Structural Analysis of a 50-meter Pulsar Radio Telescope

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Abstract

A pulsar radio telescope of 50 m in diameter is proposed at Beijing Astronomical Observatory. A fully steerable exposed design of the telescope complying with issued specification is studied. Designed with aid of CAD software, the telescope is then exported into the ANSYS software and analysed there. Divided parts of the whole FEM of the telescope are investigated before being assembled to perform full analysis. In this paper, static and dynamic calculations of the telescope as a whole and its dish as a part are presented. During analyses, significant simplification and substitution are included. Driving systems are represented with MASS element applied with assumed mass, coupling technique is employed, and in order to extract interesting eigenvalues of the whole system, big elastic modulus is assigned to the quadripod to eliminate its ill influence on the extraction process and results.

Introduction

Cosmic radio signal from a pulsar appears with extremely stable periodicity, several milli-seconds pulsars can even be used for timing for crosschecking with atomic clocks. This "clock" is called "pulsar clock", which is essentially a radio telescope working at some special wavelength. There already exists such "clock" and called pulsar radio telescope or antenna.

In 1999, Chinese Academician Shouguan Wang proposed to build a pulsar telescope. Afterwards, general specifications were given. With help from Dr. Jingquan Cheng, the author drafted a preliminary design by the middle of the year 2001. It has been a 50 m diameter wire-meshed paraboloidal reflecting dish on an elevation-azimuth mounting which serves as tracker and pointer. To large radio telescope of this size, it is very necessary and important to investigate its performance in different working cases. The overall profile and dimension are shown in Figure 1. Its working band is 18 cm wavelength, so, in any cases, the normal deflection (RMS) of dish surface cannot be over ~1/20 of operational wavelength, namely, no greater than 1 cm. Dynamical requirements cover that the separate dish part should reach 2~3 Hz as lowest eigenfrequency while the whole telescope system must stiff enough to reach 1.5 Hz at least.
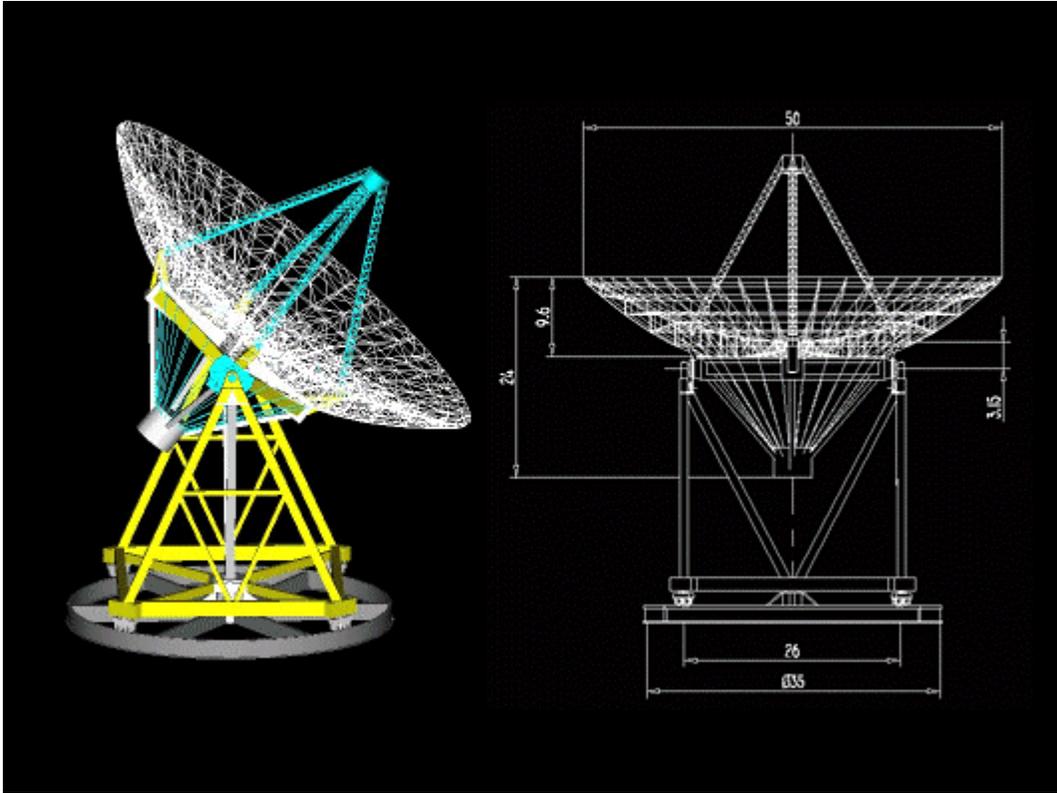
Figure 1 - Overall view of 50 m pulsar radio telescope

