

TESTING OF BUBBLE AND PENDULUM SEXTANTS

by
Dr. H. C. FREIESLEBEN, HAMBURG.

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(Translated from the German)

As Captain Johannes MÜLLER states in N° 12, 1937, of this Review, the Mercantile Marine will show but little interest in observations without horizon so long as no cheap and handy instrument is available for this purpose. The Navy is naturally more interested in being able to take astronomical fixes even in a mist or at night.

The fundamental difficulty for the representation of the horizon by a pendulum or a bubble for maritime or aerial navigation is that both devices indicate the horizontal plane by means of the earth's acceleration of gravity; if, in addition to gravity, other accelerations occur, then bubble and pendulum are subjected to these also, and therefore no longer indicate the true plumb line, but the direction of an apparent vertical, resulting from the combined action of the two accelerations.

The nature of the disturbing accelerations at sea and in the air is not the same. It may happen that instruments adequate for aerial navigation are inadequate for maritime navigation. The effect of a disturbing acceleration on the bubble or the pendulum is not necessarily done away with by the suppression of this acceleration. A pendulum once moved away from its position of rest accomplishes oscillations about this position of rest before it resumes its initial position. Such oscillations may also be imagined for the bubble. The position of rest is attained quickly by suitable damping, whereby too much is just as harmful as too little. As long as pendulums or bubbles are oscillating, they have also momentary positions without movement, namely, the point of reversal, whereas when passing the position of rest they are subjected to the maximum movement. This is particularly disadvantageous when making observations.

When the devices for the representation of the horizon are firmly fixed to the observing instrument, as is the case with almost all pendulum and bubble sextants, the observer himself causes disturbing accelerations in the appliance. Through training these disturbances may be considerably attenuated. With disturbances by the aircraft, this is possible only to a small extent, due to the fact that these disturbances can be perceived only partially.

Experiments were therefore undertaken :- first to determine with what accuracy observations may be carried out ashore with bubble or pendulum sextants, thereafter how observations at sea can be made and how their accuracy decreases with increasing ship movement. Two German bubble sextants of the usual commercial type were used — made by the firms of PLATH and LUDOLPH, the latter designed by COLDEWEY (Fig. 1), the former by the Portuguese Admiral

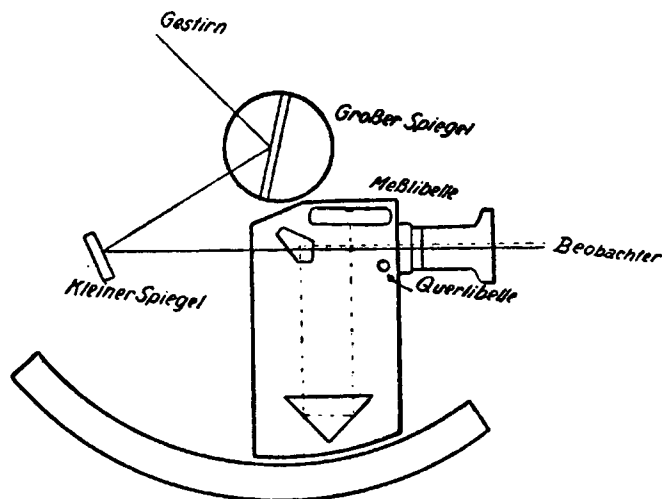


FIG. 1.
Ray Path in the Coldewey-Ludolph Sextant.

COUTINHO. In both the heavenly body is brought into coincidence with the bubble by displacing the alidade. The vertical position of the instrument, assured in horizon observations by bringing the heavenly body to the horizon while inclining the instrument to the right or left, is obtained by means of a transverse level which is visible when measuring the altitude.

In addition an English bubble sextant by HUGHES & Son was tested. This sextant resembles the models used in America (BOOTH). Instead of two crossed levels a spherical level is used here; the procedure consists in bringing the heavenly body into the image of the level, thus avoiding a tilt since the bubble is freely movable in all directions. Stars are sighted directly, the Sun and Moon through a mirror (Fig. 2). Besides, two pendulum instruments were tried out. In one of these sextants (Fig. 3) the pendulum carries a graduated arc, on which the position of the heavenly body, *i. e.* the altitude angle under which the heavenly body is sighted, is read off directly. In the other system the ray from the observed heavenly body is first cast as usual directly by the horizon mirror into the observation telescope, then on to a pendular mirror; from which, after reflection from the horizon mirror, it comes in the field of vision. The observation then consists in bringing both images into coincidence. In both pendulum

