

CAE Analysis of Secondary Shaft Systems in Great Five-axis Turning-Milling Complex CNC Machine

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Abstract

The commercial computer aided engineering (CAE) software is used to analyze the linear-static construction, stress and deformation for the secondary shaft systems in great five-axis turning-milling complex computer numerical control (CNC) machine. It is convenient and always only three dimensional (3D) graphic parts needed firstly prepared and further more detail used for the commercial CAE. It is desirable to predict a deformed position for the cut tool under external pressure loads in the working process of CNC machine. The linear results for static analysis of stresses, displacements in corresponding to the screw shaft locates at top, medium and bottom positions of the secondary shaft systems are obtained by using the simulation module of SOLIDWORKS®.

Keywords: CAE, static analysis, linear analysis, SOLIDWORKS, shaft systems, stress analysis, CNC

1. Introduction

There are many computer aided engineering (CAE) commercial software used to develop and design the computer numerical control (CNC) machine for saving the cost of production. In 2016, Afkhamifar et al. [1] used the finite element method (FEM) analysis to simulate the position error of the tooltip in the 3-axis vertical milling machining centers CNC series. In 2015, Max et al. [2] used CATIA® and NX™ software to create 3D models for the teaching and studies of FEM analysis in the CNC milling machine. In 2014, Altintas et al. [3] simulated and optimized the cutting process in the virtual machining (VM) of CNC system. In 2014, Soori et al. [4] developed a VM software and created machined parts in the virtual environments for 3-axis CNC. In 2013, Chang [5] introduced computer-based technology in the VM to provide a relatively low setup cost when compared with physical CNC. In 2012, Wang et al. [6] used software ANSYS® (one of the FEM codes) to compute the static-structural results of the frame and tool carrier for the hydraulic swing-type plate shears of CNC equipments. There are also some other commercial CAE software used in the structural analysis for the engineering system, for example: SOLIDWORKS®, Creo®, Inventor®, FreeCAD (an open-source), Abaqus®, HyperSizer® and midas® etc.. In 2016, MacKrell [7] introduced the multi-mechanics module of software Abaqus® for engineer used to work and design in the field of CAE. In 2013, Paulo et al. [8] used software Abaqus® to simulate mechanical behavior for the stiffened aluminum panels. In 2010, Younis [9] presented the Autodesk software Inventor® used for the structural simulation in the engineering. To execute the fourth industrial revolution for the CNC systems, the design and analysis experiences of CAE are novel for the conventional company. In 2016, Hong et al. [10] presented the static-structural CAE analysis of great five-axis turning-milling complex machine for the CNC system with the SOLIDWORKS® simulation module. Simple, clear and easy steps in the simulated process are the specific reason of selecting SOLIDWORKS software for present work. Educational version of

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SOLIDWORKS 2014 software has been used for conducting the present simulation. In this paper, the linear static stresses and displacements of secondary shaft system of the CNC machines are studied more details and obtained with the SOLIDWORKS® simulation module. The maximum values of stress and displacement are usually provided to give a basic data for the detail construction of CNC machine. The highlight notes of this paper are also included as follows: (1) It is helpful for engineers to investigate great five-axis turning-milling complex CNC machine data under CAE analysis. (2) Commercial CAE solution for the secondary shaft systems under external pressure loads is provided. (3) The linear results are provided by using the simulation module of SOLIDWORKS®. For the meaning of "great five-axis" in this study usually notes that bigger dimensions of work piece e.g. length 5000 mm, diameter 950 mm than smaller one can be machined at working time by the five axes: X-axis, Y-axis, Z-axis (three translations), A-axis and B-axis (two rotations) of working platform which moving respectively to the cutting tools. In 2015, Yang et al. [11] presented the general stiffness model of rigidity for tool path planning in five-axis CNC machining to restrain the chatter of the machine. In 2015, Wagner [12] presented an optimization computer aided design (CAD)/computer aided manufacture(CAM)/ CAE technique for the processing of cutting tool of the complex 3D surfaces on 5 axes CNC machines. The main novelty of their research is used the commercial CAE simulation module to investigate the linearly static structure analysis in CNC machine for time saving and obtain the basic data for the construction of CNC machine parts.

