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GYROCOMPASS, AUXILIARY GYROCOMPASS, AND DEAD RECKONING ANALYZING INDICATOR AND TRACER SYSTEMS

A. THEORY OF THE GYROCOMPASS

17A1. Construction of a gyroscope. A free gyroscope is a wheel, constructed similarly to a flywheel and suspended with 3 degrees of freedom. (See Figure 17-1.) The gyroscope may spin around the spinning axis, and turn around the horizontal axis and the vertical axis. The center of mass of the wheel is at the intersection of the 3 axes. The gyro wheel should be constructed so as to have as much material near the rim as practicable and to run at high speeds. Naturally it must also be well-balanced and be as frictionless as possible.

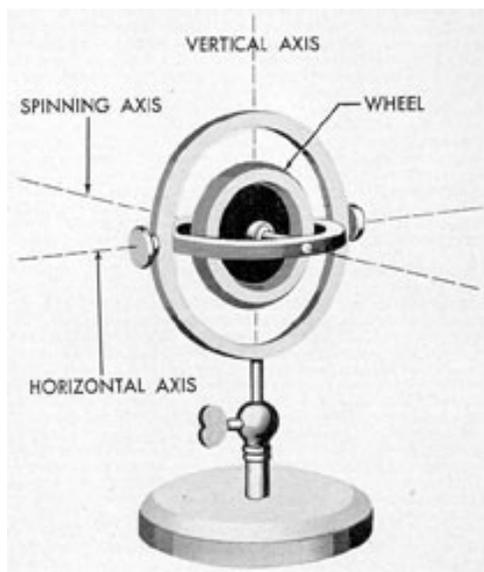


Figure 17-1. A free gyro.

17A2. Properties of a gyroscope. Gyroscopic phenomena are exhibited in all rotating bodies. Common examples are a spinning top, a car going around a curve, and a moving bicycle.

All known gyroscopic phenomena are dependent upon two properties of the gyroscope: 1) *rigidity in space* and 2) *precession*.

Rigidity in space is manifest in the gyroscope's tendency to remain pointing in the same direction at all times or to maintain its plane of spin parallel to itself. This is based on Newton's First Law of Motion which states: *Every body continues in its state of rest or of uniform motion in a straight line, unless it is compelled by external forces to change that state.*

17A3. Apparent rotation. If a gyroscope having complete freedom is spun continuously and is set at the earth's equator with its spinning axis horizontal in the east and west direction (see Figure 17-2), the wheel while spinning also apparently rotates about a horizontal axis that forms a right angle with the spinning axis. This apparent rotation proceeds at the rate of a single revolution in a day. Actually, however, the gyro spinning axis remains parallel to its original position in space, though the gyro is carried along with

the earth by the revolution of the latter about its polar axis. Thus, as shown in Figure 17-2, at the end of 3 hours the west end of the axle, viewed looking north, is depressed 45 degrees, and at the end of 6 hours it is vertical to the surface of the earth, having been carried through 1/4 of a revolution in 1/4 of a day. At the end of 12 hours, the axle is again horizontal, but its ends are reversed as viewed by an observer looking north. Actually the gyro axle still is parallel to its original position in

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space and is pointing in its original direction in space. The apparent motion continues, and at the end of a complete revolution of the earth in 24 hours, the original position of the gyro axle is regained.

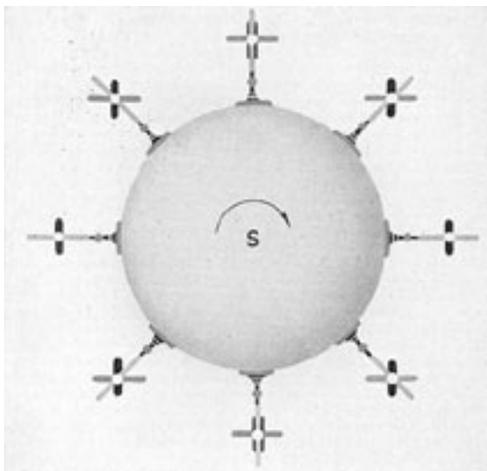


Figure 17-2. Gyro spinning at equator with its axis horizontal.

If a gyro with complete freedom is spun with the gyro axle horizontal at either the North or South Pole of the earth the axle will be at a right angle to the polar axis of the earth. But since a spinning gyro maintains the direction of its plane of rotation in space and the direction of its axis in space, it has an apparent motion about its vertical axis (Figure 17-3).

It should be noted that at the poles the apparent rotation is entirely about a vertical axis, but at the equator the apparent rotation

movement of the gyro axle corresponds with a daily period (Figure 17-5) and is partly about the vertical line passing through the center of the earth, and partly about the horizontal axis of the gyro.

17A4. Resting position. If the gyro is set spinning at the equator, with the gyro axle in the meridian and horizontal, the gyro axle will remain horizontal and in the meridian. Thus, the axle would continue to point north. This is equivalent to pointing north and parallel to the earth's polar axis, as illustrated in Figure 17-6, and there would be no apparent rotation. The gyro axle remains parallel to the earth's axis, though carried around it by the earth's rotation. Furthermore, the gyro axle remains stationary relative to the surroundings on the earth, although still rigid in direction relative to space. A condition in which those conditions prevail is termed a *resting position*, and it is the only resting position at the equator. The numbers in Figure 17-6 indicate the hours.

At high latitudes, the only true resting position for a gyro with complete freedom is that in which the gyro is set spinning with its axis parallel to the earth's polar axis. For latitude 50 North, the gyro, spinning in its true resting position, would be tilted so that the gyro axle would make an angle with the horizontal equal to the angle of latitude as shown in Figure 17-7, with the gyro axle in the meridian and the north end of the gyro axle pointing upward.

is entirely about a horizontal axis.

If a gyro with complete freedom is spun at an intermediate latitude, with the gyro axle horizontal and in the meridian, the gyro axle will neither be parallel to nor at a right angle to the earth's axis, but will be at an angle to it equal to the latitude, as shown in Figure 17-4.

Rigidity of direction in space, or *gyroscopic inertia*, will therefore cause the gyro axle to rotate apparently about a line (A-B, Figure 17-4) passing through the center of the gyro parallel to the polar axis of the earth. This apparent

However, there are reasons for this tilt being impracticable with respect to gyrocompasses. A gyrocompass must have the gyro axle nearly horizontal. Means must therefore be applied to secure a resting position in the meridian and in the horizontal. Accordingly the axle of the gyrocompass is parallel to the polar axis of the earth only when the compass is operating at the equator.

17A5. Effect of applied force of translation.

A completely free gyroscope may be moved anywhere or carried around by the earth's rotation without altering the direction of its axle relative to space. It is therefore unaffected by forces of translation.

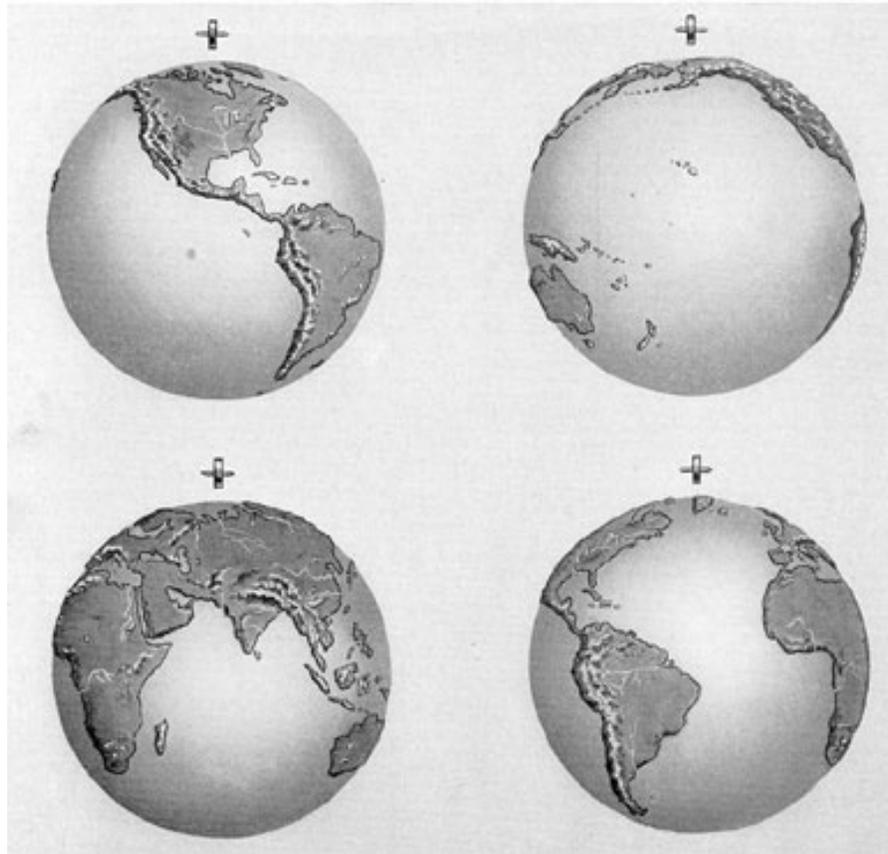


Figure 17-3. Gyro spinning of pole with its axis horizontal.

17A6. Precession. The gyroscopic property referred to as *precession* may be demonstrated by applying a force to the gyroscope so as to tend to change the plane of rotation of the spinning wheel.

If the gyroscopic wheel is spinning in the upward direction as indicated by the arrow B and a force is applied to turn the gyroscope about the horizontal axis (Figure 17-8), it will be found that there is a great resistance to the force, and instead of motion taking place in the direction of the applied force the wheel turns around in the direction of the arrow labelled PRECESSION. It continues to turn in that direction during the application of the force until

the plane of spin of the wheel coincides with the plane of the force or until the force is removed. When the direction of spin is reversed and the experiment is repeated (Figure 17-9), similar phenomena are exhibited, except that the wheel turns around in the opposite direction. The observed motion, precession, is always about an axis at a right angle to the axis of the impressed force.

17A7. Rule for precession. By comparing the final positions taken under conditions represented in Figures 17-8 and 17-9, respectively, it may be seen that in these experiments the wheel not only sets its place of rotation into coincidence with that of the force, but that the

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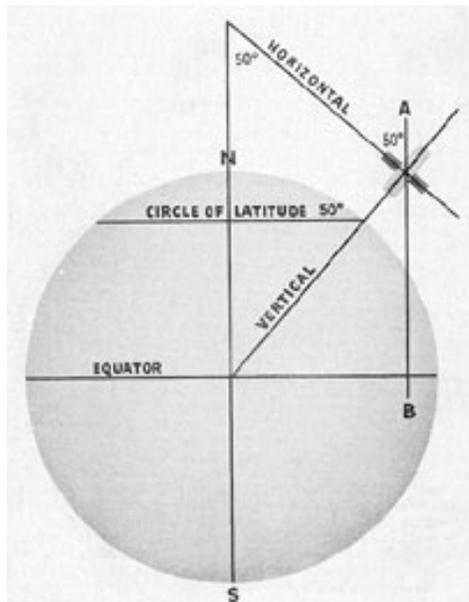


Figure 17-4. Gyro spinning at intermediate positions.

direction of rotation is also in coincidence.

The experiments may be repeated in many ways and the results will always be as expressed

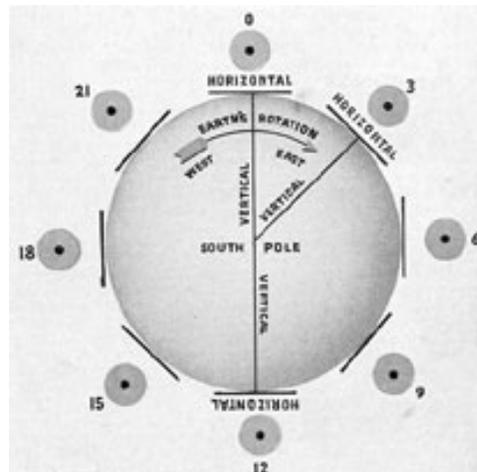


Figure 17-6. Resting position of a gyro spinning at equator.

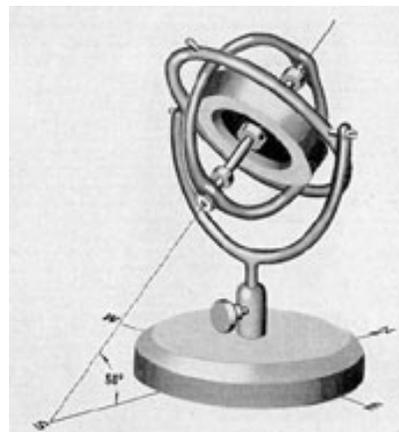


Figure 17-7. Resting position of a gyro spinning at high latitudes.

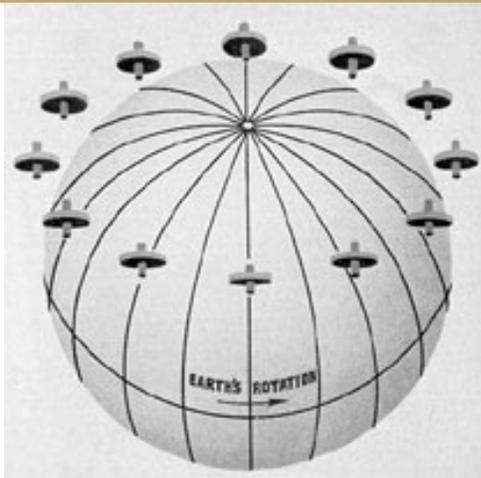


Figure 17-5. Gyro wheel with its rotating axis set in north-south position and level away from the equator moves about its horizontal and vertical axes.

by the following rule: The movement is such as to place the plane and direction of spinning rotation of the wheel in coincidence with the plane and direction of the force by the *shortest* path.

