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A COMBINATION TELESCOPE AND DOME.

By A. E. DOUGLASS.

By a curious coincidence this form of telescope mounting was completed in its essentials on the day in which the writer first heard of Sir Howard Grubb's "aquatic" mounting for a reflector.[1] The two mountings have features in common, of which the most important is an attempt to procure rigidity of support and steadiness of movement.

Complaints of unsteadiness while using the micrometer are common against the ordinary form of mounting. This instability is due to irregularities of the clock movement and lack of rigidity in the mounting. A slight wind becomes a most annoying visitor and an accidental touch sets the tube vibrating in a most aggravating manner. The first idea in the development of the spherical telescope (a provisional name adopted here for convenience) was that much movement could be eliminated by applying the motive power near the eye-end of the tube. Still further stability would be insured if the tube were held at each end instead of at the middle. The final step was to place the tube inside a sphere mounted like an ordinary globe. The following pages will present various mechanical difficulties of the plan and suggest solutions. As a matter of convenience the dimensions recommended will be such as might apply to a sphere 100 feet in diameter and a lens of seventy-two inches.

I. SUPPORT AND ADJUSTMENT OF SPHERE.

The sphere floats on water which is confined in a circular cistern of sufficient diameter and depth. At the bottom are several supports upon which it can rest while in process of construction or repair. Its normal position would be less than one foot above these. The sphere itself should be made of thin steel, well braced. It is not necessary that it should have a perfectly

[1] In *New York World* (about) November 11, 1894. For original article see *Knowledge* for May, 1894.

domes in the ordinary mounting. Through the courtesy of the Director and Secretary of the Lick Observatory, and of Messrs. Warner & Swasey, I have received data on this subject which I can here present:

RIGHT ASCENSION MOVEMENT.

Telescope	Size in.	Weight moved tons	Slow motion H.P.	Quick motion H.P.	Time 1 Rot. m.	Work ft. lbs.	Maker
Lowell...	18	about 1	0.0003	0.0455	0.5	750	Clark
Naval Ob.	26	—	0.0020	—	—	—	Warner & Swasey
Lick	36	14.2	0.0033	0.0295	3.2	3,110	"
Yerkes...	40	—	0.0107	0.1175	4.0	15,510	"

POWER REQUIRED FOR TURNING DOMES.

Dome	Diam. ft.	Weight tons	Power	Time 1 Rot. m.	Work ft. lbs.	Designer
Lowell[1]...	35	3	0.22	2.0	14,400	W. H. Pickering
Naval Ob..	45	—	0.07	2.5	5,773	Warner & Swasey
Lick	75	100	1.18	8.0	312,000	Union Iron Works, San Francisco
Yerkes....	90	165	—	—	—	Warner & Swasey

From an examination of the above figures it seems probable that one horse-power is not an over-estimate for a telescope of seventy-two inches aperture. If we could entirely disregard friction this would undoubtedly be far more than sufficient; but in a new machine friction is a very uncertain factor as well as a most important one, and actual experiments are the only reliable source of information. The only satisfactory form that such experiments could take would be to try the dome on a small scale, as, for instance, arranged for an eighteen-inch telescope. A study of the different sources of friction leads me to think that the mechanical power required will be small.

LOWELL OBSERVATORY,
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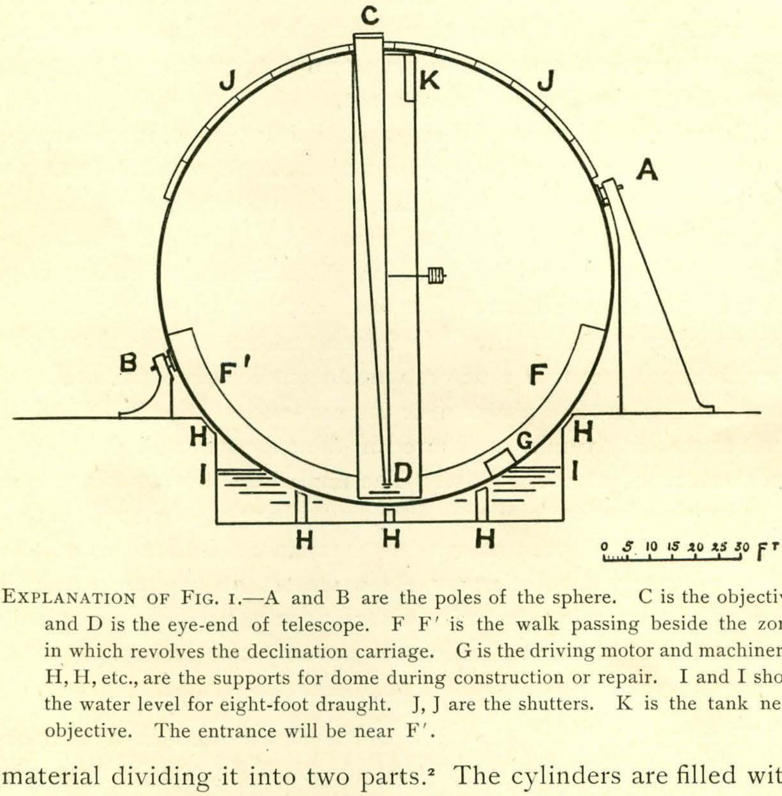
[1] The design of this dome closely follows that suggested in *A. and A.*, January, 1894. The work of turning it could be enormously reduced by substituting iron for wooden tracks and stiffening the live-ring horizontally.

