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instrument. The bubble chamber is placed in the focal plane so that the image of the bubble appears in the same field as the image of the celestial body. In the measurement of an altitude, the index prism is moved until the image of the body is adjacent to that of the bubble. The altitude is then read from the sextant scale.

Mark 5 bubble sextant

2103. The instrument shown in figure 2103 is a device capable of measuring the altitude of a celestial body by reference to either a self-contained artificial horizon or the natural horizon.

The optical system consists essentially of a prismatic telescope system with two movable prisms ahead of the objective lens: an **index prism** whose angular movement can be measured, and a **horizon prism** which can be inserted or removed at will from the optical path of the instrument. The index prism reflects light rays from the object observed into the telescope system. If the sextant is set at zero reading, the sextant functions as a telescope having a magnification of two diameters and a visual field of 12°. If the horizon prism is in the optical path, the image from the index prism at zero setting should coincide with that from the horizon prism as seen through the eyepiece. If the line of sight is held on the natural horizon, using the horizon prism, objects elevated above the horizon can be brought into view by rotating the index prism. If the image of a body is brought into coincidence with the image of the horizon, the reading of the scales is the altitude of the body above the natural (visible) horizon.

Shade glasses.—The sextant is provided with light filters of various densities and colors to reduce the glare of the sun. These are mounted on the shade glass assembly (see fig. 2103), which can be rotated until the filter giving the greatest visual comfort is in the optical path. A **polarizing filter** can be inserted in the eyepiece tube to reduce glare from clouds or from water when using the natural horizon.

Astigmatizer.—The image of a bright star normally appears as a point of light when viewed through the eyepiece. When the astigmatizer is inserted in the optical path, the point of light is drawn out to a line.

2104. Artificial horizon.—The bubble cell (fig. 2102b) is permanently located in the optical path at the principal focus of the objective lens. The top of the bubble cell is the field lens of the eyepiece system, while the bottom is a flat plate of glass. The earth's gravitational field forces the bubble to the highest point in the cell. When the bubble is seen to be in the center of the field, the instrument is horizontal; that is, light passing through the horizon prism, or the index prism at zero setting, is horizontal. The bubble, therefore, is an **artificial horizon.** If the index prism is rotated until the image of a celestial body is seen adjacent to the bubble at the center of the field, the reading of the altitude scales is the altitude of the body.

It is not necessary that the two images be held exactly in the center of the field, since the bottom of the field lens in the bubble chamber has a curvature such that the bubble will move the same distance as the image of the body, if the sextant is tipped slightly. However, coincidence should take place near the vertical center line of the field. Coincidence obtained near the top or bottom of the center line is accurate, but when obtained near the right or left edge may be in error by as much as several minutes.

Forming the bubble.—If no bubble is seen through the eyepiece, the ***bubble chamber adjustment screw*** (fig. 2103) is turned in a clockwise direction. This retracts a flexible diaphragm in the bubble chamber, *reducing* the pressure on the liquid (xylene) which