17A8. Continuous precession. When the applied force acting on the gyro system is arranged

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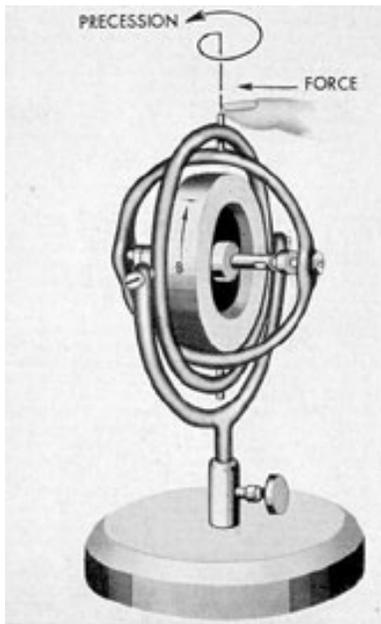


Figure 17-8. Effects of applied force on vertical axis with gyro wheel spinning in upward direction.

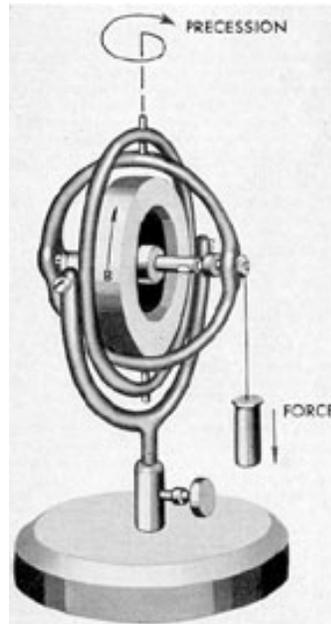


Figure 17-10. Continuous precession.

so that the force is constant, precession becomes continuous. This is illustrated in Figure 17-10, which shows a spinning gyro with horizontal axis and with a weight hung on one end of the axle. The spinning wheel will turn about its vertical axis as indicated in Figure 17-1Q. The wheel continues to follow the weight and continuous precession results. Precession ceases immediately upon removal of the weight.

17A9. Relation of applied force to

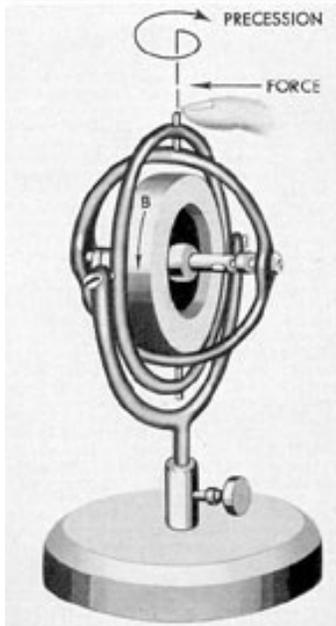


Figure 17-9. Effects of applied force on vertical axis with gyro wheel spinning in downward direction.

B. FUNDAMENTAL CHARACTERISTICS OF THE GYROCOMPASS

17B1. Characteristics of the gyrocompass.

It has been shown that if a spinning gyro wheel is placed on land at the equator, with the gyro axle parallel to the earth's polar axis, it will remain in the meridian, because there is no force tending to deflect it.

However, when it is placed on a ship it is subjected to the disturbing forces of a ship's motion, which deflect it from the meridian.

To be of use as a compass on board ship, the gyro wheel must remain rigidly in the meridian at any latitude and must be unaffected by the ship's motion.

Hence, a gyrocompass must be made to seek and hold the meridian against the friction of its supports and other disturbing forces. For example, a ship changing course turns about the compass, and as friction cannot be entirely eliminated, the friction of its support tends to deflect the gyro.

17B2. North seeking. The *Arma compass* is

precession. The speed of precession is directly proportional to the applied force, and inversely proportional to the weight of the spinning wheel and to its speed in rpm.

horizontal and the torque is zero. The precessional motion is also zero because there is no torque. But the earth continues to rotate under the gyroscope, so the gyro axis now has a slight tilt downward, and the torque or pull is reversed with the corresponding reversal of direction of precession. This downward tilting continues until the axis is pointing along the meridian where the precessional motion is the most rapid toward the east. At this point, the tilt diminishes, the torque diminishes, and finally the gyro axis is again pointing horizontally at the point where the oscillation first started.

a pendulous gyro. It is made north-seeking by placing a weight below the spinning axis as shown in Figure 17-11.

Let us assume that the gyroscope is at the equator with its spinning axis horizontal and pointing to the east of the meridian. The north end of the gyroscope will appear to tilt upward since the gyro maintains its direction in space as the earth revolves under it. Gravity will attract the weight toward the center of the earth -straight down as shown in Figure 17-12. This pull of gravity has the same effect as an applied force or torque around the horizontal axis. Due to the direction of rotation of the wheel, clockwise looking at the south face, the precessional motion will take place to the west as shown in Figure 17-12.

As the upward tilting increases, the torque, or gravity pull, increases with a corresponding increase in the rate of precession toward the west. When the gyro is on the meridian, the maximum upward tilt of the axis is attained and the rate of precession is greatest. The tilt will now be reduced and with it the rate of precession, until the north end of the axis is

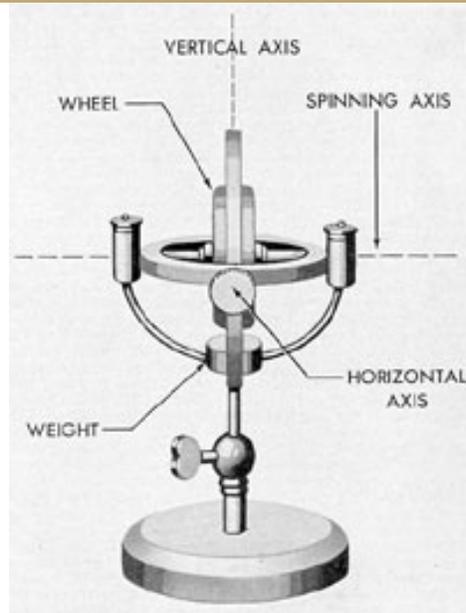


Figure 17-11. Simple pendulous type gyro.

The north end of the pendulous gyroscope oscillates back and forth across the meridian in a period of approximately 84.3 minutes. On each passage of the meridian of the north end of the spinning axis, the gyro is tilted either upward or downward. Also the axis points to the meridian only momentarily, making it useless as a navigational instrument. (See Figure 17-14.)

In order to make a compass of a pendulous

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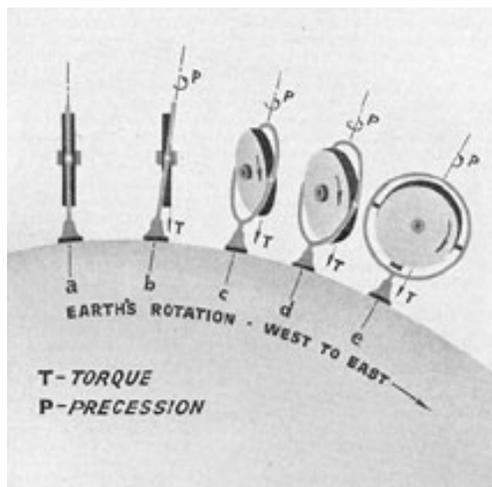


Figure 17-12. Effect of gravity and resultant precessional motion.

weight is, therefore, reduced as the gyro axle approaches the meridian and the rate of precession is materially reduced. By properly proportioning the gyro's pendulous factor and the rate of transfer of oil, the initial oscillation may be completely suppressed or damped in about 2 1/2 cycles. (See Figure 17-15.)

gyroscope it is necessary to cause it to point along the meridian at all times. To do this

the oscillations must be damped out.

17B3. Damping the oscillations. In order to damp the oscillations, the Arma compass employs an arrangement called an oil ballistic. It consists of two tanks located on the north and south sides of the gyro wheel and connected at the bottom by a pipe.

Let us assume that the north end of the gyro axis points to the east of the meridian, with the two tanks secured as shown in Figure 17-13, the axis horizontal, and with equal amounts of oil in both tanks.

The gyro axis then tilts upward, due to the earth's rotation, and at the same time oil flows to the south or low tank. The pendulous mass of the weight causes the gyro to precess toward the meridian, to the west. During this period oil continues to flow from the north tank to the south tank. The rate of flow is low, due to the resistance offered by the small passage in the pipeline. By the time the north axle of the gyro has reached the meridian, a considerable quantity of oil has been transferred from the north tank to the south tank. The excess oil gathering in the south tank provides a force which opposes the force of the weight. The effect of the

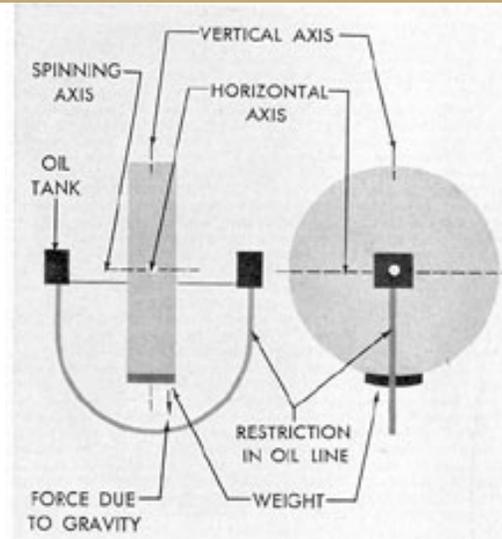


Figure 17-13. Oil ballistic arrangement for damping oscillation.

17B4. Continuous precession toward the meridian. In order that the gyro may be constantly in the meridian at all latitudes, it must be made to precess continuously about its vertical axis to the west as fast as the earth is carrying the gyro off to the east.

In northern latitudes the gyro, if it maintains its direction in space, is no longer in the meridian, and hence after several hours it would indicate an error of large magnitude as shown in Figure 17-16 (dotted lines).

This constant westerly precession about the vertical axis is caused by a turning force about the horizontal axis. A force about the horizontal axis takes place only when the gyro is tilted upward or downward. In northern latitudes, the Arma gyro settles in the meridian with a slight upward tilt of the rotor axis, causing a turning force to the west due to the pendulous factor which keeps the compass in the meridian as shown in Figure 17-17.

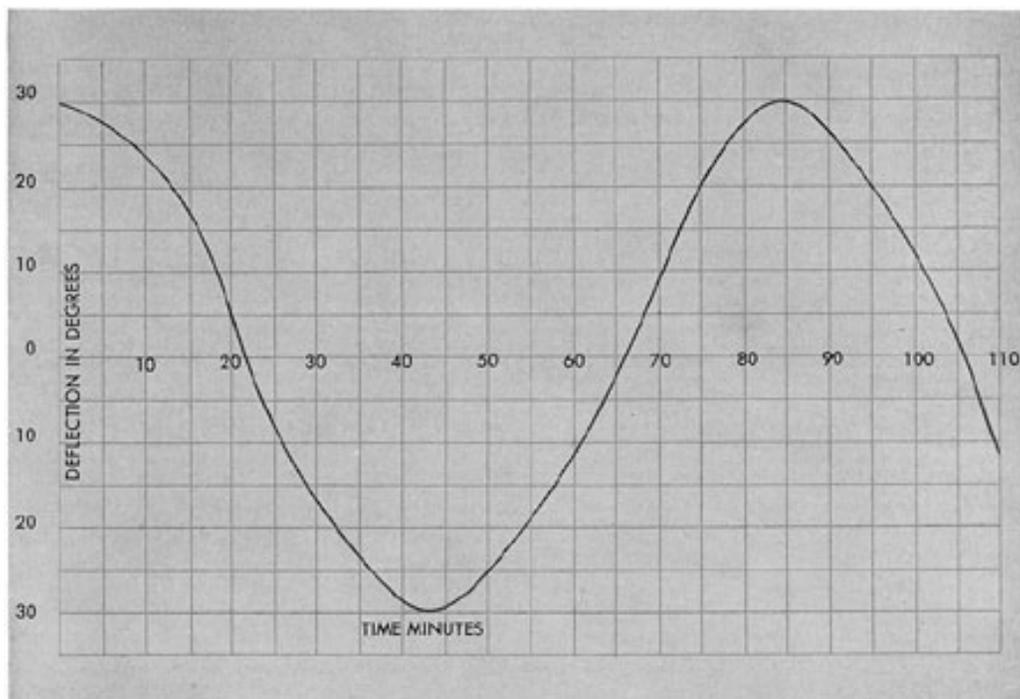


Figure 17-14. Effect of undamped oscillation.

C. CONSTANT MOTION ERRORS

17C1. General. This section deals with the errors encountered in the gyrocompass and the method of correcting them in the pendulous type compass when installed on board ship.

17C2. Speed error. The magnitude of the speed error is dependent upon the speed, course, and latitude of the ship in which the compass is installed. A ship at the equator is being carried around by the earth's rotation at a velocity of 900 knots. At any latitude other than the equator, this velocity becomes 900 times the cosine of the latitude. If a ship is steaming due west, its speed opposes that of the earth; if steaming due east its speed is added to the movement of the earth. Neither course causes a speed error, but both have a slight effect on the directive force of the wheel.

If, however, a ship starts at the equator and sails due north, its speed is at a right angle to the speed with which the rotation of the earth is carrying the gyrocompass around in space.

