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Analysis of Spatial Motion Static and Dynamic performance of Gantry Type Large Machine Tools

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Abstract:
The efficiency of machining and the quality of the surface are both directly affected by the static and dynamic rigidity of the machine tool. For machine tool design and development, static and dynamic analytical evaluations are critical to achieving optimal machine tool performance under difficult and demanding machining conditions. Structural analysis is the most direct and effective control structure. Dynamic analysis and static analysis of the large machine tool is performed based on a reduced static analysis model using the ANSYS software to determine the static deformation and static stiffness of the tool. finite element method analyzes the structure, static force, modal, natural frequencies spectrum, and corresponding vibration modes of and transient state of the machine tool by considering the time-varying structural load and static and dynamic machine movements We identify the first three different frequencies—17.0, 24.5, and 37.5—by applying model analysis, which may be indicating a weak link. By comparing the data with the FEA findings, it is possible to validate the correctness and efficiency of the finite element model created for the research as well as the data quality of static and dynamic features. The difference in error between experimental static rigidity the two was 6.2%.

NOMENCLATURE

FEA = Finite element method
VMC = Vertical machining center
CNC= Computer numerical control
HSM= High-speed machining center
FDW=Fixed double column center

1. Introduction

Due to the rising demands of many industries, such as the aerospace, military, and 3C sectors, there is an increase in the demand for high-speed and high-precision machine tools. The development of ultra-precision machine tool technology has been highly valued by all countries. Taiwan has devolved considerably, primarily in terms of the main factors in the high-speed large machine and accuracy of ultra-precision machine tools, there is still a big gap compared to other countries. High-speed and high-precision objectives in the design of tool manufacture are very important [1]. The machine's development aims to overcome the drawbacks of conventional machine tools, such as their increased processing costs, poor efficiency, high energy consumption, and relatively slow spindle speeds. To determine the processing characteristics necessary for dependable, high-performance, and high-speed machine tool processing, used mathematical models [2]. The efficiency of machining and the quality of the surface are both directly affected by the static and dynamic rigidity of the machine tool. For machine tool design and development, static and dynamic analytical evaluations are required to ensure optimal machine tool performance under difficult and demanding machining circumstances. A reduced static analysis model is used in the static and dynamic analysis of the large machine tool to determine the static deformation and static stiffness of the tool. It has been demonstrated that a multi-body dynamics model for five-axis machine tools is 90% quicker than older structural multi-body models [3].

The accuracy of a machine tool is directly impacted by its dynamic performance, and in past years, interest has grown in using the finite element method to study these characteristics. One type of mathematical analytical technique utilized to examine the machine tool's structural details is finite element analysis. Both local and international researchers have conducted extensive studies in this area. In order to investigate the impact of the dynamic properties of the machine tool's linear guide rail, using a finite element simulation [3]. The accuracy of the finite element model's prediction of the machine tool's dynamic properties has been confirmed. This study performed static and modal analysis on a CNC vertical lathe using the finite element program ANSYS to identify the machine tool's weak point

[4]. The first created a finite element analysis model of the car body to compute the bending strength and torsional strength of the automobile body in accordance with the real scenario. Then they optimized the structure of the car body. In this method analyzed the static and dynamic analysis of the milling machine in gantry using the finite element method. The study of how each component contributes to the overall system serves as the theoretical foundation for the optimization design [5].

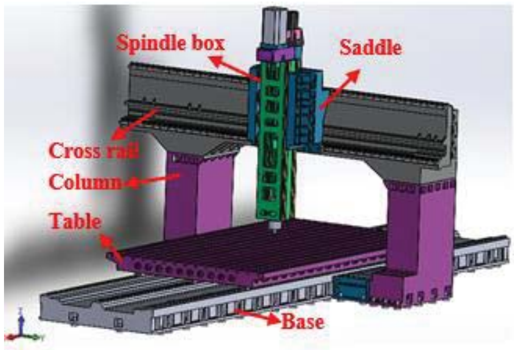
Large machine tools are more in need of such research because they should be able to do a variety of machining tasks as well. Large machine tools' static and dynamic properties are examined utilizing the finite element analysis approach in order to look into how well they function in terms of their spatial motion properties. The manufacturing of intelligent machine tools is gradually improving in the machine tool industry. [6] The developed method not only improves the manufacturability of products resulting from structural optimization but also provides designers with diverse and competitive solutions. As a consequence, while studying the machine tool's dynamic characteristics, the tool or structure cannot be isolated. [7].

A change in the machine tool's spatial position will cause a change in the system's mass matrix, stiffness matrix, and damping matrix, resulting in a change in the machine tool's dynamic characteristics. As early as the last decade, research on the dynamic properties of the machine tool should be comprehensively analyzed from the workspace. In this investigation, three tests were performed model, structural and simulation verification that finite element analysis has a considerable number of application cases for structural analysis collectively known is that the machine-tool structure's inherent properties are irrespective of excitation. Finite element analysis may be used to do the model's static and dynamic analyses, and it can also be used to determine the machine's natural frequency. This strategy proposed in this article can adequately represent the static and dynamic spatial motion characteristics of large machine tools.

