Adaptive Cable-mesh Reflector for the FAST

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Abstract The adaptive cable-mesh reflector is an Arecibo-type reflector with the additional capability to adjust the illuminated area to activate the antenna surface. The key knowledge in this newly proposed engineering concept is to use the equilibrium shape of the cables under gravity, catenary, to form the parabola. The adaptive control for the cable mesh reflector is to allocate the nodal points of the mesh to appropriate position on the illuminated parabola so that the parabola is formed within given precision. To test the feasibility of this idea, a finite element software is developed to simulate the concept. The preliminary results are encouraging.

Key words: Radio telescope, Spherical reflector

1 Brief Introduction to FAST

China has embarked on a project to build the world's largest radio telescope FAST, Five hundred-meter Aperture Spherical Telescope, in a karst depression in southwest of the country (Nan,1996). The FAST is an Arecibo-type telescope with a number of innovations. The optical geometry and 3-D computer image of FAST are shown in Figure 1. The main reflector is a spherical cap with a radius of ~300 m and an opening up to 500 m in diameter. The effective aperture of ~300 m is illuminated by the feed moving on the focus surface halfway from reflector to its center. The telescope is pointed by moving the focus cabin and simultaneously adjusting the shape of the illuminated area. The geometrical configuration together with the offset illumination at the edge of the reflector enables FAST to observe at larger zenith angle. FAST is expected to continuously cover frequency range 200-2000MHz, with capability up to C-band or even X-band.

The active main reflector (Qiu 1998) corrects the spherical aberration on the ground, which breaks the bandwidth and polarization limits without involving a complex feeding system. A so-called integrated optical-mechanical-electronic design (Duan 1996) for FAST feed support has been intensively investigated to replace the heavy platform in air (see 3-D image in Fig.1b). The feed cabin is supported and driven by sets of cables and servomechanisms. Feasibility study on these critical technologies for FAST as well as science case, site surveying, layout of the focus package, complicated measurement and control has been selected as one of the key projects and supported by the Chinese Academy of Sciences in 1999.

2 Summary on Scaled Model Experiments for FAST Main Reflector

To deform the reflector, it is necessary to divide it into small elements. Each element is a small part of a spherical surface whose curvature optimized carefully for FAST is R=335 m, which is slightly different from the one of the neutral curve of the main reflector in

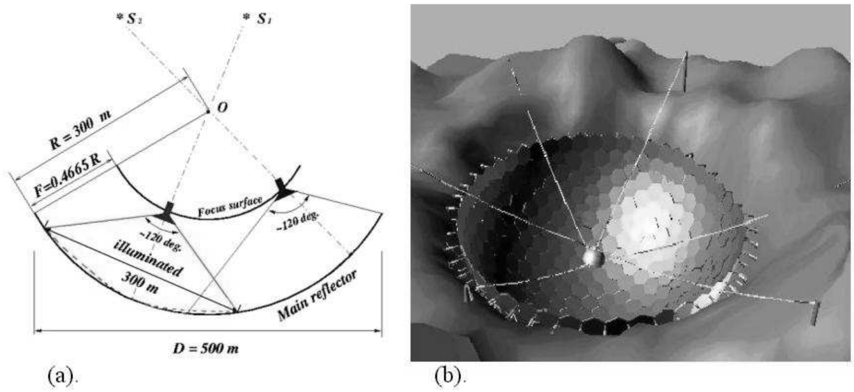

Fig. 1 The full view of the FAST. (a) The optic geometry of the FAST. The parabola surface deformed is shown by the dashed line. (b)The 3-D computer image of the FAST.

Figure 1. One proposed way of dividing it is to have ∼1800 hexagons as shown in Figure 2. Each element has three actuators to fix its position and connect it with adjacent ones, and there would be an average of one actuator per element. As FAST is tracking and forming a real-time parabola, the actuators move along the radial direction with a maximum throw of 67 cm.

