Modelling of spindle nodes for machining centers

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Abstract. Unified spindle nodes constructions of machining centres for drilling-milling and boring types are considered in this paper. 3D modelling of the main components for the spindle units on the rolling bearings is performed, including the construction of complex assemblies, kinematic schemes for shaping the body parts and various kinds of tool modules for machining. The efficiency of transparency mapping procedure both in realistic and grid mode is noted. Parametric models of spindle nodes are developed on the basis of dyplexed angular contact ball bearings, established according to the schemes "dyplex" and "triplex". The geometric core of the APM Graph module is used to parametrically set the position of the rod elements and the coordinates of their nodes in the 3D-representations of the machine spindle. Two feedback loops have been introduced in the complementary procedure for spindle modeling related to the change in the types of supports and calculation methods. A study of the efficiency to design of the spindle-boring block assembly by the rigidity criterion is carried out.

1. Introduction

Metal processing has been industrially applied for drilling-milling and boring machines that have significantly increased technological capabilities due to the integration of processing centers into complex-automated systems [1-3]. These machining centers are distinguished by module design principle of their construction and possibility to create numerous machine tool modifications. Meanwhile, the effectiveness of its introduction is largely related to the development of forming units using the modular principle. Growing diversity of tool blocks nomenclature (as auxiliary and cutting tools) and rising requirements top-product quality need complex studies of spindle nodes for machining centers in Computer Aided Design (CAD) environment [4].

In numerous studies of workability associated with stress-strain state of spindle nodes (ShN), the initial stage of research efficiency is creating 3D model of these nodes in CAD environment. Based on 3D model, new approach for the estimation of static stiffness in machine working space has been analyzed by means of high-performance computerized Computer Numerical Control (CNC) [5], which considers a parametric model with six directional static rigidity for designing and evaluating rigidity in machine working space. Products machinability during its life cycle of a triaxial milling machine equipped with tool rigging of type Bridgeport DIN 69871 are considered in [6]. The authors use system approach to estimate processing efficiency based on the interaction between basic forming units of machine tool like feed drive, spindle unit and tool system by author. Application of ISO 230 series as auxiliary tool corresponds to machines of first and second sizes. CAD SOLIDWORKS and CAD ANSYS software was fully used for building 3D model of a spindle with a CNC lathe and its finite element method [7]. When the spindle is formalized, a 10-node rod model with three degrees of freedom is used in each node. Analysis of dynamic characteristics at 5 natural frequencies and spindle
oscillation modes with allowance for changing load made it possible to predict the behavior of the product outside the resonance zone and to estimate the rigidity index with the domination of bending stresses. At the same time, the authors noted the need to simplify the original 3D model (removing bevels, small holes and other structural elements) in the process of converting 3D file formats between SOLIDWORKS and ANSYS.

For effective design and research of the forming units for the machining center, the corresponding sections of the parameterized databases of spindle nodes structures and specialized tooling are needed. To enhance the competitiveness of such 3D models for construction must be supplemented by a photorealistic representation using rendering and animation programs. Hence the requirements for resources and capabilities of applied CAD. The variety of technological operations and the corresponding design schemes leads to the need to take into account feedback in the process of creating construct. The choice of support bearings (especially the front spindle supports) and loading methods predetermines the position and coordinates of the rod elements and their nodes, and thus the shape and dimensions of the 3D model. Moreover, the calculation methods and procedures of the investigation will depend on the loading scheme, as well as the number of iterations in the mode of multivariate design for the spindle units.

This article is devoted to the creation of sets of 3D models for spindle nodes of the most common third-level and fourth-dimensional machining centers and modeling of their designs. The main software product is integrated CAD/CAM/CAE KOMPAS-3D with built-in modules Artisan Rendering and APM FEM finite element analysis of structures.

The article deals with the features of the process for designing two-bearing construction of spindle assemblies, which are mounted on rolling bearings with different layouts and various preload forces. For varied machining operations, the applied tool blocks (for drilling, milling and boring), introduce changes in the procedures for constructing models of the structures spindle unit and the methods for calculating them.

