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Virtual Analysis of Machine Tools

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Abstract: The article describes the identification of the impacts of the machining process itself, as well as the influence of the properties of the machine tool construction, allows to predict and subsequently optimize its design in terms of its working accuracy. The practical importance of virtual machining is primarily the reduction of financial costs and acceleration of machine design without the need to produce a physical prototype. Using simulation models, it is possible to repeatedly analyze the weaknesses of machine construction, to identify the impacts of individual machine components on their properties and to optimize them, but also to take account of ergonomic and other requirements.

Keywords: *Virtual reality, VRML, CNC lathe.*

1. Introduction

Production at the beginning of the 21st century is affected by the global financial and general crises. However, perhaps because of this, we are witnessing significant shifts towards the variety of products demanded with prices equal to or lower than those of standard products and delivered anywhere in the world to a brief customer call. In general, it is possible to say that there is obviously no human activity field that is not related to the production technique, with the dominant position obviously the machine tools. Machine tools are involved (whether directly or indirectly) in the production of virtually any product, so improving, streamlining, increasing the quality of production, and being able to respond flexibly to customer requirements are essential. Machine tool manufacturers are constantly working to reduce the time and cost needed to bring the new machine to market. Considerable time savings can be achieved at the development stage of the new machine by gradually eliminating the need to manufacture its prototype, and the properties of the newly engineered machine will be verified on simulation models. This principle of so-called Virtual prototyping is already commonly used, for example, In the aerospace and automotive industry, and is supported by the existence of powerful hardware, as well as perfect software products. Computational design support for machine tools with finite element analysis is now a common part of their development process. Standard calculations of static, dynamic (modal analysis) and thermal properties of constructions are performed. However, the requirements for the level of machining of machine tools are constantly increasing. Solution is also required on the market to shorten production times and to make the production process more efficient, while increasing the accuracy of workpieces. High-Speed Cutting applications are highly dynamic processes that have to be tailored to the design and construction of machines as well. Standard computational simulation methods can no longer be sufficient to successfully meet all of the requirements for the construction of advanced leveling machines.

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2. Supporting the design of production systems by using virtual reality systems

Developing virtual reality systems designed for applications in technical practice is constantly struggling with a lot of difficulties. In order to fulfill the assumption of a more massive expansion of virtual reality systems, it is necessary to align several virtual reality subsystems into a single coherent system in different workgroups. Only with the perfect coordination of virtual reality systems is it possible to achieve the desired results. Therefore, it is necessary to focus the efforts of development teams on the problem of defining communication protocols and open interfaces to allow communication between different types of virtual reality systems. One of the ways at least to help solve this problem is distributed virtual reality systems that allow technicians in different locations to work simultaneously on the same virtual prototypes. The world's most popular computer network is now the most popular transmission path for this purpose.

The Fraunhofer Research Institute in Germany is one of the most renowned foreign institutions involved in the development of virtual reality systems for planning and designing manufacturing factories. At this workplace, Mowib has been developed to allow users to manipulate individual devices during the process of designing production units. For example, it is possible to change the layout of the machinery in the production hall and to immediately determine the impact of this change on the production process. By using direct feedback and tightly linking the interactive virtual reality system with the dynamic simulator, it is easier to design optimal layout of production facilities in a factory building. Such a way of using virtual reality in designing production systems makes it possible to exploit the rich experience of factory workers who are usually not part of the design group. However, these have several years of experience with the use of devices and systems that are designed and may even be the future workers in the production workshop that they help design.

An interesting application developed by the staff of this institute is a virtual system designed to plan assembly technology. It is ideally suited for the automotive industry and can be used to verify the reality of the optimal assembly of the assembled components, the real-time manual installation and the ergonomic aspects of the manual assembly (for example, if the installer's hand has enough space to handle the part without problems). Taking into account the mobility of the wrist, the heel and the shoulders. A significant development of such ergonomic design is the use of virtual models of the human body with its own biomechanical intelligence. In our current practice in virtual reality, the greatest attention is paid to the ability of CAD / CAM / CAE systems of the higher class to create an export (export) VRML format. The created file can then be sent to the collaborating organization via the Internet if it does not have the CAD / CAM / CAE system directly available, but the VRML file can be viewed either by specially developed browsers or directly by an Internet browser (eg Netscape Navigator from Netscape). An example of an industrial robot image in the CAD / CAM / CAE EDS / Unigraphics system from Unigraphics Solutions, USA, is in figure 1.

