1981raoa.conf..133D

Harold L. Johnson and Christine Allen (Eds.),
Symposium on Recent Advances in Observational Astronomy, Ensenada, Mexico, 1981, 133-139.

THE MEXICAN 2.12-m TELESCOPE FOR THE NATIONAL ASTRONOMICAL OBSERVATORY AT SAN PEDRO MARTIR, BAJA CALIFORNIA, MEXICO

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ABSTRACT

Telescope design and construction activity at the Institute of Astronomy from 1970 on. Need for a larger instrument at San Pedro Mártir Observatory. Design considerations for a 1.5-m telescope and its scaling to 2.12 m. Project execution. Console design and construction. Shipping and installation. Preliminary tests. Instrument characteristics.

RESUMEN

Diseño y construcción de telescopios en el Instituto de Astronomía a partir de 1970. La necesidad de un instrumento mayor en el Observatorio de San Pedro Mártir. Consideraciones de diseño para un telescopio de 1.5 m y su aumento a 2.12 m. Ejecución del proyecto. Diseño y construcción de la consola. Embarque e instalación del instrumento. Pruebas preliminares. Características del telescopio.

Professional work on the design and construction of telescope mountings began at the Institute of Astronomy of the Universidad Nacional Autónoma de México (UNAM) in 1970. During the following year we finished a 0.3-m fork-mounted telescope, totally Mexican made including the eyepiece. This telescope was exhibited in 1972 at the University Annual Show, giving us some renown and confidence as designers; eventually, we installed it at the University of Tabasco. This was the beginning of a program to provide universities in Mexico with small observatories, so as to increase the interest of students in science. In 1972 we made a 0.4-m yoke-mounted telescope following Johnson's (1968) concept design; this telescope was also on exhibiton for a perid of time; it was finally installed at UNAM in Mexico City. In 1973 we made a similar instrument of 0.5 m diameter, that is now in successful operation at the University of Zacatecas. Currently, we are making two 0.55-m telescopes, one for the University of Guanajuato and the other for the Sociedad Astronómica de México; both instruments contain the innovations developed during the design of our 2.12-m telescope, the major topic of this paper.

The National Observatory of Mexico became operational at its new site in San Pedro Mártir, Baja California during 1971; at the beginning it was equipped with an 0.84-m general-purpose telescope, whose optics were made at the Institute of Astronomy (Malacara *et al.* 1969) and a 1.5-m infrared telescope with an aluminum primary mirror (the first one of this kind ever built) both with yoke mountings designed by Johnson and manufactured by Astromechanics.

The excellent observing conditions at the site soon indicated the need of a larger optical telescope. Therefore, in 1973 quotations were obtained from manufacturers in several countries for 1.5 and 2-m telescopes; these quotations showed us that our 300 000 dollar budget for the instrument was short by a factor of at least 2.5, causing us to consider Mexican design and construction.

With a cost-saving philosophy of minimum weight and simplified, non-traditional design, but keeping in mind not to sacrifice quality or performance, work on a 1.5-m diameter yoke-mounted telescope was started at the Institute in 1974; the immediate objective was to obtain a cost estimate of the mounting, optics and control console.

The basic features of the design concepts were:

1. To obtain the lightest possible primary mirror, support system and mirror cell.
2. To achieve a very short primary focal length.
3. To eliminate massive counterweights.
4. To use an economical, simple construction approach.

After studying several already-made telescope designs and applying previous experiences gained designing for industry, we were able to produce a set of drawings of a solid but light mounting, which would be easy to construct and which would include several innovations connected with the features listed above.

With the set of improved yoke mounting design drawings at hand, we started talks with Campos Hermanos (a crane, tools and steel alloy manufacturing plant in Mexico City) seeking quotations on the instrument. Their estimate was within our small budget, leading us to purchase a 1.5-m cervit mirror blank from Owens-Illinois and to contact N. Cole of Tucson, Arizona, for the necessary optical work.

A new grant of 250 000 dollars obtained by Dr. A. Poveda, Director of our Institute, caused us to seriously consider increasing the telescope diameter to 2 meters, in spite of the fact that the 1.5-m blank was already shaped and ready to be figured; this resulted in a complete recalculation of the telescope mounting.

