Study of Development & Application about Assembly Technology of Optical Fiber in High-capacity Satellite

Xiaohui Song1,2*, Jiulin Xie1,2, Wei Wang1,2, Liang Guo1, Qiang Zhang1,2, Yue Cheng1, Xiaoyi Liu1
1Beijing Institute of Spacecraft Environment Engineering, Beijing, China
2Beijing Engineering Research Centre of the Intelligent Assembly Technology and Equipment for Aerospace Product, Beijing, China
songhsiahui@126.com

Abstract. This article proposed a method for final assembly of optical fiber cables based on the needs of satellite installation of optical fiber cables, the structural features of optical fiber cables, and on the basis of fully demonstrating the installation conditions of optical fiber cables. The articles also analyzed factors that affect the quality of the final assembly of optical fiber cables based on the rationality of wiring and the effectiveness of cable protection and the reliability of electrical connector insertion. The method proposed by the article greatly improves the assembly efficiency while effectively ensuring the safety and reliability of the final assembly of the product.

1. Introduction
As the carrier of optical signal transmission, optical fiber has the advantages of high frequency bandwidth, large communication capacity, and anti-electromagnetic interference. It has already begun to be used in the spacecraft field. There are two types of fiber optic cables: fiber jumpers and pigtails. A large-capacity communications satellite used pigtail fiber optic cables for the first time. Due to the complex structure of the fiber optic cable and the easy breakage of the roots at both ends of the fiber fusion splicing sleeve, the strain sensor, that is, the bare fiber, is easily damaged. The situation increased the difficulty of the final assembly operation of the optical fiber cable and the requirements of operation technology. Unreasonable fiber optic cable wiring is unreasonable, inaccurate protection, and incompact fiber connector will affect the performance and reliability of the fiber optic cable connection and the transmission of optical signals.

The application of optical fiber in the assembly of spacecraft is at the exploration stage. The process method is immature, and due to the limited operation space and other problems, if the operator is not careful in the assembly process, it is often prone to problems such as cable damage caused by rework.

2. Features of fiber optic assembly

2.1 Composition of fiber optic cable
Optical fiber cable is mainly composed of optical fiber (thin glass fiber as thin as hair), plastic protective sleeve and plastic sheath. A cable core is composed of one or a certain number of optical fibers in a certain way, and is sheathed with an outer sheath, and some are covered with an outer sheath. Optical fiber is a communication line used to implement optical signal transmission. The optical cable, the optical cable, and the equipment can be connected to each other to complete the transmission of the
optical signal. The connection is made by a connector or a fusion splicing method, the optical cable can be divided into two types: optical fiber jumper and pigtail [1].

Optical fiber cable is mainly composed of optical fiber (thin glass fiber as thin as hair), plastic protective sleeve and plastic sheath. A cable core is composed of one or a certain number of optical fibers in a certain way, and is sheathed with an outer sheath, and some are covered with an outer sheath, which is a communication line used to implement optical signal transmission. The optical cable, the optical cable, and the equipment can be connected to each other to complete the transmission of the optical signal. When the connection is made by a connector or a fusion splicing method, the optical cable can be divided into two types: optical fiber jumper and pigtail. The pigtail used by a large-capacity satellite is divided into optical cables, strain sensors, temperature sensors, fiber fusion points, fiber connectors, and fiber adapters.

2.2 Assembly conditions

The optical fiber cable includes optical fiber measurement demodulation and four sensing head optical fibers in between. The optical fiber measurement demodulator is installed in the load compartment and is installed during the installation of the load compartment. The 4 optical fiber cables are installed after the communication and measurement and control equipment are installed. Since the final assembly time of the optical fiber cable is not synchronized with the first-stage assembly of the satellite, the installation of the optical fiber cable cannot be laid out in the first time like a conventional cable. When the device is plugged into place, the state in the cabin is more complicated.

At the same time, the fiber optic cable has a wide layout area and a large cable length, which is distributed throughout the load compartment and runs through the north and south boards. The total length of the fiber optic cable is not less than 6.5 meters. The diameter of the optical fiber itself is 0.25mm, and the diameter of the outer Teflon sleeve is 0.9mm. The texture is brittle, the mechanical strength is low, and the temperature sensor and strain sensor in the optical cable have fixed position requirements. The optical fiber must not be subjected to any external force during the laying process. Therefore, the wiring path of the optical fiber cable is complicated, and the assembling operation is difficult.