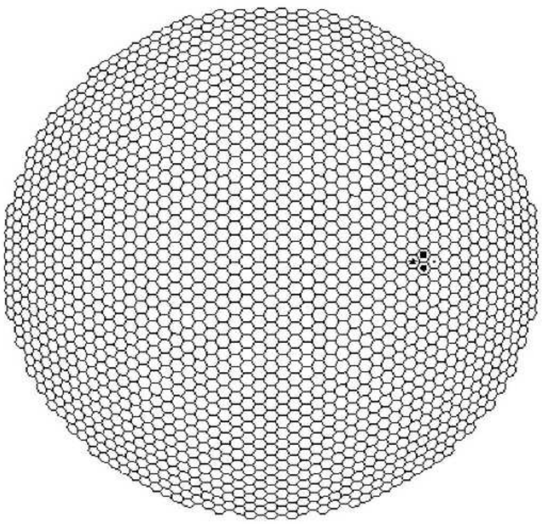

Fig. 2 The FAST main reflector is divided into about 1800 hexagons

Four pieces of elements at moderate altitude of the spherical cap as marked in Figure 2 were selected for scale modeling. Figure 3 shows the fieldwork of the experiment while the last element was being mounted. The up-to-date field bus technology, LonWorks, was employed to serve as the actuator control network. This photo also illustrates that future FAST main reflector will be a buildup of 4 layers – surface and its back structure, self–adaptive connector, actuator, and civil engineering in depression. This model experiment basically has approved the feasibility of the engineering concept of the FAST main reflector on the whole.

Many questions, as many as those positive results, were raised from the experiment. Investigations addressed these questions have made notable progresses. These include a new scheme of segmentation to largely reduce the species number of hexagons for mass production, kinematics study on the adaptive connector to modify its controllability, innovated tense grid design for the reflector element to lighten it and to reduce bearing force of the actuators at the tangent direction, test on reliability and life-time, layout of the civil engineering structure in depression, and etc. In this paper, a completely different realization for the active main reflector of FAST is proposed based on our learning and understanding of the FAST from prophase feasibility study.

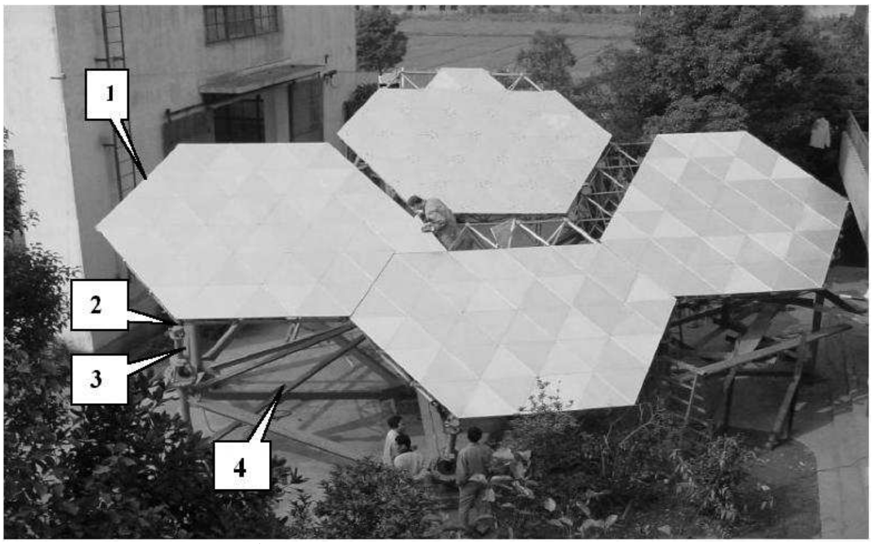

Fig. 3 The scaled model of the FAST active reflector. The marked numbers indicate the 4 layers of the main reflector construction: 1-surface and its back structure, 2-self-adaptive connector , 3-actuator, 4-civil engineering between actuators and depressions (here, experiment mount).

3 The Engineering Concept of Adaptive Cable-mesh Reflector

As a piece of massless and ideally stretched rope is slightly pulled away from the tense position at its middle, the total length varies almost invisibly. The increment in length of 500-meter-long rope, for an example, is about 4 mm, less than $10^{-5}$of the total, while the central offset is 1 m as shown in Figure 4. This hints us that an antenna surface supported by cable net as Arecibo telescope could be activated in some extend without extra-servos controlling the lengths of those supporting ropes.

