

# HANDBOOK OF MAGNETIC COMPASS ADJUSTMENT



NATIONAL  
GEOSPATIAL-INTELLIGENCE AGENCY  
BETHESDA, MD  
2004

(Formerly Pub.No. 226)

AS ORIGINALLY PUBLISHED BY  
DEFENSE MAPPING AGENCY  
HYDROGRAPHIC/TOPOGRAPHIC CENTER  
WASHINGTON, D.C.  
1980

## INTRODUCTION

This document has been prepared in order to present all pertinent information regarding the practical procedures of magnetic compass adjustment in one text. As such, it treats of the basic principles of compass deviations and their correction, and not of the details of particular compass equipment.

Although this text is presented as a systematic treatise on compass adjustment, ship's personnel who are inexperienced with compass correction will find sufficient information in Chapters I and XIV to eliminate compass errors satisfactorily without intensive study of the entire text. Reference should also be made to figure 318 for condensed information regarding the various compass errors and their correction.

In this handbook, the term *compass adjustment* refers to any changes of permanent magnet or soft iron correctors whereby normal compass errors are reduced. The term *compass compensation* refers to any change in the current supplied to compass compensating coils whereby the errors due to degaussing are reduced.

The basic text is the outgrowth of lecture notes prepared by Nye S. Spencer and George F. Kucera while presenting courses of instruction in adjustment and compensation during World War II at the Magnetic Compass Demonstration Station, Naval Operating Base, Norfolk, Virginia.

## CHAPTER I

### PROCEDURES FOR MAGNETIC COMPASS ADJUSTMENT (CHECK-OFF LIST)

NOTE: If the magnetic adjustment necessitates (a) movement of degaussing compensating coils, or (b) a change of Flinders bar length, the coil compensation must be checked. Refer to Chapter XIV.

#### 101. Dockside tests and adjustments

1. Physical checks on the compass and binnacle.
  - (a) Remove any bubbles in compass bowl (article 402).
  - (b) Test for moment and sensibility of compass needles (article 403).
  - (c) Remove any slack in gimbal arrangement.
  - (d) Magnetization check of spheres and Flinders bar (article 404).
  - (e) Alignment of compass with fore-and-aft line of ship (article 405).
  - (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 all gyro repeater peloruses or dial peloruses with fore-and-aft line of ship (article 405).
  - (b) Synchronize gyro repeaters with master gyro.
  - (c) Make sure azimuth circle and peloruses are in good operating condition.\*
3. Necessary data.
  - (a) Past history or log data which might establish length of Flinders bar (articles 407 and 607)
  - (b) Azimuths for given date and observer's position (Chapter VIII).
  - (c) Ranges or distant objects in vicinity (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. (Chapter X).
  - (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 (articles 318 and 613).
5. Adjustments.
  - (a) Place Flinders bar according to best available information (articles 407, 608 and 609).
  - (b) Set spheres at midposition, or as indicated by last deviation table.
  - (c) Adjust heeling magnet, using balanced dip needle if available (Chapter XI).

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\* Applies when system other than gyro is used as heading reference

**102. Adjustments at sea.** These adjustments are made with the ship on an even keel and after steadying on each heading. When using the gyro, swing from heading to heading slowly and check gyro error by sun's azimuth or ranges on each heading if desired to ensure a greater degree of accuracy (article 706). Be sure gyro is set for the mean speed and latitude of the vessel. Note all precautions in article 101(4) above. "OSCAR QUEBEC" international code signal should be flown to indicate such work is in progress. Chapter VII discusses methods for placing the ship on desired headings.

1. Adjust the heeling magnet, while the ship is rolling, on north and south magnetic heading 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 an east (090°) cardinal magnetic heading. Insert fore-and-aft *B* magnets, or move the existing *B* magnets, in such a manner as to remove all deviation.
3. Come to a south (180°) magnetic heading. Insert athwartship *C* magnets, or move the existing *C* magnets, in such a manner as 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 heading, as discussed in article 501.*)
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 (Chapter V).
11. Record deviations and the details of corrector positions on standard Navy Form NAVSEA 3120/4 and in the Magnetic Compass Record NAVSEA 3120/3 (article 901).
12. Swing for residual degaussed deviations with the degaussing circuits properly energized (Chapter XIV).
13. Record deviations for degaussed conditions on standard Navy Form NAVSEA 3120/4.

**103.** The above check-off list describes a simplified method of adjusting compasses, designed to serve as a simple 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", and if neglected may lead to spurious results or needless repetition of the procedure at sea. Hence, it is strongly recommended that careful considerations be given these dockside checks prior to making the final adjustment so as to allow time to repair or replace faulty compasses, anneal or replace magnetized spheres or Flinders bar, realign binnacle, move gyro repeater if it is affecting the compass, or to make any other necessary preliminary repairs. It is further stressed that expeditious compass adjustment is dependent upon the application of the various correctors in a logical sequence so as to achieve the final adjustment with a minimum number of steps. This sequence is incorporated in the above check-off list and better results will be obtained if it is adhered to closely. Figure 318 presents the various compass errors and their correction in condensed form. The table in figure 103 will further clarify the mechanics of placing the corrector magnets, spheres, and Flinders bar. Chapter IV discusses the more efficient and scientific methods of adjusting compasses, in addition to a more elaborate treatment of the items mentioned in the check-off list. 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** (article 1003) 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.

Fore-and-aft and athwartship magnets			Quadrantal spheres			Flinders bar		
<b>Deviation</b> → <b>Magnets</b> ↓	Easterly on east <i>and</i> westerly on west. (+ B error)	Westerly on east <i>and</i> easterly on west. (– B error)	<b>Deviation</b> → <b>Spheres</b> ↓	E on NE'ly, W on SE'ly, E on SW'ly, <i>and</i> W on NW'ly. (+ D error)	W on NE'ly, E on SE'ly, W on SW'ly, <i>and</i> E on NW'ly. (– D error)	<b>Deviation change with change in latitude</b> → <b>Bar</b> ↓	E on E'ly <i>and</i> W on W'ly when sailing toward equator from N latitude or away from equator to S latitude	W on E'ly <i>and</i> E on W'ly when sailing toward equator from N latitude or away from equator to S 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 amount 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 outward or remove.	Bar forward of binnacle.	Increase amount of bar forward.	Decrease 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 forward.	Increase amount of bar forward.
<b>Deviation</b> → <b>Magnets</b> ↓	Easterly on north <i>and</i> westerly on south. (+ C error)	Westerly on north <i>and</i> easterly on south. (– C error)	<b>Deviation</b> → <b>Spheres</b> ↓	E on N'ly, W on E'ly, E on S'ly, <i>and</i> W on W'ly (+ E error)	W on N'ly, E on E'ly, W on S'ly, <i>and</i> E on W'ly (– E error)	↑ <b>Bar</b> <b>Deviation change with change in latitude</b> →	W on E'ly <i>and</i> E on W'ly when sailing toward equator from S latitude or away from equator to N latitude	E on E'ly <i>and</i> W on W'ly when sailing toward equator from S latitude or away from equator to N 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 inter-cardinal positions.	Place spheres at starboard forward and port aft inter-cardinal positions.	<b>Heeling magnet</b> (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 or 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 or 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 103 – Mechanics of magnetic compass adjustment

## CHAPTER II

### MAGNETISM

**201. The magnetic compass.** The principle of the present day magnetic compass is in no way different from that of the compass used by the ancients. It consists of a magnetized needle, or array of needles, pivoted so that rotation is in a horizontal plane. The superiority of the present day compass results from a better knowledge of the laws of magnetism, which govern the behavior of the compass, and from greater precision in construction.

**202. Magnetism.** Any piece of metal on becoming magnetized, that is, acquiring the property of attracting small particles of iron or steel, will assume regions of concentrated magnetism, called poles. Any such magnet will have at least two poles, of unlike polarity. Magnetic lines of force (flux) connect one pole of such a magnet with the other pole as indicated in figure 202. 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 side by side, the like poles will repel each other and the unlike poles will attract each other.

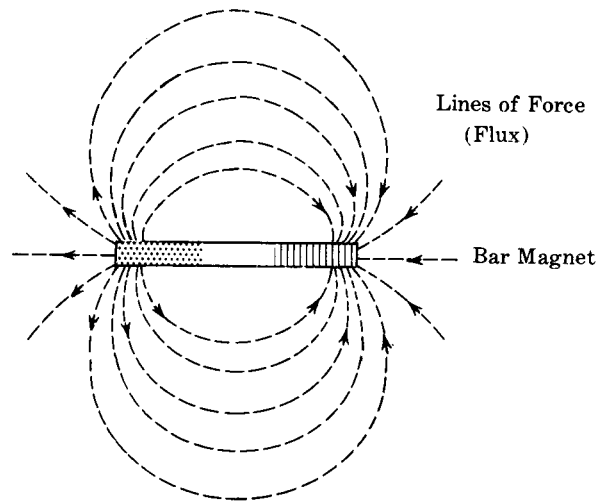


Figure 202 – Lines of magnetic force about a magnet

**203.** Magnetism is in general of two types, permanent and 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.

**204. Terrestrial magnetism.** The accepted theory of terrestrial magnetism considers the earth as a huge magnet surrounded by lines of magnetic force that connect its two magnetic poles. These magnetic poles are near, but not coincidental, with the geographic poles of the earth. Since the north-seeking end of a compass needle is conventionally called a red pole, north pole, or positive pole, it must therefore be attracted to a pole of opposite polarity, or to a blue pole, south pole, or negative pole. The magnetic pole near the north geographic pole is therefore a blue pole, south pole, or negative pole; and the magnetic pole near the south geographic pole is a red pole, north pole, or positive pole.

**205.** Figure 205 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 latitudes. This angle is called the angle of magnetic dip,  $\theta$ , and increases from zero, at the magnetic equator, to  $90^\circ$  at the magnetic poles. The total magnetic field is generally considered as having two components, namely  $H$ , the horizontal component, and  $Z$ , the vertical component. These components change as the angle  $\theta$  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.

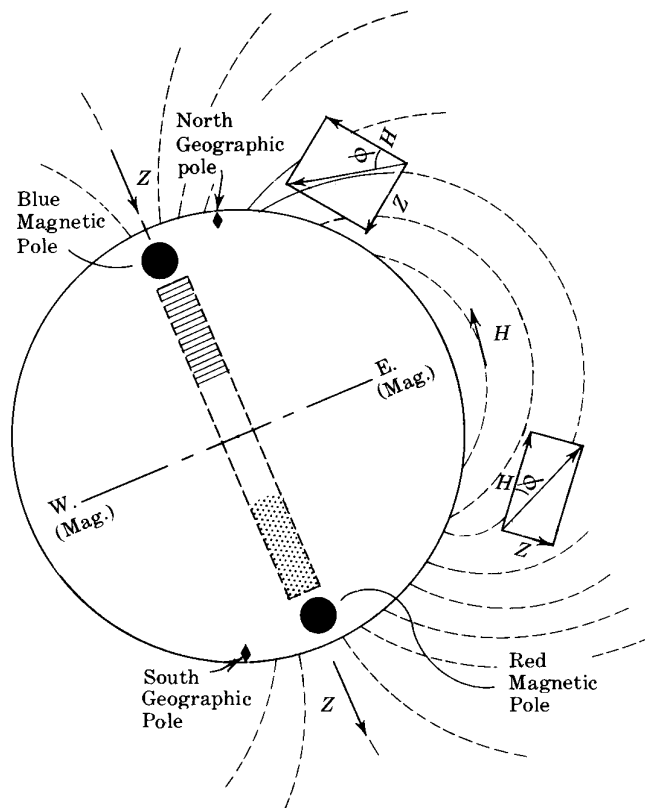


Figure 205 – Terrestrial magnetism

**206.** Inasmuch as the magnetic poles of the earth are not coincidental with the geographic poles, it is evident that 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 the compass rose of navigational charts. The variation for most given areas undergoes an annual change, the amount of which is also noted on all charts. See figure 206.

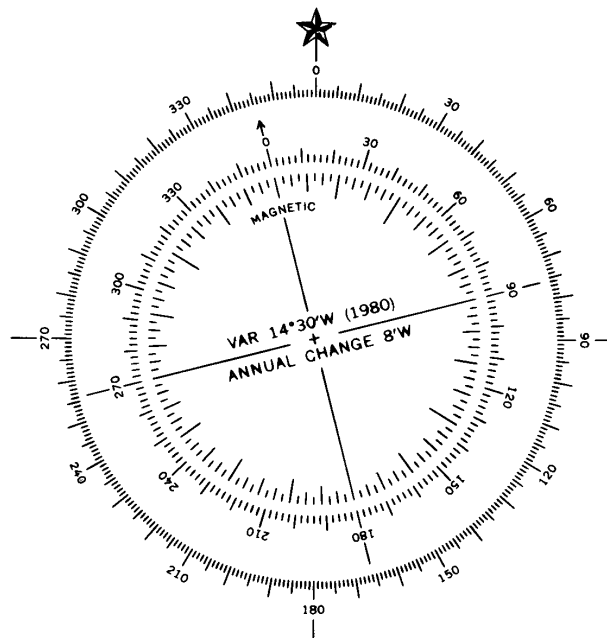


Figure 206 – Compass rose showing variation and annual change

**207. Ship's magnetism.** A ship, while in the process of being constructed, will acquire magnetism of a permanent nature under the extensive hammering it receives in the earth's magnetic field. After launching, the ship will lose some of this original magnetism as a result of vibration, pounding, etc., in varying magnetic fields, and will eventually reach a more or less stable magnetic condition. This magnetism which remains is the permanent magnetism of the ship.

**208.** The fact that a ship has permanent magnetism does not mean that it cannot also acquire induced magnetism when placed in a magnetic field such as the earth's field. The amount of magnetism induced in any given piece of soft iron is dependent upon 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 induced by the earth's magnetic field and the more readily it will give up its magnetism when removed from that field.

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

**210.** A ship, then, has a combination of permanent, subpermanent, and induced magnetism, since its metal structures are of varying degrees of hardness. Thus, the apparent permanent magnetic condition of the ship is subject to change from deperming, excessive shocks, welding, vibration, etc.; and the induced magnetism of the ship will vary with the strength of the earth's magnetic field at different magnetic latitudes, and with the alignment of the ship in that field.

**211. Resultant induced magnetism from earth's magnetic field.** The above discussion of induced magnetism and terrestrial magnetism leads to the following facts. A long thin rod of soft iron in a plane parallel to the earth's horizontal magnetic field,  $H$ , will have a red (north) pole induced in the end toward the north geographic pole and a blue (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 that create maximum and zero induction, it would be induced by an amount that 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 blue (south) pole induced at the upper end and a red (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.

