Research on the Design of a Mill-turn Center

Zhun Wang
Anhui Polytechnic University, China. E-mail: CADCAM_246@126.com

Mill-turn center is an advanced CNC machine tool. This paper presents a novel approach to the conceptual design of a mill-turn center. Firstly, the feature model of a mill-turn center is created based on a RW (representative workpiece) in a Top-down way. After that, two concurrent works are studied: the verification model of the machine tool is setup by transforming its finished feature model; the NC programming is done with the help of the technology of CAM (computer-aided manufacturing). Thirdly, the production verifying of the mill-turn center is fulfilled in the NVMS (NC verification manufacturing system). Lastly, the optimum structure dimension of two functional subassemblies and the correct layout of the machine tool can be confirmed with the modification and feedback. This is a universal method and can be used by the designer of CNC machine tool to promote their job target of quality, efficiency and cost.

Keywords: Design of Mill-turn Center, RW, Top-down Design, NVMS, MCS (Machine Coordination System)

1 Introduction

1.1 The evolvement of the mill-turn center

The structure of mill-turn center is evolved from two kinds of machine tools and two types of layouts: The two kinds of machine tools are the NC lathe and the NC milling machine tool; the two types of layouts are the vertical and the horizontal configurations [1]. There are two constructions with the horizontal NC lathe, as shown in Fig. 1. Fig. 2 shows the vertical machine center (VMC) with a swing milling head.

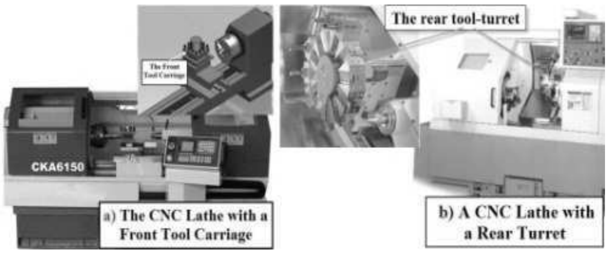

Fig. 1 *Two kinds of horizontal CNC lathe*

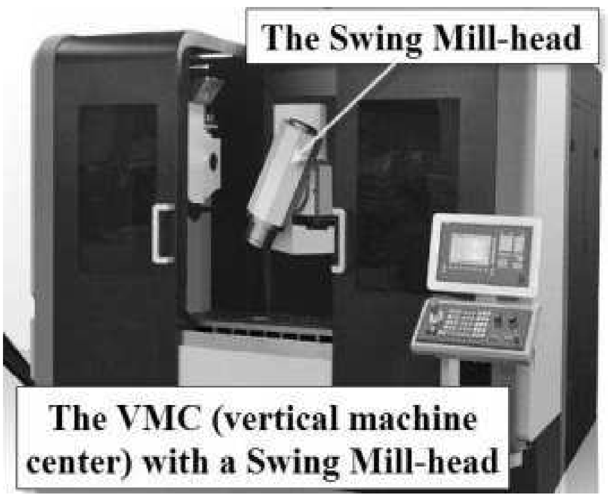

Fig. 2 *The VMC (vertical machine center) with a swing mill-head*

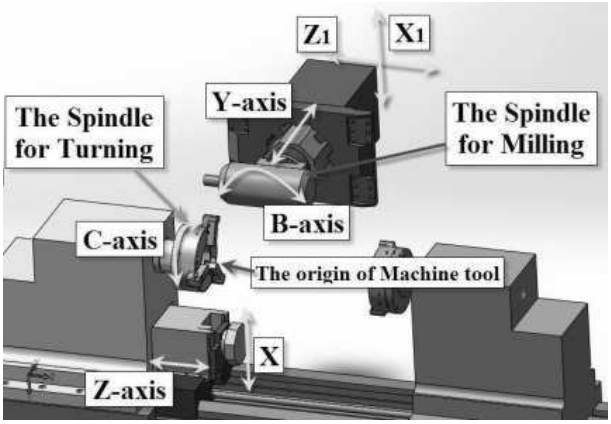

Fig. 3 *The initial layout of a mill-turn center*

The structure of mill-turn center evolved from a horizontal NC lathe consists of an additional milling spindle, which possesses more translational axes and rotational axes, as shown in Fig.3.

