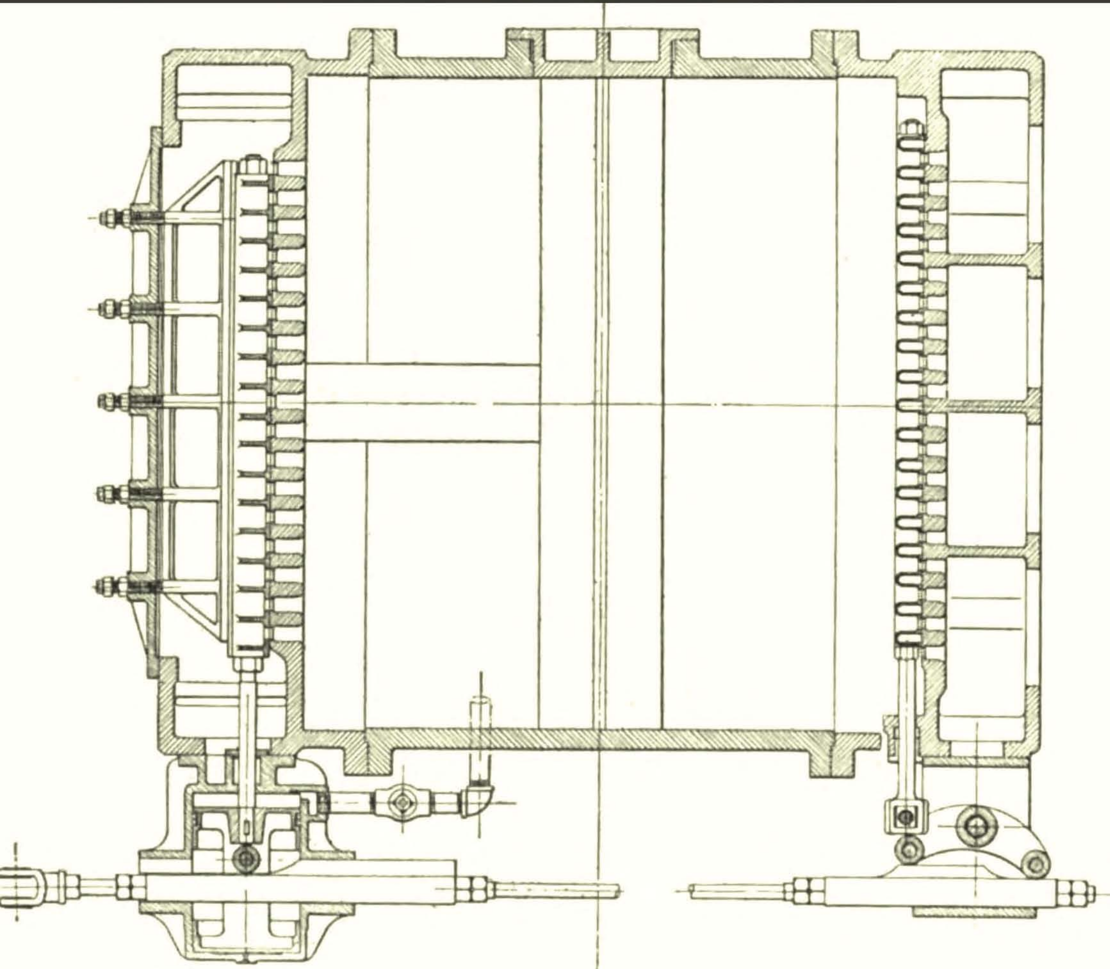

Journal of the American Society of Mechanical ...

American Society of Mechanical Engineers

THE TURRET EQUATORIAL TELESCOPE

A NEW ASTRONOMICAL OBSERVATORY

By James Hartness

ABSTRACT

This paper describes a new type of astronomical observatory which was designed to protect the observer from the cold to which he is exposed in most of the observatories now in use. It accomplishes this purpose by the use of a revolving turret for the polar axis of the instrument, making the instrument and building integral. By this change in scheme of mounting it has been possible to avoid the use of the large reflecting mirrors employed in all previous designs where the comfort of the observer has been the controlling motive.

The problem in making an observatory of this kind is to maintain an equal temperature within and without the telescope tube, in order to avoid establishing disturbing air currents. and of course it is necessary to receive the beam of light coming from any object above the horizon.

In all previous work at least one relatively large plain reflector has been used to change the direction of the beam of light from that in which it comes from the celestial object to the fixed direction requisite for the eyepiece. In the present instrument the eyepiece has a slight motion, and therefore does not possess the ideal feature for comfort of the observer that is possessed by the previous instruments, but by sacrificing a trifle in this respect it has been possible to avoid the use of a large mirror. The point at which the direction of the cone of light is changed is about one-quarter of the distance from the ocular to the objective; this gives an area of about one-sixteenth of mirrors located near the objective. This is so small that it is possible to use a prism instead of a mirror, although even with a mirror it would be a distinct gain.

The paper includes a description of the means for heating and ventilating, and also touches on the delicate subject of patent rights for scientific instruments and the adverse effect to science of the present policy of allowing such things to go unprotected by patent rights.

THE TURRET EQUATORIAL TELESCOPE

A NEW ASTRONOMICAL OBSERVATORY

By James Hartness, Springfield, Vt.

Member of the Society

The subject of this paper cannot be properly considered without acknowledgment of indebtedness to at least three of our members, each one preëminent in one or more branches of astronomical science. Notwithstanding their great variety of interests, these men have found time to write long letters of advice and criticism in response to questions or on submission of drawings suggesting the various steps in the evolution of the present scheme. Years ago the writer thought he was favored in this respect, but later observation has proven that the same earnest, personal consideration is given to anyone. It was from these men that the microbe of work in the astronomical field was taken, and it is a pleasure to acknowledge indebtedness to our Honorary Member John A. Brashear, and to Past-Presidents Worcester R. Warner and Ambrose Swasey, for advice and criticism of the optical and general features of the various schemes out of which this new observatory has evolved. Indebtedness is also acknowledged to James B. McDowell and other members of the staff of John A. Brashear Co., Ltd., and to Alvin Clarke Son Corporation for painstaking care in answering questions and giving advice regarding the optical parts.

The new observatory grew out of an attempt to make an observatory in which the observer could work in comfort, independent of the outside temperature. To accomplish this end without serious handicap to good seeing and instrumental precision involved a departure from previous forms.

2 For the purpose of defining the relation of the new observatory to preceding types it is necessary to refer to diagrammatic illustrations, Figs. 1A, 2A and 3A. These sketches are purely schematic and are not true to important details.

3 Fig. 2A for the purpose of this paper will be referred to as the Standard Observatory, since it represents a type most highly developed by reason of the greater number of instruments of this kind

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that have been made. This instrument is not only the most efficient optically, but is probably the most reliable in point of mechanical precision when compared with any other instruments designed for covering the whole heavens and for general purposes. It has, however, the one serious handicap of requiring within the building a temperature equal to that of the outside air. It is for the purpose of overcoming this handicap that the instrument to be described was designed.

4 Fig. 1A is known as the Equatorial Coudé, or Elbow Equatorial. This instrument was designed to shelter the observer in comfortable

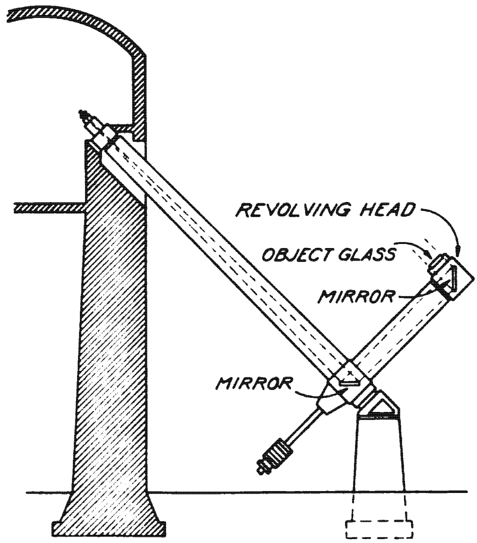


Fig. 1A Diagrammatic Sketch of the Equatorial Coudé
Object glass, 23 in. in diameter with 25:1 focal length; largest diameter of larger mirror, 32 in.; largest diameter of mirror at elbow, 23 in.

quarters. It is of French origin and a number of these are in use in Paris and elsewhere.

5 Fig. 3A is a schematic sketch of the new instrument which we propose to designate as the Turret Equatorial.

6 All of these instruments are refractors, using an object glass for collecting the rays of light and delivering them to a focal point within reach of the eyepiece.

7 In the standard equatorial the optical parts consist merely of the object glass and the ocular; for this reason it has the highest efficiency of any instrument for this purpose.