During our talks with N. Cole the importance of decreasing the mass of the primary mirror and its focal length was emphasized, as this was fundamental for the cost reduction of the whole project. Based on the use of the axial pneumatic system and mercury flotation concept for radial support proposed by Burris (1975), Cole agreed to use a 1:8 mean thickness-to-diameter-ratio, and also to grind off (to bevel off) part of the inferior outer rim of the blank, and to go as short as *f*/2.25 in focal ratio without impairing the contracted final resolution of 95% of the light in less than 1 arc second. In this way, the primary mirror mass was reduced from the conventional 2,800 to 2,020 kilograms (Figure 1) and thus our Ritchey-Chrétien optical system's focal ratio became the shortest one made up to that date. The beveling shown in Figure 1 helps also to significantly decrease the outer mirror cell diameter. This cell was specifically conceived to match the proposed air/mercury support system, and its design is very light-weight.

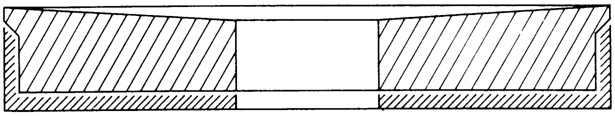


Fig. 1. Cutaway of primary mirror showing the reduction of mass attained.

When horizontal, the mirror rests with its back surface upon three air cushions, pressurized through a variable angle-to-pressure regulator fed by a small compressor, both fixed to the cell. These cushions are about 6 mm thick and support about 95% of the mirror mass, the rest being carried by three position-defining pads; when the mirror is in a nearly vertical position, it rests mainly upon a mercury belt that fits its beveled portion.

The mirror cell design consists of a weldment of two steel discs of different diameters spaced by two sets of beams; one forms a square with its corners ending in the direction of the Serrurier trusses to which the cell is bolted; the other forms, in the same plane, a radial array that ends on the outer rim of the cell, as shown in Figure 2.

The resultant primary mirror, support system and cell have a calculated mass of less

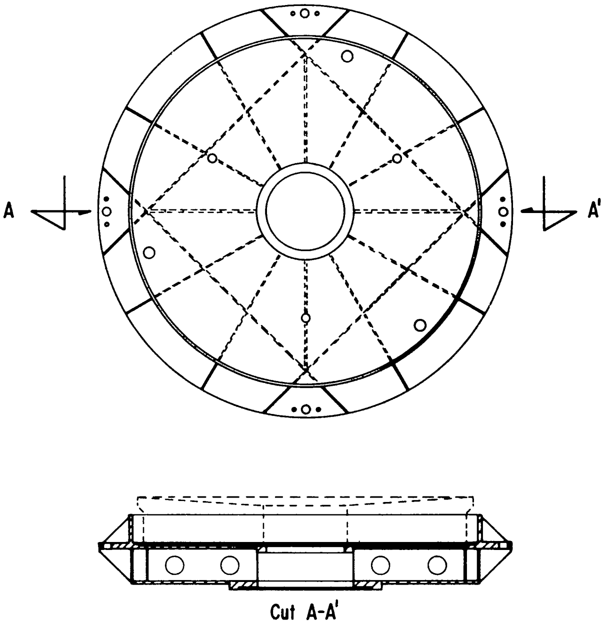


Fig. 2. Schematic drawing of the mirror cell.

than half that of a conventional configuration of the same size.

The center section and Serrurier trusses of the tube were calculated conventionally, with the upper ring assembly designed to be interchangeable, so that several Cassegrain focal ratios could be used. The focal ratios chosen were *f*/7.5 and *f*/13.5 assemblies, both for general applications, and an *f*/27 assembly optimized for infrared work in the same way as in the Wyoming telescope; currently, we are making a fourth ring for an *f*/98 secondary that will be used in high-resolution Michelson-Fourier spectrometry (Johnson, 1980), thus eliminating the need for a very expensive coudé spectrograph. (In any case, facilities were provided in the tube for a future coudé configuration, which will operate taking the light beam out through the declination and polar axes by means of six mirrors). The ring assemblies have their masses distributed in such a way that the center of gravity of the tube is always coincident with the declination axis, thus avoiding any need for additional counterweights when they are changed. The final product was a tube with a mass of a little over 10 000 kg, including three small motorized counterweights which serve as trimmers for balancing the tube with different loads at the instrument rotator.