1.2 The research focus

A large amount of research literatures had discussed the detail design of a machine tool [2-3] and the local optimum of some functions [4-5], but little literatures involved the verification of the general layout and total structure dimension of a CNC machine tool in the early design stage. Based on the case study of a mill-turn center, this paper researches to fine out the layout of the turn-functional subassembly and the mill-functional subassembly, and define the relationship between the two subassemblies and the total structure of the mill-turn center at the conceptual stage.

The paper focuses on the CAD and NC manufacturing verification to the mill-turn center. The algorithm of the overall design of the mill-turn center is shown in Fig. 4: The upper part [a)] in Fig. 4 shows deduction about the structure of the mill-turn center in a CAD package, and the algorithm for NC manufacturing verification to the mill-turn center is present in the lower part [b)] of Fig. 4.

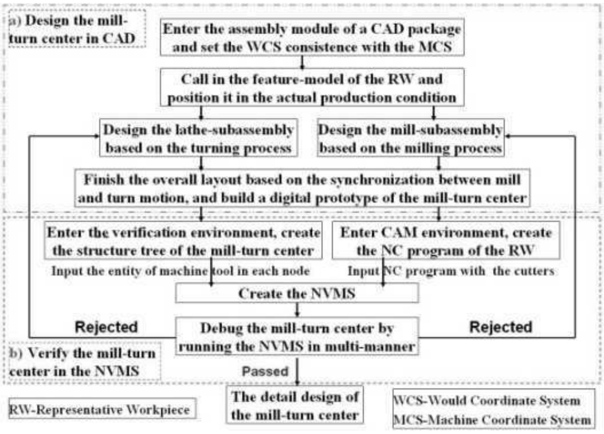

Fig. 4 *The algorithm of the overall design of a mill-turn center*

The paper is organized as follows. The computer-aided conceptual design of a mill-turn center is proposed in section 2; the reasons of using NC manufacturing verification is present in section 3; two parallel preparing jobs are analyzed in section 4-5; the debugging job in NVMS (NC verification manufacturing system) is illustrated in section 6; two case studies are analyzed in section 7; the last part is the conclusion.

2 Computer-aided overall design to the mill-turn center

2.1 The representative workpiece (RW)

The most advantage functions of a mill-turn are present at such production process as the cutting of a rotational workpiece with the asymmetric shape, for example, the crankshaft, the camshaft, etc. [6-8]. In this research, a single-crank shaft is selected as the representative workpiece (RW) for the initial data of the design. As shown in Fig. 5, each surface on the crankshaft is been cut with different cutting method. So, the configuration between the turn-functional subassembly and the mill-functional subassembly can be figured out according the different machining requirements.