In general, the using of commercial CAE software have the trustable and acceptable experience in the data, but the cost of module software is respectively higher when compared with personal developed software. Usually the commercial CAE software e.g. SOLIDWORKS® used for the educational version has the great discount in the universities and schools. The main scope of this research is to use the reasonable cost of commercial CAE software to save developing time of software and find the useful data of computation. There are some commercial CAE softwares in educational version had by the university e.g. CATIA®, ANSYS® and SOLIDWORKS®. They are all very good commercial CAE softwares to provide the calculation solution. When the commercial CAE software had for the industry is usually very expensive and needed some teaching courses to provide for the user. To choose which type of commercial CAE software is very important based on the user's like of industrial company when the researcher and teacher of university are in the corporation relationship. The advantages of this paper in comparison with the other researches performed in this subject are the using SOLIDWORKS® simulation module is also used by the employee of industrial company, the upgrading of new CNC machine design performed by the owners of industrial company and the reliable data calculated from the commercial CAE software.

2. Method

The steps of simulation with the software SOLIDWORKS® simulation module in the static structural linear analysis and the general matrix equation of mathematical model were used in the computer program to solve for stress and displacement results by Hong et al. [10] as follows.

$$[K]\{u\} = \{f\} \quad (1)$$

where $[K]$ is material stiffness matrix, $\{u\}$ is displacement vector, $\{f\}$ is external load vector. It is necessary to prepare the assembling 3D parts of the secondary shaft systems as shown in Fig. 1. The dimensions of main parts are provided for the secondary shaft system is 1397mm 845mm 1426mm. The main components of secondary shaft system are screw shaft and base. The tool is fixed on the end of screw shaft to provide drilling and milling functions. The secondary shaft system can be rotated by the base in rotational motion with respect to Y axis. It is necessary to define the individual material of assembling 3D parts for the secondary shaft systems. The main materials of the secondary shaft system are cast steel. The yield stress of cast steel material is 241MPa. To present normal working in the CNC machine, the value of working stress in each material of components should under its yield stress value.

Three contact boundary conditions (B. C.) of secondary shaft systems are used to computed and analyzed for corresponding to the screw shaft locates at top, medium and bottom positions with 100mm apart along Y axis, respectively. The boundary conditions of the secondary shaft system for the base are four sides in clamp B.C. and shown in Fig. 2.

External pressure loads on left-end of screw shaft and hydraulic pressure loads on the base in secondary shaft system for the screw shaft locates at top position typically is also shown. Mesh of grids in the secondary shaft system is shown in Fig. 3 and Fig. 4. Mesh of grids with parameter element length equal to 27.21mm based on curvature mesh is shown in Fig. 3, also with proper mesh controlled base on the size of parts, medium mesh density and used to generate a proper mesh of grids in the computation and analyses. A typical mesh of grids in secondary shaft system for the screw shaft locates at top position is shown in Fig. 4. A table is provided to define the characteristics of materials used in the simulation as shown in Table 1.

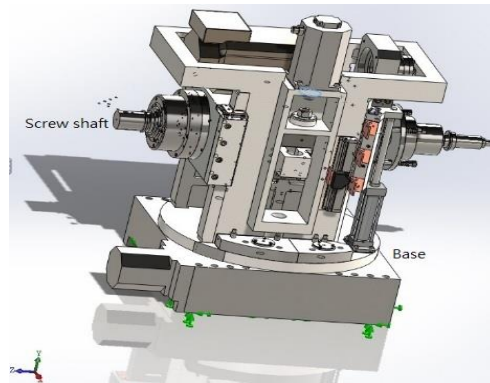
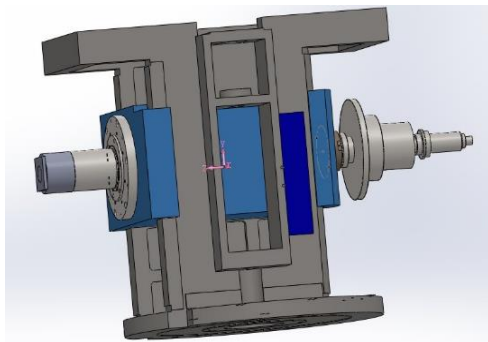
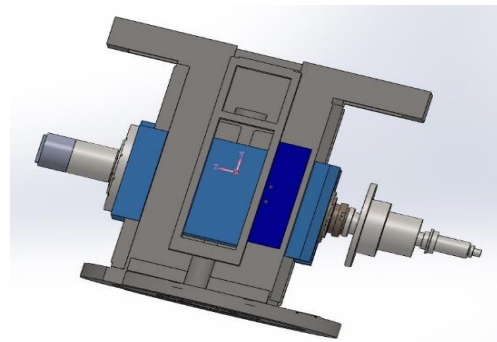