Assume that the vessel in Figure 17-18 starts at A and is making a speed of 2,026 feet per minute or 20 knots, along the course line A-A'; the speed of rotation of the earth is 92,400 feet per minute along A-B. The actual speed and direction in which the compass is being carried around in space is A-C, and the actual axis about which it is carried around is not the earth's polar axis N-S, but an axis at a right angle to A-C. The gyro axle will, therefore, settle on a line N'-S' and not on the true meridian. The true north will be toward the east of the indicated north by an angle N'-A-N which will be 1.25 degrees for a speed of 20 knots. If the ship starts from the equator and sails due south, the deviation will be toward the opposite side, that is, the true north will be west of the indicated north. If the course is neither due north nor due south, the deviation will have a value between zero and 1.25 degrees. If the ship is at 60 degrees north latitude, steaming at 2,026 feet per minute, or 20 knots, due north as at E-E', and the earth's rotation at this latitude

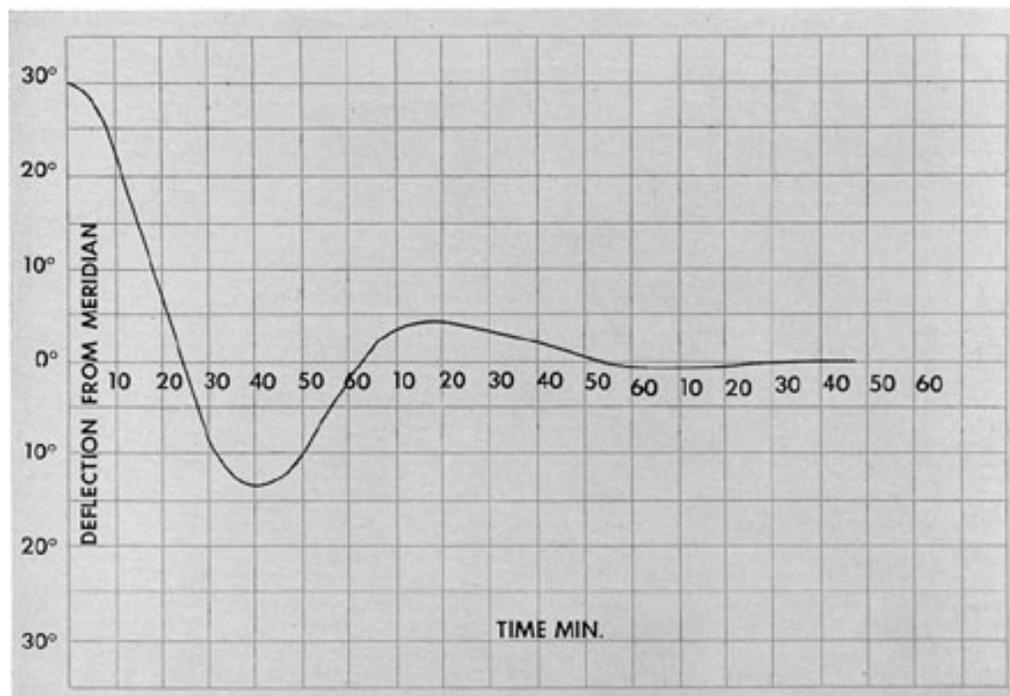


Figure-17-15. Effect of damped oscillation.

E-F is 46,200 feet per minute, the compass is being carried around with a velocity E-G and is being rotated about an axis N"-S" at a right angle to the resultant E-G. The axle will align itself with N"-S". Thus, in this latitude and at the given speed, the true north will be 2.5 degrees eastward of that indicated by the compass. On northeasterly- or northwesterly courses, the deviation will be between zero and 2.5 degrees.

17C3. Ballistic deflection error. In Figure 17-19, the gyro axis is assumed to be pointing along OA. ON is the true north. The angle NOA is the speed error for an assumed course of north and an assumed speed of 20 knots. For a true east course for any speed or latitude, the speed error is zero. Therefore, the axis of the gyro points along ON if the course is east. Let us suppose that the ship, which is on a northerly course and is traveling at a speed of 20 knots, should change to an easterly course. This change of course is made in about 2 minutes. During this time, the north end of the gyro must

precess to the east so that by the time the ship is headed east, the axis of the gyro will point along the line ON. If the gyro, by the time the ship is on an easterly course, is not pointing along the meridian ON, it will produce an erroneous reading on the compass and its repeaters.

Fortunately, the north end of the gyro will have a tendency always to precess toward its proper settling point on a change of course.

If the compass is to have the proper ballistic deflection during the time that the vessel is actually changing course, it must have a definite amount of pendulousness for the latitude which will make it precess exactly to the settling point required for the new course in a deadbeat manner. The ballistic deflection error is prevented in the Arma compass by varying the speed of the gyro rotors in accordance with the cosine of the latitude of the vessel's position. This variation in speed is effected by changing the speed of the motor generator through a field rheostat on the control panel.

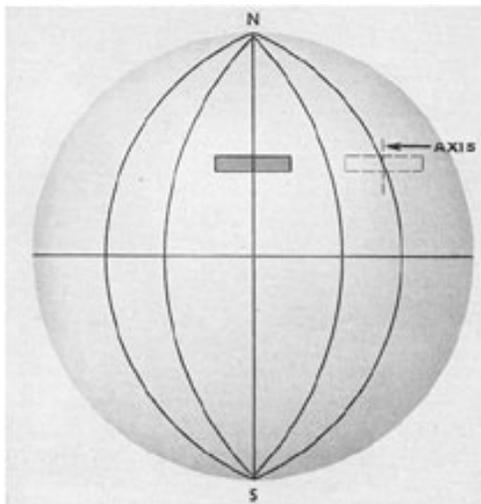


Figure 17-16. Gyro axis parallel to the north-south axis.

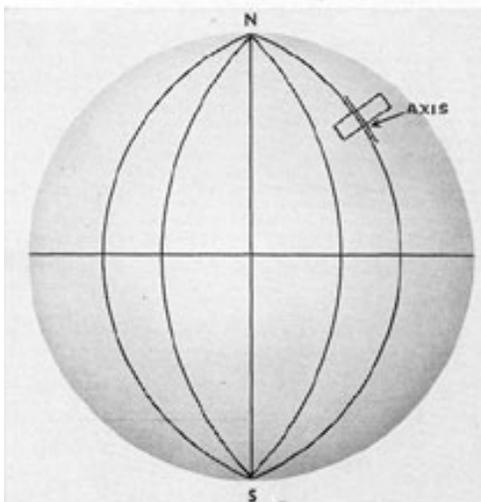


Figure 17-17. Gyro axis parallel to the meridian.

17C4. Ballistic damping error. The oil damping arrangement of the Arma compass allows a small quantity of oil to flow from one tank to the other when the compass is subjected to the inertia forces caused by acceleration or deceleration of the ship during a change of course or speed so that an unbalanced condition is set up. This unbalanced condition results in a precession about the vertical axis and causes an oscillation which must be damped out in the

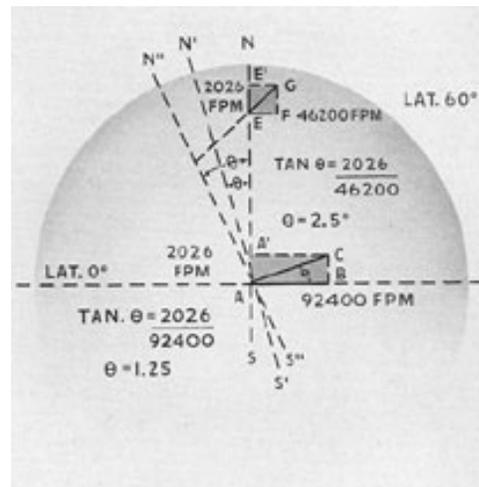


Figure 17-18. Speed course latitude errors.

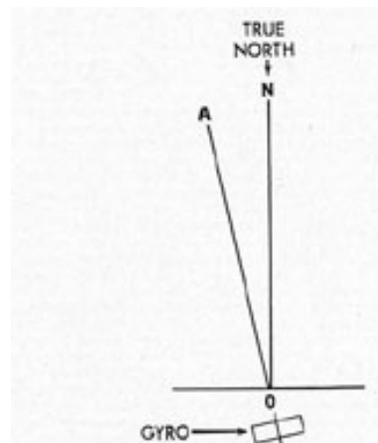


Figure 17-19. Ballistic deflection error, ship on northerly course.

regular manner. In all the later Arma compasses, damping is eliminated for changes of course of 15 degrees or over, thereby eliminating this error. This is accomplished by a solenoid-operated valve controlled by contacts in the follow-up system.

17C5. Quadrantal errors. Centrifugal forces resulting from roll and pitch are neutralized in the Arma compass by maintaining uniform distribution of the sensitive element masses in the horizontal plane. This is accomplished by supporting the sensitive element on a hollow steel

sphere which floats in a concentric tank of mercury.

Acceleration forces caused by roll and pitch are neutralized in the Arma compass by east-west stabilization of the sensitive element. This is accomplished by using two gyroscopes instead of one. In this way, swinging of the compass in the east and west direction is prevented, giving both east and west stabilization as well as north and south.

D. UNITS OF THE COMPASS EQUIPMENT

17D1. Units comprising the compass equipment. The principal units of the compass equipment are as follows:

1. *Master compass* (Figure 17-20). This includes the north-seeking element, its housing, and a follow-up mechanism.
2. *Control panel* (Figure 17-21). This panel carries meters, switches, and ballistic adjustment for the master compass.
3. *Repeater panel*. This panel is mounted directly below the control panel, on the same frame. It carries switches for controlling the repeater compasses.
4. *Follow-up panel*. This panel carries the vacuum tubes that drive the follow-up mechanism of the master compass. It is mounted directly below the repeater panel and on the same frame.
5. *Motor generator set*. This unit converts the ship's supply to a three-phase, variable frequency supply for driving the gyros.
6. *Repeater compasses*. These receive and indicate the ship's heading at remote stations.

17C6. Latitude error. The Arma compass settles on the meridian in a tilted position and has no latitude error, hence correction for this error is not required.

17C7. Speed error. The Arma compass has a correcting mechanism that compensates for speed error so that the true course readings are indicated on the compass card and repeaters.

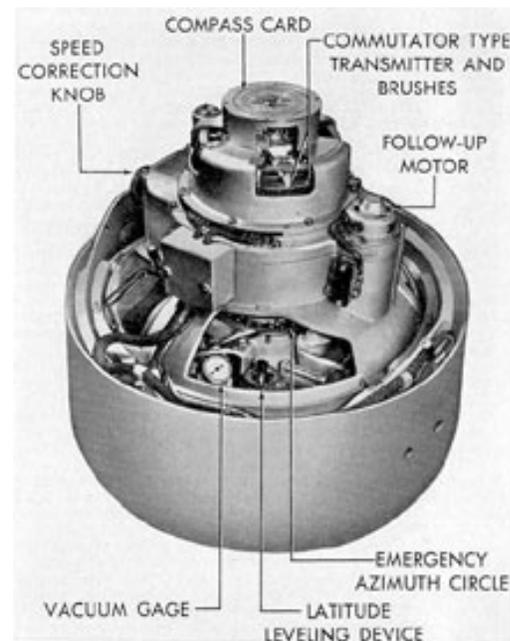


Figure 17-20. Arma master compass installed, binnacle cover removed.

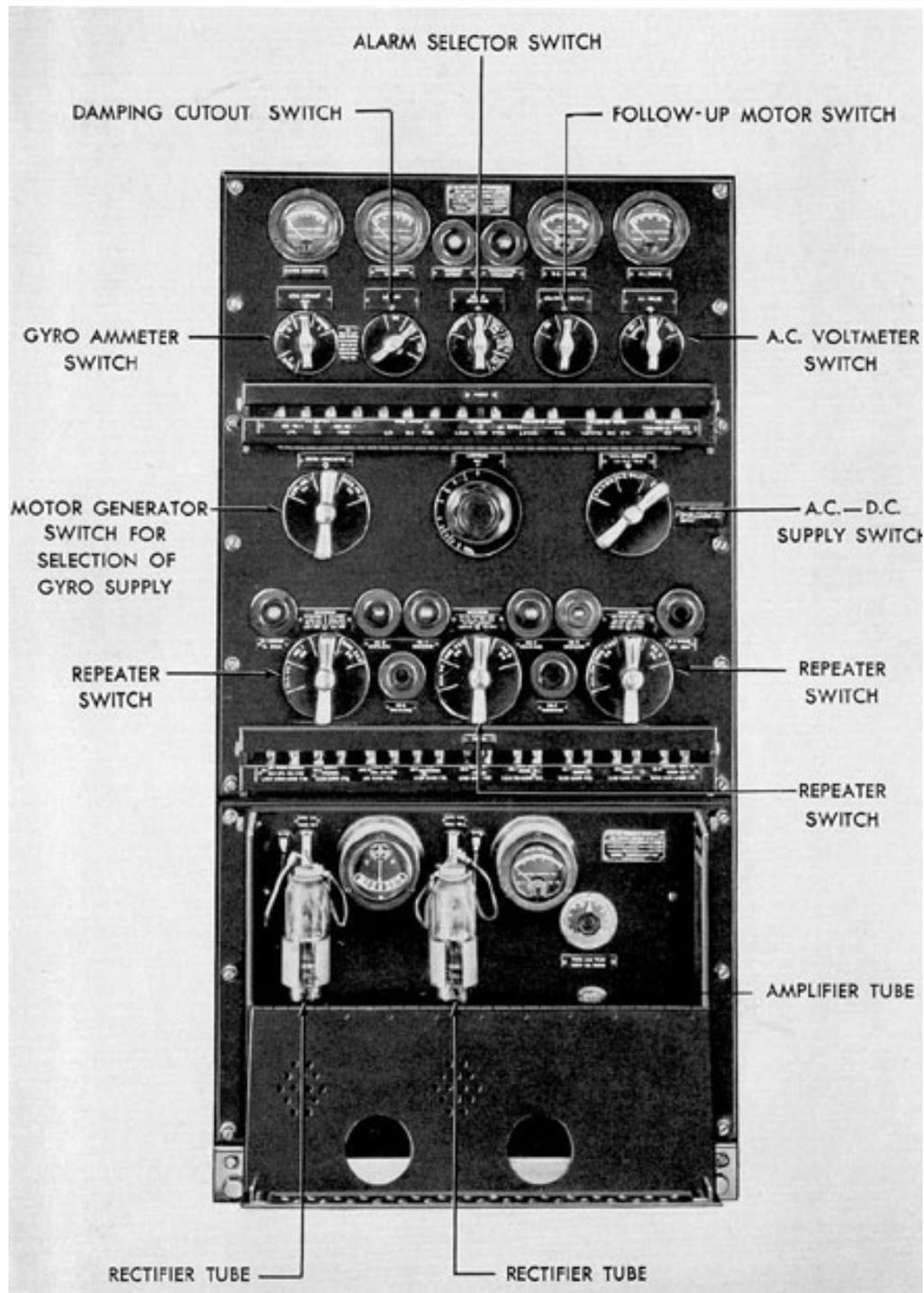


Figure 17-21. Arma master compass control, repeater and follow-up panels.