After being designed with CAD software, it is transported part by part into ANSYS via IGES file to analyze and revise, afterwards, such sub-FEM's are assembled and calculated in ANSYS. Various evaluations, such as deflections due to dead weight and eigenvalues of its whole structure, are carried out. In the following sections, analyses of the dish support structure and the whole telescope are described. As mentioned, the paraboliodal surface is a mesh of stainless steel wire arranged on a "back structure" dish which supports and maintains right paraboloid as reflector, and the lower yoke serves as elevation-azimuth mounting. Deflections under dead weight and extractions of eigenvalue are performed to investigate how the system behaves so as to guide improvement.

Reflector dish

The reflector dish is a space truss, which is forming a paraboloid of 20 m focus length, namely, the generatrix equation of its section is governed by

$$Z=y^2/80$$

where, Z is symmetrical axis.

Torus area on the paraboloid is computed by

$$Torus = \frac{8}{3} \cdot \pi \cdot \sqrt{f} \cdot \left[\left(\frac{r_2^2}{4f} + f \right)^{\frac{3}{2}} - \left(\frac{r_1^2}{4f} + f \right)^{\frac{3}{2}} \right]$$

where, f is focus length, 20 m; r_1 is inner radius of torus, r_2 is outer radius.

The central hole is 4 m in diameter, so, $r_1=2$, $r_2=25$, and the paraboloidal area of the whole reflecting surface is therefore 2144 m^2.

Since the structure has been designed and drawn in CAD software, and seeing clearly that it is more cumbersome to establish finite element models directly in ANSYS, the structure drawing can be saved as an intermediate format IGES which ANSYS can recognize. The dish assembly of the whole telescope structure is first imported into ANSYS via IGES to perform analysis.

Using 3D structural mass element MASS21 to simulate the mesh wires with diameter of 0.55 mm at 10 mm grid span, and taking consideration of unseen additional weight, each mass element on the superficial nodes carries around 3 kg. The truss members are emulated with PIPE16, a 3D elastic pipe element.

As indicated in Figure 1, referred to the Effelsberg 100 m radio telescope, the reflector dish is rested in a pyramid whose two bottom vertexes are mounted on azimuth yoke. Quadripod legs go though the mesh grid and settle on the four arms stretching out from pyramid bottom vertexes. On dish bottom there connect 24 radial pipes forming an umbrella-like stabilizer cap, on its extremity sets counter weight that is also represented with MASS21.

As to assess the performance of reflector dish, the reflector is taken out separately, so, boundary condition is assumed to constrain all those nodes on dish bottom connecting with the radial umbrella pipes. Gravitational effect is realized by applying accelerator 9.806m/s^2 in counter direction of gravity.