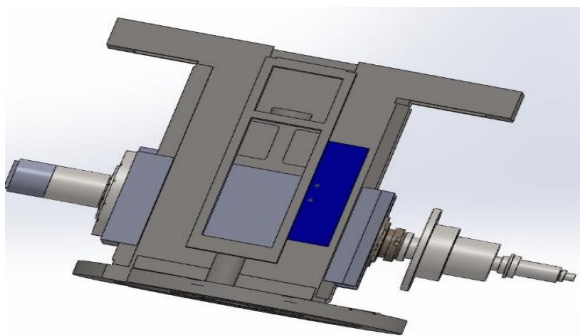
Fig. 1 Assembling 3D parts of the secondary shaft system



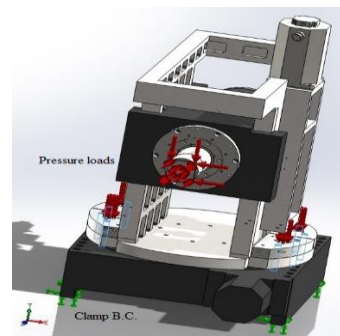
(a) Contact B.C. for the screw shaft locates at top position



(b) Contact B.C. for the screw shaft locates at medium position



(c) Contact B.C. for the screw shaft locates at bottom position



(d) Four sides in clamp B.C. for the base

Fig. 2 Boundary conditions in the secondary shaft system

External pressure loads on left-end of screw shaft and hydraulic pressure loads on the base in secondary shaft system for the screw shaft locates at top position typically is also shown. Mesh of grids in the secondary shaft system is shown in Fig. 3 and Fig. 4. Mesh of grids with parameter element length equal to 27.21mm based on curvature mesh is shown in Fig. 3, also with proper mesh controlled base on the size of parts, medium mesh density and used to generate a proper mesh of grids in the computation and analyses. A typical mesh of grids in secondary shaft system for the screw shaft locates at top position is shown in Fig. 4. A table is provided to define the characteristics of materials used in the simulation as shown in Table 1.

Table 1 Characteristics of materials

Component	Material	Dimensions	Yield stress
Screw shaft	Carbon steel	1397mm	220MPa
		ϕ 303mm	
Base	Cast steel	1042mm	241MPa
		815mm	
		231mm	
Sliding box 1	Carbon steel	600mm	282MPa
		540mm	
		350mm	
Sliding box 2	Carbon steel	600mm	220MPa
		540mm	
		350mm	