2.3 Analysis of laying difficulties

A satellite contains 4 fiber-optic cables. Because each fiber-optic cable has a different path, it must be laid separately. And the optical fiber itself is a thin glass fiber with a diameter of only 0.25 mm. The optical fiber has a long length, and each fiber has a matching FC-type optical fiber plug, a PLC, multiple temperature sensors, strain sensors, and optical fiber splicing sleeves.

Due to the characteristics of the fiber optic cable and its complex assembly background, during the wiring process, special attention should be paid to the bending radius of the fiber optic cable, which should not be less than 50mm. Special attention should also be paid to the stress relieve of the fiber optic cable when passing through the cabin board, the temperature sensor and the ends of the optical fiber welding sleeve are not stressed to excessive bending, and the strain sensor, that is, the bare fiber does not hook the on-board equipment and cables, resulting in damage to the fiber. These characteristics make the fiber optic cable wiring difficult to operate, the risk factor is high, and there is a certain quality hazard. Therefore, it is the key to ensure that the optical fiber is not damaged during the fiber optic cable wiring process [2].

2.4 Analysis of Difficulties in Connecting Connectors

The optical fiber connector is mainly used to realize the connection of the optical fiber. High-precision component (composed of two pins and a coupling tube) is used to realize the alignment and connection of the optical fiber and complete the transmission of optical signals. The optical fiber connector inserts and fixes the optical fiber into the pin. The butt end of the pin is ground and polished to achieve alignment in the coupling tube. The coupling tube is generally two halves made of ceramic or bronze and synthetic, fastened cylindrical components. The tube is often equipped with metal or plastic flanges
to facilitate the installation and fixation of the connectors. In order to accurately align the optical fiber to transmit the optical signal, the processing accuracy of the pin and the coupling tube and the cleanliness of the plug connection surface are very high [3].

The structure of the optical fiber connector is different from other electrical connectors, its pins are completely exposed outside the housing without any protection device. When inserting, the optical fiber connector is first connected with the pins, and the rear housing is positioned and locked, which is contrary to the principle of electrical connector inserting and greatly increases the difficulty and risk of inserting. At the same time, the splicing of optical fibers places extremely high requirements on the end faces of the optical fiber connectors. Therefore, the operation details and the level of operation technology are particularly important. If the operation is not meticulous and the process is not rigorous, it will have serious consequences and cause quality accidents.

3. Fiber laying

The fiber optic cable should be protected before laying, that is, take necessary protective measures for the sensor (bare fiber). Use 3M tape to protect the exposed optical fiber to ensure that the optical fiber is not subjected to transverse stress when the 3M tape is removed, and to avoid fiber breaking; mark the temperature and strain measurement points on the satellite, and accurately place the measurement points on the satellite according to the overall star layout of the design documents. Make a mark on the board to prepare for the subsequent optical cable wiring.

Fiber optic cable wiring is not only simply laying fiber optic cables on the spacecraft, but also includes positioning requirements for temperature sensors and strain sensors. The length of the optical fiber between the sensors in the optical fiber cable is generally longer than the positioning distance between the sensors on the satellite. It is not possible to directly lay the optical fiber cable on the satellite, which will easily lead to the wrong location of the sensor on the satellite. According to the above-mentioned characteristics and requirements, the operation method of "sensor positioning first, optical cable arrangement second, and glue dispensing fixed" is proposed.
3.1 Sensor positioning
The wiring of the fiber optic cable is laid out from the fiber connection head end, and the sensor fiber is wired according to the entire star layout of the temperature and strain measurement points. During operation, the sensor fiber is routed according to the measuring point, and the fiber should be laid on the bulkhead as much as possible. The fiber should not be stretched forcefully, bend the fiber violently, or use a sharp object to cut the fiber. When positioning the temperature sensor, pay attention to the identification of the mounting surface of the sensor, and the wide surface closer to the pigtail is the mounting surface. Then, use 3M tape to temporarily fix the sensor body and the fibers at both ends to ensure the sensor fiber is firm and reliable. When installing the strain sensor, place the strain sensor flat on the position to be measured, and the fiber axis is consistent with the direction to be measured.

3.2 Optical cable finishing
After fixing the optical fiber sensor, arrange the optical fiber cables between the sensors in time. In order to avoid the problem of insufficient fiber length due to rework and other reasons in the actual layout of the transmission fiber, the length of the fiber between the fiber sensors on each transmission fiber should be greater than the length specified by the entire satellite layout requirements. The remaining optical fiber between the sensors can be bent or coiled into a ring according to the specific situation, and the bending radius of the transmission fiber bend or coiled into a ring should be greater than 20mm. As shown in Figure 3.