2. 3D modelling of spindle nodes
Modern forming units of metal-cutting machines are closed dynamic systems using modular tooling equipment [8]. In order to examine the stress-strain state and to use finite element methods it is necessary to build 3D models of individual parts and assemblies of ShN in the integrated CAD KOMPAS-3D with the APM FEM module [9-11].

As a basic construct, the ShN of CNC machining centers the MTs200, SF68, SF16 and SBM1 models [12], embedded in the main drive of the machine tools is considered. The developed 3D model of drive for the SF68VF4 machine with the use of KOMPAS-3D resources specifying the parametric links and connection between 3D assembly individual components is presented in Figure 1.

The drive under consideration in the matching mode with the turntable provides machining of the parts from all sides, as well as coaxial boring of the holes without reinstalling workpieces. The kinematic chains realizing the execution of a complex for technological operations typical for drilling-milling and boring machines are shown in Figure 2a and 2b.

![Figure 1. Two-stage drive of the main movement of machine tool SF68VF4 model.](image-url)
3. Controlling the image of the spindle assembly

To create ShN 3D models we used image control operation related to the transparency display gaining modeling procedure productivity. Although computer resources were not fully used, fast loading of complex assemblies and fast rotation were carried out.

The grid and realistic transparency mapping was also used in assembly editing mode (these settings were applied only to objects that were not edited). Nevertheless, there were difficulties in realistic transparency design (Figure 3a) due to errors in displaying objects behind semi-transparent object. Therefore, we used mesh transparency promoting correct mapping of overlapped objects. Figure 3b shows ShN 3D model for the machining center MTs200VF4 developed by the authors in the mode of grid transparency.

![Figure 2](image1.png)

**Figure 2.** 3D kinematic schemes of machine tool SF16MF3 (a) and SVM1VF4 (b).

![Figure 3](image2.png)

**Figure 3.** Effects for ShN in 3D modeling.

To provide information support and the promotion of machine tool production, it was necessary to represent product using attractive and informative images of its form and design. Artisan Rendering application is generally used since it is integrated into CAD KOMPAS-3D CAD and allows obtaining high-quality image and design documentation [12]. So, we applied Artisan Rendering settings to obtain photorealistic view of spindle nodes of MTs200VF4 machines (Figure 4a) and SF16MF3
(Figure 4b) based on the control of lighting parameters, camera characteristics, and background selection.

![Image](image1.png)

**Figure 4.** Spindle node rendering: a – MTs200VF4; b – SF16MF3.

It is often required to evaluate the mutual motion of ShN parts and to monitor the trajectories to identify design limitations. Creation of animation rollers for projected ShN helps designers and technologists to quickly understand the arrangement of the product and to learn assembly-disassembly order. For SF16MF3 machines (Figure 5a) and SVM1VF4 (Figure 5b), assembling-disassembly animations have been built.

![Image](image2.png)

**Figure 5.** Animation tools in CAD KOMPAS-3D: a – SF16MF3; b – SVM1VF4.

Along with spindle nodes unification, we consolidated and tooled machining centers. Figure 6 shows the design of the tool blocks used in the above-mentioned CNC machine tools – boring for hole machining (Figure 6a) and milling for processing flat surfaces (Figure 6b).

![Image](image3.png)

**Figure 6.** Tool blocks of machining centers: a – boring tool; b – milling tool.
4. Discussion

When constructing ShN 3D model for CNC machining centers of drilling-milling-boring type equipped with a variety of tooling, there is strong attention to the relationship between tooling type and design and constructive features of ShN models [4]. This refers both to spindle schemes and to 3D models based on the rod elements. In the process of constructing the rod element on the stage of determining its length, the construct of the front support was taken into account. Here rod node position was determined by type, number, and installation scheme of bearings. Three-rod representations connecting the drive element assemblies (gear [13], toothed half coupling [14] and belt transmission [13] – coordinate b) are used for spindle nodes for machining center; the support nodes are the coordinate l and the spindle offset from the front support is the coordinate a. The high-precision radial-thrust two-row tapered roller bearing [15] is installed on the front support of the spindle in the machine SF16MF3 [15], providing increased stiffness of the support (Figure 7a). The node’s position of the rod 2-3 is determined by coordinate a (Figure 7b). The front support of triplex-X type of MTs200VF4 machine, is mounted in the dyplexed radial-thrust bearings (Figure 8a) and the node of the rod 2-3 is determined by the coordinate a.

