Study of Installation Method for Large Parts of Spacecraft Based on Zero-gravity Unloading

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Abstract. The zero-gravity unloading method is a process method commonly used in the spacecraft field. It has been widely used in the docking installation and ground deployment test of load equipment such as solar wing and antenna, and it is used according to the situation of solar wing, antenna or other load equipment. Different gravity unloading tooling. This article analyzes and compares various unloading methods according to the installation requirements of a certain model of large parts in the zero-gravity state. On the basis of analysis, it is concluded that the traditional five methods of uninstallation are not suitable for the installation and uninstallation of large-scale equipment modules of this model. It is necessary to carry out targeted design according to the configuration characteristics, main structure characteristics and installation requirements of large-scale equipment to realize large-scale modules. Stress-free assembly in zero-gravity state. As a result, a method for installing large parts of spacecraft based on zero-gravity unloading was proposed, which formed a large-scale component docking technology and realized the smooth assembly of the product.

1. Introduction
The overall assembly is the final stage and key link in the realization of the functions and performance of aerospace products. It is an important factor affecting the development quality and service performance of aerospace products. The final assembly technology and equipment level of aerospace products directly affects the quality, efficiency, and even the development of aerospace products. Success or failure. At present, the assembly of aerospace products mainly relies on manual operations, supplemented by process equipment such as spreaders and carriages for positioning and support. With the implementation of major national special projects such as the national high-resolution Earth observation system and space civil infrastructure, the functions of the new generation of spacecraft's stand-alone equipment tend to be integrated, the integration of satellites continues to increase, and the degree of modularization of satellite components is also increasing. The size and weight are getting bigger and bigger, and there are more and more heavy parts in the final assembly stage, and the diversification of the spacecraft body configuration makes the final assembly conditions more complicated. For the heavy parts outside the satellite cabin, you can use cranes, etc[1]. The tool assists the operator to complete the installation. The large-size structure presents the characteristics of large-scale, light-weight, and high-precision installation.

The main structure of a large spacecraft is a large-size frame structure, in which the large equipment module is located inside the frame, and the weight reaches 1000kg. The overall requirement is to ensure
the shape and posture of the frame structure and the equipment module during the installation stage to ensure that the structure cannot be affected. The external force cannot be deformed, and at the same time, the equipment module and the main structural frame are required to be assembled in a zero-gravity state during the installation of the large-scale equipment module.

The main structure of the frame structure is a hexagonal column configuration. Large equipment modules are installed inside, and 6 outer panels are installed on the outside of the frame structure. The connection mode of the equipment modules and the frame is connected by 6 columns, and is supported by 6 support rods at the lower part. After the structure is assembled, the structure has good rigidity through mutual reinforcement of the structure, which satisfies the purpose of light weight of the spacecraft structure. Since the satellite structure is assembled without stress during installation, the overall requirement is that the structure should be in a state of no additional stress and zero gravity during installation. Assemble to ensure structural accuracy[2].

In order to ensure the butt installation quality of the large-size frame and the equipment module, and to meet the overall requirements of the structure shape and posture maintenance and the stress-free, zero-gravity installation and docking requirements, this paper assists in increasing the structural rigidity and complex profile position and posture maintenance during the final assembly. The method proposed a zero-gravity butt installation method for large-size components, which solves the problem of stress-free and zero-gravity installation of complex large-scale component assembly structures.

2. Introduction to Zero Gravity Unloading Method

The zero-gravity unloading method is widely used in the field of spacecraft. It has been widely used in the docking installation and ground deployment test of load equipment such as solar wing, antenna, etc., and different gravity unloading tools are used according to the situation of solar wing, antenna or other load equipment. The current methods of gravity unloading include cantilever rotatable gravity unloading, pulley type gravity unloading, two-dimensional plane slide rail type gravity unloading, rope suspension type gravity unloading, and air-floating gravity unloading.

2.1 The cantilever can rotate gravity unloading hanger equipment state

Figure 1 is a schematic diagram of the principle of the cantilever rotatable gravity unloading hanger. The axis of rotation of the hanger must be in a straight line with the center line of the antenna deployment axis, and the suspension wire must pass through the center of mass of the reflector.

The cantilever rotatable gravity unloading hanger is characterized by fewer lifting points, simple structure and low cost, and is suitable for the deployment of small-caliber solid reflector antennas.

2.2 Pulley type gravity unloading hanger

The pulley system shown in Figure 2 is suitable for the deployment of the antenna's center of mass moving along a horizontal straight line. The suspension wires of the two systems require the centroid of
the test piece, and the size of the counterweight is determined on the principle of overcoming the
dynamic friction of the system[3].

The characteristics of the pulley-type gravity unloading system are simple principle, saving
installation space, low cost, and reusable. The disadvantage is that the adjustment of the center of mass
and the weighting process are complicated, and the levelness of the track is high, and it is not applicable
to the antenna deployment of the complex motion track.