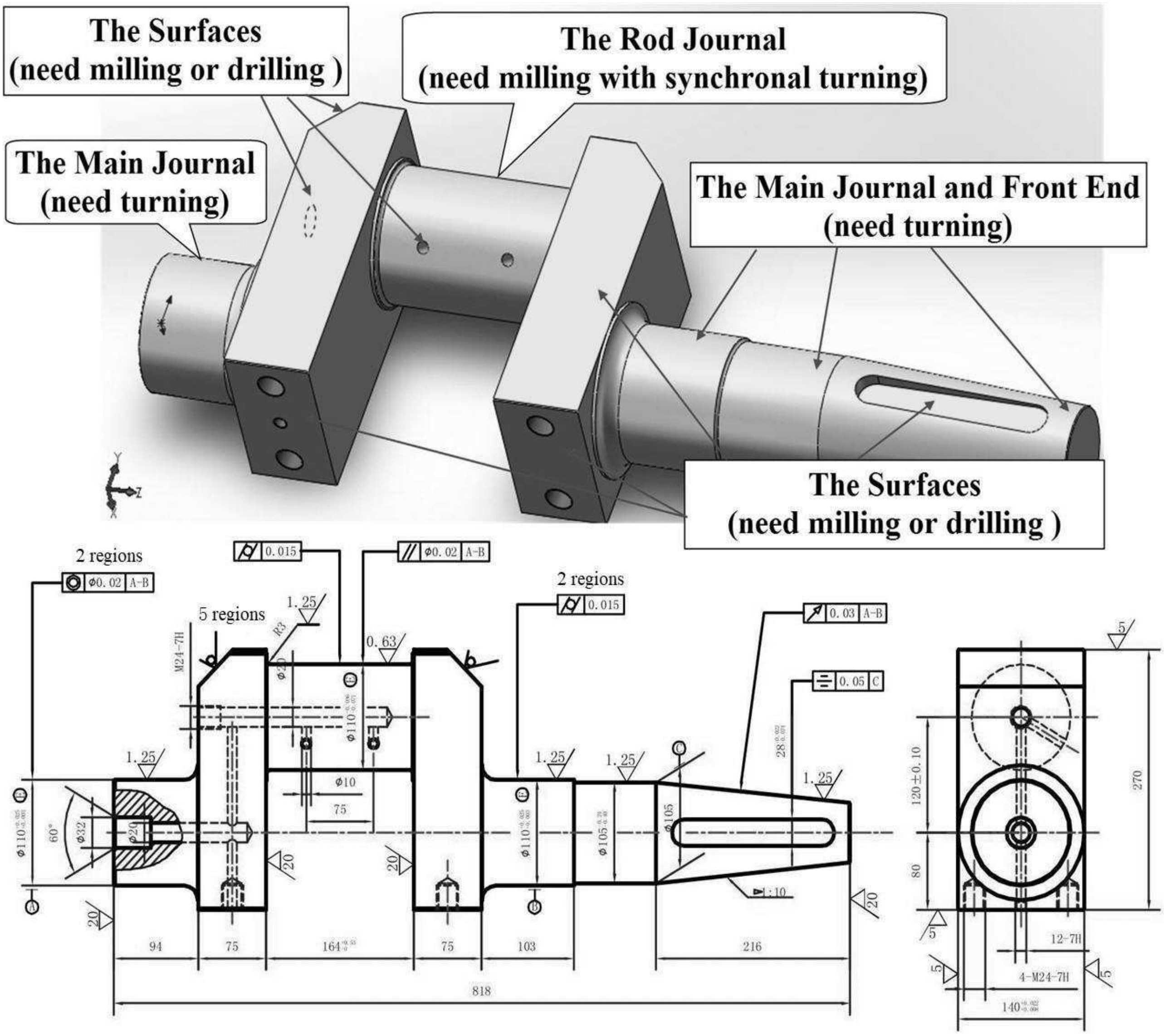

Fig. 5 *The single-crank shaft (=RW)*

2.2 Establish the coordinate system (CS) in a CAD package

Generally, the origin of the MCS (machine coordination system) of a CNC lathe is located in the center of the chuck end [9]: The positive direction of the Z-axis is set toward the right direction; the positive direction of the X-axis goes outward the radials of the turn-spindle. The top CS of the assembly module in a CAD package should match these demands, as shown in Fig. 6.

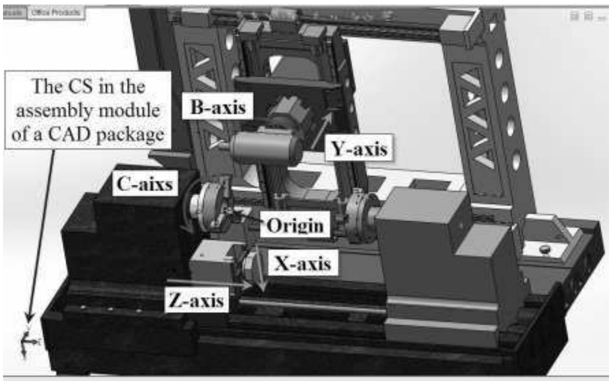

***Fig. 6** The axes in the mill-turn center*

2.3 Creating the feature model of the mill-turn center with Top-down way

The RW is the foundational reference for the overall layout of the mill-turn center; the actual workpieces that the mill-turn center will deal with are of changeful. So, the techniques that the variables are used to control the model in CAD package are applied to create the feature-model of the RW. The structure and size of the RW can be changed with the feature-variables. Furthermore, the overall structure dimension and layout of the mill-turn center can also be controlled with the variables. So, the RW should be the top node in the feature tree under the assembly environment of a CAD package, as shown in Fig. 7.