The central part of a spherical surface is very close to a paraboloid of revolution when a proper focal length is chosen. The focal length of the FAST could be accurately determined as f=0.4665 R according the formulae given by Li (1959), which minimizes the peak deviation of the spherical surface from the paraboloid of revolution across the $\sim$300 m of illuminated aperture. The integrated length of the dashed line (Fig.1a) indicating the deformed parabola is only 0.36 m shorter than the spherical curve, about one in a thousand of the total length. This small difference required by deforming could be easily achieved within the elasticity of ordinary wire ropes, although the mechanical analysis is much more intricate. Instead of

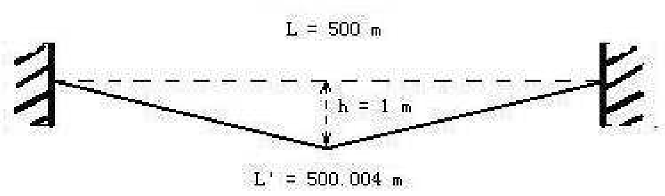

Fig. 4 The increment of long rope

elastic deformation, adjusting the meshes outside the illustrated area can also compensate this small difference in length.

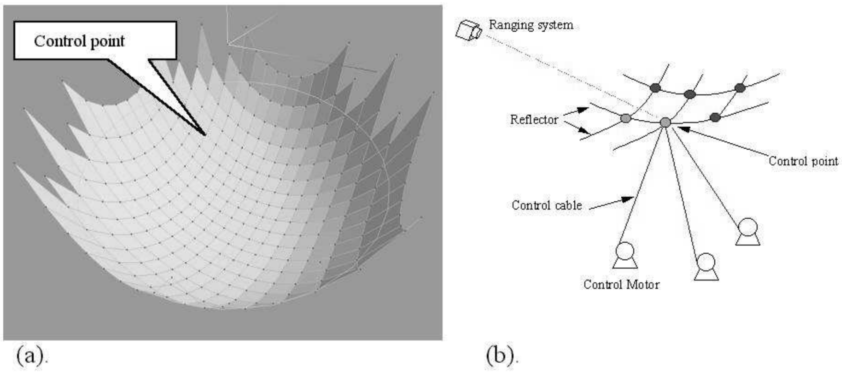

Fig. 5 The cable-mesh reflector with control points and the control cable for the adaptive reflector.

Ignoring the active control, the newly proposed FAST surface adopts a similar structure of Arecibo telescope. The cable-mesh consists of two sets of cables respectively in two orthogonal directions, as shown in Figure 5. Above the cable network aluminum plates, expanded and flattened metal mesh, or welded stainless steel mesh are attached. The crossing-nodal points of the cable mesh are used as the control points. The neutral equilibrium of the reflector is taken as the optimized spherical cap. The full 3-D controllability around the equilibrium is assumed for the control points. In practical implementation, three downward cables are to be used to realize the control along the radial and tangent direction, see figure 5b. Motors adjust these cables with feedback from the ranging system for the control points. The proposed ranging system will be consisted of 6 rangefinders which have been equipped on the Green Bank Telescope(100 m). We plan to have $\sim$300 targets attached to the control points on the cable-mesh reflector of FAST, and monitor positions of $\sim$140 targets located within illuminated area in observing time. For individual target, the position data with an accuracy up to 100 μm will be obtained by the ranging system with a flash period of 15 seconds, during which the maximum movement of each target is estimated as 3 mm and the real time position could be worked out by combining the discrete measurement and interpolation based on kinematic and dynamic analysis.

4 Simulating

In order to test the feasibility of the concept, a finite element software is developed for simulating. Grating is firstly made across the aperture of 500 m in diameter, following by vertical projection on reflector considering that the equilibrium position of a cable under gravity is in a vertical plane. Grating intervals are 30 m in this experiment, which configures two orthogonal sets of cables and 305 control points on the spherical surface. Diameter of cables is 3 cm and typical characteristics of ordinary wire ropes are supposed.