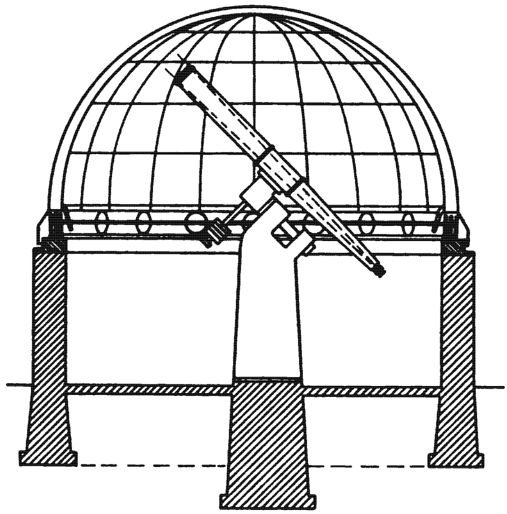


FIG. 2A STANDARD EQUATORIAL
Object glass, 10 in. in diameter with 15:1 focal length.

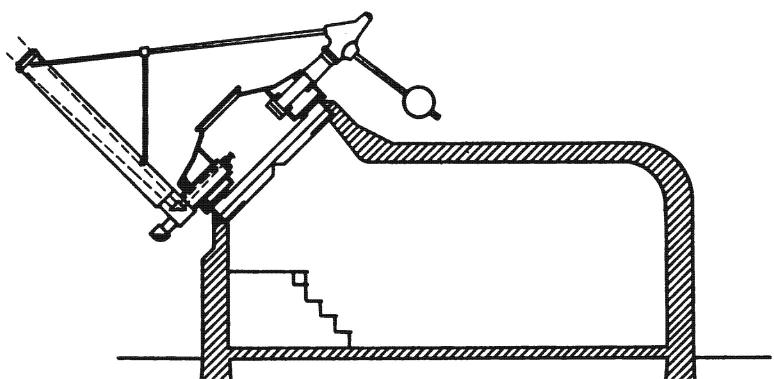


FIG. 3A TURRET EQUATORIAL
Object glass, 10 in. in diameter with 15:1 focal length, 2½-in. prism at bend, which is approximately ¼ the distance from eyepiece to objective. Actual size of beam of light is 2½ in. at this point, or $\frac{1}{16}$ the area of objective.

8 The equatorial coudé purchases its comfort for the observer at the expense of a more or less serious optical loss, for between the object glass and the eyepiece two diagonal plane mirrors are interposed. In this instrument the beam of light comes to the eye at about the same angle as from a microscope on a table. The mirror at the object glass, of course, must be large enough to deliver the full bundle of rays, and since it stands at an angle of 45 deg., its major diameter must exceed the diameter of the object glass by about 40 per cent. This is also true of the diagonal plane at the elbow, although the diameter of the cone of rays is about 0.6 the diameter of the object glass. Notwithstanding this handicap, the equatorial coudé has doubtless been considered the best instrument which could be used by an observer comfortably housed.

9 There is another instrument, not shown in the sketches, somewhat similar to the equatorial coudé. It is called the broken equatorial coudé, and is joined at the bend in the elbow, avoiding the necessity of the large mirror at the objective. It has been excluded from this description because it does not cover the whole heavens. Its building obscures the circumpolar stars and that part of the heavens that happens to be north of the building.

10 Mention should also be made of the Tower telescope at Mount Wilson, Cal., designed for solar work. In this the beam of light is delivered downward by means of two reflectors through the object glass also located at the top of the tower. Reference might also be made to the various horizontal telescopes that have been used. But these instruments have thus far been used for only a limited part of the range covered by the standard equatorial.

11 In addition to the standard equatorial and equatorial coudé, both of which should be classed as refractors, special mention should be made of the common reflector as it is now mounted at Harvard University. This instrument delivers the beam of light to the observer, who may be seated at a desk, just as in the equatorial coudé observatory. It is, however, a reflector, and should perhaps be kept in a class by itself. It also uses two auxiliary mirrors to deliver into the eyepiece, and furthermore, like the broken equatorial, its working range is limited by the obscuring of part of the heavens by its own structure.

12 In all of the instruments designed for the comfort of the observer it has been necessary to introduce one or more reflectors, and barring the common reflector at Harvard and the broken equatorial, these auxiliary reflectors have been located near the objective.

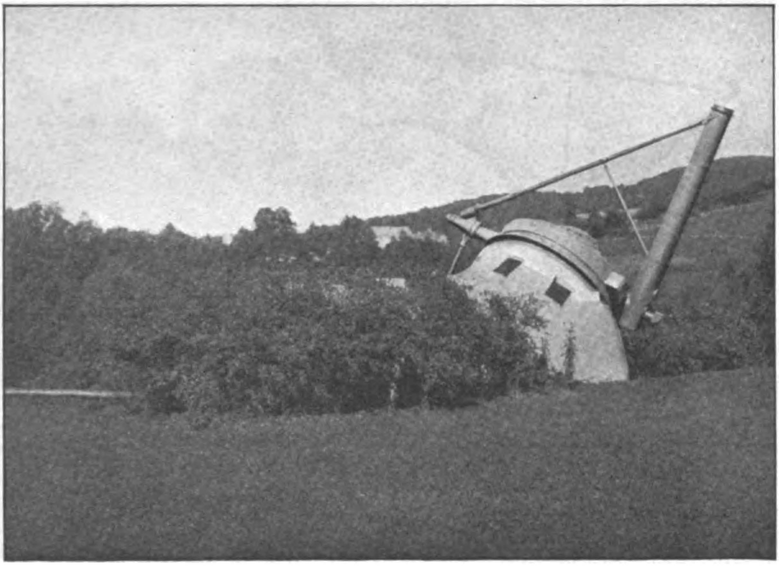


Fig. A View from a Point Southeast of the Observatory
Note the various positions of the turret on its axis and the positions of the tube in Figs. A–G

Fig. B View from a Point about Northeast of the Observatory

Fig. C View showing West Side and South End

Fig. D Winter View taken just after Completion of Grading, showing North End and East Side

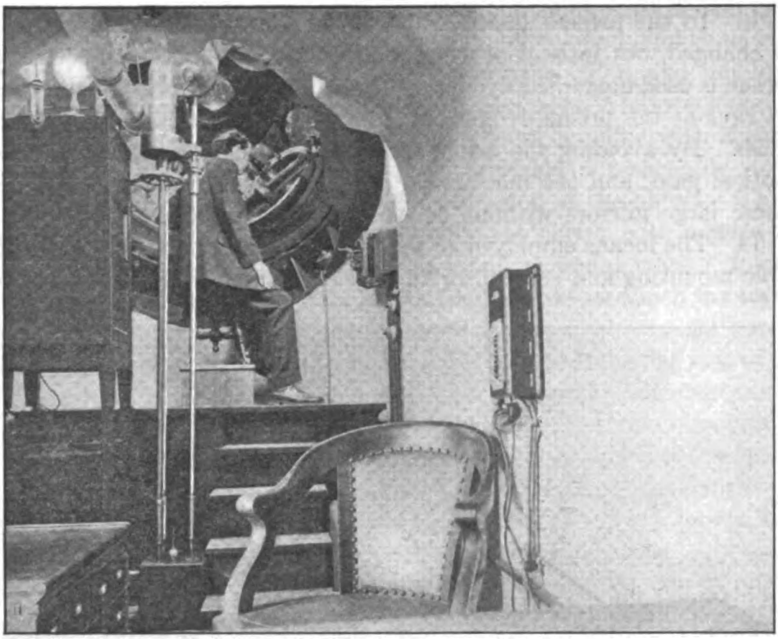


FIG. E INTERIOR OF OBSERVING ROOM

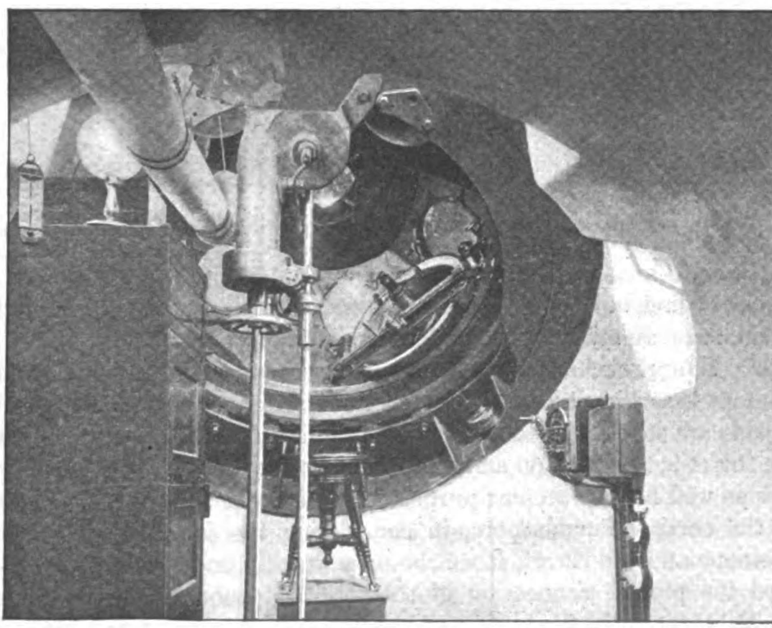


FIG. F ENLARGED VIEW OF INTERIOR OF DOME

13 In the present instrument the direction of the beam of light is changed, but instead of using a large mirror near the objective, a prism is used nearer the eyepiece. The area of the bundle of the cone of rays at the prisms is approximately $\frac{1}{16}$ of the area of the object glass. By avoiding the use of large mirrors there is, of course, the optical gain, and the mechanical difficulties encountered in holding these large mirrors without flexure are also obviated.