2.3 Two-dimensional plane slide rail type gravity unloading hanger

Figure 3 is a schematic diagram of the principle of a two-dimensional plane slide rail type gravity
unloading hanger. The horizontal rail in the picture can slide on the extended rail, and the sling can drive
the test piece to slide along the horizontal rail. The feature of the two-dimensional plane slide-type
gravity unloading is that it can meet the needs of movement in any direction in the horizontal plane in a
larger range. However, the frictional force of the bearing moving along the guide rail is not compensated,
which will cause additional unfolding torque. Therefore, during development, processing and
adjustment must be used to ensure that the guide rail achieves a high straightness, levelness and
smoothness, thereby reducing the unfolding frictional force. This kind of slide rail also needs an
auxiliary support hanger, and the rigidity of the support hanger must ensure that the deformation is small
under the load state. The cost of this kind of unloading device is moderate, and the disadvantage is that
it occupies a large space. It is generally suitable for the deployment of large-size (4 meters or more) flat
solar cell arrays and flat array antennas[4].

2.4 Rope suspension type gravity unloading device

The rope-suspended gravity unloading device uses ropes to unload at individual points of the antenna.
This method is simple and easy to implement, and is especially suitable for unloading in a purely
unfolded static state. During the unfolding process, it is necessary to ensure that each sling must be in a
tensioned state during the movement process in order to have the unloading effect. It is only suitable for
specific deployment methods, and the cost is low. Under normal circumstances, the unloading efficiency is not high\cite{5}.

2.5 Air-floating gravity unloading device
The air-floating gravity unloading device uses an air-floating bearing to jet downwards to form a layer of air film, so that the bearing can drift freely in the horizontal plane. It requires high-precision air flotation platforms, air compressors and gas storage tanks and other auxiliary equipment. The feature of the air-floating gravity unloading device is to ensure that it can follow any complex motion trajectory of the antenna during the unfolding process, and maintain the unloaded state all the time, and has low friction and smooth movement. The disadvantage is that the auxiliary system is complicated and the cost is high. It is suitable for deployment of antennas that move in a horizontal plane with high accuracy requirements.

3. Analysis of the installation conditions of a certain model of large parts
However, due to the large weight of the modules in the frame structure, the main structure of the large-scale equipment module installation process The frame is more likely to be deformed, resulting in the structural deformation of the 6 struts below. After analysis, the difficulties in the process of docking installation of large-scale equipment modules and frame structures are as follows\cite{6}.

3.1 Large equipment weight and wide format
The overall weight of the large-scale equipment module and the frame structure combination is more than 1000Kg, and the size is relatively large. It cannot be achieved by pure artificial means, it is difficult to stably maintain the position and posture of the equipment, it is prone to shaking, and the equipment itself has no available handles and other supportable supports, there is a risk that the equipment cannot be lifted, and it is difficult to align the installation during installation Hole position and keep.

3.2 It is difficult to maintain the relative position of each part
The structure is assembled in a stress-free state during assembly. The large equipment module and the main structure are positioned by positioning pins. The support rods connect the support of the large equipment module and the main structure frame column. They are all connected by pins, and there is no installation gap. High structural rigidity and precision, because there are multiple connections, and they are not on the same plane, it is an over-positio ning connection. When the equipment on a large equipment module is installed, the structure will be slightly deformed. If no auxiliary means are used, the connection points cannot be connected at the same time. Therefore, the need for using tooling and operating skills is proposed to realize the zero gravity state of the large equipment module without stress assembly.

3.3 Small safety distance during installation
When large-scale equipment modules are installed in butt connection with the frame structure, the dynamic distance between each other is about 50mm, and the gap is small. In addition, the product area is large, and the safe distance during installation is not easy to observe, and there is a risk of collision with stars. Therefore, it is necessary to reasonably plan the equipment installation process and walking path so that the operating part is relatively open.

3.4 Assembly sequence of each connecting rod
During the assembly process, the large structural frame and the equipment module are connected at the same time through the mounting surface of the bracket and 6 support rods. After any connection point is connected, the force state of the module will be changed, which may cause the appearance of additional stress. Destroy the zero-gravity unloading state of the module, and ultimately result in the structure being unable to connect. Therefore, it is necessary to reasonably plan the assembly sequence to ensure that the connectors can be connected synchronously and avoid uneven forces.
4. Zero gravity installation method

Aiming at the difficulty of connecting large-scale structural frames and equipment modules, a method of zero-gravity unloading by hoisting was proposed. Together with designers and technicians, an adjustable hoisting device was designed to ensure the shape and position of complex-shaped products were maintained. This was finally confirmed. The feasibility of the plan. This method mainly works from three aspects.

