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A new vibration mechanism of balancing machine for satellite-borne spinning rotors

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Abstract The centrifugal force and overturning moment generated by satellite-borne rotating payload have a significant impact on the stability of on-orbit satellite attitude, which must be controlled to the qualified range. For the satellite-borne rotors' low working revs and large centroidal deviation and height, and that the horizontal vibration produced by centrifugal force is not of the same magnitude as the torsional vibration by overturning moment, the balancing machine's measurement accuracy is low. Analysis shows that the mixture of horizontal vibration and torsional vibration of the vibrational mechanism contribute mainly to the machine's performance, as well as the instability of vibration center position. A vibrational mechanism was put forward, in which the horizontal and torsional vibration get separated effectively by way of fixing the vibration center. From experimental results, the separation between the weak centrifugal force signal and the strong moment signal was realized, errors caused by unstable vibration center are avoided, and the balancing machine based on this vibration structure is able to meet the requirements of dynamic balancing for the satellite's rotating payloads in terms of accuracy and stability.

1. Introduction

The rotating antenna mechanisms, such as the microwave scanning radiometer and the microwave imager, are important remote sensing instruments as well as primary payloads in the meteorological and oceanographic satellites,[1,2] generally working in the mechanical rotary scanning mode. If the inertial force itself within the antenna scanning mechanism cannot counteract internally, huge trouble could be caused to satellites suspended in space with interference torque generated by the rotation acting on the satellite body.[3–6] Firstly, the aroused vibration in the satellite will directly affect the image pixel registration accuracy and reduce geographic positioning accuracy due to image distortion in the detection equipment, the satellite's technical working index is lowered in consequence; Secondly, large unbalanced force and moment lead to the reduction of accuracy and stability of the satellite's attitude, so that satellites has to constantly adjust itself in order to maintain the normal operation at the cost of increasing the fuel and electricity consumption, which could shorten the working life and degrade the operational reliability. Obviously, it is required for rotating antenna elements to be balanced in

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advance on the ground, which has an important significance to satellites' stable operation in orbit.

Brought from rotating antenna parts' processing errors and asymmetric integration assembly work, the dynamic unbalance will generate a certain amount of centrifugal force and the moment of inertia. In the balancing control for an antenna, it needs to be installed in a vertical double-plane balancing machine, so as to simulate working conditions in orbit for test. According to the test results, the mass distribution of the rotating parts gets improved by trim and correction at specific locations, minimizing the deviation between the mass center, inertial principal axis and the rotation axis, adjusting the unbalance to be within the control target range.

Horizontal balancing machines have achieved good results in many aspects, e.g., self or automatic balancing technology,[7,8] kinetic model optimization,[9,10] corresponding balancing theories at different working speeds,[11,12] multi-plane separation techniques,[13] optimization algorithm.[14,15] In comparison, many key techniques are not mature yet at present in the vertical hard bearing double-plane dynamic balancing machine, of which the separation ratio is unsatisfactory and the measurement accuracy is low. Lee and Warkotsch use a frame-style vibration structure to detect vibration signals through sensors mounted on different planes of the rotor.[16,17] In the study of vertical automatic balance, Royzman and Drach created automatic balancing units made as hollow rotor partially filled with liquid, and in their units passive balancing is used and those units are direct controllers as their sensitive element produces force enough to balance rotor;[18] Rajalingham and Bhat presented an automatic balancer consisting of several balancing balls which are guided to move in a circular track. In the study the suitability of a two-ball automatic balancer to balance the residual unbalance in a vertical rotor is investigated, and the nonlinear analysis revealed that under certain conditions, the system ultimately settles down to the balanced steady state and thereby balance the residual unbalance in a vertical rotor completely.[19] Ferraris, Andrianoely, Berlioz et al. investigated the balancing procedure of a rotary refrigerant compressor subjected to fairly well-known eccentric masses and to a cylinder pressure force. Particular attention is paid to the influence of pressure force on the response of the compressor. It demonstrates that cylinder pressure plays a negligible role in the case of the rotary machine presented here, but must be taken into account when high pressure and weak bearing characteristics are combined.[20] Hredzak and Guo proposed a new type of electromechanical balancing device that can be used for active compensation of variable unbalance of a rotational machine, the main advantage of which is in its capability to reduce rotational unbalance in applications where the value and position of unbalance is variable.[21]

In the study of spaceborne rotor balancing, Wilson and Mah presented an approach for automatic balancing and intelligent fault tolerance and the research focused on the automatic on-line balancing and the associated fault tolerance. In the automatic balancing system, feedback from sensors measuring rotor motions or forces is used to drive active counterweights to null the unbalance and resulting vibrations.[22] To reduce two types of unbalances in the spinning rocket vehicles and satellites in the atmosphere, static and dynamic unbalances, Sethunadh and Mohanlal developed a novel virtual instrument-based measurement system which consists of a single acquisition board and a power supply unit.[23] Brusa and Zolfini carried out a numerical and experimental investigation on the dynamic behaviour of a fixed multi-body fast-spinning rotor in order to validate the design approach proposed for a spacecraft.[24] However, satellites with multi-body rotors as a whole are usually balanced through air-bearing spacecraft simulators. Schwartz and Wiener address the problem of statically and dynamically balancing a satellite with antenna rotor mounted supported on its own bearings and driven by a motor in the satellite body.[25,26]

The study found that large height and centroidal deviation give rise to nonlinear deformation of the antenna on one hand; therefore, there exists large test error; on the other hand, since the working rev is low, the vibration signals are poor, and the signals of torque during the test interfere with the signals of centrifugal force severely. To meet the requirements of high precision for the rotating antenna balance, sufficient separation is necessary between the two components so as to reduce the coupling interference. Accordingly, the reflection in the mechanical system is the separation of the horizontal and torsional vibration aroused by the rotor unbalance. The effective separation between the two is directly related to the measurement accuracy, which is the key technique of vertical double-plane balancing machines and also the technical difficulties that has long been not resolved well.

The objective of this paper is to investigate the vibration mechanism of the balancing machine for the single satellite-borne rotor's balancing in advance on the ground. According to the analysis of the vibration structures of the existing vertical balancing machines and combined with the properties of satellite-borne rotating antennas, a new type of vibration mechanism is presented, then the vibration model is established and the structural parameters is researched. Finally, experiments are provided for the verification of the correctness of the separation principle of horizontal vibration and torsional vibration, and the performance of the balancing machine based on this new vibration mechanism.

2. Unbalance of satellite-borne rotating antenna

Shown in Fig. 1, the satellite-borne antenna mechanism consists of the reflector, bracket, rotating cylinder and other components. The cylinder is driven by a built-in motor and connects with the main satellite body at the bottom. Due to long-term use under the vacuum of space, the oil-bearing structure is used between the cylinder and the stator. To ensure the safety of work, the mechanism typically operates at about 10–50 r/min.

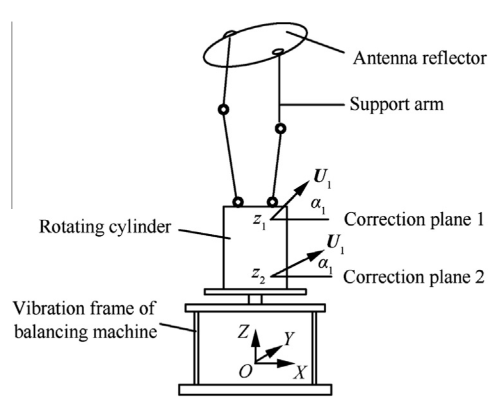

Fig. 1 Unbalance test for satellite-borne rotating antenna.