

SHIP'S MAGNETIC COMPASS



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CHAPTER 1

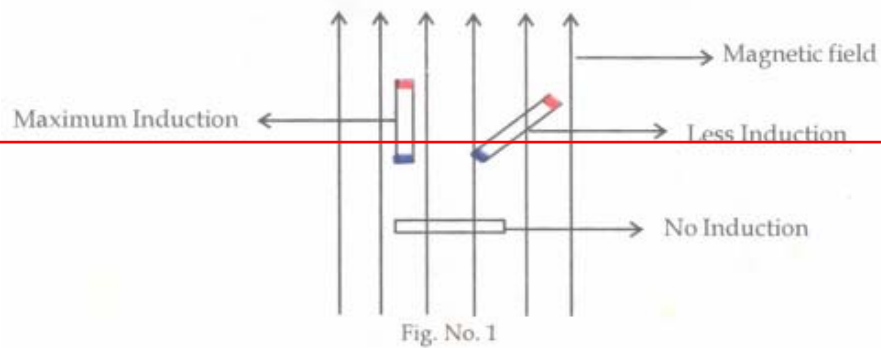
TERRESTRIAL MAGNETISM

INTRODUCTION

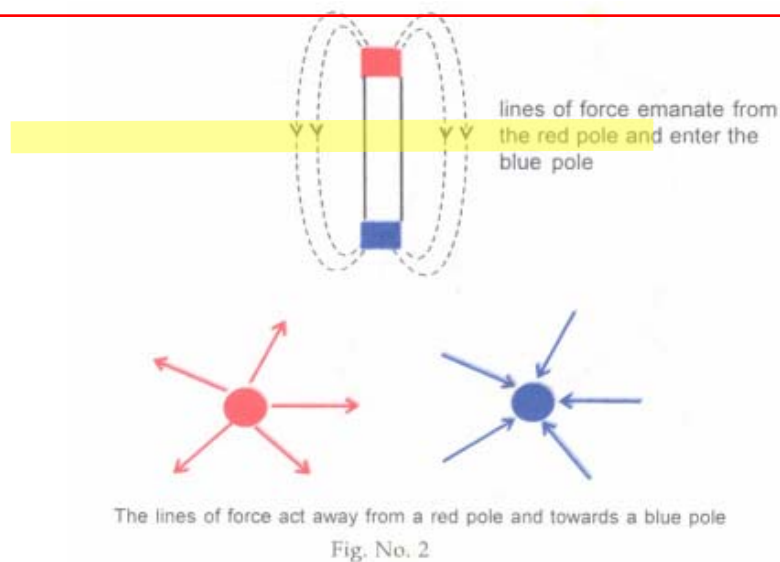
To commence studies of the magnetic compass, a few basic concepts of magnetism should be recapitulated.

A magnetic material may be magnetised by direct contact with a magnet or by the influence of a magnetic field. When a material is magnetised by the influence of a magnetic field, we say that the material has acquired induced magnetism.

The material will acquire a blue pole where the lines of force enter the material and a red pole where they leave the material. The strength of magnetism acquired by the material will depend upon the strength of the inducing magnetic field and on the alignment of the material with respect to the inducing field.



The magnetic lines of force emanate from the red pole of the magnet and re-enter the magnet at its blue pole. Thus the lines of force always act away from a red pole and towards a blue pole.

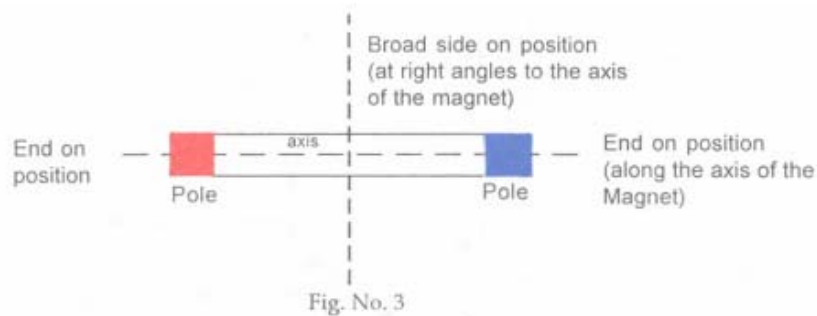


PROPERTIES OF A MAGNET

A magnet exhibits two basic properties.

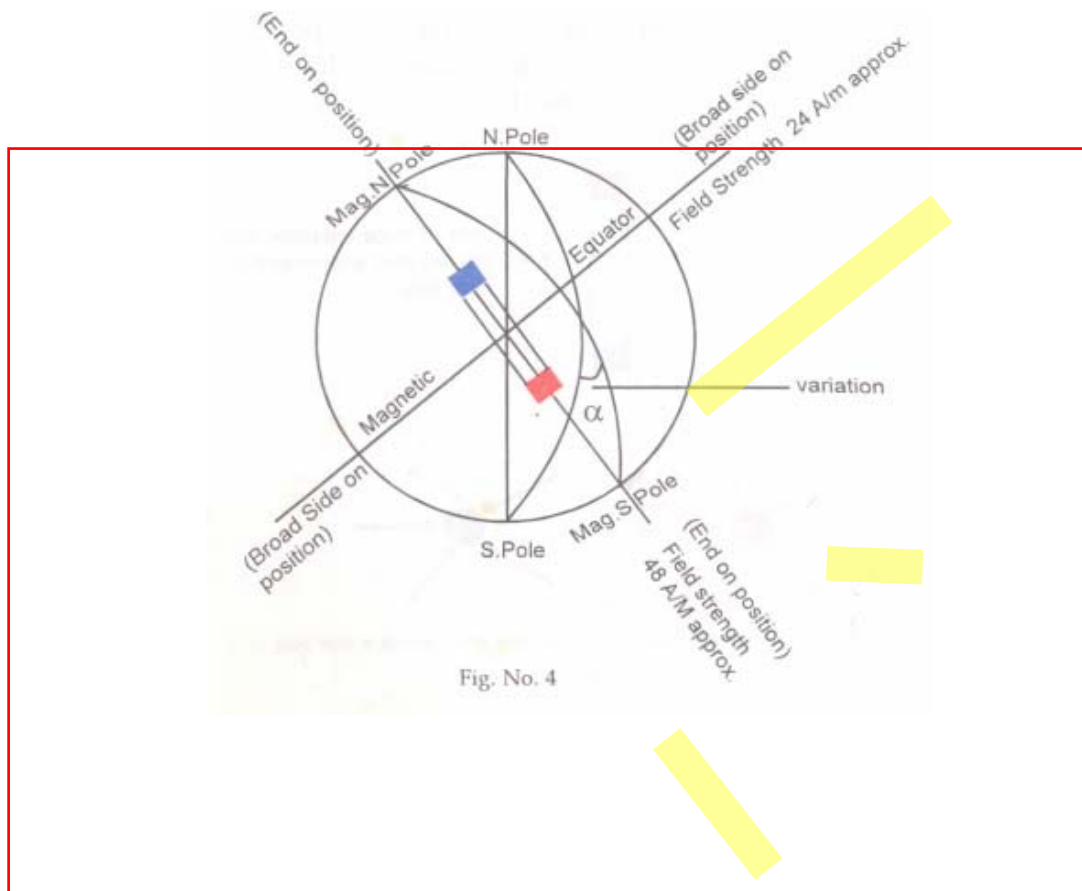
- 1) A freely suspended magnet, on the Earth, will align its magnetic axis in the direction of magnetic meridian, with its red pole towards the North magnetic pole of the Earth and its blue pole towards the Earth's South magnetic pole.
- 2) Like poles repel each other and unlike poles attract each other.