14 The means employed to shelter the observer and provide suitable mounting and control for this telescope may be briefly described

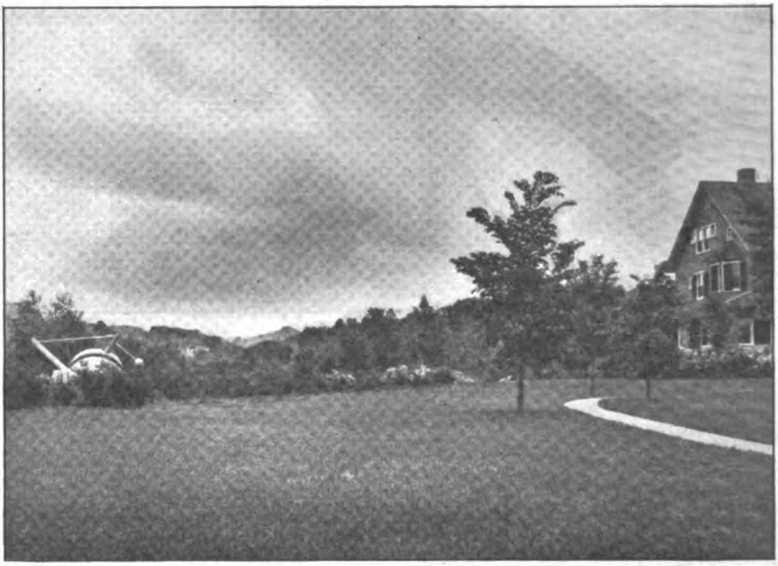


Fig. G Turret Equatorial Observatory and Residence to which it is connected by Underground Passageway

as a building having a turret-like dome, this dome being mounted to rotate on an axis parallel to the axis of the earth.

15 In approaching this problem it is perhaps well to bear in mind the fact that the distances between the instrument and the celestial objects are so great as to be practically infinite; hence, in saying that the turret is mounted on an axis parallel to the earth's axis, it will be just as well for our present purpose to consider it located at the axis of the earth. Furthermore, in considering the joint between the telescope and the turret, it will be more readily understood if we regard the pivotal connection of the telescope tube to the dome as located directly in the middle of the turret instead of at one side

16 Regarding the mechanical precision of the present instrument, it is very natural for us to question the reliability of a turret in serving the place of an arbor for the main polar axis. This axis not only provides a control of the motion of the telescope as it follows a star in offsetting the earth's motion, but it also must combine with it some means for knowing with considerable precision a reasonably exact reading of the hour position or right ascension of the object. These two things make it necessary to provide the turret with a perfectly planed surface on its under side and a truly circular track. It also requires in the building a stable mounting for rolls on which the turret rests.

17 There are two sets of rolls: one set on which the flat face of the turret rests must keep the axis of the turret parallel with the axis of the earth. The circular part of the turret bears on the other set of rolls. The office of the second set is to hold the axis of the turret in a fixed position relative to the building to facilitate convenience in measurement of the angular position of the telescope as to hour position or right ascension.

18 If we can assure ourselves of the reliability of the turret for axial control and means for measuring the angular position of the tube around this axis, the author thinks we should be ready to accept the present scheme on account of its making possible the comfortable housing of the observer.

19 In mechanism for obtaining the greatest precision of axial control of a rotating object, machine designers invariably prefer an arbor of relatively small diameter mounted in two bearings, with the distance between the bearings of at least half a dozen diameters. Small diameters also furnish a most reliable center control around which to measure angular position.

20 In the present case as in nearly every problem of machine design, there are, however, other elements to be considered. The best solution is to determine what compromise to make. Even the almost ideal mounting of the standard telescope, such as exemplified in the great Yerkes refractor, an instrument which undoubtedly measures the highest attainment along these lines, seems handicapped by a delicacy of poise which is not the most favorable for stability of control.

21 It is entirely beyond and outside the object of this paper to discuss these various instruments, but it seems necessary, in order to set forth the object of the present instrument, to call attention to those that have preceded it, and in doing so to set forth the apparent

advantages and disadvantages as they appear to a novice, giving a view which, while it may not be correct, has at least the advantage of being a fresh one.

22 The refracting telescope having standard equatorial mounting is not only the best, optically considered, but it is undoubtedly superior to all others when made in the smaller sizes and for use in pleasant weather. The mechanical difficulties, however, increase very fast with the size of the telescope, and there are, of course, many latitudes and altitudes at which these instruments are used where the observer must be exposed to very cold weather.

23 The mechanical handicaps of the larger telescopes are due to the overhanging tube and counterweights. Not even the highest excellence in workmanship in making these machines nor the skill in their use seems to offset this instability. To the beginner, at least, it would appear that a breath of air or a change of adjustment would be sufficient to cause a quiver.

24 Referring now to the use of large mirrors, such as are used in the equatorial coudé and others, we have already mentioned the mechanical difficulties encountered in controlling the position of these mirrors without distortion. In the tower telescopes for solar work exceedingly thick mirrors have been used, and in the other telescopes devices have been employed by which the mirrors have been equally supported by many contact points; but notwithstanding this, no scheme seems to prevent fully the bending of the mirror and distortion of the image. The problem is especially difficult because these mirrors must be held in so many different positions. It would be a comparatively simple matter if there were no change of position. Furthermore, there is a temperature disturbance which is greater in a mirror than in a refractor. For this reason it is necessary to maintain an even temperature through the mirror.

25 In addition to the distortion of the image by lack of mechanical control of the mirror, there is the serious objection of absorption by even the most perfect reflectors. This absorption reduces the total light that reaches the eyepiece, and since the object in using telescopes of larger light-gathering power is to get more light, the use of a mirror is equivalent to a reduction of the diameter of the objective.

26 Furthermore, this cannot be offset by mere increase in size, for the loss in definition due to atmospheric disturbance increases with the diameter of the telescope, resulting in a net loss in definition. Therefore the price paid for comfort is not only the amount which must be expended for the large object glasses and still larger reflec-

tors to go with them, but also an actual loss in definition. This loss of definition, of course, is greatest in the low altitudes and least in the rarefied air of the best mountain top observatory sites.

27 In all equatorial telescopes provision must be made for changing the angular direction of the telescope to and from the pole; in other words, north and south. The axis on which the telescope turns for this position of declination must stand, of course, at right angles to the polar axis.

28 In the standard equatorial the arbor which furnishes the polar axis is provided with an opening transverse to it, which serves as a bearing for the arbor that is affixed to the side of the telescope tube and it is on the precision of this axis that the instrument depends for its true position in declination. It is undoubtedly due to the attachment of this secondary axis to the primary axis that this standard equatorial has the appearance of instability. It is, however, nicely counterbalanced, and the great precision of control is due to the excellence of workmanship and manipulation of a very high order. Nevertheless, it would seem desirable to provide some suitable control for the tube itself on this as well as on the primary axis.

29 In the new instrument the telescope is not pivoted at the middle, but at a point near the focus, and it is at this point that the prism is introduced and the rays are delivered into the turret through the hollow declination axis.

30 The scheme of counterweight resembles in some respects the old-fashioned well sweep. This counterweight is fulcrumed at the opposite side of the turret and reaches over to a point near the head of the telescope, supporting it without adding the weight to the telescope head, thus relieving a part of the weight of the declination axis and also all torsional strain.

31 This well sweep acts also as a brace in one direction. Its duty changes from that of a counterweight to one wholly of a brace. For instance, when the turret has been turned so that the declination axis is at the lowest part, and the tube has been pointed directly to the pole, then the counterweight is inoperative as a counterweight for the tube, but the arm becomes a brace. Therefore this scheme changes from one that is wholly a counterpoise to one that holds the telescope in position by a diagonal brace, and, of course, there are positions in which there is an equal service of each in the change from one extreme to the other. The brace always operates to stiffen the instrument against the action of the wind in certain positions

and the exact form may be varied to get the best results. The one shown in the illustrations was made to use available material.