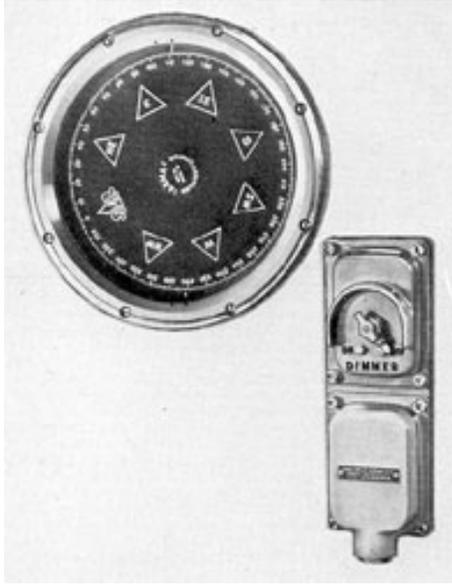


Figure 17-22. Single dial repeater with dimmer.



Figure 17-23. Conning tower double dial steering unit with dimmer switch.

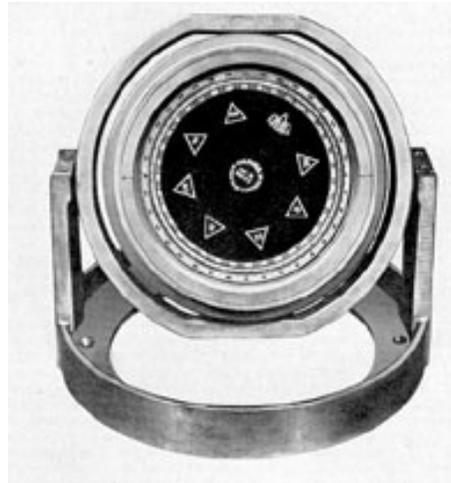


Figure 17-24. Gimbal-mounted double-dial bridge pelorus, pressure-proof type.

E. THE MASTER COMPASS

17E1. Components of the master compass.

The master compass shown in Figure 17-25 is the principal unit in the compass equipment. For purposes of description, the master compass may be divided into its major parts as follows:

17E2. Binnacle stand. The binnacle stand (Figures 17-25 and 17-26) which supports and encloses the whole master compass, is made in 3 sections. The center section is cylindrical and connects the upper and lower

card may be read. Near the forward and after sides of the cover are 2 hinged doors for gaining access to the speed correction knob and other parts. These doors are provided with hasps and padlocks.

17E3. Gimbal rings. To provide a relatively stable support for the compass, the frame, consisting of bowl and spider, is supported on gimbal rings (see Figure 17-25) within the binnacle stand. The outer ring is trunnioned fore and aft in the binnacle midsection on ball

sections. The bottom of the lower section is bolted to the binnacle base.

The midsection carries the gimbal rings. It is rigidly bolted to the lower section. Inside the lower section near its base, 4 terminal blocks are fastened, for making connections with the control panel.

The binnacle top section is a cover attached to the midsection by latches. Its upper surface is shatterproof glass through which the compass

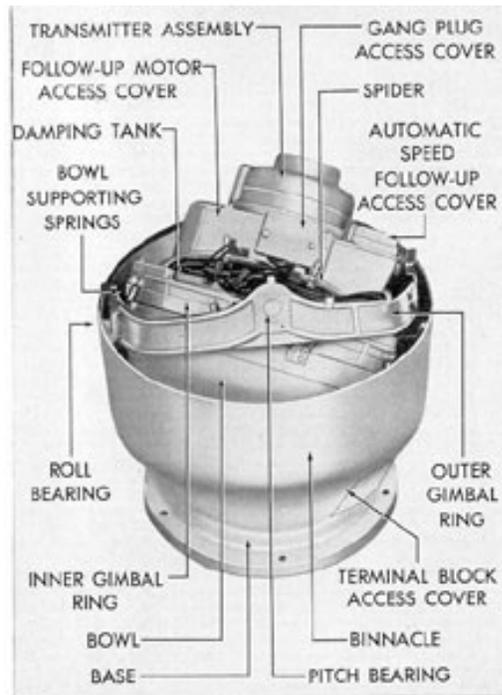


Figure 17-25. Master compass with cover removed showing position for 15 degree pitch and 35 degree roll.

bearings mounted in bakelite bushings to insulate the rings from the binnacle. The inner ring is trunnioned athwartship within the outer ring. To prevent the compass frame from swinging excessively in the rings when the ship rolls, the inner ring carries on its upper surface 3 steel damping tanks partially filled with mercury.

17E4. Spider and bowl. The compass frame consists of a large bowl suspended from the inner gimbal ring by 16 helical springs, and a spider attached to the upper surface of the bowl. (See Figure 17-25.) The supporting springs are divided into 8 sets of 2 springs each. This construction allows freedom of the suspended parts in the horizontal plane and yet exerts a centering effect when the frame has been displaced from its normal position. Small metal damping tubes inserted in the springs damp out any oscillations of the frame.

The enclosure formed by the bowl on the bottom is completed on top by the spider which is fitted with 4 removable transparent covers. The spider provides a mounting for the speed-course correction mechanism and supports the transmitter assembly, follow-up motor, and follow-up coil. To the top of the spider is fastened the follow-up motor and transmitter support casting which in turn carries the driving arm support.

17E5. Sensitive element. The north-seeking portion of the master compass is the sensitive element; (See Figures 17-27 and 17-28.) This unit through gyroscopic action and by virtue of the earth's rotation tends to keep its axis in the meridian. By means of the follow-up system and

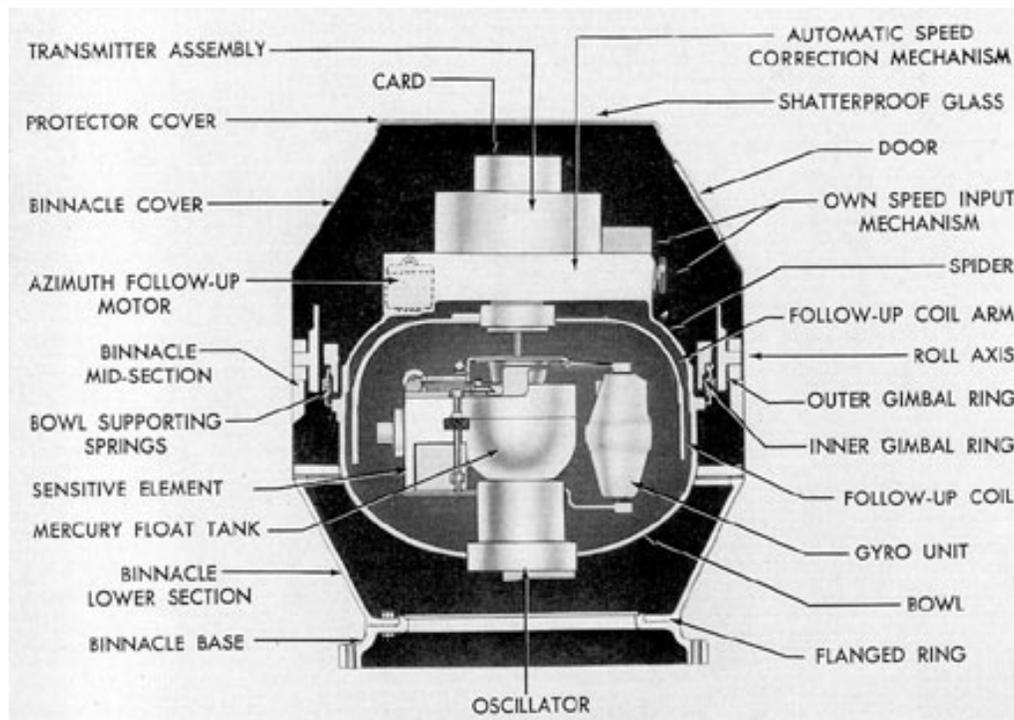


Figure 17-26. Diagrammatic drawing of master compass.

transmitter, the position of the element controls the reading of repeater compasses throughout the ship. Since the element must be extremely free to turn about any axis, it is supported by a steel ball which floats in mercury.

The sensitive element consists of a frame on which are mounted 2 gyro units and an oil damping device. Each gyro unit is free to rotate about a vertical axis but the 2 units are coupled together by a linkage. On the element are 2 magnets for exciting the follow-up system, and an emergency azimuth scale to be used if the follow-up system should fail.

17E6. Gyro units. Two gyro units provide directive force for the sensitive element; that is, they turn it toward the meridian. One of these units is shown in Figure 17-29.

The casing of each unit is equipped externally with upper and lower spindles and ball bearings so that it is free to rotate about a

vertical axis. Around the sight glasses, and other joints, neoprene gaskets are used to make the case airtight.

The gyro wheel and its axle are machined in one piece from alloy steel. Each end of the axle is accurately fitted with ball bearings which are supported inside the gastight casing. One side of the gyro wheel is machined out around the axle to make room for the induction motor windings. The squirrel cage winding is pressed into the gyro wheel. The primary, or stator, projects into the center of the rotor squirrel cage. Leads from the stator are carried through the casing to terminals on the outside for connections to the supply line. Around the periphery of the wheel a spiral groove is turned and enameled black. This groove is observed through a sight glass on the case to determine whether or not the wheel is rotating in the correct direction when it is started.

The lubrication system consists of an oil sump at the bottom of the casing from which

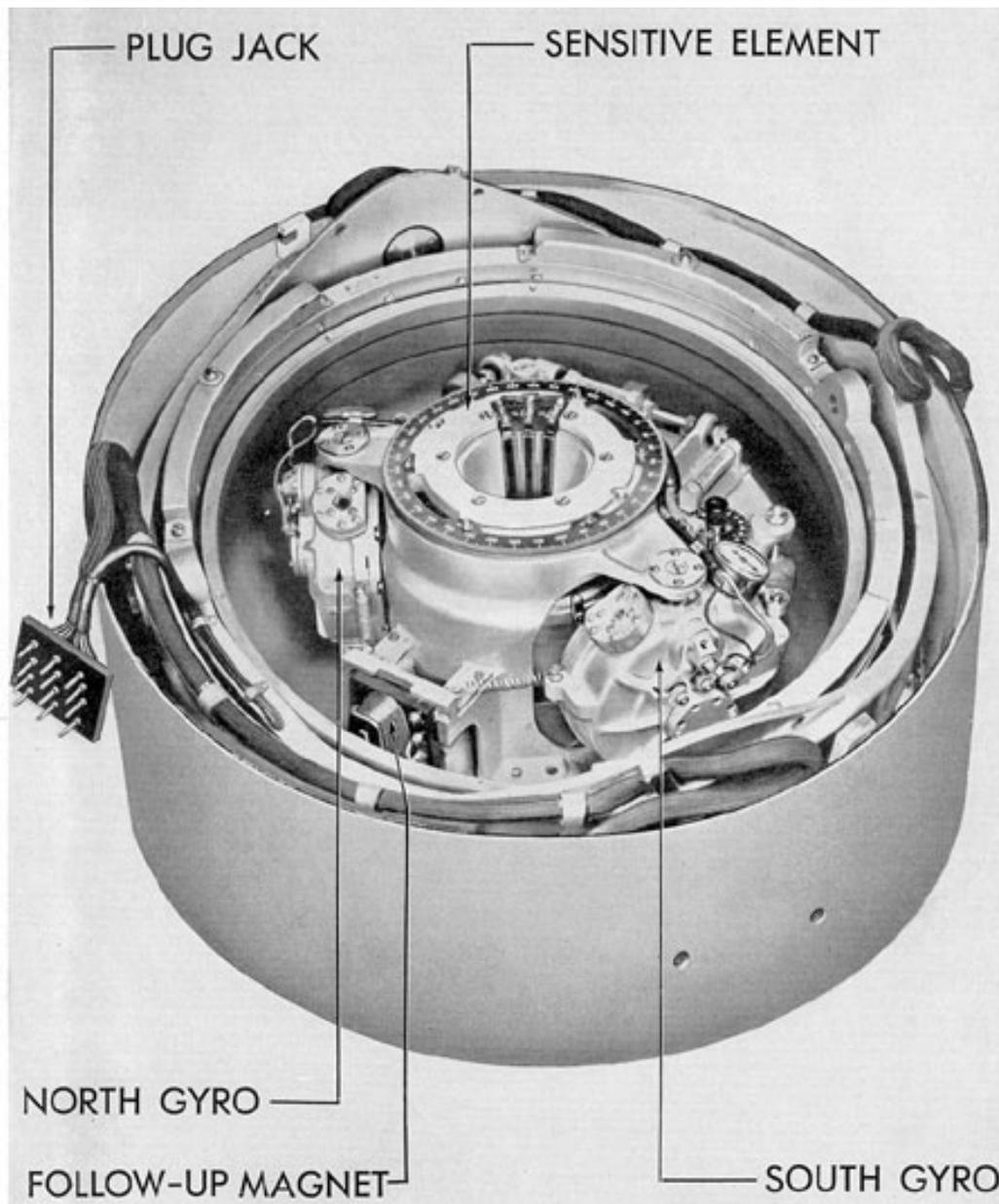


Figure 17-27. Arma master compass, cover and spider removed to show sensitive element.