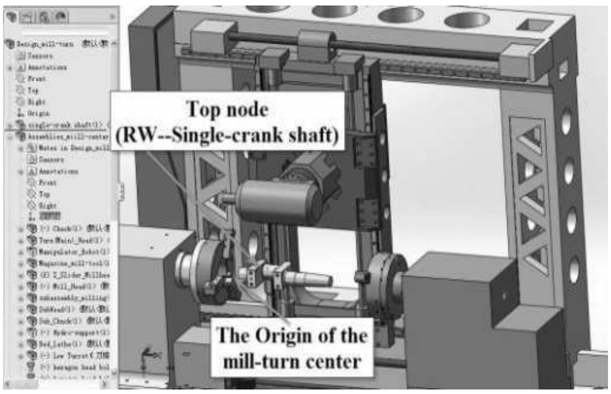

***Fig. 7** The top-node and the feature tree of the mill-turn center*

After activating the respective node of a component or parts, the feature model in each level can be sequentially created with the Top-down design techniques [10]. In addition, the longitudinal span of the bed way, the X-travel limit of the turning cutter holder, the X/Y-travel limit of the milling head, and the like, is assigned with the initial value after fully considering the potential work loads. These assigned values that are associated with the RW may be treated as the global variables of the machine tool. When the customer requirements change in the actual application to the mill-turn center, the design job for a new machine tool is just the modification to these global variables.

In this research, the Solidworks is selected as a CAD package [11], and the finished feature-model of the mill-turn center is present in the Fig. 8.

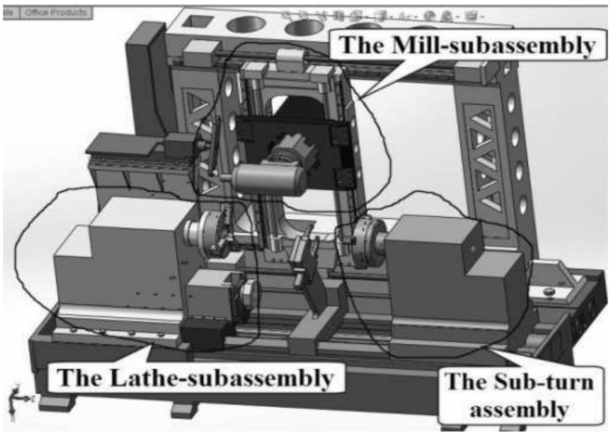

***Fig. 8** The feature model of the mill-turn center*

3 Verify the configuration of the mill-turn center with NC machining simulation

3.1 Reasons for applying the NC machining verification to check the CAD outcome

Comparing with other machine center (MC), the dynamic operating condition of the NMS (NC manufacturing system) based on a mill-turn center is much more complicated [12]. Whether any collisions or interferences will occur among the different functional units during production can not be manually predicted; the real-time spatial position of different functional units is more difficult to be figured out by the human mind. These problems can not be solved by any CAD packages including CAE (computer-aided engineering) module. The technology of NC manufacturing verification can be applied to deals with the abovementioned issues. After running the NC manufacturing simulation, each kind of design default can be find out, bidirectional fed back to the CAD stage and finally modified. As a result, the physical machine tool will be free of some fatal errors [13-14].

3.2 The algorithm of NC manufacturing verification

The lower part in Fig. 4 [b)] shows the algorithm for NC verification to the mill-turn center. There are three tasks in applying the NC manufacturing simulation for checking the NC machine tool: Two parallel preparing work should be done firstly, in which, one job is the creation of the matrix of the machine tool, the other things are the programming and matching the CNC; Secondly, the NVMS (NC verification manufacturing system) can be built upon; lastly, the mill-turn center can be improved by debugging the mill-turn center in the NVMS with multi-mode. The details will be discussed in the next sections.