It can be shown that, at the same distance from the center of a short bar magnet, the field strength in the end on position is twice the field strength in the broad side on position.



THE EARTH'S MAGNETISM

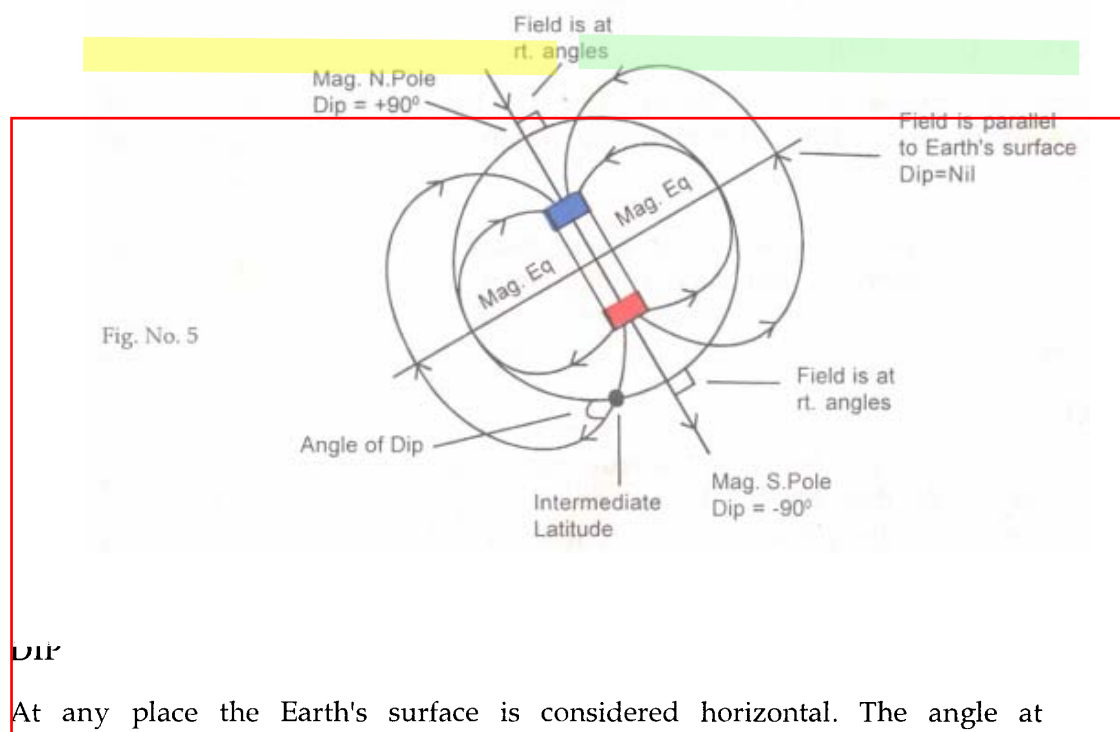
We are aware that the Earth has a magnetic field around it. If a sphere is magnetised, the magnetic field around it will be almost identified to the field of a short bar magnet at the centre of the sphere.



This imaginary short bar magnet at the centre of the Earth has its blue pole towards Geographic North and its red pole towards Geographic South of the Earth. The poles of this imaginary short bar magnet point to Magnetic North and Magnetic South poles of the Earth which are slightly away from the Geographic North and South poles of the Earth.

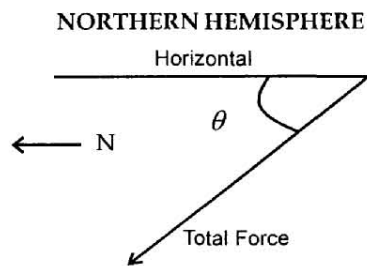
THE EARTH'S MAGNETIC FIELD

At the magnetic poles of the Earth, the lines of force of the Earth's magnetic field are vertical (perpendicular to the Earth's surface). At the magnetic equator, they are horizontal (parallel to the Earth's surface). At any intermediate latitude, they are at an oblique angle to the Earth's surface i.e. at an angle to the horizontal. A freely suspended magnetic needle will lie vertically at the magnetic poles, horizontally at the magnetic equator and at an angle to the horizontal at any intermediate latitude.

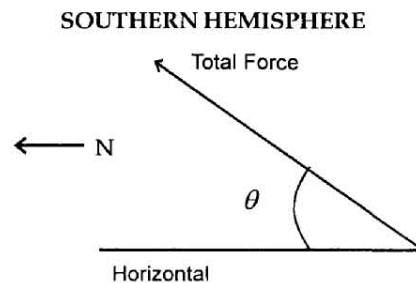


DIP

At any place the Earth's surface is considered horizontal. The angle at which the magnetic field of the Earth acts with respect to the horizontal, at any place, is the dip at that place. The Earth's field has a northward and a downward component in the N.hemisphere. In the S.hemisphere it has a northward and an upward component. Dip is therefore conventionally designated positive in the N. hemisphere and negative in the S. hemisphere. At the magnetic N. pole, dip is +90° and at the magnetic South pole it is -90°. At the magnetic equator, dip is nil. At intermediate magnetic latitudes, dip will have some intermediate value between 0° and 90°.



(angle of dip θ is +ve)



(angle of dip θ is -ve)

By Convention

Fig. No. 6

MAGNETIC POLES

The points on the Earth's surface where the magnetic field is perpendicular to the surface are known as the magnetic poles of the Earth. There are two such points - the N and S magnetic poles.

MAGNETIC EQUATOR

The magnetic equator is an imaginary line on the Earth's surface, joining all places having zero dip. The magnetic equator lies near the geographic equator.

In all further discussions in this book, unless stated otherwise, the word 'pole' would refer to the 'magnetic pole', the word 'equator' would imply the 'magnetic equator' and the word 'N or S hemispheres' would imply the 'magnetic N or S hemispheres'.

VARIATION

At any place, the angle between the true meridian and magnetic meridian is the variation at that place. In fig no. 4 at the point where the two meridians intersect, the variation is α° . Variation is Easterly if the magnetic north is to the east of true north. It is westerly if the magnetic north is to the west of true north.

TOTAL FORCE

The Total Force at any place is the magnetic field strength of the Earth, at that place. As stated earlier, the field strength of the imaginary short bar magnet at the centre of the Earth, in the end on position is twice that in the broad side on position, at the same distance from the centre of the magnet. The total force of the Earth's magnetic field is therefore maximum at the magnetic poles (about 48 A/m) and reduces as the latitude reduces. It is minimum at the magnetic equator (about 24 A/m).

MAGNETIC ELEMENTS

To fully define the magnetic field of the Earth at any location, three elements are required, namely:

- 1) The total force at that location,
- 2) The variation there (which indicates the angle at which the total force acts with respect to the true meridian) and
- 3) The dip at that position (which indicates the angle at which the total force acts with respect to the horizontal).

These three elements are therefore referred to as the magnetic elements of the Earth. The magnetic elements differ from place to place. Also, at any one place, they are not constant. They change mainly because the magnetic poles of the Earth are slowly shifting around the geographic poles. This slow change taking place in the magnetic elements, in the same direction over hundreds of years is termed the **secular change** in the magnetic elements. The annual secular change in the variation is shown on the compass roses on navigation charts. This change must be allowed for when determining the variation at that place in any particular year.