The third feature of the list was achieved after modifying the customary tube-yoke configuration in two ways:

a) By rising the declination axis with respect to the central plane of the yoke just enough to permit its installation upon the yoke frame itself.

b) By also rising the right ascension axis with respect to the same plane by such an amount as to make it coincide with the center of gravity of the tube-yoke system

Several advantages were obtained: because of (a) it became possible to point the telescope to the north pole with more than 50% of the primary tube unobscured; the mounting and aligning of the declination axis bearing housings on the yoke was greatly simplified and, because any borings through the arms of the yoke were eliminated, a simpler, lighter and stiffer design was achieved. Because of (b), the

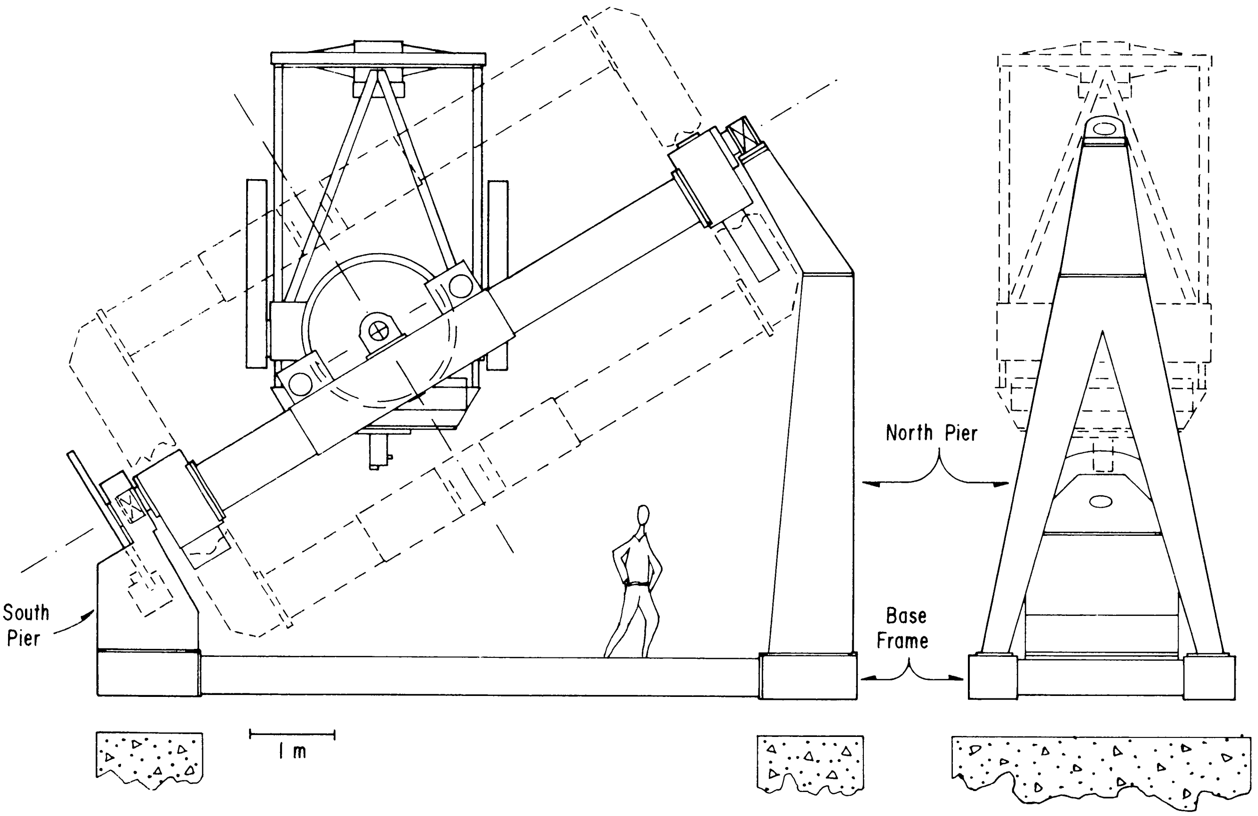


Fig. 3. General configuration of the telescope

yoke and tube became a self-balanced system, and any massive counterwights carried by the yoke to balance the tube became superfluous; this permitted an even lighter yoke frame design with the corresponding reduction in manufacturing cost.