![Bending Radius](image)

Figure 3. Schematic of Fiber Turning Radius

For fiber optic cables that cannot be directly laid on the bulkhead, they can be fixed together with other cables according to the actual laying environment. Taking into account that the use of nylon cable ties is too tight and the optical fiber has obvious deformation, combined with many years of operating experience, it is proposed to use a binding wire or 3M tape to wrap the optical fiber and the cable together, and then fix it with GD414 silicone rubber at 4 points. Or the optical fiber is directly fixed on the cable with GD414 silicone rubber. The fixed area should be able to firmly fix the optical fiber (the bonding area is not less than 10mm×10mm, and the optical fiber sleeve is covered by the adhesive glue visually).

3.3 Dispensing and fixing
Perform dispensing and fixing operations on the arranged and fixed optical fibers, temperature sensors, strain sensors, and optical fiber fusion splice sleeves.

Fixing the temperature sensor: After the temperature sensor is arranged at the position to be measured, apply a small amount of GD414 glue (even and thin) on the bottom surface of the sensor, fully contact the sensor with the measured point, and then apply the GD414 glue to the sensor head and cover the Teflon sleeves on both sides (near 3cm from the end of the sensor head), and stick it firmly.

Fixing the strain sensor: When installing the strain sensor, you need to gently remove the 3M tape at the tail and the protective sleeve at the lower end (be careful not to subject the optical fiber to transverse stress to avoid breaking the optical fiber), and then straighten the optical fiber , put it on the device under test. The strain sensor consists of two parts: strain grating and temperature compensation grating, both of which are in bare fiber form [4].
When installing, place the strain grating flat on the position to be measured, the axis of the optical fiber is consistent with the direction to be measured, use 3M tape to fix the optical fiber to the position to be measured in the tape fixing area, then bond the strain sensor to the surface of the substrate and clean with alcohol. Untie the 3M tape on both ends of the strain sensor series heat shrink rod and then remove the heat shrink rod and remove the Φ0.9 Teflon sleeve for protecting the strain grating from the Teflon sleeve interface.

![Figure 4. Schematic of Sensor protection disassembly diagram](image)

After the test surface is cleaned, a small amount of 502 glue is evenly coated on the surface of the cleaned area, and then the 3cm bare fiber on the left end of the strain grating and the 10cm outer sleeve connected to the rear end of the strain grating are bonded to the test surface through a small amount of 502 and covered with PTFE. After filming, use finger pressure for ten seconds to wait for 502 to cure. Note that during the curing period of 502, ensure that no 502 is attached to the temperature compensation grating. Coat the GD414 glue uniformly on the above fixed parts. GD414 glue is mainly used for the protection of the strain grating. The coating is required to be uniform, and the coating thickness is about 1mm~2mm.

Fixing of optical fiber fusion tube: GD414 silicone rubber should be used to fix the fusion tube. GD414 should be used to fix the optical fiber fusion tube firmly (the bonding area is not less than 20mm×10mm, and the optical fiber fusion tube is covered by the adhesive glue visually), the physical and bonding diagram of the fiber fusion splice sleeve is shown in Figure 5.

![Figure 5. Schematic of optical fiber fusion splicing](image)

Fixing of PLC: According to the selected fiber fixing position and PLC sticking position; winding the four-channel fiber output from the flange into a ring, the diameter of the ring is greater than or equal to 50mm. Fixing the PLC in sequence. First use alcohol to clean the surface to be fixed. Then spread a little 502 glue on the bottom surface of the PLC (the side that indicates the serial number is not attached), a thin layer of 502 glue should cover the entire bottom surface. Then fix it on the fixed position of the instrument, and then use 3M tape to fix both ends of the PLC.
4. Fiber connector plug
The final assembly of the spacecraft has strict requirements on the insertion of optical fiber connectors and operation technology. Combining the accumulation of years of work experience and operation practice, an optical fiber connector plug operation method of "clean first, then detect, and then plug" is summed up. Which ensures that the optical fiber pin is pollution-free, and the performance of optical transmission is stable and reliable.