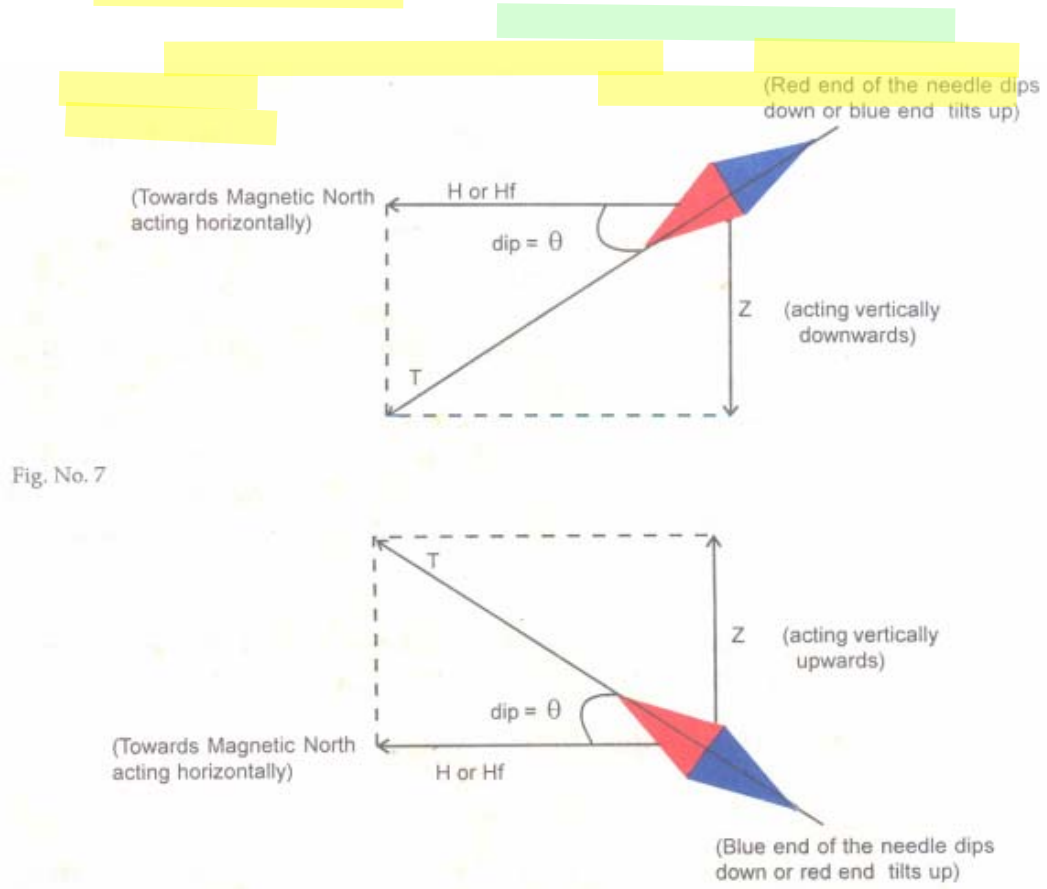
TRANSIENT CHANGES

In addition to the secular change, small fluctuations occur in the magnetic elements due to transient changes. These include:

- 1) a twice daily change due to the Moon,
- 2) a daily change caused by the Sun,
- 3) a 27 day cycle of change due to the Sun's 27 day cycle of rotation,
- 4) an yearly change due to the Earth orbiting the Sun,
- 5) a 11 year cycle of change due to the 11 year cycle of Sun spot activity and
- 6) irregular changes caused due to electrical disturbances in the Earth and its atmosphere.

These transient changes are very small and their effects on the magnetic compass may be disregarded except in very high latitudes.

The total force at any place may be resolved into two components acting at mutually perpendicular directions - the horizontal component H or H_f and the vertical component Z . H always acts towards magnetic north, whether in the N or S hemisphere. H is conventionally always +ve. Z acts vertically downwards in the N. hemisphere and vertically upwards in the S. hemisphere. Like dip, therefore, Z is also conventionally +ve in the N. hemisphere and -ve in the S. hemisphere.



Thus, mathematically, we have

1. Horizontal Component $H = T \cos \text{dip}$ (always +ve)
2. Vertical Component $Z = T \sin \text{dip}$ (+ve in N and -ve in S. hemispheres)
3. $\frac{Z}{H} = \tan \text{dip}$ (+ve in N. hemisphere as H and Z are +ve and -ve in S. hemisphere as H is +ve and Z is -ve)
4. $T = \sqrt{H^2 + Z^2}$

It is the horizontal force H which provides the directive property to the magnetic compass. A freely suspended magnetic needle, anywhere on the Earth's surface (N or S hemispheres) would point towards the Earth's magnetic poles with the red end of the magnetic needle pointing to the north magnetic pole of the Earth which is blue. H is therefore referred to as the **DIRECTIVE FORCE** of the magnetic compass. The horizontal force H is maximum at the magnetic equator and it reduces as the latitude increases till it is nil at the poles, as the entire total force there is vertical. The directive property of a magnetic compass is therefore highest at the equator. It is very little near the poles. H also governs the extent to which horizontal soft iron structures on the ship are magnetised by induction due to the Earth's magnetic field.

The vertical component Z acts downwards in the N. hemisphere and upwards in the S. hemisphere. It does not contribute to the directive property of the compass. It only tends to dip the compass card. But the compass card is so made as to not dip under the influence of Z . This is achieved by having the centre of gravity of the compass card and magnetic needles well below its point of suspension.

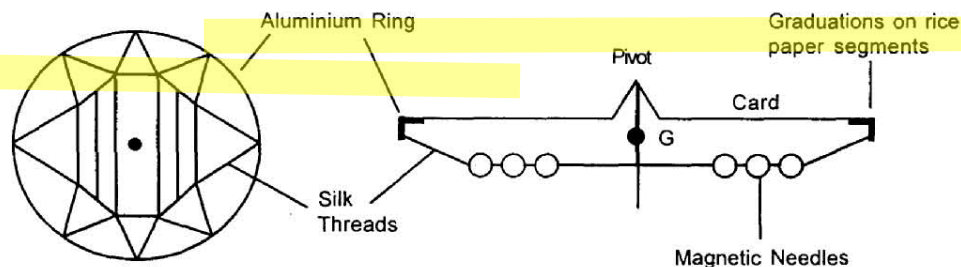


Fig. No. 8

The components which contribute to the weight of a dry card compass are the circular ring at its periphery, made of aluminium and the three or four pairs of magnetic needles suspended from the ring by silk threads.

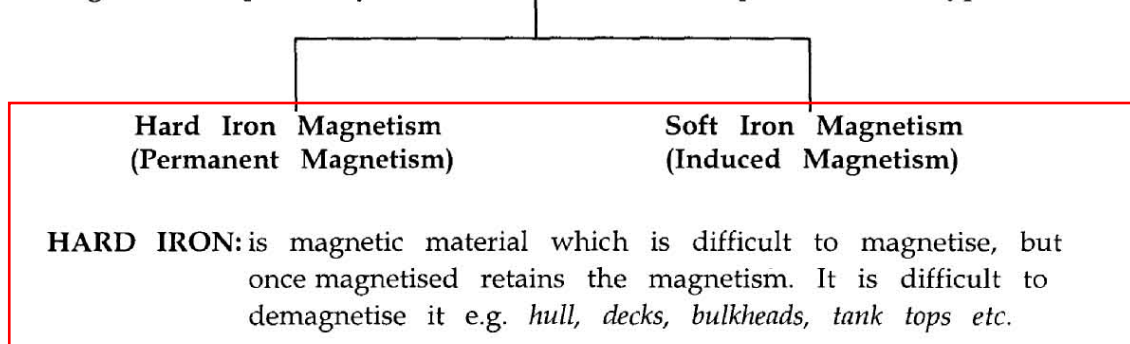
Z is maximum at the poles. It reduces as the latitude reduces, till it is nil at the equator where the entire total force is horizontal. Z governs the extent to which vertical soft iron structures are magnetised by induction due to the Earth's magnetic field.