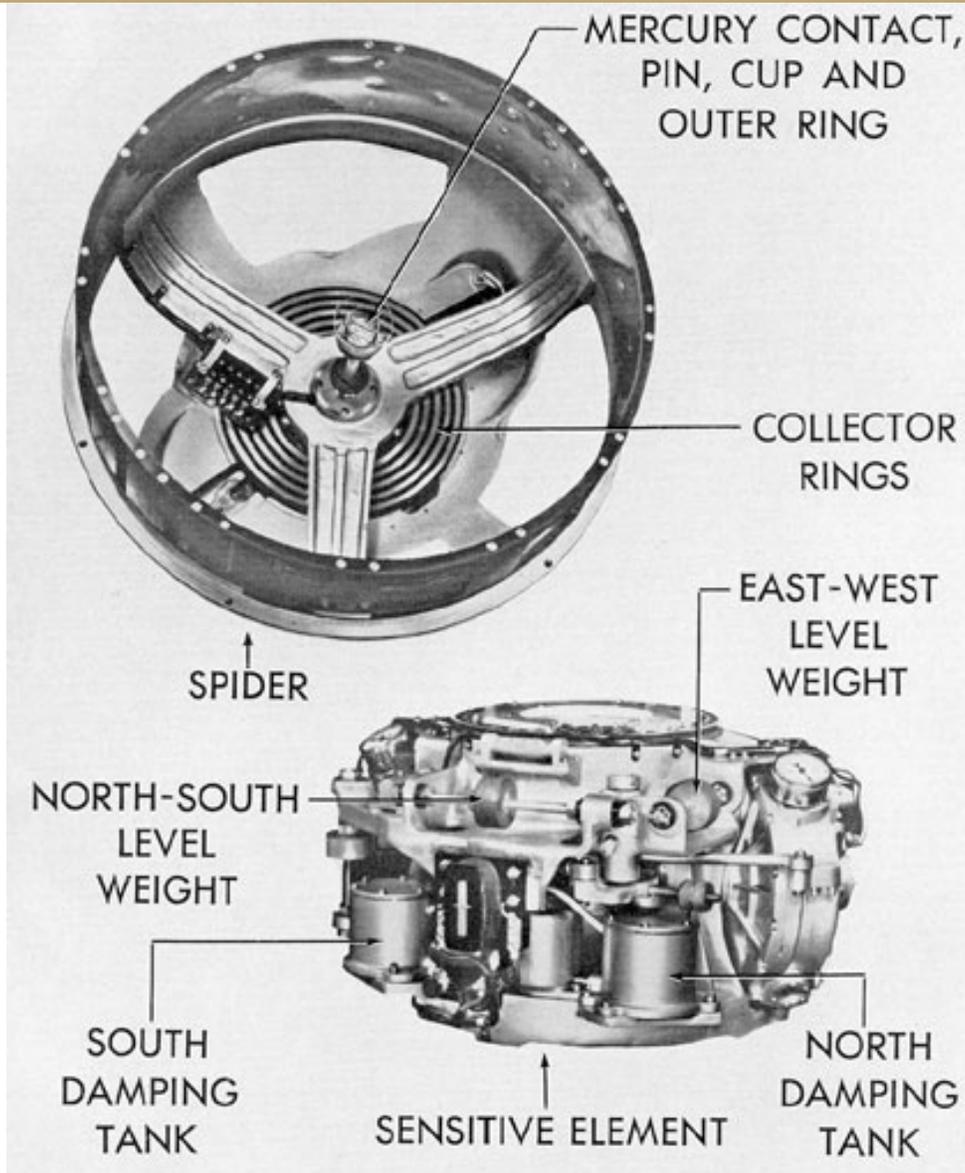


Figure 17-28. Bottom view of spider, sensitive element.

pipe. (See Figure 17-30.) Were it not for this damping system, the element would continually oscillate back and forth across the meridian instead of settling down into its correct position. The illustration shows the tanks in a sectional view. They are aligned parallel to the meridian and are totally enclosed. The tanks are connected by a pipeline at the bottom for oil, and by another at the top for air. They are filled to a depth of 1 1/4 in.

In order to obtain the proper damping percentage, it is necessary to restrict the flow of oil between the tanks. This is accomplished

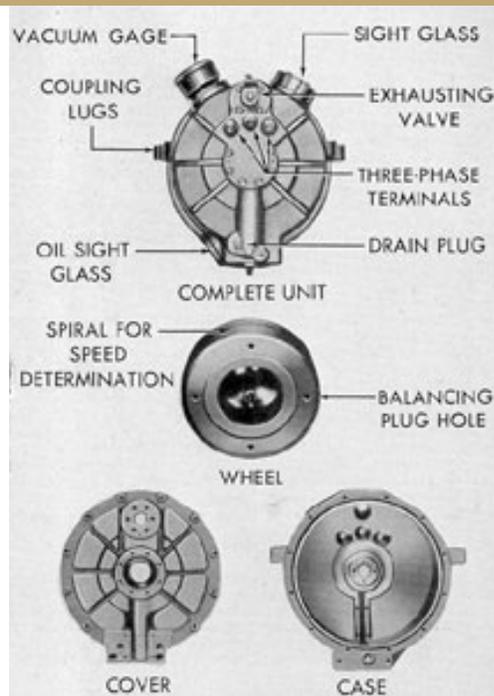


Figure 17-29. Gyro unit, disassembled.

cotton wicks carry the oil up and around each of the axle ball bearings. The oil sump is provided with a drain plug end with a circular sight glass to show the oil level, the correct level being at the midpoint of the glass. A high-grade oil that is free from moisture and other volatile substances is used.

A vacuum is maintained within the case to eliminate windage losses, to reduce the heating of the rotor, and to prevent gumming of oil in the bearings. A gage on the unit shows the degree of vacuum and so serves to indicate possible leakage. The casing is fitted with an exhaust valve that is used in evacuating the case. On the north gyro unit, the positions of the vacuum gage and sight glasses are opposite to what they are on the south gyro. Therefore the units are not interchangeable.

17E7. Oil damping system. On the east side of the sensitive element frame are 2 tanks partly filled with oil and connected at the bottom by a

by means of an obstruction inserted in the pipeline.

To avoid the damping error, it is necessary to nullify the effect of the damping system during changes in course. To prevent the flow of oil due to the accelerating forces present during a turn, a damping cutout valve is placed in the oil line connecting the two damping tanks. This valve operates whenever the change in ship's course is greater than 15 degrees and it is controlled automatically by a pair of contacts in the transmitter assembly. The valve consists of a steel ball, inside the oil line, which can be drawn up vertically against a spherical seat by an external electromagnet when the oil flow is stopped. Thus, the valve is operated without disturbing the equilibrium of the sensitive element.

17E8. Mercury flotation. The directive force of any gyrocompass is small when nearly on the meridian. It is therefore necessary to suspend it in as nearly a frictionless support as possible. This is accomplished by supporting the sensitive element on a hollow steel sphere which floats in a concentric tank of mercury (see Figure 17-31).

The element is constrained from drifting laterally by the center electrical contact pin which fits loosely into a guide at the center of the floating sphere. This pin, together with a pair of concentric contact rings, projects from a shaft which is carried at the center of rotation of the follow-up arms. Thus, there is practically no relative rotation between the contact pin and rings and the sensitive element. The vertical position of the element is governed by the

quantity of mercury in the tank. The sphere should clear the bottom of the tank by 3/16 in. For convenience in checking this position, a line has been placed on the contact support tube. This line is level with the topmost surface of the sensitive element when the flotation is correct.

17E9. Oscillation mechanism. To eliminate any possible static friction in the mercury

17E10. Follow-up mechanism. a. General. The follow-up mechanism is that part of the master compass that drives the card dials and controls the repeater compass readings without reacting upon the sensitive element. This is accomplished by amplifying a small voltage which is induced in the follow-up coils by magnets on the sensitive element, and using this amplified

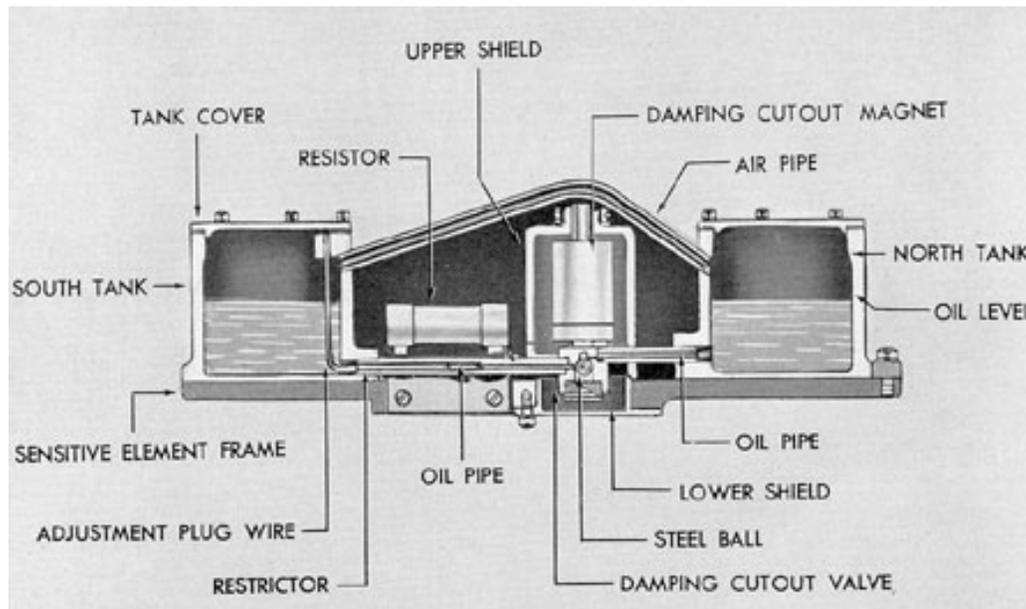


Figure 17-30. Oil damping system.

which would slightly reduce the freedom of the sensitive element, the tank is suspended from leaf springs and caused to oscillate continuously through a small angle several times a second. The oscillating mechanism is located below the tank. (See Figure 17-26.) The mechanism consists of a split-phase motor driving an eccentric and connecting linkage.

voltage to control a motor geared to the card and follow-up coil. The motor operates to keep the follow-up coil and the card in their proper position relative to the sensitive element. The follow-up mechanism is part of the master compass. It is distinguished from the follow-up system that includes the mechanism and the follow-up panel.

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b. *Speed correction mechanism.* The automatic speed correction mechanism is provided with a synchronous motor which receives an indication of ship's speed from the underwater

introduced into the multiplier, and the resulting product is applied to an eccentric bearing in the correction mechanism. The speed corrector requires manual resetting only for changes in

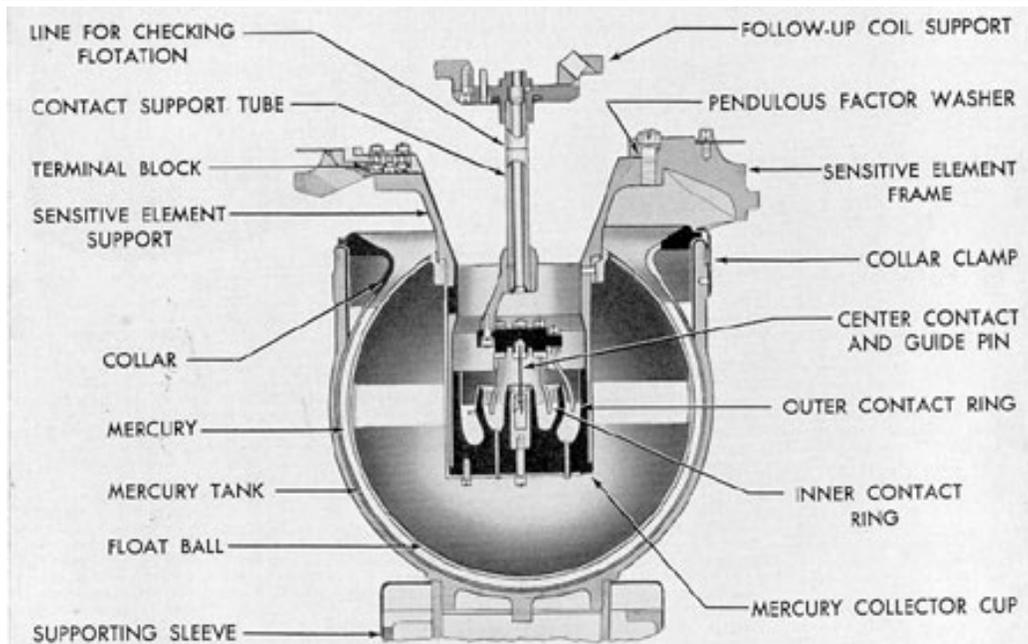


Figure 17-31. Flotation and contact assembly.

log, and a follow-up motor which applies this quantity to a lever type multiplier. By means of a manual control which is graduated in degrees of latitude, the secant of the latitude is

latitude; speed variations are taken care of automatically. Provisions are made for hand setting of the ship's speed when the underwater log is secured.

