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Research on key technologies for installation and maintenance of reflector of FAST

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Abstract The reflector of the Five-hundred-meter Aperture Spherical radio Telescope (FAST) consists of 4450 reflector units. Installation of the reflector faces the challenges of large span, complex terrain, serious interference, complex processes, high position and inability to use conventional equipment. The installation technology for the flexible reflector with a large span was specially studied and designed. Two half-span arc-moving cable cranes and two transfer trucks were jointly operated along a path that follows a circular beam. After installation of the reflector was completed, two half-span cable cranes were merged into a set of full-span cable cranes for maintenance of the reflector. Installation of the reflector combines features of unit and site topography of FAST. The installation technology follows scientific and reasonable practices, and is highly efficient and convenient. It represents a breakthrough in many key technologies in construction and maintenance techniques. It has promoted related technical progress in the construction and maintenance of complex projects. It has also provided an important reference for the construction and maintenance of similar projects, and has strong significance and applicability.

Key words: FAST — Reflector — Installation — Maintenance — Cable crane

1 PREFACE

Reasonable technologies for installation and maintenance can also be applied as key technologies in large-scale structure projects. At present, such installation technologies include the conventional method of installation, jacking installation, sliding installation, block installation, etc. (Gao et al. 2007; Zhu et al. 2004). A reasonable installation scheme should be studied and designed according to the specific project characteristics. However, a cable crane is utilized to install rated loads in a specific construction field. In recent years, such approaches have been widely employed in projects for water conservation and hydropower, and the projects related to mines and disaster prevention which are difficult to construct by conventional equipment and methods. Such a crane can span the environment of a complex project through application of its cableway. Compared with conventional equipment, a cable crane has the advantages of less environmental damage, less land occupancy and less investment (Lü & Zhang 2009; Tang 2013). It also has the advantages of reducing labor intensity, and improving efficiency, safety and reliability (Niu et al. 2006; Zhang et al. 2011).

2 PROJECT OVERVIEW

The Five-hundred-meter Aperture Spherical radio Telescope (FAST) is currently the largest single-dish radio telescope in the world (Nan 2009). It was completed in Sep. 2016. The site of FAST is located at Dawodang in Kedu Town, Pingtang County, Guizhou Province, China. At present, the deformable surface design is successfully operating and many new pulsars have been discovered. A panoramic photo of FAST is displayed in Figure 1. The active reflector of FAST consists of a circular beam, reflector, cable net, actuators, anchors and so on. The cable net with 2225 nodes was installed on the circular beam. Each node is connected with a pull-down cable, the end of the pull-down cable is connected with an actuator and the actuator is connected with the ground anchor. There are 4450 reflector units installed on the cable net. A diagram of the cable net for the circular beam is depicted in Figure 2. Reflector units are divided into triangular and quadrilateral units. The total number of triangular units is 4300, with a scale of 10.4–12.4 m. The weight of ordinary triangular structures is about 500 kg and there are 186 types. The total number of quadrilateral units is 150 and the weigh of each one is about 1000 kg, with all of them being spatial grid structures. There are connecting

Fig. 1 A panoramic photo of FAST.

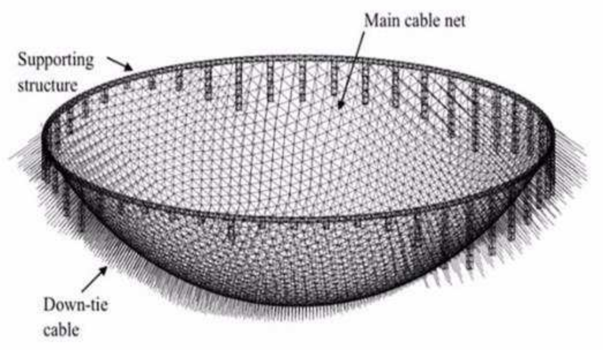

Fig. 2 Diagram of the circular beam and cable net.

Fig. 3 The prototype of a reflector unit.

joints on the back frame of each reflector unit, which are connected with the node disk of the main cable net through the joints. The installation process of a reflector unit connects 4450 reflector units on nodes of the cable net to form the reflector of FAST, and the maintenance of the reflector should also be considered. The installation period of a reflector unit was not more than one year, and the rate of installation was not less than 20 pieces per day. The prototype of a reflector unit is shown in Figure 3.

3 KEY TECHNOLOGIES FOR REFLECTOR INSTALLATION

Installation of the reflector should consider not only a reasonable and reliable scheme, but also the operation and maintenance of the reflector (Jiang et al. 2019).

