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Description of a new altitude and azimuth repeating circle

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[...] By solidly mounting good levels on a telescope of considerable magnification and collimating it with a terrestrial object while the bubble indicates for example zero, I observed that if the telescope is lowered or raised and then returned to the point it was previously sighted at, the bubble does not always return to its original position. Likewise if the bubble is returned to zero, the telescope is no longer directed at the object it was previously sighted at. This defect is a consequence of the considerable time that is required for the bubble to return to its position; and the bubble is sometimes judged to be stationary when in reality it is moving slowly towards its proper equilibrium. This imperfection is therefore more serious the less time is given to the level to return to equilibrium. This is exactly what happens when using repeating circles. As these instruments are used to find the altitude of a star, the time available for observation is necessarily limited to just a few minutes, during which time it is necessary to proceed without delay from one observation to the next in order to benefit from the advantage of the repetitions of angles. It is therefore hardly surprising that apprehension about the lack of time available may cause the observer to incorrect judge the position of the level bubble or neglect some of the instrument handling precautions that may contribute to greater measurement precision.

[...] I thought that these difficulties could be solved by devising a new system whereby the repetition of the arcs is rendered independent of the observations of the stars and of their movement, making it possible to prolong the repetitions of altitude as desired without being constrained to a limited time.

[...] The figure drawn in perspective view shows the construction of the altitude and azimuth repeating circle, which serves for a dual astronomical and geodetic use. The internal azimuth circle carrying the verniers is firmly attached to a robust steel shaft *AB*, which is joined to a bronze pillar integral with the foot.

The external azimuth circle *D* on which the graduations are marked rotates around the conical portion *C* of this shaft. It may perform its rotary movement together with the vernier, otherwise a clamp *T* may be used to keep it stationary while the vernier moves.

With this distribution of parts, the supports of the horizontal shaft *F*, which rest on the internal circle, acquire greater solidity than they would have if the limb circle were fixed to the vertical axis and if the vernier circle, which is the one that bears the greatest weight, were to rotate around the limb circle by means of friction on the short cone, an arrangement I have seen adopted by certain instrument makers.

An analogous construction has been used for the vertical circles. The vernier circle *G* bearing the telescope remains screwed to the shaft *F*, which at its other end receives the counterweight on which the level *L* is mounted. So in addition to the movement in common with the shaft *F*, the limb circle *H* also rotates around the shaft itself. It can be fastened with the aid of the downward pivoting clamp *S* mounted on one arm of the internal azimuth circle. Lastly a spring *M* resting on the centre *A* supports much of the weight loaded on the horizontal shaft, prevents said shaft from bending, eliminates excessive friction on the shaft supports, and prevents the azimuth circle from bending.

This instrument allows a single person to make altitude observations without the need for assistance in situating the level and noting the hour. The repetition of the altitudes is performed as follows. The vernier is set to zero and by turning the circles together the bubble is positioned at the centre of the level; the external circle is then fixed and the telescope sighted on the object by turning only the internal circle; this way the simple arc is measured. The two circles are again rotated together until the level returns to the first position, which establishes a second starting point for performing the second altitude observation in the same manner. This way the angle is doubled and subsequently tripled, quadrupled, etc., following the arithmetic progression of the natural numbers.

If the observed object is moving, a device that can be used to perform the altitude observation just once and then repeat the angle for an arbitrary time consists of a compound microscope *Q* which is mounted by means of a foot on the azimuth vernier circle and is able to move in a plane parallel to the vertical circle independently of all the other movements of the machine. This microscope can be pointed at an extremely fine sign made on a crystal disc adhering to the tube of the telescope and illuminated with light passing through the other disc *N* opposite to it. Consequently, once the first observation of the altitude of the star has been made and the hour noted and the microscope has been collimated with the sign marked on the disc of the telescope, the presence of the star is no longer necessary in order to perform the angle repetition. Instead this is done using the microscope, which by remaining in its position takes the place of the star itself, and represents it constantly at the altitude at which it was positioned at the noted time of the first observation.

The objection could perhaps be made that sighting the object only once sacrifices the probable advantage of compensation of sighting errors. Indeed, if the telescope is sighted poorly from the start, the error will be carried completely through to the final result because with the new method of repeating it is renewed in the same direction with every observation. But I do not believe that for this reason the repetition performed with the microscope is secondary in importance to the use of the telescope. Indeed, no longer having the preoccupation of the limitation of time, one’s attention can be devoted entirely to the original observation and to choosing the moment at which the star is steadiest and most accurately aligned with the wires of the micrometer. Furthermore, after performing a series of altitude observations corresponding to a given time, it is possible to make others corresponding to different times and then combine them to produce a higher degree of precision. If, for example, the power of the telescope is such that an angle of three seconds can be measured, we can be certain that the error of the first observation will be no greater than this limit. This is sufficient to achieve an equal precision in reading the divisions given that the arc is repeated by means of the microscope as many times as is considered necessary.

I will not describe at length the means for correcting the instrument, as an inspection of the drawing alone will be sufficient for experts. A bracket-mounted level *V* serves to position the shaft *F* at right angle to the shaft *BA* and to position the latter vertically. The collimation line of the telescope relative to the plane of the circle *H* is corrected by the movement of the reticle *R*, and the error can be ascertained in two ways: either using the divisions of the azimuth circle by observing a very distant object with the telescope first in its normal position and then inverted; or raising shaft *F* from its supports with the parts that are affixed to it and inverting it as is done with transit instruments. However, this second method is more inconvenient because it is necessary to remove the counterweight given that it is unable to pass through the ring around which the compound microscope moves. The level *L* is provided with suitable movements such that the bubble indicates zero when the line of collimation of the telescope is parallel to the horizon. The corresponding error can be evaluated with a high degree of precision by taking a series of altitudes of an object with the limb in the east, and another series with the limb in the west, given that their sum should be 180 degrees in the event of perfect adjustment. Experience has taught me that after carrying out this verification once, the said instrument, which has both circles of diameter of eight inches, remains correct for a long period of time. As regards its use for measuring the angles subtended by two terrestrial objects, it is evident that it can be used as an ordinary theodolite, in which case the error introduced into the results by the eccentricity of the telescope must be corrected by calculation; or even better it can be used in such a way that the repetition of the angle is performed with the telescope on the right and then on the left in alternation, thus eliminating the error caused by the eccentricity of the telescope.

In the other Figure, *X* and *Y* represent the two terrestrial objects and *C* the centre of the circle. If we assume the telescope aimed at *X* is positioned at *B* and then moved by means of the sole movement of the azimuth vernier circle to *B′* where it collimates with *Y*, we will obtain the angle *BCB′* on the graduated limb. Now rotating the entire system around the vertical axis in such a way that the telescope, after being positioned at *D*, is able to point at *X*, and moving only the vernier circle in the same way as before, it will take it to *D′* in the direction *Y*; it is clear that an arc equal to the sum of the two angles *BCB′* and *DCD′* will be described on the limb, half of which is precisely equal to the angle at the centre *XCY*.

[...] I must also point out that the contrivance of the microscope for representing the invariable position of a star can also be used to great advantage for converting a meridian circle mounted stably between two marble pillars into a repeating circle. If this new idea is considered from the point of view of economics and precision and ease of construction, it appears to me that it is to be recommended in terms of each of these aspects. Using a circle of diameter of just eight inches divided into 10" intervals and a telescope of focal length of five feet, it is possible to achieve a greater precision than is achieved using circles that are incomparably larger, more expensive and more difficult to construct.

(English Translation by John Freeman)