MACE TELESCOPE

Mechanical Structure

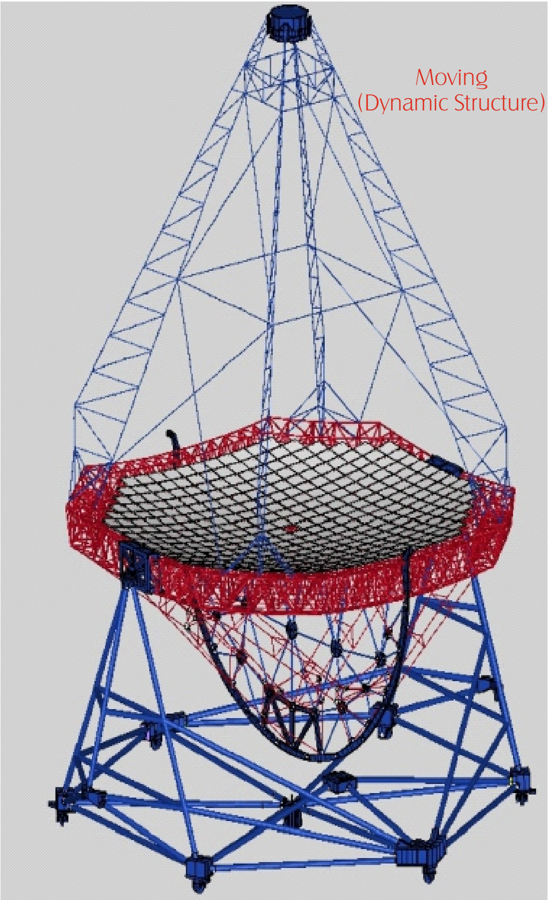
*Sunil K. Gupta, A. Ravi Kiran, Y.M. Parulekar,
M.K. Agrawal, J. Chattopadhayay

The mechanical structure of MACE mainly consists of a basket structure for supporting the 21m diameter quasi-parabolic large optical system, a boom structure for supporting the high-resolution imaging camera of the telescope at a focal distance of 25m and to servo drive systems for steering the telescope. Due to provision of active mirror alignment control, it has been possible to design the telescope structure with reasonable rigidity where a deflection limit of 50mm at the camera plane is acceptable under limiting operational conditions. The mechanical structure of MACE is designed with adequate strength/ rigidity to withstand the wind, thermal, snow and seismic loads in all orientation and to achieve a specified tracking/pointing accuracy, dimensional stability and spot size. The MACE mechanical structure along with two servo drive systems, namely, elevation and azimuth, enables the telescope light collector/ reflector dish to be steered to track and point it towards any part of the sky and achieve a stable focus and pointing accuracy.