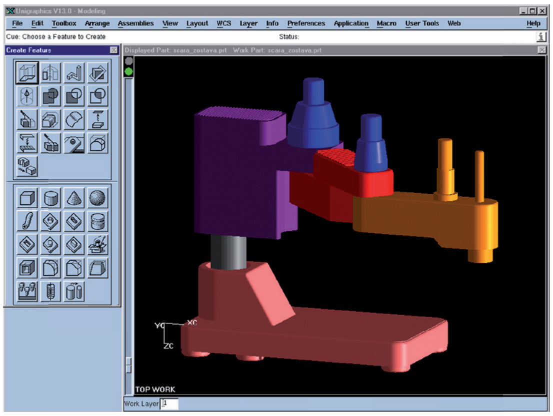


Fig. 1: *Example of industrial robot imaging in the CAD / CAM / CAE system environment.*

VRML (Virtual Reality Modeling Language) is a special 3D definition ASCII file format that is supported by the latest web browsers. The VRML option picks up the current view of the volume and surface bodies in the CAD / CAM / CAE system and writes this data to the VRML file. The program converts the body into polygons and adjusts the properties of the materials, and uses the existing data from the photorealistic module (eg Photo module) in the current view to define light. Depending on the type of Internet browser you are using, a VRML file can be viewed in 3D using zoom, rotation, and model flight techniques. The VRML output dialog box uses the part name as the default output file name in most CAD / CAM / CAE systems that support this output. The output file name can also be changed when specifying the VRML file version. Latest versions of CAD / CAM / CAE systems support both output formats VRML 1.0 and VRML 2.0.

A VRML export filter for some CAD / CAM / CAE systems allows you to add a so-called "anchors. The anchor is a hyperlink that can be routed from a body geometry or a wall to another source in the WWW system. This source can be e.g. HTML page, other VRML file, image, or any type of data that can be processed via the WWW. An anchor can be added to a part by a string attribute that contains the address (URL) of the source (e.g., http://www.mcord.com). This attribute must also be assigned to the wall or body. The value of the string attribute becomes an anchor in the VRML file.

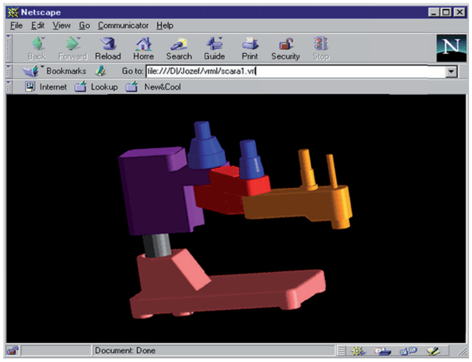


Fig. 2: *View of an industrial robot in Netscape environment.*

This feature extends the output options to VRML and allows you to link VRML data with additional information. You can, for example, Create a product library based on VRML. As soon as the user clicks on the VRML model, the product description page may appear. This feature can significantly improve data access over the Internet or corporate intranet. In figure 2 is a view of an industrial robot displayed in the Netscape Internet browser environment via a VRML file.

3. The virtual machining methodology

The virtual machining methodology was also applied to the EMCO PC TURN 50 virtual machine model. This CNC lathe is designed for machining less rigid basic types of materials by turning in various CNC control modes (point, segment, continuous). The lathe has three driven axes (X, Z, C). The machine's conceptual character is the solid spindle, the unchanged height of the tool head, and the possibility of undercutting the machined part with the hook. In mathematical modeling, we will not consider bevel support and one end of the machined part will be free. The basic position of the spindle axis is horizontal. The longitudinal and transverse support is inclined at an angle of 45°. The design arrangement allows simple and effective removal of the chips from the machining area. The overall view of the EMCO PC TURN 50 lathe is in figure 3.