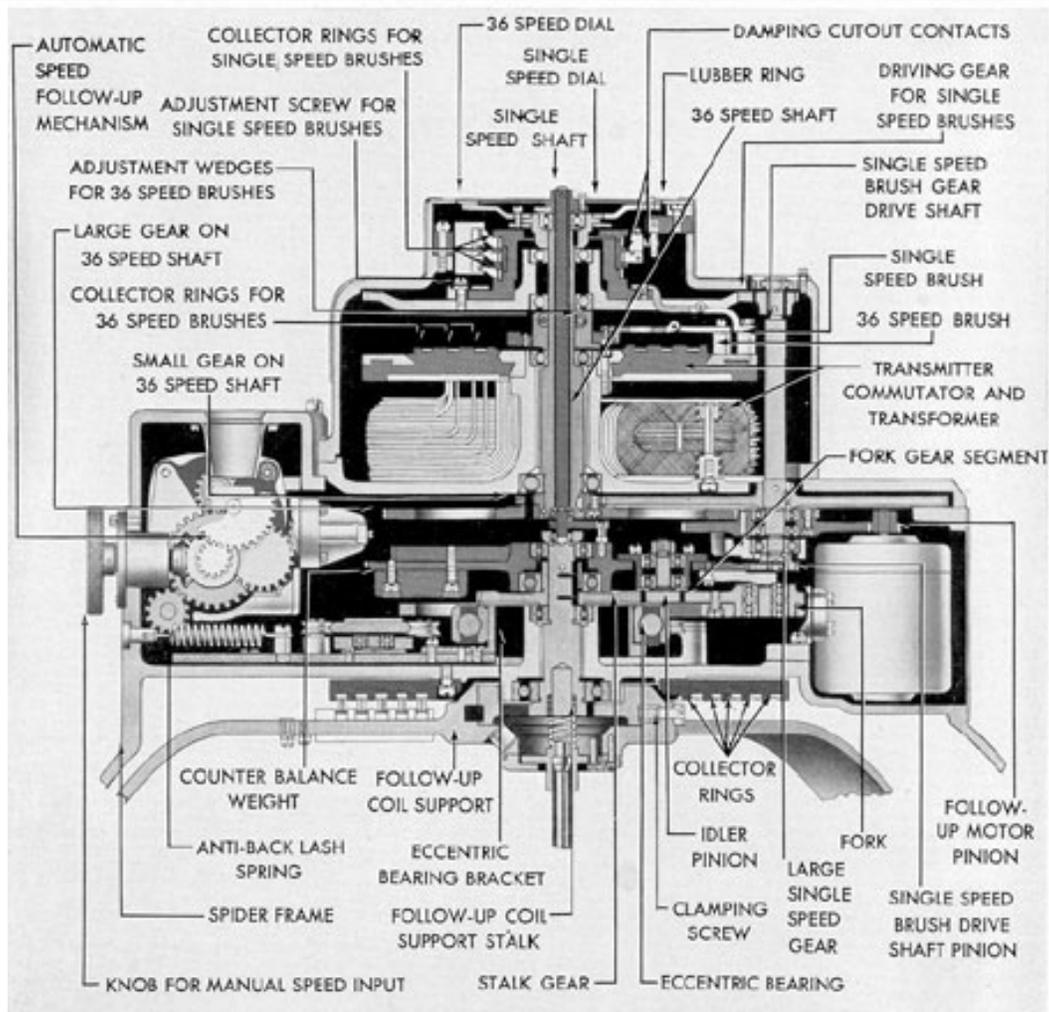


Figure 17-32. Automatic speed correction and driving mechanism.

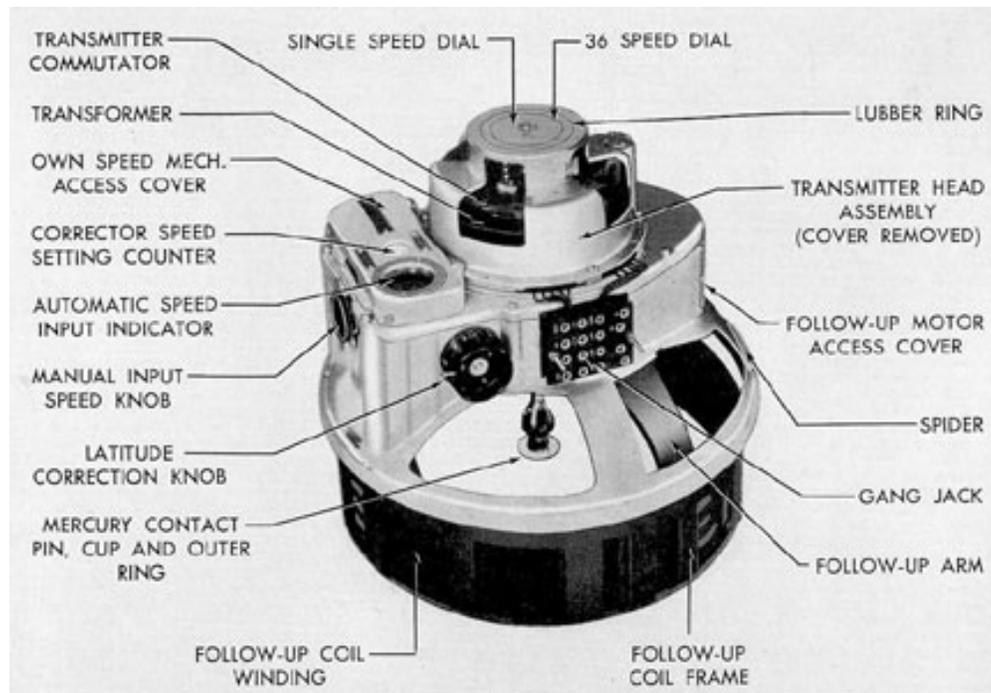


Figure 17-33. Spider assembly.

F. MOTOR GENERATOR

17F1. Function. The motor generator set converts the ship's direct current power supply to a 3-phase supply of variable frequency for driving the gyro wheels.

17F2. Construction. The motor and generator are enclosed in a drip-proof housing. Their rotors are on a shaft which is supported at the frame ends on ball bearings, each bearing being lubricated by a grease cup. The generator is driven by a compound-wound direct-current motor, rated at 115 volts, 3.0 amperes, and 3,000 rpm. Speed control is obtained by means of an external rheostat in the motor field circuit. The motor has been specially designed for good speed

regulation so that the effect of variations of the supply voltage on the motor speed has been reduced to a minimum.

Motor generator sets supplied with the various modifications of the master compass are similar in external appearance but vary slightly in capacity. The Mark X Mod. 2, generator is rated at 67.5 volts, 2.0 amperes, and 300 cycles at 3,000 rpm.

When the motor speed is reduced, the generator voltage and frequency are correspondingly reduced. Direct current required to excite the generator field is obtained through the control panel from the ship's supply.

G. CONTROL PANEL

17G1. General. Figure 17-34 shows the repeater, control, and follow-up panels. The control panel is used for controlling the operation

of the master compass and for indicating conditions of operation such as current and voltage values.

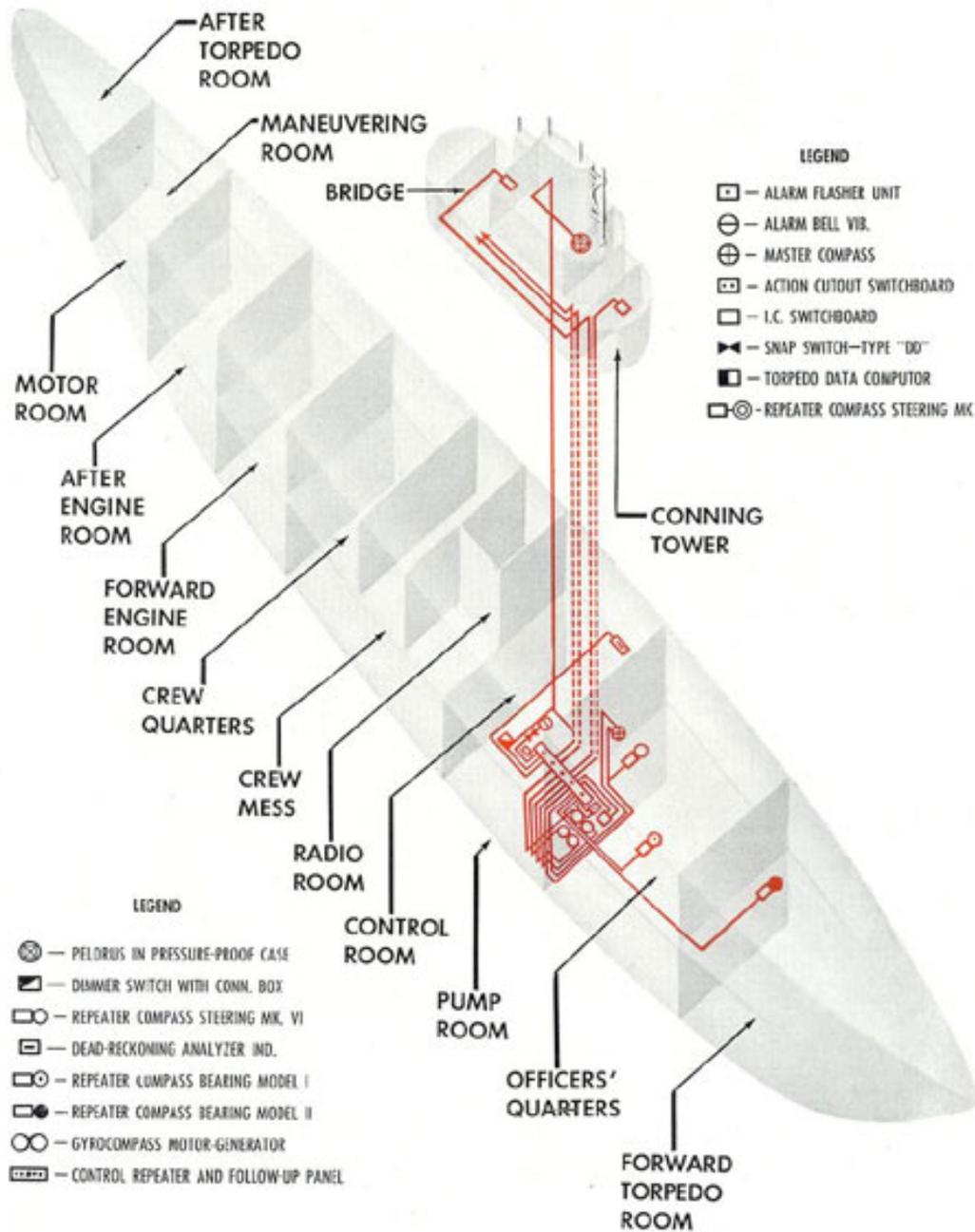


Figure 17-34. Schematic diagram of gyrocompass system.

Connection to motor generators, master compass, and other equipment is made through this panel.

17G2. Instruments. At the top of the control panel are 2 ammeters, 2 voltmeters, and a neon indicator lamp. The lamp serves as an indicator for the damping cutout and operates when the oil flow system between the damping tanks has been cut off. The 4 instruments indicate:

1. The gyro drive current in each phase.
2. The current drawn by the repeater system.
3. The d.c. supply voltage.
4. The gyro variable frequency supply

voltage and the 60-cycle, single phase a.c. supply voltage.

17G3. Repeaters. Outgoing circuits are provided on late fleet type submarines to repeaters located as follows:

1. forward torpedo room-1 speed
2. commanding officer's stateroom-1 speed
3. control room steering station - double dial, concentric 1 and 36 speed
4. conning tower steering station-double dial, concentric 1 and 36 speed
5. bridge pelorus-double dial, concentric 1 and 36 speed with illuminated relative bearing ring

H. OPERATION

17H1. General. The gyrocompass is a sensitive instrument. The first essential in its operation is to see that it is operated by trained personnel only. No attempt should ever be made to disassemble or adjust it. Only qualified gyrocompass repair personnel should ever attempt a major repair or adjustment.

17H2. Starting the master compass. The following procedure should be followed in starting the master compass:

1. The compass should be started about 4 hours before it is required for service.
2. Check the vacuum gage reading of the north and south gyro units. The vacuum should be approximately 29 inches.
3. Check the oil level in the gyro case. The level should be approximately halfway up the sight glass at the bottom of the case. This check may be easily made by holding a mirror next to the sight glass

6. Start the compass and check its operation as described in the manufacturer's instruction book.

7. Read the gyro current in each phase every hour. The current should be about 1.25 to 2.25 amperes. An abnormally high current indicates trouble which should be investigated immediately.