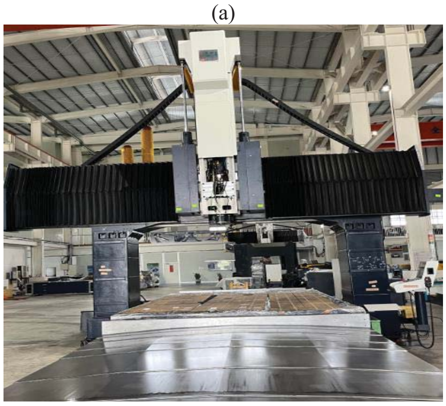
2. Gantry Type Large Machine Tools

2.1 Modeling

Using Solid work to establish the model, the major parts of it include a sliding table (X-axis), sliding cross-rail (Y axis), base (Y axis), Colum, spindle box (Z axis), saddle (Z axis), and column (Z axis) these all parts material cast iron and other parts motorized spindle, fixed sports, gearbox, motor, slider and machine tool made by structural steel. In particular for motorized high-speed, their performance significantly influences the cutting quality of the machine system. The main part of a high-speed machine tool is a motorized spindle that unites an inverter motor shaft with the spindle of the machine tool. Provide ANSYS Workbench access to the solid work file. through performing static analysis, modal analysis, harmonic response, and finite element modeling of the big machine tool's spatial motion characteristics using ANSYS Workbench. Figure 1 depicts the model that was employed in this investigation employing solid works. The spatial motion static and dynamic performance of gantry type large machine tools, which is the study object of this article. The work area of the machine table size length of 5000 mm widths 2600 mm and the maximum table load is 25 tons. The spindle speed is 0~6000rpm, the spindle is driven by a spindle motor.



(a)



(b)

Fig. 1 Structure (a) and equipment (b) illustration of the multi-function giant sliding double column machine.

2.2 Materials and Methods

2.2.1 Machine Analysis

The material needs to be set properly first. The machine's main parts of it include a sliding table, sliding cross-rail, base, Colum, spindle box, and saddle these are all parts material cast iron whose properties. Other parts are motorized spindle, fixed sports, gearbox, motor, slider, and machine tool made of structural steel, which has the properties are shown in Table 1.

Table 1 Material properties

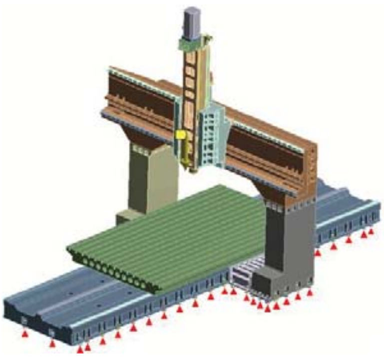
FC300	
Density（kg/m^-3）	7300
Young's modulus（Pa）	1.15E+11
Poisson's ratio	0.25

Structural Steel	
Density（kg/m^-3）	7850kg/m^-3
Young's modulus（Pa）	2E+11Pa
Poisson's ratio	0.3

2.2.2 Finite Element Modeling

The spatial motion characteristics of large machine tools include a lot of connecting holes and process slots, which makes it difficult to mesh them and increases calculation accuracy. Before creating the finite element model, it is important to simplify the geometric solid model of the large machine tool [8]. The angles of chamfers, surface areas, bolt holes, and other technological structures are not considered. Figure 2 shows the fixed support of model.

Fig.2 Analysis condition



2.2.3 Meshing

The element used during mesh division is solid 158 bodies use tetrahedral mesh, the mesh size of the base, column, saddle, bed, and spindle head is set to 50 mm, and the fixed support, screw, machine tool, spindle, etc. are set to 20mm. The mesh average is 0.54 The total number of grid nodes is 1849987, and there are 1030507 elements.

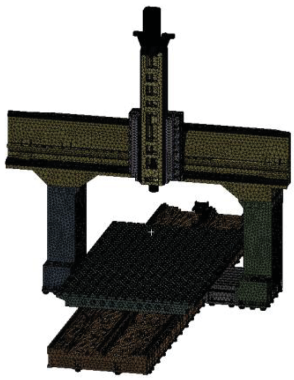


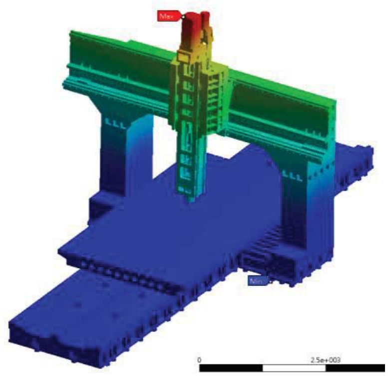
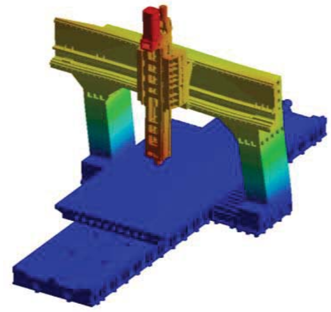
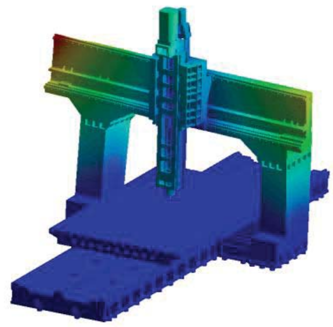
Fig.3 Complete machine mesh model