spherical surface, but it can be put together of flat plates. The bearings for the axis consist in anti-friction wheels which are mounted in a single casting capable of vertical motion, between guides, of about one foot. Fine polar adjustment can be effected by some movement within this casting. Each casting is supported on a rod which passes into a cylinder below and is attached to the center of a transverse diaphragm of slightly flexible



EXPLANATION OF FIG. 1.—A and B are the poles of the sphere. C is the objective and D is the eye-end of telescope. F F′ is the walk passing beside the zone in which revolves the declination carriage. G is the driving motor and machinery. H, H, etc., are the supports for dome during construction or repair. I and I show the water level for eight-foot draught. J, J are the shutters. K is the tank near objective. The entrance will be near F′.

material dividing it into two parts.[2] The cylinders are filled with water and the upper part of one is joined to the lower part of the other, so that by a transmission of pressure from one diaphragm to the other any variation in one pole causes an equal variation

[2] The idea of using a diaphragm instead of an ordinary piston is due to Mr. G. Sykes of this town. I have also to thank him for other important suggestions and for much assistance with mechanical problems.

in the other. By this arrangement also the sphere sinks deeper into the water with added weight, or rises with lessened weight, and pressure on the bearings is only momentary. For high latitudes the plan should be somewhat modified, but I am inclined to think that large telescopes of the future, if properly located, will be between 15° and 25° from the equator.

A brief computation shows that a spherical shell of half-inch steel (which I am told is a reasonable allowance for bracing), 100 feet in diameter, must weigh approximately 300 tons, and when floating on water have a draught of eight feet. The addition of 300 pounds (one person's weight doubled by the balancing system adopted) would cause it to sink $\frac{1}{40}$ inch deeper in the water. If the diameter of the cistern is seventy feet and the water is allowed to crowd up around the dome its theoretical sinkage will be only $\frac{1}{250}$ inch.

II. RIGHT ASCENSION MOVEMENT.

a. Driving mechanism; slow motions.

The driving-gear is located within the dome at its equator, nearly opposite the opening for the lens. Fig. 2 gives a scheme for the driving apparatus, in which B is an electric motor whose rate of revolution is controlled by a tuning-fork (see F. L. O. Wadsworth in THE ASTROPHYSICAL JOURNAL, February 1895, pages 176–7). A is a sprocket wheel which is, in connection with an ordinary weight driving-gear, to be used when the electric power fails. This wheel is ordinarily loose on its axle, but can be connected at will. Wheels C and E carry the power to G, where it passes a "mouse control" of the Greenwich pattern. From M the motion passes through P and Q and the beveled wheels R and S. The last mentioned, being the last wheel inside the dome, should have an index connected with it which will easily give the hour angle within one second of time. The axle of S passes through the floor of the dome to the wheel T outside, which, engaging with a circular rack, whose radius is slightly greater than that of the dome, causes the entire sphere to revolve. As the dome is made to sink deeper in the water with increase of weight, the rack must descend with it. The required motion can be imparted by using as support to the rack suitable bearings placed upon the surface of the sphere, while the rack itself is prevented from revolving by stops which slide against fixed brackets in the tank.

b. Rapid motion in right ascension.