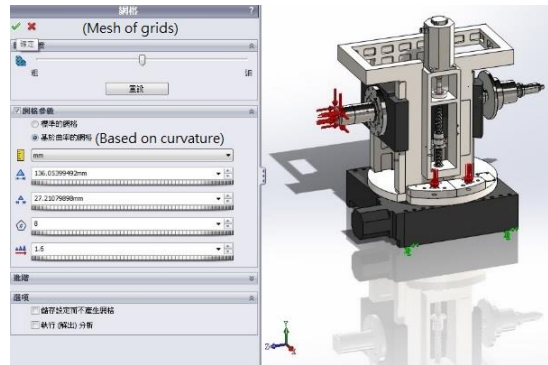


Fig. 3 Mesh of grids parameters in the secondary shaft system

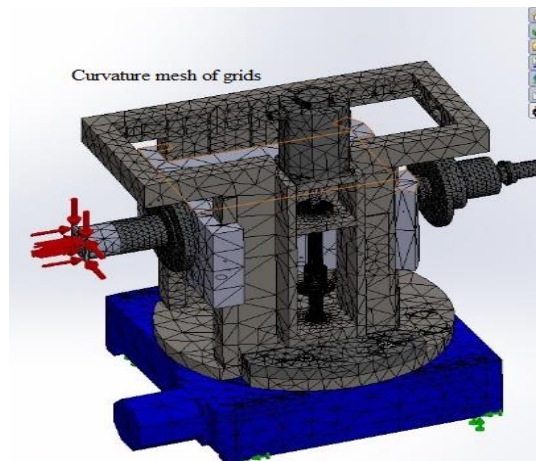


Fig. 4 Typical grids in the secondary shaft system

3. Results and Discussion

Firstly, used the SOLIDWORKS® simulation module to obtain the stresses and displacements of static results due to external pressure loads (10MPa perpendicular to XY plane, parallel to X axis and Y axis, respectively) on left-end of the screw shaft and hydraulic pressure loads (10MPa on the base) of secondary shaft system. The external loads and their positions are determined in Table 2. Static stress and displacement results of secondary shaft system for screw shaft locates at top position are shown in Fig. 5 and Fig. 6, respectively. The maximum value 131MPa of stresses is found in the area of base and the maximum value 0.522mm of displacements is found in the top area of secondary shaft system. The maximum value (131MPa) of stress due to external pressure loads (10MPa in X, Y and Z) and hydraulic pressure loads (10MPa) are less than yield stress value 241MPa, so the parts of machinery are in safety condition. It suggests that the machinery of secondary shaft system can stand 10MPa external loads. A linear analysis is considered and clarified that the behavior of structure is also linear in fact, for the maximum value 0.522mm of displacements found in the top area of secondary shaft system is very much less than the dimension length 1397mm of the screw shaft.

Table 2 External loads and their positions

External load	Position	Value	Direction
External pressure loads	On left-end of the Screw shaft	10MPa	Perpendicular to XY plane
External pressure loads	On left-end of the Screw shaft	10MPa	Parallel to X axis
External pressure loads	On left-end of the Screw shaft	10MPa	Parallel to Y axis
Hydraulic pressure loads	On top of the Base	10MPa	Parallel to Y axis