CHAPTER 2

SHIP'S MAGNETISM

On a ship built of wood, a magnetic compass would point to magnetic North. Knowing the variation at that particular place, the magnetic direction can be corrected and the true direction obtained. Present day ships are built of steel - a substance which can be magnetised.

Magnetism acquired by steel structures of a ship is of two types.



SOFT IRON: is magnetic material which is easy to magnetise, but also loses its magnetism easily. Such structures are magnetised when influenced by a magnetic field and that too only when their lengths are aligned in the direction of the field (see fig. no. 1). As soon as the magnetic field is removed, soft iron loses its magnetism. e.g. *beams, girders, masts, Funnel etc.*

Very correctly, no structure on board is completely Hard Iron and no structure is completely Soft Iron. They are always a combination of both. However, structures which predominantly exhibit hard iron qualities are referred to as Hard Iron and we refer to structures which predominantly exhibit soft iron qualities as Soft Iron structures.

SHIP'S PERMANENT MAGNETISM

This is magnetism acquired permanently by the H.I. structures of the ship, when she is built.

With the ship heading in a constant direction when built, the incessant heating, hammering and heavy welding currents passed through the ship cause the molecules and domains of the hard iron structures of the ship to align themselves in the direction of the Earth's total force at that location, her magnetic poles being located in the line of the total force. Since this magnetism is acquired in hard iron, it would be permanent magnetism and the position of the poles so acquired is also permanent.

The vessel thus attains permanent magnetism both in the horizontal and vertical planes. This permanent magnetism acquired by the ship remains with her for her entire life except for a small amount shaken out during the first six months or so of her service due to the vibration, pounding etc. A very slow and a very small reduction in the strength of the permanent magnetism takes place over the next twenty years or so of her life, before she attains an equilibrium value.

Magnetic materials acquire a blue pole where the lines of force enter the material and a red pole where they leave the material. In other words, close to the red of the Earth, a blue is formed and close to the blue of the Earth, a red is formed on the ship.

The horizontal position of the poles will depend on the heading of the vessel during building.

The vertical position of the poles will depend on the hemisphere in which she is built.

PERMANENT POLES (IN HORIZONTAL PLANE)

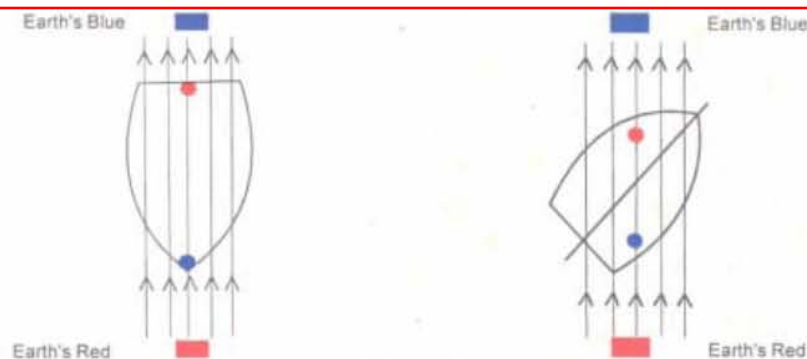


Fig. No. 9

PERMANENT POLES (IN VERTICAL PLANE)

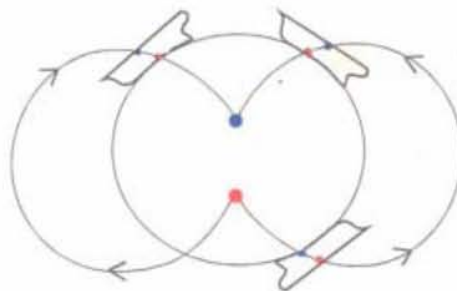


Fig. No. 10

- In Northern Hemisphere - She acquires a Blue deck and Red keel.
 - In Southern Hemisphere - She acquires a Red deck and Blue keel.
- (Regardless of ship's head)

(Recapitulate)

- The position of poles of the permanent magnetism in the Horizontal plane acquired by the ship when she is built depends entirely on ship's head when building. It does not depend on the hemisphere the ship is built in.
- The position of poles of the permanent magnetism in the Vertical plane acquired by the ship when she is built depends entirely on the hemisphere she is built in and not on the ship's head when built.

Northern Hemisphere - Blue deck and Red keel

Southern Hemisphere - Red deck and Blue keel

The amount of permanent magnetism acquired by the vessel in the horizontal and vertical planes will depend on the magnetic latitude in which she was built. She would acquire maximum magnetism in the horizontal plane if built at the equator, reducing to nil if built at the poles as H is maximum at the equator and reduces to nil at the poles. Similarly she would acquire maximum magnetism in the vertical plane if built at the pole and reducing to nil if built at the Equator as Z is maximum at the poles and reduces to nil at the equator.

The permanent magnetism of the vessel loses some of its intensity during the first six months of service. After that it remains stable. The positions of the poles however remain unchanged.

Since the permanent poles acquired by the ship can be in any oblique direction, the ship's permanent magnetic field at the compass, also acts in some oblique direction. We divide the vessel's magnetic field at the compass position due to her permanent magnetism into 3 components at mutually perpendicular directions.

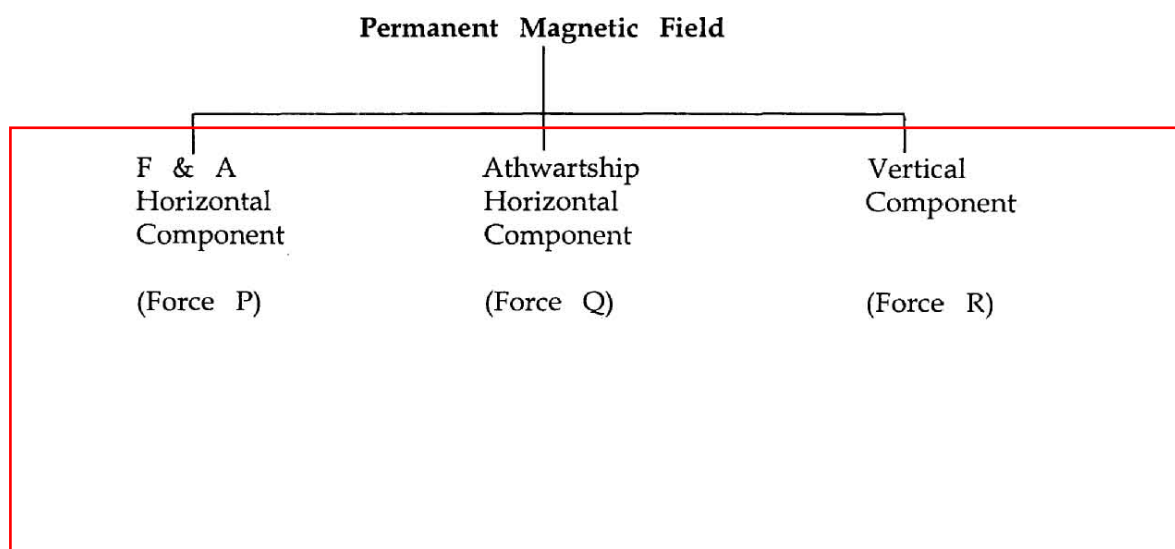
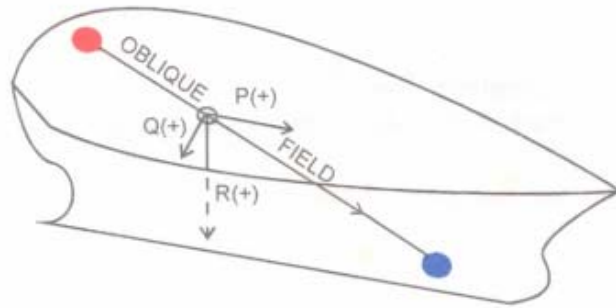