However, to have equal deflections at the load line of the yoke, that is, to maintain the imaginary right ascension axis with the same deflection when the yoke changes from a horizontal to a vertical position, the moment of inertia in the section of the longitudinal yoke arms was made asymmetrical. This was obtained by welding at the inside of its arm pipes diametrically opposed steel compensating plates with a variable section, calculated to fulfill this requisite. The cause of the unequal deflection is that when the telescope points to the meridian, the yoke works nearly as a bifurcated simply-supported beam, but when the telescope is turned to the horizon, the yoke works mainly as a closed rigid frame, having thus a smaller overall deflection. With the compensating plates, this difference is eliminated, allowing the north and south angle-contact ball bearings to "look" at a nearly equally deflected "shaft" in any position of the right ascension axis of the telescope. This makes possible an optimum alignment, providing a constant load to the right ascension motor drive system.

To bring the torsional effect of the eccentric load of the telescope tube on the yoke to a value below the maximum specified misalignment accepted by the declination bearings (when the right ascension axis is rotated), a set of rectangular plates of calculated section was welded to its arm pipes in a circumscribed parallelepiped configuration. The upper side of it serves also as a seat for the declination bearing housings and for the two motor drive assemblies. Their mass is balanced by fixed steel plates on the opposite side of the yoke. Three motorized counterweights on the yoke serve as trimmers for precisely balancing the telescope.

In order to avoid the inconvenience of having the north and south piers bolted to separate concrete columns, a steel baseframe was designed to tie both piers together below the floor, making a one-piece solid telescope mounting. This permitted optimum right ascension drive and bearing alignment at the factory, which was not changed either during installation at the site or when orienting the telescope to the north pole. The north pier was designed more from an aesthetical point of view, and may seem heavier than necessary. Figure 3 shows the general configuration of the instrument.

The complete telescope has a calculated mass of less than 38 metric tons, or about half of the mass conventionally accepted in 1974 for a telescope of this size. We opted for using helical gear systems instead of the conventional worm and gear drives for the telescope, taking advantage of the Kitt Peak experience (Barr, 1969); we thought that this system would be much more flexible to adapt to new concepts in console design, and also less expensive. The idea of using torque motors, tachometers and optical or magnetic encoders sounded very promising for future developments, specially for the automatic balancing feature to be described later. Figure 4 shows the drive gear assemblies arrangement.

At this stage, we started to draw the plans for the manufacture of the drive gear assemblies, following the outlines of the Kitt Peak 4-meter telescope. We also obtained quotations for torque motors, encoders, tachometers and brakes for these assemblies.

A decision was reached to make the telescope console at the Institute and concept design started at our electronics laboratory, first headed by J. Warman and later by E. Ruiz. A portable prototype of the console was developed for testing its performance and that of the telescope prior to shipping to the Observatory. This prototype in block diagram is shown in Figure 5.

The impossibility of obtaining precision gears in Mexico and the fact that Campos Hermanos, our only capable manufacturer, could not meet our schedule, caused us to look for foreign manufacturers. With the valuable help of W.W. Baustian, who accepted to be consultant for the project after studying our design, it was possible to have at the end of 1974 a general outline for the project execution as follows: we were introduced to Marlow Marrs, President of L. & F. Industries of Los Angeles, California, who from the beginning was very much interested in the project. As he and his staff became better acquainted with our design innovations, Mr.