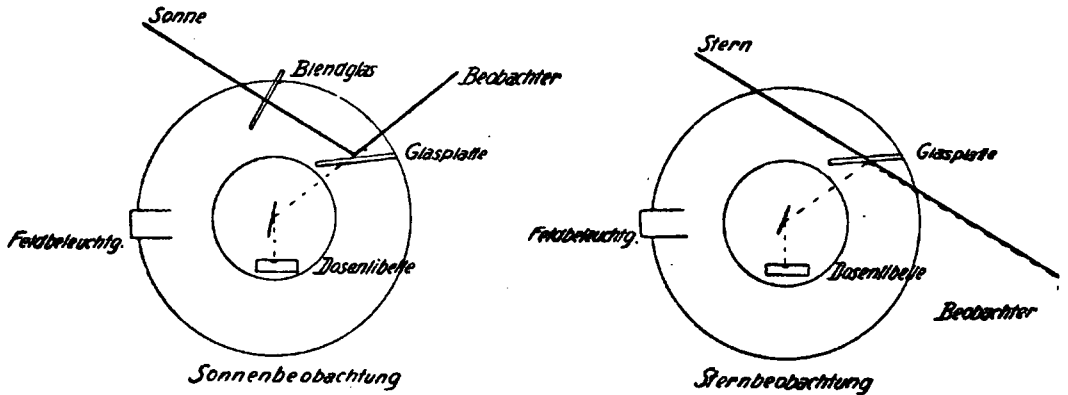


Abb. 2 Strahlengang beim Sextanten von Hughes

FIG. 2.
Ray Path in the Hughes Sextant.

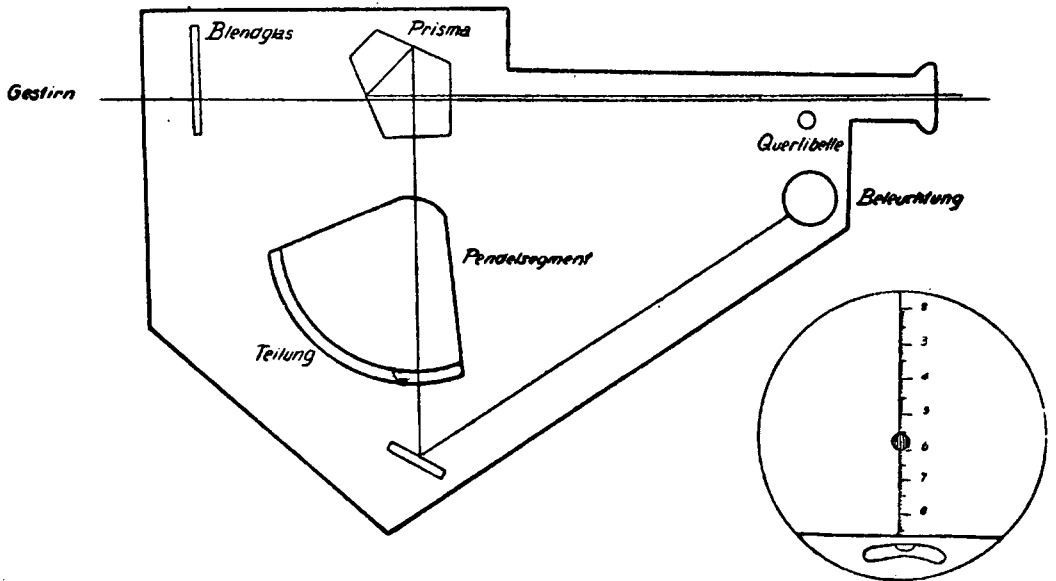


FIG. 3.
Ray Path and Field of Vision in the Schmidt-Haensch Sextant.

sextants (by SCHMIDT and HAENSCH, D.R.P., 459 865, hereafter indicated, in short, as by SCHMIDT; and by RINKEL), there is a transverse level in order to avoid inclination of the instrument to the right or the left. The observational method in both instruments (not graphically represented) by PLATH-COUTINHO and by RINKEL, corresponds technically to that of the LUDOLPH sextant. Here, as with LUDOLPH, the point is, during the observation to catch three things, viz.- the heavenly body, the measuring level and the transverse level. This is not a simple matter and requires much training. The measuring process with the HUGHES sextant is fundamentally more convenient, but departs so much from the method of observation above the horizon, that its practical use is fraught with difficulties. The measurement with the sextant shown in the figure is particularly natural, as the heavenly body is sighted directly, and therefore the value of the altitude can be readily read off in the field of vision. From a technical point of view, as concerns observation, this solution is the most desirable.

Experience shows that isolated measurements are not very accurate and it is necessary, by means of a series of measurements, to enhance the accuracy. It is known that from manifold measurements a measure of the internal accuracy can be deduced:- in the present case, when the actual altitude variation is taken into account. It soon appears, however, that the internal coincidence is not a sufficient criterion of the reliability of the observations with pendulum or bubble sextants.

The complete reproduction of the results of the numerous measurements takes us too far afield, and will presently be given elsewhere. For the moment a brief statement as to the mean errors of observation in their relation to seaway is given, together with a series of conclusions derived from observations.