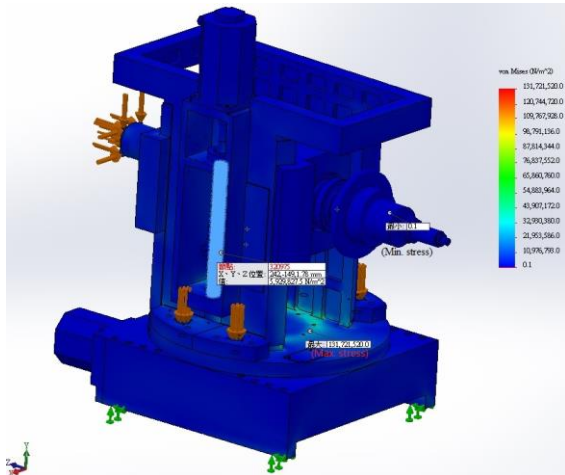


Fig. 5 Stress for the screw shaft locates at top position

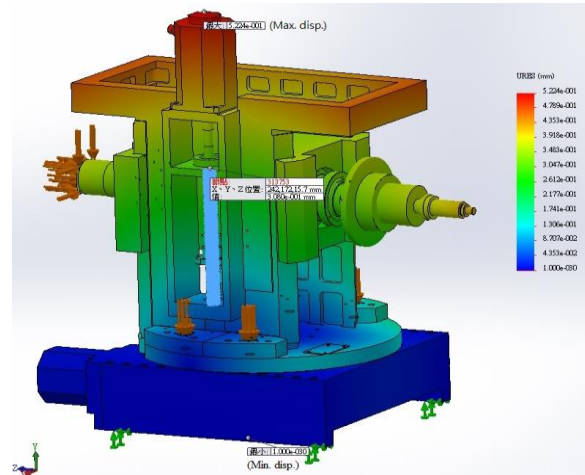


Fig. 6 Displacement for the screw shaft locates at top position

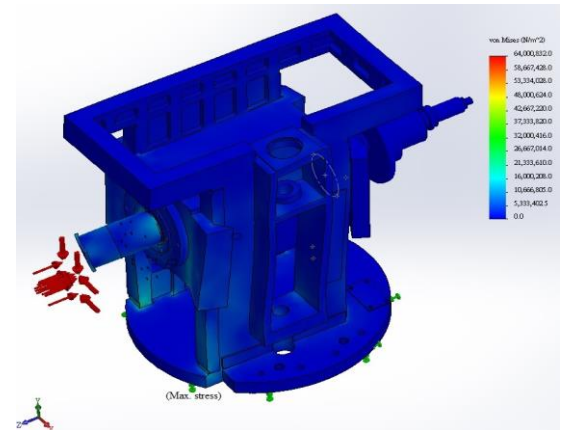


Fig. 7 Stress for the screw shaft locates at top position

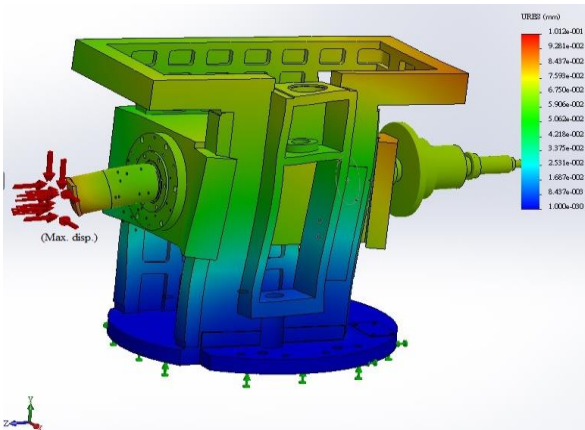


Fig. 8 Displacement for the screw shaft locates at top position

Secondly, the simplicity stresses due to the same external pressure loads (10MPa) place on left-end of screw shaft are studied, when the screw shaft locates at top, medium and bottom positions of the secondary shaft system, respectively. Static stress and displacement results for the screw shaft locates at top position are shown in Fig. 7 and Fig. 8, respectively.

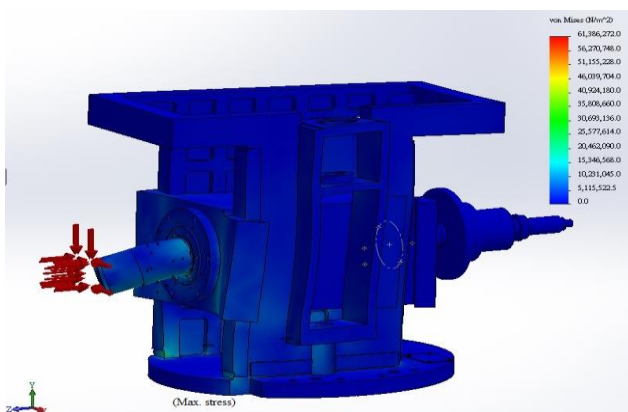


Fig. 9 Stress for the screw shaft locates at medium position

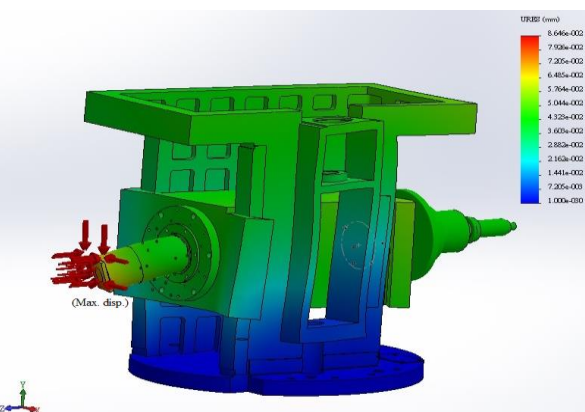


Fig. 10 Displacement for the screw shaft locates at medium position

The maximum value 64MPa of stresses is found in the area of base and the maximum value 0.1012 mm of displacements is found in the left-end area of screw shaft and in the left-top-end area of frame. Static stress and displacement results for the screw shaft locates at medium position are shown in Fig. 9 and Fig. 10, respectively. The maximum value 61MPa of stresses is found in the area of base and the maximum value 0.0864 mm of displacements is found in the left-end area of screw shaft. Static stress and displacement results for the screw shaft locates at bottom position are shown in Fig. 11 and Fig. 12, respectively. The maximum value 67MPa of stresses is found in the area of base and the maximum value 0.07839mm of displacements is found in the left-end area of screw shaft. The maximum value (0.1012mm) of displacement due to static-uniform pressure external loads (10MPa) can be occurred at the left-end area of screw shaft, so the cut tool deflection in the secondary shaft systems should be reconsidered for the accuracy operation and safety condition.