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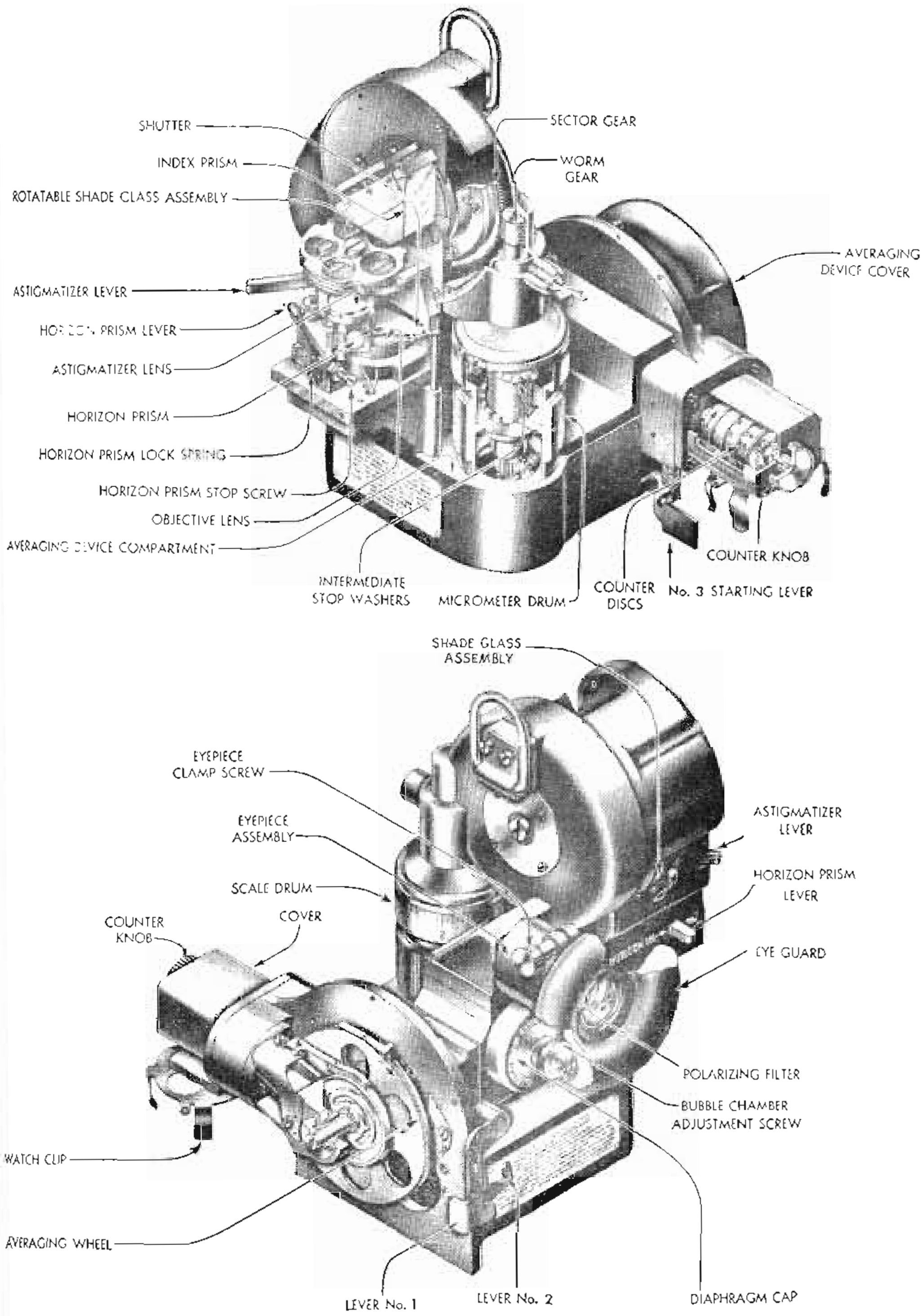

FIGURE 2103.—Mark 5 bubble sextant.

completely fills the bubble chamber and cell. When the vapor tension of the liquid is greater than the pressure, a bubble of vapor forms. This is usually accompanied by a pronounced *click*. If the screw is turned counterclockwise after a bubble has formed, the *increased* vapor pressure causes the molecules of vapor in the bubble to re-enter the liquid, thus decreasing the size of the bubble. If difficulty is experienced in forming the bubble, the sextant should be tipped until the adjusting screw points downward about 45°. In this position, reducing and increasing the pressure on the bubble chamber several times will usually cause a bubble to form. To remove the bubble, turn the adjusting screw counterclockwise, putting increased pressure on the liquid. Gently shaking the instrument accelerates the absorption of the vapor bubble. The bubble should always be removed after all observations are completed and the sextant is to be stowed.