## CHAPTER III

### THEORY OF MAGNETIC COMPASS ADJUSTMENT

**301. Magnetic adjustment.** The magnetic compass, when used on a steel ship, must be so corrected for the ship's magnetic conditions that its operation approximates that of a nonmagnetic ship. Ship's magnetic conditions create deviations of the magnetic compass as well as sectors of sluggishness and unsteadiness. Deviation is defined as deflection of the card (needles) to the right or left of the magnetic meridian. Adjustment of the compass is the arranging of 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, thus reducing the deviations and eliminating the sectors of sluggishness and unsteadiness.

The magnetic conditions in a ship which affect a magnetic compass are permanent magnetism and induced magnetism, as discussed in Chapter II.

**302. Permanent magnetism and its effects on the compass.** The total permanent magnetic field effect at the compass may be broken into three components mutually  $90^\circ$  apart, as shown in figure 302a. The effect of the vertical permanent component is the tendency to tilt the compass card and, in the event of rolling or pitching of the ship to create oscillating deflections of the card. Oscillation effects that accompany roll are maximum on north and south compass headings, and those that 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 will produce sine and cosine curves, as shown in figure 302b. These deviation curves are called semicircular curves because they reverse direction in  $180^\circ$ .

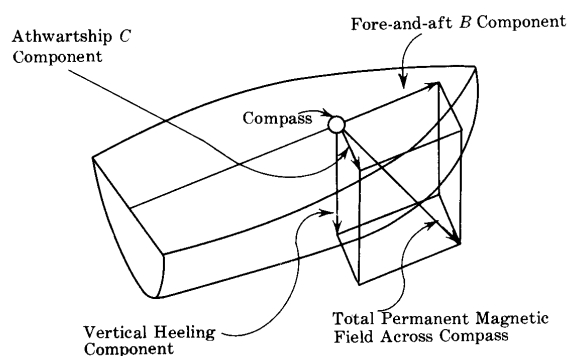


Figure 302a – Components of permanent magnetic field at the compass

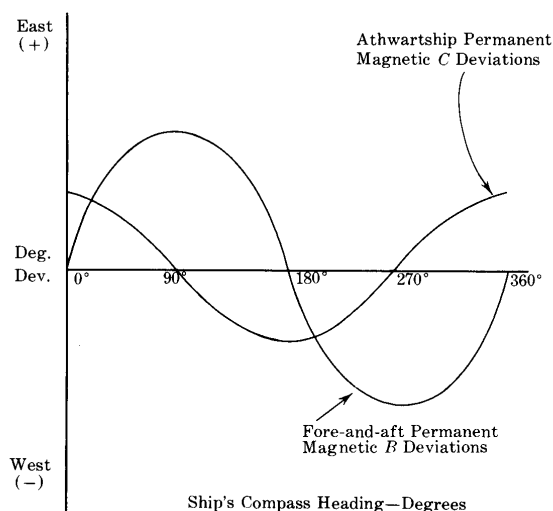


Figure 302b – Permanent magnetic deviation effects

**303.** The permanent magnetic semicircular deviations can be illustrated by a series of simple sketches, representing a ship on successive compass headings, as in figures 303a and 303b.

**304.** The ships illustrated in figures 303a and 303b are pictured on cardinal compass headings rather than on cardinal magnetic headings, for two reasons:

- (1) Deviations on compass headings are essential in order to represent sinusoidal curves that can be analyzed mathematically. This can be visualized by noting that the ship's component magnetic fields are either in line with or perpendicular to the compass needles only on cardinal compass headings.
- (2) Such a presentation illustrates the fact that the compass card tends to float in a fixed position, in line with the magnetic meridian. Deviations of the card to right or left (east or west) of the magnetic meridian result from the movement of the ship and its magnetic fields about the compass card.

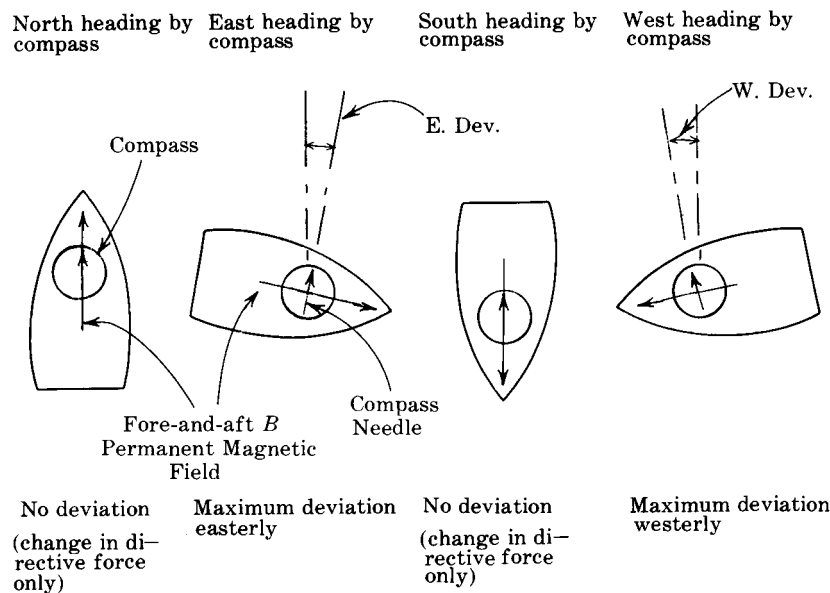


Figure 303a – Force diagrams for fore-and-aft permanent *B* magnetic field

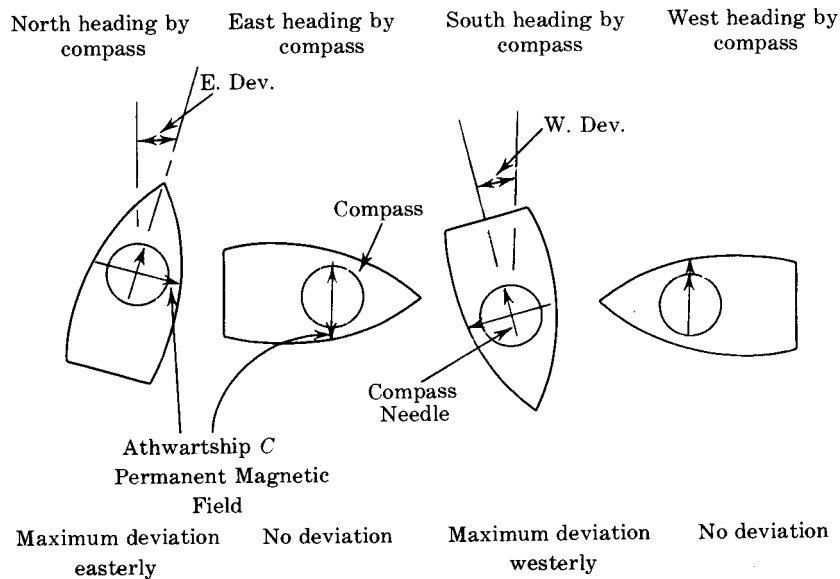


Figure 303b – Force diagrams for athwartship permanent *C* magnetic field

**305.** Inasmuch as a compass deviation is caused by the existence of a force at the compass that is superimposed upon the normal earth's directive force,  $H$ , a vector analysis is helpful in determining deviations or the strength of deviating fields. For example, a ship as shown in figure 305 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 on the ship in figure 305 will reveal that the resulting directive force at the compass would be maximum on a north heading and minimum on a south heading, the deviations being zero for both conditions.

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.

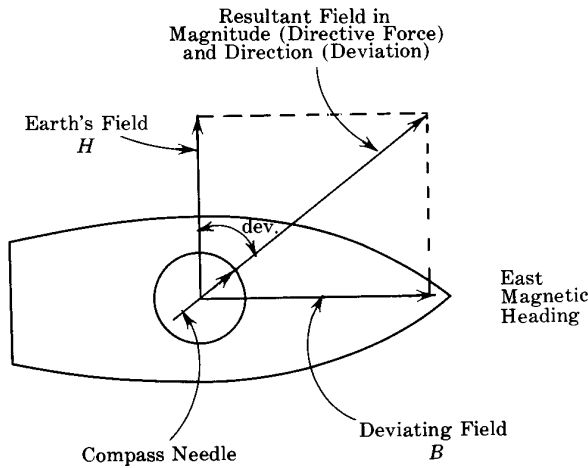


Figure 305 – General force diagram

**306. 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.

**307.** With the ship on an even keel, the resultant vertical induced magnetism, if not directed through the compass itself, will create deviations that 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. Figure 307a illustrates the vertical induced poles in the structures of a ship.

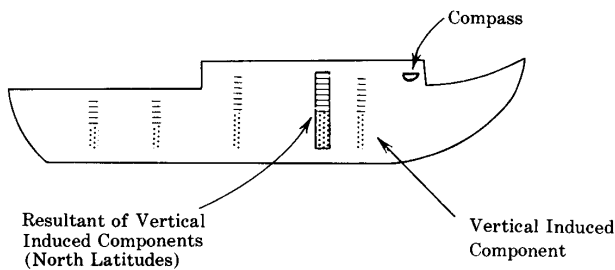


Figure 307a – Ship's vertical induced magnetism

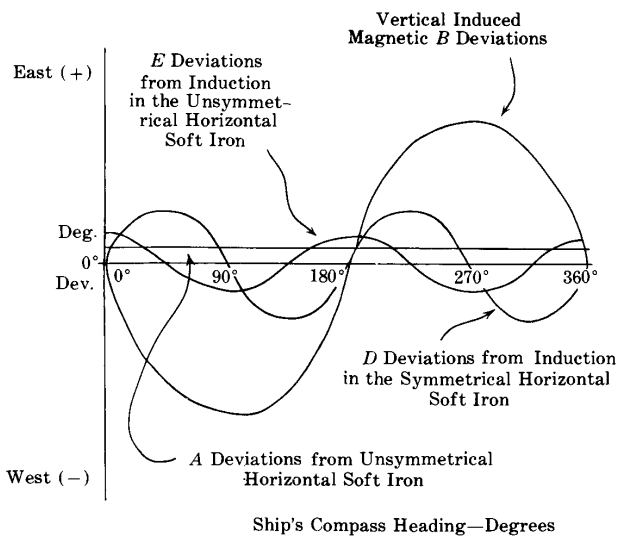


Figure 307b – Induced magnetic deviation effects

Generally, this semicircular deviation will be a *B* sine curve, as shown in figure 307b, since most ships are symmetrical about the centerline and have their compasses mounted on the centerline. The magnitude of these deviations will change with magnetic latitude changes because the directive force and the ship's vertical induction both change with magnetic latitude.

**308.** The masses of horizontal soft iron that are subject to induced magnetization create characteristic deviations, as indicated in figure 307b. The *D* and *E* deviation curves are called quadrantal curves because they reverse polarity in each of the four quadrants.

**309.** Symmetrical arrangements of horizontal soft iron may exist about the compass in any one of the patterns illustrated in figure 309.

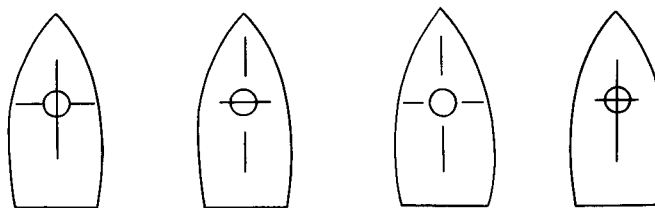


Figure 309 – Symmetrical arrangements of horizontal soft iron

**310.** The deviation resulting from the earth's field induction of these symmetrical arrangements of horizontal soft iron are illustrated in figure 310, showing the ship on various compass headings. The other heading effects may be similarly studied. Such a *D* deviation curve is one of the curves in figure 307b. It will be noted that these *D* deviations are maximum on the intercardinal headings and zero on the cardinal headings.

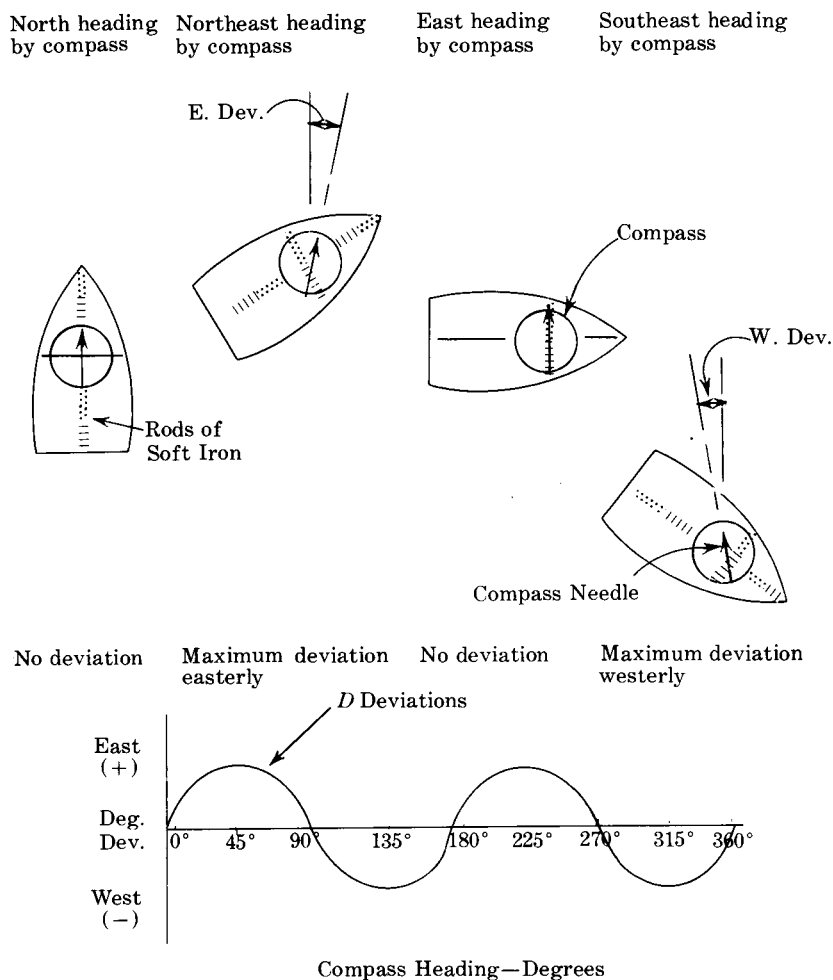


Figure 310 – Effects of symmetrical horizontal *D* induced magnetism

**311.** Asymmetrical arrangements of horizontal soft iron may exist about the compass in a pattern similar to one of those in figure 311.

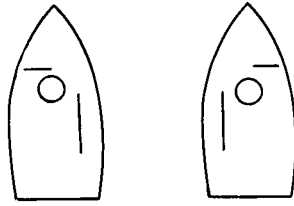


Figure 311 – Asymmetrical arrangements of horizontal soft iron

**312.** The deviations resulting from the earth's field induction of these asymmetrical arrangements of horizontal soft iron are illustrated in figure 312, showing the ship on different compass headings. The other heading effects may be similarly studied. Such an *E* deviation curve is one of the curves in figure 307b. It will be observed that these *E* deviations are maximum on cardinal headings and zero on the intercardinal headings.