4.1 Design large equipment modules to lift and maintain tooling

Aiming at the characteristics of large format, heavy weight and large span of large equipment modules, a cross-beam hoisting process equipment is designed. This equipment is connected with four evenly distributed hoisting points on the equipment module to lift the equipment module while maintaining the equipment. The shape and posture between the various parts of the module. The span of the four lifting points of the lifting device is adapted to the lifting points of the large modules to ensure that the lifting points are evenly stressed, and the span of the lifting points can be adjusted according to the site implementation, which further increases the compatibility of the lifting device. Use adjustable hoisting tooling to adjust the large equipment modules to a horizontal state. The assembly process can ensure that the satellite main structure is parallel to each other, and the surface is parallel to the surface, avoiding the occurrence of partial stress on some connection points, resulting in uneven stress. At the same time, according to the characteristics of the high-altitude dangerous operation of this operation, anti-falling measures have been formulated: for example, the anti-skid stripping of the upper star tool, the adhesive tape between the fastener and the wrench during installation, and the bolt and the lifting block in the middle of the lifting block. The improvement measures such as connecting it on the ground first and then sticking it firmly with a white tape at the bottom, so as to avoid any slipping and falling accidents during the actual production process.

4.2 Design a large-scale frame structure to maintain the shape and posture of the tooling

Due to the limited rigidity of the large-scale frame structure, during the installation of large-scale equipment modules, the frame may be slightly deformed, causing the structure to fail to connect. Considering that the frame structure is a hexagonal prism configuration, the connection of each surface mainly relies on beams or vertical beams, and the ability to stably maintain the shape and posture is weak, and there is the possibility of excessive stress or even deformation during the installation process. Through the retention function of the structural craft board, the large-format frame structure greatly increases the structural rigidity without significantly increasing the weight, ensuring that the structure is maintained in a zero-gravity state during the assembly process, and ensuring the stress-free assembly of large equipment modules.

![Figure 4. Schematic of adding a holding device to a large frame structure](image)

In the assembly process, due to the irregular shape of the equipment module, during the docking process of the module with the large frame structure, if the installation sequence of each connection point is unreasonably planned, it will inevitably cause the unbalanced force of each connection point,
resulting in part of the structure being in Over-stress state. Therefore, it is necessary to reasonably plan the process route. In view of the even distribution of the 6 support rods, a plan for the simultaneous assembly of the 6 support rods is planned. When the equipment module is hoisted to a distance of about 1mm from the docking part of the frame structure, stabilize the hoisting posture, arrange 6 people to install the support rod of the equipment module with the large frame structure at the same time, pre-thread the fastening screws according to the command command, and continue to hoist the falling equipment module. When the supporting rod and the large frame structure are fully attached to the joint surface, 6 people assemble and tighten the screw fasteners synchronously according to the unified password, then remove the spreader, and measure the torque of the fasteners. The process route of synchronously assembling the support rods ensures that the 6 support rods are assembled synchronously during the dropping process of the large-scale equipment module, ensuring that no additional stress is generated, and the problem of large-scale frame structure and equipment module deformation will not occur.

5. Benefit Analysis
Based on the zero-gravity unloading method for the installation of large parts of the spacecraft, according to the actual needs of the model, a large-scale component docking technology is proposed to realize the smooth assembly of the product. While solving the actual problems of the final assembly, it has a certain degree of innovation. In the process of the spacecraft final assembly, the integrated shape is stable and the process equipment is maintained to ensure the safety of the components. On the basis of traditional hoisting assembly, this method adopts zero-gravity unloading technology and plans a 6-point synchronous assembly process route, which can effectively improve the stability of the final assembly process and ensure the high quality of the final assembly operation.

6. Conclusion
Aiming at the docking conditions of large-scale equipment modules and large-scale frame structures, this paper proposes an installation method based on zero-gravity unloading of large components and auxiliary means to improve the rigidity of the main structure during the assembly process of the satellite, and designs a set of installation methods based on the full analysis of the equipment characteristics. It is suitable for the process equipment for the zero-gravity and stress-free assembly of large components. A reasonable assembly process route is planned, which effectively solves the problem of over-positioned installation of large-scale components without stress. At the same time, it has accumulated experience and made a reserve of skills for the subsequent installation of large parts of the spacecraft.

References
[1] Xu Fuxiang, satellite Engineering, China Aerospace Press, 2002, pp.69.
[2] Song Xiaohui. Research on Torque Loading Technology based on L Lever in Spacecraft Bolt [C]. 2015 International Conference on Engineering Technology and Application. 2015: 224-228.
[3] Wang Yingyan, Xu Yeping, “The low frequency electric cable network design for satellite,” Spacecraft Environment Engineering, 2013, 30 (2) :200~202.
[4] Song Xiaohui. Research of Bolt Pre-Tightening Technology in Narrow Space for Spacecraft[J]. AERONAUTICAL MANUFACTURING TECHNOLOGY, 2020, 63(13): 97-101.
[5] Tan Weichi, Hu Jingang, Spacecraft System Engineering, China Science& Technology Press, 2009:131.
[6] Song Xiaohui. Experimental Study on Thermal Characteristics of Spacecraft. Cylindrical Roller Bearings[J]. LUBRICATION ENGINEERING, 2016, V01. 41 (8) : 121-125.
[7] Song Xiaohui. Research on Application of Digital Assembly Technology based on MBD in Spacecraft Field[C]. 2018 2nd International Conference on Advanced Technologies in Design, Mechanical and Aeronautical Engineering, 2018: 163-166.