3.1 Flexible Installation Technology for the Long Span of FAST

Because the locations where the reflector units are installed are high, there is much interference, and the operating conditions are complex. According to the characteristics of FAST, site roads and other issues, the conventional installation process for equipment cannot be utilized, the feed cabin will often stay on the platform in the center of the reflector and installation of the reflector will interfere with the driving cables of the feed cabin. Considering the operation and maintenance requirements of the reflector, after research, the installation scheme of the reflector was implemented as follows: two half-span cable cranes and two transfer trucks. That is to say, a central circular beam with a servo trolley was installed in the center of the reflector, and a running track for the installation equipment was laid on the circular beam. The half-span cable crane has been placed between the rail truck and the servo trolley at the center circular beam. Considering the installation efficiency of the reflector and the stress of the central circular beam, the two cable cranes and two transfer trucks are symmetrically operated. At the same time, considering that the qualified reflector units are assembled on the ground, and they need to be transported to the transfer truck on the circular beam, a fixed tower crane has been installed on the assembly site near the circular beam. The installation scheme is depicted in Figure 4. The installation process for a reflector was designed as follows: a qualified reflector unit was assembled and transferred to the transfer truck on the circular beam through tower crane in the air, and the transfer truck carried the reflector unit along the circular beam to the cable crane at the adjusted position. The cable crane transported the reflector unit radially to the designated position on the cable net, and the reflector unit was installed on the node of the cable net. The three connecting joints were assembled and connected with the upper disk of the cable net node to complete an installation process cycle.

3.2 The Technology for Shape Preservation and Position Adjustment in the Reflector Unit

In view of the installation technique for a reflector unit, two kinds of installation tools were researched and designed. The technical characteristics of the installation tools are as follows: (1) Ensure the shape of the reflector unit is not

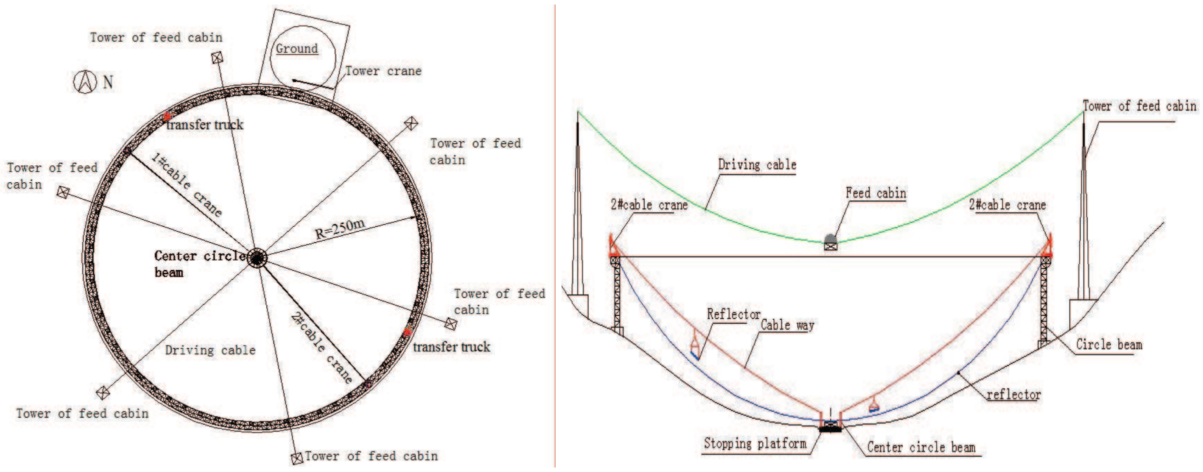

Fig. 4 A schematic diagram demonstrating installation of a reflector unit.