8. Read all voltages and currents every hour. Normal values are as follows:

Gyro drive	1.25 to 2.25 amperes
A.C. single phase	115 volts
A.C. gyro drive voltage	23-68 volts
D.C. voltage	115 volts
Repeater system current	See below

The instrument marked REPEATER SYSTEM CURRENT indicates the current drawn by the transmitter circuit and repeaters. It will read about 5 to 6 amperes when no repeaters are connected. The reading should increase about 0.6

and viewing the reflection of the oil level in the mirror.

4. See that all switches on the control and repeater panel are in the OFF position. The damping cutout switch is an exception to this rule and should be in the ON position when the ship is not making way.

5. Have the power supplies to the control panel energized.

amperes for each additional synchronous motor added to the load.

17H3. Use of level in settling element or meridian. If it is necessary to put the compass in operation on short notice, considerable time may be saved by precessing the element on to the meridian by hand. Proceed as follows:

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1. Start the compass in the usual manner.

2. Determine the approximate ship's heading.

3. Precess the element until the card indicates the ship's heading. This is done by pressing down lightly on the north or south side of the element.

4. Bring the bubble in the north-south level to the center of the scale. To do this press against the end of the bubble tube in the direction the bubble must go.

5. It is impractical to set the compass and

have it remain exactly in its settled position because the damping oil must seek its final level and because temperature changes as the instrument warms up cause slight disturbances.

17H4. Shutting down the compass. To stop the compass, turn all the switches on the control and repeater panels to the OFF Position. No further attention is required. The gyro wheels will continue to rotate for about an hour. Do not attempt any work on the element until the wheels have stopped.

I. CARE AND MAINTENANCE

17I1. Inspection and checks. The gyrocompass requires little attention if operating instructions are carefully followed. Inspection, cleaning, and oiling should be done regularly in accordance with the schedule below. Visual inspection may, of course, be made at any time, but as long as the compass is operating satisfactorily, it is best not to perform the other checks more often than indicated by the schedule.

Never shift a weight or make any other adjustment until it is definitely known that trouble exists, and until that trouble has

6. *Twice a year.* Check the depth of oil in the damping tanks. This should be from 1 1/8 to 1 1/4 inches average value in the 2 tanks. The depth in each tank may be measured by removing the cover. If the average depth is low, add clean oil to bring it to the correct value. Be very careful to keep out dirt, or any foreign particles.

7. *Once every 24 months.* Lubricate the synchro bearings if they have not been lubricated in the previous 18 months. Use 1 drop of oil in each bearing.

The upper spider bearings and all gearing should also be lubricated every 24 months, although this

been analyzed.

17I2. Maintenance schedule.

1. *Every hour.* Check the gyro current and voltages.

2. *Every watch.* Inspect the vacuum tubes. Make immediate replacement of defective tubes.

3. *Once a week.* Check the vacuum gage readings. Small changes from previous readings may be due to variations in barometric pressure, but a large change indicates trouble.

Clean the control and repeater panels. Inspect the connections and look for blown fuses.

Clean the motor generator set. Turn down each grease, cup one turn.

4. *Once a month.* Clean the binnacle inside and out, making certain that no foreign objects have fallen across the terminal blocks in the base.

Clean the bowl and spider.

When the gyro wheels are not rotating, clean the entire sensitive element.

5. *Once in 3 months.* Put a drop of gyro oil in each gimbal ring bearing.

is not absolutely necessary.

8. *After extended shutdown.* Before starting the compass after it has been out of service for some time, all the checks that are made once in 3 months or more often should be gone over. In addition, the transmitter commutator, all collector rings, and the damping cutout contact should be examined and, if necessary, wiped off with a cloth dampened with an approved solvent.

17I3. Compartment pressure test. Before any compartment of the ship is submitted to a 15-pound pressure test, all repeater compasses in the compartment must have the small plug in the lower cover removed to equalize the pressure on the glass. A master compass in the compartment must have the vacuum cocks of both gyro casings opened to equalize the pressure on the casings and to protect the vacuum gages from breakage.

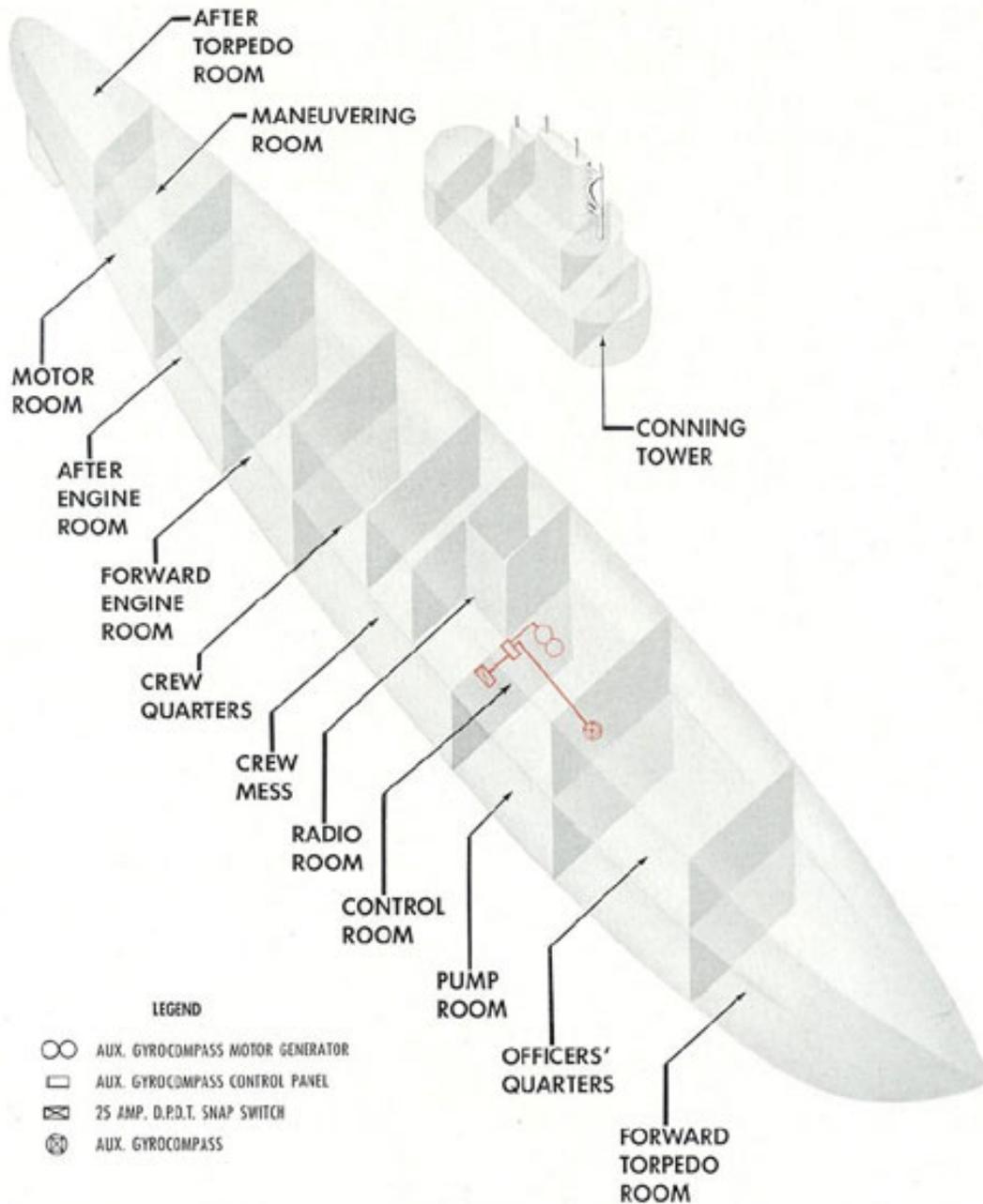


Figure 17-35. Schematic diagram of auxiliary gyrocompass system.

J. AUXILIARY GYROCOMPASS

17J1. Description. a. *General.* The Arma Mark 9 gyrocompass has been developed as an auxiliary compass for submarines, to indicate accurately the ship's true heading. It is designed primarily for emergency use when the main compass is inoperative. The auxiliary compass is light, compact, simple to operate, and readily accessible for maintenance.

The equipment consists of 3 main units, the compass proper, which is enclosed in a binnacle, the motor generator, and the control panel.

b. *Compass unit.* The compass unit houses the north-seeking sensitive element, which has gyros arranged in such a manner that the rotation of the earth tends to maintain the element

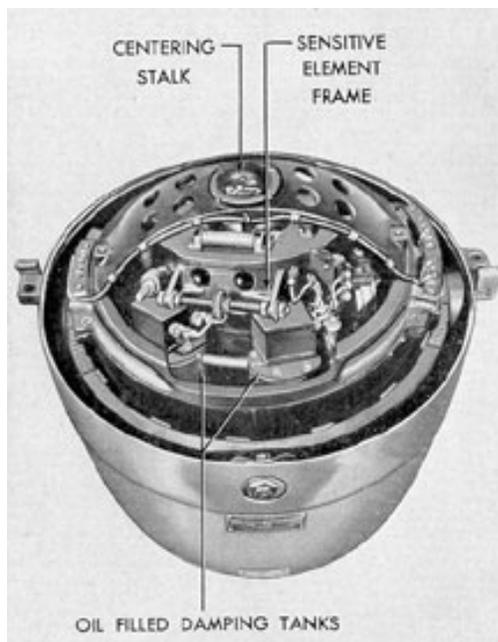


Figure 17-36. Arma auxiliary gyrocompass Mark 9, cover removed.

on the meridian. The sensitive element floats freely in a tank of mercury and carries 2 gyros mounted at an angle of 25 degrees to the meridian. Two wheels are used to stabilize the sensitive element in an east-west direction, thereby

eliminating the intercardinal rolling error. The gyros run at about 18,000 rpm and are supplied with power from a motor generator, driven by the ship's supply. A pair of oil-filled damping tanks, connected by a restricted pipe, are also mounted on the element, level with the center of flotation, so that tilting of the element of gimbal rings will not cause an apparent change in course. The dial is read through the binnacle cover glass. The element is restrained from drifting sidewise in the mercury by means of a centering stalk, which also provides an almost frictionless method of making an electrical connection to the gyros. The other connection is made through the flotation mercury. The mercury tank is oscillated back and forth through a small angle, several times a second, in order to break up surface friction between the mercury and the pot. The entire inner member containing the pot is pendulous and is spring-mounted in a pair of gimbals. The gimbal pivots are damped by means of felt washers saturated with an

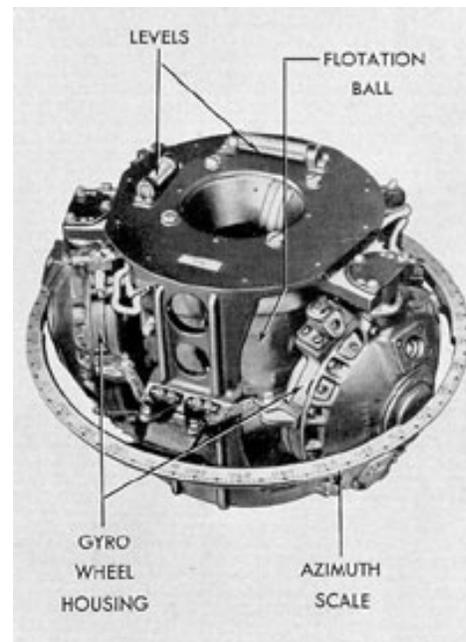


Figure 17-37. Arma auxiliary gyrocompass Mark 9, sensitive element.

extremely viscous oil. Access to the sensitive element is obtained by removing the top portion of the binnacle and the bridge cover over the element.

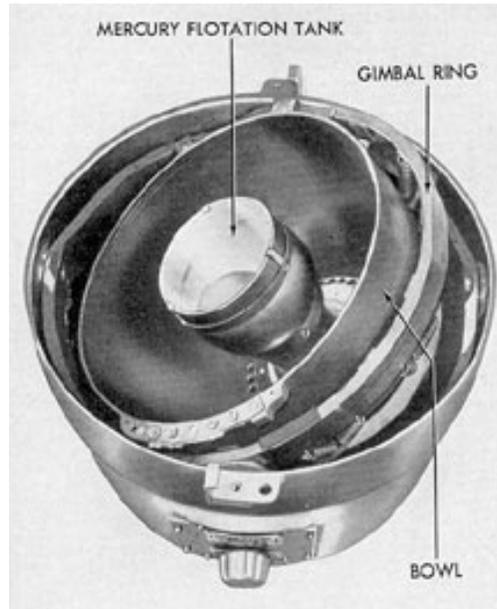


Figure 17-38. Arma auxiliary gyrocompass Mark 9, lower housing, gimbals and mercury flotation tank.

The gyro wheels are driven by squirrel cage, induction motors, whose high frequency supply is furnished by the motor generator. The single phase output of the generator is made 2-phase in effect, by running one side of the line through a condenser network to split the phase. The starting load on the gyro rotors is naturally much higher than the running load. To keep the phase relationship correct for both conditions, one of the condensers is cut out of the circuit when the wheels are nearly up to their normal speed. This is accomplished by a thermal relay mounted on the sensitive element. When the thermal relay is cold, its contacts are open. Its heating element is connected in series with one winding of the gyro motors, and consequently is subjected to the current drawn by

the gyros. The relay contacts are adjusted to open when the wheels are about up to speed, which requires approximately 10 minutes.

c. *Motor generator.* The motor generator (Figure 17-39) is designed to operate from 115 volts, d.c., and run at about 3,000 rpm. There are 2 generators in the unit. One, a 120-volt, 300-cycle, single-phase generator is for the gyro supply; the other, a 24-volt, d.c. generator is for operating the oscillator motor and compass lights.