32 The means for controlling the declination position of the telescope is a wormwheel in which two worms engage. All of this is clearly shown in the drawings Figs. 17 to 20.

33 It will be seen, then, that the observer sits inside the dome and receives the light coming from any celestial object above the horizon, and although it is necessary for him to change the position of the chair about 1 ft. east and west and 3 or 4 in. vertically, such a change does not constitute any serious inconvenience.

34 The beam of light comes into the observatory in a horizontal position when the telescope is pointed along the meridian, and it changes from the horizontal position to one in which the observer looks down towards the north at an angle of about 45 deg. at this latitude. The control of the dome, both for its quick motion for changing from one position to another, and also for providing movement to offset the rotation of the earth, is all effected by levers within convenient reach of the observer.

35 The rotation of the dome, instead of being effected by a wormwheel or gearing directly connected to the dome, is through the means used for driving four of the supporting rolls. These rolls take bearing on the circular track. They are hardened and ground to the proper diameter to get the desired relation of speeds. All of the other rolls are merely idlers for maintaining the fixity of axis of dome, and all rolls are mounted in ball bearings to reduce the total power required in turning the dome. Ball bearings keep the resistance more nearly uniform than could be maintained with plain bearings.

36 The motor which furnishes the power was originally located within the building, but on account of its noise it was placed in a separate box outside of the building.

37 As shown in Fig. G this observatory is located a short distance from the observer's residence. It is connected by an underground passageway which not only serves as a shelter in going to and from the observatory, but also as a means for carrying telephone and electric wires, hot and cold water, and the hot water for heating.

38 It is located on the brow of a terrace on which the residence stands, at a level a trifle lower, so that the tunnel rises in going from the lower room in the observatory to the residence, about 9 ft. in the 240 ft. of length. This difference in level, although it makes necessary the use of a small centrifugal pump to induce the hot water to circulate in the observatory, serves as an aid in ventilation.

39 The location of the observatory on the brow of a hill or terrace, makes it possible to get a fresh air inlet from the lower part of the lower room by running an air duct out through the side of the bank to the open air. In cold weather the air rushes through this air duct into the observatory, through the ventilators in the top of the door into the tunnel, and thence out of the tunnel either at the place where the tunnel joins the residence, or through the house. In summer, when it is hot outside, the current of air flows in the opposite direction. At such a time the door to the residence at the head of the tunnel is kept closed and another door is opened to the outside air. This takes the fresh air from the outside, which travels down through the tunnel by gravity, giving up some of its heat to the tunnel walls and reaching the lower room of the observatory at a fairly comfortable temperature. Then, by the aid of a small portable fan this air from the lower part of the room of the observatory is blown through an air duct into the dome.

40 In this connection, perhaps, it would be well to state that the dome is lagged with wood on the inside and the windows are all double, that is, there is one set of windows in the wooden lagging on the inside, and another in the metal dome outside. This air space is desirable in winter as well as in summer.

41 Regarding the form of the building, this may be almost anything from a large spherical dome to one having a hip roof. The one feature essential to this scheme is the proper neck for supporting the turret. This neck should be substantially the same as that shown in the present illustrations. The author selected the present form, partly to make it the least conspicuous from his residence, and perhaps it was influenced by the earlier form of the scheme in which it was intended to use a reflector instead of a refractor.

42 Closely connected with this subject is, of course, the cost, which must be based on the way such things are produced. If more instruments of this kind are to be made at different times and in various places, there is no hope of getting them produced at a low figure. There seems to be only one way of insuring the success of an instrument of this kind. Every machine builder knows it, and yet the mere mention seems to establish an antagonistic attitude at once in the mind of the average man.

43 It has not been considered ethical to take out patents on scientific instruments, and although the writer has not the courage of a reformer to wage battle against this sentiment, yet when it is such common knowledge that machinery cannot be successfully and eco-

nomically built without the concentration of the energies of a number of men for a given purpose, and since this cannot be accomplished without patent protection, it has been thought best to apply for patents on the new features of the present instrument. Although this will be done without dedicating it outright to the public, it is needless to say that no barrier will be allowed to prevent these instruments being built by any one until some business arrangement is made for the exclusive manufacture of some one size by some builder, and even then, others may be permitted to build other sizes; but all such permission will be given only by letter and not in a broadcast way that would in any way handicap the main purpose of making these machines available at a low cost to anyone who may desire them. It goes without saying that with patents there is always the thought of the exclusive right and profit of the patentee and manufacturer, but regarding this point it is well-known that the low cost of such things, as well as the best workmanship and results, can be obtained only by concentrating all of the work in one plant.

44 The writer does not contemplate manufacturing these instruments. More may be built experimentally, but not for the market. If others wish to build instruments of this kind, permission will doubtless be freely given, but with certain restrictions; but all this must be arranged in each case by correspondence.

45 If patent is granted no charge of any kind will be made for license to build until some arrangement has been made for manufacture on an efficient scale, and then only such restrictions as in the opinion of the patentee will be for the best interests of the science.

46 In closing, the writer begs to call attention to the fact that the great advancement in the world's knowledge, due to the work of the astronomers, has been carried on by the men who have braved the mosquitoes in summer and observed long hours in the most unfavorable temperatures. These men have been recruited from those who have taken up the work as an avocation and for every man of this number there have undoubtedly been ten or a hundred who have grown faint-hearted at the mere thought of the exposure incident to observing and at the high cost of the large instruments. With means of this kind made generally available it is thought that there will be more men in this work, and that from the greater number perhaps even greater work may be accomplished in the future.

DATA REGARDING THE TURRET EQUATORIAL

Object glass, 10 in. in diameter, and 150 in. in focal length.

Inside dimensions of building, 6 ft. by 18 ft.

Outside diameter of dome, 7 ft., 4 in.

Weight of dome casting, about 1½ tons.

Total weight of dome with counterweight, tube, etc., about 2 tons.

Weight of ring-casting on which the dome is mounted, 1½ tons.

The optical parts were furnished by The John A. Brashear Co., Ltd. All of the other work was home-made, except the two large castings which were cast and turned in Fitchburg, Mass.

The hour circle consists of a flat ring having approximate dimensions of 52 in. outside, 48 in. inside, and ¾ in. thickness.

The inner diameter is graduated down to divisions of 1 minute. These divisions are about 0.1 in. apart. Vernier edges were provided for division of the minutes into seconds, but thus far a crude substitute has been used in preference. It consists of a rotating dial driven by gearing which also turns the dome. Its connection is such that the dial makes 1 r.p.m. With the 60 graduations on dial, the division of time into seconds is very readable.

In use the hour circle may be set to the even minute of position, leaving the plus or minus of seconds to be allowed for at the zenith point by the time piece.

The declination wormwheel is 24 in. in diameter, and is provided with two worms located on opposite sides. These are rotatively connected by means of a cross shaft and spiral gears.

In order to prevent conflict of action an eccentric bearing is provided for accurately gaging the depth of engagement of each worm. A separate means for turning each a very slight amount is also provided.

Graduations for minutes of degrees are carried by hubs on worm shafts.

The proximity of the two eyepieces led to the disuse of the finder, but if it is needed in future work, there are a variety of schemes for overcoming this difficulty.

Attention should be called to the rigidity of the eyepiece and the opportunity afforded for attaching photographic and spectroscopic apparatus. This feature is to be found in other telescopes designed for comfort, but as this instrument seems to partake more of the good seeing qualities of the standard telescope, it does not seem out of place to call attention to this advantage it has over the standard in which the delicacy of the poise is disturbed by added weight and adjustment of counterbalances.