This is obtained by moving C and D bodily towards the

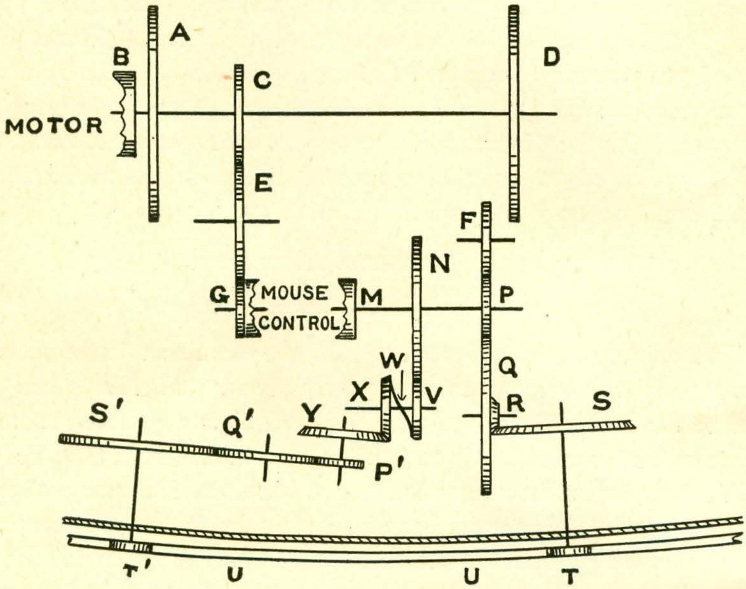


FIG. 2

motor so that C is wholly disengaged from E, and D transmits the power to P through F. By this means and by an arrangement of brushes the mouse control and the tuning-fork are cut out during rapid motion.

c. Backlash absorber.

T′, S′, R′, Q′, P′, Y, and X are so geared with respect to T, S, R, Q, P, N, and V, that V and X revolve at the same rate and in the same direction. If, therefore, by means of a spring, W, we produce in V and X a tendency to turn in opposite directions, the teeth of T and T′ will oppose each other by a force depending on the strength of W. This will produce an increase of friction between T and U, but the amount can be regulated by the tension of W. By means of this spring, however, both backlash and accidental slipping of T in U may be avoided. The displacement of a star in the focus is twice the amount of such slipping.

d. Automatic balance.

A tank of thirty to sixty cubic feet capacity is placed near the objective and moves with it. When the sphere is thrown out of balance a change occurs in the otherwise constant strain upon each wheel of the driving-gear. The wheel M (Fig. 2) is therefore made in two parts, held in a normal position by a spring, but capable of a slight motion with reference to each other in either direction. Electrodes are so placed that different circuits are closed according to the direction of motion of these parts, and an arrangement is connected with the right ascension index so that on the meridian these circuits are reversed. One circuit, by opening valves, admits water into the tank and the other allows water to escape. In this manner and by a proper arrangement of wires balancing can be effected automatically. To avoid possible disturbance during delicate work a switch at the observing chair can clamp the two parts of M together.

III. DECLINATION MOVEMENT.

The sphere has a long opening in it extending from the upper pole along a meridian to within a reasonable distance of the opposite horizon. The great circle including this opening is the declination circle. The declination axis, in the center of this circle and perpendicular to it, is stationary in the sphere. The tube passes up to one side of the axis and is supported in a special framework which rotates about the axis, the other side of the framework, or carriage, being extended for balancing purposes; a ladder runs from top to bottom. A strong clamp is desirable at each side of the top and bottom to keep the carriage perfectly steady and aid in rigidity of the dome. By taking the best advantage of every opportunity of bracing there seems to be no doubt that the two halves can be made sufficiently rigid with respect to each other. At the top of the declination carriage is the tank previously mentioned. Its best form is tubular and it should be placed parallel to the telescope. By making the objective project ten or twenty feet and surrounding the upper part of the tube by an air space connecting with the interior, the size of the sphere may perhaps be appreciably reduced. The declination carriage will be rotated by a crank and cog-wheel near the observing chair. An index can be placed on the carriage moving along a stationary scale of which each degree will be about one foot; setting within a small part of a degree will be easy.

IV. SUSPENSION OF THE TELESCOPE TUBE.

The lens is supported in a massive compass-mounting which will allow the eye-end of the tube to occupy any part of a circle whose diameter is about 1°. The chief function of the tube will be to preserve the alignment between the objective and eyepiece, and it may be made as light as will be consistent with rigidity. The position of the eye-end will be controlled by two large micrometer screws, whose revolutions may be read off from a scale, thus giving us a micrometer of unusually extensive field. This plan, or some modification allowing rotation, admits the use of high-power negative eyepieces for measuring purposes. A small position micrometer should be attached to the draw-tube.

Finder.

The finder need not be very large, but should be mounted so that its focus would be decidedly below that of the great telescope. Then by means of two mirrors its optical axis could be brought near and parallel to that of the other instrument and its focus rendered equally accessible to the observer. A rotating disk near its focus would carry eyepieces of different power. When an object had been found with a low power and large field and brought to the intersection of cross-threads, a high power could be turned in at once which would insure its visibility in the large instrument. A rotary movement in either one of the elbows will throw the eye-end of the finder out of the way when the object is finally in position.