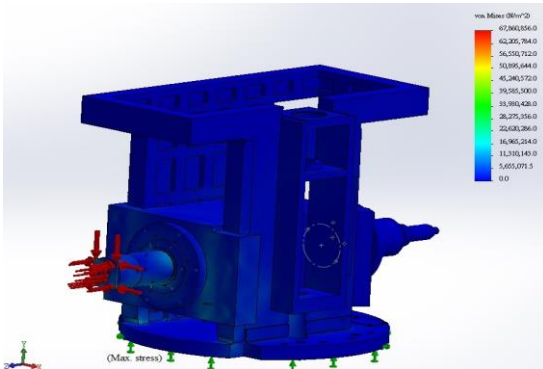


Fig. 11 Stress for the screw shaft locates at bottom position

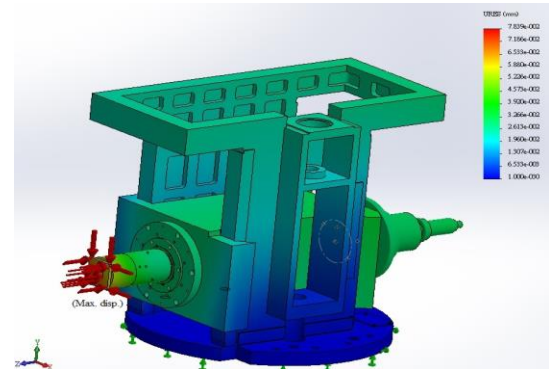


Fig. 12 Displacement for the screw shaft locates at bottom position

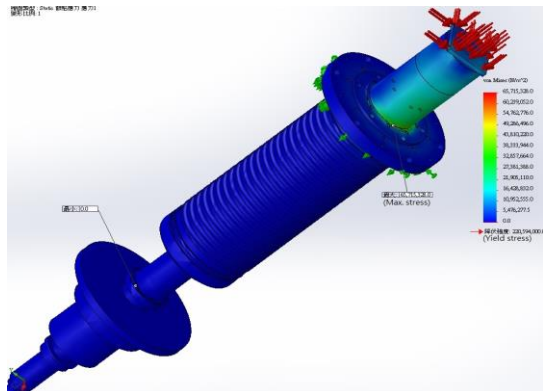


Fig. 13 Stress for the screw shaft

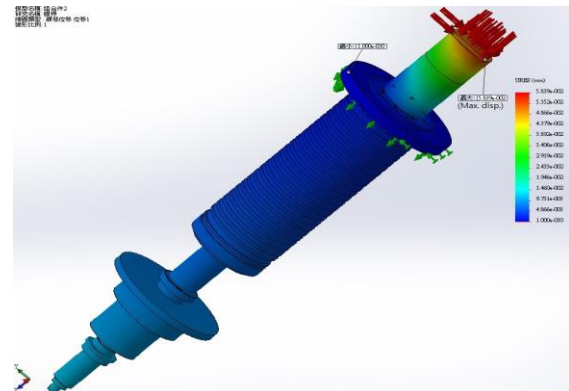


Fig. 14 Displacement for the screw shaft

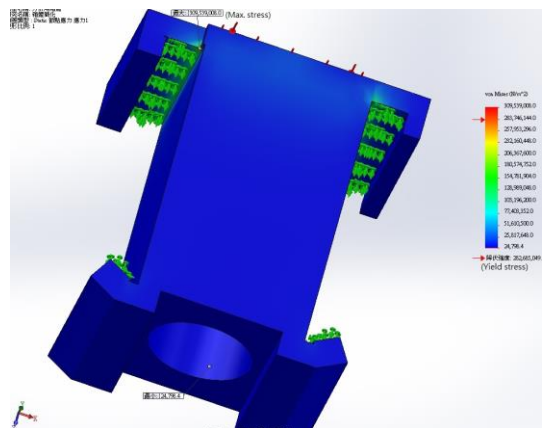


Fig. 15 Stress for the sliding box 1

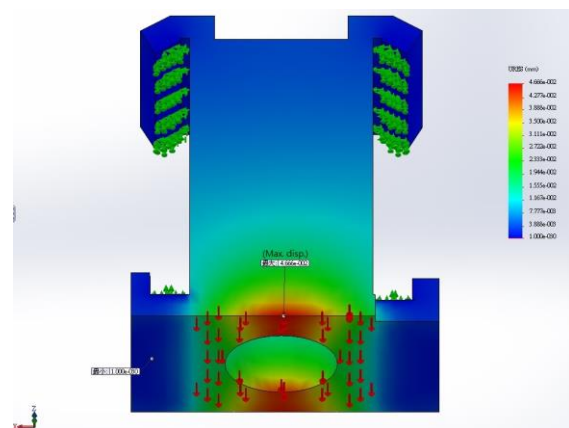


Fig. 16 Displacement for the sliding box 1

Thirdly, the screw shaft in the detail studies are investigated due to the same external pressure loads (10MPa perpendicular to XY plane, parallel to X axis and Y axis, respectively) on left-end of the screw shaft. Static stress and displacement results for the screw shaft are shown in Fig. 13 and Fig. 14, respectively. The maximum value 65MPa of stresses is found in the corner area of shaft and the maximum value 0.058mm of displacements is found in the left-end area of the screw

shaft. The sliding box in the detail studies are investigated due to the same external pressure loads (10MPa downward to Z axis) on the one-end-side of sliding box. Static stress and displacement results for the sliding box 1 material are shown in Fig. 15 and Fig. 16, respectively.

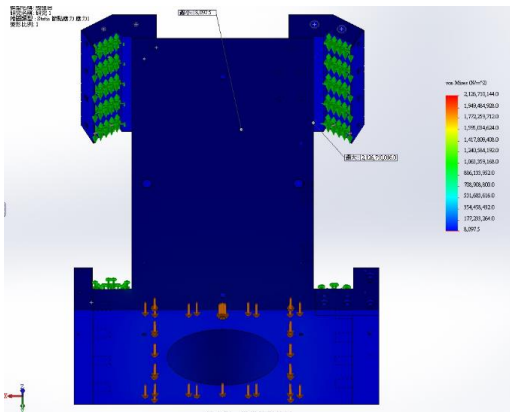


Fig. 17 Stress for the sliding box 2

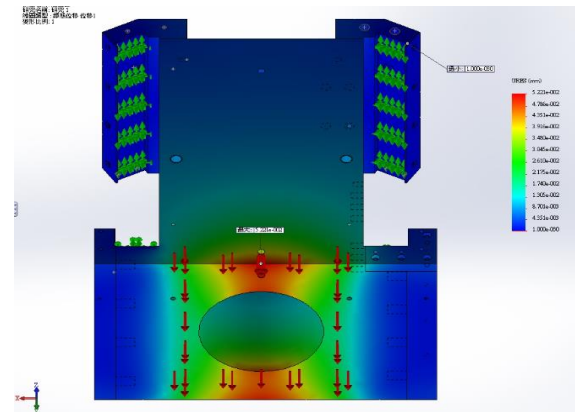


Fig. 18 Displacement for the sliding box 2

The maximum value 309MPa of stresses is found in the sliding-groove area of box and the maximum value 0.046 mm of displacements is found in the front-central area of the sliding box. The maximum value (309MPa) of stress due to external pressure loads (10MPa downward to Z axis) is greater than yield stress value 282MPa, so the sliding box of machinery is in un-safety condition. It suggests that the machinery of the sliding box 1 material