After the bubble has been formed, its size can be regulated by turning the adjusting screw. The correct size is largely a matter of personal preference. In general, however, the bubble should be from one-sixth to one-quarter the diameter of the field. This is three to four times the size of the sun as seen through the eyepiece. It should be small enough so that when the astigmatizer is used, the line will extend beyond the bubble. A bubble which is too small is sluggish and recovers slowly if displaced by acceleration. One that is too large is subject to excessive motion during observation and is difficult to align with the image of a body. A smaller bubble can be used with a star than with the sun or moon.

The bubble appears to move *across* the circular field as the sextant is tipped left or right out of the vertical position, and *up or down* as the sextant is tilted backward or forward from the vertical.

If altitude is to be measured accurately, the index prism must be adjusted to align the image of the star horizontally with the center of the bubble. The alignment should take place near the vertical center line, as stated above. Some navigators prefer to use the astigmatizer for observations of the sun, planets, and brighter stars, bisecting the bubble horizontally by the astigmatized line. This feature should be used with caution in moon sights unless the moon is full.

When the astigmatizer is not used, the image of the body should be centered with the bubble, as shown in figure 2104a. When the moon is observed in the crescent or gibbous phase, allowance should be made for the dark portion, avoiding the tendency to center only the illuminated part. If this precaution is not followed, a considerable error may be introduced in the measured altitude, as indicated in figure 2104b. An observer who finds it difficult to estimate accurately the center of the moon may obtain better results by keeping the upper or lower limb at the center of the bubble during observation, and applying a correction for semidiameter, as with observations using the visible horizon.

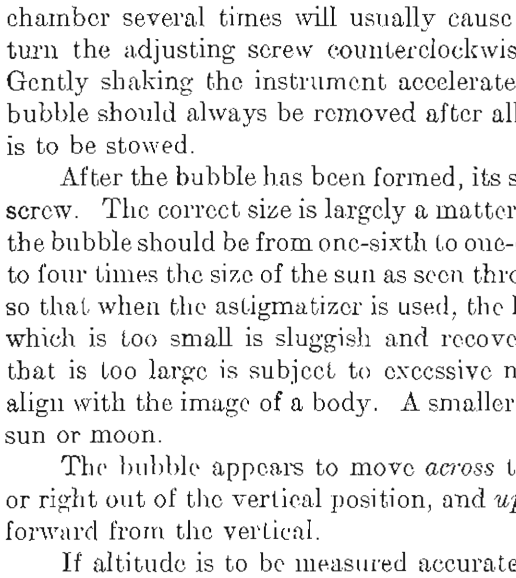

FIGURE 2104a.—The images of the bubble and body are centered in the field.

2105. Altitude scales.—The altitude of a body is read from two scales, the **main scale** and the **micrometer scale.** The main scale is graduated for each 5° from (−)10°

to 100°, although the maximum reading that can be made is a little more than 95°. The micrometer scale is graduated for each 2′ and can be read to 1′ by visual interpolation. One complete turn of the **micrometer drum** (fig. 2103) is equivalent to 5°. The scale on the micrometer drum serves as a vernier to the main scale. Thus, if the micrometer scale reads 4°28′ and the next lower mark on the main scale is 30°, the angle measured is 34°28′. If the next lower mark is 35°, the angle is 39°28′.

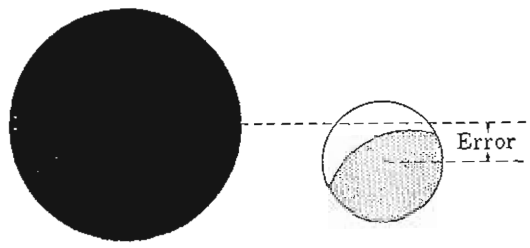

FIGURE 2104b.—A considerable error may be introduced if only the illuminated portion of the moon is centered.

The rotation of the micrometer drum, and hence the index prism, is limited to a little more than 21 turns, by intermediate stop washers (fig. 2103) which engage with each other in succession.