Fig. 3: *View of the EMCO PC TURN 50 Lathe.*

The simplified machine model is illustrated in figure 4 and consists of the following six model bodies: T1 - spindle, T2 - spindle, T3 - bed, T4 - longitudinal sash, T5 - transverse sash and T6 - tool head.

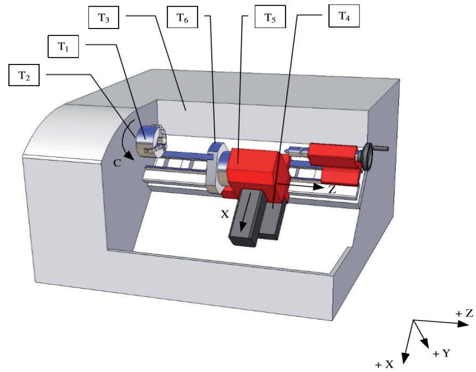


Fig. 4: *Simplified computational model of the EMCO lathe.*

On the basis of the detailed calculation models of each machine node it is possible, as in the previous cases, to define the individual transformation matrices and vectors necessary to compose the equation of the ideal trajectory of the tool contact point, respectively. For virtual machining. The computational model of the EMCO lathe is shaped

$$\{K_{43}\} = \{d - e\, z_{04}\}^T$$

because the position of the start of the longitudinal carriage coordinate system is not in the vertical plane of the bed symmetry.

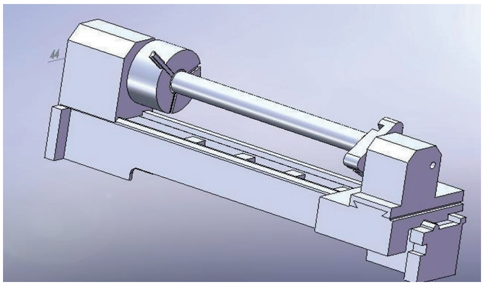


Fig. 5: *Dynamic calculation model of the EMCO lathe.*

4. Modal analysis of the EMCO lathe

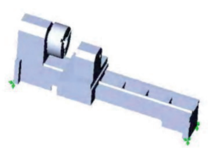
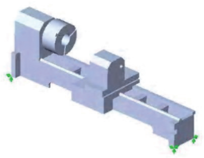
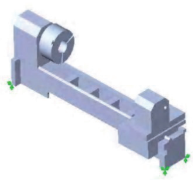
Modal analysis of the virtual EMCO lathe model was performed on the basis of the modified dynamic calculation model shown in figure 5. The calculation of the custom frequencies and the custom oscillations in the free oscillation of the lathe was carried out in Cosmos DesignStar 4. The individual parts of the machine were modeled in Solid Works 2008.The numerical analysis of EMCO's free vibration was performed at three positions on the machine bed (see Table 1):

- ***The support is in the left extreme position (with the spindle) - variant A;***
- ***The support is at the middle of the bed - variant B;***
- ***The support is in the right extreme position - Variant C.***

Numerical analyzes did not address the influence of spindle or horses on the spectrum of the machine's own frequencies because these model bodies are located above the "legs" of the machine that are firmly anchored to the base structure of the lathe.

