CHAPTER 6

MAGNETIC COMPASS ADJUSTMENT

GENERAL PROCEDURES FOR MAGNETIC COMPASS ADJUSTMENT

600. Introduction

This chapter presents information and procedures for magnetic compass adjustment. Sections 601 and 613 cover procedures designed to eliminate compass errors satisfactorily. Refer to Figure 607 for condensed information regarding the various compass errors and their correction.

The term **compass adjustment** refers to any change of permanent magnet or soft iron correctors to reduce normal compass errors. The term **compass compensation** refers to any change in the current slupplied to the compass compensating coils to reduce degaussing errors.

601. Adjustment Check-Off List

If the magnetic adjustment necessitates (a) movement of degaussing compensating coils, or (b) a change of Flinders bar length, check also the coil compensation per section 646.

Expeditious compass adjustment depends on the application of the various correctors in an optimum sequence designed to minimize the number of correction steps. Certain adjustments may be made conveniently at dockside, simplifying the at sea adjustment procedures.

Moving the wrong corrector wastes time and upsets all previous adjustments, so be careful to make the correct adjustments. Throughout an adjustment, special care should be taken to pair off spare magnets so that the resultant field about them will be negligible. To make doubly sure that the compass is not affected by a spare magnet's stray field, keep them at an appropriate distance until they are actually inserted into the binnacle.

A. Dockside tests and adjustments.

1. Physical checks on the compass and binnacle.
   a. Remove any bubbles in compass bowl (section 610).
   b. Test for moment and sensibility of compass needles (section 610).
   c. Remove any slack in gimbal arrangement.
   d. Magnetization check of spheres and Flinders bar (section 610).
   e. Alignment of compass with fore-and-aft line of ship (section 610).
   f. Alignment of magnets in binnacle.
   g. Alignment of heeling magnet tube under pivot point of compass.
   h. See that corrector magnets are available.

2. Physical checks of gyro, azimuth circle, and peloruses.
   a. Alignment of peloruses with fore-and-aft line of ship (section 610).
   b. Synchronize gyro repeaters with master gyro.
   c. Ensure azimuth circles and peloruses are in good condition.

3. Necessary data.
   a. Past history or log data which might establish length of Flinders bar (sections 610 and 623).
   b. Azimuths for date and observer's position (section 633 and Chapter 17).
   c. Ranges or distant objects in vicinity if needed (local charts).
   d. Correct variation (local charts).
   e. Degaussing coil current settings for swing for residual deviations after adjustment and compensation (ship's Degaussing Folder).

4. Precautions.
   a. Determine transient deviations of compass from gyro repeaters, doors, guns, etc. (sections 636 and 639).
   b. Secure all effective magnetic gear in normal seagoing position before beginning adjustments.
   c. Make sure degaussing coils are secured before beginning adjustments. Use reversal sequence, if necessary.
   d. Whenever possible, correctors should be placed symmetrically with respect to the compass.

5. Adjustments.
   a. Place Flinders bar according to best available information (sections 610, 622 through 625).
   b. Set spheres at mid-position, or as indicated by last deviation table.
   c. Adjust heeling magnet, using balanced dip needle if available (section 637).

B. Adjustments at sea. Make these adjustments with the ship on an even keel and steady on each heading. When using the gyro, swing slowly from heading to heading and check

Fore-and-aft and athwartship magnets			Quadrantial spheres			Flinders bar		
Deviation → **Magnets** ↓	Easterly on east *and* westerly on west. (+B error)	Westerly on east *and* easterly on west. (-B error)	**Deviation** → **Spheres** ↓	E. on NE, E. on SE, W. on SW, *and* W. on NW. (+D error)	W. on NE, E. on SE, W. on SW, andE. on NW. (-D error)	**Deviation change with latitude change** → **Bar** ↓	E. on E. *and* W. on W when sailing toward equator from north latitude or away from equator to south latitude.	W. on E. *and* E. on W when sailing toward equator from north latitude or away from equator to south latitude.
No fore and aft magnets in binnacle.	Place magnets red forward.	Place magnets red aft.	No spheres on binnacle.	Place spheres athwartship.	Place spheres fore and aft.	No bar in holder.	Place required of bar forward.	Place required amount of bar aft.
Fore and aft magnets red forward.	Raise magnets.	Lower magnets.	Spheres at athwartship position.	Move spheres toward compass or use larger spheres.	Move spheres outwards or remove.	Bar forward of binnacle.	Increase amount of bar forward.	Deacrease amount of bar forward.
Fore and aft magnets red aft.	Lower magnets.	Raise magnets.	Spheres at fore and aft position.	Move spheres outward or remove.	Move spheres toward compass or use larger spheres.	Bar aft of binnacle.	Decrease amount of bar aft.	Increase amount of bar aft.
Deviation → **Magnets** ↓	Easterly on north *and* westerly on south. (+C error)	Westerly on north *and* easterly on south. (-C error)	**Deviation** → **Spheres** ↓	E. on N, W. on E, E. on S, *and* W. on W. (+E error)	W. on N, E. on E, W. on S, *and* E. on W. (-E error)	↑ **Bar** **Deviation change with latitude change** →	W. on E. *and* E. on W. when sailing toward equator from south latitude or away from equator to north latitude.	E. on E. *and* W. on W. when sailing toward equator from south latitude or away from equator to south latitude
No athwartship magnets in binnacle.	Place athwartship magnets red starboard.	Place athwartship magnets red port.	No spheres on binnacle.	Place spheres at port forward and starboard aft intercardinal positions.	Place spheres at starboard foreward and port aft intercardinal positions.	Heeling magnet (Adjust with changes in magnetic latitude)		
Athwartship magnets red starboard.	Raise magnets.	Lower magnets.	Spheres at athwartship position.	Slew spheres clockwise through required angle.	Slew spheres counter-clockwise through required angle.	If compass north is attracted to high side of ship when rolling, raise the heeling magnet if red end is up and *lower* the heeling magnet if blue end is up.		
Athwartship magnets red port.	Lower magnets.	Raise magnets.	Spheres at fore and aft position.	Slew spheres counter-clockwise through required angle.	Slew spheres clockwise through required angle.	If compass north is attracted to low side of ship when rolling, *lower* the heeling magnet if red end is up and *raise* the heeling magnet if blue end is up. NOTE: Any change in placement of the heeling magnet will affect the deviations on all headings.		

Figure 601. Mechanics of magnetic compass adjustment.

gyro error by sun’s azimuth or ranges on each heading to ensure a greater degree of accuracy (section 631). Be sure gyro is set for the mean speed and latitude of the vessel. Note all precautions in section A-4 above. Fly the “OSCAR QUEBEC” international code signal to indicate such work is in progress. Section 631 discusses methods for placing the ship on desired headings.

1. Adjust the heeling magnet while the ship is rolling on north and south magnetic headings until the oscillations of the compass card have been reduced to an average minimum. This step is not required if prior adjustment has been made using a dip needle to indicate proper placement of the heeling magnet.
2. Come to a cardinal magnetic heading, e.g., east (090°). Insert fore-and-aft B magnets, or move the existing B magnets, to remove *all* deviation.
3. Come to a south (180°) magnetic heading. Insert athwartship C magnets, or move the existing C magnets, to remove *all* deviation.
4. Come to a west (270°) magnetic heading. Correct *half* of any observed deviation by moving the B magnets.
5. Come to a north (000°) magnetic heading. Correct *half* of any observed deviation by moving the C magnets.

   The cardinal heading adjustments should now be complete.
6. Come to any intercardinal magnetic heading, e.g., northeast (045°). Correct any observed deviation by moving the spheres in or out.
7. Come to the next intercardinal magnetic heading, e.g., southeast (135°). Correct *half* of any observed deviation by moving the spheres.

The intercardinal heading adjustments should now be complete, although more accurate results might be obtained by correcting the D error determined from the deviations on all four intercardinal headings, as discussed in section 615.

8. Secure all correctors before swinging for residual deviations.
9. Swing for residual undegaussed deviations on as many headings as desired, although the eight cardinal and intercardinal headings should be sufficient.
10. Should there still be any large deviations, analyze the deviation curve to determine the necessary

corrections and repeat as necessary steps 1 through 9 above.

11. Record deviations and the details of corrector positions on the deviation card to be posted near the compass.
12. Swing for residual degaussed deviations with the degaussing circuits properly energized.
13. Record deviations for degaussed conditions on the deviation card.

The above check-off list describes a simplified method of adjusting compasses, designed to serve as a workable outline for the novice who chooses to follow a step-by-step procedure. The dockside tests and adjustments are essential as a foundation for the adjustments at sea. Neglecting the dockside procedures may lead to spurious results or needless repetition of the procedures at sea. Give careful consideration to these dockside checks prior to making the final adjustment. This will allow time to repair or replace faulty compasses, anneal or replace magnetized spheres or Flinders bars, realign the binnacle, move a gyro repeater if it is affecting the compass, or to make any other necessary preliminary repairs.

Expeditious compass adjustment depends upon the application of the various correctors in a logical sequence so as to achieve the final adjustment with a minimum number of steps. The above check-off list accomplishes this purpose. Figure 607 presents the various compass errors and their correction in condensed form. Frequent, careful observations should be made to determine the constancy of deviations, and results should be systematically recorded. Significant changes in deviation will indicate the need for readjustment.

To avoid Gaussin error (section 636) when adjusting and swinging ship for residuals, the ship should be steady on the desired heading for at least 2 minutes prior to observing the deviation.

602. The Magnetic Compass And Magnetism

The principle of the present day magnetic compass is no different from that of the compasses used by ancient mariners. It consists of a magnetized needle, or an array of needles, allowed to rotate in the horizontal plane. The superiority of the present day compasses over ancient ones results from a better knowledge of the laws of magnetism which govern the behavior of the compass and from greater precision in construction.

Any piece of metal on becoming magnetized will develop regions of concentrated magnetism called **poles**. Any such magnet will have at least two poles of opposite polarity. Magnetic force (flux) lines connect one pole of such a magnet with the other pole. The number of such lines per unit area represents the intensity of the magnetic field in that area. If two such magnetic bars or magnets are placed close to each other, the like poles will repel each other and the unlike poles will attract each other.

Magnetism can be either **permanent** or **induced**. A bar having permanent magnetism will retain its magnetism when it is removed from the magnetizing field. A bar having induced magnetism will lose its magnetism when removed from the magnetizing field. Whether or not a bar will retain its magnetism on removal from the magnetizing field will depend on the strength of that field, the degree of hardness of the iron (retentivity), and also upon the amount of physical stress applied to the bar while in the magnetizing field. The harder the iron, the more permanent will be the magnetism acquired.

603. Terrestrial Magnetism

Consider the earth as a huge magnet surrounded by magnetic flux lines connecting its two **magnetic poles**. These magnetic poles are near, but not coincidental with, the earth's geographic poles. Since the north seeking end of a compass needle is conventionally called the **north pole**, or **positive pole**, it must therefore be attracted to a **south pole**, or **negative pole**.

Figure 603a illustrates the earth and its surrounding magnetic field. The flux lines enter the surface of the earth at different angles to the horizontal, at different magnetic atitudes. This angle is called the **angle of magnetic dip**, θ, and

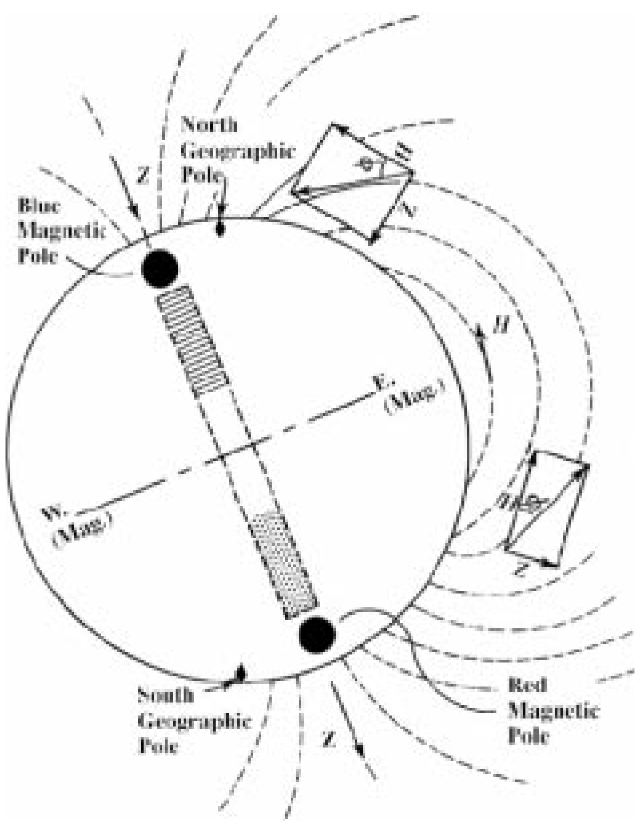


Figure 603a. Terrestrial magnetism.

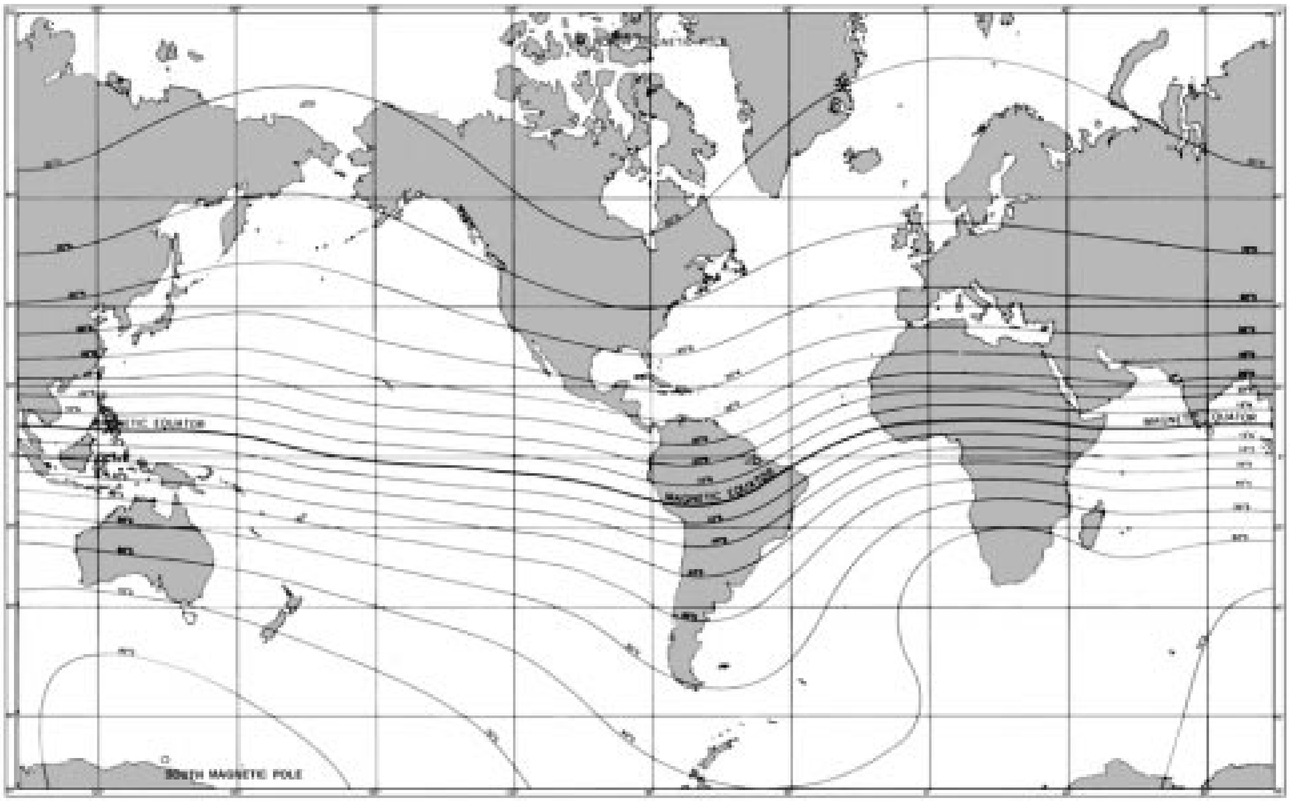


Figure 603b. Magnetic dip chart, a simplification of chart 30.