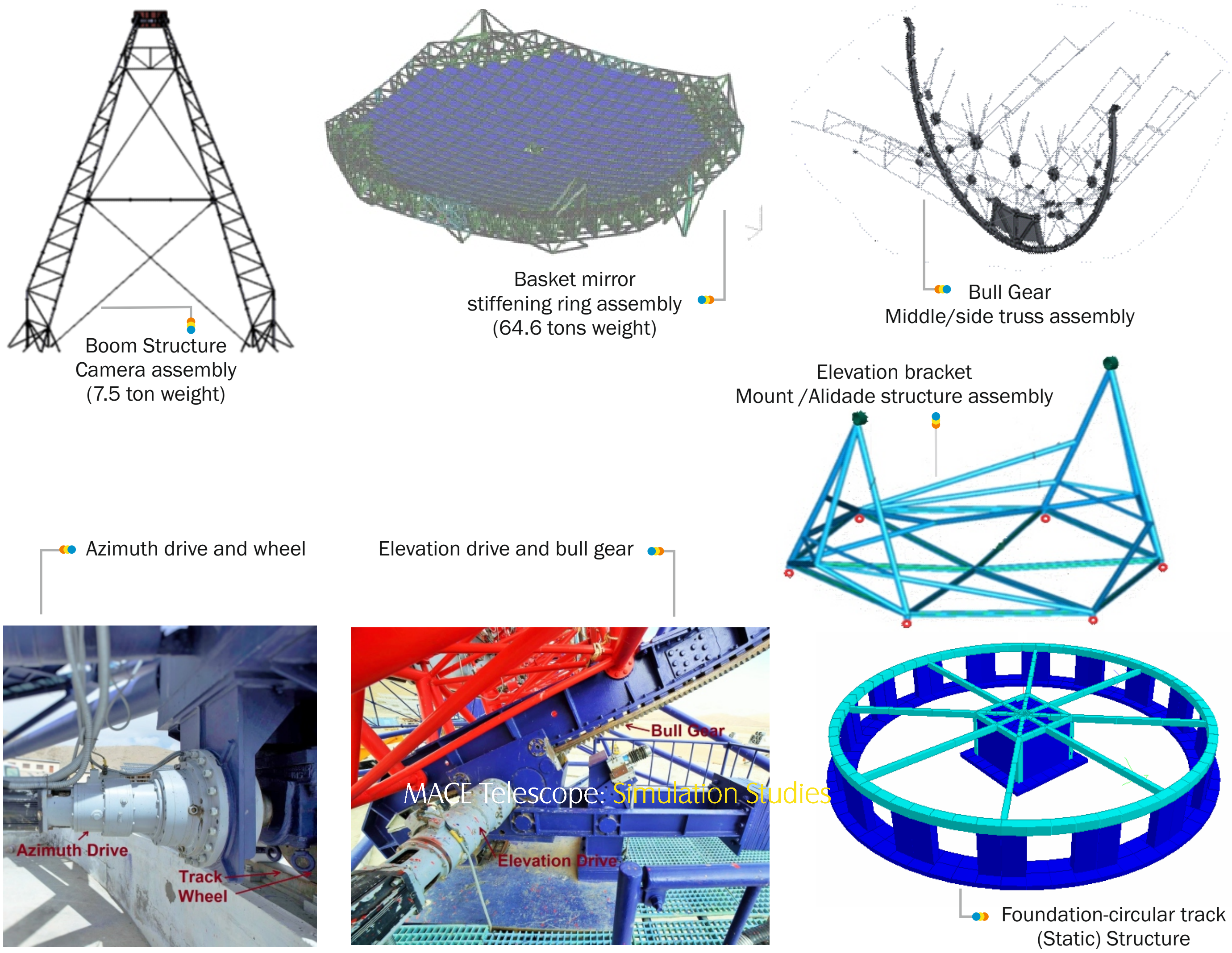
The overall weight of the mechanical structure is about 179 ton and its overall size is about 30m wide, 45m high above the ground. The total weight of the rotating structure of the MACE telescope is about 164 ton. Due to the large size/weight of the moving (dynamic) structure of MACE, the design challenges were also large when compared to similar size stationary/static structures. As the MACE site at Hanle is a remote mountain terrain region, the transportation and installation aspect posed additional challenges which were duly considered in the mechanical design of the telescope. The harsh climatic condition of Hanle site has been duly considered in the design/material selection processes. The telescope has been designed for the dead load, wind load, snow load, temperature load and seismic load along with appropriate load combinations.

The design aims to achieve mechanical stability of telescope optical system under "operating" and "survival" conditions. Modest wind loads and temperature variations along with self-weight are considered under "operating conditions" while the "survival conditions" consider high wind, snow loads, temperature and seismic loads which the telescope must tolerate without suffering damage. The performance of the mechanical structure is assessed in terms of the spot size, stability of focus and shadow area due to structure members on light collector surface.

BARC has developed the initial conceptual design of the MACE Telescope[1-2]. M/s. Designtech Systems Ltd. has contributed in detailing the design of the telescope[3] while it has been fabricated by Electronics Corporation of India Limited (ECIL), Hyderabad. The Critical Design Review (CDR) of the MACE telescope mechanical design[4] was carried out by the Department of Atomic Energy-appointed expert team where the performance of the mechanical structure, drive system and mirror alignment system were evaluated. Before shipping the telescope to Hanle site, proof assembly of the mechanical structure was made at ECIL, Hyderabad to evolve the installation procedure, to conform design of mechanical structure/systems and most importantly to know challenges/resource requirements beforehand to better plan the installation activities at the final destination of the telescope, which is remotely located with harsh climatic condition.



▲ MACE TELESCOPE mechanical structure.



MACE Telescope

The picture of MACE telescope structure along with its major structural subsystem is shown in figure. These include camera bracket, boom structure assembly, basket-mirror stiffening ring assembly, bull gear-middle/side truss assembly, elevation bracket-mount/alidade structure assembly, circular track-foundation structure, elevation drive system and azimuth drive wheel assembly. All key constituents of the telescope, including its moving (dynamic) portion and the stationary (static) portion of telescope structure have been clearly highlighted in the main image.