Fig. No. 11



- (i) Horizontal Fore and Aft component (Force P)
- (ii) Horizontal Athwartship component (Force Q)
[Resultant of P and Q is known as Force 'O']
- (iii) Vertical component (Force R)
(FORCES P, Q AND R ARE PERPENDICULAR TO EACH OTHER)

Sign Convention:

Force P is +ve if the field at the compass acts towards the Bow, and -ve if the field at the compass acts towards the Stern.

Force Q is +ve if the field at compass acts towards Starboard and -ve if the field at compass acts towards Port.

Force R is +ve if the field at the compass acts downwards, and -ve if the field at the compass acts upwards.

P, Q and R are constant forces as they are due to the ship's permanent magnetism. They do not vary with change of course nor with change of ship's latitude. Their effect in producing deviation of the compass however is not constant. It changes with change of ship's head and with change of magnetic latitude. e.g. if P was to make an angle with H, the compass would be deviated and will lie in the direction of the Resultant of H and P. Force P will affect the directive force at the compass and also cause deviation of the compass.

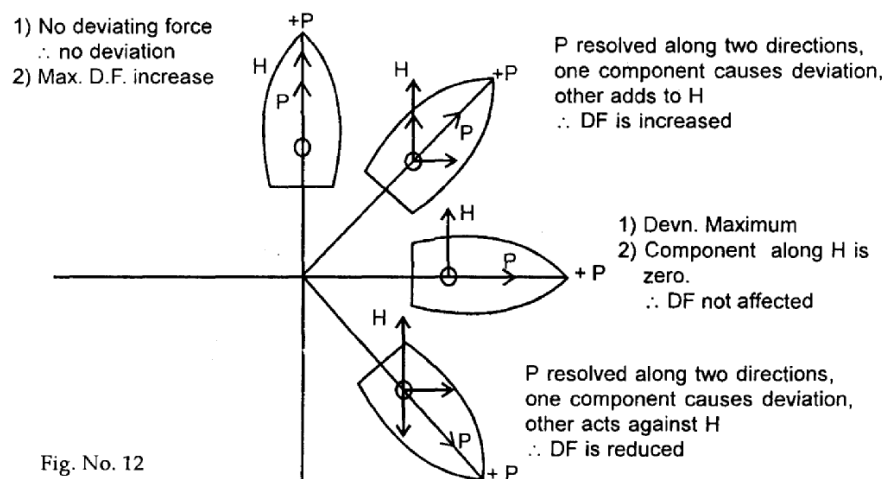


Fig. No. 12

(Recapitulate)

- P, Q, R - are constant forces
- They are not affected by ship's head or change of magnetic latitude of ship
- Their effect on the compass changes with ship's head and with change of latitude.

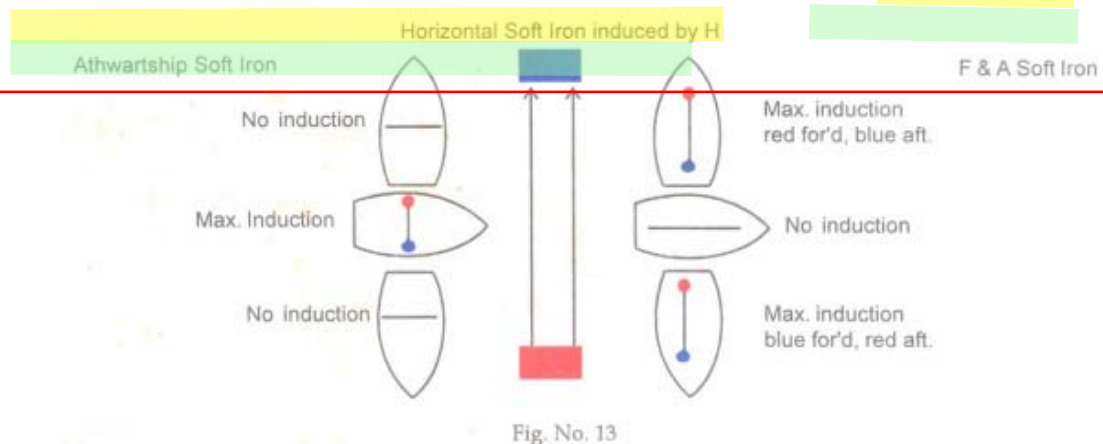
SHIP'S INDUCED MAGNETISM

Horizontal Soft Iron
(induced by H)

Vertical Soft Iron
(induced by Z)

Since magnetism is induced either by H or Z, the strength of the induced magnetism depends on the *latitude* the ship is in presently, as H is maximum at the equator and reduces to nil at the poles and Z is maximum at the poles and reduces to nil at the equator.

Horizontal Soft Iron:

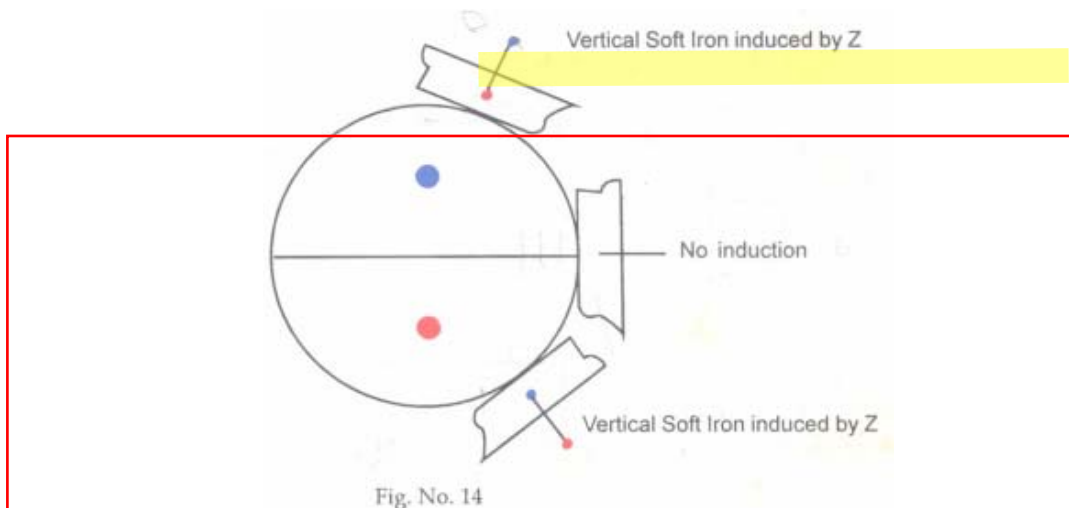


1. These are induced by H. Z does not induce magnetism in horizontal soft iron.
2. H.S.I. receives maximum induction near magnetic equator where H is largest and nil at magnetic poles, where H is nil.
3. Since H acts in line with the magnetic meridian, the induction in the horizontal Soft Iron, whether F and A or Athwartship will depend on the ship's head presently, relative to magnetic meridian. Therefore the strength of induced magnetism in H.S.I. changes with ship's head. It is maximum when its length is N - S (in the direction of H) and nil when its length is E - W.