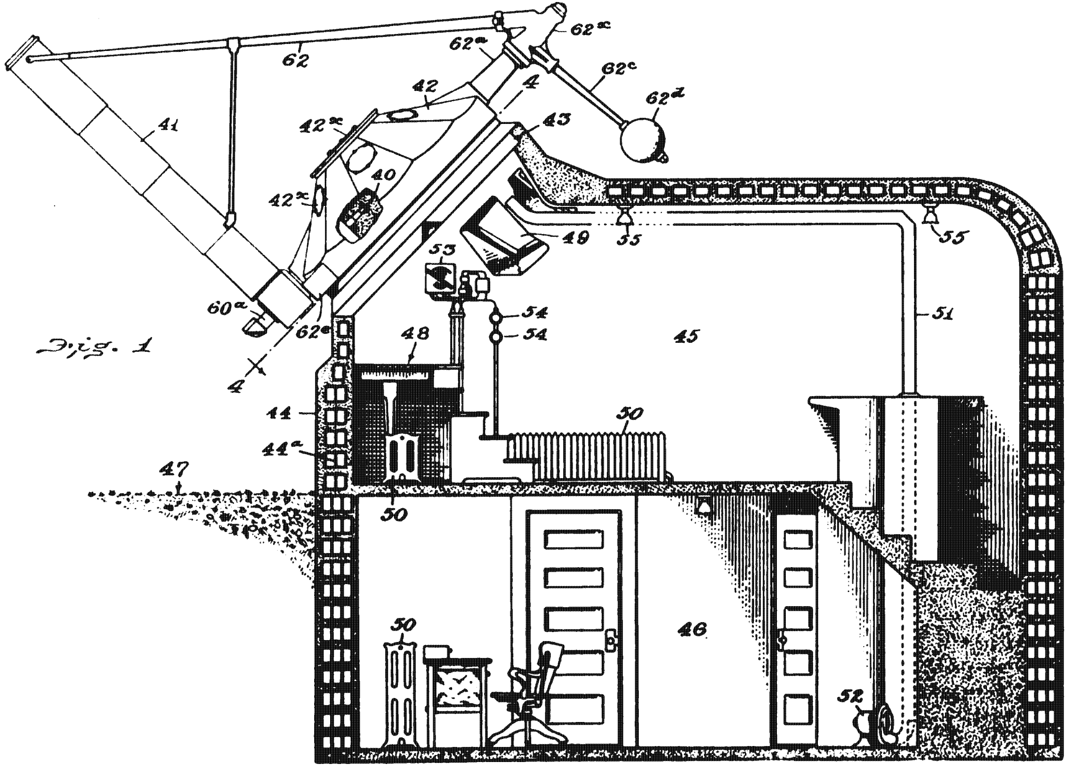


FIG. 1 SIDE ELEVATION OF THE TELESCOPE AND DOME AND A LONGITUDINAL VERTICAL SECTION OF THE BUILDING WHICH FORMS THE HOUSE FOR THE OBSERVER

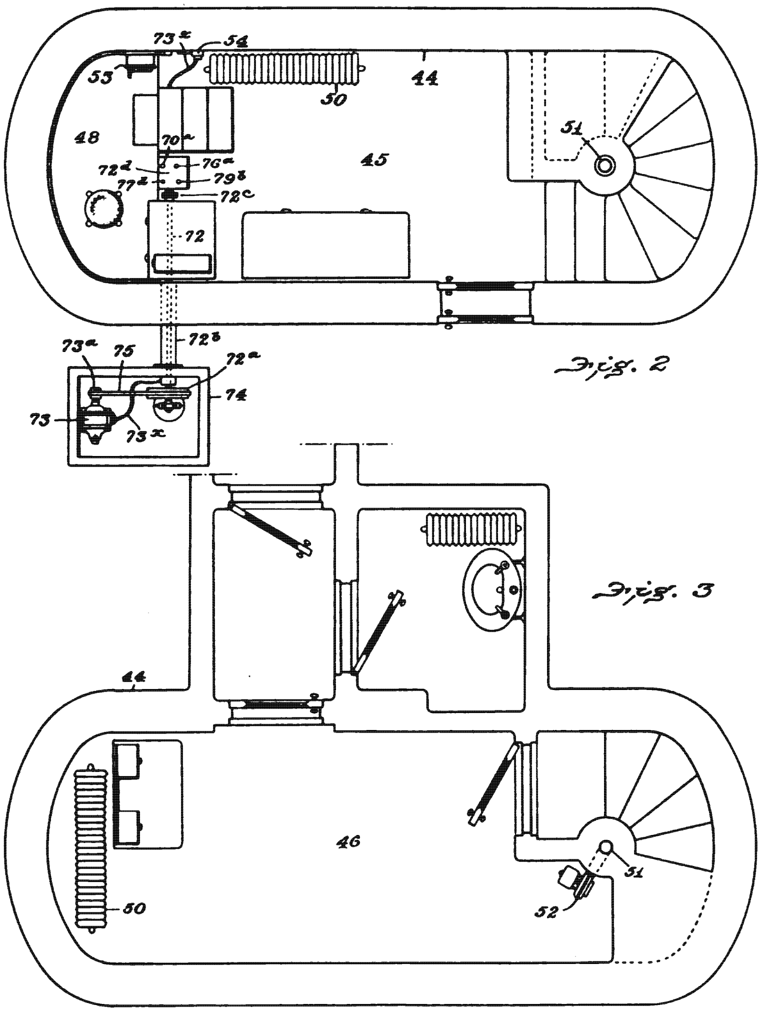
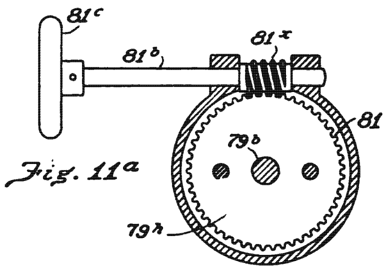


Fig. 2 Floor Plan of the Upper Compartment of Observing Room and the Box outside the Building in which the Motor is located

Fig. 3 Floor Plan of Lower Compartment and Subway Entrance



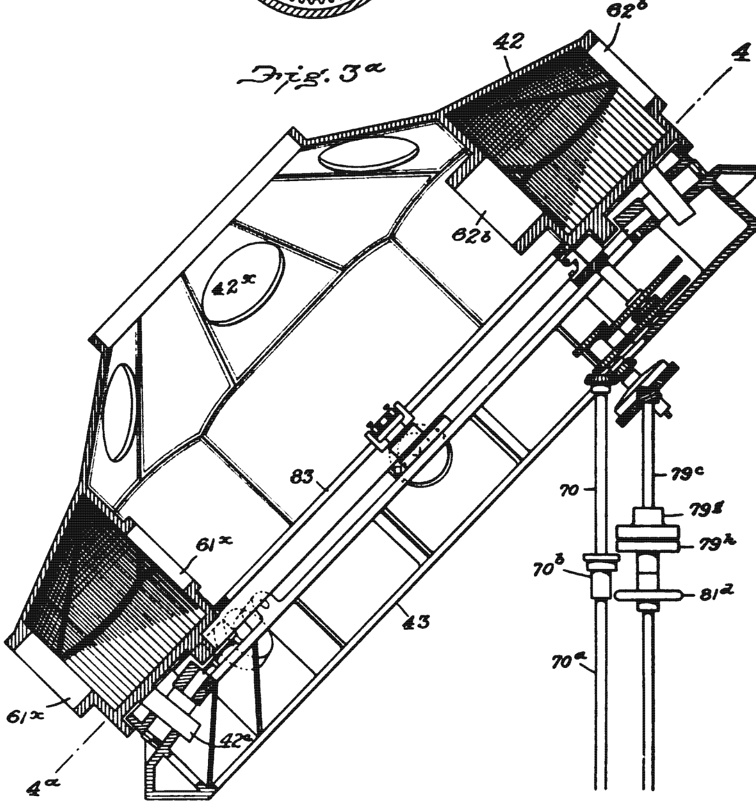


FIG. 3a LONGITUDINAL VERTICAL SECTION THROUGH THE TURRET

FIG. 11a ORIGINAL FORM OF DIFFERENTIAL MOTION FOR MANUALLY VARYING THE ADVANCE OF DOME AS IT IS TURNED BY MOTOR TO FOLLOW A STAR

This has been superseded by Fig. 11, but may be reinstated again.

Fig. 4a

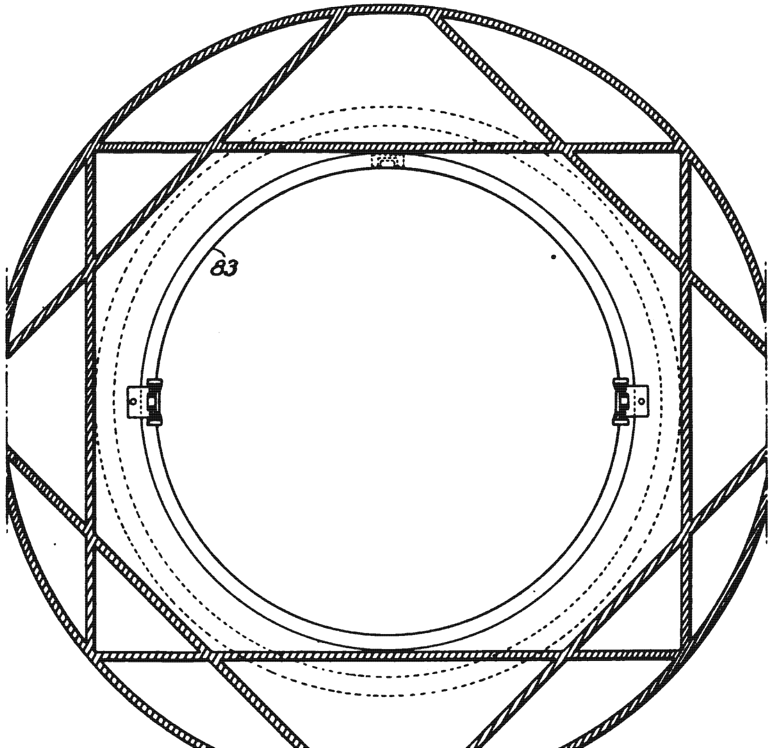


FIG. 4a CROSS-SECTION THROUGH TURRET ON THE PLANE INDICATED BY LINE 4a4a IN FIG. 3a It clearly illustrates the scheme of ribbing which was chosen to resist warping or change of plane of under side of turret. It also shows its stability to resist any tendency to lose its true circular form of track, 42f in Fig. 4. The entire precision depends on the reliability of this plane and circular face of turret. This may be considered the most essential element in the whole structure.