A Camera Mount Bracket at the top of boom structure is provided to support the high-resolution CCD camera assembly weighing about 1.2 ton. The Camera Mount Bracket assembly weighing about 2 tons is supported near the optical center of the light collector which is about 42m above ground and about 25m above the optical surface center. The boom structure is made of planar trusses which are held at a designated position with the help of guy rod assembly on the two sides and its weight is about 6.3 ton. The boom structure is mounted on the stiffening ring brackets. The boom structure and camera mounting bracket assembly are listed in the image. The next important sub-structure is the basket assembly which forms a parabolic light collector surface by supporting 356 mirror panel assemblies. The basket assembly weight is about 43.6 tons which includes 29 tons of 356 mirror panel assemblies. The basket is a three-dimensional space frame/truss structure with a spherical top layer and is connected to the three-dimensional stiffening ring structure. The basket-mirror-stiffening ring assembly weighing ~ 64.6 ton is shown in the image.

The boom structure on which the imaging camera is mounted is also connected to the stiffening ring structure. The combined camera-boom-basket-stiffening ring structure assembly is supported on an elevation axis through elevation bracket bearings/ shafts which in turn are supported on mount/alidade structure. The mount/alidade structure is shown in the image. A large bull gear that rotates the basket in the meridian direction about the elevation axis is connected to the stiffening ring and elevation brackets through side/middle trusses. The elevation drive system which drives the bull gear is also located on the mount/alidade structure. The bull gear along with side and middle trusses is shown in the image. The whole system with the alidade structure is mounted on a circular rail track structure and a Pintle bearing. The circular track of the telescope is supported on a RCC ring foundation and the Pintle bearing is supported on a central RCC circular beam. The Pintle bearing enables azimuth rotation of the telescope alidade structure rail track. The azimuth drive system is also mounted on alidade structure. The foundation structure, as shown in the main image, consists of a 27m diameter circular rail track and a central circular beam of 0.95m diameter to support the MACE alidade structure and the central pintle bearing respectively. The rail track is mounted on a circular ring beam supported by 16 nos. of RCC pedestals placed circularly. The central circular beam and track ring beam is connected by 8 nos. of radial beams. An equipment room (5m × 5m × 3.5m) of RCC framed structure is constructed below the pintle bearing to house all control system racks and the associated equipments. The foundation structure is designed for survival wind, seismic loads in combination with dead load, live load and other loads as per relevant IS Codes (e.g. IS 1893-2002 for seismic loads). Two servo drive systems, namely elevation and azimuth, as shown in the main image at the beginning, are provided to enable the telescope light collector dish to be steered to track and point it towards any part of the sky. The azimuth drive rotates the telescope basket structure from -270° to +270° about a vertical axis passing through the center of the basket (azimuth axis) while an elevation drive rotates it from -26° to +165° about a horizontal axis passing through the basket top (elevation axis). The telescope has a pointing and tracking accuracy of about ±1 arc-minute in the presence of wind blowing at a speed of up to 45 km/hr.

Mechanical Design: Major Considerations

The challenges and difficulties in design and development were hard to assess during the initial stage. Due to the extraordinary characteristic of site geographical condition and large size of the telescope, a few of the special considerations made in the design are as follows.

Material Selection-Low Temperature

Temperature at the site varies from -35°C to 30°C during winter and summer respectively. The large temperature load cycle has been considered carefully in selecting the material for the telescope structure. Materials have been selected such that reasonable properties are retained at low temperatures to ensure structural integrity and the performance of the telescope.

> THE mechanical structure of MACE- equipped with two servo drive systems- enables the telescope's light collector/reflector dish to be steered to track and point towards any part of the sky and achieve a stable focus and pointing accuracy.

Design and Structural Integrity

The MACE telescope structure was designed to withstand the dead loads, wind load, snow load, temperature load and seismic load with appropriate load combinations. Finite element-based analyses of the telescope structure were carried for the dead weight, wind loads, earthquake loads for several orientations of the telescope structure. The wind speeds of 45, 60 and 150 km/hr are respectively considered for normal tracking operation, initiating stowing and survival. Seismic analysis is carried out using response spectra in three directions and resulting displacements in three directions, forces and moments are obtained. The design of the structure is checked as per the applicable IS-code subjected to different design loads/load combinations. Under self-weight and normal operation wind loads, in all orientations, the maximum deflection was found to be less than 50mm. The deflection plots of MACE telescope for self-weight plus wind load case as obtained from finite element analysis for a typical orientation AZ0EL30 i.e. 0° azimuth angle and 30° elevation angle are presented above. Free vibration analysis of the telescope has also been carried out for all orientations and significant natural frequencies, mass participation and mode shapes of the telescope were obtained. This is required to assess the possibility of oscillations of the structure during the operation due to wind and track unevenness.

The natural frequencies are found to be above the specified limits. Further, Computational Fluid Dynamic (CFD) analysis for the MACE Telescope structure was also carried out to assess the generation/shedding of the vortices on the trailing edge and induced dynamic effects/forces on the body. As the ratio of the natural frequency of foundation soil structure to that of the telescope structure on rigid base is found to be very large, soil-structure-interaction was ruled out.

