Design and analysis of two-shaft omnibearing scanning mechanism

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Abstract. A two-shaft omnibearing scanning mechanism was designed as carrying device for full polarized microwave radiometer, and the 3D model of two-shaft omnibearing scanning mechanism established in CATIA environment was imported into ANSYS finite element analysis software to establish a finite element model for frame of two-shaft omnibearing scanning mechanism In this paper. The statics computational analysis on frame is conducted to get distortion condition and stress state of turnplate's frame, then modal analysis was made to get corresponding cloud maps of vibration frequency, amplitude and vibration. The analytic result shows the mechanical structure of two-shaft omnibearing scanning mechanism designed by this paper can meet strength and accuracy requirements.

Introduction

Recent years saw vital function of two-shaft omnibearing scanning mechanism in the field of aviation space remote sensing and observation. The research on critical technologies such as structure and control system of scanning mechanism in other countries has made great breakthrough, with the turnplate produced by American CGC being typical representative of the highest-level turnplate in America, and the company serves as main supplier of American war industry INS test equipment. The West Germany Aerospace Research Test Institute developed 53G three-shaft turnplate, which adopts air bearing, making shafting's perpendicular precision and gyration precision all achieve arcsecond level. It is worth mentioning that this turnplate adopts control system of 30H precision angular position, which synthesizes modern electronic and encapsulation technology and can provide diversified coding and control functions [1]. The first high-precision autocontrolled three-shaft inertial navigation test equipment of our country was developed in Aerospace 303 Institute, which is the first computer-controlled high-precision three-shaft turnplate in China, with control system using MPACS30H modular system which is leading in the world [2]. In 2005, Harbin Institute of Technology developed three-shaft flight simulation turnplate system which solves the prolongation problem of system waveband in big offset load, and can test inertia and simulation equipment testing for flight control system, achieving advanced international standard [3]. Due to the strict control exercised by foreign countries on export of related products to our country, we must depend on our own research and development to solve above problems, which can make the turnplate developed by China reach the international advanced level [4]. In complex environment and high altitude, the turnplate is required to work safely and reliably with precision guaranteed, which requires good static and dynamic characteristics of the turnplate. Although traditional design method can meet strength requirement, yet the dynamic stiffness of designed member is difficult to reach the optimal level. Besides, dynamic stiffness is an emphasis to be considered during the design course of key elements in electro-optical system tracking rack [5]. We established model for two-shaft turnplate, based on which to research model's stiffness and vibration by dint of finite element analysis software ANSYS to get a reasonable structure in this paper.

Structural design of two-shaft omnibearing scanning mechanism. The two-shaft omnibearing scanning mechanism is an electromechanical integrative system in this paper. Fig.1 is outline of two-shaft omnibearing scanning mechanism. The stepping motor is fixed to pedestal to bring along turning of internal-toothed turntable bearing, while the bearing is connected to frame to bring along turning of frame to realize azimuth turning. Another stepping motor is fixed to frame to bring along turning of boom hoisting mechanism. The positions of frame and pedestal are fixed, and various cables of precision elements such as motor wire, sensor wire, etc. are led out through center slip ring of pedestal [6]. Fig. 2 is frame diagram of omnibearing scanning mechanism. Due to the mechanism's necessity of working in ventral position, hanging upside-down structure is adopted to remote sense and observe and shoot lower part of frame. This two-shaft omnibearing scanning mechanism adopts stepping motor to realize two actions of azimuth and pitching. The working theories of azimuth and pitching are same: PLC sends direction and rotation angle impulse, then stepping motor's rotation is controlled through stepping motor driver, to bring along azimuth turning of turnplate and pitching turning of carrying device. The step angle of biphase stepping motor adopted is 1.8°, and the precision can achieve $1'$ through setting reduction factor of stepping motor reducer as 100:1, which can meet the accuracy requirement of 0.1° for azimuth of microwave radiometer system and 0.05° for pitching and enabling omnibearing high precision turning and finish scanning and shooting.

