QUADRANT WITH SPHERICAL LEVEL FOR FIXING THE POSITION IN A BALLOON.

by

M. L. FAVÉ, INGÉNIEUR HYDROGRAPHE EN CHEF ((*French Navy*)

GENERAL.

The Quadrant with spherical level is specially intended for fixing the position in a balloon by the observation of heavenly bodies. The accuracy attained varies according to the circumstances. It is generally useless to try to attain great accuracy, owing to the rapid movement of dirigibles and often even of free balloons. In ordinary circumstances, the result is accurate enough if the position is fixed within 10 kilometres. Observations should be taken very rapidly because of the unknown distance which the balloon has travelled between the measurements of altitude, of which at least two are necessary to fix the position. Generally two measures must suffice, and the absence of verification makes it particularly important to avoid confusing the star observed with another star.

In this respect, the Quadrant with spherical level offers advantages over other quadrants, for it is fitted with neither tube nor telescope. The star is seen directly, and not by reflection to the horizon, as in ordinary sextants. The sight is taken without loss of time in finding the star, and with no possibility of confusion. . The instrument has no magnifying attachment but, given completely stable conditions, the sight with the naked eye permits an approximation of one minute and, moreover, when an instrument held in the hand is used, the addition of a magnifying lens, which makes the apparent displacement greater, does not notably improve the accuracy of the sight.

The instrument offers further advantages over most other quadrants; for example, it ensures the verticality of the limb. The most important characteristic is that the observer establishes the coincidence of the mark with the star without having to consider the position of the bubble with reference to the plane of the limb, whereas, in general, when the air bubble is used, it is necessary to establish the coincidence of the star with the centre of the bubble and, at the same time, to bring the bubble between marks on the level. (1)

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(1) In 1907 an apparatus similar to the present instrument was fitted to a compass, and described by the author, who evidently believed it to be a new principle, under the title of *Spherical level sight*. This principle had, however, been previously adapted to a sextant which was furnished with a tabular level and was described ten years earlier by Jaederin.

As a result, not only is the observation made easier, but it is possible to ascertain and study causes of error, which other instruments do not disclose.

When an observation is taken on land with the quadrant, the mark appears to oscillate in relation to the star, which seems to be in contradiction to the property described above. These oscillations are due to two causes. The bubble cannot instantly take up its position of equilibrium, and the small changes of tilt, which the instrument inevitably undergoes when it is held in the hand, result in oscillations of the mark, of small amplitude and of short period. Its mean position is determined easily enough.

A translatory movement of the instrument produces greater deflections, as may be found by bending the body backwards and forwards without altering the tilt of the instrument. These deflections may be even greater, and continue for a long time when the observer, in a car, is being carried forward by a balloon.

The line of sight on the star is related to the direction of gravity. The level resembles an inverted pendulum; the position of the bubble indicates the line of the vertical, as would a small pendulum bob, suspended from the instrument, the oscillations of which would be rapidly damped. When the point of suspension of a pendulum is moved along in a horizontal straight line, and at a constant speed, the rod of the pendulum remains vertical, but it is inclined if the speed or the direction is changed ; the line of *apparent* gravity is altered. This fact is shown when an observation is taken with the quadrant by a deflection between the mark and the star, the coincidence of which has been momentarily established. Every deviation from the vertical is immediately shown, and the angular value can be calculated approximately from it, by comparing the deflection with the distance from the vertical white lines. The difficulty is to know at what moment gravity has its true direction. The very few experiments as yet made in dirigibles show that the deviations may be considerable, and it is easy to perceive them.

Let us suppose that a dirigible is moving in a straight line with a speed of 17 m. per second, about 60 kms per hour, and that, during ten seconds, its speed increases regularly, so that, in this interval, its velocity is increased by 1/566, and therefore attains 17.5 m per second. During these ten seconds gravity will be deflected 10' and the curve of altitude, resulting from the observation of the star, situated ahead or astern, will be displaced about 20 kilometres.