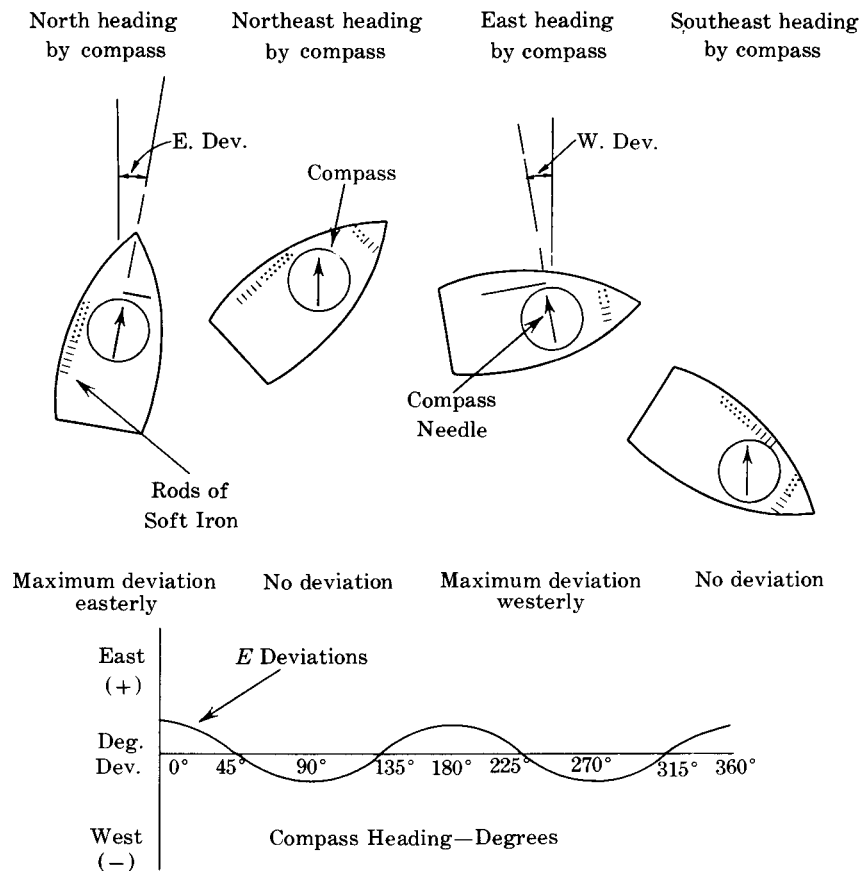


Figure 312 – Effects of asymmetrical horizontal *E* induced magnetism

**313.** The quadrantal deviations will not vary with latitude changes, because the horizontal induction varies proportionally with the directive force, *H*.

**314.** The earth's field induction in certain other asymmetrical arrangements of horizontal soft iron creates a constant *A* deviation curve. The magnetic *A* and *E* errors are of smaller magnitude than the other errors, but, when encountered, are generally found together, since they both result from asymmetrical arrangements of horizontal soft iron. 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.

**315.** 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.

**316.** 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.

**317. Adjustments and correctors.** Since some magnetic effects remain constant for all magnetic latitudes and others vary with changes of magnetic latitude, each individual effect should be corrected independently. Further, it is apparent that the best method of adjustment is to use (1) permanent magnet correctors to create equal and opposite vectors of permanent magnetic fields at the compass, and (2) soft iron correctors to assume induced magnetism, the effect of which will be equal and opposite to the induced effects of the ship for all magnetic latitude and heading conditions. The compass binnacle provides for the support of the compass and such correctors. Study of the binnacle in figure 317 will reveal that such correctors are present in the form of:

- (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 spheres.

The heeling magnet is the only corrector that corrects for both permanent and induced effects, and consequently must be readjusted occasionally with radical changes in latitude of the ship. (It must be noted, however, that any movement of the heeling magnet will require readjustment of other correctors.)

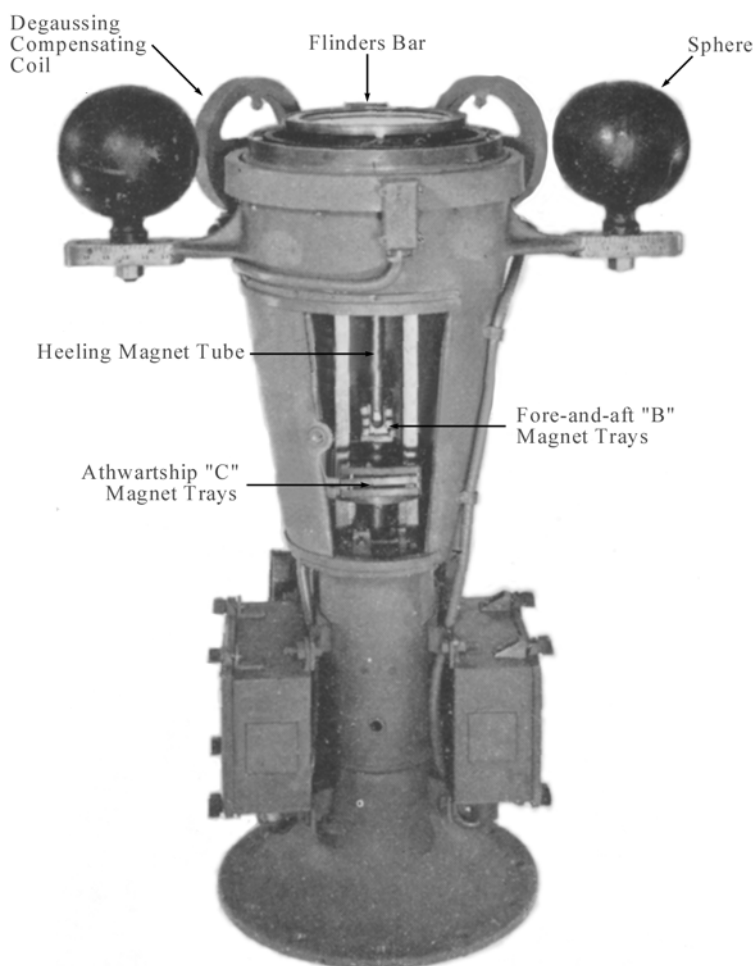


Figure 317 – Binnacle with compass and correctors

**318.** The tabular summary of "Compass Errors and Adjustments," figure 318, 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. Correctors should be applied symmetrically under all but exceptional conditions (discussed in detail later) and as far away from the compass as possible to preserve uniformity of magnetic fields about the compass needle array. Other details of corrector procedure are emphasized in chapter VI. Fortunately, each magnetic effect has a slightly different characteristic curve that makes identification and correction convenient. A complete deviation curve can be analyzed for its different components and, thus, the necessary corrections anticipated. A method for analyzing such curves is described in chapter V.

Coefficient	Type deviation curve	Compass headings of maximum deviation	Causes of such errors	Corrections for such errors	Magnetic or compass headings on which to apply correctors
<i>A</i>	Constant.	Same on all.	Human: error in calculations..... Physical: compass, gyro, pelorus alignment..... Magnetic: asymmetrical arrangements of horizontal soft iron .....	Check methods and calculations Check alignments  Rare arrangement of soft iron rods	Any.
<i>B</i>	Semicircular $\sin \theta$ .	090° 270°	Fore-and-aft component of permanent magnetic field.... Induced magnetism in asymmetrical vertical iron forward or aft of compass .....	Fore-and-aft <i>B</i> magnets. Flinders bar (forward or aft)	090° or 270°.
<i>C</i>	Semicircular $\cos \theta$ .	000° 180°	Athwartship component of permanent magnetic field.... Induced magnetism in asymmetrical vertical iron port or starboard of compass.....	Athwartship <i>C</i> magnets Flinders bar (port or starboard)	000° or 180°.
<i>D</i>	Quadrantal $\sin 2\theta$ .	045° 135° 225° 315°	Induced magnetism in all symmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (athwartship for + <i>D</i> ) (fore and aft for - <i>D</i> ) <i>See sketch a</i>	045°, 135°, 225°, or 315°.
<i>E</i>	Quadrantal $\cos 2\theta$ .	000° 090° 180° 270°	Induced magnetism in all asymmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (port forward, starboard aft for + <i>E</i> ) (starboard forward, port aft for - <i>E</i> ) <i>See sketch b</i>	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 re-adjusted for latitude changes)	090° or 270° with dip needle. 000° or 180° while rolling.

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

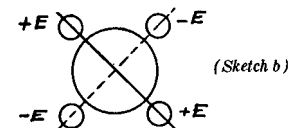
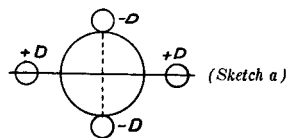


Figure 318 – Summary of Compass Errors and Adjustments

**319. Compass operation.** Figure 319 illustrates a point about compass operation. Not only is an uncorrected compass subject to large deviations, but there will be sectors in which the compass may sluggishly turn with the ship and other sectors in which the compass is too unsteady to use. These performances may be appreciated by visualizing a ship with deviations as shown in figure 319, as it swings from west through north toward east. Throughout this easterly swing the compass deviation is growing more easterly; and, whenever steering in this sector, the compass card sluggishly tries to follow the ship. Similarly, there is an unsteady sector from east through south to west. These sluggish and unsteady conditions are always characterized by the positive and negative slopes in a deviation curve. These conditions may also be associated with the maximum and minimum directive force acting on the compass (see article 305). It will be observed that the maximum deviation occurs at the point of average directive force and that the zero deviations occur at the points of maximum and minimum directive force.

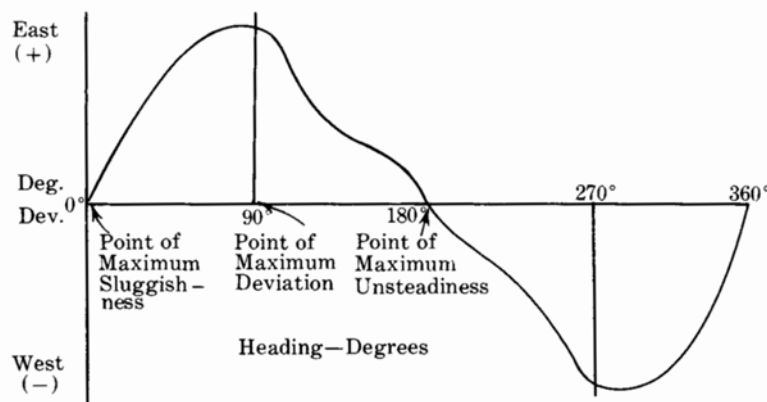


Figure 319 – Uncompensated deviation curve

**320.** Correction of compass errors is generally achieved by applying correctors so as to reduce the deviations of the compass for all headings of the ship. Correction could be achieved, however, by applying correctors so as to equalize the directive forces across the compass position for all headings of the ship. The deviation method is more generally used because it utilizes the compass itself to indicate results, rather than some additional instrument for measuring the intensity of magnetic fields.

**321.** 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 be 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 red ends forward in order to neutralize the existing blue pole that attracted the compass. If made on an east heading, such an adjustment would be practically complete when the compass card was freed so as to indicate an east heading.

**322.** Listed below 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) Although a common belief is that it does not matter what the deviations are, as long as they are known, this is in error inasmuch as conditions of sluggishness and unsteadiness accompany large deviations and consequently make the compass operationally unsatisfactory. This is the result of unequal directive forces on the compass as the ship swings in heading.
- (3) Furthermore, even though the deviations are known, if they are large they will be subject to appreciable change with heel and latitude changes of the ship.

**323.** Subsequent chapters will deal with the methods of bringing a ship to the desired heading, and the methods of isolating deviation effects and of minimizing interaction effects between correctors. 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.

## CHAPTER IV

### PRACTICAL PROCEDURES FOR MAGNETIC COMPASS ADJUSTMENT

NOTE: If the adjuster is not familiar with the theory of magnetic effects, the methods of analyzing deviation curves, and the methods of placing a ship on any desired heading, it is recommended to review Chapters II, V and VII, respectively, before beginning adjustment.

**401. Dockside tests and adjustments.** Chapter I, "Procedures for Magnetic Compass Adjustment" is, in general, self-explanatory, and brings to the attention of the adjuster many physical checks which are desirable before beginning an adjustment. The theoretical adjustment is based on the premise that all the physical arrangements are perfect, and much time and trouble will be saved while at sea if these checks are made before attempting the actual magnet and soft iron corrector adjustments. A few of these checks are amplified below.

**402.** Should the compass have a small bubble, compass fluid may be added by means of the filling plug on the side of the compass bowl. If an appreciable amount of compass liquid has leaked out, a careful check should be made on the condition of the sealing gasket and filling plug. U.S. Navy compass liquid may be a mixture of 45% grain alcohol and 55% distilled water, or a kerosene-type fluid. These fluids are NOT interchangeable.

**403.** The compass should be removed from the ship and taken to some 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. (See NAVSEA 3120/3 for such test data on standard Navy compass equipment.)

**404.** A careful check should be made on 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 ( $2^\circ$  or more) of the compass needles resulting from this rotation indicates residual magnetism in the spheres. This test may be made with the ship on any steady heading. The Flinders bar magnetization check is preferably made with the ship on steady 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 ( $2^\circ$  or more) between these observed readings indicates residual magnetism in the Flinders bar. Spheres or Flinders bars that show signs of such residual magnetism should be annealed, i.e. heated to a dull red and allowed to cool slowly.

**405.** Correct alignment of the lubber's line of the compass, gyro repeater, and pelorus with the fore-and-aft line of the ship is of major importance. Such a misalignment will produce a constant  $A$  error in the curve of deviations. 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. In the case of an instrument off the centerline, a metal tape measure is used to measure the distance from the centerline of the ship to the center of the instrument. A similar measurement from the centerline is made forward or abaft the subject instrument and reference marks are placed on the deck. Sights are then taken on these marks.

Standard compasses should always be aligned so that the lubber's line of the compass 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 article 411.

**406.** In addition to the physical checks listed in Chapter I, there are other precautions to be observed in order to assure continued satisfactory compass operation. These precautions are mentioned to bring to the attention of the adjuster certain conditions that might disturb compass operation. They are listed in Chapter I and are discussed further in Chapter X.

Expeditious compass adjustment is dependent upon the application of the various correctors in an optimum sequence so as to achieve the final adjustment with a minimum number of steps. Certain adjustments may be made conveniently at dockside so as to simplify the adjustment procedures at sea.

**407.** Inasmuch as the Flinders bar is subject to induction from several of the other correctors and, since its adjustment is not dependent on any single observation, this adjustment is logically made first. This adjustment is made by one of the following methods:

- (1) Deviation data obtained at two different magnetic latitudes may be utilized to calculate the proper length of Flinders bar for any particular compass location. Details of the acquisition of such data and the calculations involved are presented in articles 605 to 609, inclusive.