Figure 2 shows the deflections under gravitational dead weight when the reflector points to zenith and horizon. The maximum displacement is 3 mm and 7 mm, respectively, which is small enough. The structure weighs, without regard of mess wires, around 45 tons, which is an acceptable number.
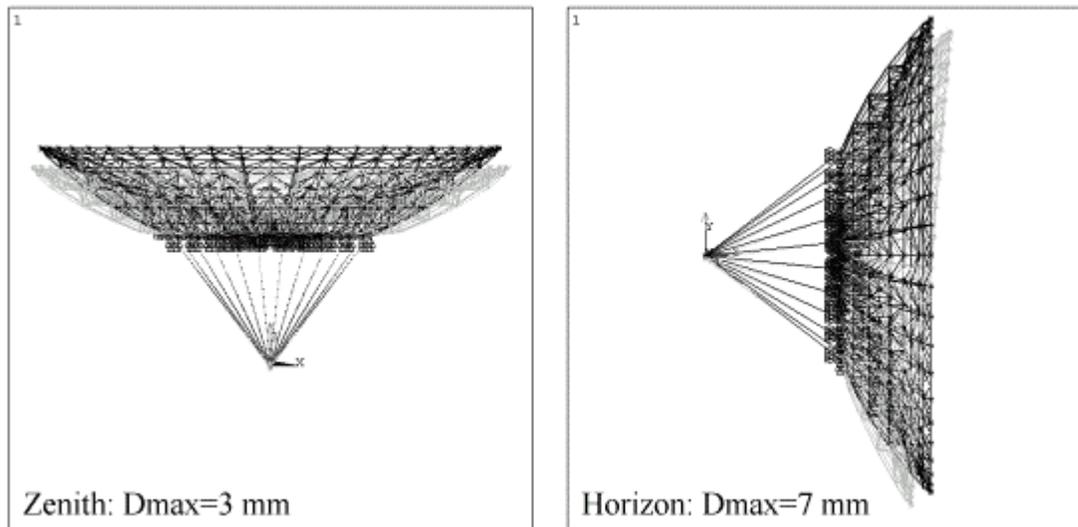

Figure 2 - Deformed shape of dish

Great advantage introduced by simplifying the wire mesh with equivalent MASS elements has been seen in the calculation above, otherwise, it is unimaginably complicated to model the complete wire mesh in ANSYS and, of course, unnecessary.

Thanks to the feature of ANSYS that element Realconstants can be shown graphically by issuing command /ESHAPE, the components of the dish structure have been seen and checked easily. In order to see continuous contour of the deformation over the paraboliodal surface, SHELL elements are created with some thickness but with zero density and zero elastic modulus, thus, no additional unexpected effects are caused. See figure 3.

Figure 3 - Finite element model and deformation contour
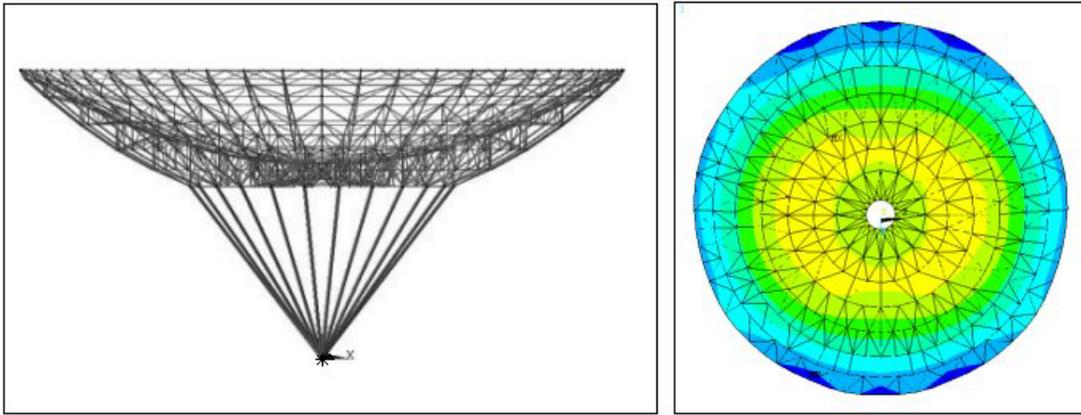
FEM with RealConstant shown by ANSYS