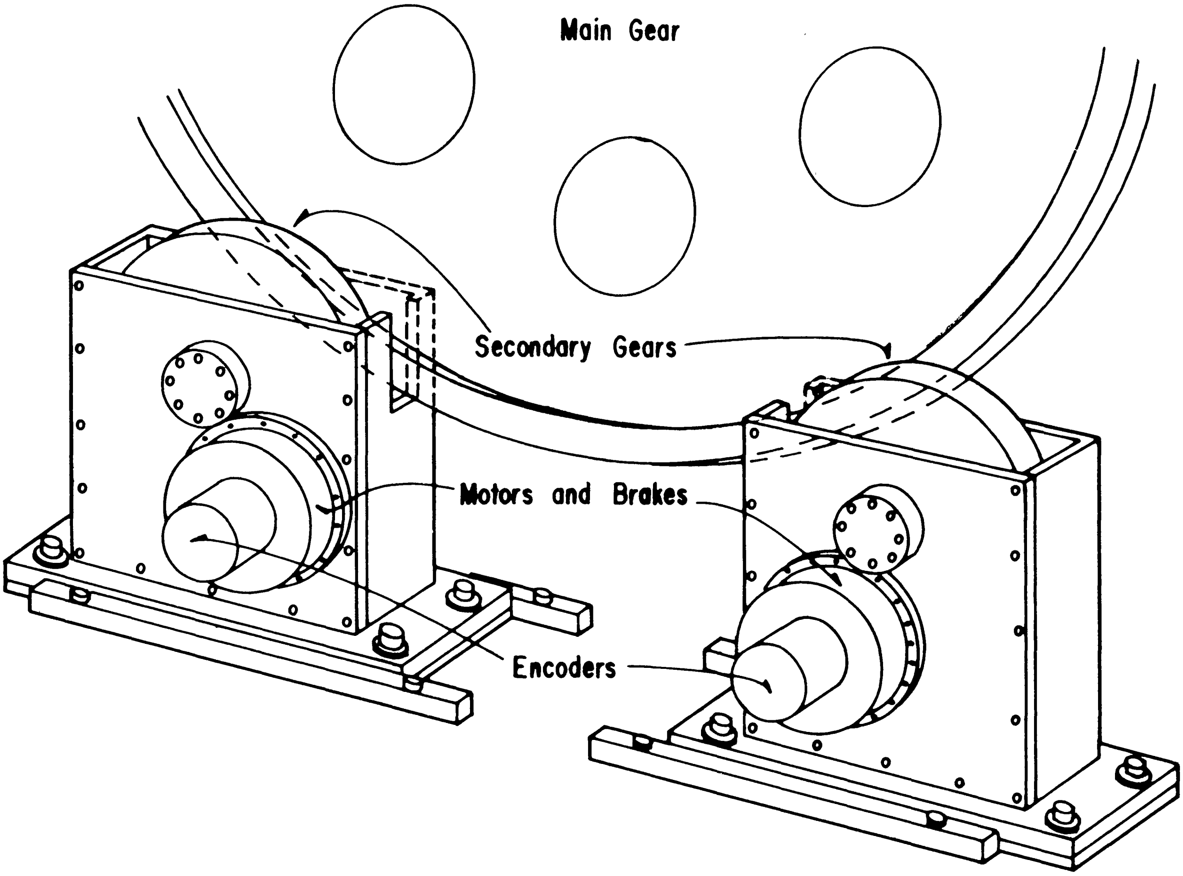


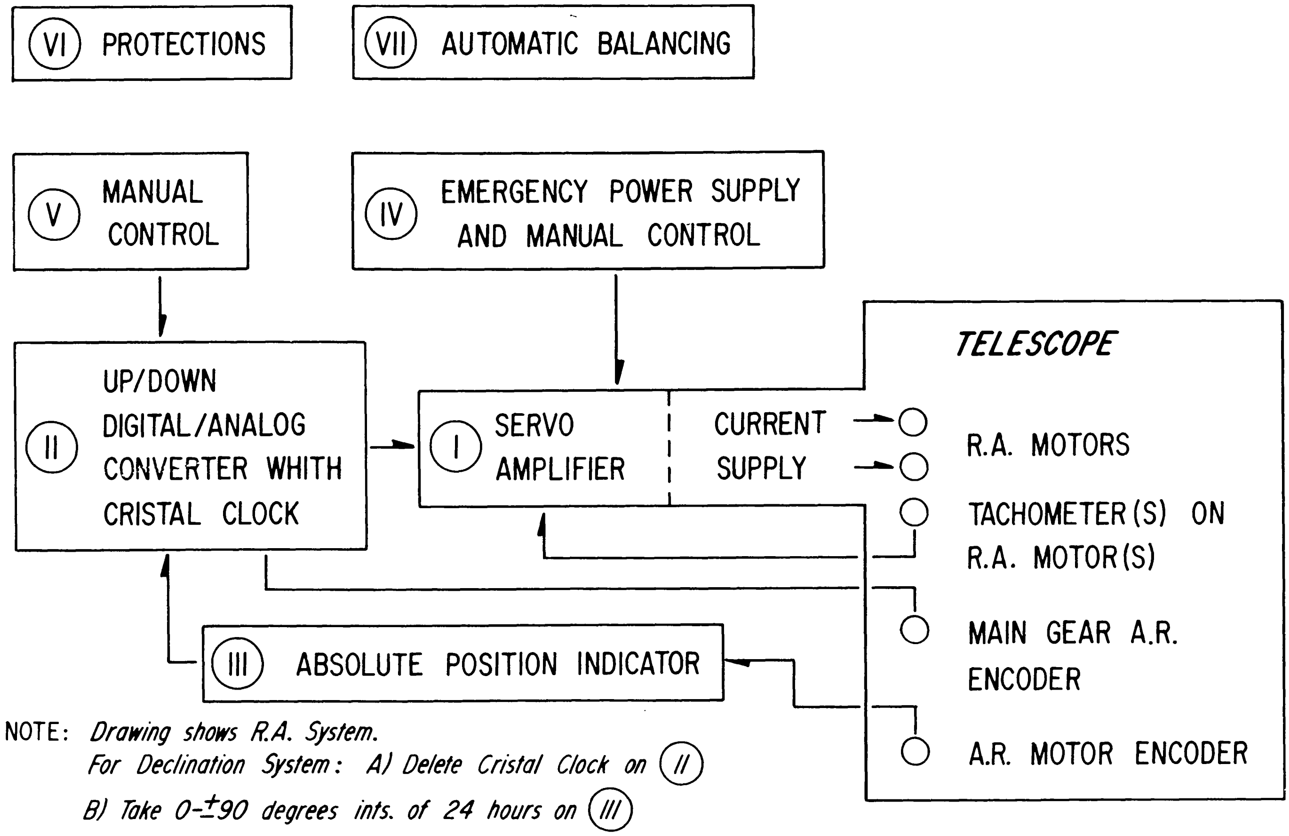
Fig. 4. Gear drive assemblies (schematic).

Marrs helped us in every respect. Contracts were made with L. & F. Industries, Western Gear and Boller & Chivens, for manufacturing, respectively, the complete mounting including its testing, all the gear systems, and the support systems for primary and *f*/13.5 secondary mirrors. The total of these contracts, together with the purchase of a 2.2 m cervit blank and the costs of design at our Institute, amounted to about 500 000 dollars; this sum was already committed early in 1975. Before starting construction, a computer program was carried out for double-checking previous calculations, including natural resonant frequencies of the yoke and vibration analysis and deflections when rotated.

During this period, Mr. Marrs brought to our attention the interest of the University of Wyoming of constructing a similar telescope based on our design. These news were received with pleasure at our Institute and Dr. A. Poveda decided to share our design work and construction experiences with the Wyoming group.

Tests of the complete telescope with the portable version of the console were scheduled for July 1976; but due to excessive friction in the grease seals of the gear reduction systems these tests were delayed until August. In the tests, the circuits for damping the natural frequencies of the telescope mounting were developed, and the parameters for making the cards were obtained. The response of the drive amplifiers regarding acceleration ramps and power capability were measured with the telescope balanced by a dummy mirror.

The weather at San Pedro Mártir, which had been good, started to deteriorate and the hurricane on September 13,- 1976 washed away some parts of the road just after the dome had arrived at the site. At L. & F., preparations for the shipping of our telescope to the mountain were begun on schedule; space there was needed to assemble the University of Wyoming telescope mounting.