If the dirigible describes, with a constant speed of 17 m. per second, a circle of radius 10 kilometres, which corresponds to a change of direction of 1° per 10 seconds, the error will be in the vicinity of 20 kilometres, for a star observed on the beam. Variations of speed, or of general direction, are certainly considerably less than those which might be produced when the rudders of the dirigible are moved.

Therefore instruments fitted with air bubble levels, in which the deflections under discussion are not in sufficient evidence, are liable to give absolutely erroneous indications. The use of the new quadrant does not do away with these errors for, as has been stated, the deflections sometimes remain

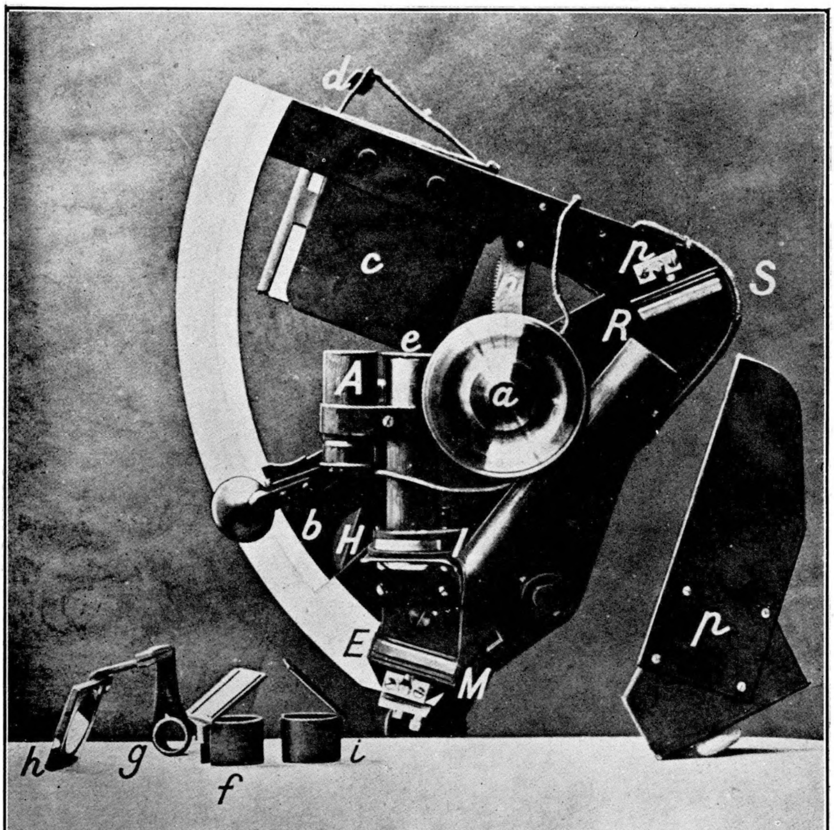

Figure 1

constant during a long enough time to give the observations all the appearances of accuracy, but the instrument is particularly suitable for studying methods of observations to adopt and the procedure to follow to reduce them to a minimum.

As yet little is known about the variations of the velocity of the wind at high altitudes; observations made with the quadrant in a free balloon will give data of great value on the question of dynamic meteorology.

SUMMARY DESCRIPTION.

The instrument is intended to measure the altitude of stars above the horizon.

It is held in the hand in the position shown in Fig. 1, and the star is observed directly through the glass plate *R S*, to which the eye is brought as close as possible (1). If the observer has not normal sight, he should be provided with glasses which allow him to see the stars clearly, as well as the image of the mark, which is formed at infinity. This plate, which is silvered over half of its width, partially reflects the luminous rays coming from the inclined tube situated below it, and proceeding from the level. Thus a luminous mark is seen projected on the sky, formed by two brilliant points situated on the same horizontal line (Fig. 2). The direction in which this mark is seen depends on the inclination of the plate *R. S.* This inclination is varied by turning the milled headed bolt *a*, the axis of which carries a pinion engaging with the toothed arc *n*.