In other words, the position of the poles and the strength of the induced magnetism in the H.S.I will depend upon the alignment of the Soft Iron with respect to Earth's field i.e. they will change with the ship's head. The northward end of the H.S.I. acquires a red pole and the southward end acquires a blue pole.

Vertical Soft Iron:

1. These are induced by Z. H does not induce magnetism in vertical soft iron.



2. They receive maximum induction at the magnetic poles where Z is largest and zero induction at the magnetic equator where Z is nil.
3. The position of the poles will depend on the hemisphere the vessel is in presently and is not effected by the ship's course. They will acquire a blue at top and a red at the bottom in the North hemisphere and vice-versa in the South hemisphere.

The magnetic field at a compass due to induced magnetism in the various horizontal and vertical soft irons on board may be depicted by the field produced by NINE imaginary soft iron rods situated around the compass. In other words the entire ship's Soft Iron, whether horizontal or vertical can be represented by combinations of these imaginary Soft Iron rods. It is important to know their placement and signs. The induced component of compass work is theoretically and mathematically dealt with more correctly by using the rod concept, since it has a more mathematical approach. Since such accuracy is not required for practical compass work, the rod method is generally avoided when solving numerical calculations.

A basic understanding of the nine rods and their applicability is however important as it makes for easier understanding of induced Coefficients.

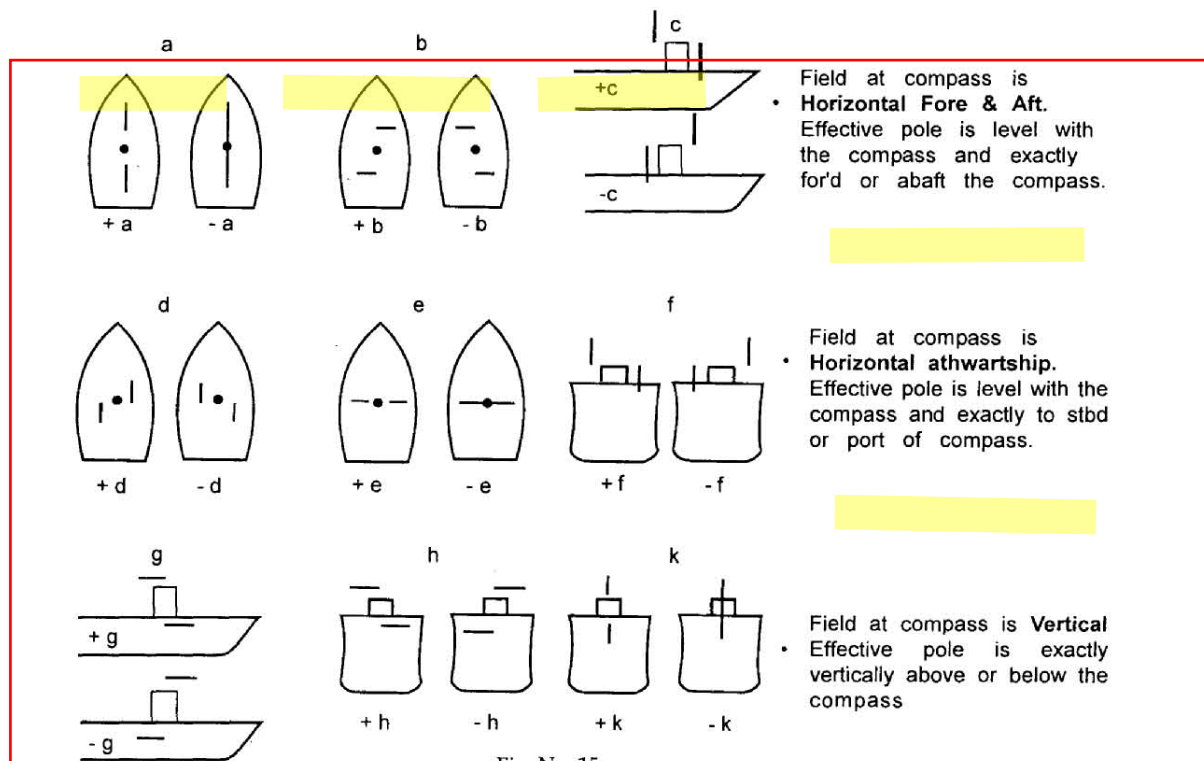


Fig. No. 15

* Wherever two rods are shown, each of them is a rod by itself.

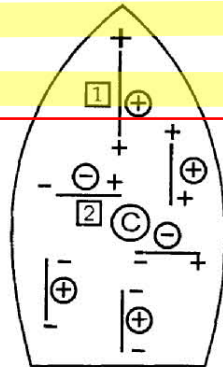
Rules for Nine Rods:

1. When a rod is induced, it acquires a red pole at one end and a blue at the other. Only the pole of the rod nearer the compass is considered effective when considering deviations they cause.
2. The pole of a rod near the compass is considered +ve if it is forward, to starbd, or below the compass.
3. The pole of a rod near the compass is considered -ve if it is abaft, to port, or above the compass.

Using rules 2 and 3, we first decide whether, in the rod under consideration, the pole near the compass is +ve or -ve. The farther pole of the rod is positive if it is for'd, stbd or below the nearer one. It is negative if it is abaft, to port or above the nearer one. Thus, we can now decide whether the farther pole is +ve or -ve.

Sign Convention for rods:

- If both poles of a rod are positive, the rod is positive.
- If both poles of a rod are negative, the rod is positive.
- If one pole is positive and the other is negative, the rod is negative.



1. Nearer pole is +ve as it is fore of compass. Farther pole is +ve as it is fore of nearer one. Both poles are +ve.
∴ rod is +ve.

2. Nearer pole is fore, +ve, farther pole is to port of nearer one and therefore -ve. Since one is +ve and one is -ve, the rod is -ve.

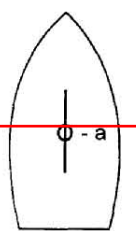
Fig. No. 16

The rods are imaginary soft iron around the compass. Many of them may not be present. At a well sited compass, the following rods are usually present:

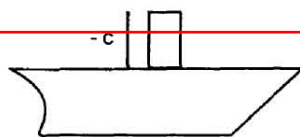
-a (F & A girders), -c (funnel), -e (athwartship beams) and +k (pillars).

At a compass which is not well sited, b, d and g rods may also be present. They may be +ve or -ve.

