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ENGINEERING ASPECTS OF THE 200-INCH HALE TELESCOPE

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The engineering designs of the 200-inch Hale Telescope were determined largely by the optical accuracy necessary. The weight and size of the telescope mounting is not overwhelming compared with modern structures, but the high accuracy required for the optical parts and for the driving mechanism made the engineering problems unusual. For example, while a comparable modern structure may safely deflect several inches under load, this telescope not only must deform less than 1/16 inch in any position but its optics must also remain collimated and its mirror surfaces must maintain their proper optical shape. The 200-inch mirror and its supporting system are secured in a 500-ton mounting which can be driven continually to follow the apparent motion of the stars. The angular rate of motion of a telescope must be very exact to maintain an image on plate or spectrograph slit for an extended period, and it must be compensated for variable atmospheric refraction and for any periodic errors of mounting and drive. The size and detail of both the telescope and its auxiliaries have made necessary a more elaborate control system than has been used heretofore.

The usual graduated circles for reading declination and hour angle were modified to allow the observer to ascertain the telescope setting while working at the various stations. It is desirable also to read the right ascension of the object viewed instead of the hour angle. These conditions among others led to the adoption of a Selsyn remote-indicating system of high accuracy for position indicators at each observing station.

Considerable preliminary design and theoretical work for dome, telescope, and drive system were confirmed as a result of extensive experimental research with scale models. The outcome of these tests together with the space requirements resulted in the construction of a hemispherical dome 137 feet in diameter on top of a cylindrical section 27 feet high. The dome is all butt-welded 3/8-inch-thick steel plates which were dished to the proper radius in the shops. On each side of the shutter opening is a structural arch three feet wide and eight feet deep terminating at the horizontal plate girder of the balcony which keeps the 1000-ton dome circular. Rotational support is provided under this ring girder by means of 32 four-wheeled trucks which roll on accurately ground circular tracks.

For studying telescope structure, two experimental models of the final proposed yoke-type mounting were constructed. A $\frac{1}{32}$-scale celluloid model was made by the Westinghouse Electric and Manufacturing Company which fabricated the large telescope parts, and a one-tenth-scale steel working model was built in Pasadena to confirm designs and computed deflections. This latter model was also used to obtain data on the bearing system, on drive and control methods, and on the correlation of auxiliary apparatus. It is now operating as a 20-inch Cassegrain telescope at Pasadena for use in special observations and for student training.

These models confirmed the feasibility of two important new engineering innovations. First, it was evident that this huge yoke-type polar axis mounting with its oil-pad system would maintain the desired accuracy and turn on its axis without excessive friction or deflections. Second, it was determined that by the unique design of the tube framework, gravity deflections of the lower end supporting the 200-inch mirror and of the upper end supporting the prime focus cage could be kept small and would not seriously affect the optical collimation. The total excursion of the 200-inch telescope prime focus image for maximum telescope positions is within one-half millimeter, which is considerably smaller than the maximum tolerable. One of the early problems of overcoming the enormous friction that 500 tons would produce at the polar axis bearing was solved by the use of a forced-feed oil film at support pads of the north and south bearings. Since the rotational speed of the telescope is slow, the shearing force in the supporting oil film during motion is very small, making possible a reduction in friction torque of a thousandfold over that possible with roller bearings, at the same time permitting the yoke to be driven from one end without requiring excessive torsion in the yoke structure. The friction coefficient of the polar axis bearing system alone is less than 4×10^{-6}, consequently only 50 ft. lbs. torque is required, and, even with the gearing and other mechanisms, a small motor delivering less than one-twelfth horsepower is sufficient for driving at tracking speed. At each corner of the seven oil bearing pads is a safety micrometer oil film switch which shuts off right ascension control if the film thickness becomes less than 0.003 inch.

The precise drive for the telescope involves the co-ordination of driving elements principally contained in two boxes, one for the declination drive inside the west yoke tube, the other for right ascension drive and computers in the cabinet below the south pedestal. In each of these boxes is also the gearing for several driving speeds covering a range of from one to 1800 for manual speeds and from one to 36,000 for automatic controls and the necessary Selsyn indicators, correcting rate drives, integrators, clutches, and electrical limits. The south box also contains the tracking drive, sidereal time motors, rate computers, phantom telescope, and an automatic printing recorder of position and of guiding operations. This latter recorder will be used to accumulate data on refraction and periodic error over an extended operating period.