3. Results and discussion

3.1 Model Analysis

The modal analysis is mostly used to examine the machine's natural frequency as a whole. The machine, as well as its vibrating components and weakly dynamically stiff components, may produce significant vibration when it operates at its inherent frequency. Only the first few natural frequencies and the associated vibration type are of importance for this system. The machine tool's dynamic structure was investigated using the FE method at frequencies between 0 and 1000 Hz. The vibration mode and natural frequency of the machine, according to the findings of the modal analysis, are 17.1 Hz, 24.9 Hz, and 37.5 Hz, respectively. Table 2 shows the first three or r natural frequencies that were obtained.

Table 2 First three natural frequencies

Natural frequency (Hz)	Mode shape	Description
17.0		The natural frequency mode shape is that the gantry swings back and forth
24.5		The natural frequency mode shape is that the gantry swinging side to side
37.5		The natural frequency mode shaper is a gantry torsion left and right

3.2.2 Static Analysis

3.2.3 Boundary Conditions and Loads

Rigidity is a significant indicator for machine tools. Another facet of machining precision will be impacted by the machine's stiffness. The impact during hard cutting will be greater the poorer the stiffness. The static deformation due to gravity and a static load may be used to determine the static analysis of a machine tool and the related static stiffness.

Fig.4 Static analysis - X axial cutting force 5000N

The most critical step in using the finite element method to examine dynamic properties is finding out the boundary conditions and the load of the machine tool. The boundary condition of the analysis is to apply a force of 5000N to a test tool holder, 100mm below the spindle nose, which showing in figure 5, and to apply a reaction force of 5000N to the force-applying jig. The analysis results are shown in Fig. 5. The deformation of the spindle end is 175 μm. that the deformation of the spindle head is larger than that of the bed when an external force is applied, so they make structural improvements.

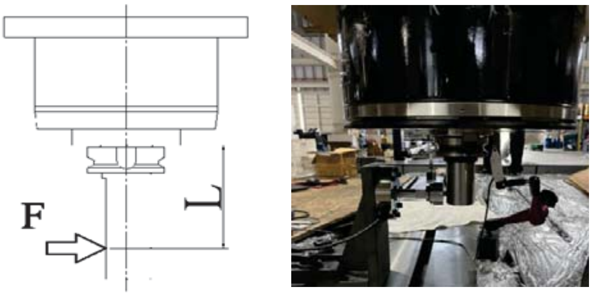


Fig.5 position applied load

4. Static Analysis Test Comparison

4.1 Static analysis test comparison

According to the static analysis results, a force of 5000N is applied to the X direction of the spindle head, and the bed is also subjected to a force of 5000N. The deformation of the spindle nose is 175 μm, and the deformation of the bed is 5350 μm. The relative deformation of the table is 3600 μm, and the rigidity of the whole machine in the X direction is 7.09 kg/μm. According to the static rigidity experiment, the rigidity of the whole machine in the X direction is 7.53 kg/μm. Therefore, the error between the static analysis and the static rigidity experiment is 6.2%.

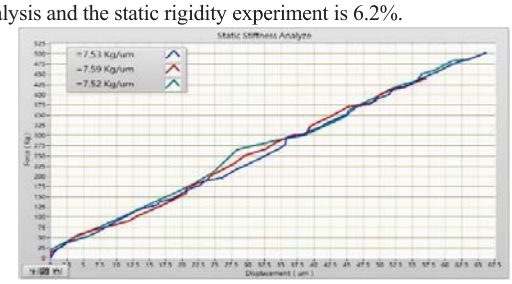


Fig.5 Static rigidity test result

5. Conclusion

By performing the static analysis, model analysis, finite element modeling, and comparison using ANSYS Workbench with the experimental static rigidity analysis, we can get the following conclusions. By using model analysis, we find the first three different frequencies 17.0,24.5, and 37.7, and vibration type, which or showing a weak link. Further static structural analysis showing the deformation of the spindle is 175 μm. The experimental static rigidity analysis of was carried out, and the experimental deformation values of the tool and spindle were obtained. Verifying the data quality of static and dynamic characteristics as well as the accuracy and efficiency of the finite element model developed in the study by comparing the data with the FEA results. The error between the two was within 6.2%.

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