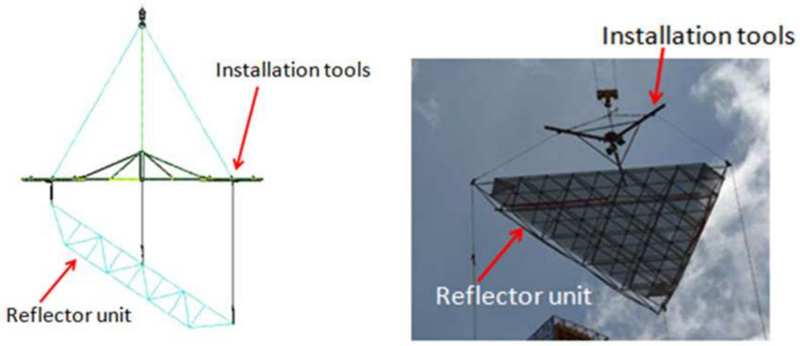

Fig. 5 Depiction of the installation tools for a reflector unit.

affected by the installation process; (2) Match all types of triangular or quadrilateral units; (3) Adjust the position of reflector units in the air, so that the position is consistent with position in the cable network. (4) The connection between installation tools and reflector units should be simple, reliable, and easy to disassemble and assemble. The structural sketch of a triangular hanger is displayed in Figure 5. There are three fixed rope-length suspension ropes under the hook connected with the hanger. Under the hanger, there are three suspension ropes. Two of them can be utilized to control the length of the rope. The fixtures of installation tools are designed at the ends of the three suspension ropes which can connect to the reflector unit. They are respectively mounted on the end rod of the reflector unit to facilitate disassembly and assembly. The position of the reflector unit can be adjusted by controlling the length of the two suspension ropes. The installation tool has solved the technical problems of shape preservation, position adjustment and transfer of the reflector unit. The installation tool played an important role during the installation process of the reflector. The installation accuracy and efficiency of the reflector units were ensured. The installation of the reflectors has successfully been completed based on the key technology of reflector installation.

3.3 Technology Enabling Multiple Transfers in Air of Reflector Units

In order to improve the installation efficiency and ensure that the surface accuracy of reflector units cannot be affected by the transport process, a qualified reflector unit is lifted by a tower crane to the transfer truck through the transfer hook in the air. The first transfer in air is completed. The reflector unit is transported by the transfer truck to the adjusted cable crane. Then, the reflector unit is transported from the transfer truck to the cable crane. The second transfer in the air was completed. The reflector unit is transported to the designated location on the cable net through the cable crane and installed on the node. A schematic diagram of the transfer hook is shown in Figure 6. Two transfers in the air are displayed in Figure 7 and Figure 8. The solution of two key technologies for transfer in the air not only improves the installation efficiency of a reflector unit, but also ensures the surface accuracy of a reflector unit, which not only represents engineering innovation, but also signifies important significance to the project.

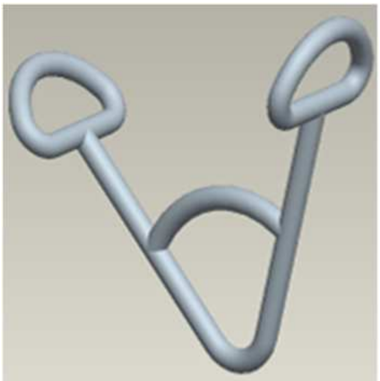

Fig. 6 A transfer hook.

Fig. 7 The first transfer in the air (from crane tower to transfer truck).

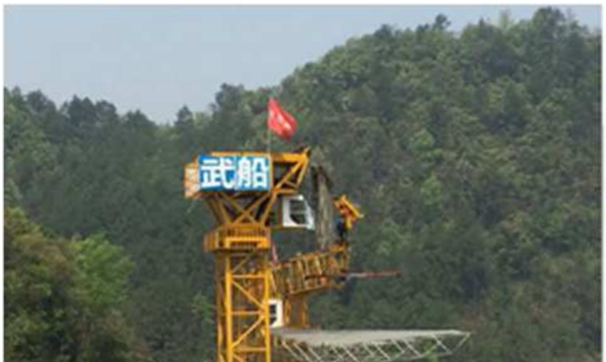

Fig. 8 The second transfer in the air (from transfer truck to cable crane).

3.4 Resolving the Problem of Interference between the Installation Equipment and Six Cables of Feed Cabin

During the installation of a reflector unit, the six driving cables connecting the feed cabin were located on the platform for installation. Even if the feed cabin was lifted up, the feed cabin needs to come back to the stop platform. Because of the shape and spatial position of the six cables, the cable crane system will interfere with the six driving cables of feed cabin, which will result in the installation equipment of the cable crane not running continuously in a circle, and the installation of reflector units which will affect the installation efficiency. A diagram illustrating the interference between installation equipment and six cables of the feed cabin is depicted in Figure 9.