- (2) If the above method is impractical, the Flinders bar length will have to be set approximately by:
  - (a) Using an empirical amount of Flinders bar that has been found correct for 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, the Flinders bar should be omitted until data is acquired.

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 to achieve such spacing.

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

**409.** The next adjustment is the positioning of the heeling magnet by means of a properly balanced dip needle, as discussed in Chapter XI.

**410.** These three adjustments at dockside - Flinders bar, spheres, and heeling magnet - will properly establish the conditions of mutual induction and shielding on the compass, such that a minimum of procedures at sea will complete the adjustment.

**411. Expected errors.** Figure 318, "Summary of Compass Errors and Adjustment", 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 more generally caused by the miscalculation of azimuths or by physical misalignments, rather than magnetic effects of asymmetrical arrangements of horizontal soft iron. Thus, if the physical alignments are checked at dockside, and if care is exercised in making all calculations, the *A* error will be insignificant. 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. This results from the fact that such readings are taken on the face of the compass card itself 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 wherein 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 (see article 405). 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. An *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*.

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 by that amount.

The *B* error results from two different causes, namely: the fore-and-aft permanent magnetic field across the compass, and a resultant asymmetrical 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. Inasmuch as the Flinders bar setting has been made at dockside, any *B* error remaining is corrected by the use of fore-and-aft *B* magnets.

The *C* error has two causes, namely: the athwartship permanent magnetic field across the compass, and a resultant asymmetrical 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; but, inasmuch as this 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.

The existence of *E* error of appreciable magnitude is rare, since it is caused by induction in the asymmetrical arrangements of horizontal soft iron. When this error is appreciable it may be corrected by slewing the spheres, as described in Chapter VI.

As has been stated previously, the heeling error is most practically adjusted at dockside with a balanced dip needle. (See Chapter XI.)

**412.** A summary of the above discussion reveals that certain errors are rare, and others have been corrected by adjustments at dockside. Therefore, for most ships, there remain only three errors to be corrected at sea, namely the *B*, *C*, and *D* errors. These are corrected by the use of fore-and-aft *B* magnets, athwartship *C* magnets, and quadrantal spheres respectively.

**413.** Study of adjustment procedure. Inspection of the general *B*, *C*, and *D* combination of errors, pictured in figure 413 will reveal that there is a definite isolation of the deviation effects on cardinal compass headings.

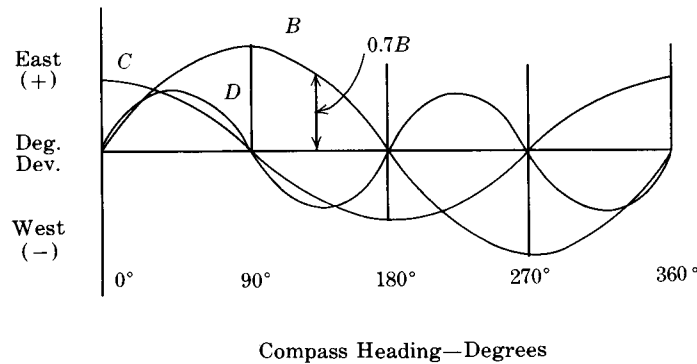


Figure 413 – *B*, *C*, and *D* deviation effects

For example, on  $090^\circ$  or  $270^\circ$  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  $090^\circ$  heading will correct the *B* deviation on the  $270^\circ$  heading by the same amount but in the opposite direction and naturally, it will not change the deviations on the  $000^\circ$  and  $180^\circ$  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  $090^\circ$  or  $270^\circ$  deviation correction, but only by seven-tenths (0.7) of that amount, since the sine of  $45^\circ$  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, as before. It will now be observed 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 the stability of the compass on these headings.

**414.** If it were not for the occasional *A* or *E* errors which exist, the above procedure of adjustment would be quite sufficient, i.e., adjust observed deviations to zero on two adjacent cardinal headings and then on the intermediate intercardinal heading. However, figure 414, showing a combination of *A* and *B* errors, will illustrate why adjusting procedure must include correcting deviations on more than the three essential headings.

If the assumption were made that no *A* error existed in the curve illustrated in figure 414, and the total deviation of  $6^\circ\text{E}$  on the  $090^\circ$  heading were corrected with *B* magnets, the error on the  $270^\circ$  heading would be  $4^\circ\text{E}$  due to *B* overcorrection. If then, this  $4^\circ\text{E}$  error were taken out on the  $270^\circ$  heading, the error on the  $090^\circ$  heading would then be  $4^\circ\text{E}$  due to *B* undercorrection.

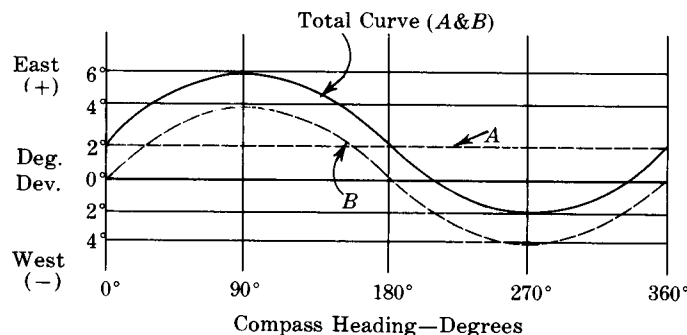


Figure 414 – *A* and *B* deviation effects

The proper method of eliminating this to-and-fro procedure, and also correcting the  $B$  error of the ship to the best possible flat curve, would be to split this  $4^\circ\text{E}$  difference, leaving  $2^\circ\text{E}$  deviation on each opposite heading. This would, in effect correct the  $B$  error, leaving only the  $A$  error of  $2^\circ\text{E}$  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.

**415.** Before anything further is said about adjustment procedures, it is suggested that care be exercised to avoid moving the wrong corrector. Not only will such practice be a waste of time but it will also upset all previous adjustments and calculations. 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 stray fields from them, they should be kept at an appropriate distance until one or more is actually to be inserted into the binnacle.

**416. 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.

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 (article 1003). Chapter VII discusses methods of placing a ship on the desired heading.

**417.** Most adjustments can be made by trial and error, or by routine procedure such as the one presented in Chapter I. However, it is more desirable to follow some analytical procedure whereby the adjuster is always aware of the magnitude of the errors on all headings as a result of his movement of the different correctors. Two such methods are presented:

- (1) A complete deviation curve can be taken for any given condition, and an estimate made of all the approximate coefficients. See Chapter V for methods of making such estimates. 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  $20^\circ$ , rough adjustments should be made on two adjacent cardinal headings before recording curve data for such analysis. The mechanics of applying correctors are presented in figure 103. A method of tabulating the anticipated deviations after each correction is illustrated in figure 417a. The deviation curve used for illustration is the one that is analyzed in Chapter V. Analysis revealed these coefficients:

$$A = 1.0^\circ\text{E}$$

$$B = 12.0^\circ\text{E}$$

$$C = 8.0^\circ\text{E}$$

$$D = 5.0^\circ\text{E}$$

$$E = 1.5^\circ\text{E}$$

Heading by compass	Original deviation curve	Anticipated curve after first correcting $A = 1.0^\circ\text{E}$	Anticipated curve after next correcting $B = 12.0^\circ\text{E}$	Anticipated curve after next correcting $C = 8.0^\circ\text{E}$	Anticipated curve after next correcting $D = 5.0^\circ\text{E}$	Anticipated curve after next correcting $E = 1.5^\circ\text{E}$
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 417a – Tabulating anticipated deviations - Analysis method.

- (2) More often it is desirable to begin adjustment immediately, eliminating the original swing for deviations and the estimate or approximate coefficients. In this case the above problem would be solved by tabulating data and anticipating deviation changes as the corrections are made. Figure 417b illustrates such procedure. It will be noted 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 are used to indicate where each change is made.

Heading by compass	Original deviation curve	Anticipated curve after first correcting $A = 1.0^\circ\text{E}$	Anticipated curve after next correcting $B = 12.0^\circ\text{E}$	Anticipated curve after next correcting $C = 8.0^\circ\text{E}$	Anticipated curve after next correcting $D = 5.0^\circ\text{E}$	Anticipated curve after next correcting $E = 1.5^\circ\text{E}$
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 417b – Tabulating anticipated deviations - One-swing method.

Since the  $B$  error is generally greatest, it is corrected first; hence, on a  $090^\circ$  heading the  $11.5^\circ\text{E}$  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  $11.5^\circ\text{E}$ , and some splitting might be desirable later. After correcting on the  $090^\circ$  heading, the swing would then be continued to  $135^\circ$  where a  $9.2^\circ\text{W}$  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  $180^\circ$  heading would be observed as  $5.5^\circ\text{W}$ . 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  $225^\circ$  a  $0.0^\circ$  deviation would be observed and recorded. On the  $270^\circ$  heading the observed error would be  $1.0^\circ\text{W}$ , which is compared with  $0.0^\circ$  deviation on the opposite  $090^\circ$  heading. This could be split, leaving  $0.5^\circ\text{W}$  deviation on both  $090^\circ$  and  $270^\circ$ , but since this is so small it may be left uncorrected. On  $315^\circ$  the observed deviation would be  $1.2^\circ\text{E}$ . At  $000^\circ$ , a deviation of  $10.5^\circ\text{E}$  would be observed and compared with  $5.5^\circ\text{W}$  on  $180^\circ$ . Analysis of the deviations on  $000^\circ$  and  $180^\circ$  headings reveals an  $8.0^\circ\text{E}$ ,  $C$  error, which should then be corrected with athwartship  $C$  magnets leaving  $2.5^\circ\text{E}$  deviation on both the  $000^\circ$  and  $180^\circ$  headings. All the deviations in column two are now recalculated on the basis of such an adjustment at  $000^\circ$  heading and entered in column three. Continuing the swing, the deviation on  $045^\circ$  would then be noted as  $6.4^\circ\text{E}$ . Knowing the deviations on all intercardinal headings, it is now possible to estimate the approximate coefficient  $D$ .  $D$  is  $5.0^\circ\text{E}$  so the  $6.4^\circ\text{E}$  deviation on  $045^\circ$  is corrected to  $10.4^\circ\text{E}$  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  $0.5^\circ\text{E}$  which was not considered large enough to warrant correction, an  $A$  of  $1.0^\circ\text{E}$  and an  $E$  of  $1.5^\circ\text{E}$ . 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. It will be noted that the ship has made only one swing, all corrections have been made, and some idea of the expected curve is available.

**418. 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 on the standard Navy Form NAVSEA 3120/4 and in the Magnetic Compass Record, NAVSEA 3120/3. Article 901 discusses the purposes of the various NAVSEA Record Forms more fully. Navy Form NAVSEA 3120/4 is complete and desirable in the interest of improved Flinders bar correction and shielding conditions. Figure 418 illustrates both sides of form 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 degaussing conditions should also be made and data recorded on NAVSEA 3120/4.

On these swings extreme care should be exercised in taking bearings or azimuths and in steadying down on each heading since this swing is the basis of standard data for that 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. Chapter X discusses these many sources of error in detail. If the

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

SHIPS HEAD MAGNETIC			DEVIATIONS			SHIPS HEAD MAGNETIC			DEVIATIONS			
			DG OFF	DG ON				DG OFF	DG ON			
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			

DEVIATIONS DETERMINED BY  SUN'S AZIMUTH  GYRO  SHORE BEARINGS

B 6 MAGNETS RED  FORE  AFT AT 12" FROM COMPASS CARD

C 4 MAGNETS RED  PORT  STBD AT 6" FROM COMPASS CARD

D 2-7"  SPHERES AT 12"  ATHWART-SHIP  COUNTERCLOCKWISE  
 CYLS  SLEWED  CTR. CLOCKWISE

HEELING MAGNET  RED UP  BLUE UP 6" FROM COMPASS CARD FLINDERS BAR  FORE 12"  AFT

LAT 18°00'N  LONG 120°00'E  
 M 0.385  Z 0.151

SIGNED (Adjuster or Navigator) \_\_\_\_\_ APPROVED (Commanding) \_\_\_\_\_

---

VERTICAL INDUCTION DATA  
(Fill out completely before adjusting)

RECORD DEVIATION ON AT LEAST TWO ADJACENT CARDINAL HEADINGS  
 BEFORE STATING ADJUSTMENT N 8 W E 0 S 4 E W 9 E

RECORD BELOW INFORMATION FROM LAST NAVSHIPS 3120 4 DEVIATION TABLE  
 DATE 5 December 1974  LAT 32 53N  LONG 117 18W  
 M .260  Z .420

12° FLINDERS BAR  FORWARD  AFT DEVIATIONS  
 N 2.5W E 7E S 6.5E W 5W

RECORD HERE DATA ON RECENT OVERHAULS, GUNFIRE, STRUCTURAL CHANGES, FLASHING DEPERMING, WITH DATES AND EFFECT ON MAGNETIC COMPASSES

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

---

PERFORMANCE DATA

COMPASS AT SEA  UNSTEADY  STEADY  
 COMPASS ACTION  SLOW  SATISFACTORY  
 NORMAL DEVIATIONS  CHANGE  REMAIN RELIABLE  
 DEGAUSSING DEVIATIONS  VARY  DO NOT VARY

REMARKS \_\_\_\_\_

---

INSTRUCTIONS

- This form shall be filled out by the Navigator for each magnetic compass as set forth in Chapter 9240 of NAVAL SHIPS TECHNICAL MANUAL.
- When a swing for deviations is made, the deviations should be recorded both with degaussing coils off and with degaussing coils energized at the proper currents for heading and magnetic zone.
- Each time this form is filled out after a swing for deviations, a copy shall be submitted to: Naval Ship Engineering Center, Hyattsville, Maryland 20782. A letter of transmittal is not required.
- When choice of box is given, check applicable box.
- Before adjusting, fill in section on "Vertical Induction Data" above.

NAVSEA 3120/4 (REV. 6-72) (REVERSE) C-26000

Figure 418 – Deviation table - NAVSEA 3120/4

419. In order to have a reliable and up-to-date deviation card at all times it is suggested that the ship be swung to check compass deviations and to make readjustments, if necessary, after:

- (1) Radical changes in magnetic latitude.
- (2) Deperming. (Delay adjustment several days, if possible, after treatment.)
- (3) Structural changes.
- (4) Long cruises or docking on the same heading such that the permanent magnetic condition of the vessels has changed.
- (5) Magnetic equipment near the binnacle has been altered.
- (6) Reaching the magnetic equator, in order to acquire Flinders bar data. (See Chapter VI.)
- (7) At least once yearly, to account for magnetic decay, etc.
- (8) Appreciable change of heeling magnet position if Flinders bar is present.
- (9) Readjustment of any corrector.
- (10) Change of magnetic cargo.
- (11) Commissioning.

With such reasonable care, the compass should be a reliable instrument requiring little attention.