2106. Averaging device.—Celestial observations taken in flight are subject to random errors due to inaccurate setting of the instrument and unsteadiness of the bubble resulting from acceleration of the aircraft about or along any of its axes. The latter, called **acceleration error,** is caused by (1) changes in ground speed, (2) changes in direction of motion, (3) the normal oscillation of the aircraft in pitch, roll, and yaw, and (4) the superimposed erratic motion due to atmospheric turbulence. Because of these errors single sights may be unreliable, and it is usually desirable that a considerable number of observations be averaged. The Mark 5 bubble sextant can be used either for single observations or for averaging 60 separate observations taken during a 2-minute period. The normal oscillations of an aircraft about each axis referred to in (3) above, are the long-period oscillations resulting from the response of the aircraft to its individual static-stability characteristics. They are essentially sinusoidal in character but are difficult to detect or measure without elaborate equipment. The amplitude of the oscillation in pitch, sometimes referred to as **phugoid oscillation,** may be as much as 15′ to 20′. It involves a variation in speed and altitude with little or no change in horizontal acceleration. The amplitude of the oscillation in roll is believed to be approximately the same as in pitch, but somewhat less in yaw.

The oscillation period for large aircraft is approximately 40^s or 50^s. If it is 40^s, the fixed, 2-minute averaging period of the Mark 5 sextant coincides with three oscillations and the effect is averaged out. If the fixed observing period includes more than an integral number of oscillations, an error is introduced which depends upon (1) the amount of the excess, and (2) the phase at the start of the observation.

The observing period of the periscopic sextant (art. 2109) is variable up to two minutes so that it can be made to coincide with the phugoid oscillations of the aircraft, if known.

The **averaging device** averages successive positions of the index prism within a range of 14° above a selected base value. The base value is established *below* the altitude to be observed, at a multiple of 10°. If a body is to be observed at an altitude of approximately 36°, the base is set at 30° so that the operating range falls within the 14° averaging range. If the body is at an altitude of approximately 41°, the base is still 30°, since individual observations may differ from the average by more than 1°. Beyond 42° the base would be set at 40°. Thus, an operating range of 2° is available on each side of the altitude being observed.

Operation of averaging device.—Referring to figure 2103, lever 1 is connected to a clutch by which the averaging mechanism can be disconnected from the micrometer (scale) drum. When lever 1 is pressed to the right against a spring, the clutch is disengaged and the micrometer (scale) drum (and consequently the index prism) can be moved through its full range independently of the averaging mechanism. Lever 1 is retained in position by lever 2. When lever 2 is pressed, releasing lever 1, a spring forces the two halves of the clutch together, and as the micrometer drum is turned, a spline on the movable half of the clutch drops into a notch on the other half. The micrometer drum is now connected to the averaging device.

The averaging device is driven by clockwork mechanism in the base of the sextant. The mainspring of this mechanism is wound by a winding key on the bottom of the sextant. The clockwork is started by pressing a **starting lever** (3) and operates for 2 minutes. The spring must be rewound before each sight if the averaging device is to be used. The starting lever (3) is locked until the spring is fully wound. Completion of the winding operation also withdraws a shutter from the optical path. The shutter is returned after 2 minutes operation of the timing mechanism, indicating the end of the observation period. The clockwork mechanism must be completely wound even if the sextant is to be used for single sights; otherwise the shutter obstructs the optical path.

During the averaging period, the image of the body observed is held as closely as possible in coincidence with the horizon (natural or bubble) by moving the micrometer drum. Every 2 seconds (or 60 times during the 2-minute period) $\frac{1}{60}$ of the difference between the base value and the instantaneous setting of the micrometer scale is added to the **counter dials** (fig. 2103). The average altitude during the 2-minute period is the sum of the base value (multiple of 10°) and the counter reading. For example, if the base value is established at 20° and the micrometer drum reading is 5°, the reading of the sextant average is $20°+5°=25°$. The counter dials should be reset to zero before each observation.