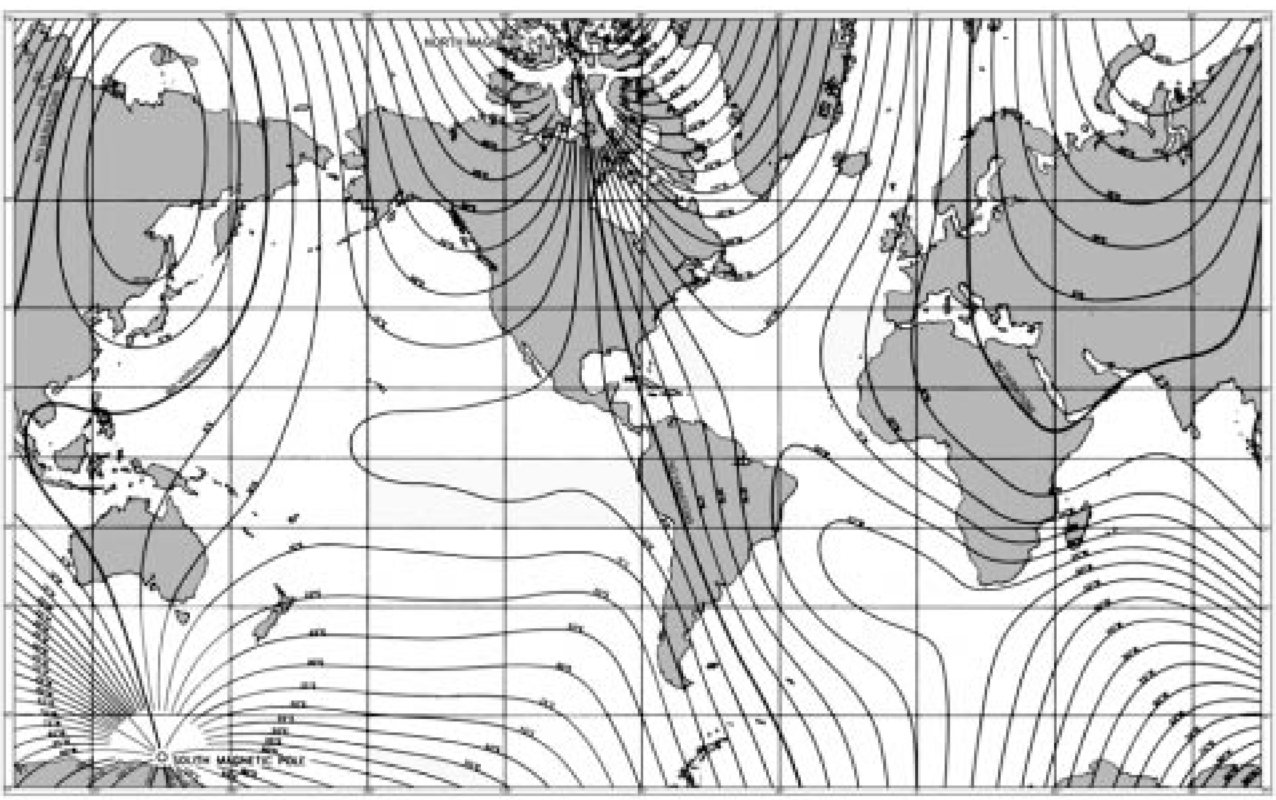


Figure 603c. Magnetic variation chart, a simplification of chart 42.

increases from 0°, at the magnetic equator, to 90° at the magnetic poles. The total magnetic field is generally considered as having two components: H, the horizontal component; and Z, the vertical component. These components change as the angle θ, changes, such that H is maximum at the magnetic equator and decreases in the direction of either pole; Z is zero at the magnetic equator and increases in the direction of either pole. The values of magnetic dip may be found on **Chart 30** (shown simplified in Figure 603b). The values of H and Z may be found on charts 33 and 36.

Since the magnetic poles of the earth do not coincide with the geographic poles, a compass needle in line with the earth's magnetic field will not indicate true north, but magnetic north. The angular difference between the true meridian (great circle connecting the geographic poles) and the magnetic meridian (direction of the lines of magnetic flux) is called **variation**. This variation has different values at different locations on the earth. These values of magnetic variation may be found on Chart 42 (shown simplified in Figure 603c), on pilot charts, and, on the compass rose of navigational charts. The variation for most given areas undergoes an annual change, the amount of which is also noted on charts.

604. Ship's Magnetism

A ship under construction or major repair will acquire permanent magnetism due to hammering and jarring while sitting stationary in the earth's magnetic field. After launching, the ship will lose some of this original magnetism as a result of vibration and pounding in varying magnetic fields, and will eventually reach a more or less stable magnetic condition. The magnetism which remains is the **permanent magnetism** of the ship.

The fact that a ship has permanent magnetism does not mean that it cannot also acquire induced magnetism when placed in the earth's magnetic field. The magnetism induced in any given piece of soft iron is a function of the field intensity, the alignment of the soft iron in that field, and the physical properties and dimensions of the iron. This induced magnetism may add to, or subtract from, the permanent magnetism already present in the ship, depending on how the ship is aligned in the magnetic field. The softer the iron, the more readily it will be magnetized by the earth's magnetic field, and the more readily it will give up its magnetism when removed from that field.

The magnetism in the various structures of a ship, which tends to change as a result of cruising, vibration, or aging, but which does not alter immediately so as to be properly termed induced magnetism, is called **subpermanent magnetism**. This magnetism, at any instant, is part of the ship's permanent magnetism, and consequently must be corrected by permanent magnet correctors. It is the principal cause of deviation changes on a magnetic compass. Subsequent reference to permanent magnetism will refer to the apparent permanent magnetism which includes the existing permanent and subpermanent magnetism.

A ship, then, has a combination of permanent, subpermanent, and induced magnetism. Therefore, the ship's apparent permanent magnetic condition is subject to change from deperming, excessive shocks, welding, and vibration. The ship's induced magnetism will vary with the earth's magnetic field strength and with the alignment of the ship in that field.

605. Magnetic Adjustment

A rod of soft iron, in a plane parallel to the earth's horizontal magnetic field, H, will have a north pole induced in the end toward the north geographic pole and a south pole induced in the end toward the south geographic pole. This same rod in a horizontal plane, but at right angles to the horizontal earth's field, would have no magnetism induced in it, because its alignment in the magnetic field is such that there will be no tendency toward linear magnetization, and the rod is of negligible cross section. Should the rod be aligned in some horizontal direction between those headings which create maximum and zero induction, it would be induced by an amount which is a function of the angle of alignment. If a similar rod is placed in a vertical position in northern latitudes so as to be aligned with the vertical earth's field Z, it will have a south pole induced at the upper end and a north pole induced at the lower end. These polarities of vertical induced magnetization will be reversed in southern latitudes.

The amount of horizontal or vertical induction in such rods, or in ships whose construction is equivalent to combinations of such rods, will vary with the intensity of H and Z, heading and heel of the ship.

The magnetic compass must be corrected for the vessel's permanent and induced magnetism so that its operation approximates that of a completely nonmagnetic vessel. Ship's magnetic conditions create magnetic compass deviations and sectors of sluggishness and unsteadiness. **Deviation** is defined as deflection right or left of the magnetic meridian. Adjusting the compass consists of arranging magnetic and soft iron **correctors** about the binnacle so that their effects are equal and opposite to the effects of the magnetic material in the ship.

The total permanent magnetic field effect at the compass may be broken into three components, mutually 90° apart, as shown in Figure 605a.

The vertical permanent component tilts the compass card, and, when the ship rolls or pitches, causes oscillating deflections of the card. Oscillation effects which accompany roll are maximum on north and south compass headings, and those which accompany pitch are maximum on east and west compass headings.

The horizontal B and C components of permanent magnetism cause varying deviations of the compass as the ship swings in heading on an even keel. Plotting these deviations against compass heading yields the sine and cosine curves shown in Figure 605b. These deviation curves are called semicircular curves because they reverse direction by 180°.

A vector analysis is helpful in determining deviations or

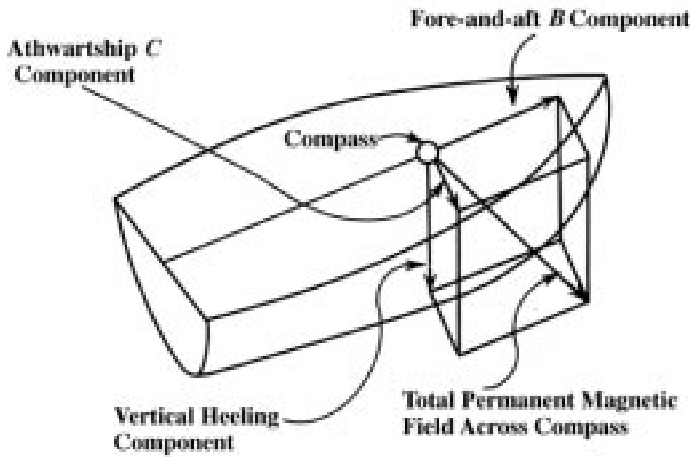


Figure 605a. Components of permanent magnetic field.

the strength of deviating fields. For example, a ship as shown in Figure 605c on an east magnetic heading will subject its compass to a combination of magnetic effects; namely, the earth's horizontal field H, and the deviating field B, at right angles to the field H. The compass needle will align itself in the resultant field which is represented by the vector sum of H and B, as shown. A similar analysis will reveal that the resulting directive force on the compass would be maximum on a north heading and minimum on a south heading because the deviations for both conditions are zero.

The magnitude of the deviation caused by the permanent B magnetic field will vary with different values of H; hence, deviations resulting from permanent magnetic fields will vary with the magnetic latitude of the ship.

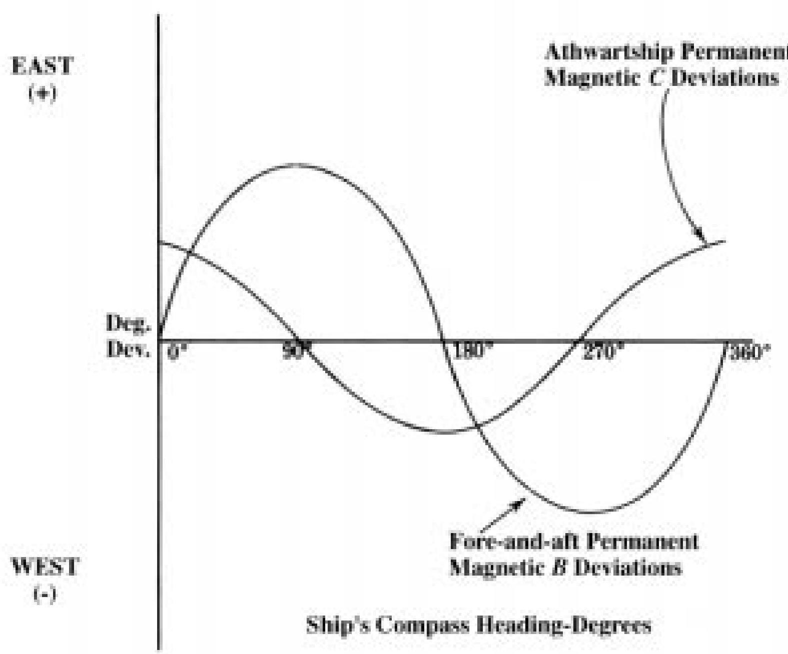


Figure 605b. Permanent magnetic deviation effects.

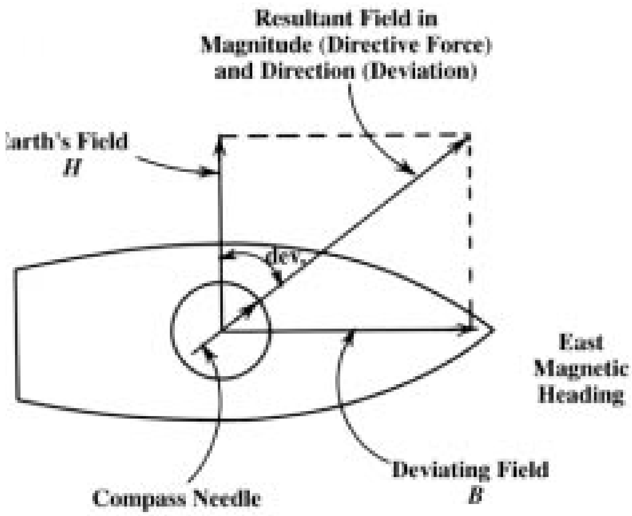


Figure 605c. General force diagram.

606. Induced Magnetism And Its Effects On The Compass

Induced magnetism varies with the strength of the surrounding field, the mass of metal, and the alignment of the metal in the field. Since the intensity of the earth's magnetic field varies over the earth's surface, the induced magnetism in a ship will vary with latitude, heading, and heel of the ship.

With the ship on an even keel, the resultant vertical induced magnetism, if not directed through the compass itself, will create deviations which plot as a semicircular deviation curve. This is true because the vertical induction changes magnitude and polarity only with magnetic latitude and heel, and not with heading of the ship. Therefore, as long as the ship is in the same magnetic latitude, its vertical induced pole swinging about the compass will produce the same effect on the compass as a permanent pole swinging about the compass.

The earth's field induction in certain other unsymmetrical arrangements of horizontal soft iron create a constant A deviation curve. In addition to this magnetic A error, there are constant A deviations resulting from: (1) physical misalignments of the compass, pelorus, or gyro; (2) errors in calculating the sun's azimuth, observing time, or taking bearings.

The nature, magnitude, and polarity of all these induced effects are dependent upon the disposition of metal, the symmetry or asymmetry of the ship, the location of the binnacle, the strength of the earth's magnetic field, and the angle of dip.

Coefficient	Type deviation curve	Compass headings of maximum deviation	Causes of such errors	Correctors for such errors	Magnetic or compass headings on which to apply correctors
A	Constant.	Same on all.	Human-error in calculations _ _ _ _ _ _ _ _ _ _ _ _ Physical-compass, gyro, pelorus alignment _ _ _ _ _ _ _ Magnetic-unsymmetrical arrangements of horiz. soft iron.	Check methods and calculations _ _ _ Check alignments _ _ _ _ _ _ _ _ Rare arrangement of soft iron rods.	Any.
B	Semicircular $\sin\phi$.	090° 270°	Fore-and-aft component of permanent magnetic field _ _ _ Induced magnetism in unsymmetrical vertical iron forward or aft of compass.	Fore-and-aft *B* magnets _ _ _ _ _ _ Flinders bar (forward or aft) _ _ _ _	090° or 270°.
C	Semicircular $\cos\phi$.	000° 180°	Athwartship component of permanent magnetic field- - - - - - Induced magnetism in unsymmetrical vertical iron port or starboard of compass.	Athwartship *C* magnets _ _ _ _ _ _ Flinders bar (port or starboard) _ _ _	000° or 180°.
D	Quadrantral $\sin 2\phi$.	045° 135° 225° 315°	Induced magnetism in all symmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (athwartship for +D) (fore and aft for -D) *See sketch a*	045°, 135°, 225°, or 315°.
E	Quadrantral $\cos 2\phi$.	000° 090° 180° 270°	Induced magnetism in all unsymmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (port fwd.-stb'd for +E) (stb'd fwd.-port aft for -E) *See sketch b*	000°, 090°, 180°, or 270°.
Heeling	Oscillations with roll or pitch. Deviations with constant list.	000° 180° } roll 090° 270° } pitch	Change in the horizontal component of the induced or permanent magnetic fields at the compass due to rolling or pitching of the ship.	Heeling magnet (must be readjusted for latitude changes).	090° or 270° with dip needle. 000° or 180° while rolling.

$$\text{Deviation} = A + B\sin\phi + C\cos\phi + D\sin 2\phi + E\cos 2\phi \quad (\phi = \text{compass heading})$$

Figure 607. Summary of compass errors and adjustments.

Certain heeling errors, in addition to those resulting from permanent magnetism, are created by the presence of both horizontal and vertical soft iron which experience changing induction as the ship rolls in the earth's magnetic field. This part of the heeling error will naturally change in magnitude with changes of magnetic latitude of the ship. Oscillation effects accompanying roll are maximum on north and south headings, just as with the permanent magnetic heeling errors.

607. Adjustments And Correctors

Since some magnetic effects are functions of the vessel's magnetic latitude and others are not, each individual effect should be corrected independently. Furthermore, to make the corrections, use (1) permanent magnet correctors to compensate for permanent magnetic fields at the compass, and (2) soft iron correctors to compensate for induced magnetism. The compass binnacle provides support for both the compass and such correctors. Typical binnacles hold the following correctors:

1. Vertical permanent **heeling magnet** in the central vertical tube.
2. Fore-and-aft **B permanent magnets** in their trays.
3. Athwartship **C permanent magnets** in their trays.
4. Vertical soft iron **Flinders bar** in its external tube.
5. Soft iron **quadrantal spheres**.