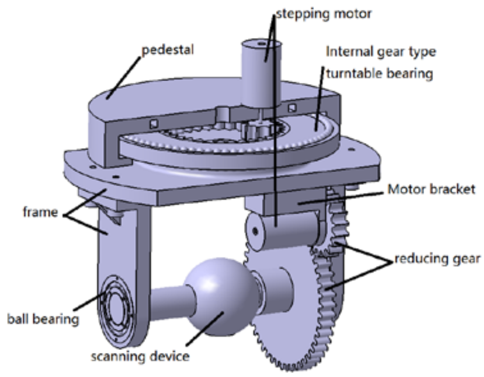

Fig. 1. ISO view of two-shaft omnibearing scanning mechanism

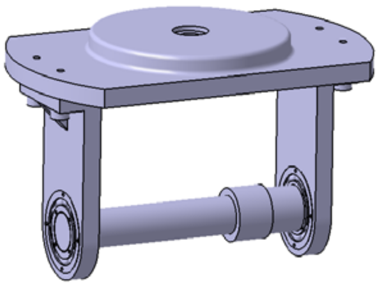

Fig. 2 Frame diagram of two-shaft omnibearing scanning mechanism

Statics analysis of two-shaft omnibearing scanning mechanism structure. The main goal of finite element analysis on mechanical mechanism is to find out the optimum scheme for structural design with structure's reliability guaranteed. The finite element method is the most widely used and most efficient method in structural analysis due to its ability to solve structure of arbitrary shape and arbitrary mechanics problem of arbitrary boundary [7]. General equivalent equation of static analysis for two-shaft turnplate linear organization is as follows:

$$[K]\ \{u\} = \{F_a\} + \{F_r\} \tag{1}$$

where［K］is total stiffness matrix, ［K］= Nm = 1Σ［Km］, ［Km］is element stiffness matrix, N is number of element; {F_a} is reverse load vector; {F_r} is total external load subjected to; {u} is nodal displacement vector. Through equation （1）, we get {u} , and expression of relation between strain and stress at unit node is got through displacement interpolating function:

$$\{\xi_{et}\} = [B]\ \{u\} - \{\xi_h\} \tag{2}$$

$$\{\sigma\} = [D]\ \{\xi_h\} \tag{3}$$

where {ξ_{et}} is strain caused by stress; ［B］ is strain on node; {ξ_h} is thermal strain vector; {σ} is stress vector; ［D］ is elasticity matrix. Correspondent stress on each node of unit is obtained through solving equations (2)and(3).

Finite element model. In ANSYS analysis, redundant calculated amount is produced for complicated model, so the frame of two-shaft omnibearing scanning mechanism under CATIA 3D modeling environment is simplified, with only frame structure left, which is imported to ANSYS. Materials of frame is Aluminum alloy , whose mechanical property is: Young's modulus is 28GPa, Poisson ratio is 0.33, and density is 2700kg / m^2.

Zonation of mesh is needed in the course of establishing finite element model. The most important is to determine stiffness matrix of structure unit [8]. To ensure accuracy and computational accuracy of analysis result, in finite element software ANSYS, it can be dispersed into entity unit through intelligent mesh zonation provided, and analysis precision can be improved by selecting denser mesh at joint while selecting non-dense mesh at disconnected point to save computation time.

The frame is divided intelligently into unit types of solid187, targe170 and conta174. The solid187 is a high-order 3-dimension 10-node solid structure unit. CONTA174 is a 3-dimension 8-node high-order quadrilateral unit. In the situation of 3D, Targe170's shape of target face can be described through triangular face, cylindrical face, circular conical face and spherical face to get finite element model of frame structure, as shown in Fig. 3 and 4. The accuracy class for the middle mesh zonation adopted is 5. After zonation, there are totally 5368 units of finite element model and 10169 nodes.