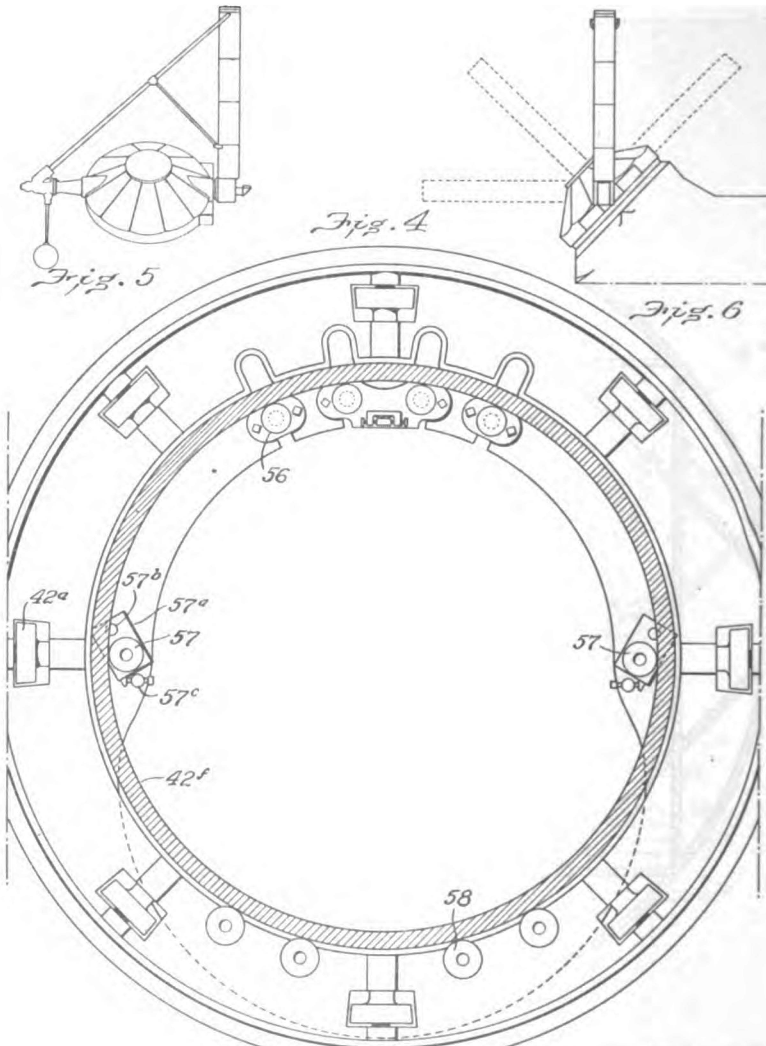
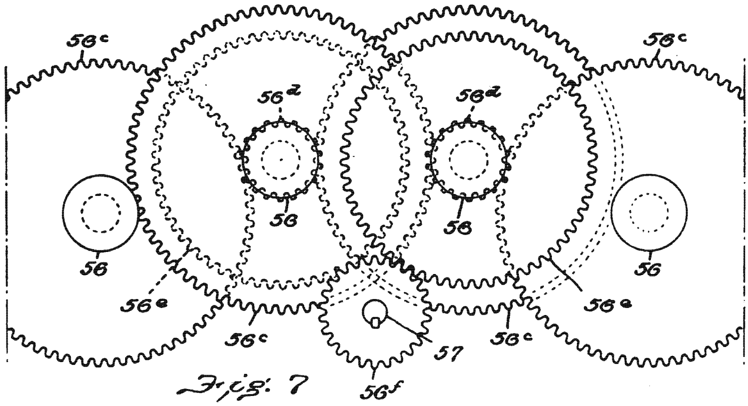


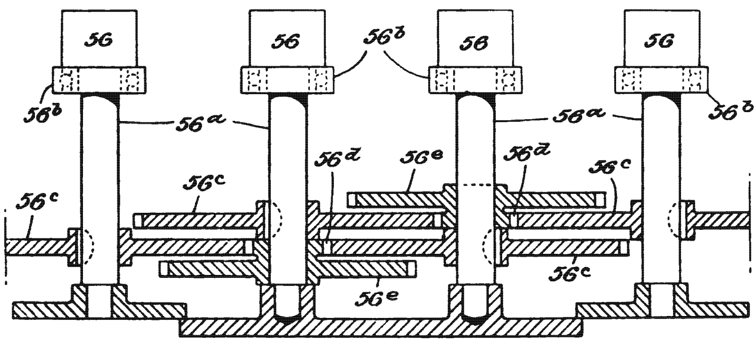
FIG. 4 SECTION THROUGH THE TURRET INDICATED BY LINE 4—4, FIG. 1

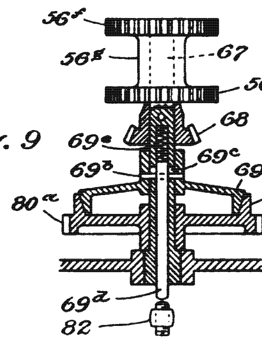
The eight conical rolls 42a furnish a support to plane the face of the turret. Their office is to keep the axis of the turret truly parallel with the axis of the earth; that is, they prevent the turret from tilting. The four rolls at the top, marked 56, are the driver rolls. The circular track of turret is shown in section 42*f*. The turret hangs on these driving rolls held in position laterally by side rolls 57.

The four rolls marked 58 at the bottom of the figure are to relieve the burden on driving rolls 56 when the instrument is not in use.

FIGS. 5 AND 6 NORTH AND WEST ELEVATIONS OF THE TELESCOPE AND DOME SHOWING TELESCOPE POINTED TO ZENITH; ALSO BY DOTTED LINES, VARIOUS OTHER POSITIONS OF THE TELESCOPE RELATIVE TO THE DOME







FIGS. 7 AND 8 PLAN AND ELEVATION OF DRIVING ROLLS AND THEIR GEARS
FIG. 9 CLUTCH MECHANISM FOR THE SLOW MOTION OF DOME (SEE FIG. 10)

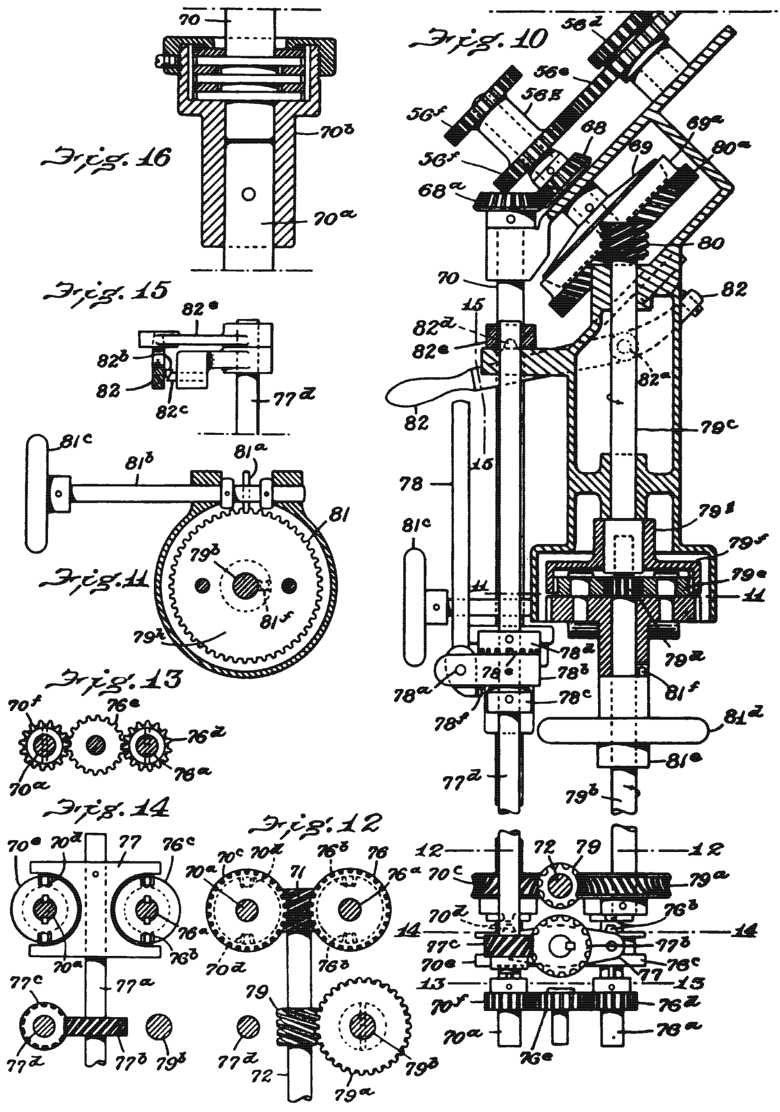


Fig. 10 Diagram showing Transmission Gearing and Clutches that give the Motions to the Turret. It Extends from the Top to the Bottom of the Page