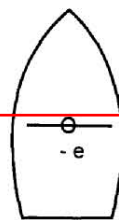
Disposition of Soft Iron on the ship:



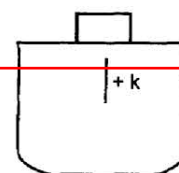
continuous
F & A girders



Funnel



Transverse
beams



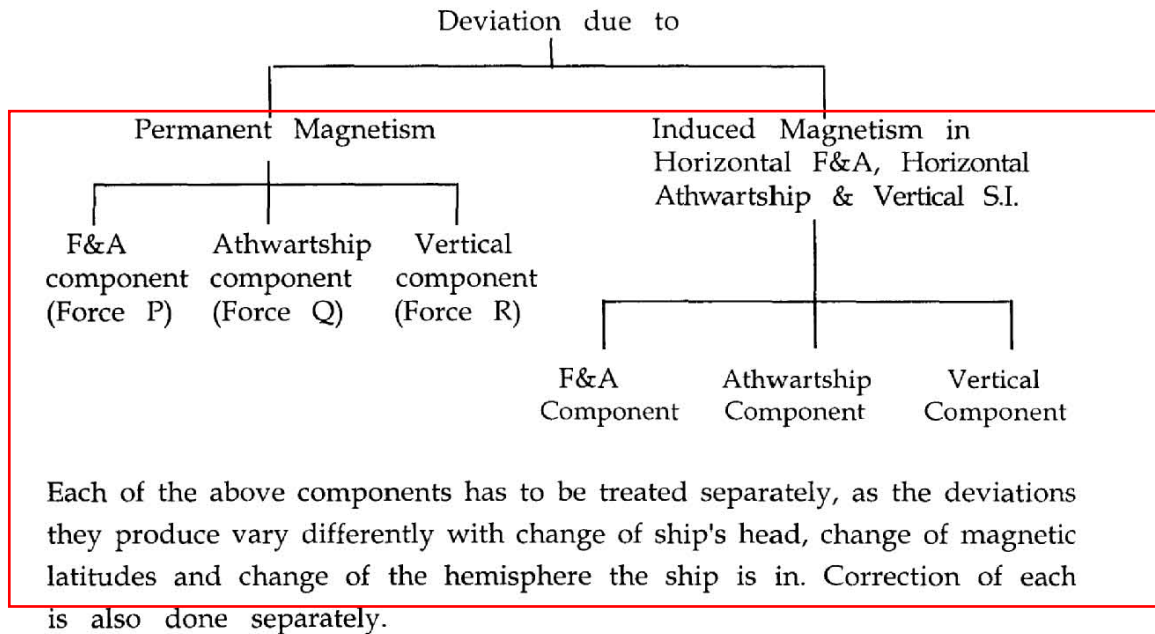
Vertical Soft Iron
below the compass
(pillars)

Fig. No. 17

CHAPTER 3

INTRODUCTION TO COMPASS WORK

The deviation of a magnetic compass is caused by the ship's magnetism.



When the vessel is upright, the total deviation of the compass is the algebraic sum of all or some of 5 component deviations. These may change with **ship's head**, the **latitude** and **hemisphere** the ship is in. The maximum values of these 5 component deviations are the coefficients, namely Coefficients A, B, C, D and E.

THE COEFFICIENTS

(A coefficient is the **maximum** deviation caused by one or more of the ship's forces acting at the compass position.) It must be clearly understood that coefficient is a deviation, measured in degrees and is NOT a force.

THREE TYPES OF DEVIATIONS CAUSED BY COEFFICIENTS

Constant	Semi Circular	Quadrantal
(Deviations of same sign and value on all headings)	(Deviations of same sign over one continuous half of the compass courses and of the opposite sign for the other continuous half of the compass courses)	(Deviations of one sign over continuous opposite quarters of the ship's head and of the opposite sign over the other two continuous opposite quarters of the ship's heading)

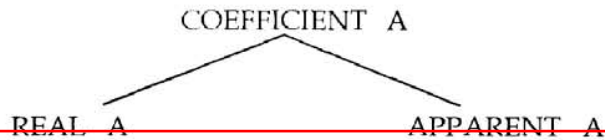
1. The value of each coefficient is the maximum deviation produced by that coefficient.
2. Deviations are considered +ve when *easterly* and -ve when *westerly*.
3. Coefficients are considered +ve if they produce *easterly* deviations on a course immediately to the *right of N. heading*. They are considered -ve if they produce a *westerly* deviation on a course immediately to the *right of N. heading* i.e. name of each coefficient goes with the name of deviation for courses between 000° to 045°.
4. The coefficients are A, B, C, D and E.
5. The total deviation on any course is obtained as

$$\delta = A + B \sin co + C \cos co + D \sin 2 co + E \cos 2 co$$

If values of the coefficients are known, using the above equation, we can find the total deviation on any particular heading.

CHAPTER 4

COEFFICIENT A



+A produces a constant *easterly* deviation on all headings

-A produces a constant *westerly* deviation on all headings

REAL A

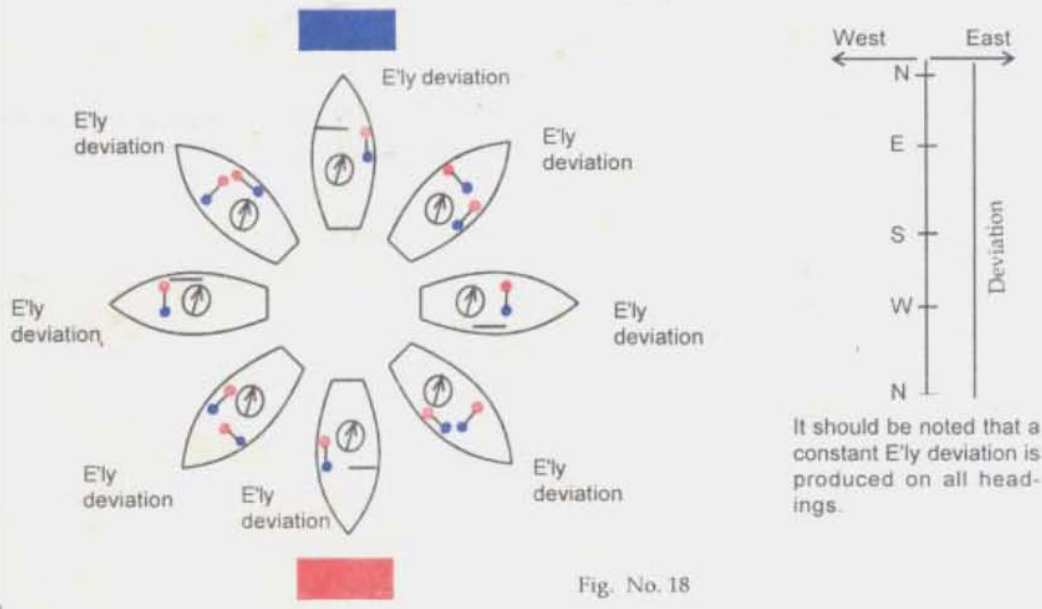
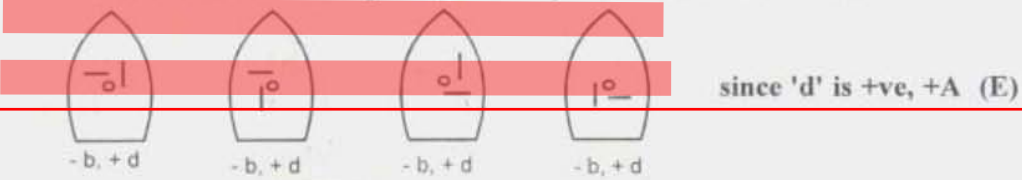
DEFINITION: Coefficient Real A is the constant deviation, both in amount and in name, caused by induced magnetism in unsymmetrical pairs of horizontal soft iron around the compass.

It can be produced by b and d rods of opposite names, but of equal value. The coefficient takes the name of the d rod.

+ A is produced by **-b** and **+d** rods

- A is produced by **+b** and **-d** rods

Coefficient +A produced by -b and +d rods



It should be noted that a constant E'y deviation is produced on all headings.

In considering the deviation that will be caused due to the induced magnetism in the rods, only the effect of the pole near the compass of each rod, is to be considered.

It should also be noted that when a rod is aligned in the N - S direction, its entire length is presented for induction and therefore, they are induced to the maximum extent. When a rod lies in the E - W direction, it does not acquire any induction. For intermediate angles, the amount of induction acquired will also have some intermediate value.