can't exceed 10MPa external loads. It is more interesting to observe some places/spots where there are some stress concentrations that will occur due to different material properties. Static stress and displacement results for the sliding box 2 material are shown in Fig. 17 and Fig. 18, respectively. The maximum value 2126MPa of stresses is found in the sliding-groove area of box and the maximum value 0.05221 mm of displacements is found in the front-central area of the sliding box. The maximum value (2126MPa) of stress due to external pressure loads (10MPa downward to Z axis) is much greater than yield stress value 220MPa (almost 10 times), so the sliding box of machinery is in un-safety condition. In the linear analysis, it suggests that the machinery of the sliding box 2 material can't exceed 1MPa external loads. More informative with further analysis related to this study would be the cut position on the screw shaft in the milling process simulation subject. It would be interesting to investigate the optimize variable pitch for the cut under the milling and turning processes with considering the effects of stress and displacement.

4. Conclusions

In this paper, the static linear stress and displacements of secondary shaft system under external pressure loads in CNC machines are obtained with the simulation module of SOLIDWORKS®. Under the action values of external pressure loads 10MPa and hydraulic pressure loads 10MPa, when the screw shaft locates at top position, the maximum value 131MPa of stresses is found in the area of base and the maximum value 0.522mm of displacements is found in the top area of secondary shaft system. The maximum values of stress and displacement are usually provided to give a basic data for the detail and good construction of secondary shaft system, so the CNC machine can present in normal working condition.

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