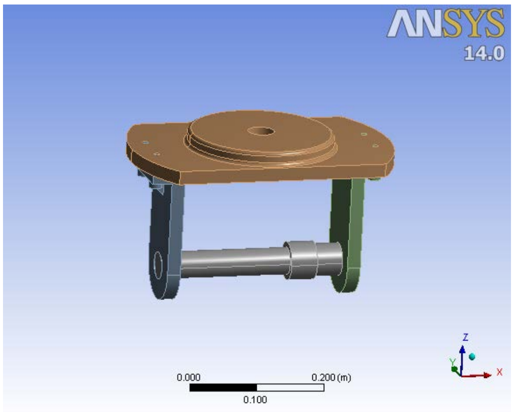

Fig. 3 Frame diagram imported to ANSYS

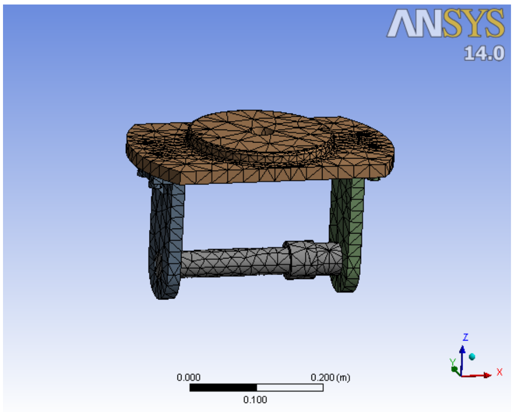

Fig. 4 Mesh zonation of frame

Boundary condition and load. The two-shaft omnibearing scanning mechanism frame applied load according to its stress situation, and applied constraint of boundary condition to the turnplate frame according to its practical situation. The influence of wind resistance is neglected in air travelling due to existence of crust. The application of load mainly includes: 1. Apply perfect restraint to frame's top surface to limit frame's top surface by six degrees of freedom. 2. Calculate the turnplate's own actual gravity and the pressure caused by other loads to frame, so the force is superimposed to binding face of shaft and frame.

Result analysis. Fig. 6 shows that the maximum displacement distortion of turnplate frame appears in the middle of pitching regulating shaft, and maximum displacement quantity is 3.53× 10$^-$

^{7}m. The strain capacity required by the system should be smaller than 10^{-6}m. For only displacement distortion under action of steady load is taken into consideration, there is no big influence on the whole frame's distortion. Fig. 5 shows that the maximum stress of turnplate's pitching regulating shaft is σ_{max} =0.3327 MPa, and maximum stress area appears in central site of turnplate's pitching regulating shaft, while the whole stress of frame construction under action of steady load is not big. For permissible stress of duralumin is σ_b=420 MPa, Taking into account the actual use of the turnplate, the safety factor is 2, $\sigma_{max}<\sigma_b$ /2=210 MPa, so the structure of turnplate's frame can meet the strength requirement.

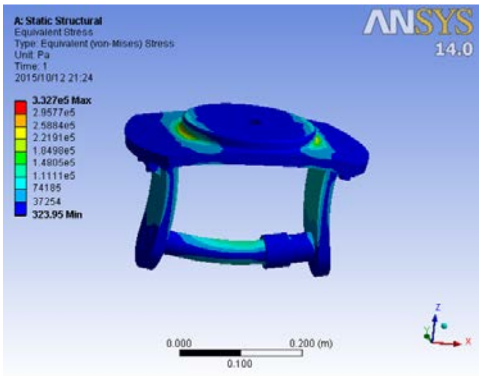

Fig. 5 Frame's equivalent stress cloud map

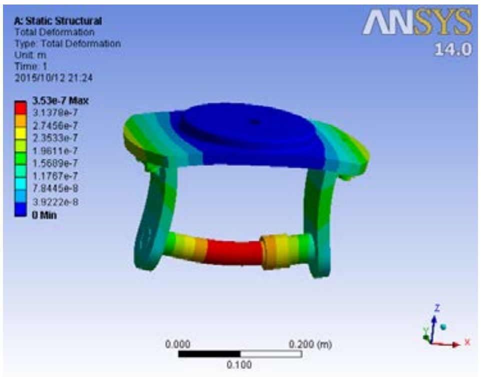

Fig. 6 Frame's displacement distortion cloud map

Modal analysis of two-shaft omnibearing scanning mechanism frame. Modal analysis mainly requires the model's natural frequency to avoid the frequency of normal operating frequency and vibration characteristics of structure or parts. The modal analysis in ANSYS is a linear analysis, while any nonlinear characteristics, such as plasticity and contact（clearance）unit will be neglected even defined. There are 7 modal extraction methods in ANSYS, but some methods (such as damping, binding surface features, etc.) cannot be determined at present, and the results calculated by the finite element method can only be an approximate value [9], so we take numerical value modal analysis. To ensure stability of two-shaft omnibearing scanning mechanism in normal movement, calculation is made through dynamic analysis, in which material model calculation, finite element analyze, restriction of boundary, zonation of mesh, etc., can be shared with statical analysis, with the distinction in applying load when making modal analysis.

Result analysis . From Fig.7-12 The natural frequency of first-order modal is 424.91 Hz, and peak amplitude is 4.45mm（Fig. 7）; the natural frequency for second-order is 634.42Hz, and peak amplitude is 5.42mm（Fig. 8）; the natural frequency of third-order modal is 908.8Hz, peak amplitude is 6.5mm（Fig. 9）; the natural frequency of fourth-order modal is 1048.5Hz, peak amplitude is 6.06mm（Fig. 10）; the natural frequency of fifth-order modal is 1514.4Hz, peak amplitude is 6.5mm（Fig. 11）. The natural frequency of the sixth modal is 1625.9Hz（Fig. 12）, peak amplitude is 4.9mm.