## CHAPTER V

### TYPICAL DEVIATION CURVE AND THE ESTIMATION OF APPROXIMATE COEFFICIENTS

**501. Simple analysis.** The data for the deviation curve illustrated in figure 501 is as follows:

Ship's compass heading	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

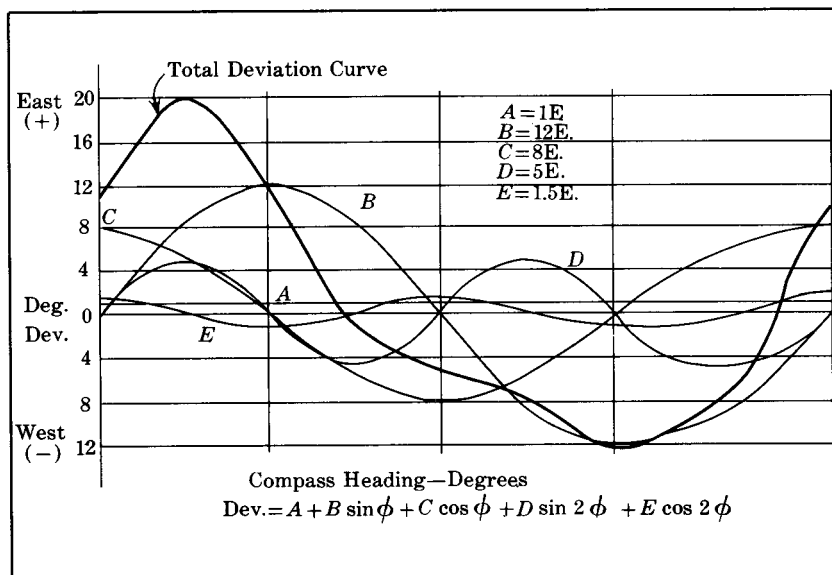


Figure 501 – Typical deviation curve and its individual components

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.

$$\begin{aligned}
 8A &= +10.5^\circ + 20.0^\circ + 11.5^\circ - 1.2^\circ - 5.5^\circ - 8.0^\circ - 12.5^\circ - 6.8^\circ \\
 8A &= +42.0^\circ - 34.0^\circ \\
 8A &= +8.0^\circ \\
 A &= +1.0^\circ \text{ (1.0°E)}
 \end{aligned}$$

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

$$\begin{aligned}
 2B &= +11.5^\circ (+12.5^\circ) \\
 2B &= +24.0^\circ \\
 B &= +12.0^\circ \text{ (12.0°E)}
 \end{aligned}$$

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

$$2C = +10.5^\circ + (+5.5^\circ)$$

$$2C = +16.0^\circ$$

$$C = +8.0^\circ (8.0^\circ E)$$

$D$  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  $135^\circ$  and  $315^\circ$  reversed.

$$40 = (+20.0^\circ) + (+1.2^\circ) + (-8.0^\circ) + (+6.8^\circ)$$

$$40 = +20.0^\circ$$

$$D = +5.0^\circ (5.0^\circ E)$$

$E$  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  $090^\circ$  and  $270^\circ$  reversed.

$$4E = (+10.5^\circ) + (-11.5^\circ) + (-5.5^\circ) + (+12.5^\circ)$$

$$4E = +6.0^\circ$$

$$E = +1.5^\circ (1.5^\circ E)$$

These approximate coefficients are estimated from deviations on compass headings rather than on magnetic headings. The arithmetic 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:

$$A = 1.0^\circ E$$

$$B = 12.0^\circ E$$

$$C = 8.0^\circ E$$

$$D = 5.0^\circ E$$

$$E = 1.5^\circ E$$

Each of these coefficients represents a component of deviation that can be plotted as shown in figure 501. The polarity of each component in the first quadrant must agree with the polarity of the coefficient. A check on the components in figure 501 will reveal that their summation equals the original curve. This method of analysis is accurate only when the deviations are less than  $20^\circ$ . 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  $\theta$  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  $D_1, D_2, \dots, D_8$  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,

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

$$B = +12$$

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

$$C = +8$$

**502. Reasons for analysis.** 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.

**503. Approximate and exact coefficients.** It is emphasized that the above estimations are for the approximate coefficients and not for exact coefficients. Approximate coefficients are in terms of angular deviations that are caused by certain magnetic forces, and as stated before, 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  $\lambda$ . 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.

**504. 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 from magnetic heading to compass heading, and vice versa. When deviations are small no conversion is necessary. Figure 504 illustrates the differences mentioned above by presenting the deviation values used in figure 501 as plotted against magnetic headings as well as against compass headings.

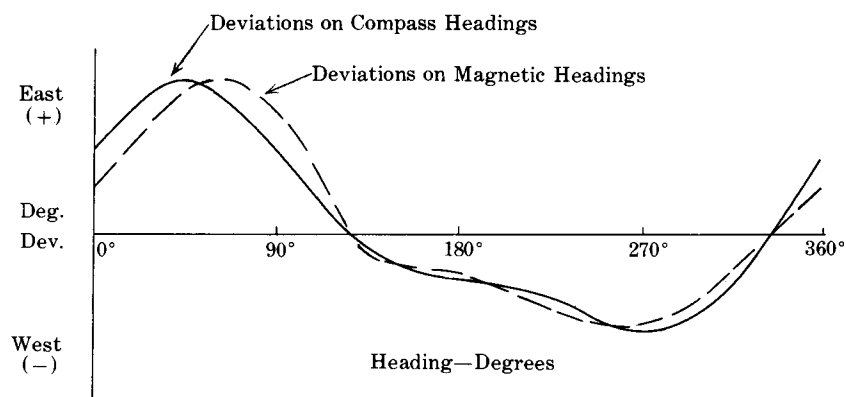


Figure 504 – Comparison of deviation curves (magnetic heading vs. compass heading).

## CHAPTER VI

### CORRECTOR EFFECTS-INTERACTIONS BETWEEN CORRECTORS

**601.** 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. Furthermore, as has been stated previously, 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, with appreciable induction effects in the latter. Consequently any shift in the relative position of the various correctors will change their interaction effects 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 therefore be familiar with the nature of these interactions so as to evolve the best methods of adjustment.

**602. Quadrantal sphere correction.** Figure 602 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 (article 613).
- (2) Utilizing special spheroidal-shaped correctors, placed with their major axes perpendicular to their axis of position.
- (3) Using larger spheres farther away from the compass.

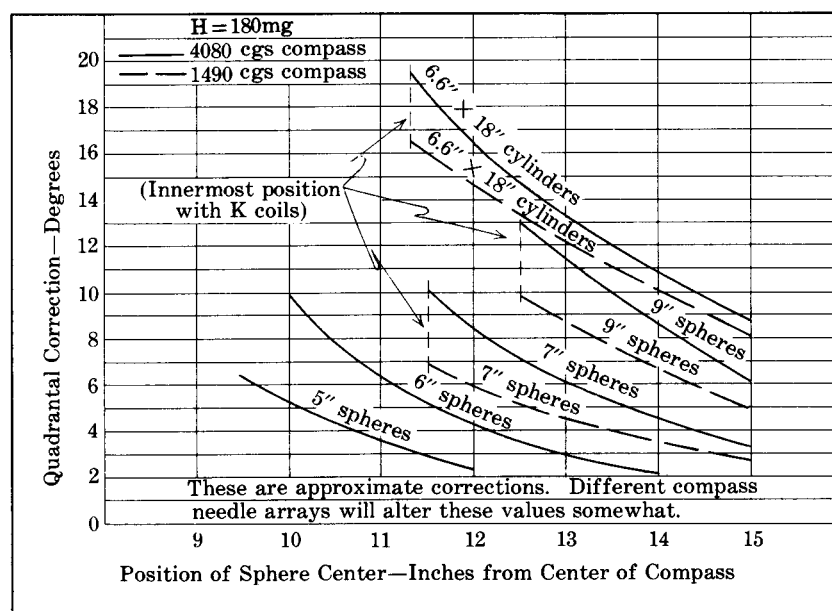


Figure 602

**603. Slewing of spheres.** Figure 603a is a convenient chart of 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 figures 602 and 603b will be useful in either procedure.

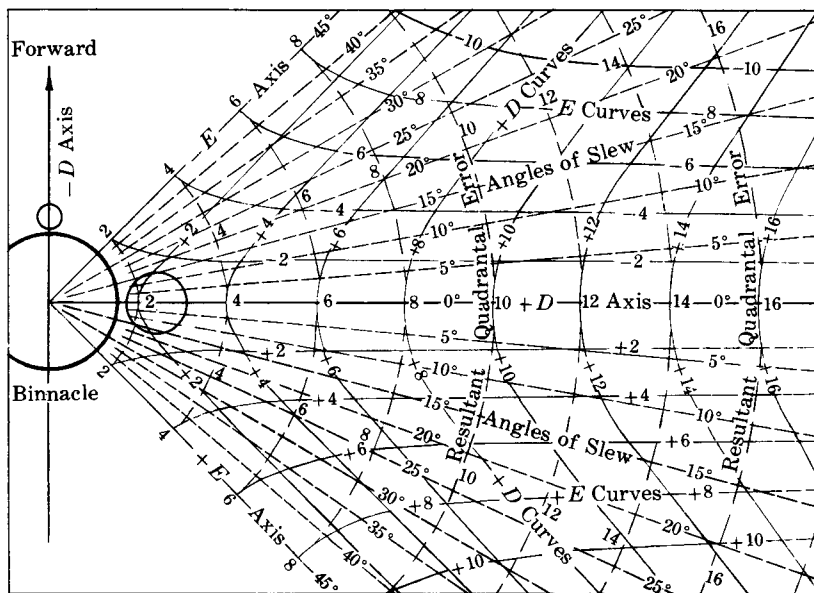


Figure 603a – Slewing of quadrantal spheres

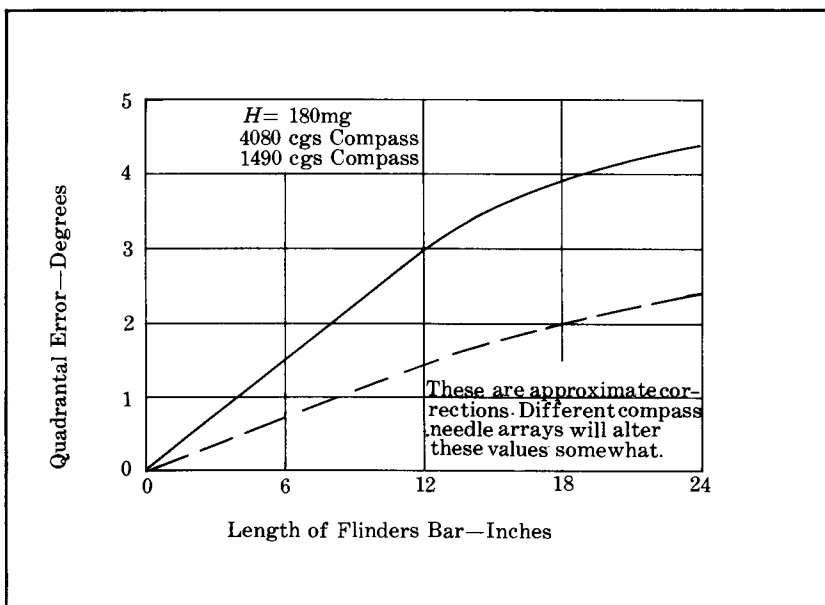


Figure 603b – Quadrantal error from Standard Navy Flinders bar.

*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 total E coefficient for the ship is 6° E, as observed. Figure 602 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 603a 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 602 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. Use of this chart will eliminate mathematical or trial-and-error methods of adjustment for quadrantal errors as well as quickly provide information for physically moving the spheres.

**604. Corrector magnet inductions in spheres.** Should a ship have spheres and many permanent  $B$  and  $C$  magnet correctors close to the compass, there will be a condition of induction existing between these correctors which will require some shuttling back and forth between headings while making adjustments. This situation can be improved by using larger spheres further out, and by approximately setting the spheres before starting adjustments, as well as by using more magnets further from the spheres and compass. Magnetized spheres, as well as magnetized Flinders bar, will not only cause some difficulty during adjustment, but might introduce an unstable deviation curve if they should undergo a shake-down or change of magnetic condition.

**605. Quadrantal error from Flinders bar.** Figure 603b presents the approximate quadrantal error introduced by the presence of the Standard Navy Flinders bar. Since the Flinders bar is generally 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 upon inserting the Flinders bar in such a position, the regular spheres should be moved closer to correct for the increased plus  $D$  error, or vice versa, if the Flinders bar is removed. This  $D$  error in the Flinders bar is due mostly to compass needle induction since the bar is small in cross-section and is close to the compass. Since such needle induction is practically constant, the deviation effects on the compass will change with magnetic latitudes because the directive force,  $H$ , changes. However, when balanced by sphere correctors this is advantageous because it tends to cancel out the variable part of the sphere correction which is due to the compass needle induction.

**606. Flinders bar adjustment.** As has previously been stated in Chapter II, it is generally impossible to place the correct amount of Flinders bar without reliable data obtained in two widely separated magnetic latitudes. The placing of Flinders bar by the use of an empirical amount, or by an inspection of the ship's structures, is merely an approximation method and refinements will usually be necessary when data is obtained. There are several methods of acquiring and utilizing such latitude data in order to determine the proper amount of Flinders bar, hence an elaboration on the following items:

- (1) The data necessary for calculation of Flinders bar length, and the conditions under which this data should be acquired.
- (2) The best method of utilizing such data to determine the proper length of the Flinders bar.

**607. Data required for Flinders bar adjustment.** 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. See figure 418 for an example of how such data is recorded on NAVSEA Form 3120/4. Should it be impossible to swing ship for a complete table of deviations, the deviations on east and west magnetic headings would be helpful. On many occasions, ship's log data is available, but is of little use for Flinders bar calculation because it is not reliable. The following precautions should be observed when such data is to be taken in order to assure that observed deviation changes are due only to changes in the  $H$  and  $Z$  components of the earth's field.

- (1) Degaussing should be secured, by a reversal process if necessary, at both latitudes before data is taken.
- (2) If the ship has been docked 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 would reduce such errors.
- (3) Deperming, structural changes, heavy gunfire, magnetic cargoes, etc., subsequent to the first set of data will make the comparative results meaningless.
- (4) Inasmuch as 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, including the heeling magnet.

In the event that an intelligent 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.

**608. Methods of determining Flinders bar length.**

(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 that 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 asymmetrical 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 asymmetrical 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, as indicated in article 613.

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

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

where

$\lambda$  = 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 that requires Flinders bar correction. If 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 (see figure 603b) which must be added to the uncorrected  $c$ , calculated by the above formula. This total value of  $c$  is used in conjunction with figure 603b 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 to achieve such spacing. 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.

(2) Should the exact amount of correction required for vertical induction in the ship at some particular magnetic dip,  $\theta$ , be known, figure 608 will directly indicate the correct amount of Flinders bar to be placed at the 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 608.