The fast motion forward and back is under control of lever 78 and the slow motion is controlled by lever 82. These levers interlock to prevent conflicting engagement. The slow-motion clutch is shown as a friction clutch at 69 and 69*a*, and the fast motion clutches are of the positive, or toothed-clutch type and are shown rather obscurely at 70*d* and 76*b*. These gears with their clutches are located in a gear box on the floor of the observing room (Fig. 2). The shafts 70 and 70*a* which transmit the motion from this box to the upper group of gearing are unfortunately obscured in this view by the lever control shaft, 77*d*. They may be more clearly seen in Fig. 3a.

Fig. 16 Slip Box or Safety Coupling between the Two Shafts 70 and 70a

It is wholly unnecessary, for the driving rolls slip when any undue resistance is encountered.

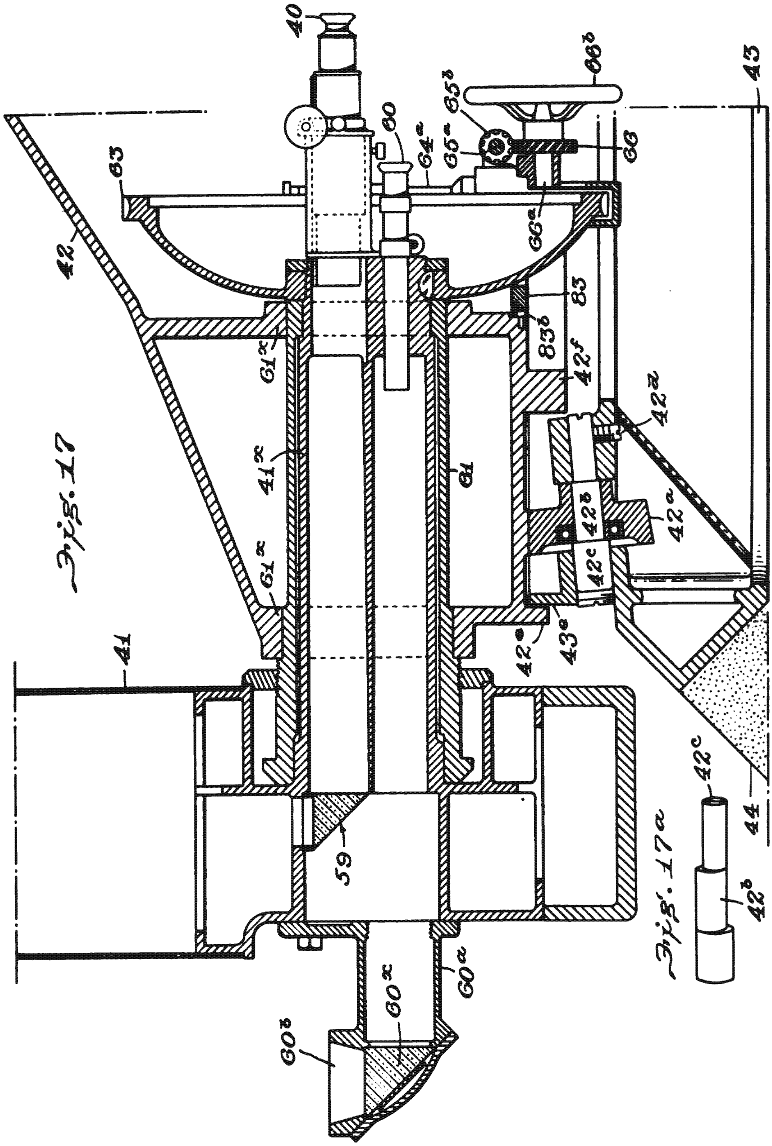
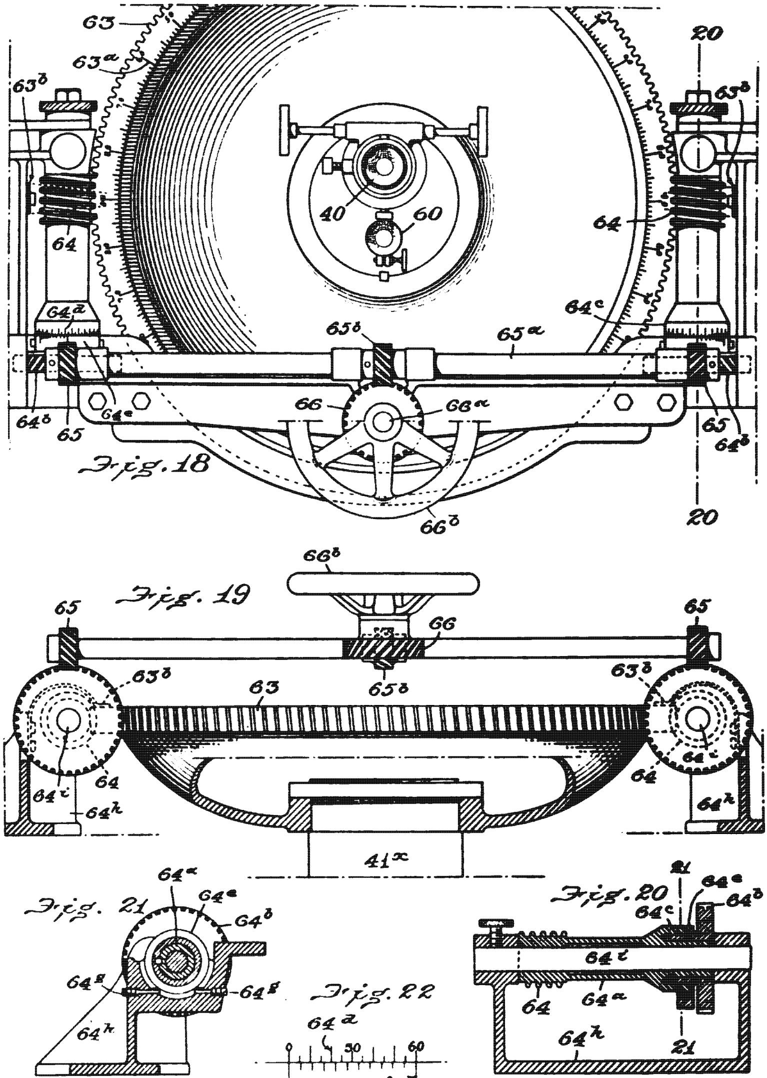


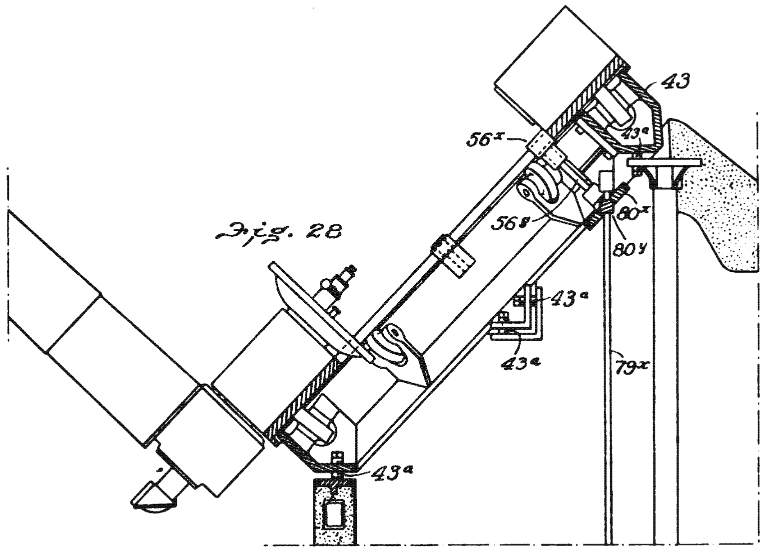
FIG. 17 SECTIONAL PORTION OF THE TURRET THROUGH THE DECLINATION AXIS, SHOWING ALSO SECTION OF THE LOWER PART OF FOUNDATION RING WITH ONE OF THE CONICAL SUPPORTING ROLLS IN SECTION

The part of the foundation ring shown is the same as the lowest part shown in Fig. 3a. In Fig. 17 the end of the telescope tube is represented by 41. It is attached to the head declination arbor 41*x*. This arbor turns in bushing 61 which is forced into turret seats at 61*x* and 61*x*.