4 Build a matrix of the mill-turn center for NC machining verification

4.1 The critical issues in the creation of NVMS

A NVMS is established in two steps: The structure tree of NVMS is planned firstly; then, all classes of datum, such as the geometry information (GI) of component and parts, the cutter info, the NC program, etc. are attached to the related node of the structure tree. The initial state of each element in the NVMS is just the reset state of a CNC machine tool. Every moving unit belonging to the matrix must keep high consistency with its actual reset state.

4.2 The structure tree of the NVMS

In the NC verification environment (for this paper, the Vericut is employed by the researcher) [15], the hierarchy and order of every element should keep in line with its counterpart in the physical NMS. Concerning the multi-axis characteristics of a mill-turn center, each node of a moving axis should be denoted a proper name, such as the main spindle be assigned with S1; the first X-axis (attached to the milling-headstock) be assigned with X, the first Y-axis (attached to the milling-headstock) be assigned with Y, and so on, as shown in Fig. 9. With respect to the rotational component (B-axis), the value of the pivotal coordinates should be accurately set. These values can be measured in a CAD environment, and the obtained coordinate values of the pivot should be inputted into the related node of the structure tree, as shown in Fig. 10~11.

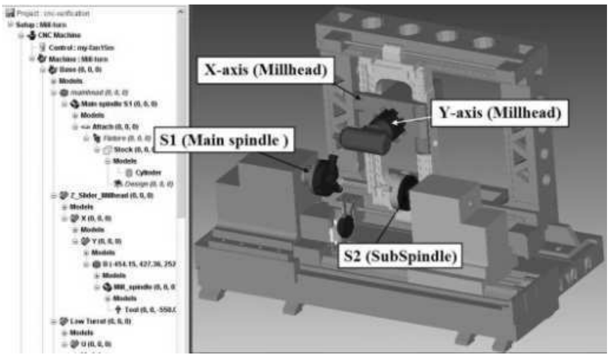

Fig. 9 *The structure and name of mill-turn center in NVMS*

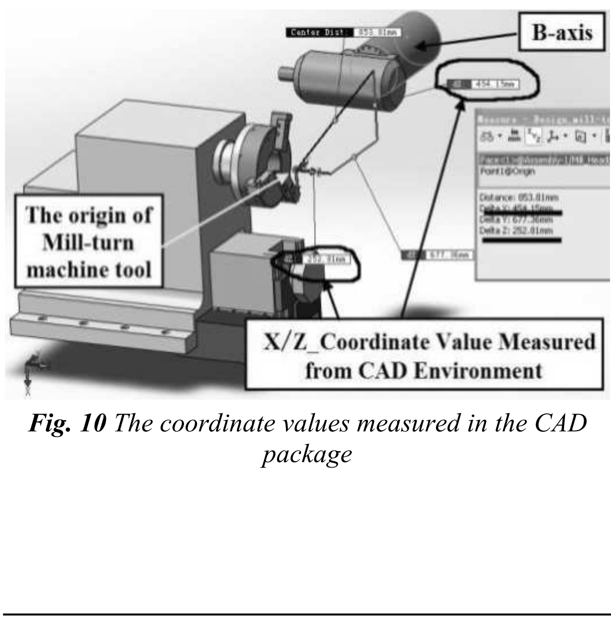

Fig. 10 *The coordinate values measured in the CAD package*

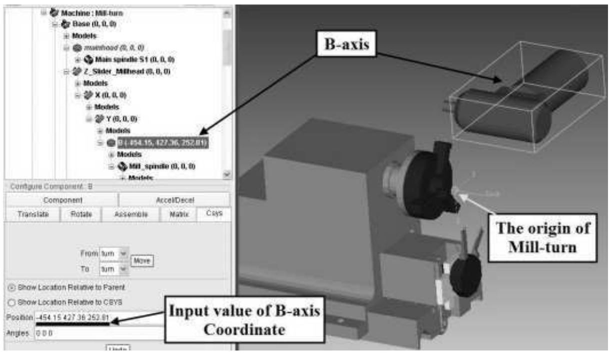

Fig. 11 *The coordinate values inputted into the verification package*

5 NC programming and CNC matching

5.1 Create the NC program

The turning and milling job of a single-crank shaft (=RW) is prepared to verify the overall design of the mill-turn center. The reset state of the crankshaft and its bar stock are shown in Fig. 12. The two elements with such spatial position can be exported out to the CAM (computer-aided manufacturing) package to be used as the initial process datum for NC programming [16]. The NC program with its corresponding cutter info will be the foundational datum in the NC manufacturing verification.