Contour with virtual shell element
Horizon: Dmax=7 mm

Released all boundary condition, eigenfrequencies are extracted by Subspace method with free body motion (six rigid FODs) included. Lowest frequency is high enough up to 2.63Hz with vibration mode seen in Figure 4, which is rotation about symmetrical axis. The next frequency is up to 2.87 Hz.
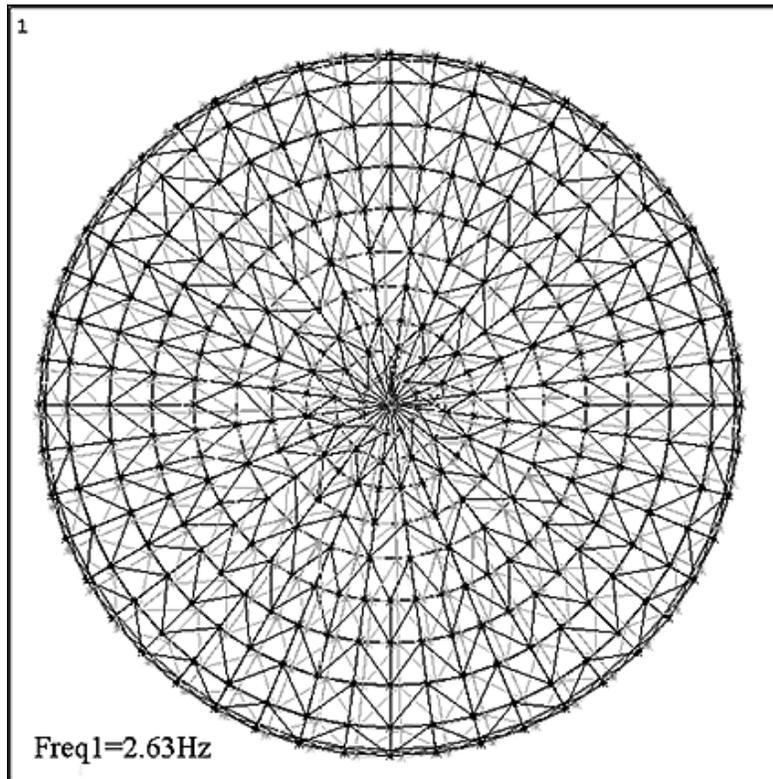

Freq1=2.63Hz

Figure 4 - Vibration mode corresponding to lowest frequency

Based on the calculation results above, the design scheme of the 50 m reflector dish structure meets general requirements and hence the evaluation of the whole telescope can be carried out in the next section.

The whole pulsar radio telescope

The 50 m diameter pulsar radio telescope is of elevation-azimuth style that is commonly adopted for large telescopes. As described in the foregoing section, the steerable reflector assemble is supported on the yoke arms by two spherical self-positioning ball bearings, and it is driven by a couple of bevel gears, with backlash elimination technique implemented, to fulfill elevation rotation. Operational elevation angle range is specified as from 15 deg. to 90 deg. above horizon. In calculation process, lower angle limit is extended to 10deg. above horizon.

The yoke is a simple straightforward steel frame welded with steel plates. Its base, centered by a pintle bearing to resist wind turn-over moment, is a rectangular frame supported by four couples of rollers running on a track of 35 m diameter to serve azimuth movement. Azimuth rotational range spans ± 270 deg. from due south, but it does not make sense to analyse.

Refer to Figure 1, the quadripod assembly is also separately imported into ANSYS via IGES to analyse and saved as a quadripod.db file, so has done to the reflector dish part above. And the same convenience is also taken to finish the lower yoke part, so, three .db files are available. Thanks to the ANSYS commands CDWRITE and CDREAD with switch COMB enabled, the full FEM of the whole telescope is therefore established with necessary simplification depicted below.

Figure 5 illustrates the finite element model of the whole telescope. In the simplified model, following strategies are taken into consideration,

1)   The roller track is omitted.

2)   Gravitational effect is actualized by means of exerting an accelerator of 9.806 m/s$^{2.}$

3)   The elevation bearing and driving system is represented with lumped mass element with estimated mass, so is done to azimuth.

4)   As described in upper section, the reflector back structure is rested in the upside-down pyramid and positioned at its central hole connecting to center of the pyramid bottom. Coupling technique is introduced to simplify the connection.

5)   In order to simulate free rotation of azimuth rollers, four base corners are constrained with displacement in Z direction, (refer to Figure 9 and Figure 10), while the node emulating pintle bearing is constrained with rotation about Z direction and translations alone X and Y.