In order to solve the problem of interference, the relationship of structure size between the cable crane with six cables and feed cabin has been studied in detail. A central circular beam was designed and built on the foundation of the central reflector. A follow-up dolly has been designed on the circular beam. The circular beam was designed to be two layers above and below, and it has a diameter of 24 m. There is no interference between the central circular beam and the platform of the feed cabin. A half-span cable crane has been placed through the cable system of the truck on the circular beam and follow-up dolly on the center circular beam. Considering the relative sizes, shapes and positions of the platform structure, the central circular beam was designed as an open form at the projected position of the six cables. The open form schematic is displayed in Figure 10. The six open positions were designed as a small railway, and the lower central circular beam was designed to have a closed form. When the six cables maneuver the feed cabin at the focus, the small railway closes, and then the cable crane can rotate 360 degrees for installation and the reflector can be fully covered. When the feed cabin needs to stop at the platform, the small railway needs to open, let the six cables descend down the top of the center circular beam, and then the railway need to be closed. The cable crane can then install the reflector unit freely. This method of resolving interference has very important significance.

3.5 The Progress on Reflector Installation

The installation of reflectors began on 2015 August 2 and ended on 2016 July 3. It lasted 335 days. The installation of 4450 reflector units was about one month earlier than planned. The installation records of 37 reflector units per day and 802 reflector units per month were established. During the installation period, the cable crane system also completed other auxiliary projects such as measuring target replacement, which is fully consistent with a scientific and reasonable installation scheme for the reflector. This work has significance for FAST and relevant fields. Statistics on the daily progress of installation for reflector units are displayed in Figure 11.

3.6 Maintenance Scheme for the FAST Reflector

After construction of the telescope was completed, the reflector needs to be maintained, including maintenance of the reflector units, cable mesh node disk, measurement tar-

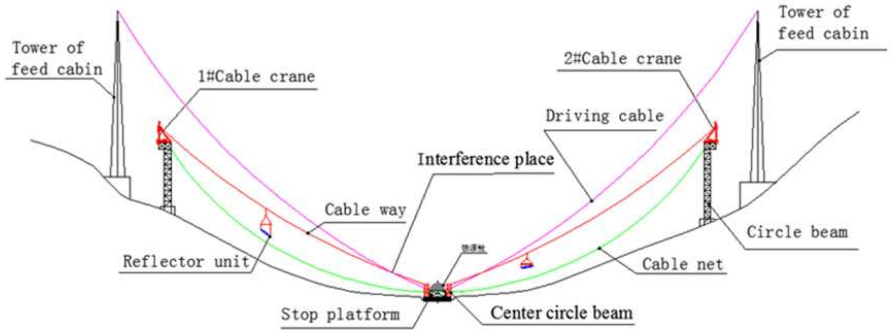

Fig. 9 Diagram illustrating installation equipment and six cables of the feed cabin.

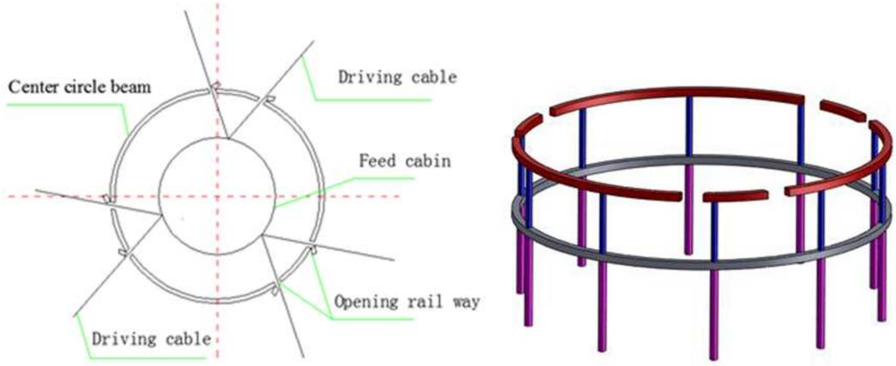

Fig. 10 Projected diagrams of the center circular beam.