The declination unit drives through a secondary gear to a single 173-inch-diameter, 720-tooth worm gear attached to the tube. Two similar gears, bolted together and supported on bearings at the south pier, drive the telescope in right ascension through a diaphragm and torque tube. Since the desired accuracy of drive is one second of arc in one hour at one revolution per day, and since the short period errors are limited to one-tenth second of arc per five seconds of time, extreme precision in cutting these gears was required. One second of arc is equivalent to only 0.000445 inch on the pitch circle of the gear.

The computer receives hour angle and declination from the telescope together with correction increments which will eventually compensate for residual structural, gear, and refraction errors. Mechanical addition through differentials gives the correct hour angle which with the sidereal time gives the right ascension being observed. This angle is read at all observing stations by precision Selsyn receivers in groups of three, one each for hours, minutes, and seconds. By setting a similar group of Selsyns at the control desk to a desired position in hours, minutes, and seconds, and comparing this position with the existing right ascension position, the controls automatically bring the telescope to the desired setting with all corrections included. A similar system is used in declination, and automatic settings are made to an accuracy of five seconds of arc. These and other detail operations may be telephonically requested from any of the four observing stations.

One other feature of the drive computer, the "phantom" or dummy telescope, has several functions: (1) contacts provide an artificial horizon limit for automatic controls; (2) the dome is rotated automatically to keep the shutter opening always in line with the telescope tube; (3) remote indicators of zenith distance are provided which (4) automatically keep the canvas wind screen following the telescope tube up or down.

The drive at sidereal and tracking rate is by means of synchronous motors supplied with controlled-frequency power from accurate yet variable frequency standards. Two vibrating wire Warren Time Standards are used, one fixed for constant sidereal time and the other for variable rate as required for tracking. The telescope drive rate as determined by a potentiometer in the mechanical computer automatically adjusts the frequency of the tracking standard to provide the proper rate. For manual or superposed planetary rates, a separate motorized potentiometer is operated from the control desk with the rates indicated by an ammeter calibrated in seconds of arc per hour deviation from sidereal rate.

Corrections and superposed rate for the declination drive unit are supplied by Selsyn-controlled motors from the computer and desk. These motors drive through mechanical rate integrators to prevent sudden changes in applied rate.

Special problems of drive and control were encountered on many of the telescope auxiliaries. Large pieces of equipment are powered with multimotor drives of two types. The parallel direct-current drive is used to drive the combination 200-inch mirror cover and iris diaphragm consisting of 16 insulated leaf sections. This type of drive also rotates the dome through two vibration-isolated rubber-tired units which frictionally drive the 1000-ton dome at automatically controlled accelerated and decelerated rate. The "Synchro-tie" method of drive using common excited wound rotor motors is applied to the dome shutters, each of which is 20 feet wide, 144 feet long, and driven independently at top, center, and bottom—such that over-all misalignment is maintained to less than 3/16 inch. The 33-foot-wide opening is automatically sealed closed to within three inches of the true center.

The Palomar Observatory as a small community is entirely independent of all outside power service. All utilities are provided underground for 18 buildings, including power and light from a modern Diesel-electric power plant of 300 kw capacity. A total of about 400 miles of wire is installed at the Palomar Observatory, of which 100 miles is on the 200-inch telescope, including over four miles of dome slip rings. The connected load for the 200-inch dome and telescope is only approximately 200 horsepower in motors, 100 kw in heaters, and 50 kw in lights. The expected average power demand of about 50 kw during winter operation is reasonably small considering the extent of necessary auxiliaries.

These are but a few of the many problems faced by the astronomers and engineers. Solutions of the usual problems encountered on this telescope project have required the close co-operation of the California Institute of Technology with many manufacturers who have made their facilities available, each assisting in the accomplishment of Dr. Hale's vision of twenty years ago. The dedication of this instrument as the Hale Telescope, therefore, is a tribute to the many scientists, engineers, and workmen whose labor, experience, and skill made this instrument possible.