6)   As a part of the whole antenna system, the quadripod legs are comparatively more stretchy and flexible. In view of assessing overall performance of the whole antenna, in order to avoid distraction of the quadripod and on basis of separate calculation of the quadripod, in whole dynamic analysis, here, namely, eigenvalue extraction, big elastic modulus is assigned to it.
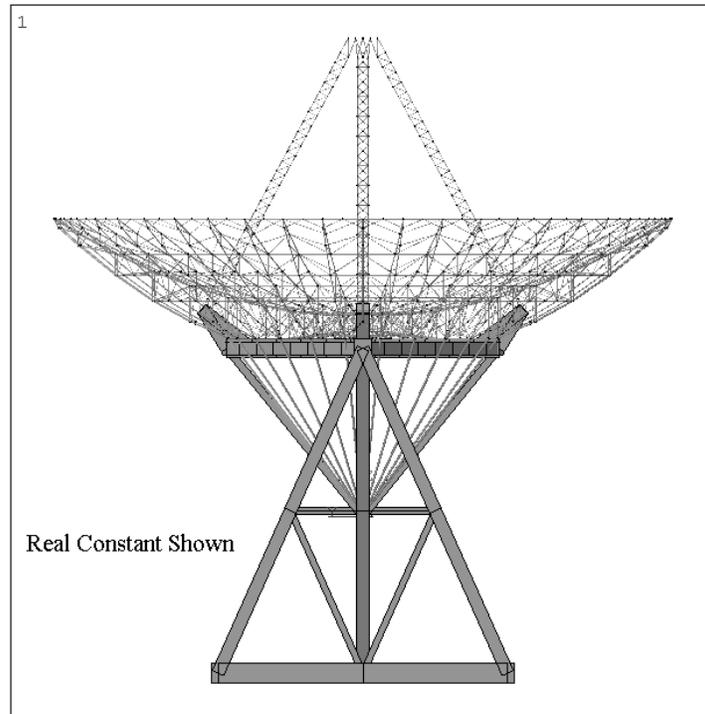
Figure 5 - Finite element model of 50 m antenna

Figure 6 shows deformations of the antenna when pointing at zenith and to 10° above horizon. The maximum deflection is 2.04 cm and 3. 38 cm, respectively, occurs both on the quadripod legs, while RMS deflection that occurs on the parabolic surface is 1.2 mm and 12.2 mm, respectively. Both meet technique requirement.
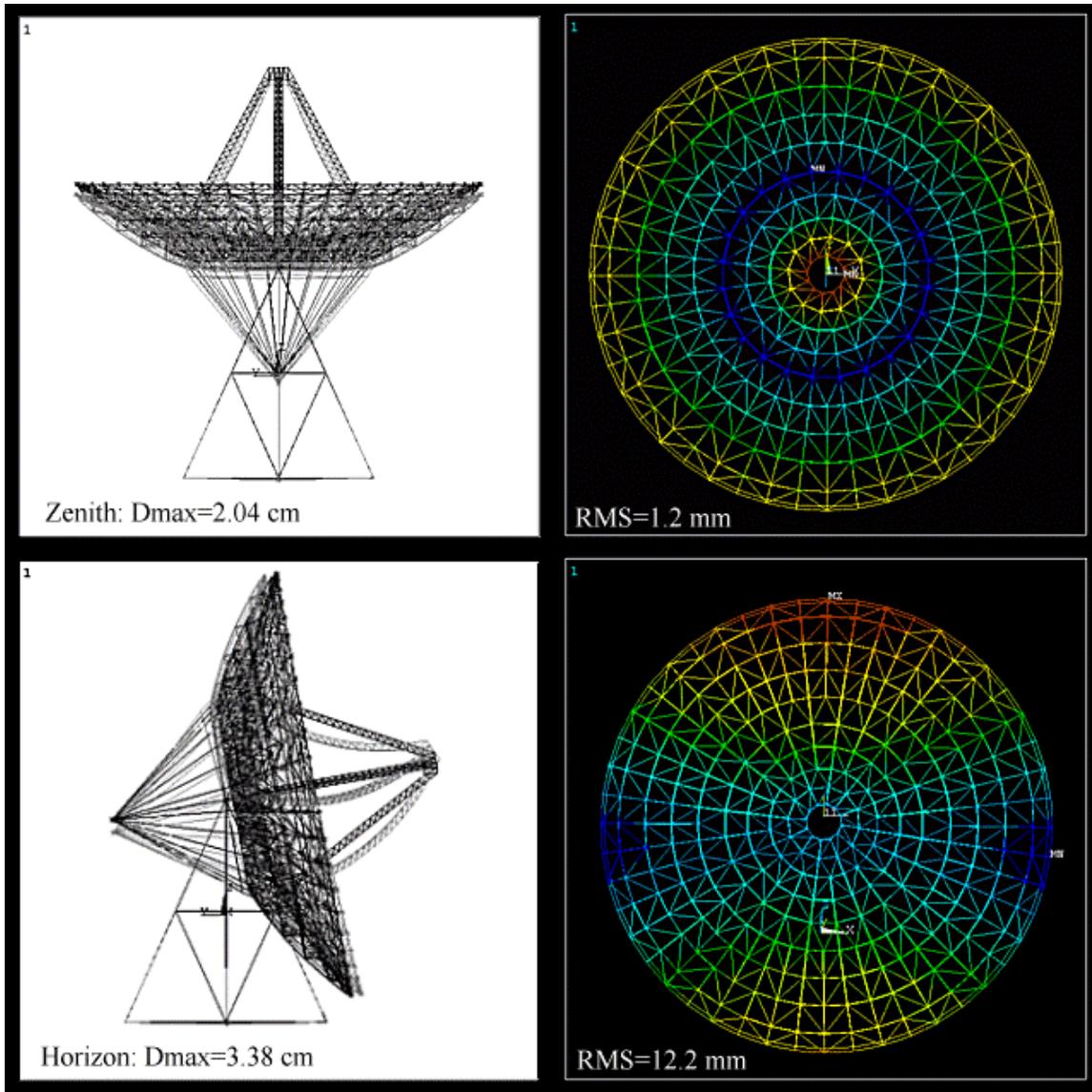
Figure 6 - Deformed shape of the antenna