4.1 Clean
Clean the end face of the optical fiber connector, remove the protective cap of the optical fiber connector, and wipe the end face of the optical fiber connector with a special dust-free paper moistened with a little absolute ethanol. The use of dust-free paper should control the amount of absolute ethanol used and should not squeeze out excess absolute ethanol to prevent dripping. When wiping, the end face of the fiber connector pin should be perpendicular to the dust-free paper and wipe in one direction. The force should not be too strong. It is strictly forbidden to wipe back and forth on the end face of the ceramic pin or make a curved or fold line movement to avoid the generation of excess and affect the operation schedule.

4.2 Detection
Use an optical fiber end face detector to detect the end face of the cleaned optical fiber ceramic pin. First, insert the optical fiber ceramic pin into the observation hole of the optical fiber end face detector, and adjust the position adjustment knob of the magnifying glass until all the graphics on the optical cable end face enter the field of view and make the graphics clearest. Then, observe the end surface of the fiber ceramic pin for more than 1 second, check the surface condition of the end surface, and confirm whether there are stains (diameter exceeding 3μm). If there are stains on the end face, as shown in the figure below, the above operation should be repeated until the end face is qualified.

![Figure 6. Schematic of end-face inspection equipment](image)

4.3 Docking
First, the protruding part on the optical fiber connector is opposite to the notch on the optical cable connector jack, and then the optical fiber connector is inserted into the jack vertically, and the insertion is ensured. During the plug-in process, in order to ensure that the cleaned end face does not touch any objects, the plug-in technique of "one stability and two standards, two supporting points" is summarized. When plugging in, try to find the bulkhead, equipment or the other hand as a support point. The ceramic pin slowly approach the socket at an angle of 150°, so that the column section of the ceramic pin contacts the wall of the socket as another support point. Then, slowly level the optical fiber connector so that it can be inserted into the jack vertically to avoid problems such as shaking left and right during the inserting process of the ceramic pin, and contamination of the pin end. If there is any contact, it must be cleaned and tested again. After the test is qualified, insert it again to ensure the cleanliness of the optical
fiber ceramic pin. Finally, manually tighten the lock nut of the optical fiber connector clockwise until the nut cannot be screwed in. No tightening torque is required, but a certain amount of manual force is required to ensure that the lock nut is as tight as possible. After the equipment is installed with correct performance test, and before the whole satellite vibration test, choose an opportunity to perform GD414 silicone rubber operation on the periphery of the connector at the thread where the optical fiber plug and the optical fiber connector are connected to improve the connection strength.

5. Conclusion
The fiber optic cable assembly method for large-capacity satellites successfully has completed the satellite fiber optic cable assembly practice. The cable wiring method of "first sensor positioning, then optical cable arrangement, and then dispensing and fixing" and the connector plugging method of "clean first, then inspect, then plug in" are summarized. These two methods are innovative.

When the optical fiber cable is routed through the cabin, it is proposed that the optical fiber is laid in a "curved" form to reduce its own stress, avoid the optical fiber to be laid at a 90° right angle, and eliminate hidden quality hazards. When fixing the optical fiber cable and the cable together, considering the characteristics of the optical fiber itself such as brittle texture and low mechanical strength, it is proposed and fixed with a binding wire or 3M tape wound and glued.

When the optical fiber connector is plugged in, the plugging technique of "stability and standards, two supporting points" is summarized. When the optical cable connector is inserted into the optical fiber end-face detection equipment and the optical fiber adapter, the tail of the connector should be held by hand. Do not only hold the optical cable to feed the connector, so as to avoid the tail of the optical cable when the connector is stressed. That is, hand is stable, the positioning pins of the two fiber connectors are accurate, and the two supporting points are the hands and the connector to find two supporting points to ensure that the fiber connector does not touch any objects and ensure the cleanliness of the connector end surface when the fiber connector is inserted.

Based on the full analysis of the characteristics of the optical fiber and the quality problems that the optical fiber cable is prone to in the spacecraft assembly, this paper proposes a highly operable method for optical fiber cable wiring and connector plug. The method effectively solves the problem of final assembly of fiber optic cables on spacecraft.

References
[1] Jihua Z 2009 Aircraft Digitized Measurement Aided Assembly Technology and Application. Aeronautical Manufacturing Technology 2009(24):49-52.
[2] Xu Fuxiang, satellite Engineering, China Aerospace Press, 2002, pp.69.
[3] Wang Yingyan, Xu Yeping, “The low frequency electric cable network design for satellite,” Spacecraft Environment Engineering, 2013, 30 (2) :200～202.
[4] Tan Weichi, Hu Jingang, Spacecraft System Engineering, China Science& Technology Press, 2009:131.