The heeling magnet is the only corrector which corrects for both permanent and induced effects. Therefore, it must be adjusted occasionally for changes in ship's latitude. However, any movement of the heeling magnet will require readjustment of other correctors.

Figure 607 summarizes all the various magnetic conditions in a ship, the types of deviation curves they create, the correctors for each effect, and headings on which each corrector is adjusted. Apply the correctors symmetrically and as far away from the compass as possible. This preserves the uniformity of magnetic fields about the compass needle array.

Fortunately, each magnetic effect has a slightly different characteristic curve. This makes identification and correction convenient. Analyzing a complete deviation curve for its different components allows one to anticipate the necessary corrections.

COMPASS OPERATION

608. Effects Of Errors On The Compass

An uncorrected compass suffers large deviations and sluggish, unsteady operation. These conditions may be associated with the maximum and minimum directive force acting on the compass. The maximum deviation occurs at the point of average directive force; and the zero deviations occur at the points of maximum and minimum directive force.

Applying correctors to reduce compass deviation effects compass error correction. Applying correctors to equalize the directive forces across the compass position could also effect compass correction. The deviation method is most often used because it utilizes the compass itself as the correction indicator. Equalizing the directive forces would require an additional piece of test and calibration equipment.

Occasionally, the permanent magnetic effects at the location of the compass are so large that they overcome the earth's directive force, H. This condition will not only create sluggish and unsteady sectors, but may even freeze the compass to one reading or to one quadrant, regardless of the heading of the ship. Should the compass become so frozen, the polarity of the magnetism which must be attracting the compass needles is indicated; hence, correction may be effected simply by the application of permanent magnet correctors, in suitable quantity to neutralize this magnetism. Whenever such adjustments are made, it would be well to have the ship placed on a heading such that the unfreezing of the compass needles will be immediately evident. For example, a ship whose compass is frozen to a north reading would require fore-and-aft B corrector magnets with the positive ends forward in order to neutralize the existing negative pole which attracted the compass. If made on an east heading, such an adjustment would be practically complete when the compass card was freed to indicate an east heading.

609. Reasons For Correcting Compass

There are several reasons for correcting the errors of the magnetic compass:

1. It is easier to use a magnetic compass if the deviations are small.
2. Even known and compensated for deviation introduces error because the compass operates sluggishly and unsteadily when deviation is present.
3. Even though the deviations are compensated for, they will be subject to appreciable change as a function of heel and magnetic latitude.

Once properly adjusted, the magnetic compass deviations should remain constant until there is some change in the magnetic condition of the vessel resulting from magnetic treatment, shock from gunfire, vibration, repair, or structural changes. Frequently, the movement of nearby guns, doors, gyro repeaters, or cargo affects the compass greatly.

DETAILED PROCEDURES FOR COMPASS ADJUSTMENT

610. Dockside Tests And Adjustments

Section 601, the Adjustment Checkoff List, gives the physical checks required before beginning an adjustment. The adjustment procedure assumes that these checks have been completed. The navigator will avoid much delay by making these checks before starting the magnet and soft iron corrector adjustments. The most important of these checks are discussed below.

Should the compass have a small bubble, add compass fluid through the filling plug on the compass bowl. If an appreciable amount of compass liquid has leaked out, check the sealing gasket and filling plug for leaks.

Take the compass to a place free from all magnetic influences except the earth's magnetic field for tests of **moment** and **sensibility**. These tests involve measurements of the time of vibration and the ability of the compass card to return to a consistent reading after deflection. These tests will indicate the condition of the pivot, jewel, and magnetic strength of the compass needles.

Next, check the spheres and Flinders bar for residual magnetism. Move the spheres as close to the compass as possible and slowly rotate each sphere separately. Any appreciable deflection (2° or more) of the compass needles resulting from this rotation indicates residual magnetism in the spheres. The Flinders bar magnetization check is preferably made with the ship on an east or west compass heading. To make this check: (a) note the compass reading with the Flinders bar in the holder; (b) invert the Flinders bar in the holder and again note the compass reading. Any appreciable difference (2° or more) between these observed readings indicates residual magnetism in the Flinders bar. Spheres or Flinders bars which show signs of such residual magnetism should be **annealed**, i.e., heated to a dull red and allowed to cool slowly.

Correct alignment of the lubber's line of the compass, gyro repeater, and pelorus with the fore-and-aft line of the ship is important. Any misalignment will produce a constant error in the deviation curve. All of these instruments may be aligned correctly with the fore-and-aft line of the ship by using the azimuth circle and a metal tape measure. Should the instrument be located on the centerline of the ship, a sight is taken on a mast or other object on the centerline. If the instrument is not on the centerline, measure the distance from the centerline of the ship to the center of the instrument. Mark this distance off from the centerline forward or abaft the compass and place reference marks on the deck. Take sights on these marks.

Align the compass so that the compass' lubber's line is parallel to the fore-and-aft line of the ship. Steering compasses may occasionally be deliberately misaligned in order to correct for any magnetic A error present, as discussed in section 611.

Adjust the Flinders bar first because it is subject to induction from several of the correctors and its adjustment is not dependent on any single observation. To adjust the Flinders bar, use one of the following methods:

1. Use deviation data obtained at two different magnetic latitudes to calculate the proper length of Flinders bar for any particular compass location. Sections 622 through 624 contain details on acquiring the data and making the required calculations.

2. If the above method is impractical, set the Flinders bar length by:

   a. Using a Flinders bar length determined by other ships of similar structure.

   b. Studying the arrangement of masts, stacks, and other vertical structures and estimating the Flinders bar length required.

If these methods are not suitable, omit the Flinders bar until the required data are acquired.

The iron sections of Flinders bar should be continuous and placed at the top of the tube with the longest section at the top. Wooden spacers are used at the bottom of the tube.

Having adjusted the length of Flinders bar, place the spheres on the bracket arms at an approximate position. If the compass has been adjusted previously, place the spheres at the position indicated by the previous deviation table. In the event the compass has never been adjusted, place the spheres at the midpoint on the bracket arms.

The next adjustment is the positioning of the heeling magnet using a properly balanced dip needle. Section 637 discusses this procedure.

These three dockside adjustments (Flinders bar, quadrantal spheres, and heeling magnet) will properly establish the conditions of mutual induction and shielding of the compass. This minimizes the steps required at sea to complete the adjustment.

611. Expected Errors

Figure 607 lists six different coefficients or types of deviation errors with their causes and corresponding correctors. A discussion of these coefficients follows:

The **A error** is caused by the miscalculation of azimuths or by physical misalignments rather than magnetic effects of unsymmetrical arrangements of horizontal soft iron. Thus, checking the physical alignments at dockside and making careful calculations will minimize the A error. Where an azimuth or bearing circle is used on a standard compass to determine deviations, any observed A error will be solely magnetic A error because such readings are taken on the face of the compass card rather than at the lubber's line of the compass. On a steering compass where deviations are obtained by a comparison of the compass lubber's line reading with the ship's magnetic heading, as determined by pelorus or gyro, any observed A error may be a combination of magnetic A and mechanical A (misalignment). These facts explain the procedure in which only mechanical A is corrected on the standard compass, by realignment of the binnacle, and both mechanical A and magnetic A errors are corrected on the steering compass by realignment of the binnacle. On the standard compass, the mechanical A error may be isolated from the magnetic A error by making the following observations simultaneously:

1. Record a curve of deviations by using an azimuth (or bearing) circle. Any A error found will be solely magnetic A.

2. Record a curve of deviations by comparison of the compass lubber's line reading with the ship's magnetic heading as determined by pelorus or by gyro. Any A error found will be a combination of mechanical A and magnetic A.

3. The mechanical A on the standard compass is then found by subtracting the A found in the first instance from the total A found in the second instance, and is corrected by rotating the binnacle in the proper direction by that amount. It is neither convenient nor necessary to isolate the two types of A on the steering compass and all A found by using the pelorus or gyro may be removed by rotating the binnacle in the proper direction.

The **B error** results from both the fore-and-aft permanent magnetic field across the compass and a resultant unsymmetrical vertical induced effect forward or aft of the compass. The former is corrected by the use of fore-and-aft B magnets, and the latter is corrected by the use of the Flinders bar forward or aft of the compass. Because the Flinders bar setting is a dockside adjustment, any remaining B error is corrected by the use of fore-and-aft B magnets.

The **C error** results from the athwartship permanent magnetic field across the compass and a resultant unsymmetrical vertical induced effect athwartship of the compass. The former is corrected by the use of athwartship C magnets, and the latter by the use of the Flinders bar to port or starboard of the compass. Because the vertical induced effect is very rare, the C error is corrected by athwartship C magnets only.

The **D error** is due only to induction in the symmetrical arrangements of horizontal soft iron, and requires correction by spheres, generally athwartship of the compass.

E error of appreciable magnitude is rare, since it is caused by induction in the unsymmetrical arrangements of horizontal soft iron. When this error is appreciable it may be corrected by slewing the spheres, as described in section 620.

As stated previously, the heeling error is adjusted at dockside with a **balanced dip needle** (see section 637).

As the above discussion points out, certain errors are rare and others are corrected at dockside. Therefore, for most ships, only the B, C, and D errors require at sea correction. These errors are corrected by the fore-and-aft B magnets, athwartship C magnets, and quadrantal spheres respectively.

612. Study Of Adjustment Procedure

Inspecting the B, C, and D errors pictured in Figure 612a demonstrates a definite isolation of deviation effects on *cardinal* compass headings.

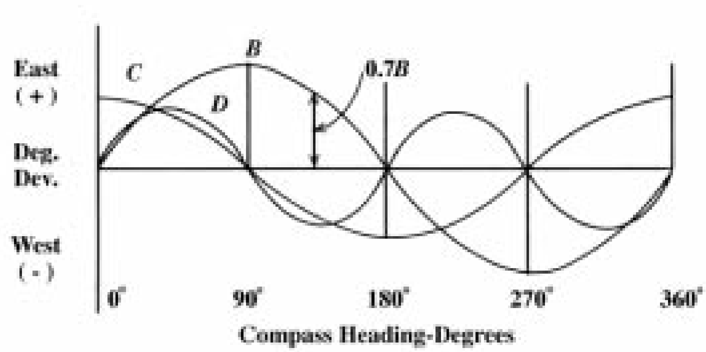


Figure 612a. B, C, and D deviation effects.

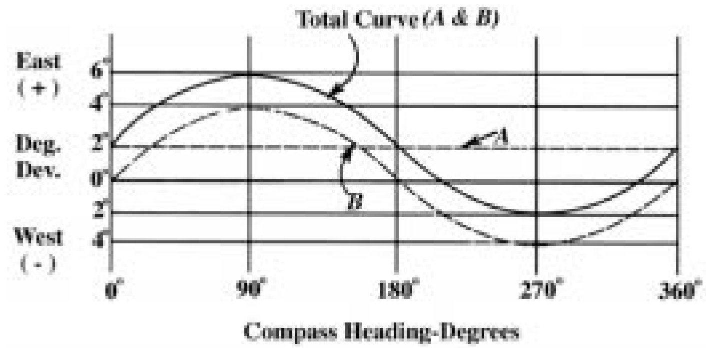


Figure 612b. A and B deviation.

For example, on 090° or 270° compass headings, the only deviation which is effective is that due to B. This isolation, and the fact that the B effect is greatest on these two headings, make these headings convenient for B correction. Correction of the B deviation on a 090° heading will correct the B deviation on the 270° heading by the same amount but in the opposite direction and naturally, it will not change the deviations on the 000° and 180° headings, except where B errors are large. However, the total deviation on all the intercardinal headings will be shifted in the same direction as the adjacent 090° or 270° deviation correction, but only by seven-tenths (0.7) of that amount, since the sine of 45° equals 0.707. The same convenient isolation of effects and corrections of C error will also change the deviations on all the intercardinal headings by the seven-tenths rule.

Note that only after correcting the B and C errors on the cardinal headings, and consequently their proportional values of the total curve on the intercardinal headings, can the D error be observed separately on any of the intercardinal headings. The D error may then be corrected by use of the spheres on any intercardinal heading. Correcting D error will, as a rule, change the deviations on the intercardinal headings only, and not on the cardinal headings. Only when the D error is excessive, the spheres are magnetized, or the permanent magnet correctors are so close as to create excessive induction in the spheres will there be a change in the deviations on cardinal headings as a result of sphere adjustments. Although sphere correction does not generally correct deviations on cardinal headings, it does improve compass stability on these headings.

If it were not for the occasional A or E errors, adjusting observed deviations to zero on two adjacent cardinal headings and then on the intermediate intercardinal heading would be sufficient. However, Figure 612b, showing a combination of A and B errors, illustrates why the adjusting procedure must include correcting deviations on more than the three essential headings.

Assuming no A error existed in the curve illustrated in Figure 612b, and the total deviation of 6° E on the 090° heading were corrected with B magnets, the error on the 270° heading would be 4° E due to B overcorrection. If this 4° E error were taken out on the 270° heading, the error on the 090° heading would then be 4° E due to B undercorrection. To eliminate this endlessly iterative process and correct the B error to the best possible flat curve, split this 4° E difference, leaving 2° E deviation on each opposite heading. This would, in effect correct the B error, leaving only the A error of 2° E which must be corrected by other means. It is for this reason that, (1) splitting is done between the errors noted on opposite headings, and (2) good adjustments entail checking on all headings rather than on the fundamental three.

613. Adjustment Procedures At Sea

Before proceeding with the adjustment at sea the following precautions should be observed:

1. Secure all effective magnetic gear in the normal seagoing position.

2. Make sure the degaussing coils are secured, using the reversal sequence, if necessary (See section 643).

The adjustments are made with the ship on an even keel, swinging from heading to heading slowly, and after steadying on each heading for at least 2 minutes to avoid Gaussin error.

Most adjustments can be made by trial and error, or by routine procedure such as the one presented in section 601. However, the procedures presented below provide analytical methods in which the adjuster is always aware of the errors' magnitude on all headings as a result of his movement of the different correctors.

Analysis Method. A complete deviation curve can be taken for any given condition, and an estimate made of all the approximate coefficients. See section 615. From this estimate, the approximate coefficients are established and the appropriate corrections are made with reasonable accuracy on a minimum number of headings. If the original deviation curve has deviations greater than 20°, rough adjustments should be made on two adjacent cardinal headings before recording curve data for such analysis. The mechanics of

Heading by compass	1 Original deviation curve	2 Anticipated curve after first correcting *A* = 1.0° E	3 Anticipated curve after next correcting *B* = 12.0° E	4 Anticipated curve after next correcting *C* = 8.0° E	5 Anticipated curve after next correcting *D* = 5.0° E	6 Anticipated curve after next correcting *E* = 1.5° E
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	10.5 E.	9.5 E.	9.5 E.	1.5 E.	1.5 E.	0.0
045	20.0 E.	19.0 E.	10.6 E.	5.0 E.	0.0	0.0
090	11.5 E.	10.5 E.	1.5 W.	1.5 W.	1.5 W.	0.0
135	1.2 W.	2.2 W.	10.6 W.	5.0 W.	0.0	0.0
180	5.5 W.	6.5 W.	6.5 W.	1.5 E.	1.5 E.	0.0
225	8.0 W.	9.0 W.	0.6 W.	5.0 E.	0.0	0.0
270	12.5 W.	13.5 W.	1.5 W.	1.5 W.	1.5 W.	0.0
315	6.8 W.	7.8 W.	0.6 E.	5.0 W.	0.0	0.0

Figure 613a. Tabulating anticipated deviations.

applying correctors are presented in Figure 601. A method of tabulating the anticipated deviations after each correction is illustrated in Figure 613a. The deviation curve used for illustration is the one which is analyzed in section 615. Analysis revealed these coefficients:

A = 1.0˚ E

B = 12.0˚ E

C = 8.0˚ E

D = 5.0˚ E

E = 1.5˚ E

One-Swing Method. More often it is desirable to begin adjustment immediately, eliminating the original swing for deviations and the estimate of approximate coefficients. In this case the above problem would be solved by tabulating data and anticipating deviation changes as the corrections are made. Figure 613b illustrates this procedure. Note that a new column of values is started after each change is made. This method of tabulation enables the adjuster to calculate the new residual deviations each time a corrector is changed, so that a record of deviations is available at all times during the swing. Arrows indicate where each change is made.