Optimization of Telescope Structure

The weight of the telescope was optimized from about 250 ton at conceptual design stage to about 179 ton of final structure by a series of design modifications in the boom and basket structure[5]. During the optimization, the structural deformations of the light collector surface due to dead load and wind loads which, in turn, affect the spot size, are kept within the limit. The total weight reduction also resulted in reduced driving power requirements of the servo systems. Since the light collecting efficiency of the telescope is inversely proportional to the shadow on the reflecting surface, the boom structure was optimized to planar trusses linked with guy rods. This reduced the shadow area to about 5% without compromising much on its rigidity.

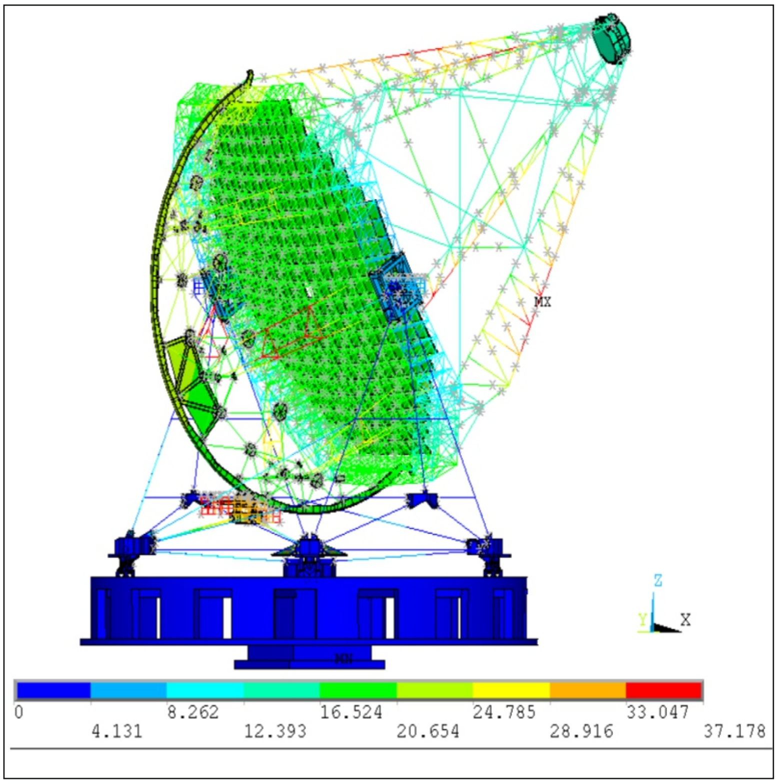
Modular/Transportable

In addition to the working functionality and structural safety, the telescope has been designed to meet the challenges of transportation to and assembly at Hanley site. Based on the survey of road condition and the limitations of the crane, the size of sub-assembly parts of the telescope was limited to 4m × 2m × 2m to facilitate smooth transportation, safe delivery and assembly/ installation at Hanle site.

Proof Assembly

After the fabrication and factory acceptance of components of the MACE telescope and before shipping them to Hanle site, proof assembly of the mechanical structure was carried out at ECIL, Hyderabad. The proof assembly aim was to evolve the installation procedure, to conform design of mechanical structures/systems and most importantly to know challenges/resource requirements beforehand to better plan installation/ assembly activities at the final destination of the telescope, which is remotely located with harsh climatic condition.

Based on the structural response/obsevation made during post installation trail operations of telescope at Hanle, of few design improvements were worked out and implemented to strengthen some of members/ joints of MACE structure. As the MACE structure is designed optimally and seeing harsh climate condition of Hanle, a comprehensive plan for inspection and health monitoring of important members/joints at regular intervals is considered.



▲ DEFECTION PLOT for self-weight plus wind load for a typical orientation AZ0EL30, 0°azimuth angle and 30° elevation angle.

Bibliography

[1] Conceptual Design Report (CDR), BARC/CDM/CDR /06/ R-01, December 2007.
[2] Optimization of the structural design of the MACE telescope, MACE TECDOC No. 01/09, May 2009.
[3] Detailed design report of MACE telescope, MACE-DDR-02, 2010.
[4] Critical Design Review for 21m MACE Telescope, DE/CDR/00 June, 2014.
[5] K. Bernloehr et al., Astroparticle Physics, 2003, 2, 111.

The authors are from Reactor Safety Division
Bhabha Atomic Research Centre
Trombay, Mumbai- 400085

suneelkg@barc.gov.in*