The results of the modal analysis of the virtual EMCO lathe model are outlined in tab. 1 (the first five custom frequencies) and figure 6 to figure 8 respective own waveforms. From the analysis of the results of the numerical simulations of the free oscillation of the lathe, we can see that the lowest value of the first machine's own frequency is in variant B, which is 149.64 Hz. This is in accordance with the physical nature of the problem because in the span of the span, the bed has the lowest stiffness and if we replaced the whole dynamic system with a single discrete model, it would also result from the solution of the corresponding differential equation for the calculation model. The numerical value of 149.64 is trouble-free because the maximum spindle speed of the machine 3000 min-1 corresponds to a possible oscillation frequency of 50 Hz, which is deep below the first resonant area. Experimental Verification of Numerical Analysis of Free Vibration of the Designed Dynamic Computational Model was performed directly on the EMCO PC TURN 50 numerically controlled turning machine using the

Tab. 1: *Description of fabrics.*

	Variant A	Variant B	Variant C
Calculated custom frequencies			
	[Hz]	[Hz]	[Hz]
f_{01}	169,59	149,64	304,02
f_{02}	267,32	241,51	387,91
f_{03}	383,03	372,16	431,62
f_{04}	463,01	435,32	465,22
f_{05}	591,78	542,12	550,23

Adash 4100-Ex vibration analyzer. In order to detect the spectrum of its own frequencies, the classical method of exciting the oscillation of the dynamic system using a resonance hammer (tapping on the bed of the machine) and sensing the acceleration of the trembling with a piezoelectric sensor was used.

Experimental Verification of Numerical Analysis of Free Vibration of the Designed Dynamic Computation Model was performed directly on the EMCO PC TURN 50 numerically controlled turning machine using the Adash 4100-Ex vibration analyzer. In order to detect the spectrum of its own frequencies, the classical method of exciting the oscillation of the dynamic system using the resonance hammer (tapping on the bed of the machine) and sensing the acceleration of the trembling with a piezoelectric sensor was used.