Since the B error is generally greatest, it is corrected first. Therefore, on a 090° heading the 11.5° E deviation is corrected to approximately zero by using fore-and-aft B magnets. A lot of time need not be spent trying to reduce this deviation to exactly zero since the B coefficient may not be exactly 11.5° E, and some splitting might be desirable later. After correcting on the 090° heading, the swing would then be continued to 135° where a 9.2° W error would be observed. This deviation is recorded, but no correction is made because the quadrant error is best corrected after the deviations on all four cardinal headings have been corrected. The deviation on the 180° heading would be observed as 5.5° W. Since this deviation is not too large and splitting may be necessary later, it need not be corrected at this time. Continuing the swing to 225° a 0.0° deviation would be observed and recorded. On the 270° heading the observed error would be 1.0° W, which is compared with 0.0° deviation on the opposite 090° heading. This could be split, leaving 0.5° W deviation on both 090° and 270°, but since this is so small it may be left uncorrected. On 315˚ the observed deviation would be 1.2° E. At 000° a deviation of 10.5°

Heading	First observation	Observed deviations after correcting *B* = 11.5° E	Anticipated deviations after correcting *C* = 8.0° E	Anticipated deviations after correcting *D* =5.0° E	Anticipated deviations after correcting *A* = 1.0° E	Anticipated deviations after correcting *E* = 1.5° E
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	...	10.5 E.→	2.5 E.	2.5 E.	1.5 E.	0.0
045	...	...	6.4 E.→	1.4 E.→	0.4 E.	0.4 E.
090	11.5 E.→	0.0	0.0	0.0	1.0 W.→	0.5 E.
135	...	9.2 W.	3.6 W.	1.4 E.	0.4 E.	0.4 E.
180	...	5.5 W.	2.5 E.	2.5 E.	1.5 E.	0.0
225	...	0.0	5.6 E.	0.6 E.	0.4 W.	0.4 W.
270	...	1.0 W.	1.0 W.	1.0 W.	2.0 W.	0.5 W.
315	...	1.2 E.	4.4 W.	0.6 E.	0.4 W.	0.4 W.

Figure 613b. Tabulating anticipated deviations by the one-swing.

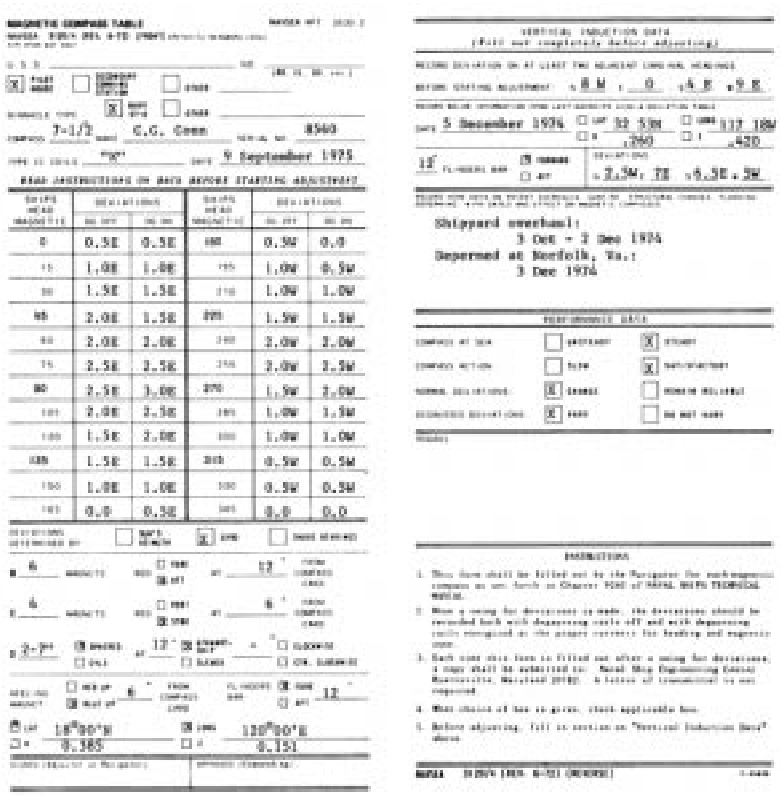
E would be observed and compared with 5.5° W on 180°. Analysis of the deviations on 000° and 180° headings reveals an 8.0° E, C error, which should then be corrected with athwartship C magnets leaving 2.5° E deviation on both the 000° and 180° headings.

All the deviations in column two are now recalculated on the basis of such an adjustment at 000° heading and entered in column three. Continuing the swing, the deviation on 045° would then be noted as 6.4° E. Knowing the deviations on all intercardinal headings, it is now possible to estimate the approximate coefficient D. D is 5.0° E so the 6.4° E deviation on 045° is corrected to 1.4° E and new anticipated values are recorded in another column. This anticipates a fairly good curve, an estimate of which reveals, in addition to the B of 0.5° E which was not considered large enough to warrant correction, an A of 1.0° E and an E of 1.5° E. These A and E errors may or may not be corrected, as practical. If they are corrected, the subsequent steps would be as indicated in the last two columns. Now the ship has made only one swing, all corrections have been made, and some idea of the expected curve is available.

614. Deviation Curves

The last step, after completion of either of the above methods of adjustment, is to secure all correctors in position and to swing for residual deviations. These residual deviations are for undegaussed conditions of the ship, which should be recorded together with details of corrector positions. Figure 614 illustrates both sides of NAVSEA 3120/4 with proper instructions and sample deviation and Flinders bar data. Should the ship be equipped with degaussing coils, a swing for residual deviations under degaussed conditions should also be made and data recorded on NAVSEA 3120/4.

On these swings, exercise extreme care in taking bearings or azimuths and in steadying down on each heading since this swing is the basis of standard data for the particular compass. If there are any peculiar changeable errors, such as movable guns, listing of the ship, or anticipated decay from deperming, which would effect the reliability of the compass, they should also be noted on the deviation card at this time. Section 639 discusses these many sources of error in detail.


MAGNETIC COMPASS TABLE

7-1/2 C.G. Conn 8560

"X" 9 September 1975

0	0.5E	0.5E	180	0.5W	0.0
15	1.0E	1.0E	195	1.0W	0.5W
30	1.5E	1.5E	210	1.0W	1.0W
45	2.0E	1.5E	225	1.5W	1.5W
60	2.0E	2.0E	240	2.0W	2.0W
75	2.5E	2.5E	255	2.0W	2.5W
90	2.5E	3.0E	270	1.5W	2.0W
105	2.0E	2.5E	285	1.0W	1.5W
120	1.5E	2.0E	300	1.0W	1.0W
135	1.5E	1.5E	315	0.5W	0.5W
150	1.0E	1.0E	330	0.5W	0.5W
165	0.0	0.5E	345	0.0	0.0

18°00'N 120°00'E

0.385 0.151

VERTICAL INDUCTION DATA

(Fill out completely before adjusting)

8 W 0 4 E 9 E

5 December 1974 33 53N 117 18W

.260 .420

12" FLINDERS BAR

2.5W, 7E 4.5E, 5W

Shipyard overhaul:
3 Oct - 2 Dec 1974
Depermed at Norfolk, Va.:
3 Dec 1974

PERFORMANCE DATA

INSTRUCTIONS

Figure 614. Deviation table, NAVSEA 3120/4.

If the Flinders bar adjustment is not based on accurate data, as with a new ship, exercise particular care in recording the conventional Daily Compass Log data during the first cruise on which a considerable change of magnetic latitude occurs.

In order to have a reliable and up-to-date deviation card at all times, swing the ship to check compass deviations and to make readjustments, after:

1. Radical changes in magnetic latitude.
2. Deperming. (Delay adjustment for several days after treatment.)
3. Structural changes.
4. Long cruises or docking on the same heading, causing the permanent magnetic condition of the vessels to change.
5. Altering magnetic equipment near the binnacle.
6. Reaching the magnetic equator to acquire Flinders bar data.
7. At least once annually.
8. Changing the heeling magnet position, if Flinders bar is present.
9. Readjusting any corrector.
10. Changing magnetic cargo.
11. Commissioning.

DEVIATION CURVES AND THE ESTIMATION OF APPROXIMATE COEFFICIENTS

615. Simple Analysis

The data for the deviation curve illustrated in Figure 615 is listed below:

Ship's Compass Heading		*Total Deviation*
N	000 °	10.5 ° E
NE	045 °	20.0 ° E
E	090 °	11.5 ° E
SE	135 °	1.2 ° W
S	180 °	5.5 ° W
SW	225 °	8.0 ° W
W	270 °	12.5 ° W
NW	315 °	6.8 ° W

Since A is the coefficient of constant deviation, its approximate value is obtained from the above data by estimating the mean of the algebraic sum of all the deviations. Throughout these computations the sign of east deviation is considered plus, and west deviation is considered minus.

$8A = +10.5^\circ + 20.0^\circ + 11.5^\circ - 1.2^\circ - 5.5^\circ - 8.0^\circ - 12.5^\circ - 6.8^\circ$

$8A = +42.0^\circ - 34.0^\circ$

$8A = +8.0^\circ$

$A = +1.0^\circ$ (1.0° E)

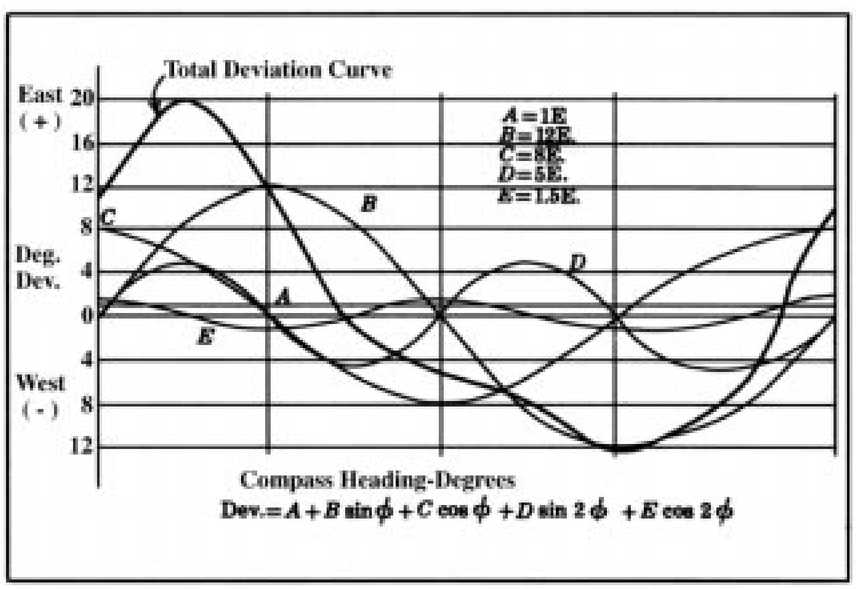


Figure 615. Example of typical deviation curve and its components.

Since B is the coefficient of semicircular sine deviation, its value is maximum, but of opposite polarity, on 090° and 270° headings. The approximate B coefficient is estimated by taking the mean of the deviations at 090° and 270° with the sign at 270° reversed.

2B = +11.5˚ (+12.5˚)
2B = +24.0˚
B = +12.0˚ (12.0˚ E)

Similarly, since C is the coefficient of semicircular cosine deviation, its value is maximum, but of opposite polarity, on 000° and 180° headings; and the approximate C coefficient is estimated by taking the mean of the deviations at 000° and 180° with the sign at 180° reversed.

2C = +10.5˚ + (+5.5˚)
2C = +16.0˚
C = +8.0˚ (8.0˚ E)

D is the coefficient of quadrantal sine deviation having maximum, but alternately opposite, polarity on the intercardinal headings. Hence, the approximate D coefficient is estimated by taking the mean of the four intercardinal deviations with the signs at 135° and 315° reversed.

4D = (+20.0˚) + (+1.2˚) + (-8.0˚) + (+6.8˚)
4D = +20.0˚
D = +5.0˚ (5.0˚ E)

E is the coefficient of quadrantal cosine deviation having maximum, but alternately opposite, polarity on the cardinal headings. Therefore, the approximate E coefficient is estimated by taking the mean of the four cardinal deviations with the signs at 090˚ and 270˚ reversed.

4E = (+10.5˚) + (-11.5˚) + (-5.5˚) + (+12.5˚)
4E = +6.0˚
E = +1.5˚ (1.5˚ E)

These approximate coefficients are estimated from deviations on compass headings rather than on magnetic headings. The arithmetical solution of such coefficients will automatically assign the proper polarity to each coefficient.

Summarizing the above we find the approximate coefficients of the given deviation curve to be:

A = 1.0˚ E
B = 12.0˚ E
C = 8.0˚ E
D = 5.0˚ E
E = 1.5˚ E

Each of these coefficients represents a component of deviation which can be plotted as shown in Figure 615. The polarity of each component in the first quadrant must agree with the polarity of the coefficient. A check on the components in Figure 615 will reveal that their summation equals the original curve.

This method of analysis is accurate only when the deviations are less than 20°. The mathematical expression for the deviation on any heading, using the approximate coefficients, is:

$$\text{Deviation} = A + B\sin\theta + C\cos\theta + D\sin 2\theta + E\cos 2\theta$$

(where θ represents compass heading).

The directions given above for calculating coefficients A and B are not based upon accepted *theoretical* methods of estimation. Some cases may exist where appreciable differences may occur in the coefficients as calculated by the above method and the accepted theoretical method. The proper calculation of coefficients B and C is as follows:

Letting D1, D2, . . ., D8 be the eight deviation data, then

$$B = \frac{\sqrt{2}}{8}(D_2 + D_4 - D_6 - D_8 + \frac{1}{4}(D_3 - D_7))$$

$$C = \frac{\sqrt{2}}{8}(D_2 - D_4 - D_6 + D_8 + \frac{1}{4}(D_1 - D_5))$$

Substituting deviation data algebraically, east being plus and west minus,

$$B = \frac{\sqrt{2}}{8}(20.0 - 1.2 - 8.0 - 6.8 + \frac{1}{4}(11.5 - 12.5))$$

$$B = +12$$

$$C = \frac{\sqrt{2}}{8}(20.0 - 1.2 - 8.0 + 6.8 + \frac{1}{4}(10.5 - 5.5))$$

$$C = +8$$

This method of estimating approximate coefficients is convenient for:

1. Analyzing an original deviation curve in order to anticipate necessary corrections.
2. Analyzing a final deviation curve for the determination of additional refinements.
3. Simplifying the actual adjustment procedure by anticipating effects of certain corrector changes on the deviations at all other headings.

616. Approximate And Exact Coefficients

The above estimations are for the approximate coefficients and not for exact coefficients. Approximate coefficients are in terms of angular deviations which are caused by certain magnetic forces, and some of these deviations are subject to change with changes in the directive force, H. The exact coefficients are expressions of magnetic forces, dealing with: (a) arrangements of soft iron, (b) components of permanent magnetic fields, (c) components of the earth's magnetic field, and (d) the shielding factor. Thus, the exact coefficients are expressions of magnetic force which produce the deviations expressed by the approximate coefficients. The exact coefficients are for mathematical considerations while the approximate coefficients are more practical for adjustment purposes. For this reason, the exact coefficients, and the associated mathematics, are not expanded further in this text.

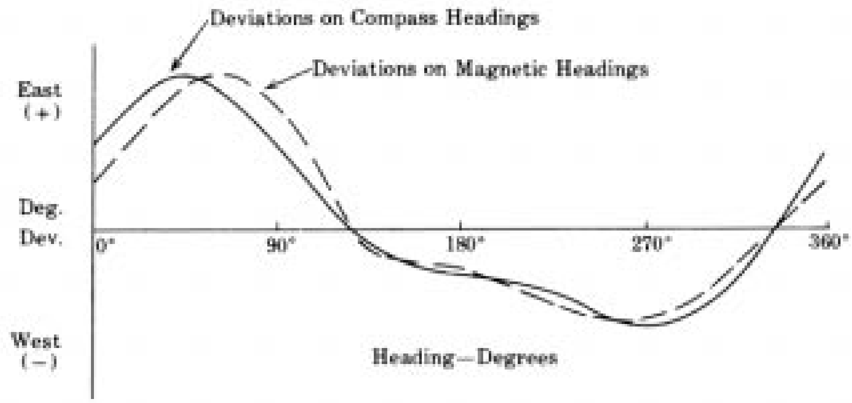


Figure 617. Comparison of deviation curves. (magnetic heading versus compass heading.)