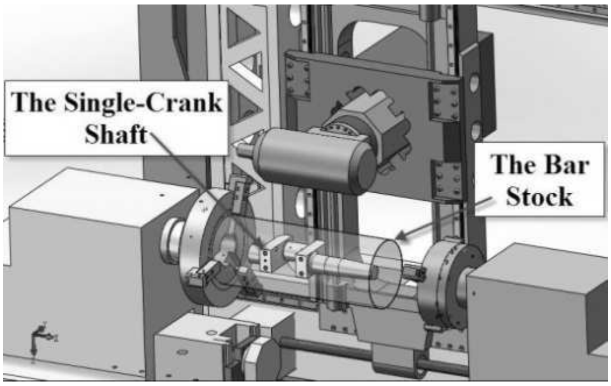

Fig. 12 *The workpiece and its blank in the machine tool*

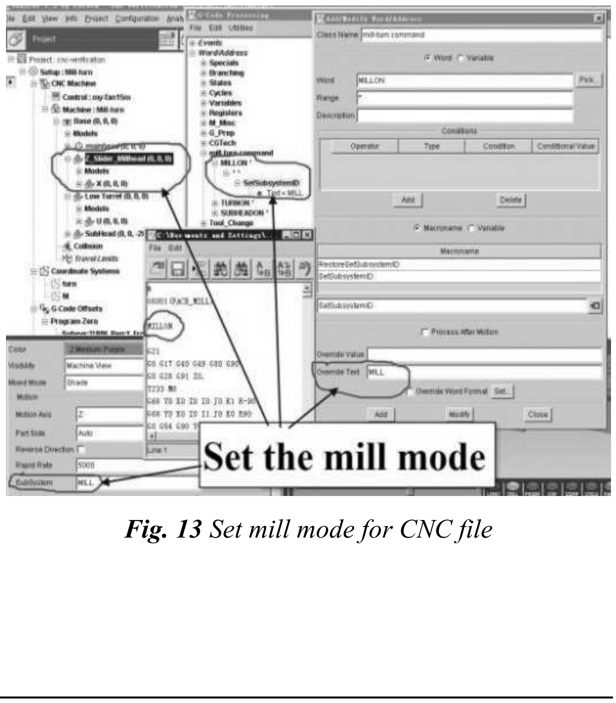

Fig. 13 *Set mill mode for CNC file*

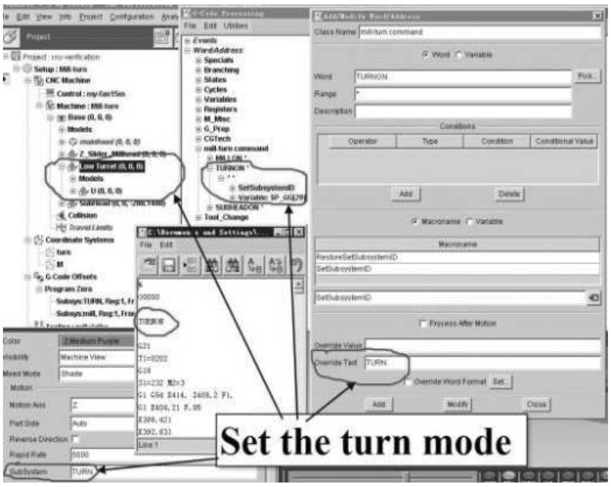

Fig. 14 *Set turn mode for CNC file*

5.2 Edit and match the CNC

There are two basic working modes in the mill-center, namely, the mill-mode (including milling with synchronous turning from the C-axis) and the turn-mode. Each moving subassembly possesses distinguishing kinematic functions in the different working mode: With milling mode, the lathe spindle is a C-axis, in which the S commands can not be used to control the motion of the turning spindle; with turning mode, the C command can not be used to control the rotation angle of the lathe spindle. The unique moving requirement in the two working modes can be satisfied by updating (or customer-design) the CNC file with the G-code processing and macro command. Some modified commands related with mill-turning processes are shown in the Fig. 13~14.