NOTE: *Drawing shows R.A. System.*
For Declination System: A) Delete Cristal Clock on (II)
B) Take 0-±90 degrees ints. of 24 hours on (III)

Fig. 5. Block diagram of prototype console.

Finally, on October 1976, we were able to erect the telescope mounting at the San Pedro Mártir site. However, the building was only partially finished, and we decided to postpone the rest of the work until the building was completed.

The final version of the console is composed of three subsystems. The power subsystem consists of 12 acid-lead batteries totaling 360 amp/hour and its respective input chargers and output regulators. The logic control subsystem provides all the signals for slew, centering and guiding, as well as local time, hour angle, right ascension and declination displays, plus the driving signals for the torque motors. Feedback from the drives is used to form a velocity loop and a position loop identical in both axes. Timing is generated by a frequency synthetizer allowing different guiding speeds. The protection subsystem monitors velocities, positions, battery charge levels, voltage supplies, etc., and commands the other two subsystems to act with special protocol operations that stop the telescope in case of human or material failure.

The maximum pointing error when selecting specified coordinates is ± 6 arc seconds in both axes (pre-selection). The position resolution and maximum error in the guiding mode operation is less than 0.20 arc seconds under balanced conditions. There is provision for remote command of the six trimmer counterweights of the telescope at the console; by setting to a minimum the currents on the right ascension and declination motor meters while moving the telescope it is possible to precisely balance the instrument. In this way, there is no need for manual installation or removal of counterweights when changing equipment at the rotator, thus saving much time. This feature will be made automatic in the future, by sensing the currents of the torque motors and using them as a control signals to move the trimmer counterweights.

TABLE 1

2.12 METER TELESCOPE CHARACTERISTICS

Primary mirror diameter	2.12 m
Focal distance	4.80 m
Focal ratio, primary	$f/2.26$
Focal ratio, Cassegrain focus	$f/7.5$ $f/13.5$ $f/27.0$ $f/98.0$
Mass of primary mirror	2020.0 kg
Mass of tube	10300.0 kg
Mass of yoke	10500.0 kg
Mass of north pier	3700.0 kg
Mass of south pier	3300.0 kg
Mass of gears and counterweights	3200.0 kg
Mass of base frame	3680.0 kg
Mass of auxlliaries, cables, etc.	955.0 kg
Total	37655.0 kg
Optics Ritchey-Chrétien, 95% of light in less than 1.0″	
Diameter of main gears	1.84 m
Diameter of secondary gears	0.30 m
Diameter of main pinion	0.092 m
Diameter of secondary pinion	0.033 m
Total gear ratio	1:180
Precision	AGMA class 15
Pointing angular rate	1.0 deg/sec
Centering angular rate	0.10 deg/sec
Guiding angular rate (variable)	0.0041 deg/sec
Pointing accuracy	± 6.00 arcsec
Guiding accuracy	0.20 arcsec
Guiding power consumption	60.0 watts

It is worth noting that we have made provisions for charging the batteries either with a wind generator that is already installed, or with solar cells. This makes the telescope operation independent of variations of frequency or voltage from our Diesel generating station.

It was not until June 1979 that the building was finished. Then the optics were shipped from Tucson and the console from Mexico City, both arriving at the site on July 3rd. We then proceeded to finish the assembly of the telescope. The first star was observed on July 14, 1979.

From this date to September 17, 1979 (Dedication Day) a program for testing the instrument and finishing details on the building was organized. During this period, an observing program was carried on, working on a sequence of stellar objects in order to check optical alignment, guiding stability, preselection accuracy and general performance. It was used also to start training the operating personnel; towards the end of this period, a photometer was installed and the time saving obtained with the preselection feature of the console was demonstrated. General instrument characteristics are given in Table 1.

At Dedication Night, many astronomers, engineers and visitors were able to look at globular clusters, double stars, etc.; the general impression received was very good. At present, we continue with the final testing of the new telescope and we expect to have it ready for operation in 1980.

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