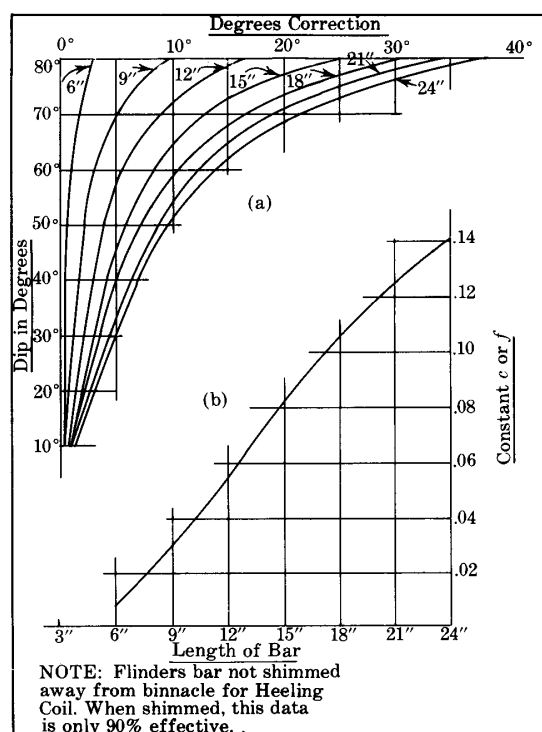


Figure 608 – Dip deviation curves for Flinders bar

(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."

**609.** 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.

**610. Heeling magnet induction in Flinders bar.** Figure 610 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.

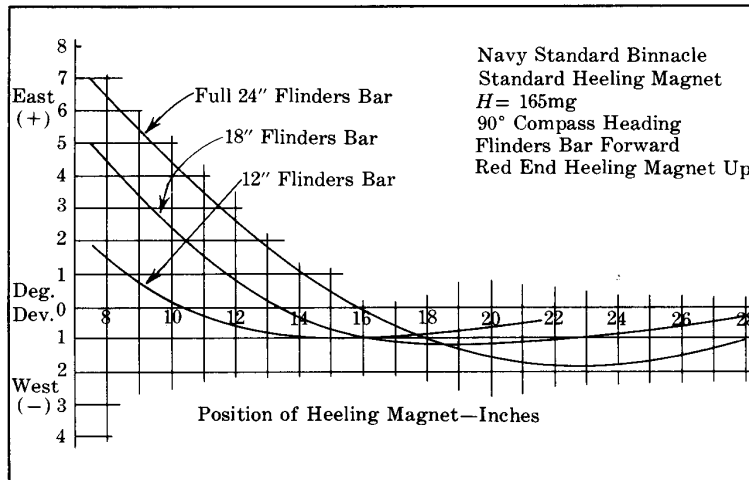


Figure 610 – Induction effects in Flinders bar due to heeling magnet

**611. 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 utilizing one bar to do the work of two; one forward or aft, and the other port or starboard.

Article 608 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 article 608, 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:

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

when

$\lambda$  = 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, *Z*, at 1st latitude.

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

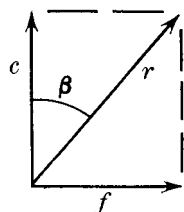
$C_2$  = degrees *C* deviation at 2nd latitude (magnetic headings).

$Z_2$  = 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 608b 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.

**612.** 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:

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



$\beta$  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 so 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:

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

The constant  $r$  is then used on the  $c$  or  $f$  constant curve in figure 603b to determine the total amount of Flinders bar necessary in the slewed position.

**613. 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 non-uniform fields across the needles. In other words, adjustment and compensation sometimes employ non-uniform fields to correct uniform fields. Figure 613a indicates the difference between uniform and non-uniform field effects on a compass.

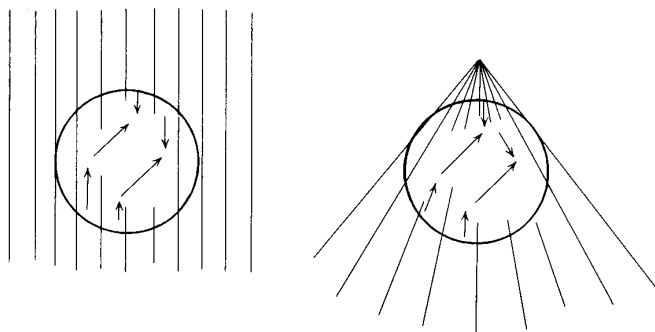


Figure 613a – Magnetic fields across compass needle arrays

Such unbalanced torques, arising from non-uniform 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 non-uniform 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 that 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 613b, 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.

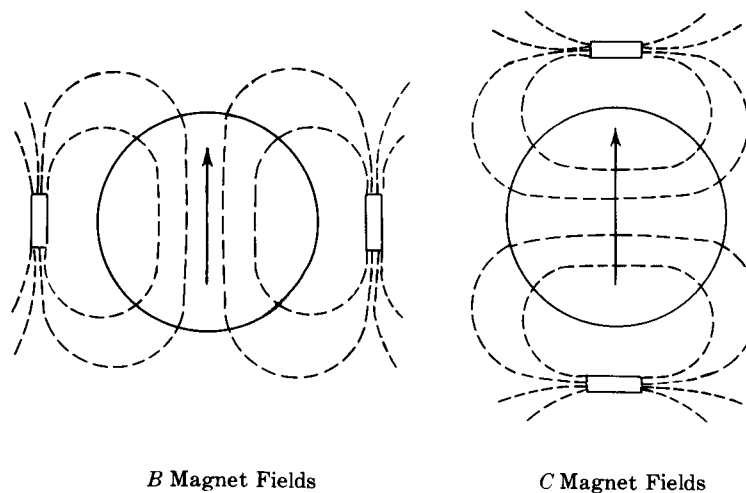


Figure 613b – Arrangements of corrector magnets

The magnetic moment of the compass needle array is another factor in compass design that ranks in importance with the proper arrangement of needles. This magnetic moment controls the needle induction in the soft iron correctors, as discussed in articles 602 and 605, and hence governs the constancy of those corrector effects with changes in magnetic latitude. The 7½" Navy No. 1 alcohol-water compass has a magnetic moment of approximately 4000 cgs units, whereas the 7½" 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 that must be considered in compass design are period, fluid, swirl, vibration, illumination, tilt, pivot friction, fluid expansion, etc. 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.

## CHAPTER VII

### SHIP'S HEADING

**701. 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.

**702. Variation.** Variation at any place is the angle between the magnetic meridian and the true meridian. 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.

**703. Deviation.** 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.

**704. 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.

The following simple rules will assist in naming errors and in converting from one heading expression to another:

- (1) Compass least (less than magnetic heading), deviation east.  
Compass best (greater than magnetic heading), deviation west.
- (2) When correcting (going from compass to magnetic to true), apply the sign algebraically (+East, -West).  
When uncorrecting (going from true to magnetic to compass), reverse the sign (-East, +West).
- (3) When correcting, easterly errors are additive. This single rule can be used to recall all four cases:  
When correcting, easterly errors are additive; westerly errors are subtractive.  
When uncorrecting, easterly errors are subtractive; westerly errors are additive.

Formed from the first letter of each key word in the correcting process (Compass, Deviation, Magnetic, Variation, True), the sentence "Can Dead Men Vote Twice?" is useful in making conversions of heading data. Although the aforementioned statement can be used for uncorrecting (going from right to left in the statement as written), the first letters of the key words in the uncorrecting process are also used to develop a memory aid for uncorrecting.

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

Typical heading relationships are tabulated below:

Compass heading 358°, magnetic heading 003°, deviation 5°E.  
 Compass heading 181°, magnetic heading 179°, deviation 2°W.  
 Compass heading 040°, deviation 3°E, magnetic heading 043°.  
 Compass heading 273°, deviation 2°W, magnetic heading 271°  
 Magnetic heading 010°, deviation 2°E, compass course 008°.  
 Magnetic heading 270°, deviation 4°W, compass course 274°.  
 Magnetic heading 358°, variation 6°E, true heading 004°  
 Magnetic heading 270°, variation 6°W, true heading 264°  
 True heading 000°, variation 5°E, magnetic heading 355°  
 True heading 083°, variation 7°W, magnetic heading 090°.

**705. Use of compass heading and magnetic heading for adjustment.** The primary object of adjusting compasses is to reduce deviations (to make the magnetic heading and the compass heading identical, or as nearly so as possible). The two methods of accomplishing this are as follows:

- (1) Place the ship on the desired magnetic heading and correct the compass so that it reads the same as this magnetic heading. This is the preferred method.
- (2) Place the ship on the desired compass heading and determine the corresponding magnetic heading of the ship, and correct the compass so that it reads the same as this known magnetic heading. This method is used whenever it is impractical to place the ship on a steady magnetic heading for direct correction.

In using the magnetic heading method, the deviations of the compass are easily observed as 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.

When using the compass heading method, the ship can easily be brought to any desired compass heading, but the difficulty is in the determination of deviations. Further difficulty arises from the fact that the steersman is steering by an uncorrected compass whose deviations are changing as the necessary adjustments are being made. Therefore, as each adjustment is being made, the steersman should attempt to hold the ship steady on that heading by some means other than the compass being corrected. Adjustments by this method are made as a series of approximations, for example:

Place the ship on any desired compass course, and correct the compass to read the corresponding magnetic heading. This will probably leave the ship on a course other than the desirable cardinal and intercardinal headings for compass adjustment. For accurate results, the above procedure should be repeated.

If the compass has no appreciable deviations, the deviations 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.

**706. Methods of placing ship on magnetic headings.** A ship may be brought on a magnetic heading by reference to a gyrocompass. The magnetic variation is applied to true heading to determine the gyro course which must be steered in order to place the ship on the desired magnetic heading. If the gyrocompass has any error, it must be taken into consideration. It is well to calculate all such problems through true headings, since shortcuts on this procedure frequently lead to errors.

Examples of such relationships are tabulated below:

To steer magnetic course	With variation	True course	With gyro error	Heading per gyro compass
000°	6°W	354°	0	354°
180°	10°E	190°	0	190°
270°	4°W	266°	1°E	265°
315°	6°E	321°	2°E	319°
225°	17°W	208°	2°W	210°
358°	0	358°	3°W	001°

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. This gyrocompass error may be determined by a comparison of the calculated true azimuth of the sun and the azimuth as observed on a synchronized repeater.

It is to be remembered that gyrocompasses have certain errors resulting from latitude and speed change as well as turning errors, and that 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.

**707.** A ship may be placed 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 Chapter VIII. 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 (as in figure 707) with the ship and sun drawn in their relative positions, will aid greatly in the visualization of each problem. The azimuth circle must always be kept level while making observations, particularly of celestial bodies.

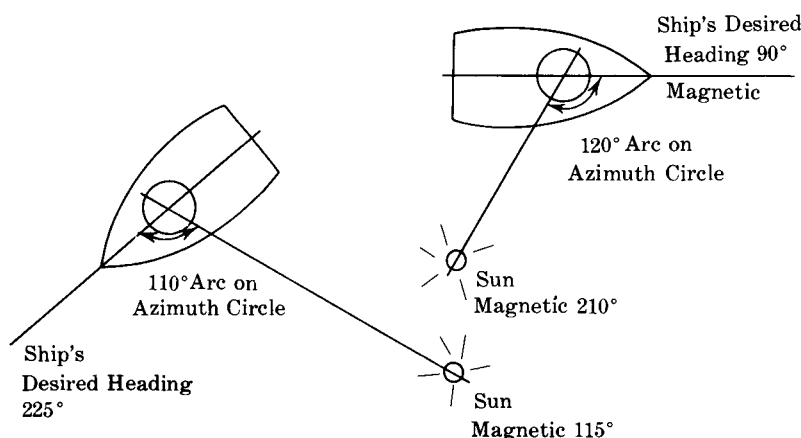


Figure 707 – Azimuth circle set-ups

**708.** A distant object (10 or more miles away) may be used in conjunction with the azimuth circle for placing the ship on magnetic headings, provided the ship stays within a small area. This procedure is similar to that used with the sun except that the magnetic heading 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  $1^\circ$ .

**709.** A pelorus may be used to place a ship on a magnetic heading using the sun's azimuth in much the same manner as with the azimuth circle. Use of the pelorus has the further advantage in that the magnetic heading of the ship can be observed continuously as the ship swings. Such a procedure would be as follows:

The forward sight vane is clamped to the dial at the value of the sun's magnetic azimuth, and the sight vanes are then trained so the sun is reflected in the mirror. As the ship turns, the magnetic heading is always observed under the forward lubber's line if the vanes are kept on the sun, and this will serve as a guide for bringing the ship onto any desired magnetic heading. As the desired magnetic course is approached, the compass can be read and corrected, even before that magnetic course is actually obtained; and a final check can be made when the ship is on the exact course. The pelorus must always be kept in a level position while making observations, particularly of celestial bodies.

**710.** A distant object can be used in conjunction with the pelorus, as with the azimuth circle, in order to place the ship on magnetic heading, provided the ship stays within a small area. (See article 708)

**711. Methods of determining deviations on a compass heading.** The deviations on compass headings may be obtained by a comparison of the calculated magnetic azimuth of the sun and the azimuth as observed on the compass by use of an azimuth circle. Methods of calculating sun's azimuth are discussed in Chapter VIII. The ship is placed on the desired compass heading and an azimuth of the sun taken of the face of the compass card. The difference in degrees between the observed azimuth and the calculated magnetic azimuth of the sun is the deviation on that compass course.

**712.** The pelorus may also be used in conjunction with the sun's azimuth to obtain deviations on compass headings. The ship is brought to the desired compass heading, and the forward sight vane is set on the calculated value of the sun's magnetic azimuth. The sight vanes are then trained on the sun, and the magnetic heading of the ship is indicated under the forward lubber's line of the pelorus. 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.

**713.** The azimuth circle or pelorus can be used 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. The true bearing of such a range is determined from a local chart; this true bearing is converted to the magnetic bearing by applying the variation, corrected for annual change, as given on the chart. Multiple ranges consist of several markers in the background and a single marker in the foreground, or vice versa. The ship is brought to the desired compass course and, at the instant of crossing the line of sight of the range, a bearing is taken with the azimuth circle or pelorus. With the azimuth circle, the difference in degrees between the observed bearing of the range on the face of the compass and the known magnetic bearing of the range is the deviation on that compass course. If using a pelorus, the forward sight vanes are set to the magnetic

bearing of the range and the magnetic heading of the ship is read under the forward lubber's line of the pelorus at the instant of taking a sight on the range. The deviation is the difference in degrees between the compass heading of the ship and the known magnetic heading of the ship as indicated by pelorus.