MEAN ERROR OF AN OBSERVATION WITH

	LUDOLPH	RINKEL	COUTINHO	SCHMIDT	HUGHES
Ashore.....	± 3'.8	± 2'.8	± 4'.9	± 4'.8	—
Steady ship.....	8.5	9.3	9.9	6.6	± 5'.9
Light rolling and pitching (1 — 2°).....	12.3	14.2	13.6	12.6	12.1
Heavy rolling and pitching (3 — 6°).....	14.7	(19.6)	13.9	17.3	21.2
Heavy rolling.....	21.6	(23.4)	22.8	(24.1)	44.1
Approximate number of observations.....	1300	900	1200	900	600

These various observations are distributed in series of 5 to 10 measurements; their errors have been almost exclusively obtained against true computed altitudes. The bracketed values indicate that under existing conditions an observation showed a manifestly impossible value.

The numerical values here reproduced have been determined from observations on the three ships. This is somewhat crude in so far as the disturbing accelerations which were noted were estimated from the heeling. A heeling of 6° however on the high deck of a tanker means an appreciably greater acceleration than on the comparatively low bridge of a small North Sea steamer. On the other hand the short North Sea waves may result in quick jerky movements which develop greater accelerations than the quieter movements of a ship in the swell of the Atlantic. As a matter of fact the decrease in the accuracy of the observations on a tanker with increased ship's movements is shown more clearly on the *Meteor* and on the tunbuoy layer. It is, however, sufficient to note here these details, which, although enriching the general scope of the table, have but little significance for the practical criterion. This general summary shows that, in the case of all instruments, even shore stations remain inferior to the ordinary horizon observations at sea, and that on the moving ship accuracy diminishes rapidly when larger ship movements occur. At the same time the pendulum sextants, and later on the HUGHES sextant, showed a quicker decrease than the two other bubble sextants. Of these again, the LUDOLPH yields the better results. Occasionally special advantages are displayed by the HUGHES sextant.

As previously stated, the great uncertainty in an isolated measurement gives rise to the assumption that serial observations yield better results. This is true only in limited cases, for a study of the different series often shows that in their average they also are not free from error, but depart considerably from the true altitude. With the great uncertainty of an observation it is natural to expect an error also in the mean of several observations which results, according to the laws of probability and error, from the mean error of an observation and from the number of observations in the series. If the mean value lies inside the error limits thus deter-

mined, there is no more to be said, but if it lies considerably outside those limits, then this must have a reason. In the present serial measurements, the mean values are often in the average too large. We must therefore confirm the fact that with observations with pendulum and bubble sextants there is a danger of systematic errors. Where do they come from?

They cannot be attributed to the index error, since observations obtained in quick succession with the same instrument often show quite different mean values, whether different heavenly bodies were measured, or several observers observed the same heavenly body, or the same observer after a short pause repeated a series of observations. It must therefore be the nature of the disturbing accelerations which causes the systematic error. For instance, with very uniform ship movements, series are obtained which, although they agree very well, are nevertheless quite wrong in their mean, when the observer favoured temporary positions of rest of the apparent vertical. By taking this state of things into consideration, it is also naturally possible to make such observations in the position of reversal of the bubble or pendular movement. They yield exactly the same results as series observed without taking this into consideration. But the lumping of all sorts of observations over all phases of the ship's movement does not preclude systematic errors, for the assumption necessary thereto that on the average all the apparent verticals yield the true vertical, is realized only in isolated cases. Let us assume, for example, a rolling movement by which the ship slowly lurches with an oncoming wave, and then quickly falls back. With this and similar irregular movements in particular, one should not expect that the observations at both opposite reversal positions yield zero on the average. This is proved by various series of observations. The accelerations to port and to starboard are unequally large with ship movements of this kind; the corresponding angle of the apparent vertical against the true vertical is also different.

If a heavenly body is situated in the direction of the principal movement of the ship, not only the inaccuracy of the isolated measurement is enhanced but, above all, also the danger of measuring systematically wrong. Perpendicularly to the ship's movement the heavenly body is more dependably observed, for instance with a rolling movement right ahead and right astern, with a pitching movement on the beam.

The instruments having a large field and which thus allow the whole movement of the pendulum and of the bubble to be followed (sextant SCHMIDT and that of HUGHES), lead less to systematic error, presumably because the observer has a general over-sight of the disturbances. With a large movement, the accuracy seems as a whole, however, to be more favourable with a small field. Observations made on call of the recorder (*i. e.* every 10 or 20 seconds) are not appropriate in a heavy seaway, because occasionally one single dropped value may falsify the whole series. With unimportant movements they offer perhaps a means of doing away with the undesired arbitrary choice of the observations and the systematic erroneous measurements obtained therewith. However, as stated they are practical only on a very steady ship.