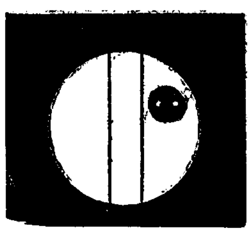

Fig. 2

This bolt is turned so that the star, or one of its limbs, if it has a perceptible diameter, is seen horizontally between the two luminous points. Then the altitude is read on the graduated arc by means of the vernier *b*, at the extremity of an alidade carried on the milled headed bolt *a*.

By night, a small electric lamp placed near the vernier and fed by a dry battery, is lit when a spring contact is pressed, permitting the angles to be read off.

The lighting of the level is obtained by means of a small electric lamp

(1) The box *p*, which is at the right of the instrument on this figure, is detached, in order to show the part which is usually covered.

in the tube *A*. It may be raised or lowered to adjust the light. It may easily be withdrawn and replaced in case of rupture of the filament.

A vertical luminous red circle, traversed by two vertical white lines, is then seen reflected in the index glass; on the red circle is seen a small black circle, on which the two bright points stand out. The black circle is the image of the air bubble of the spherical level, the horizontal face of which appears vertical by reflection.

This level (Fig. 3) is formed by a metallic cylinder, the base of which is closed by a plate of flat glass, and the top by a plate, flat on the upper, and concave on the lower side. The cylinder is partly filled with liquid, and the small air bubble takes up a position on the highest part of the *spherical hollow*, formed in the upper glass plate. This bubble changes its position according to the inclination of the level.

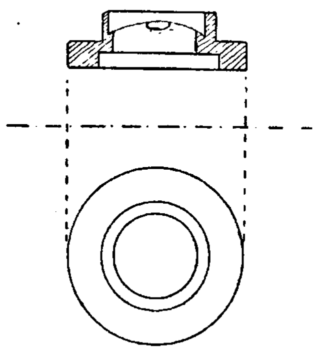

Fig. 3

By rocking the instrument, the black circle, which generally at first appears in contact with the limb of the illuminated circle, is seen to move over this circle.

For altitudes below 70°, it is, moreover, not necessary, while turning the milled headed bolt *a*, to place the centre of the mark exactly in the middle of the space between the two vertical white lines, nor to bring the star exactly on this point. It is sufficient for the star to be seen on the horizontal line joining the luminous points, which can be produced as desired.

The position of the bubble in the vertical direction is of no importance, and that is one of the characteristics of the instrument.

To observe the sun, a coloured glass *h* is inserted before the mirror *R S*, by placing the socket *g* over the extension of the axis of the instrument, situated below the plane of the limb.

The light from the electric lamp would not be sufficient. The reflector in the *upper* part of the tube *e* is withdrawn, and the socket *f* is fitted over this tube, so that the upper face of the translucent plate that it carries may be turned towards the sun. Under these conditions, a third luminous point is seen, between those which appear with the electric light.

In order to observe the moon or any other object, by day, the socket *i*, carrying a metallic reflector which can be pointed towards the most lighted portion of the horizon, is fitted over the tube *e*.

THEORY.

To follow the path of the rays, let us take for the plane of the figure (fig. 4) a plane parallel to the plane of the limb of the instrument, which when an observation is taken, is coincident with the vertical from the observed