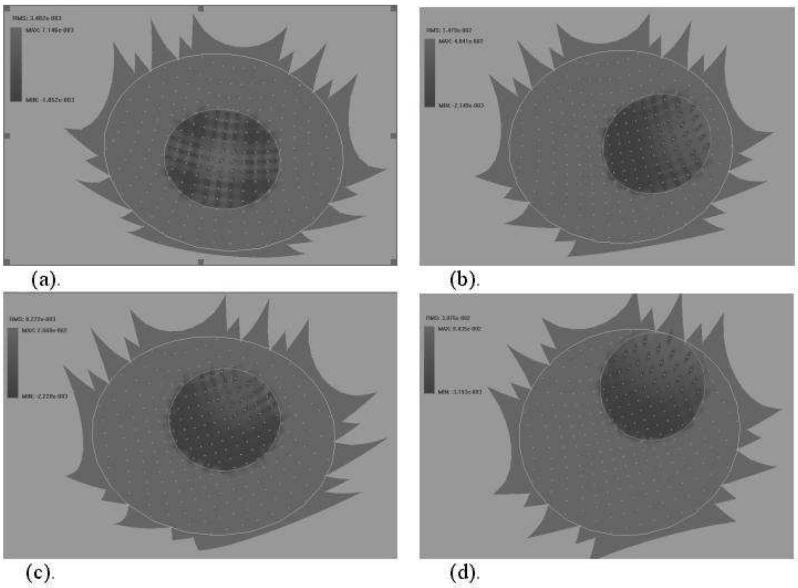

Fig. 6 Preliminary simulation results with the conditions: Diameter of the cable: 0.03 m; Horizontal distance between cables: 30 m; Total number of control points: 305. (a)Elevation 0° , Azimuth 0° , actual control points: 137, RMS error: 0.0034. (b)Elevation 20° , Azimuth 0° , actual control points: 132, RMS error: 0.014 m. (c)Elevation 15° , Azimuth 45° , actual control points: 135, RMS error: 0.008 m. (d)Elevation 30° , Azimuth 45° , actual control points: 122, RMS error: 0.031 m.

The deformation is realized by reallocating those control points within illuminated area and its vicinity from equilibrium positions on spherical curve onto the parabola. The whole process starts from the area center and radiates out to the whole area to be deformed. There are two conditions to be held during the interactive process — minimizing the displacement of each nodal point from its equilibrium position on spherical curve and equalizing the distances on the two curves between the adjacent points. The equilibrium shapes of cables under gravity are calculated and the fit errors are estimated while the reallocation process converges. Figure 6a through Figure 6d show the simulation results at different elevation and azimuth angles. The RMS fit error is 3.4 mm as FAST points to the zenith (Fig.6a), which meets the accuracy request at highest frequency for FAST. The errors increase as the illuminated area goes to high altitudes, reaching 30 mm at the edge where control points are sparse and the mechanical structure of the system becomes more asymmetric, and the continuation of deformation loses at the up edge due the lack of control points in the vicinity. These drawbacks could be easily overcome by further optimization.

5 Remarks

The preliminary results from the simulating are encouraging. If the feasibility of this concept, adaptive cable-mesh reflector for FAST, is finally approved, it will benefit future construction of the telescope in several aspects: (1) Simplify the structure of FAST main reflector, reducing the number of layers from 4 to 2 and the number of control points from ~2000 to ~400; (2) Largely cut down the number of moveable parts, e.g. bearings, screws and joints, easing machinery work and improving reliability; (3) Need not to divide the surface into solid elements with fixed curvature, relaxing appeals to fabrication accuracy and leaving space for further telescope upgrading; (4) Almost avoid the civil engineering between actuators and ground. These possible advantages mentioned above may be potentially beneficial to FAST in construction price, time limit for the project, future operating reliability and telescope maintenance.

The simulation shows that the adaptive cable-mesh reflector is feasible from the point of mechanics. From the present understanding, better controls can also be found to reduce the RMS errors of the illuminated parabola. Further research on the mechanics and control of the adaptive cable-mesh reflector is definitely required. Many questions, moreover, should be answered in details, e.g. material and techniques of the surface, attachment between surface and adaptive cable-mesh, ranging system of high accuracy and high sampling rates. A scaled model is necessary for finally confirming the feasibility of this new realization of the FAST reflector.

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