogue/automation_systems/software/configuration/cx-one/default.html, *Accessed*: 2015-08-15.

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