**714.** Deviations on compass courses may be obtained by the use of reciprocal bearings. A pelorus is set up on shore and the south end of the dial is aligned with magnetic north. A ship can then sight 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 and must be so arranged as to provide simultaneous observations. Two methods of such communication are by flashing lights, and preferably, by short range two-way voice radio.

Additional methods of determining deviations are by the use of azimuths of the moon, stars, and planets. For information as to the calculation of azimuths of these celestial bodies, refer to Pub. No. 9, The American Practical Navigator.

## CHAPTER VIII

### AZIMUTHS

**801. Azimuths of the sun.** Since accurate compass bearings of the sun can readily be observed for comparison with the sun's calculated true bearing or azimuth (for time, date, and place of the observer) to obtain the compass error, the sun is a valuable reference point for compass adjustment. The azimuths of other celestial bodies can similarly be determined, but are less practical for compass work because of the poor visibility of stars and the more variable time rates and declinations of the moon and planets. Hence, subsequent explanations concern themselves only with the sun and its azimuths.

**802. Astronomical triangle.** The azimuth of the sun at any instant and place of the observer is determined by solving the astronomical triangle for azimuth angle,  $Z$ , using the observer's latitude and longitude and the celestial coordinates of the sun for the time of the observation as taken from the Nautical Almanac to effect the solution.

The astronomical triangle is formed on the celestial sphere by:

- (1) the elevated pole of the observer (the radial projection of the geographic pole of the observer according to whether his latitude is north or south);
- (2) the zenith of the observer (the radial projection of the observer's position on earth); and
- (3) the celestial body.

**803. Local hour angle, LHA.** The Greenwich hour angle, GHA, of the sun as taken from the Nautical Almanac for the time and date of the observation is combined with the observer's longitude to obtain the local hour angle, the angle at the elevated pole between the local celestial meridian (the observer's meridian) and the hour circle of the sun, always measured westward from  $0^\circ$  to  $360^\circ$ .

$$\text{LHA} = \text{GHA} \begin{array}{l} - \text{west} \\ + \text{east} \end{array} \text{ longitude}$$

Meridian angle,  $t$ , is sometimes used instead of local hour angle to express the angle at the elevated pole between the local celestial meridian and the hour circle of the sun. The meridian angle,  $t$ , of the sun is the angle at the elevated pole measured from the meridian of the observer to the hour circle of the sun eastward or westward from  $0^\circ$  to  $180^\circ$ . Thus,  $t$  denotes the sun's position east or west of the local celestial meridian. When the sun is west of the meridian,  $t$  is equal to LHA; when east,  $t$  is equal to  $360^\circ$  minus LHA.

**804. Declination,  $d$ .** Also taken from the Nautical Almanac for the time and date of the observation, declination,  $d$ , of the sun is used with local hour angle, LHA, and the latitude,  $L$ , of the observer to calculate the azimuth angle,  $Z$ .

**805. Azimuth angle,  $Z$ .** The azimuth angle of the sun is the angle at the zenith between the principal vertical circle (coincident with the local celestial meridian) and the vertical circle through the sun. It is measured from  $0^\circ$  at the north or south reference direction clockwise or counterclockwise through  $180^\circ$ . It is labeled with the reference direction (direction of elevated pole of observer) as a prefix and direction of measurement from the reference direction as a suffix. Thus, azimuth angle  $S144^\circ W$  is the angle between the principal vertical circle of an observer in the Southern Hemisphere and another vertical circle  $144^\circ$  westward.

Azimuth angle is converted to azimuth by use of the following rules:

1. For north latitudes:
  - (a)  $Z_n = Z$  if the sun is east of the meridian.
  - (b)  $Z_n = 360^\circ - Z$  if the sun is west of the meridian.
2. For south latitudes:
  - (a)  $Z_n = 180^\circ - Z$  if the sun is east of the meridian.
  - (b)  $Z_n = 180^\circ + Z$  if the sun is west of the meridian.

It must be remembered that in order to obtain magnetic azimuths from true azimuths, the appropriate variation must be applied to the true azimuths.

**806. Azimuth by tables.** One of the more frequent applications of sight reduction tables is their use in computing the azimuth of a celestial body for comparison with an observed azimuth in order to determine the error of the compass. In computing the azimuth of a celestial body, for the time and place of observation, it is normally necessary to interpolate the tabular azimuth angle as extracted from the tables for the differences between the table arguments and the actual values of

declination, latitude, and local hour angle. The required triple-interpolation of the azimuth angle using Pub. No. 229, Sight Reduction Tables for Marine Navigation, is effected as follows:

- (1) Refer to figure 806a. The main tables are entered with the nearest integral values of declination, latitude, and local hour angle. For these arguments, a base azimuth angle is extracted.

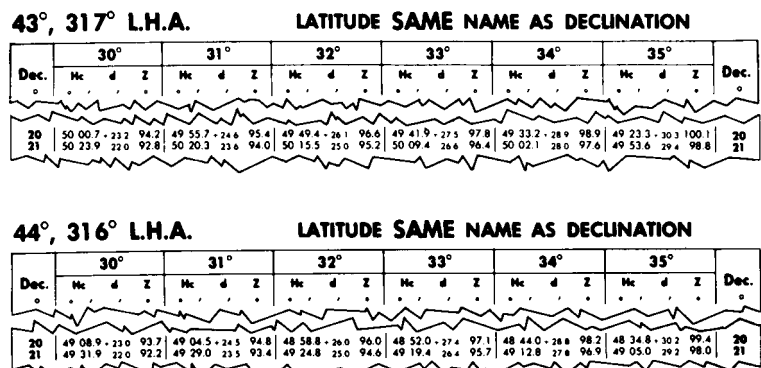


Figure 806a – Extracts from Pub. No. 229

- (2) The tables are reentered with the same latitude and LHA arguments but with the declination argument 10 greater or less than the base declination argument depending upon whether the actual declination is greater or less than the base argument. The difference between the respondent azimuth angle and the base azimuth angle establishes the azimuth angle difference, Z Diff., for the increment of declination.
- (3) The tables are reentered with the base declination and LHA arguments but with the latitude argument 10 greater or less than the base latitude argument depending upon whether the actual (usually DR) latitude is greater or less than the base argument to find the Z Diff. for the increment of latitude.
- (4) The tables are reentered with the base declination and latitude arguments but with the LHA argument 10 greater or less than the base LHA argument depending upon whether the actual LHA is greater or less than the base argument to find the Z Diff. for the increment of LHA.
- (5) The correction to the base azimuth angle for each increment is

$$Z \text{ Diff.} \times \frac{\text{Inc.}}{60'}$$

The auxiliary interpolation table can normally be used for computing this value because the successive azimuth angle differences are less than 10.0° for altitudes less than 84°.

*Example* – In DR lat. 33°24.0'N, the azimuth of the sun is observed as 096.5° pgc. At the time of the observation, the declination of the sun is 20°13.8'N; the local hour angle of the sun is 316°41.2'.

*Required* – The gyro error.

*Solution* – By Pub. No. 229:

The error of the gyrocompass is found as shown in figure 806b.

	Actual	Base Arguments	Base Z	Tab Z	Z Diff	Increments	Correction (Z Diff x Inc/60)
Dec.	20°13.8'N	20°	97.8°	96.4°	– 1.4°	13.8'	– 0.3°
DR L	33°24.0'N	33° (same)	97.8°	98.9°	+ 1.1°	24.0'	+ 0.4°
LHA	316°41.2'	317°	97.8°	97.1°	– 0.7°	18.8'	– 0.2°
Base Z	97.8°					Total corr.	– 0.1°
Corr.	(–) 0.1°						
Z	N97.7°E						
Zn	097.7°						
Zn pgc	096.5°						
Gyro error	1.2°E						

**807. Azimuth by calculator.** When calculators are used to compute the azimuth, tedious triple interpolation is avoided. Solution can be effected by several formulas.

The azimuth angle ( $Z$ ) can be calculated using the altitude azimuth formula if the altitude is known. The formula stated in terms of the inverse trigonometric function is

$$Z = \cos^{-1} \left[ \frac{\sin d - (\sin L \sin Hc)}{(\cos L \cos Hc)} \right]$$

If the altitude is unknown or a solution independent of altitude is required, the azimuth angle can be calculated using the time azimuth formula. The formula stated in terms of the inverse trigonometric function is

$$Z = \tan^{-1} \left[ \frac{\sin LHA}{(\cos L \tan d) - (\sin L \cos LHA)} \right]$$

The sign conventions used in the calculations of both azimuth formulas are as follows: (1) If latitude and declination are of contrary name, declination is treated as a negative quantity; (2) If the local hour angle is greater than  $180^\circ$ , it is treated as a negative quantity. If the azimuth angle as calculated is negative, it is necessary to add  $180^\circ$  to obtain the desired value.

*Example* – In DR lat.  $41^\circ 25.9'S$ , the azimuth of the sun is observed as  $016.0^\circ$  pgc. At the time of the observation, the declination of the sun is  $22^\circ 19.6'N$ ; the local hour angle of the sun is  $342^\circ 37.6'$ .

*Required* – The gyro error by calculation of

$$Z = \tan^{-1} \left[ \frac{\sin LHA}{(\cos L \tan d) - (\sin L \cos LHA)} \right]$$

*Preliminary* – Convert each known quantity to decimal degrees:

Latitude  $41^\circ 25.9'S = 41.432^\circ$

Declination  $22^\circ 19.6'N = (-) 22.327^\circ$

LHA  $342^\circ 37.6' = (-) 342.627^\circ$

– Prepare form on which to record results obtained in the several procedural steps of the calculations.

*Solution* – Procedure varies according to calculator design and the degree to which the user employs the features of the design enabling more expeditious solutions.

– In this example, only the initial step of substituting the given quantities in the formula, in accordance with the sign conventions, is given before the azimuth angle is obtained by the calculator is stated.

$$Z = \tan^{-1} \left[ \frac{\sin (-) 342.627^\circ}{(\cos 41.432^\circ \times \tan (-) 22.327^\circ) - (\sin 41.432^\circ \times \cos (-) 342.627^\circ)} \right]$$

$$Z = (-) 17.6^\circ$$

– Since  $Z$  as calculated is a negative angle ( $-17.6^\circ$ ),  $180^\circ$  is added to obtain the desired azimuth angle,  $162.4^\circ$ .

$Z$        $S162.4^\circ E$

$Z_n$       $017.6^\circ$

$Z_n$  pgc  $016.0^\circ$

*Answer* – Gyro error  $1.6^\circ E$ .

**808. 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. If a celestial body is used to provide the magnetic reference, the azimuth is continually changing as the earth rotates on its axis. Frequent and numerous computations can be avoided by preparing, in advance, a table or curve of magnetic azimuths. True azimuths at frequent intervals are computed. The variation at the center of the maneuvering area is then applied to determine the equivalent magnetic azimuths. These are plotted on cross-section paper, with time as the other argument, using any convenient scale. A curve is then faired through the points.

Points at intervals of half an hour (with a minimum of three) are usually sufficient unless the body is near the celestial meridian and relatively high in the sky, when additional points are needed. If the body crosses the celestial meridian, the direction of curvature of the line reverses.

Unless extreme accuracy is required, the Greenwich hour angle and declination can be determined for the approximate midtime, the same value of declination used for all computations, and the Greenwich hour angle considered to increase  $15^\circ$  per hour.

An illustration of a curve of magnetic azimuths of the sun is shown in figure 808. This curve is for the period 0700-0900 zone time on May 31, 1975, at latitude  $23^{\circ}09.5'N$ , longitude  $82^{\circ}24.1'W$ . The variation in this area is  $2^{\circ}47'E$ . At the midtime, the meridian angle of the sun is  $66^{\circ}47.23'$ , and the declination is  $21^{\circ}52.3'N$ . Azimuths were computed at half-hour intervals, as follows:

Zone time	Meridian angle	Declination	Latitude	Magnetic azimuth
0700	$81^{\circ}47.1'E$ (5h 27.1m E)	$21.9^{\circ}N$	$23.2^{\circ}N$	$069^{\circ}39'$
0730	$74^{\circ}17.1'E$ (4h 57.1m E)	$21.9^{\circ}N$	$23.2^{\circ}N$	$071^{\circ}57'$
0800	$66^{\circ}47.2'E$ (4h 27.1m E)	$21.9^{\circ}N$	$23.2^{\circ}N$	$074^{\circ}06'$
0830	$59^{\circ}17.2'E$ (3h 57.1m E)	$21.9^{\circ}N$	$23.2^{\circ}N$	$076^{\circ}08'$
0900	$51^{\circ}47.2'E$ (3h 27.1m E)	$21.9^{\circ}N$	$23.2^{\circ}N$	$078^{\circ}07'$

This curve was constructed on the assumption that the vessel would remain in approximately the same location during the period of adjustment and swing. If the position changes materially, this should be considered in the computation.

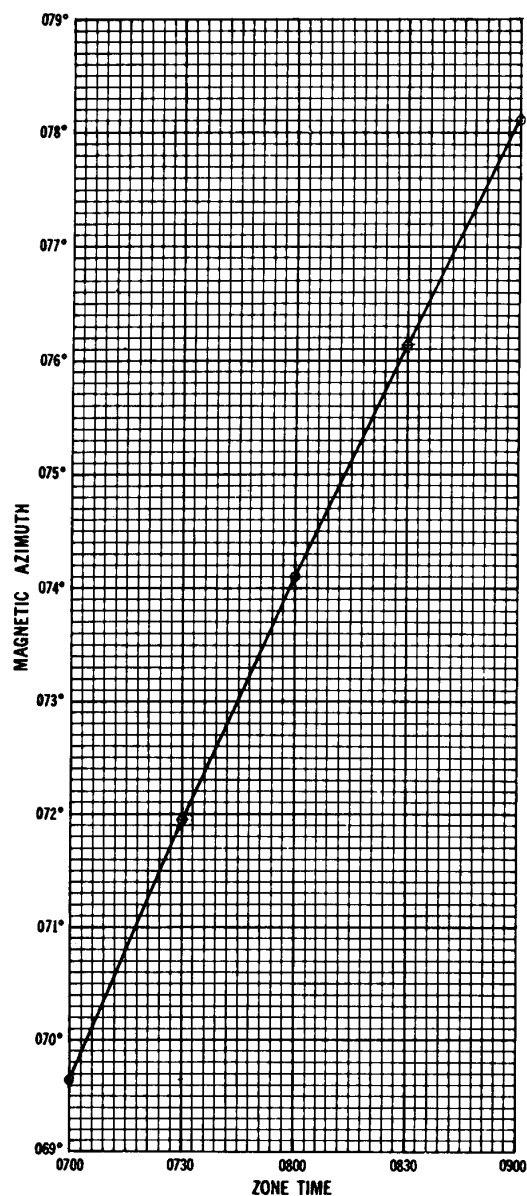


Figure 808 – Curve of magnetic azimuths

Extreme care must be exercised when using the sun between 1100 and 1300 LMT, since the azimuth changes very rapidly during this time and the sun is generally at a high altitude.