CORRECTOR EFFECTS

617. Compass Heading And Magnetic Heading

When deviations are large, there is an appreciable difference in the deviation curve if it is plotted on cross-section paper against compass headings or against magnetic headings of the ship. Not only is there a difference in the shape of the curves, but if only one curve is available, navigators will find it difficult in applying deviations when converting between magnetic and compass headings. When deviations are small, no conversion is necessary. Figure 617 illustrates the differences mentioned above by presenting the deviation values used in Figure 617 plotted against both magnetic and compass headings.

618. Understanding Interactions Between Correctors

Until now the principles of compass adjustment have been considered from a qualitative point of view. In general this is quite sufficient since the correctors need merely be moved until the desired amount of correction is obtained. However, it is often valuable to know the quantitative effects of different correctors as well as their qualitative effects. All the correctors are not completely independent of each other. Interaction results from the proximity of the permanent magnet correctors to the soft iron correctors. Consequently any shift in the relative position of the various correctors will change their interactive as well as their separate correction effects. Additional inductions exist in the soft iron correctors from the magnetic needles of the compass itself. The adjuster should be familiar with the nature of these interactions.

619. Quandrantal Sphere Correction

Figure 619 presents the approximate quadrantal correction available with different sizes of spheres, at various positions on the sphere brackets, and with different magnetic moment compasses. These quadrantal corrections apply whether the spheres are used as D, E, or combination D and E correctors. Quadrantal correction from spheres is due partially to the earth's field induction and partially to compass needle induction. Since compass needle induction does not change with magnetic latitude but earth's field induction does, the sphere correction is not constant for all magnetic latitudes. A reduction in the percentage of needle induction in the spheres to the earth's field induction in the spheres will improve the constancy of sphere correction over all magnetic latitudes. Such a reduction in the percentage of needle induction may be obtained by:

1. Utilizing a low magnetic moment compass.
2. Utilizing special spheroidal-shaped correctors, placed with their major axes perpendicular to their axis of position.

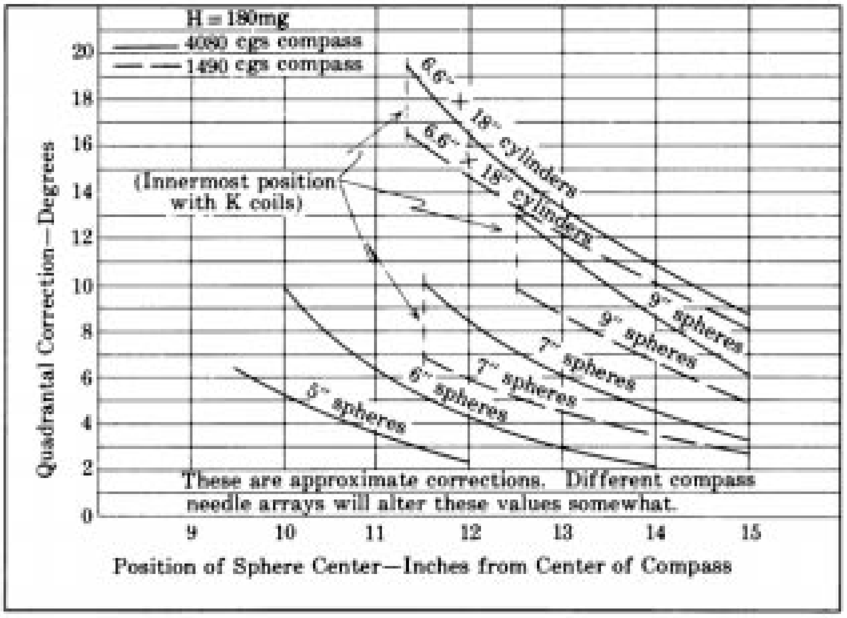


Figure 619. Quandrantal correction curves.

3. Using larger spheres farther away from the compass.

620. Slewing Of Spheres

Figure 620 shows a chart for determining the proper slewed position for spheres. The total values of the D and E quadrantal coefficients are used on the chart to locate a point of intersection. This point directly locates the angle and direction of slew for the spheres on the illustrated binnacle. This point will also indicate, on the radial scale, the resultant amount of quadrantal correction required from the spheres in the new slewed position to correct for both D and E coefficients. The total D and E coefficients may be calculated by an analysis of deviations on the uncorrected binnacle, or by summarizing the uncorrected coefficients with those already corrected. The data in Figure 619 and 622 will be useful in either procedure.

Example: A ship having a Navy Standard binnacle, with 7" spheres at 13" position athwartship, and a 12" Flinders bar forward, is being swung for adjustment. It is observed that 4° E D error and 6° E E error exist with the spheres in position. Since the spheres are athwartship, the

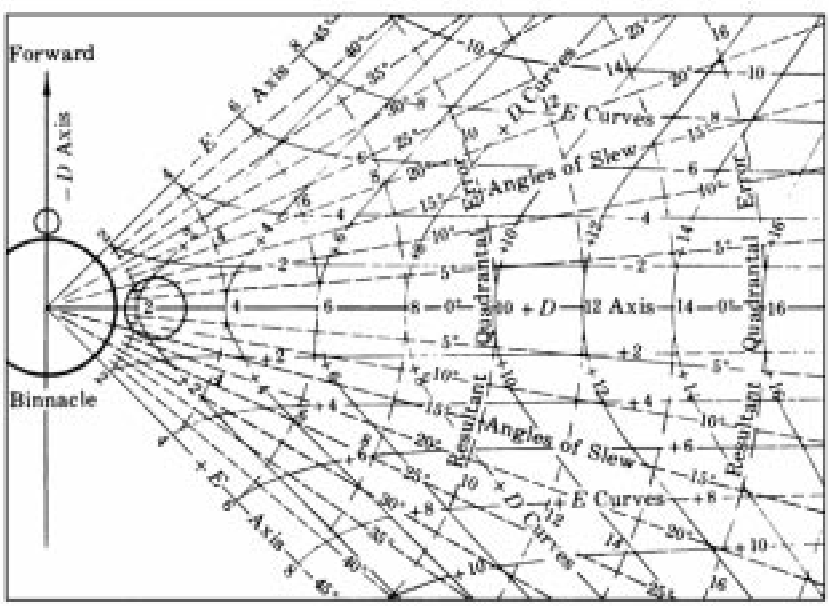


Figure 620. Slewing of quandrantal spheres.

total E coefficient for the ship is 6° E, as observed. Figure 619 indicates that the spheres in their present position are correcting 6° E D error, hence the total D coefficient of the ship and Flinders bar is 10° E. Figure 620 indicates that 6° E E and 10° E D coefficients require slewing the spheres 15.5° clockwise from their present athwartship position. The resultant quadrantal error is indicated as 11.7°. Figure 619 indicates that the 7" spheres should then be moved to the 11" position after slewing 15.5° clockwise so as to correct both the D and E errors. Using this chart eliminates trial-and-error adjustment methods for quadrantal errors and provides information for moving the spheres.

621. Corrector Magnet Inductions In Spheres

Should a ship have both spheres and many permanent B and C magnet correctors close to the compass, induction will exist between these correctors. This induction will require some shuttling back and forth between headings while making adjustments. This situation can be improved by using larger spheres further out, by approximately setting the spheres before starting adjustments, and by using more magnets further from the spheres and compass. Magnetized spheres Flinders bars will cause difficulty during adjustment, and introduce an unstable deviation curve if they suffer a change of magnetic condition.

622. Flinders Bar Effects

Figure 622 presents the approximate quadrantal error introduced by the presence of the Standard Navy Flinders bar. Since the Flinders bar is usually placed in the forward or aft position, it acts as a small minus D corrector as well as a corrector for vertical induced effects. This means that when inserting the Flinders bar, move the regular spheres closer to correct for the increased plus D error. Conversely, move the regular spheres away when removing the Flinders bar. This D error in the Flinders bar is due mostly to compass needle induction because the bar is small in cross-section and close to the compass. Such needle induction is practically constant; therefore, the deviation effects on the compass will change with magnetic latitudes because the directive force, H, changes. However, when balanced by sphere correctors, this effect tends to cancel out the variable part of the sphere correction caused by the compass needle induction.

623. Flinders Bar Adjustment

One must have reliable data obtained in two widely separated magnetic latitudes to place the correct amount of Flinders bar. Placing the Flinders bar by any other method is merely an approximation. Obtaining the required magnetic data will necessitate further refinements. There are several methods of acquiring and using latitude data in order to determine the proper amount of Flinders bar:

The data required for correct Flinders bar adjustment consists of accurate tables of deviations with details of corrector conditions at two different magnetic latitudes; the farther apart the better. Should it be impossible to swing ship for a complete table of deviations, the deviations on east and west magnetic headings would be helpful. Ship’s log data is usually not reliable enough for Flinders bar calculation. Observe the following precautions when taking data. These precautions will ensure that deviation changes are due only to changes in the H and Z components of the earth’s field.

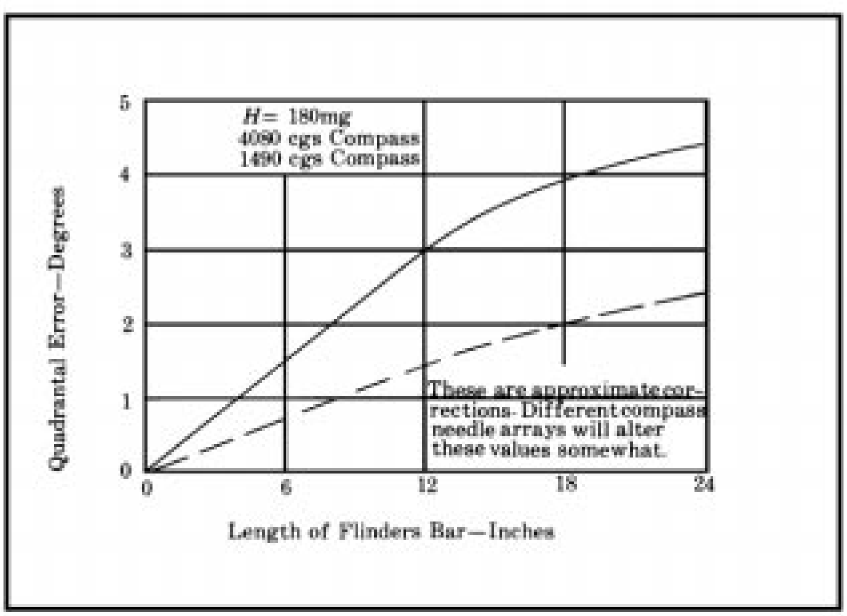


Figure 622. Quadrantal error from standard Navy Flinders bar.

1. Degaussing should be secured, by a reversal process if necessary, at both latitudes before data are taken.

2. If the ship has been in dock or steaming, on one heading for several days prior to the taking of these data, the resulting temporary magnetism (Gaussin error) would create erroneous deviations. A shakedown on other headings prior to taking data will reduce such errors.

3. Any major change in the ship's magnetic field (caused, for example, by deperming, structural changes, heavy gunfire, shifting magnetic cargoes) between data sets will make the comparative results meaningless.

4. Because the data will not be reliable if the ship's permanent magnetism changes between the two latitudes, it will likewise be unreliable if any of the binnacle correctors are changed.

In the event that an approximation as to Flinders bar length cannot be made, then the deviations at the two latitudes should be taken with no Flinders bar in the holder. This procedure would also simplify the resulting calculations.

624. Methods Of Determining Flinders Bar Length

Method 1. Having obtained reliable deviation data at two different magnetic latitudes, the changes in the deviations, if any, may justifiably be attributed to an incorrect Flinders bar adjustment. E/W and N/S deviations are the ones which are subject to major changes from such an incorrect adjustment. If there is no change in any of these deviations, the Flinders bar adjustment is probably correct. A change in the E/W deviations indicates an unsymmetrical arrangement of vertical iron forward or aft of the compass, which requires correction by the Flinders bar, forward or aft of the compass. A change in the N/S deviations indicates an unsymmetrical arrangement of vertical iron to port or starboard of the compass, which requires correction by the Flinders bar to port or starboard of the compass. This latter case is very rare, but can be corrected.

Determine the B deviations on magnetic east/west headings at both latitudes. The constant c may then be calculated from the following formula:

$$c = \lambda \frac{H_1 \tan B_1 - H_2 \tan B_2}{Z_1 - Z_2}$$

where

λ = shielding factor (0.7 to 1.0 average).

H_1 = earth's field, H, at 1st latitude.

B_1 = degrees B deviation at 1st latitude (magnetic headings).

Z_1 = earth's field, Z, at 1st latitude.

H_2 = earth's field, H, at 2nd latitude.

B_2 = degrees B deviation at 2nd latitude (magnetic headings).

Z_2 = earth's field, Z, at 2nd latitude.

This constant c represents a resultant mass of vertical iron in the ship which requires Flinders bar correction. If the Flinders bar is present at the time of calculations, it must be remembered that it is already correcting an amount of c in the ship which must be added to the uncorrected c, calculated by the above formula. This total value of c is used in conjunction with Figure 624a to indicate, directly, the necessary total amount of Flinders bar. If this total c is negative, Flinders bar is required on the forward side of the binnacle; and if it is positive, a Flinders bar is required on the aft side of the binnacle. The iron sections of Flinders bar should be continuous and at the top of the tube with the longest section at the top. Wooden spacers are used at the bottom of the tube. It will be noted that the B deviations used in this formula are based on data on E/W magnetic headings rather than on compass headings, as with the approximate coefficients.

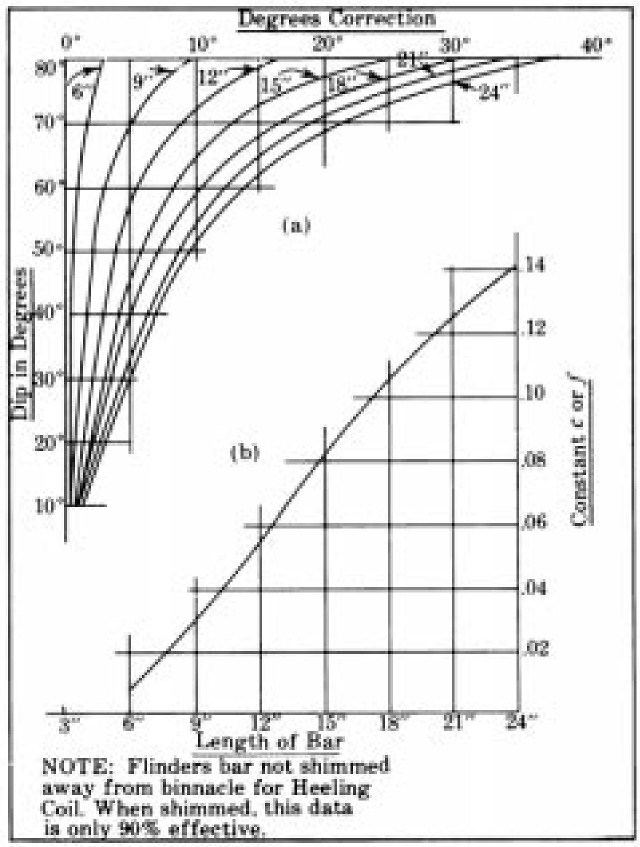


Figure 624a. Dip deviation curves for Flinders bar.

Method 2. Should the exact amount of correction required for vertical induction in the ship at some particular magnetic dip, q, be known, Figure 624a will directly indicate the correct amount of Flinders bar to be placed at the

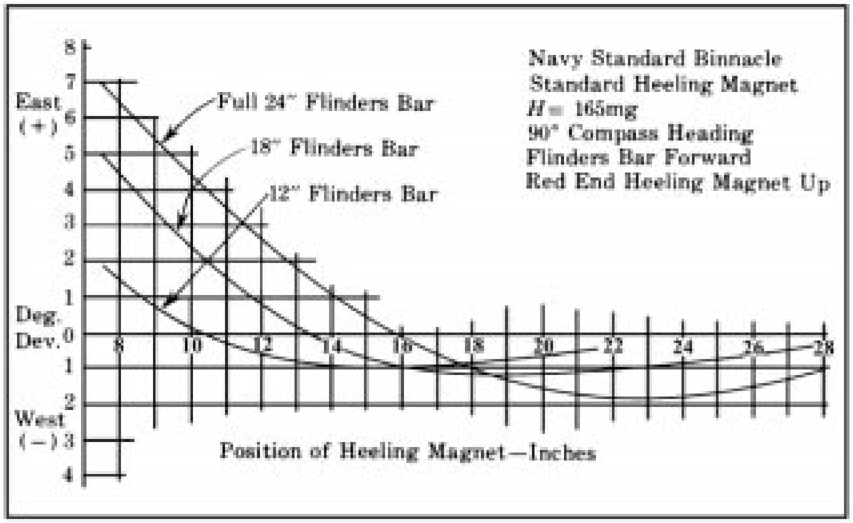


Figure 624b. Induction effects in Flinders bar due to heeling.

top of the holder. The exact amount of correction would be known when one of the latitudes is the magnetic equator, and the deviations there are negligible. Then the B deviation, in degrees, on magnetic headings at the other latitude, is the exact amount to correct by means of curves in Figure 624a.