6 Debug the mill-turn center in NVMS

6.1 Operate the machine tool with multiple manners

The mill-turn center can be run in MDI (Manual Dada Input) mode. Under the MDI mode, the circumferential range of the rotatable parts can be observed, and the travel limit of the translating parts can be found.

The mill-turn center can also be operated in auto-run mode, in which the complete NC program of the RW can be executed. Any collisions and interferences can be unveiled instantly.

6.2 Improve the design of the machine tool with feedback information

Under the NC verification environment, the possible collided entities (the components or subassembly) can be setup as a collision couple, and the least distance avoiding collision can be given. So, the varieties of abnormal situations occurred in the actual production can be uncovered.

If the abnormal conditions are contributed by the mill-turn center, the design defect can be further investigated and fed back to the CAD state (redesign the lathe-subassembly or mill-subassembly, see Fig.4), in which the related variables of the feature-model of the machine tool can be regulated. The modified feature-mode can be second verified in the updated NVMS, and final reasonable overall design of the mill-turn center can be confirmed.

7 Two cases of improving the design of mill-turn center

7.1 Case one

In initial consideration, the space of the lathe-cutter carriage is designed smaller. With the help of the NC manufacturing simulation, the collision is found among the cutter, bed and workpiece when the cutter-carriage indexes. The improved carriage has been proved no any collision problems by second verification, as shown in Fig. 15.

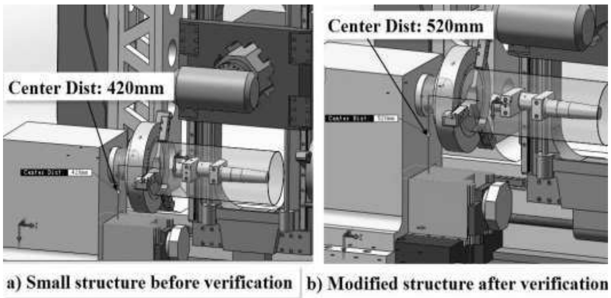

Fig. 15 *The structure of headstock and its lathe-cutter carriage*

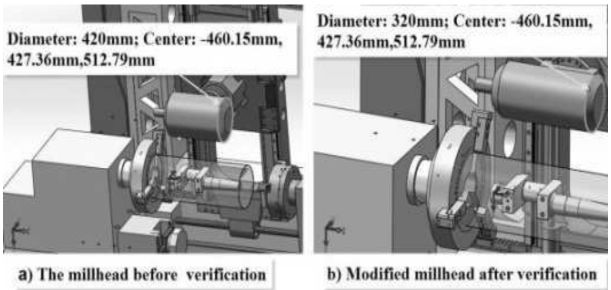

Fig. 16 *The structure of B-axis headstock*

7.2 Case two

In the initial concept, a greater diameter is assigned to the swing headstock of B-axis, in which the collision often occurs among the swing headstock, the crankshaft and the chuck during milling with synchronous turning. The modified headstock of B-axis has been demonstrated, in which no any collision happens, as shown in Fig. 16.

8 Conclusion

In order to satisfy the demand of high accuracy, shorten the operation routing, and reduce the cost of tooling, different kinds of production process are integrated into one machine tool. When a machine tool integrated with multifunctional devices is been operated, the correctness of the layout and structure dimension is a critical factor and should be confirmed during the preliminary design phase. The paper presents the working principles and methods, in which the CAD technology is used for the overall design of the mill-turn center, and the NC manufacturing simulation is applied for verifying the running of the machine. The structure dimension and the layout rationality of the mill-turn center can be figured out quickly and accurately.

In addition, the machine tool developer may provide the end-user with the NC verification-model in order to make their end-user apply the equipment more efficiently. As a result, the cooperation relationship between the maker and the user become closer, and the competitive ability of the product can be promoted.

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