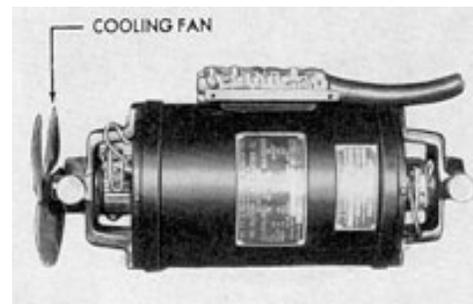


Figure 17-39. Arma auxiliary gyrocompass Mark 9 motor generator set with end covers removed.

d. *Control panel.* (See Figure 17-40.) One type of control panel is used where the compass power supply is between the limits of 88 to 125 volts d.c. This condition exists on ships in which the compass is run from the 88- to 125-volt lighting bus, which normally is controlled to 115 volts d.c. On other vessels using this panel, the compass normally is supplied from the 115-volt lighting motor generator, with an auxiliary supply from the 88- to 125-volt tap on the main battery, controlled to 115 volts. Here, both normal and auxiliary supplies come over the same leads from the I.C. switchboard. A green pilot lamp is provided to show when the power supply is available.

To insure positive starting of the motor generator, in case the voltage is allowed to drop to 88, a START position is provided on the motor generator switch. In this position, a

resistance is placed in series with the field of the motor, which is the shunt-wound type, and resistance is cut out of the generator field circuit. This gives sufficient speed and output voltage to start the gyros. The switch should be left in this position for 3 minutes, before being thrown to ON. The compass operates best when the supply voltage is kept within 10 percent of 115 volts.

17J2. Operation. In general, the operating procedures for the auxiliary compass are the same as for the main compass. Detailed instructions may be found in the manufacturer's instruction book.

17J3. Maintenance. Complete instructions for the maintenance of this compass are given in the manufacturer's instruction book which should be consulted prior to servicing the compass.



Figure 17-40. Arma auxiliary gyrocompass Mark 9 control panel.

K. DEAD RECKONING ANALYZING INDICATOR AND TRACER SYSTEMS

17K1. General. The Arma dead reckoning system consists of a Mark 5 Mod. 0 dead reckoning analyzer indicator located in the control room, and a Mark 7 Mod. 1 dead reckoning tracer located in the control room, or in some ships, in the conning tower.

The system, when properly set at the starting point, indicates at all times the latitude and longitude of the ship's position on dials visible through windows in the cover of the analyzer indicator, and traces the ship's movements on a chart placed on the tracer. The total distance traveled by the ship, regardless of its course, is also indicated on the analyzer.

17K2. Analyzer indicator. The analyzer indicator (Figures 17-41, 17-42, and 17-43) is an instrument for converting the ship's course and distance into direct readings of latitude, longitude, and miles traveled. It receives the ship's course from the gyrocompass, and its distance,

from the underwater log system. In some units, 2 transmitters have been installed in the analyzer indicator for transmitting distance and direction of ship's movement to the dead reckoning tracer motors which drive a pencil over a chart.

17K3. Distance converter. The distance converter is comprised of the distance input motor, energized by the underwater log distance transmitter, and the gearing that connects the motor to the component carriages.

These carriages are mounted in guide rollers to permit vertical motion which determines the position of a friction disk and consequently the speed of the gear train.

Crank arms, controlled by the input from the gyrocompass, position the carriages vertically. By their movement, the ship's travel, through the rotation of 2 disks, is resolved into

components in a north-south and east-west direction. Through an arrangement of gears and disks, the motions of the disks are transmitted to longitude and latitude dials and drive the dead reckoning tracer transmitters. Arrangement is made for shifting the latitude mechanism for either north or south operation when the equator is crossed. Likewise, the longitude mechanism must be shifted when crossing 0 or 180 degrees longitude.

17K4. Dead reckoning tracer. The tracer is enclosed in a metal box with hinged glass cover (Figure 17-44). The principal parts of the tracer mechanism include the cross screw motor which drives the tracing pencil in an east-west direction across the chart by rotating the cross screw. The north-south motion of the pencil is derived

from the lead screw motor which, through a screw shaft and nut, moves the cross screw, pencil, and support arms in a north-south direction.

To permit the use of the tracer on differently scaled charts, the speed of the cross screw and lead screw can be regulated by means of the friction disks between the drive motors and screw shafts. This setting is made by turning the handwheels to the scale of the chart being used. These handwheels are located outside the tracer box and are designated as *scale selectors*. Switches are provided to stop and start the screw motors. Illumination is controlled by means of a rheostat. Pilot lamps indicate when the mechanism has reached the end of the screw shafts. The initial starting point of the pencil is set by means of hand cranks.

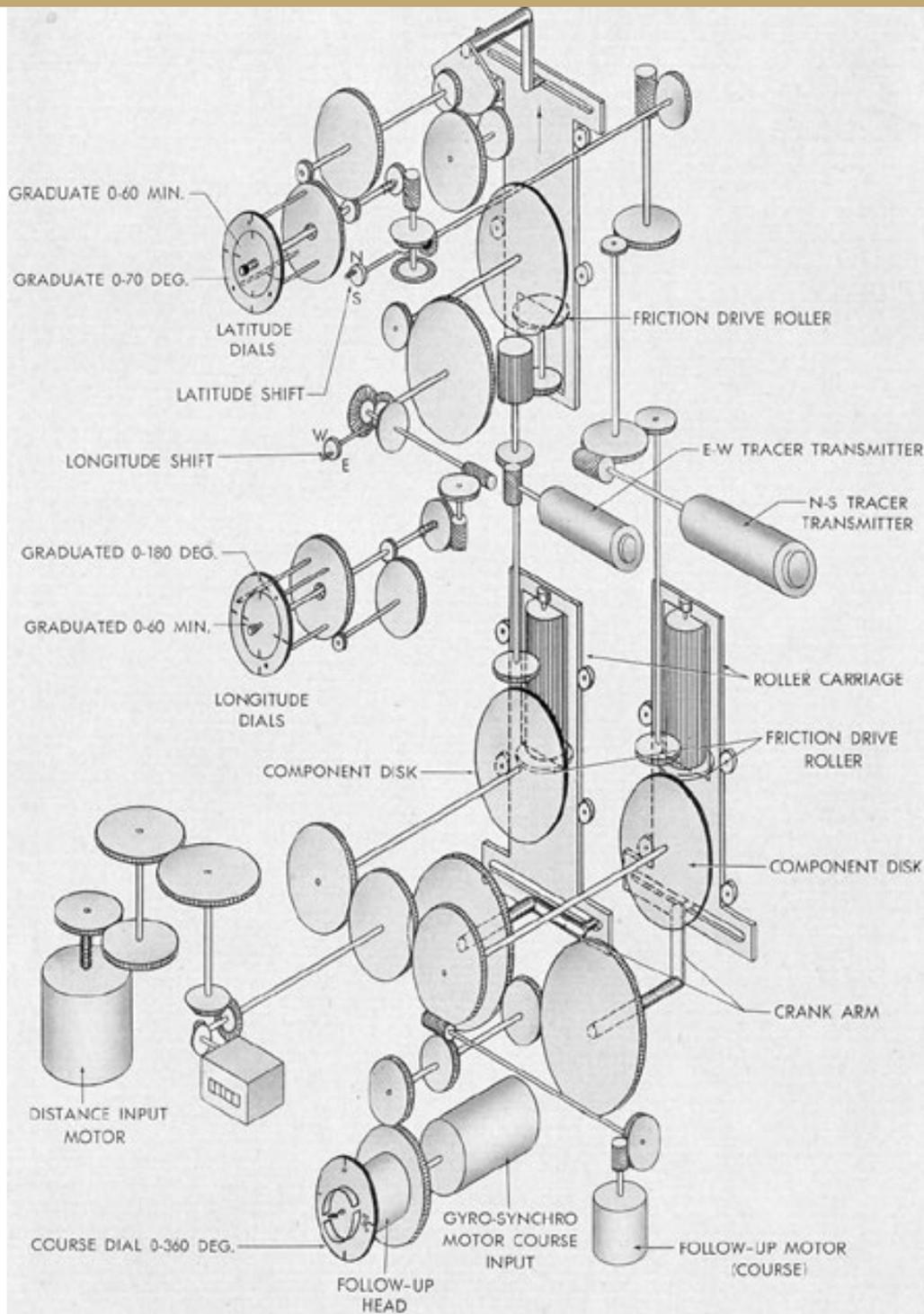


Figure 17-41. Dead reckoning analyzer Indicator gear diagram.

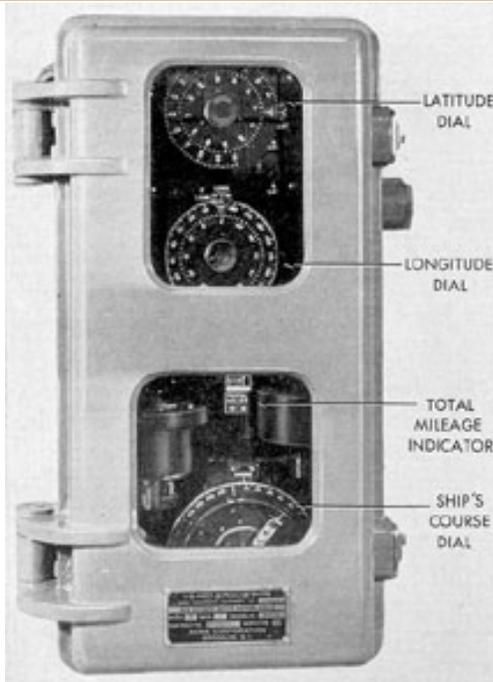


Figure 17-42. Dead reckoning analyzer indicator.

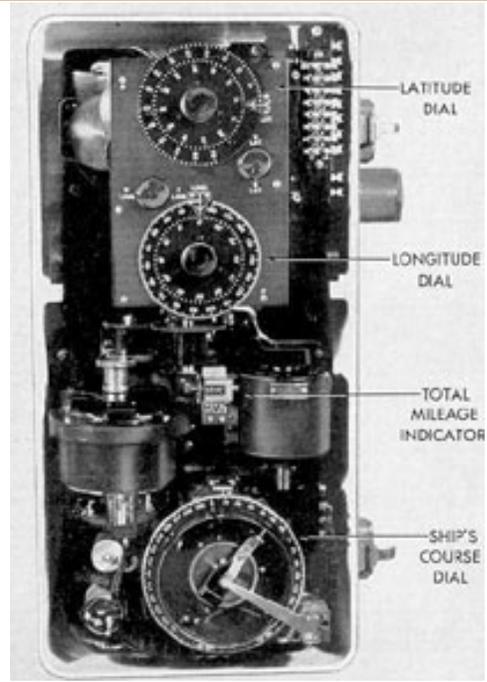


Figure 17-43. Dead reckoning analyzer Indicator with cover open.

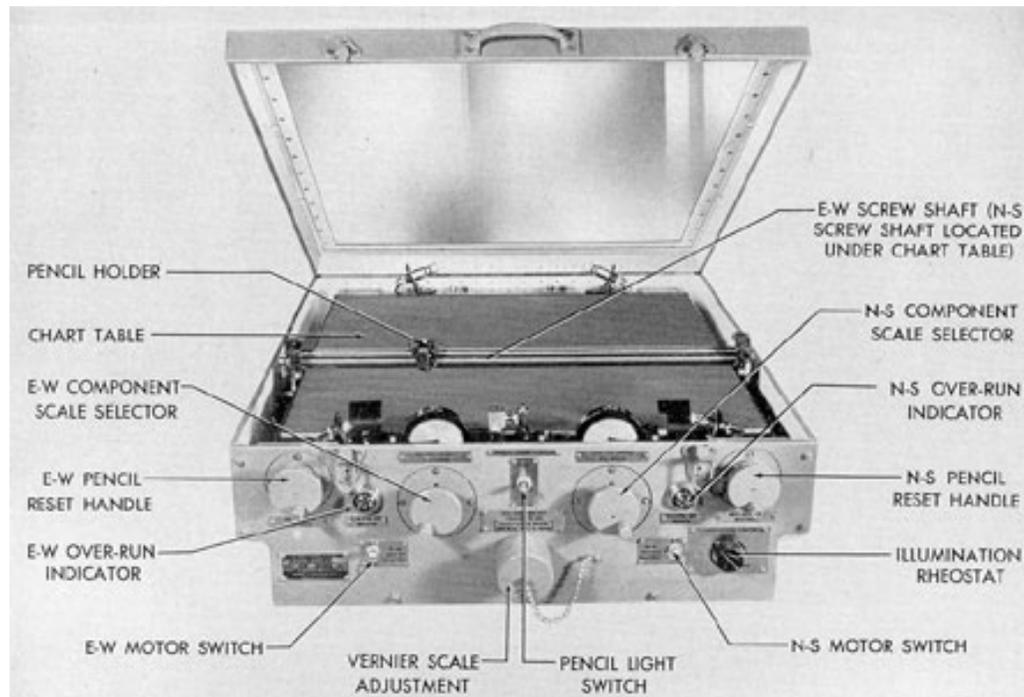


Figure 17-44. Dead reckoning tracer with cover raised.

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