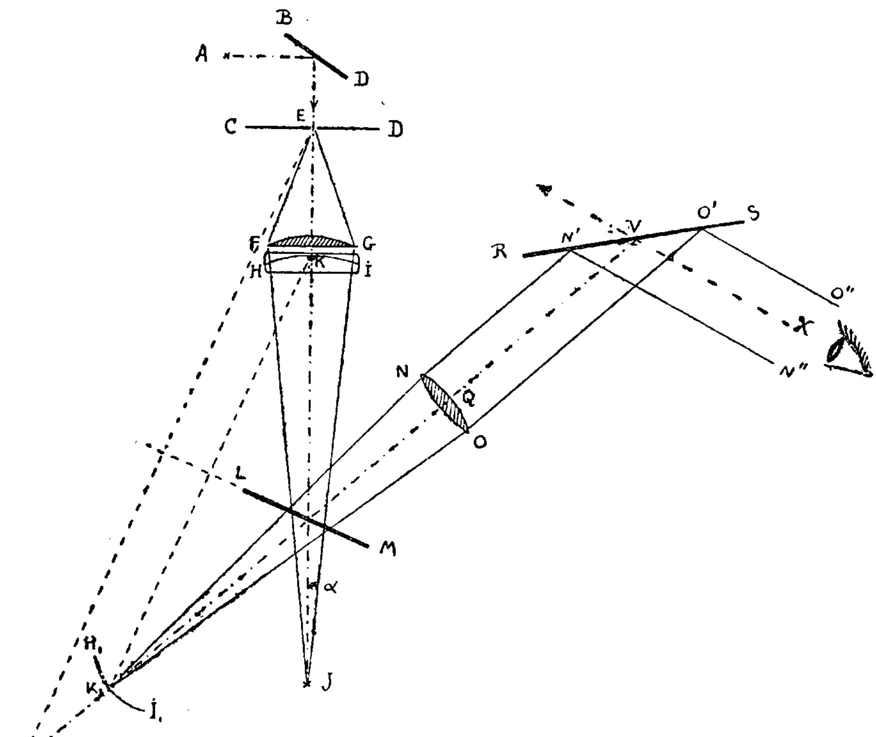

fig. 4

star. The reflector $B D$ throws back the light from top to bottom, onto a diaphragm $C D$, pierced with a very small hole E, which may be considered as a luminous source reduced to a point. The rays, emanating from E, pass through a lens $F G$, which makes them converge at a point J, distant about 10 c/m from the lens. This pencil of rays falls on the spherical level shown in Fig. 3 the internal surface of which is cut by the plane of the figure 4, in the direction of the arc $H I$, the centre of which is at J. As the lower part of the level is made of glass, and the liquid it contains is transparent, the rays, proceeding from E, pass through it. The bubble, which we will at first assume to be reduced to a point, takes up a position at the highest point of the spherical hollow of the level, i.e., on the vertical of the centre J of the sphere, of which it forms part. Let K be the position of the bubble. The rays emanating from K will fall on the mirror LM, the plane of which is perpendicular to the plane of the limb. To follow their path after reflection, let us substitute for the point K its virtual image K_1, which is symmetrically situated to K with reference to the plane $L\,M$. If, when the instrument is inclined to the vertical from the star, the bubble moves over the arc $H\,I$, its image describes the arc $H_1\,I_1$, which is symmetrically situated with regard to the plane of the mirror $L\,M$, At the centre Q of the arc $H_1\,I_1$ is found the optical centre of a converging lens $N\,O$, the focal distance of which is equal to the radius of curvature $J\,K$ of the level. The rays, emanating from any point K_1 of the arc $H_1\,I_1$, all become parallel after passing through this lens. They fall on the mirror $R\,S$ (the plane of which is also perpendicular to the plane of the limb), which turns, with the alidade, around the centre of the limb. The ray, passing through the optical centre Q of the lens $N\,O$, falls on the mirror at V, and is reflected in the direction VX. Since all the rays emanating from K_1 are parallel, if the eye is placed in the cylindrical pencil of rays, cut by the plane of the figure in the direction of the generatrices $N\,N'\ N''$, $O\,O'\ O''$, an image of the bubble will be seen at infinity in the direction $X\,V$. This direction is independent of the position of the eye in the pencil. The mirror $R\,S$, composed of a silvered glass plate, reflects only a portion of the light coming from the bubble; a star may be observed by setting the plane of the limb in the direction of that star and, by giving the mirror $R\,S$ the required inclination, the image of the bubble is superimposed on the star.