When the base value is more than 10° below the average reading, care should be used in interpreting the dial reading, since dials do not read to greater than 9°59′. Thus, if the approximate altitude is 51°, the base value is normally established at 40°. If the counter dial reads 1°17′ at the end of the cycle, the average altitude is $40°+11°17'=51°17'$. The average reading should normally be within 2° of the final reading of the main scale. In this example the main scale reads just over 50° at the end of the observing period.

2107. Making an observation.—The following steps are involved in making an observation with a Mark 5 bubble sextant, using the bubble feature:

(1) Wind the clockwork by turning the winding key counterclockwise as far as it will go.

(2) Form the bubble and adjust its size.

(3) Press lever 2, connecting the averaging device.

(4) Rotate the micrometer drum clockwise (decreasing readings) until it stops. This positions the clutch so that the base value will be established at the next lower multiple of 10°.

(5) Without moving the micrometer drum, press lever 1, disconnecting the averaging device.

(6) Set the counter dial to zero.

(7) Set the sextant to the approximate altitude to be measured. This value may be determined by preliminary observation, by computation, or by means of a star finder.

If the sun is to be observed, introduce suitable shade glasses. Focus the eyepiece if necessary.

(8) Check the horizon prism lever and the astigmatizer lever to see that they are in the desired positions.

(9) If a 2-minute average is to be taken, establish the base value by pressing lever 2, connecting the averaging device, and rotate the micrometer drum clockwise to the stop. This should occur at the next lower multiple of 10° on the main scale. Be sure that this rotation is at least 2° on the micrometer scale; otherwise the lower limit of the averaging range may be encountered during the observation, rendering it useless. This is particularly important if the altitude is decreasing. If there is less than 2° between the preliminary sight and the base value, the base value should be re-established at the next smaller multiple of 10°.

(10) Bring the image of the celestial body in alignment with the bubble, near the center of the field and press lever 3, noting the time or having an assistant do so. Maintain coincidence until the shutter obstructs the optical path after 2 minutes.

(11) Read the average altitude as the sum of the main scale and counter dial. Use the middle time of the observation, 1 minute later than the time of starting.

If a single observation is to be made, the following steps are involved:

(1) Wind the clockwork by turning the winding key counterclockwise as far as it will go.

(2) Form the bubble and adjust its size.

(3) Press lever 1, disengaging the averaging device.

(4) If the sun is to be observed, introduce suitable shade glasses. Focus the eyepiece if necessary.

(5) Bring the image of the celestial body into alignment with the bubble, near the center of the field.

(6) Note the time and read the altitude as the sum of the main scale and the micrometer scale readings.

With practice, the entire preparation for making an observation can be performed in a few seconds. When taking sights at 4-minute intervals (art. 2007, example 3), an experienced navigator finds no difficulty in reading the sextant and preparing it for the next observation in the 2 minutes between the ending of one observation and the beginning of the next, even though a new base value must be set. It is wise to acquire enough familiarity with the sextant so that the various controls can be manipulated in total darkness.

The clockwork mechanism should always be permitted to run down after all observations are completed and the sextant is to be stowed.

2108. Additional features.—To permit observation at night, the bubble is illuminated by a ring of luminous paint, and small electric lights are provided to illuminate the various dials.

A spring clip to hold a stop watch is attached under the counter dials. If desired, the watch can be started at some convenient time and then placed in the clip with its stem adjacent to starting lever 3. When lever 3 is pressed to start the 2-minute observation period, it also *stops* the watch, and the middle time of sight is the instant the watch was started plus the elapsed time as shown by the watch, plus 1 minute.