## CHAPTER IX

### COMPASS RECORDS AND REPORTS

**901.** OPNAV Instruction 3120.32, Standard Organization and Regulations of the U.S Navy, of 30 July 1974, requires the navigator to make frequent checks of the magnetic compass to determine its error, and to make frequent comparisons with the gyrocompass while the ship is underway. Specific information relative to compass observations, records, and reports is outlined below.

- (1) The Magnetic Compass Record, NAVSEA 3120/3 is part of the official record of a ship and is maintained as an adjunct to the Deck Log aboard every U.S. Naval ship in commission. It is a complete history of each magnetic compass on board.
- (2) Each volume of the Magnetic Compass Record contains a sufficient number of Compass Check Log forms for 3 months' continuous entries, based upon half-hourly observations. Observations may be made at shorter than half-hourly periods if desired. In those cases where the ship is not operating continuously, the book will be usable for a more extended period. Provision is made in this book for accommodating the record of both the standard and steering magnetic compasses. The latitude and longitude columns of the check log may be left blank when this information would make the record confidential.
- (3) Whenever a magnetic compass is adjusted or the deviations on all cardinal and intercardinal headings are observed, the results are recorded on a Magnetic Compass Table NAVSEA 3120/4. A copy of the latest completed table should be kept in the envelope attached inside the back cover of the Magnetic Compass Record. On ships equipped with degaussing circuits and compass compensation coils, the residual deviations are recorded with "DG-OFF" and "DG-ON". A copy of NAVSEA 3120/4 should be posted near the compass so as to be readily accessible to the navigator and other personnel concerned with the navigation of the ship. Each time a new NAVSEA 3120/4 is prepared as a result of the adjustment of the compass, a duplicate copy of the completed form should be forwarded to the Naval Ship Engineering Center. A transmittal letter is not required. Special attention should be given to completing all the information requested on the back of the NAVSEA 3120/4 form, so that the changes in deviation with latitude may be correctly evaluated in terms of Flinders bar requirements.
- (4) A NAVSEA 8950/41 should be filed with the compass manuals at the rear of the Degaussing Folder. One copy of the form should be forwarded to Naval Ship Engineering Center at the time of initial compensation and upon any subsequent compensations made as a result of adding additional compensating equipment or of changing the type of this equipment. In the case of changing or adding equipment, this form will normally be made out by the installing activity. However, if this activity does not perform the compensation, the form should be submitted by the ship.

## CHAPTER X

### TRANSIENT DEVIATIONS OF THE MAGNETIC COMPASS

**1001. Stability.** The general treatise on compass adjustment concerns itself only with the principles of steady-state magnetism; i.e., the effects of permanent and induced magnetism and their appropriate correctors. This knowledge, along with the ability to handle sun's azimuth and ship's heading, is the backbone of compass adjustment. However, a correction may be very carefully and accurately made and still prove disastrous to the ship; for example, a compass may have a perfect deviation curve, but when a nearby gun is trained the magnetic effects on the compass are changed. Although a compass adjuster cannot place correctors on the binnacle for such variable effects, it is definitely his duty to recognize and handle them in the best possible manner. If it is impossible to eliminate the source of trouble, or impractical to relocate the binnacle, the details of alignment or excitation of the sources of error should be specified on the deviation card. With such information, the navigator would know when or when not to rely on his magnetic compass. In other words, a good adjuster should not only provide a good deviation curve which is reliable under specifically stated conditions, but also point out and record probable causes of unreliability which cannot be eliminated.

**1002. Sources of transient error.** The magnetic circle about the magnetic compass is intended to reduce such transient conditions, but there still are many items, both electrical and magnetic, which cause erratic effects on the compass. The following list is presented to assist in the detection of such items. If in doubt, 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 the other.

1. Some magnetic items which cause variable deviations if placed too close to the compass are as follows:
  - (a) Guns on movable mounts.
  - (b) Ready ammunition boxes.
  - (c) Variable quantities of ammunition in ready boxes.
  - (d) Magnetic cargo.
  - (e) Hoisting booms.
  - (f) Cable reels.
  - (g) Metal doors in wheelhouse.
  - (h) Chart table drawers.
  - (i) Movable gyro repeater.
  - (j) Windows and ports.
  - (k) Signal pistols racked near compass.
  - (l) Sound powered telephones.
  - (m) Magnetic wheel or rudder mechanism.
  - (n) Knives or ash trays near binnacle.
  - (o) Watches, wrist bands, spectacle frames.
  - (p) Hat grommets, belt buckles, metal pencils.
  - (q) Heating of smoke stack, or exhaust pipes.
  - (r) Landing boats.
2. Some electrical items which cause variable deviations if placed too close to the compass are as follows:
  - (a) Electric motors.
  - (b) Magnetic controllers.
  - (c) Gyro repeaters.
  - (d) Unmarried conductors.
  - (e) Loudspeakers.
  - (f) Electric indicators.
  - (g) Electric welding.
  - (h) Large power circuits.
  - (i) Searchlights.
  - (j) Electrical control panels or switches.
  - (k) Telephone headsets.
  - (l) Windshield wipers.
  - (m) Rudder position indicators, solenoid type.
  - (n) Minesweeping power circuits.

- (o) Engine order telegraphs.
- (p) Radar equipment.
- (q) Magnetically controlled switches.
- (r) Radio transmitters.
- (s) Radio receivers.
- (t) Voltage regulators.

**1003.** There is another source of transient deviation trouble known as 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 conditions of induction. Although this effect is not too large and generally decays within a few hours, it may cause incorrect observations or adjustments, if neglected. 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 of shorter 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 change to the heading.

**1004.** Deperming and other magnetic treatment will change the magnetic condition of the vessel and therefore necessitate readjustment of the compass. 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 Finders bar, compass, and such related equipment is sometimes removed from the ship during these operations.

## CHAPTER XI

### USE OF THE DIP NEEDLE FOR HEELING ADJUSTMENTS

**1101.** As indicated in Chapter III, 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:

- (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 (article 1103).
- (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.

Inasmuch as it is desirable to establish the condition of induction between the heeling magnet and Flinders bar and to reduce the heeling oscillations to a minimum before making the adjustments at sea, the heeling magnet is usually set at dockside by the first method above. Further, it would be difficult to correct the heeling error by rolling at sea before making the other adjustments because the spheres and Flinders bar produce a certain measure of heeling correction and shielding effect, hence they should be positioned (at least approximately) before making the heeling adjustments by either method.

**1102.** The fact that the heeling magnet corrects for induced effects as well as permanent effects requires that it be readjusted with radical magnetic latitude changes of the ship. Movement of the heeling magnet, with Flinders bar in the holder, will change the induction effects in the Flinders bar and consequently change the compass deviations. (See article 610.) Thus, the navigator is responsible for:

- (1) Moving the heeling magnet up or down (invert when necessary) as the ship changes magnetic latitude so as to maintain a good heeling adjustment for all latitudes.
- (2) Maintaining a check on 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.

**1103.** To elaborate on the details of the dip needle method of adjustment, it is pointed out that there are two types of dip needles: one of which assumes the angle of inclination, or dip, for its particular location, and one on which the magnetic torque is balanced by a movable weight. The latter is a nullifying type instrument which renders the final position of the needle more independent of the horizontal component of magnetic fields, and hence is more useful on uncorrected compasses.

For ships which introduce no shielding to the earth's field at the compass, the procedure for adjusting the heeling magnet is quite simple. Take the dip needle into a nearby area where there is no local magnetic attraction, level the instrument, and set the weight so as to balance the needle under those conditions of earth's magnetic field. It is preferable to align the instrument such 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. The degaussing circuits are secured during this adjustment.

In the case of ships which have shielding effects on the earth's field at the compass, as in metal enclosed wheelhouses, the procedure is essentially the same as above, except that the weight on the dip needle should be moved toward the pivot so as 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  $\lambda$ , for the compass location by the original distance of the weight from the pivot in centimeters. Should  $\lambda$  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 in to 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 by means of a dip needle should be employed only with the ship on east or west magnetic headings, so as to avoid heeling errors resulting from asymmetrical, fore-and-aft, induced magnetism. If it is impractical to place the ship on such a heading, approximations may be made on any heading and refinements made when convenient.

**1104.** In the final analysis, a successful heeling magnet adjustment is one whereby the objectionable oscillations due to rolling of the ship (maximum effects on north and south compass headings) are minimized. 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 asymmetrical 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 and the heeling magnet is generally set for the average minimum oscillation condition.

## CHAPTER XII

### USE OF THE HORIZONTAL FORCE INSTRUMENT

**1201.** Occasionally it will be necessary to determine the actual strength of the magnetic field at some compass location. This problem may arise for one of the following reasons:

- (1) It may be desired to determine accurately the horizontal shielding factor,  $\lambda$ , 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) It may be desired to make a dockside magnetic adjustment, and hence determine the existing directive force at the magnetic compass both for its magnitude and direction.

$\lambda$ , is the horizontal shielding factor or ratio of the reduced earth's directive force,  $H'$ , on the compass to the horizontal earth's field,  $H$ , as:

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

From this, it is apparent that  $\lambda$  may easily be determined 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, as indicated later.  $\lambda$ , should be determined for every compass location on every ship.

**1202.** The actual measurement of such magnetic fields may be made by use of a suitable magnetometer, or by the use of a horizontal force instrument. The magnetometer method is a direct reading method, which needs no calculation. The force instrument is by far the simpler form of equipment, hence the force instrument 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 that will indicate the direction of the resultant magnetic field. The method used to determine the strength of this resultant field is 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 magnetic field. The stronger the magnetic field the shorter the period of time for each cycle of swing; in fact, the ratio is such that the squares of the period of vibration are inversely proportional to the strengths of the magnetic fields, as:

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

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. Should it be desired to find the strength of an unknown magnetic field,  $H'$ , a comparative measurement of time in seconds,  $T'$ , for 10 cycles of vibration of the same needle in the unknown field will enable calculation of  $H'$ .

Since  $\lambda$  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  $4^\circ$

To obtain the value of  $\lambda$  more precisely, and where deviations of the compass exceeds  $4^\circ$ , the following equation should be used:

$$\lambda = \frac{T^2}{4} \left[ \frac{\cos d_n}{T_n^2} + \frac{\cos d_e}{T_e^2} + \frac{\cos d_s}{T_s^2} + \frac{\cos d_w}{T_w^2} \right]$$

where:

$T$  is the time period for the field  $H$ .

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

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

## CHAPTER XIII

### INTRODUCTION TO DEGAUSSING

**1301. 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, within the effective region of the field of a vessel, the total field is the combined total of the earth's field and that due to the vessel. Consequently, the field due to earth's magnetism alone is altered or distorted due to the field of the vessel.

Certain mines and other explosive devices are designed to be triggered by the magnetic influence of a vessel passing near them. It is therefore desirable to reduce to a practical minimum the magnetic field of a vessel. One method of doing this is to neutralize each component by means of an electromagnetic field produced by direct current of electricity in electric cables installed so as to form coils around the vessel. A unit sometimes used for measuring the strength of a magnetic field is the gauss. The reduction of the strength of a magnetic field decreases the number of gauss in that field. Hence, the process is one of degaussing the vessel.

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, as nearly as practicable, by introducing at each compass an equal and opposite force of the same type – one caused by direct current in a coil – for each component of the field due to the degaussing currents. 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 the neutralization may not be perfect, a small amount of deviation due to degaussing may remain on certain headings. This is the reason for swinging ship twice – once with degaussing off and once with it on – and having two separate columns in the deviation table.

If a vessel passes over a device for detecting and recording the strength of the magnetic field, a certain pattern is traced. Since the magnetic field of each vessel is different, each has a distinctive trace, known as its 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 which neutralize induced magnetism need to be changed to suit the conditions. 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 information given in the degaussing folder should be checked from time to time by a return to the magnetic station.

**1302. Degaussing coils.** For degaussing purposes, the total field of the vessel is divided into three components:

- (1) vertical
- (2) horizontal fore-and-aft
- (3) horizontal athwartships

Each component 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.

## CHAPTER XIV

### DEGAUSSING COMPASS COMPENSATION

**1401. Degaussing effects.** The degaussing of ships for protection against magnetic mines has created additional effects upon magnetic compasses that are somewhat different from the permanent and induced magnetic effects usually encountered. These effects may be considered as electromagnetic effects that depend upon:

- (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.

**1402.** The magnetic fields at the binnacle must be considered separately for each degaussing coil. The magnetic field from any individual degaussing coil will vary proportionately with the excitation of the coil, and its direction will completely reverse with changes in the coil polarity.

Uncompensated degaussing coil effects create deviations of the compass card and conditions of sluggishness and unsteadiness which are similar to, and generally larger than, the effects of normal ship's magnetism on the magnetic compass.

**1403. Degaussing compensation.** The fundamental principle of compass compensation is to create magnetic fields at the compass that are at all times equal and opposite to the magnetic effects of the degaussing system. To accomplish this it is necessary to arrange coils about the binnacle so they create opposing effects for each degaussing circuit that affects the compass. These opposing effects can be created directly or by a combination of component parts. In most cases it is best to create the compensating field by a combination of three vectors along mutually perpendicular axes rather than by one vector adjusted to the proper angle. Figure 1403 illustrates the concept of the resultant magnetic field established by three separate mutually perpendicular components.

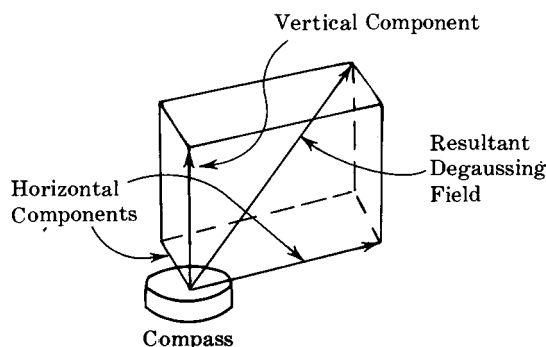


Figure 1403 - Resultant degaussing field and its equivalent three vector components

**1404.** The various standard compass coil installations utilize a three-coil arrangement, of one type or another, to achieve compensation by the three-component method. Such a group of coils are so interconnected that they can be individually adjusted; and each group is so connected to its associated degaussing coil that its compensating effect will automatically change with changes in the degaussing coil effect.

**1405.** Degaussing compass coil compensation consists of regulating the current delivered to the coils so that no change in the magnetic field occurs at the center of the binnacle when the degaussing coils are energized, or the degaussing currents are varied. This regulation is accomplished in a control box by means of control resistors for each degaussing circuit. When these resistors have once been set, their settings need not be altered with current changes in the degaussing circuits.

It is best to check coil installations electrically and compensate at dockside before the ship leaves the yard. Although accuracy of compensation is impaired by welding, adjacent ships, and moving cranes, time and trouble are still saved for the ship during final compensation at sea. All this results from the fact that troubleshooting is the greater part of coil compensation.