![Figure 7](https://via.placeholder.com/150)

**Figure 7.** Front bearing on double row roller bearing: a – 3D construct; b – constructive scheme.

![Figure 8](https://via.placeholder.com/150)

**Figure 8.** Front support on double angular contact bearings: a – 3D-construct; b – constructive scheme.

Depending on support type, the coordinates of rod solid model for the spindle unit have been determined, and in particular the initial coordinate of the third rod (rod 2-3, Figure 8 and Figure 9) simulating the spindle cantilever part in the point of tool block fixation. This problem is effectively solved at the parametric level [16-18] in the APM Graph module, a fragment of the variable window for determining the coordinate a is shown in Figure 9.
To the position of the rod nodes is also affected by the preloading force in bearings mounted as "Duplex" and "Triplex" [19]. There are empirical dependencies associated with the change in the contact angle \( \alpha \) from the value of the preloading force in radial-thrust bearings. The developed program for parametric determination of the coordinates of the nodes of the 3D model for the spindle takes into account the pre-loading change factor. This makes it possible to specify the points of application of the applied load and to obtain a more real picture of the displacement and stress fields in the spindles.

In the process of research of the projected construction, the condition for single-valued fixation in space should be specified, and also check for the presence of the rod nodes with allowed displacement under the forces. To represent the spindle unit in the form of a beam on two hinged supports, with prohibited displacement in the direction of the external force, such free nodes are absent. In this case, you have to enter an additional free node in which it is allowed move on certain coordinates. As an example of such a node it is possible to bring a node of a rod simulating the effect of a drive element - a toothed half-coupling (Figure 4a) [14]. Thus, there is a feedback between the stage of building the 3D model and the stage of the research construct operability, for example, by the criterion of rigidity.

Another aspect is related to the choice of the method for solving problems in evaluating the construct rigidity [20]. Thus, for tool holders working on bending with an insignificant torque (this refers to the operation of thin boring), it is sufficient to use the initial parameters in the power calculation. Otherwise, with a significant fraction of the torque (for end milling), the finite element method is used. In this case, the cross-section of the tool holders (in the form of a rod) is divided into flat finite elements that interact with each other by means of nodes. This situation leads to feedback (the second type) between the stage of building the 3D model and the stage of choosing the calculation method of the projected construction [21]. For the thin boring operation, the method of initial parameters in the matrix formulation [12] was used and static forms for estimating the rigidity (compliance) were obtained. For MTs200VF4 machining center for the case of a standardized ShN with installed boring holder, the compliance \( \delta \) will be defined as a function of the length holder \( l_k \) according to the analytical dependence

\[
\delta = (3395+31.47l_k+0.13 l_k^2) \times 10^{-8}, \text{ mm/N}
\]

This method can serve as an alternative one to the finite element method to provide simplified and fast evaluation of stiffness characteristics of unified ShN designs with a changing tooling that is typical for the machining centers of a drilling-milling-boring group.

**Conclusion**

A complex research of spindle units for machining centers of drilling-milling-boring type in the environment of integrated CAD KOMPAS-3D and APM Win Machine, equipped with a variety of instrumental block for processing complex body parts was implemented. 3D-models of the elements for the main motion drive with spindle forming units were developed using the parameterization apparatus in the APM Graph module and rendering in the Artisan Rendering module. On the basis of these modules the workability research is carried out and the competitiveness of the machines created increases. Three-dimensional solid models of spindle nodes for various construct and their kinematic schemes are presented. The algorithms for parameterization of construct schemes on the basis of rod elements are developed, their position is determined depending on the bearing type in the support, the method of mounting and the value of the preload. This makes the process of designing spindle nodes more efficient and accurate.
in the multivariate mode more efficient. Investigations of the ShN according to the rigidity criterion are carried out, and analytical relations to evaluating the compliance of unified two-bearing ShN equipped with a variety of tooling is obtained.

The proposed approach to structures modeling allows a complex procedure for research spindle nodes of machining centers are implemented. This procedure on the basis of developed parametric models, drawings and 3D models in the mode of multivariate design is completed.

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