If the size of the bubble is reduced below certain limits it loses its mobility. The visible diameter is too large to estimate the position of its centre with great precision and, in consequence, is too large to bring this centre point exactly coincident with a star, or the limb of the sun or moon. Moreover, the outline of the bubble is seen only if it stands out against an illuminated background, the brilliance of which eclipses, by contrast, that of the stars, thus making the observation difficult or impossible when the stars are not very bright.

These disadvantages are overcome by means of a contrivance for reducing the luminosity of the field, whereby only two luminous points and two vertical white lines are seen (Fig. 2). The luminous points follow the movements of the bubble. When the centre of the line joining the two points is in the middle of the space between the vertical white lines, the plane of the limb is vertical. In order that the measure of the angle between the star and the horizon may be exact, this condition is necessary, and provides a check. The mirror is turned, keeping the bubble between the vertical white lines, so as to bring the mark onto the star, without troubling about the position the star occupies with regard to the vertical white lines. Coincidence, established for any position of the bubble, will continue, however the instrument be inclined in the plane of the limb, as long as the bubble does not touch the side of the level.

In fact, if the instrument is inclined to the vertical of the star at an angle α (fig. 4), the path of the reflected ray turns through an angle α, with regard to the trace of the mirror on the plane of the figure, but this trace having itself turned through an angle α, the line of the ray remains the same. Hence the line of direction $V\,X$ has not changed.

We have assumed that the bubble was reduced to a point; in reality, it has a diameter of 2 or 3 millimetres. The difficulty of estimating the position of the centre is avoided by substituting for this point, which would naturally be taken as the mark, the centre of the interval between two luminous points on the same horizontal, which appear on the image of the circle of the bubble (fig. 2). For this purpose the diaphragm is pierced, not only by the central hole *E*, but also by two holes 2.5 m/m apart, on a line perpendicular to the plane of the figure at *E* ; *the images of the two points appear on the same horizontal line at infinity.* The illumination of the field proceeds from the central hole only.

On the lower surface of the lens in contact with the upper surface of the level, lines are drawn parallel to the plane of the limb. (fig. 2). These lines, being unpolished, diffuse the light falling on them from the holes in the diaphragm, through the lens *F G*. They are very near the surface on which the virtual images of the holes, formed by the bubble, move, and are seen very clearly at infinity.

The illumination of the field is necessary, since it attracts attention and simplifies the placing of the eye into the correct position, and also, it ensures that the bubble does not touch the side of the level. Nevertheless, for night observations, the sight of an excessively bright field will diminish the sensibility of the eye for some moments. The light, passing through the central hole, is reduced by means of a translucent red shade ; *in this circumstance, the image of this hole is eclipsed in contrast with the two much more brilliant adjacent images.* For day observations, this shade and the electric light reflector are withdrawn and three luminious points are seen.

ADJUSTMENT OF THE INSTRUMENT.

The following conditions must be fulfilled in order that the angular measurements may be accurate :

a) When the central luminous point is in the centre of the interval of the two white vertical lines, the plane of the limb should be vertical.

b) The direction in which this point is seen by reflection in the mirror on the alidade should be parallel to the limb, whatever may be its position with regard to the vertical white lines, and whatever may be the inclination of the mirror.

c) This direction should be horizontal when the alidade is at zero.

d) The coincidence of the central point and a point at infinity being established for any one position in the centre of the interval of the two vertical white lines, it should be maintained when a change in the inclination of the instrument displaces the central point parallel to the vertical white line.

The various parts of the instrument are sufficiently protected, so that a knock or small accidental strain will not alter the adjustment. It can only be endangered by the action of weather, prolonged vibrations, or violent knocks on any part of the instrument.

Only the mirror *R S* can be easily displaced, and the observer should be able to rectify the adjustment of it.

This mirror should be perpendicular to the plane of the limb. The angle which it makes with this plane is corrected by turning the square headed screw of its mounting with a key.