Method 3. Lord Kelvin's rule for improving the Flinders bar setting is: "Correct the deviations observed on east or west courses by the use of fore-and-aft B magnets when the ship has arrived at places of weaker vertical magnetic field, and by the use of Flinders bar when she has arrived at places of stronger vertical magnetic field, whether in the Northern or Southern Hemisphere."

After determining the correct amount of Flinders bar, by either method (1) or (2) above, the bar should then be inserted at the top of the holder, and the fore-and-aft B magnets readjusted to correct the remaining B error. Sphere adjustments should likewise be refined.

It is quite possible that on inserting the Flinders bar, no visible deflection of the compass will be observed, even on an east or west heading. This should cause no concern because certain additional induction effects exist in the bar, from:

1. The heeling magnet.
2. The existing fore-and-aft magnets.
3. The vertical component of the ship's permanent magnetic field.

Figure 624b presents typical induction effects in the Flinders bar for different positions of heeling magnet. An adjuster familiar with the nature of these effects will appreciate the advantages of establishing the Flinders bar and heeling magnet combination before leaving dockside. Deviations must also be checked after adjusting the heeling magnet, if Flinders bar is present.

625. Slewing Of Flinders Bar

The need for slewing the Flinders bar is much more rare than that for slewing spheres. Also, the data necessary for slewing the Flinders bar cannot be obtained on a single latitude adjustment, as with the spheres. Slewing the bar to some intermediate position is, in effect, merely using one bar to do the work of two; one forward or aft, and the other port or starboard.

Section 624 explains that a change of the E/W deviations, with changes in latitude, indicates the need for Flinders bar forward or aft of the compass; and a change of the N/S deviations, with changes in latitude, indicates the need for Flinders bar to port or starboard of the compass.

A change of the B deviations on magnetic E/W headings is used, as explained in section 624, to determine the proper amount of Flinders bar forward or aft of the compass, by calculating the constant c.

If there is a change of the C deviations on magnetic N/S headings, a similar analysis may be made to determine the proper amount of Flinders bar to port or starboard of the compass by calculating the constant f from:

$$f = \lambda \frac{H_1 \tan C_1 - H_2 \tan C_2}{Z_1 - Z_2}$$

when

λ = shielding factor (0.7 to 1.0 average).

H_1 = earth's field, H, at 1st latitude.

C_1 = degrees C deviation at 1st latitude (magnetic headings).

Z_1 = earth's field, H, at 1st latitude.

H_2 = earth's field, H, at 2nd latitude.

C_2 = degrees C deviation at 2nd latitude (magnetic headings).

Z_2 = earth's field, Z, at 2nd latitude.

Any value of this *f* constant indicates the need for Flinders bar adjustment athwartship of the compass, just as a value of the c constant indicates the need for Flinders bar adjustment forward or aft of the compass. The *f* constant curve in Figure 624b is used for the determination of this Flinders bar length. If *f* is negative, Flinders bar is required on the starboard side of the binnacle.

Should both c and f exist on a ship, the angular position for a Flinders bar to correct the resultant vertical induction effects may be found by:

$$\tan\beta = \frac{f}{c} \quad \text{or} \quad \beta = \tan^{-1}\frac{f}{c}$$

β is the angle to slew the Flinders bar from the fore-and-aft axis. If *c* and *f* are negative, the bar will be slewed clockwise from the forward position; if *c* is negative and *f* is positive, the bar will be slewed counterclockwise from the aft position.

After determining the angle to slew the Flinders bar from the fore-and-aft line, the total amount of Flinders bar necessary to correct the resultant vertical induction effects in this position is found by:

$$r = \sqrt{c^2 + f^2}$$

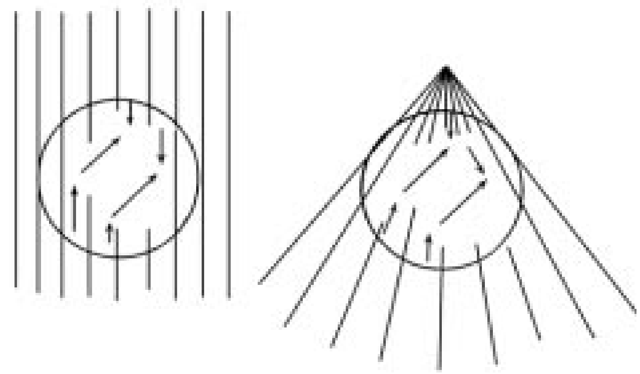


Figure 626a. Magnetic fields across compass needle arrays.

The constant *r* is then used on the *c* or *f* constant curve in Figure 624b to determine the total amount of Flinders bar necessary in the slewed position.

626. Compasses

Compasses themselves play a very important part in compass adjustment, although it is common belief that the compass is only an indicating instrument, aligning itself in the resultant magnetic field. This would be essentially true if the magnetic fields were uniform about the compass; but, unfortunately, magnetism close to the compass imposes nonuniform fields across the needles. In other words, adjustment and compensation sometimes employ non-uniform fields to correct uniform fields. Figure 626a indi-

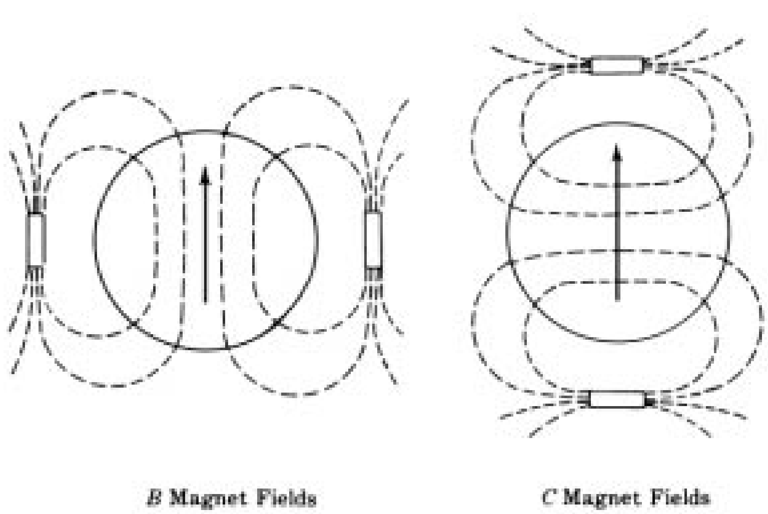


Figure 626b. Arrangements of corrector magnets.

cates the difference between uniform and nonuniform field effects on a compass. Such unbalanced torques, arising from nonuniform magnetic fields, create deviations of the compass which have higher frequency characteristics. Compass designs include many combinations of different length needles, different numbers of needles, and different spacings and arrangements of needles all designed to minimize the higher order deviations resulting from such nonuniform magnetic fields. Although compass design is rather successful in minimizing such deviations, it is obvious that different compasses will be affected differently by the same magnetic fields. It is further stressed that, even with proper compass design, it is the responsibility of all adjusters to exercise care in applying correctors, in order to create the most uniform magnetic field possible.

This is the basis for the rule which requires the use of strong correctors symmetrically arranged, as far away from the compass as possible, instead of weak correctors very close to the compass. In general it is better to use larger spheres placed at the extremities of the brackets, equally distant from the center of the compass. B and C permanent magnet correctors should always be placed so as to have an equal number of magnets on both sides of the compass where possible. They should also be centered as indicated in Figure 626b, if regular tray arrangements are not available. The desire for symmetrical magnetic fields is one reason for maintaining a sphere of specified radius, commonly called the **magnetic circle**, about the magnetic compass location. This circle is kept free of any magnetic or electrical equipment.

The **magnetic moment** of the compass needle array, another factor in compass design, ranks in importance with the proper arrangement of needles. This magnetic moment controls the needle induction in the soft iron correctors, as discussed in section 619 and section 622, and hence governs the constancy of those corrector effects with changes in magnetic latitude. The $7^1/_2$" Navy No. 1 alcohol-water compass has a magnetic moment of approximately 4000 cgs units, whereas the $7^1/_2$" Navy No. 1 oil compass has a magnetic moment of approximately 1650 cgs units. The lower magnetic moment compass allows considerably less change in quadrantal correction, although the periods are essentially comparable, because of the difference in the compass fluid characteristics.

Other factors which must be considered in compass design are period, fluid, swirl, vibration, illumination, tilt, pivot friction, fluid expansion, and others. These factors, however, are less important from an adjuster's point of view than the magnetic moment and arrangement of needles, and are therefore not discussed further in this text.

SHIP'S HEADING

627. Ship's Heading

Ship's heading is the angle, expressed in degrees clockwise from north, of the ship's fore-and-aft line with respect to the true meridian or the magnetic meridian. When this angle is referred to the true meridian, it is called a **true heading**. When this angle is referred to the magnetic meridian, it is called a **magnetic heading**. Heading, as indicated on a particular compass, is termed the ship's compass heading by that compass. It is always *essential* to specify heading as true heading, magnetic heading, or compass heading. In order to obtain the heading of a ship, it is essential that the line through the pivot and the forward lubber's line of the compass be parallel to the fore-and-aft line of the ship. This applies also to the peloruses and gyro repeaters, which are used for observational purposes.

628. Variation And Deviation

Variation is the angle between the magnetic meridian and the true meridian at a given location. If the northerly part of the magnetic meridian lies to the right of the true meridian, the variation is easterly, and if this part is to the left of the true meridian, the variation is westerly. The local variation and its small **annual change** are noted on the compass rose of all navigational charts. Thus the true and magnetic headings of a ship differ by the local variation. Chart 42 shows approximate variation values for the world.

As previously explained, a ship's magnetic influence will generally cause the compass needle to deflect from the magnetic meridian. This angle of deflection is called **deviation**. If the north end of the needle points east of the magnetic meridian, the deviation is easterly; if it points west of the magnetic meridian, the deviation is westerly.

629. Heading Relationships

A summary of heading relationships follows:

1. **Deviation** is the difference between the compass heading and the magnetic heading.
2. **Variation** is the difference between the magnetic heading and the true heading.
3. The algebraic sum of deviation and variation is the **compass error**.

Figure 629 illustrates these relationships. The following simple rules will assist in naming errors and in converting from one heading to another:

1. Compass least, deviation east, compass best, deviation west.
2. When correcting, add easterly errors, subtract westerly errors.
3. When uncorrecting, subtract easterly errors, add westerly errors.

Typical heading relationships are as follows:

Compass	Deviation	Magnetic	Variation	True
358°	5°E	003°	6°E	009°
120°	1°W	119°	3°E	122°
180°	6°E	186°	8°W	178°
240°	5°W	235°	7°W	228°

Figure 629. Magnetic heading relationships.

Use the memory aid "Can Dead Men Vote Twice at Elections" to remember the conversion process (Compass, Deviation, Magnetic, Variation, True, add east). When converting Compass Heading to True Heading, add east deviations and variations and subtract west deviations and variations.

Complete facility with conversion of heading data is essential for expeditious compass adjustment.

630. Use Of Compass Heading And Magnetic Heading For Adjustment

The primary object of adjusting compasses is to reduce deviations; that is, to minimize the difference between the magnetic and compass headings. There are two methods for accomplishing this:

Method 1. Place the ship on the desired magnetic heading (section 631) and correct the compass so that it reads the same as this magnetic heading. This is the preferred method.

Method 2. Place the ship on the desired compass heading and determine the corresponding magnetic heading of the ship. Correct the compass so that it reads the same as this known magnetic heading. Use this method whenever it is impractical to place the ship on a steady magnetic heading for direct correction.

One can easily observe compass deviation when using the first method because it is simply the difference between the compass reading and the known magnetic heading of the ship. The difficulty in using this method lies in placing the ship on the desired magnetic heading and holding the ship steady on that heading while adjustments are being made.

The difficulty in using the second method lies in the determining deviation. Further difficulty arises because the

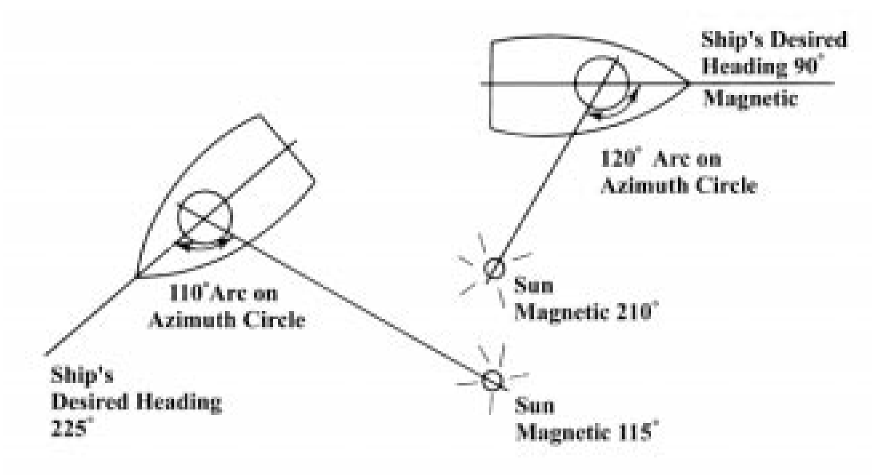


Figure 630. Azimuth circle set-ups.

helmsman steers by an uncorrected compass whose deviations are changing while the technician is making the necessary adjustments. Therefore, as each adjustment is being made, the helmsman should hold the ship's heading steady by some means other than the compass that is being corrected.

If the compass has no appreciable deviation, the deviation taken on compass headings will closely approximate those taken on magnetic headings. However, as the magnitude of errors increases, there will be a marked difference between the deviations taken on compass headings and those taken on magnetic headings.

631. Methods Of Placing Ship On Magnetic Headings

Method 1. Bring the ship onto a magnetic heading by referencing a gyrocompass. The magnetic variation applied to true heading determines the gyro course to be steered to place the ship on the required magnetic heading. Take gyrocompass error into consideration in determining gyro course to be steered.

The difference between gyro heading and magnetic heading will be constant on all headings as long as the gyrocompass error is constant and the variation does not change. Determine gyrocompass error by comparing the calculated true azimuth of the sun and the azimuth as observed on a synchronized repeater.

It should be remembered that gyrocompasses have certain errors resulting from latitude and speed changes, and these errors are not always constant on all headings. For these reasons, the gyro error must be checked constantly, especially if the gyro is being used to obtain data for determining residual deviation curves of the magnetic compass.

Method 2. Place the ship on a magnetic heading by aligning the vanes of an azimuth circle with the sun over the topside compass. The sun is a distant object whose azimuth (angle from the north) may be computed for any given time. Methods of calculating sun's azimuths are discussed in the next section. By setting the line of sight of the vanes at an angle to the right (or left) of the fore-and-aft line of the ship equal to the difference between the computed magnetic azimuth and the desired magnetic heading of the ship, and then swinging the ship until the sun is aligned with the vanes, the ship will be on the desired magnetic heading. Simple diagrams with the ship and sun drawn in their relative positions, will aid in visualizing each problem. Always keep the azimuth circle level while making observations. This holds especially true for observing celestial bodies.

Method 3. Use a distant object (10 or more miles away) with the azimuth circle when placing the ship on magnetic headings. This procedure is similar to that used with the sun except that the magnetic bearing of the object is constant. With an object 11.4 nautical miles distant, a change in position of 400 yards at right angles to the line of sight introduces an error of 1°.

Method 4. Use a pelorus to place a ship on a magnetic heading using the sun's azimuth in much the same manner as with the azimuth circle. Using the pelorus allows the magnetic heading of the ship to be observed continuously as the ship swings. Clamp the forward sight vane to the dial at the value of the sun's magnetic azimuth. Then, train the sight vanes so that the sun is reflected in the mirror. As the ship turns, observe the magnetic heading under the forward lubber's line. As the desired magnetic course is approached, the compass can be read and corrected even before that magnetic course is actually obtained. A final check can be made when the ship is on the exact course. Always keep the pelorus level while making observations, particularly of celestial bodies.