Go on with eigenvalue extraction. Kept with the boundary conditions defined in static analysis, the lowest four frequencies are got with Subspace modal analysis method, they are, f1=0.73 Hz, f2=1.34 Hz, f3=1.53 Hz and f4=3.37 Hz and corresponding modal shapes are shown in Figure 7.

It is seen that the lowest frequency f1=0.73 Hz corresponds to the vibration mode of global spin about pintle bearing, i.e., Z direction. F1 is definitely too low, but if the four couples of azimuth rollers are all braked on the track, this mode is no double to be avoided, namely, f2=1.34 Hz is to be lowest and can be stiffened by reinforcing the components around the center hole of the reflector dish (refer to Figure 7), because the corresponding mode is rotation of the whole dish about its center hole. F3 and f4 character the frequencies of the two side swing modes, respectively. F3 is presently 1.53 Hz that is basically okay.

By having assumed giant elastic modulus to quadripod part, we see, refer to Figure 7, the quadripod remain straight, namely, its own vibration modes have been overridden, thus the global modal evaluation of the whole telescope is therefore well performed free from ill influence from its flexible local components.
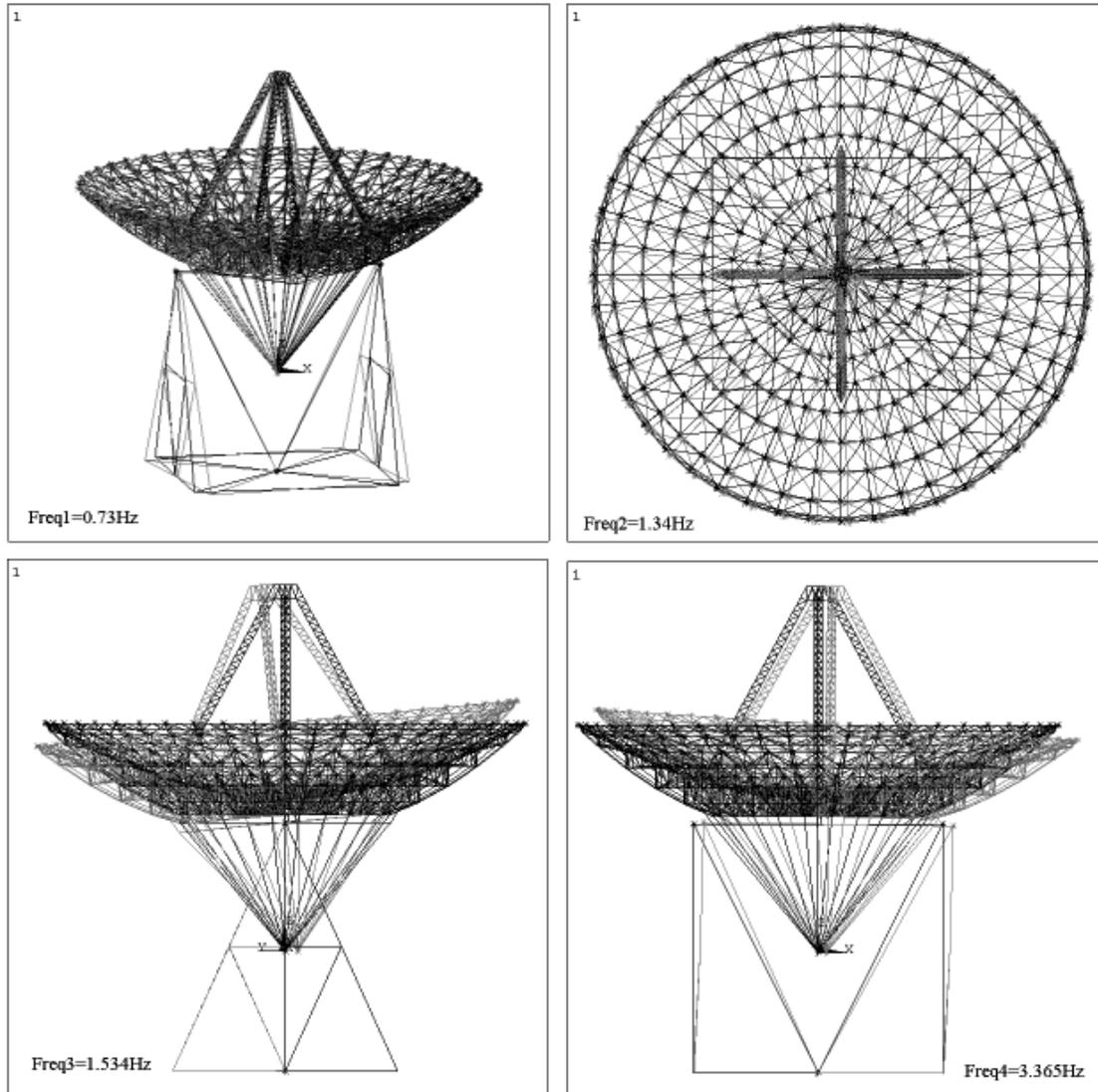
Figure 7 - Vibration modes of four frequencies

Conclusion

So far, after static and modal analyses, the current design meets static requirements very well. By appropriate stiffening methods, as mentioned in upper text, for example, its lowest eigenfrequecy can be high enough to meet specification. And it is also clearly seen that necessary simplification and equivalence

are of great importance for eigenfrequency extraction. For analysing big and complex system, especially for structure of linear components, it is a good way to design it with CAD software then convey it into ANSYS via some intermediate format, and it is also a good idea to take use of the Model Archiving function of ANSYS to incorporate separate FEMs into a final configuration.

References

1) Dehua Yang, et. al, Proposal of a 50 m Pulsar Radio Telescope, Nanjing, Jun, 2001

2) C. R. Blackwell Freeman. Fox & Partners, The Reflector Dishes of the 210 ft. Diameter Radio Telescope At Parks, Australia & The 150 ft. Diameter Radio Telescope At Lake Traverse, Ontario

3) S. Pugh & D. E. Walker, Reflector Surface for Communications and Radar Aerials, English Electric Co. Ltd & The Marconi Co. Ltd.

4) K. Schneider and W. Schonbach MAN. Gustarsburg Works, Design Study for 80-Meter Radio Telescope

5) Cheng Jingquan, Steerable Parabolic Antenna Design, Ph.D. thesis,1984