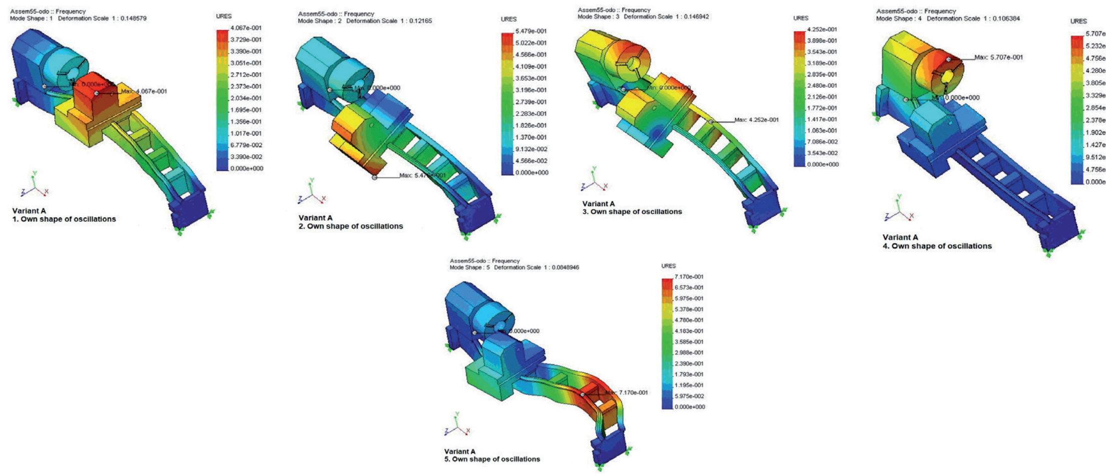


Fig. 6: *Custom Shapes of the EMCO Lathe - Variant A.*

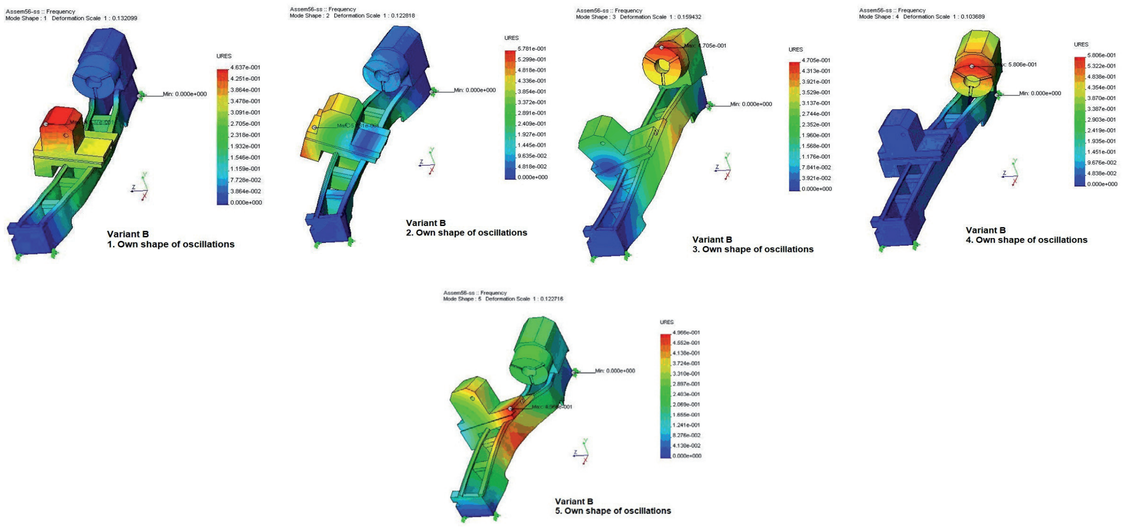


Fig. 7: *Custom shapes of the EMCO lathe - variant B.*

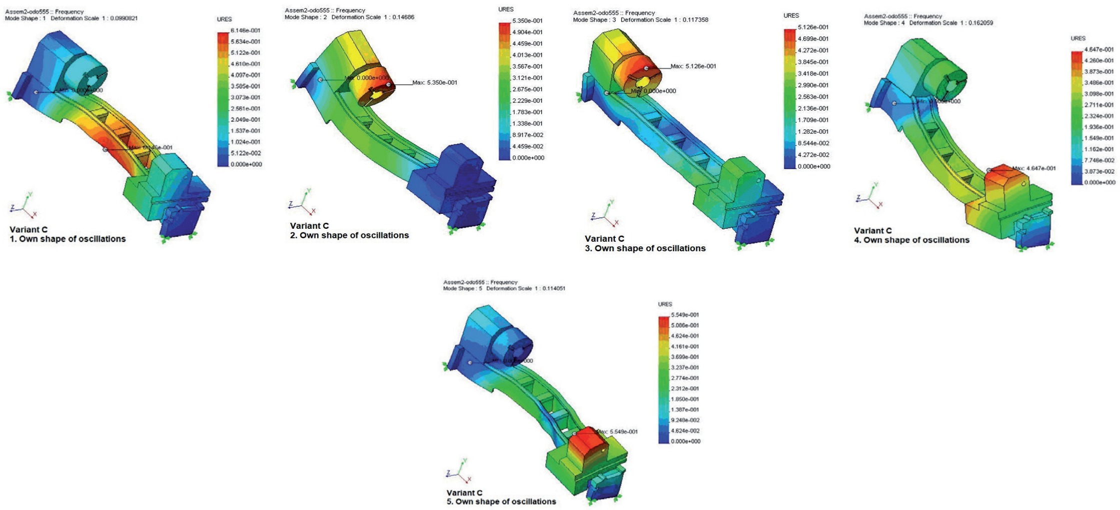


Fig. 8: *Custom Shapes of the EMCO Lathe - Variant C.*

5. Conclusion

The behavior simulation of the mechanical part of the design of the machine is to be judged taking into account the processes and processes that are directly related to the operation of the machine and which significantly affect its properties and the achievable accuracy of machining. At the world's EMO machine exhibitions, a number of computational simulation solutions have been recorded over the years in all of the listed areas. The production and testing of the physical prototype of any technical facility are time consuming and financially demanding. Therefore, it is necessary to intensify the research, development, verification and implementation of various methods of rapid prototyping. One of the possibilities is virtual prototyping of machine tools based on the principle of virtual machining, in which the properties of the proposed technical work on its mathematical models are tested.

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