To support the weight of the sextant during observations, a link is attached which can be engaged with a hook on a support arm installed in the astrodome. This reduces operator fatigue; tends to steady the instrument during observation; and keeps the

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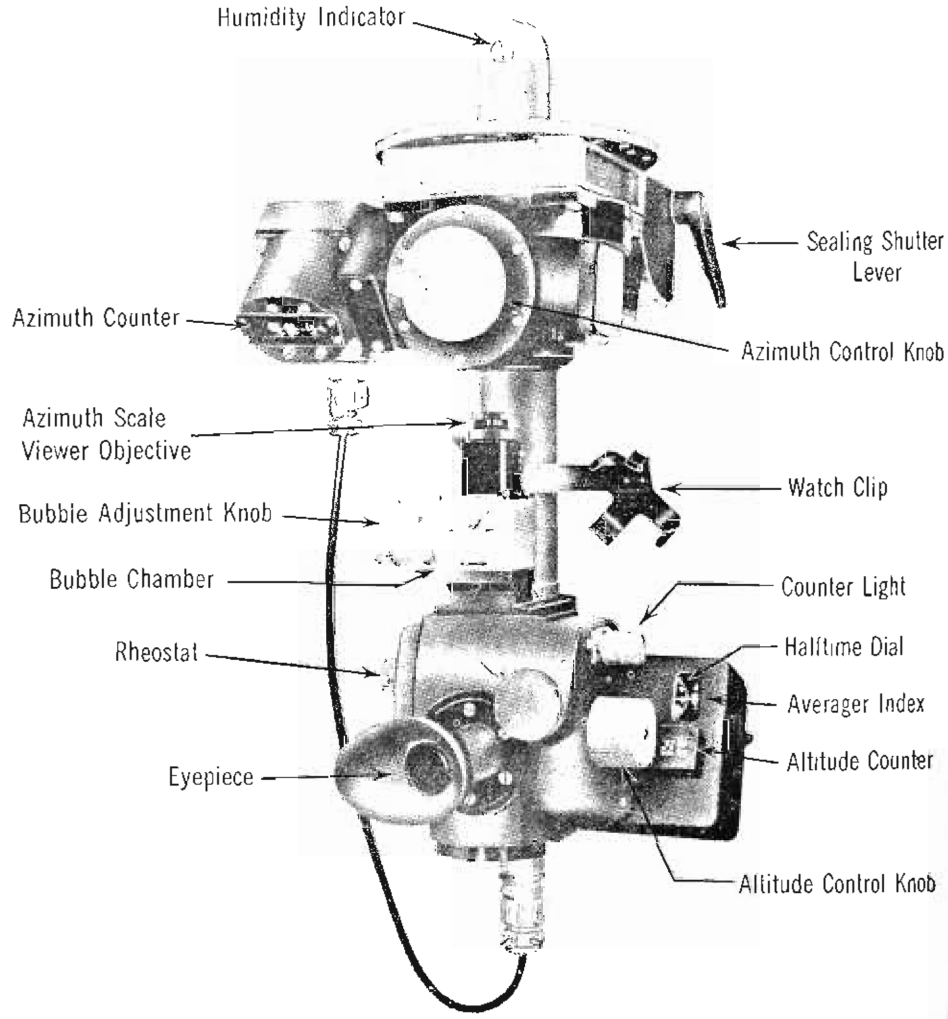
sextant centered in the astrodome, thus reducing error due to irregular astrodome refraction.

Periscopic sextant

2109. Introduction.—The astrodome through which celestial observations are made is undesirable for several reasons. By protruding above the skin of the aircraft, it creates drag which is increasingly objectionable as speeds become greater. Moreover, when it is used in a pressurized cabin at high altitudes, the pressure differential between the inside and outside air creates strain, sometimes causing rupture of the dome. Also, light is refracted in passing through the dome, necessitating an additional correction which cannot always be accurately determined. These disadvantages are avoided by using a periscopic sextant.

2110. Sextant mount.—To accommodate the periscopic sextant, a mount (fig. 2110) is affixed to the overhead of the aircraft. When the sextant is not in use, the



Courtesy of Kollsman Instrument Corp.

FIGURE 2110.—A periscopic sextant and mount.