Method 5. A distant object can be used in conjunction with the pelorus, as with the azimuth circle, in order to place the ship on magnetic headings.

632. Methods Of Determining Deviations On Compass Heading

Method 1. Determine the compass' deviation by comparing the sun's calculated magnetic azimuth to the azimuth observed using an azimuth circle. The next section discusses methods of calculating the sun's azimuths. Place the ship on the desired compass heading and take an azimuth of the sun on the compass card's face. The difference between the observed azimuth and the calculated magnetic azimuth of the sun is the deviation on that compass course.

Method 2. Use the pelorus with the sun's azimuth to obtain deviations on compass headings. Bring the ship to the desired compass heading and set the forward sight vane on the value calculated for the sun's magnetic azimuth. Then train the sight vanes on the sun. The pelorus indicates the ship's magnetic heading. The difference in degrees between the compass heading and magnetic heading of the ship indicated by the pelorus is the deviation on that compass course.

Method 3. Use the azimuth circle or pelorus in conjunction with ranges or a distant object to obtain deviations on compass courses. The procedure is similar to that used with the sun. A range consists of any two objects or markers, one in the foreground and the other in the background, which establishes a line of sight having a known magnetic bearing. Determine the range's true bearing from a chart; then, convert this true bearing to the magnetic bearing by applying the variation listed on the chart. Bring the ship to the desired compass course and, at the instant of crossing the line of sight of the range, take a bearing to the range. With the azimuth circle, the difference between the observed range bearing and the known magnetic range bearing represents the deviation on that compass course. If using a pelorus, set the forward sight vanes to the magnetic bearing of the range and read the ship's magnetic heading when taking a sight on the range. The deviation is the difference between the compass heading of the ship and the known magnetic heading of the ship as indicated by pelorus.

Method 4. Obtain deviations on compass courses by using reciprocal bearings. Set up a pelorus on shore and align the dial's south end with magnetic north. A ship then sights the pelorus on shore, using an azimuth circle or pelorus, at the same instant the observer on shore sights the ship. The ship's bearing from shore on the reversed pelorus is the magnetic bearing of the shore position from the ship. Continuous communication between ship and shore is necessary when employing this method.

Additional methods of determining deviations are by the use of azimuths of the moon, stars, and planets.

AZIMUTHS

633. Azimuths Of The Sun

The sun is a valuable reference point for compass adjustment because one can easily obtain accurate compass bearings of the sun and compare these bearings with the sun's calculated true bearing (azimuth) to obtain compass error. One can use the azimuths of other celestial bodies to make this comparison; however, none are as convenient as the sun.

Calculating an azimuth of the sun is covered in Chapter 17.

634. Curve Of Magnetic Azimuths

During the course of compass adjustment and swinging ship, a magnetic direction is needed many times, either to place the vessel on desired magnetic headings or to determine the deviation of the compass being adjusted. The sun's azimuth continually changes as the earth rotates. Compensate for this by preparing a **curve of magnetic azimuths**. Compute true azimuths at frequent intervals. Then, apply the variation at the center of the maneuvering area to determine the equivalent magnetic azimuths. Plot the magnetic azimuths versus time and fair a curve through the points. Plotting at least three points at intervals of half an hour is usually sufficient. If the sun is near the celestial meridian and relatively high in the sky, plot additional points.

Unless extreme accuracy is required, determine the Greenwich hour angle and declination for the approximate midtime. Additionally, use the same declination for all computations. Assume the Greenwich hour angle increase at 15° per hour.

TRANSIENT DEVIATIONS OF THE MAGNETIC COMPASS

635. Stability

So far this chapter has discussed only the principles of steady-state magnetism. However, a carefully made correction based on these steady-state phenomenon may turn out to be inaccurate due to transient magnetic effects. A compass adjuster cannot place correctors on the binnacle for such variable effects; he must recognize and handle them in the best possible manner. A good adjuster not only provides an accurate deviation curve which is reliable under steady state conditions, but he also records transient magnetic effects which cannot be eliminated.

636. Sources Of Transient Error

The magnetic circle about the magnetic compass is intended to reduce any transient conditions, but there still are many items which cause the compass to act erratically. The following is a list of some such items. If in doubt about the effect of an item on compass performance, a test can be made by swinging any movable object or energizing any electrical unit while observing the compass for deviations. This would best be tried on two different headings 90° apart, since the compass might possibly be affected on one heading and not on another.

Some magnetic items which cause variable deviations if placed too close to the compass are as follows:

1. Guns on movable mounts.
2. Ready ammunition boxes.
3. Variable quantities of ammunition in ready boxes.
4. Magnetic cargo.
5. Hoisting booms.
6. Cable reels.
7. Metal doors in wheelhouse.
8. Chart table drawers.
9. Movable gyro repeater.
10. Windows and ports.
11. Signal pistols racked near compass.
12. Sound powered telephones.
13. Magnetic wheel or rudder mechanism.
14. Knives or tools near binnacle.
15. Watches, wrist bands, spectacle frames.
16. Hat grommets, belt buckles, metal pencils.
17. Heating of smoke stack, or exhaust pipes.
18. Landing boats.

Some electrical items which cause variable deviations if placed too close to the compass are:

1. Electric motors.
2. Magnetic controllers.
3. Gyro repeaters.
4. Nonmarried conductors.
5. Loudspeakers.
6. Electric indicators.
7. Electric welding.
8. Large power circuits.
9. Searchlights.
10. Electrical control panels or switches.
11. Telephone headsets.
12. Windshield wipers.
13. Rudder position indicators, solenoid type.
14. Minesweeping power circuits.
15. Engine order telegraphs.
16. Radar equipment.
17. Magnetically controlled switches.
18. Radio transmitters.
19. Radio receivers.
20. Voltage regulators.

Another source of transient deviation is the **retentive error**. This error results from the tendency of a ship's structure to retain some of the induced magnetic effects for short periods of time. For example, a ship traveling north for several days, especially if pounding in heavy seas, will tend to retain some fore-and-aft magnetism hammered in under these induction conditions. Although this effect is transient, it may cause incorrect observations or adjustments. This same type of error occurs when ships are docked on one heading for long periods of time. A short shakedown, with the ship on other headings, will tend to remove such errors. A similar sort of residual magnetism is left in many ships if the degaussing circuits are not secured by the reversal sequence.

A source of transient deviation trouble shorter in duration than retentive error is known as **Gaussin error**. This error is caused by eddy currents set up by a changing number of magnetic lines of force through soft iron as the ship changes heading. Due to these eddy currents, the induced magnetism on a given heading does not arrive at its normal value until about 2 minutes after changing to the heading.

Deperming and other magnetic treatment will change the magnetic condition of the vessel and therefore require compass readjustment. The decaying effects of deperming are sometimes very rapid. Therefore, it is best to delay readjustment for several days after such treatment. Since the magnetic fields used for such treatments are sometimes rather large at the compass locations, the Flinders bar, compass, and related equipment are sometimes removed from the ship during these operations.

HEELING ADJUSTMENTS

637. Use Of The Dip Needle In Heeling Adjustments

The heeling effects of both the permanent and induced magnetism are corrected by adjusting the position of the vertical permanent heeling magnet. This adjustment can be made in either of two ways:

Method 1. With the ship on an even keel and as close to the east or west magnetic heading as possible, adjust the heeling magnet until a dip needle inserted in the compass position is balanced at some predetermined position.

Method 2. Adjust the heeling magnet, while the ship is rolling on north and south headings, until the oscillations of the compass card have been reduced to an average minimum.

To establish an induction condition between the heeling magnet and Flinders bar and to minimize heeling oscillations before at-sea adjustments, set the heeling magnet at dockside by the first method above. Further, position the Flinders bar and spheres before making any heeling adjustments because of the heeling correction and shielding effect they produce.

Readjust the heeling magnet when the ship changes magnetic latitude appreciably because the heeling magnet corrects for induced as well as permanent magnetic effects. Moving the heeling magnet with Flinders bar in the holder will change the induction effects in the Flinders bar and consequently change the compass deviations. Thus, the navigator is responsible for:

1. Moving the heeling magnet up or down (invert when necessary) as the ship changes magnetic latitude, to maintain a good heeling adjustment for all latitudes.

2. Checking his deviations and noting changes resulting from movements of the heeling magnet when Flinders bar is in the holder. Any deviation changes should be either recorded or readjusted by means of the fore-and-aft B magnets.

There are two types of dip needles. One assumes the angle of inclination for its particular location, and one uses a moveable weight to balance any magnetic torque. The latter type renders the needle's final position more independent of the horizontal component of magnetic fields. It, therefore, is more useful on uncorrected compasses.

For ships with no shielding of the earth's field at the compass (having no surrounding metal structure), the procedure for adjusting the heeling magnet is quite simple. Take the dip needle to a nearby area where there is no local magnetic attraction, level the instrument, and set the weight to balance the needle. It is preferable to align the instrument so that the north seeking end of the needle is pointing north. Next, level the instrument in the compass position on board ship, place the spheres in their approximate position, and adjust the heeling magnet until the needle assumes the balanced condition. This presumes that all the effects of the ship are canceled, leaving only the effect of the vertical earth's field. Secure the degaussing circuits during this adjustment.

Some ships have shielding effects at the compass. Such would be the case for a metal enclosed wheelhouses. In this case, the procedure is essentially the same as above except that the weight on the dip needle should be moved toward the pivot to balance against some lesser value of earth's field. The new position of the weight, expressed in centimeters from the pivot, can be approximately determined by multiplying the value of lambda, λ, for the compass location by the original distance of the weight from the pivot in centimeters. Should λ, for the compass location be unknown, it may generally be considered as about 0.8 for steering compass locations and 0.9 for standard compass locations. By either method, the weight on the dip needle should be moved into its new position. Next, level the instrument in the compass position on board ship and adjust the heeling magnet until the needle assumes the balanced condition.

Theoretically, these methods of adjusting the heeling magnet with a dip needle should be employed only with the ship on east or west magnetic headings. This avoids heeling errors resulting from unsymmetrical induced magnetism. If it is impractical to place the ship on such a heading, make approximations on any heading and refine these approximations when convenient.

To summarize, a successful heeling magnet adjustment is one which minimizes the compass oscillations caused by the ship's rolling. Therefore, the rolling method is a visual method of adjusting the heeling magnet or checking the accuracy of the last heeling magnet adjustment. Generally, the oscillation effects due to roll on both the north and south compass headings will be the same. However, some unsymmetrical arrangements of fore-and-aft soft iron will introduce different oscillation effects on these two headings. Such effects cannot be entirely eliminated on both headings with one setting of the heeling magnet. Therefore, the heeling magnet is generally set for the average minimum oscillation condition.

USE OF THE HORIZONTAL FORCE INSTRUMENT

638. Determining The Horizontal Shielding Factor

Occasionally, the navigator must determine the magnetic field strength at some compass location for one of the following reasons:

1. To determine the horizontal shielding factor, lambda (λ), for:
    a. A complete mathematical analysis.
    b. Accurate Flinders bar adjustment.
    c. Accurate heeling adjustment.
    d. Calculations on a dockside magnetic adjustment.
    e. Determining the best compass location on board ship.
2. To make a dockside magnetic adjustment for determining the magnitude and direction of the existing directive force at the magnetic compass.

The **horizontal shielding factor** is the ratio of the reduced earth's directive force, H', on the compass to the horizontal earth's field, H.

$$\lambda = \frac{H'}{H}$$

The navigator can determine λ for a compass location by making a measurement of the reduced earth's directive force, H'. On a corrected compass, this value H' may be measured with the ship on any heading, since this reduced earth's directive force is the only force acting on the compass. If the compass is not corrected for the ship's magnetism and the deviations are large, H' is determined from the several resultant directive forces observed with equally spaced headings of the ship. The Horizontal Shielding Factor should be determined for every compass location on every ship.

639. Measurement Of Magnetic Fields

Use a suitable **magnetometer** or a **horizontal force instrument** to measure magnetic fields. The magnetometer method is a direct reading method requiring no calculation. However, the force instrument method requires much less complicated test equipment so this method is discussed below.

The horizontal force instrument is simply a magnetized needle pivoted in a horizontal plane, much the same as a compass. It will settle in some position which will indicate the direction of the resultant magnetic field. Determine the resulting field's strength by comparing it with a known field. If the force needle is started swinging, it will be damped down with a certain period of oscillation dependent upon the strength of the surrounding magnetic field. The stronger the magnetic field, the shorter the period of time for each cycle of swing. The ratio is such that the squares of the period of vibration are inversely proportional to the strengths of the magnetic fields. This relationship is expressed as follows:

$$\frac{H'}{H} = \frac{T^2}{T'^2}$$

In the above formula, let H represent the strength of the earth's horizontal field in gauss and T represent the time in seconds for 10 cycles of needle vibration in that earth's field. A comparative measurement of time in seconds, T', for 10 cycles of vibration of the same needle in the unknown field will enable the navigator to calculate H'.

Since λ is the ratio of two magnetic field strengths, it may be found directly by the inverse ratio of the squares of the periods of vibration for the same horizontal force instrument in the two different magnetic fields by the same formula, without bothering about the values of H and H'.

$$\lambda = \frac{H'}{H} = \frac{T^2}{T'^2}$$

The above may be used on one heading of the ship if the compass deviations are less than 4°.

Use the following equation to obtain a more precise value of λ, and where compass deviations exceed 4°:

$$\lambda = \frac{T^2}{4}\left[\frac{\cos d_n}{T^2{}_n} + \frac{\cos d_e}{T^2{}_e} + \frac{\cos d_s}{T^2{}_s} + \frac{\cos d_w}{T^2{}_w}\right]$$

where:

T is the time period for the field H.

T_n is the time period for the resultant field on a north heading, etc.

cos d_n is the cos of the deviation on the north heading, etc.

DEGAUSSING (MAGNETIC SILENCING) COMPENSATION

640. Degaussing

A steel vessel has a certain amount of **permanent magnetism** in its "hard" iron and **induced magnetism** in its "soft" iron. Whenever two or more magnetic fields occupy the same space, the total field is the vector sum of the individual fields. Thus, near the magnetic field of a vessel, the total field is the combined total of the earth's field and the vessel's field. Therefore, the earth's magnetic field is altered slightly by the vessel.

Since certain mines are triggered by a vessel's magnetic influence of a vessel passing near them, a vessel tries to minimize its magnetic field. One method of doing this is to neutralize each component of the field with an opposite electromagnetic field produced by electric cables coiled around the vessel. These cables, when energized, counteract the permanent magnetism of the vessel, rendering it magnetically neutral. This obviously has severe effects on magnetic compasses.

A unit sometimes used for measuring the strength of a magnetic field is the **gauss**. Reducing of the strength of a magnetic field decreases the number of gauss in that field. Hence, the process is called **degaussing**.

When a vessel's degaussing coils are energized, the magnetic field of the vessel is completely altered. This introduces large deviations in the magnetic compasses. This is removed by introducing at the magnetic compass an equal and opposite force with energized coils. This is called **compass compensation**. When there is a possibility of confusion with compass adjustment to neutralize the effects of the natural magnetism of the vessel, the expression **degaussing compensation** is used. Since compensation may not be perfect, a small amount of deviation due to degaussing may remain on certain headings. This is the reason for swinging the ship with degaussing off and with it on. This procedure leads to having two separate columns in the deviation table.

641. A Vessel's Magnetic Signature

A simplified diagram of the distortion of the earth's magnetic field in the vicinity of a steel vessel is shown in Figure 641a. The field strength is directly proportional to the line spacing density. If a vessel passes over a device for detecting and recording the strength of the magnetic field, a certain pattern is traced. Figure 641b shows this pattern. Since the magnetic field of each vessel is different, each produces a distinctive trace. This distinctive trace is referred to as the vessel's **magnetic signature**.

Several **degaussing stations** have been established to determine magnetic signatures and recommend the currents needed in the various degaussing coils. Since a vessel's induced magnetism varies with heading and magnetic latitude, the current settings of the coils may sometimes need to be changed. A **degaussing folder** is provided each vessel to indicate the changes and to give other pertinent information.

A vessel's permanent magnetism changes somewhat with time and the magnetic history of the vessel. Therefore, the data in the degaussing folder should be checked periodically at the magnetic station.