The cone-shaped beam of light from the object glass comes down through tube 41, passes through prism 59 which changes its direction 90 deg., delivering it to the focal point near ocular 40. The light for the finder enters through opening 60*b* directly into prism 60*x*, thence through an object glass (not shown) which is located in the inner opening of 60*a*. From this object glass it converges to focal point near the finder eyepiece 60.



Figs. 18 to 22 Various Views of Declination Wormwheel and its Control by Double Worms
The form of the wheel and its connection to the arbor is not ideal, but may be very much improved in any later work.



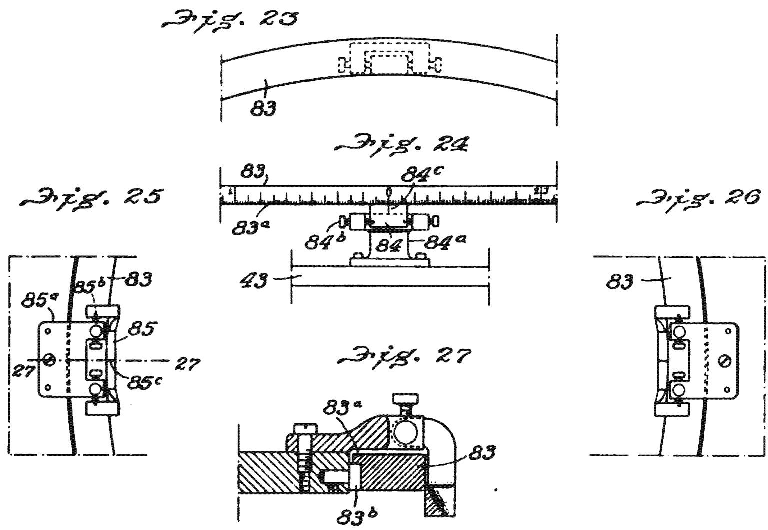
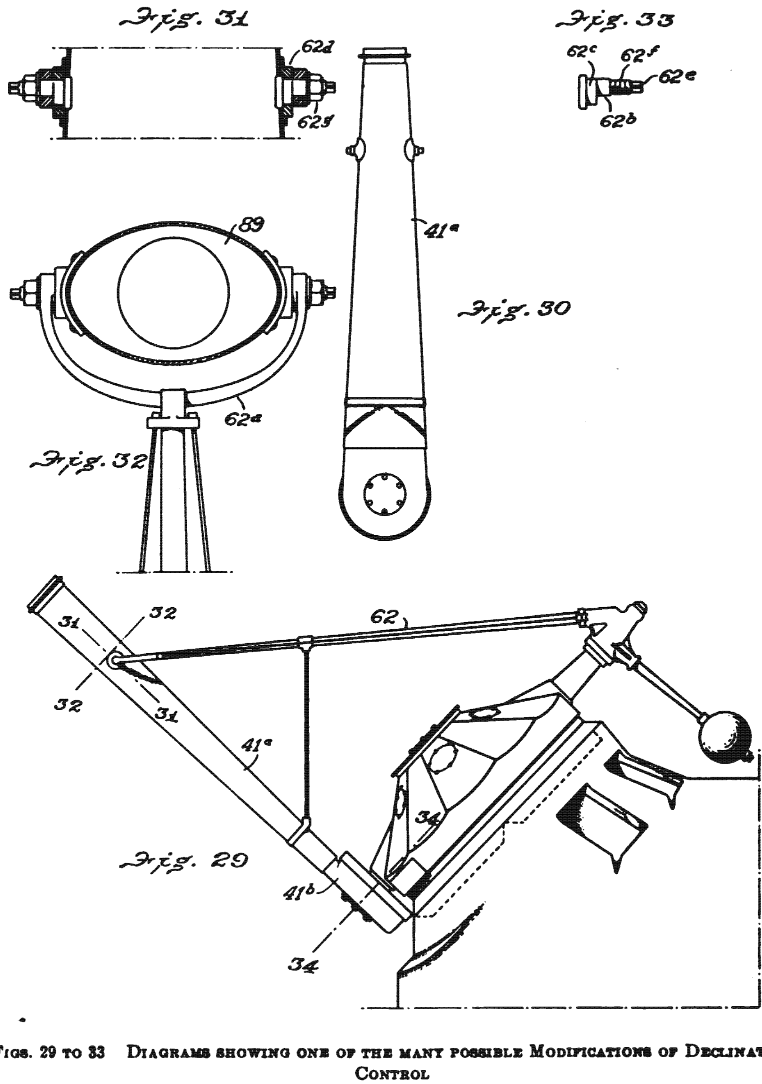


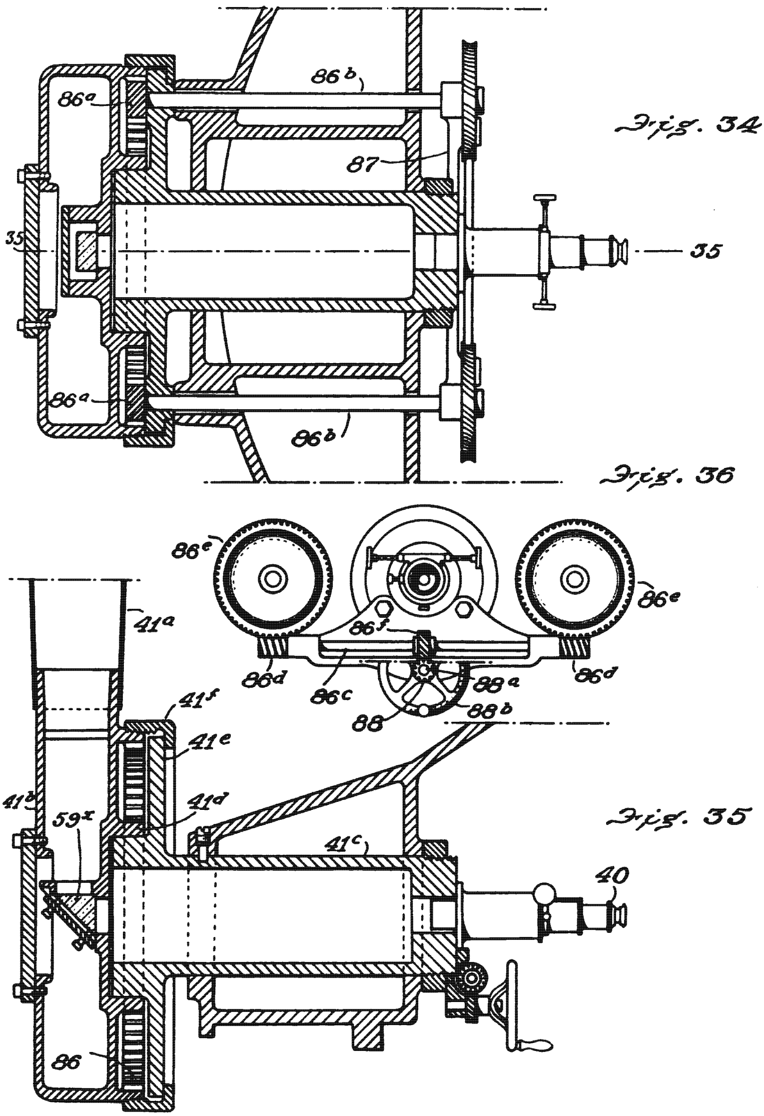
FIG. 28 A SCHEMATIC ARRANGEMENT OF THE ESSENTIAL ELEMENTS IN THE MOUNTING OF THIS TELESCOPE, NAMELY, THE FLAT CIRCULAR RING MOUNTED ON CONICAL AND CYLINDRICAL ROLLS, MEANS FOR ADJUSTING FORMATION RING AND FOR DRIVING ROLLS

Smaller turrets might be made without use of supporting rolls and by going back to the worm drive instead of the roller drive. A great variety of circular hollow bearings might be used for smaller turrets, but for one of the present size a single true plane and a single circular track with rolls seem to be the best.

FIGS. 23 TO 27 VARIOUS VIEWS OF VERNIERS FOR HOUR CIRCLE



Figs. 29 to 33 Diagrams showing one of the many possible Modifications of Declination Control



Figs. 34 to 36 Details of Scheme shown in Figs. 29 to 33