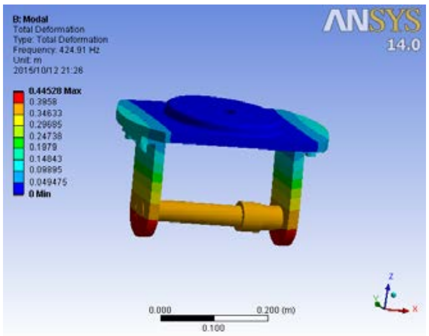

Fig. 7 Frame's first-order vibration mode

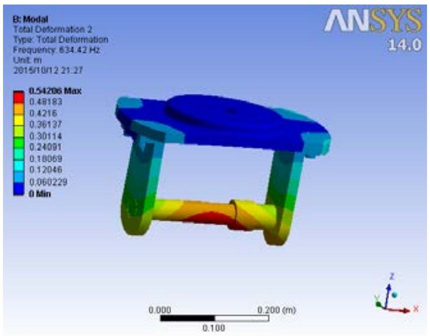

Fig. 8 Frame's second-order vibration mode

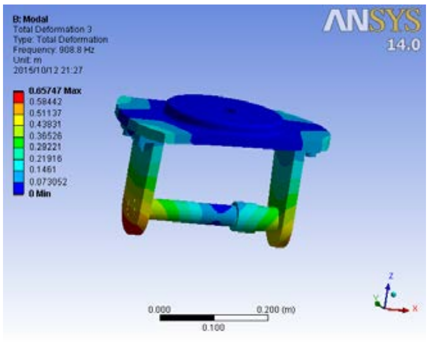

Fig. 9 Frame's third-order vibration mode

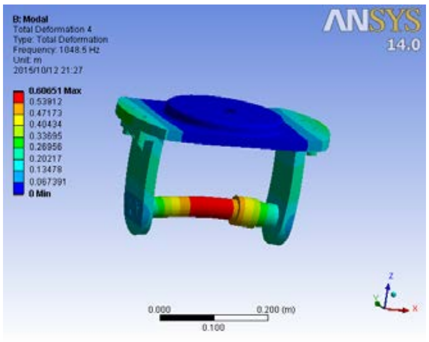

Fig. 10 Frame's fourth-order vibration mode

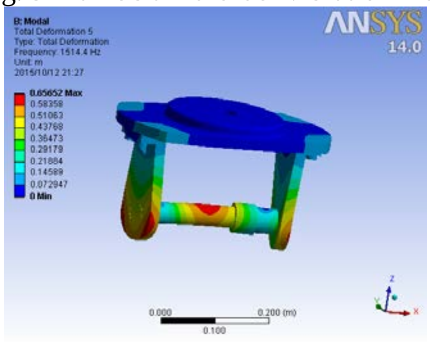

Fig. 11 Frame's fifth-order vibration mode

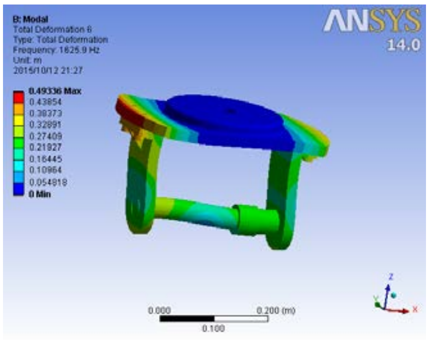

Fig. 12 Frame's sixth-order vibration mode

Through combination of structure's natural frequency, amplitude and vibration mode of natural frequency, it is observed that the two-shaft omnibearing scanning mechanism structure's natural frequency scope of the first six orders is 424.91-1625.9Hz, and first order vibration frequency of the whole structure is 424.91Hz. For general aircraft, the natural frequency distribution of its frequency aircraft vibration system is 1.2Hz ~ 20Hz [10]. The design requirement is met in terms of stiffness and frequency response requirements of structural design.

Summary

The two-shaft omnibearing scanning mechanism as carrying device was designed for full polarized microwave radiometer, and made a finite element analysis on the structure's frame in this paper. The statical analysis shows this frame meets requirements on strength and stiffness and can guarantee scanning accuracy of two-shaft omnibearing scanning mechanism. Besides, the dynamic analysis proves good dynamic characteristics of the frame, and no resonance.

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