V. SHUTTERS AND CAP.

The long portions of the opening which are not covered by the top of the declination carriage are closed by automatic shutters which open on the approach of the lens and close on its retreat. This is effected by a system of cog-wheels and eccentrics. It will probably be found best to extend the top of the carriage in either direction by a light screen to prevent too free entrance of outside air. The entrance of cold night air might be regulated by ventilators capable of adjustment.

The cap for the lens consists of two halves which separate in opposite directions to balance each other, controlled by a windlass near the observing chair.

VI. OBSERVING CHAIR AND ACCESSORIES.

An iron post projects from the floor of the declination carriage in line with the optical axis of the telescope in its central position. About this as an axis a car revolves on a circular track, supporting the observing chair proper on radial tracks. The chair may be constructed to suit individual taste ; the following plan will serve as an example. Near the center of the chair-base two boards are hinged, one supporting the back and head, and the other the knees and feet. The latter has a second hinge at the knees, so that by drawing the footboard from its outermost position towards the center a seat is formed (for observations at low altitudes). The headboard should be kept raised a little and made adjustable through a small arc, and the whole cushioned. At the top of the headboard is a transverse strip of wood which can be raised or lowered through the space of two inches by a lever which passes down beside the headboard to be within reach of the hand. Upon this strip a small head-rest is placed having a lateral sliding motion. On either end of the rest is a mirror placed at an angle of 45°, by means of which the micrometer readings may be taken; otherwise the eye can scarcely get far enough away to see the scale. Eyepieces should be kept in a drawer in one side of the chair so that they can be reached without getting up. A switchboard containing all necessary electric connections can be suspended by the slack of its wires from some point above so that it can be hooked on to the observing chair within reach.

Time.

Time had best be brought in to a sounder from a standard clock in an adjoining building. This may be used to correct a watch mounted, I would suggest, on the telescope itself, facing the observer, so that the time may be noted as soon as an observation is complete.

Recording.

It might be possible to attach to the telescope or head-rest two mirrors which would bring the record-book into view with one eye while the other was occupied at the eyepiece. This would be especially serviceable in making drawings of planetary detail.

VII. ENTRANCE.

The outside door is in the declination circle, and as far as possible below the lower pole without interfering with the motion of the carriage. The door itself is arranged to rotate about its center so that in any position of the dome it can be turned upright. It is reached by a U-shaped stairway. Inside, from the level of the door throughout the whole range of movement of the lower end of the carriage, a pathway, a quadrant in section, is built on each side of the declination zone. The two pathways if placed together would make a semicircle with its center tangent to the inner surface of the sphere. When the hour angle is zero a person may step from the carriage to the pathway on either side, the nearest part of it being then level; for eastern hour angles, he can find on the eastern pathway a part where the east and west inclination will be very small; for western hour angles he will turn to the western pathway. The radius of curvature of the section of these pathways could be perhaps five feet, and the ways themselves could be divided into separate paths by raised strips so as to make it easier to walk on them. Each of these separate paths will be supplied with steps of the proper height or with cleats nailed across, as best suits the inclination at which it will be used. At the equator a side path will extend at right angles to give access to the motors, driving-gear and desk. One-half of this path will have cleats across for small inclinations of the dome and the other half will be a stairway which can be used for large inclination in either direction. The desk will be of a form suited to the necessities of the case. The stand in front of it and its own top will both be curved surfaces so that one may always find a level standing place and a level part of the desk to write upon. These two surfaces will be portions of concentric cylinders whose axis is parallel to the axis of the dome.

A second entrance is placed near the objective, with a ladder bolted to the outside of the sphere for approaching it.

VIII. COMPARISON WITH OTHER MOUNTINGS.

The forms of equatorial mountings now in use differ as to their stability; perhaps the best in this respect is the *Equatorial Coudé*. By shortening the equatorial arm increased firmness will result, but it always has a disadvantage in requiring two mirrors. Irregularities in clock motion may occur in the *Coudé* as well as in any other form, whereas with a spherical telescope, the power being applied at the greatest possible distance from the axis, imperfections in the clock appear unchanged instead of highly magnified. Its great inertia also will aid in giving a constant motion. Apparently the individual feature in this mounting which cannot be duplicated in any other is the application of clock-power so far from the axis, resulting in great strength and steadiness.

In this connection it will be interesting to note what power is now in use in telescopes of some size — remembering that the single right ascension movement of the design under consideration includes both right ascension movement and turning of