642. Degaussing Coils

For degaussing purposes, the total field of the vessel is divided into three components: (1) vertical, (2) horizontal fore-and-aft, and (3) horizontal athwartships. The positive (+) directions are considered downward, forward, and to port, respectively. These are the normal directions for a vessel headed north or east in north latitude. Each component

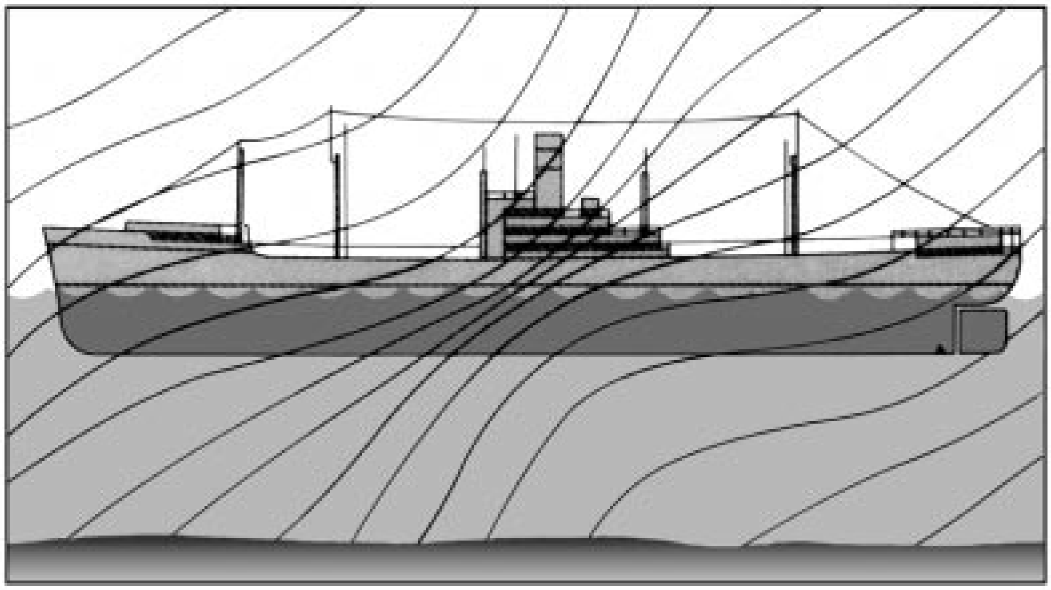


Figure 641a. Simplified diagram of distortion of earth's magnetic field in the vicinity of a steel vessel.

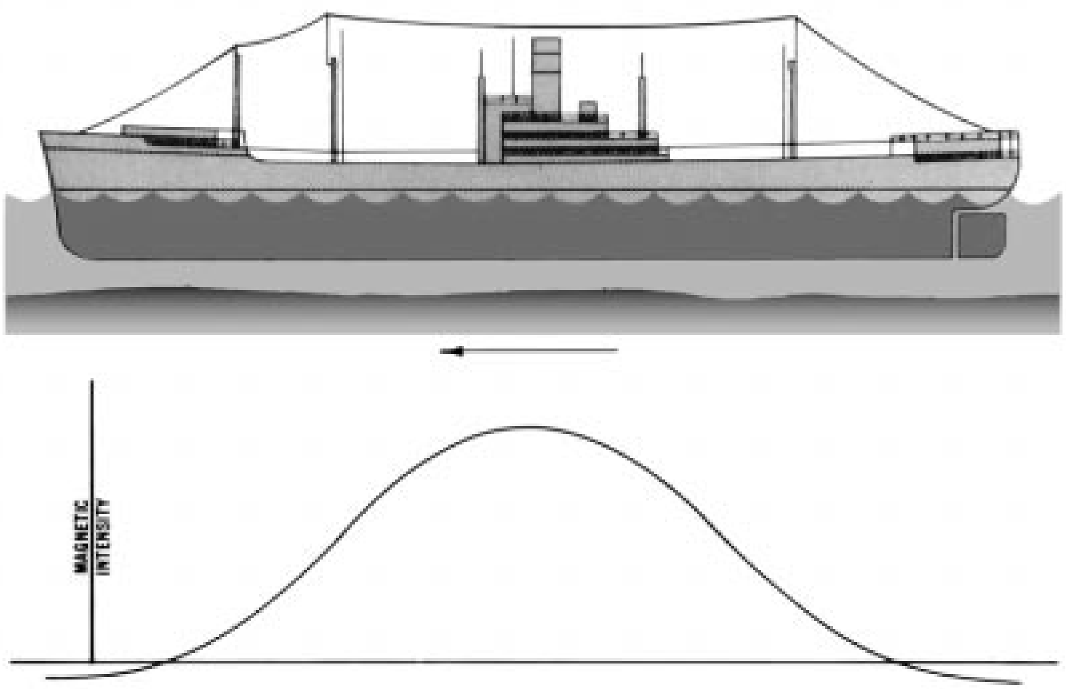


Figure 641b. A simplified signature of a vessel of Figure 641a.

is opposed by a separate degaussing field just strong enough to neutralize it. Ideally, when this has been done, the earth's field passes through the vessel smoothly and without distortion. The opposing degaussing fields are produced by direct current flowing in coils of wire. Each of the degaussing coils is placed so that the field it produces is directed to oppose one component of the ship's field.

The number of coils installed depends upon the magnetic characteristics of the vessel, and the degree of safety desired. The ship's permanent and induced magnetism may be neutralized separately so that control of induced magnetism can be varied as heading and latitude change, without disturbing the fields opposing the vessel's permanent field. The principal coils employed are the following:

Main (M) coil. The M coil is horizontal and completely encircles the vessel, usually at or near the waterline. Its function is to oppose the vertical component of the vessel's permanent and induced fields combined. Generally the induced field predominates. Current in the M-coil is varied or reversed according to the change of the induced component of the vertical field with latitude.

Forecastle (F) and **quarterdeck (Q) coils**. The F and Q coils are placed horizontal just below the forward and after thirds (or quarters), respectively, of the weather deck. The designation "Q" for quarterdeck is reminiscent of the days before World War II when the "quarterdeck" of naval vessels was aft along the ship's quarter. These coils, in which current can be individually adjusted, remove much of the fore-and-aft component of the ship's permanent and induced fields. More commonly, the combined F and Q coils consist of two parts; one part the FP and QP coils, to take care of the permanent fore-and-aft field, and the other part, the FI and QI coils, to neutralize the induced fore-and-aft field. Generally, the forward and after coils of each type are connected in series, forming a split-coil installation and designated FP-QP coils and FI-QI coils. Current in the FP-QP coils is generally constant, but in the FI-QI coils is varied according to the heading and magnetic latitude of the vessel. In split-coil installations, the coil designations are often called simply the P-coil and I-coil.

Longitudinal (L) coil. Better control of the fore-and-aft components, but at greater installation expense, is provided by placing a series of vertical, athwartship coils along the length of the ship. It is the field, not the coils, which is longitudinal. Current in an L coil is varied as with the FI-QI coils. It is maximum on north and south headings, and zero on east and west headings.

Athwartship (A) coil. The A coil is in a vertical fore-and-aft plane, thus producing a horizontal athwartship field which neutralizes the athwartship component of the vessel's field. In most vessels, this component of the permanent field is small and can be ignored. Since the A-coil neutralizes the induced field, primarily, the current is changed with magnetic latitude and with heading, maximum on east or west headings, and zero on north or south headings.

The strength and direction of the current in each coil is indicated and adjusted at a control panel accessible to the navigator. Current may be controlled directly by rheostats at the control panel or remotely by push buttons which operate rheostats in the engine room.

Appropriate values of the current in each coil are determined at a degaussing station, where the various currents are adjusted until the vessel's magnetic signature is made as flat as possible. Recommended current values and directions for all headings and magnetic latitudes are set forth in the vessel's degaussing folder. This document is normally kept by the navigator, whose must see that the recommended settings are maintained whenever the degaussing system is energized.

643. Securing The Degaussing System

Unless the degaussing system is properly secured, residual magnetism may remain in the vessel. During degaussing compensation and at other times, as recommended in the degaussing folder, the "reversal" method is used. The steps in the reversal process are as follows:

1. Start with maximum degaussing current used since the system was last energized.
2. Decrease current to zero and increase it in the opposite direction to the same value as in step 1.
3. Decrease the current to zero and increase it to three-fourths maximum value in the original direction.
4. Decrease the current to zero and increase it to one-half maximum value in the opposite direction.
5. Decrease the current to zero and increase it to one-fourth maximum value in the original direction.
6. Decrease the current to zero and increase it to one-eighth maximum value in the opposite direction.
7. Decrease the current to zero and open switch.

644. Magnetic Treatment Of Vessels

In some instances, degaussing can be made more effective by changing the magnetic characteristics of the vessel by a process known as **deperming**. Heavy cables are wound around the vessel in an athwartship direction, forming vertical loops around the longitudinal axis of the vessel. The loops are run beneath the keel, up the sides, and over the top of the weather deck at closely spaced equal intervals along the entire length of the vessel. Predetermined values of direct current are then passed through the coils. When the desired magnetic characteristics have been acquired, the cables are removed.

A vessel which does not have degaussing coils, or which has a degaussing system which is inoperative, can be given some temporary protection by a process known as **flashing**. A horizontal coil is placed around the outside of the vessel and energized with large predetermined values of direct current. When the vessel has acquired a vertical field of permanent magnetism of the correct magnitude and polarity to reduce to a minimum the resultant field below the vessel for the particular magnetic latitude involved, the cable is removed. This type protection is not as satisfactory as that provided by degaussing coils because it is not adjustable for various headings and magnetic latitudes, and also because the vessel's magnetism slowly readjusts following treatment.

During magnetic treatment all magnetic compasses and Flinders bars should be removed from the ship. Permanent adjusting magnets and quadrantal correctors are not materially affected, and need not be removed. If it is impractical to remove a compass, the cables used for magnetic treatment should be kept as far as practical from it.

645. Degaussing Effects

The degaussing of ships for protection against magnetic mines creates additional effects upon magnetic compasses, which are somewhat different from the permanent and induced magnetic effects. The degaussing effects are electromagnetic, and depend on:

1. Number and type of degaussing coils installed.
2. Magnetic strength and polarity of the degaussing coils.
3. Relative location of the different degaussing coils with respect to the binnacle.
4. Presence of masses of steel, which would tend to concentrate or distort magnetic fields in the vicinity of the binnacle.
5. The fact that degaussing coils are operated intermittently, with variable current values, and with different polarities, as dictated by necessary degaussing conditions.

646. Degaussing Compensation

The magnetic fields created by the degaussing coils would render the vessel's magnetic compasses useless unless compensated. This is accomplished by subjecting the compass to compensating fields along three mutually perpendicular axes. These fields are provided by small **compensating coils** adjacent to the compass. In nearly all installations, one of these coils, the **heeling coil**, is horizontal and on the same plane as the compass card, providing a vertical compensating field. Current in the heeling coil is adjusted until the vertical component of the total degaussing field is neutralized. The other compensating coils provide horizontal fields perpendicular to each other. Current is varied in these coils until their resultant field is equal and opposite to the horizontal component of the degaussing field. In early installations, these horizontal fields were directed fore-and-aft and athwartships by placing the coils around the Flinders bar and the quadrantal spheres. Compactness and other advantages are gained by placing the coils on perpendicular axes extending 045°-225° and 315°-135° relative to the heading. A frequently used compensating installation, called the **type K**, is shown in Figure 646. It consists of a heeling coil extending completely around the top of the binnacle, four **intercardinal coils**, and three control boxes. The intercardinal coils are named for their positions relative to the compass when the vessel is on a heading of north, and also for the compass headings on which the current in the coils is adjusted to the correct amount for compensation. The NE-SW coils operate together as one set, and the NW-SE coils operate as another. One control box is provided for each set, and one for the heeling coil.

The compass compensating coils are connected to the power supply of the degaussing coils, and the currents passing through the compensating coils are adjusted by series resistances so that the compensating field is equal to the degaussing field. Thus, a change in the degaussing currents is accompanied by a proportional change in the compensating currents. Each coil has a separate winding for each degaussing circuit it compensates.

Degaussing compensation is carried out while the vessel is moored at the shipyard where the degaussing coils are installed. This is usually done by civilian professionals, using the following procedure:

Step 1. The compass is removed from its binnacle and a dip needle is installed in its place. The M coil and heeling coil are then energized, and the current in the heeling coil is adjusted until the dip needle indicates the correct value for

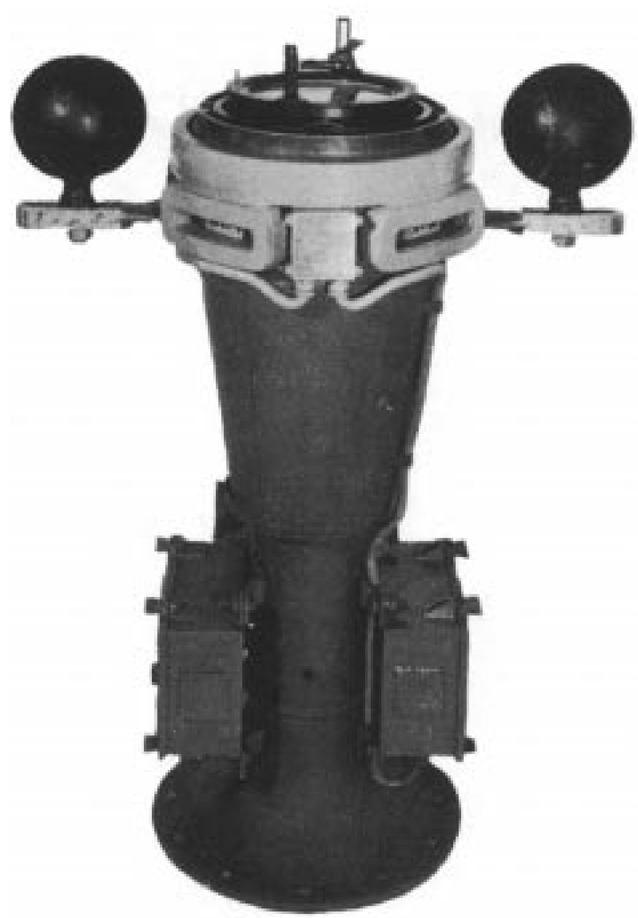


Figure 646. Type K degaussing compensation installation.

the magnetic latitude of the vessel. The system is then secured by the reversing process.

Step 2. The compass is replaced in the binnacle. With auxiliary magnets, the compass card is deflected until the compass magnets are parallel to one of the compensating coils or set of coils used to produce a horizontal field. The compass magnets are then *perpendicular* to the field produced by that coil. One of the degaussing circuits producing a horizontal field, and its compensating winding, are then energized, and the current in the compensating winding is adjusted until the compass reading returns to the value it had before the degaussing circuit was energized. The system is then secured by the reversing process. The process is repeated with each additional circuit used to create a horizontal field. The auxiliary magnets are then removed.

Step 3. The auxiliary magnets are placed so that the compass magnets are parallel to the other compensating coils or set of coils used to produce a horizontal field. The procedure of step 2 is then repeated for each circuit producing a horizontal field.

When the vessel gets under way, it proceeds to a suitable maneuvering area. The vessel is then headed so that the compass magnets are parallel first to one compensating coil or set of coils and then the other, and any needed adjustment is made in the compensating circuits to reduce the error to a minimum. The vessel is then swung for residual deviation, first with degaussing off and then with degaussing on, and the correct current settings for each heading at the magnetic latitude of the vessel. From the values thus obtained, the "DG OFF" and "DG ON" columns of the deviation table are filled in. If the results indicate satisfactory compensation, a record is made of the degaussing coil settings and the resistance, voltages, and currents in the compensating coil circuits. The control boxes are then secured.

Under normal operating conditions, the settings need not be changed unless changes are made in the degaussing system, or unless an alteration is made in the amount of Flinders bar or the setting of the quadrantal correctors. However, it is possible for a ground to occur in the coils or control box if the circuits are not adequately protected from moisture. If this occurs, it should be reflected by a change in deviation with degaussing on, or by a decreased installation resistance. Under these conditions, compensation should be done again. If the compass will be used with degaussing on before the ship can be returned to a shipyard where the compensation can be made by experienced personnel, the compensation should be made at sea on the actual headings needed, rather than by deflection of the compass needles by magnets. More complete information related to this process is given in the degaussing folder.

If a vessel has been given magnetic treatment, its magnetic properties have been changed. This necessitates readjustment of *each* magnetic compass. This is best delayed for several days to permit stabilization of the magnetic characteristics of the vessel. If compensation cannot be delayed, the vessel should be swung again for residual deviation after a few days. Degaussing compensation should not be made until after compass adjustment has been completed.