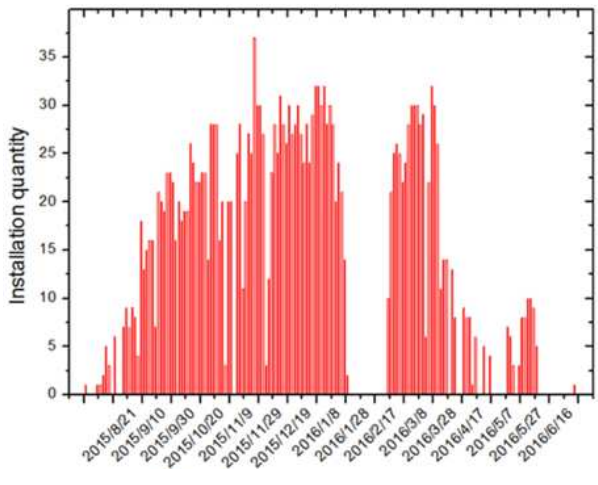

Fig. 11 Statistics on the daily progress of installing reflector units.

get and so on. According to the requirements, the key technology for maintenance of the surface was also studied and solved: two half-span cable cranes were connected together and changed to a set of 500 m full-span cable cranes, which can reach all positions on the reflecting surface and carry out maintenance of the reflector. When FAST needs to observe or the feed cabin must go back to the platform, the full-span cable crane can retract the cable system. Two cable trucks are parked side by side at the 1H of circular beam. When the reflector needs to be maintained, the full-span cable crane needs to be deployed and equipped with a hanging basket to maintain the reflector. A schematic diagram of the maintenance scheme is provided in Figure 12. The scheme design of reflector maintenance is scientific, reasonable, simple and reliable, which has significance and practical value for the project.

3.7 The Maintenance Plan for the FAST Reflector

During a heavy rain in an evening of May 2017, about a 1 ton stone dropped and hit the down pull cable at the 3H of FAST site, which impacted the joint disk of the cable net. It caused damage to seven reflector units. In view of this situation, full-span cable crane maintenance technology was adopted. The cable crane was expanded to 500 meters on the circular beam. The cable crane loaded with installation equipment and the damaged reflector unit were lowered to the ground. Then a qualified reflector unit was installed onto the node of the cable net. In the process cycle, the damaged reflector unit was repaired, and some targets were also repaired. Maintenance of the reflector is demonstrated in Figure 13. Practice indicates that the maintenance equipment of the reflector not only represents a breakthrough in key technology for changing a half-span into a full-span cable crane, but also performs maintenance of the reflector rapidly and efficiently with no blind area. It has great significance for the project.

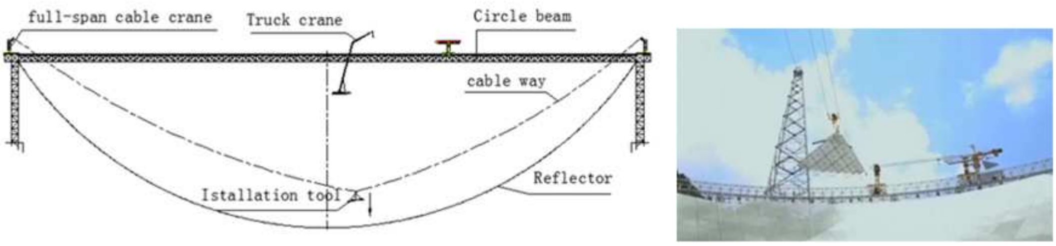

Fig. 12 Schematic diagram (*left*) and photo (*right*) of maintenance scheme for reflector.

Fig. 13 Photos of maintenance scheme for reflector.

4 CONCLUDING REMARKS

FAST reflector installation and maintenance have been successfully completed, which represent a breakthrough in many key technologies for large-span flexible installation and reflector maintenance. It has been evaluated by a leading expert group in the world as overcoming technical difficulties, signifying high level technology, and representing a number of key technical breakthroughs, which solve the construction and maintenance issues of a large-span complex project as follows: (1) the installation and maintenance technology of reflector; (2) the technology of shape preservation and position adjustment for reflector unit; (3) the technology of two transfers in the air for a reflector unit; (4) the technology of an arc-shaped railway running the installation equipment; (5) the technology of a half-span cable crane changing to full-span cable crane; (6) the technology of interference resolution for installation equipment operation and the six-cable feed cabin entry onto platform. The installation and maintenance technology of the reflector were designed according to the characteristics of site terrain, road and FAST, and combined with the technical requirements of installation for the reflector unit. It effectively solves the technical problems of installation and maintenance for the reflector. The reflector unit for the first installation and the last installation were broadcast live on CCTV, which represents a significant milestone. The program "Glorious China" on CCTV states "In the construction of the sky eye, every step is a difficult problem ..." There is no precedent for this kind of large-span and high-precision installation in the world. The installation and maintenance of reflector technology has important project significance and application value, which promoted the progress of related technology, and provides technical reference for the construction and maintenance of other such large-span projects.

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