-A is caused by a combination of **+b** and **-d** rods. It will produce a constant westerly deviation on all headings.

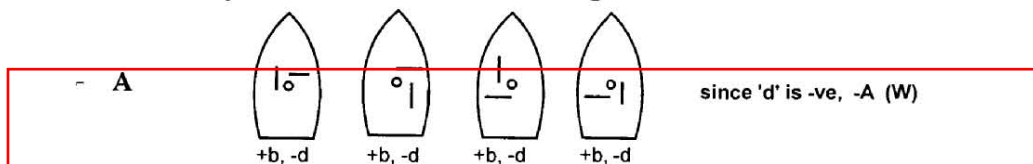


Fig. No. 19

Effect of Coefficient A on Directive Force:

DF at the compass position is the horizontal magnetic field which acts towards magnetic North. It is this field which gives the compass the directive property of pointing North. Though magnetism induced in b and d rods is different on every heading, the sum of the fields caused by the rods at the compass position is the same on each heading and is always directed exactly in the East - West line. There is therefore no component of this field towards North or South. Therefore it will have no effect on DF at the compass, on any heading.

(Recapitulate)

- sum of field caused by b and d rods is constant, on all headings.
- field always directed towards east or west.
- $\therefore$ no N/S component.
- $\therefore$ DF not effected.

Effect of change of Latitude:

We know that the compass needle will point in the resultant direction, if two forces act on it. The earth's horizontal component (H) is causing it to point towards Magnetic North and the disturbing field F, due to coefficient A is acting towards East or West magnetic. Let us say we are in latitude 40° N and value of H is x units. If we proceed towards the equator H will increase. Say it becomes 2x units. The induction in horizontal soft iron also increases in the same proportion as it is the same

Earth's horizontal field which induces magnetism in the horizontal S.I. rods

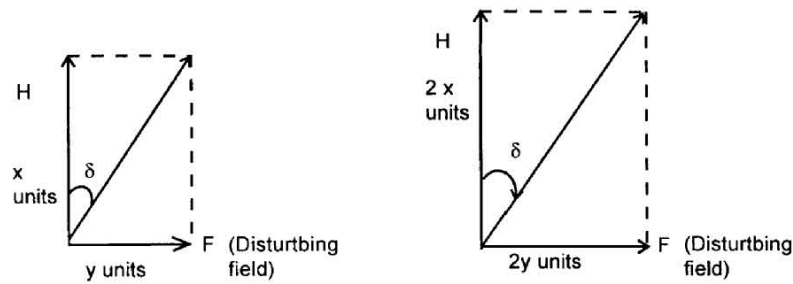


Fig. No. 20

The deviation therefore remains the same, because both H and F increase in the same proportion. The value of coefficient A, that is the deviation due to A, does not therefore change with change of magnetic latitude.

It may be worth remembering for future, that the same argument will hold good for all other coefficients caused due to induced magnetism in horizontal soft iron i.e. coefficients D & E.

(Recapitulate)

- Deviation is caused due to F.
- Since the deviating force, F is dependant on H, F increases or decreases proportionately with H.
- Since proportion of H & F will always be same, deviation due to Coefficient A is not affected by change of latitude.
- Same is the case with all other deviations caused due to induced magnetism in horizontal soft iron i.e. Coefficient D & E.

Correction of Real A is generally not attempted. It is very rare that a coefficient A exists. Even when present, it is likely to be very small. If however it exists, the error is constant on all headings. It is like an index error and therefore can be easily applied.

It may however be allowed for, by shifting the lubber line of the compass by the amount of coefficient A. This would ensure that courses steered will not be affected by the error. However, the error would still be applicable to bearings observed.

NON MAGNETIC COEFFICIENT A (APPARENT A)

is the value of the constant error, which remains same in name and in amount for all directions of the ship's head, and is caused by factors other than the magnetic field of the ship at the compass position.

Causes of Apparent A:

- i) The magnetic axis of the needle system not being parallel to the 0° - 180° direction of the card.
- ii) The lubber line of the compass not being parallel to the ship's fore and aft line. This will produce a constant error on all courses steered, but not on the bearings observed.
- iii) A constant error in observing the bearing of the object, using which the compass was adjusted e.g. an index error in the azimuth measuring device.
- iv) An error in computing the magnetic bearing of the object, using which the compass was adjusted e.g. application of the wrong variation to the true bearing.
- v) Too rapid a swing, when observing the bearings of the object by which the compass is adjusted.
- vi) Hour angles worked out incorrectly leading to error in the calculated bearing of the sun.

Presence of Coefficient A:

If an appreciable coefficient A is found at a compass, the cause should be investigated, by checking the following :

1. Azimuth Mirror
2. Variation used
3. Lubber line alignment
4. Alignment of card graduation with magnetic axis of the compass needles
5. Hour Angle

If none of the above are present, coefficient A can only be due to magnetic causes. It is not possible to accurately separate the two components of the total coefficient A, where both real and apparent A exist simultaneously.

(Recapitulate)

- If appreciable coefficient A present - rule out apparent A by checking (1) Az. Mirror, (2) variation, (3) Lubber line, (4) Alignment of card graduation and needles, (5) Hour Angle.
- If Appt. A not present by above checks - it implies that a Real A is present.
- If both are present together - it is not possible to obtain their separate values.

If a Coefficient A exists, its value may be obtained as the mean of the deviations on at least four equidistant headings. Normally this is done using deviations on the eight cardinal and intercardinal compass headings.

Example: Calculate the value of Coefficient A if the following deviations were known to exist.

Comp. Hdg.	N	NE	E	SE	S	SW	W	NW
Deviation	8°E	3°E	2°W	5°W	1°W	5°E	2°E	8°W

$$\text{Coefficient A} = \frac{18\text{E} + 16\text{W}}{8} = \frac{2\text{E}}{8} = 0.25^\circ \text{ E}$$

∴ we have a +A of 0.25°

CHAPTER 5

COEFFICIENT B

DEFINITION: Coefficient B is the maximum value of the semicircular deviation which varies as the sine of the compass course and is caused by the horizontal, fore and aft component of the magnetic field due to the ship at the compass position. Coefficient B is the algebraic sum of Permanent B and Induced B.

A $+B$ is caused if the horizontal F&A field at the compass position acts towards the bow and a $-B$ is caused if it acts towards the stern. Therefore, a $+B$ will be caused if there is a blue pole for'd of the compass and a red pole abaft the compass or a blue pole alone for'd of the compass or a red pole alone abaft the compass as the field at the compass in each case will be towards the bow. (Refer to figure no. 21).

Conversely, a $-B$ will be caused if there is a red pole for'd of the compass and a blue pole abaft the compass or a red pole alone for'd of the compass or a blue pole alone abaft the compass, as the field at the compass in each case will act towards the stern. (Refer to figure no. 21).

COEFFICIENT B

Permanent B

PB (due to Force P)
(F & A horizontal component
of the ship's Permanent magnetic
field at the compass.)

$+ B$

(Due to the ship's field acting
towards the bow)



Easterly deviation on Easterly
Courses

and

Westerly deviation on Westerly
Courses

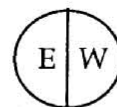
The deviation is semicircular.

Induced B

iB (due to c rod)
(F&A horizontal magnetic field
due to induced magnetism in
vertical soft iron for'd or abaft
compass. Induction is due to Z.)

$- B$

(Due to the ship's field acting
towards the stern)



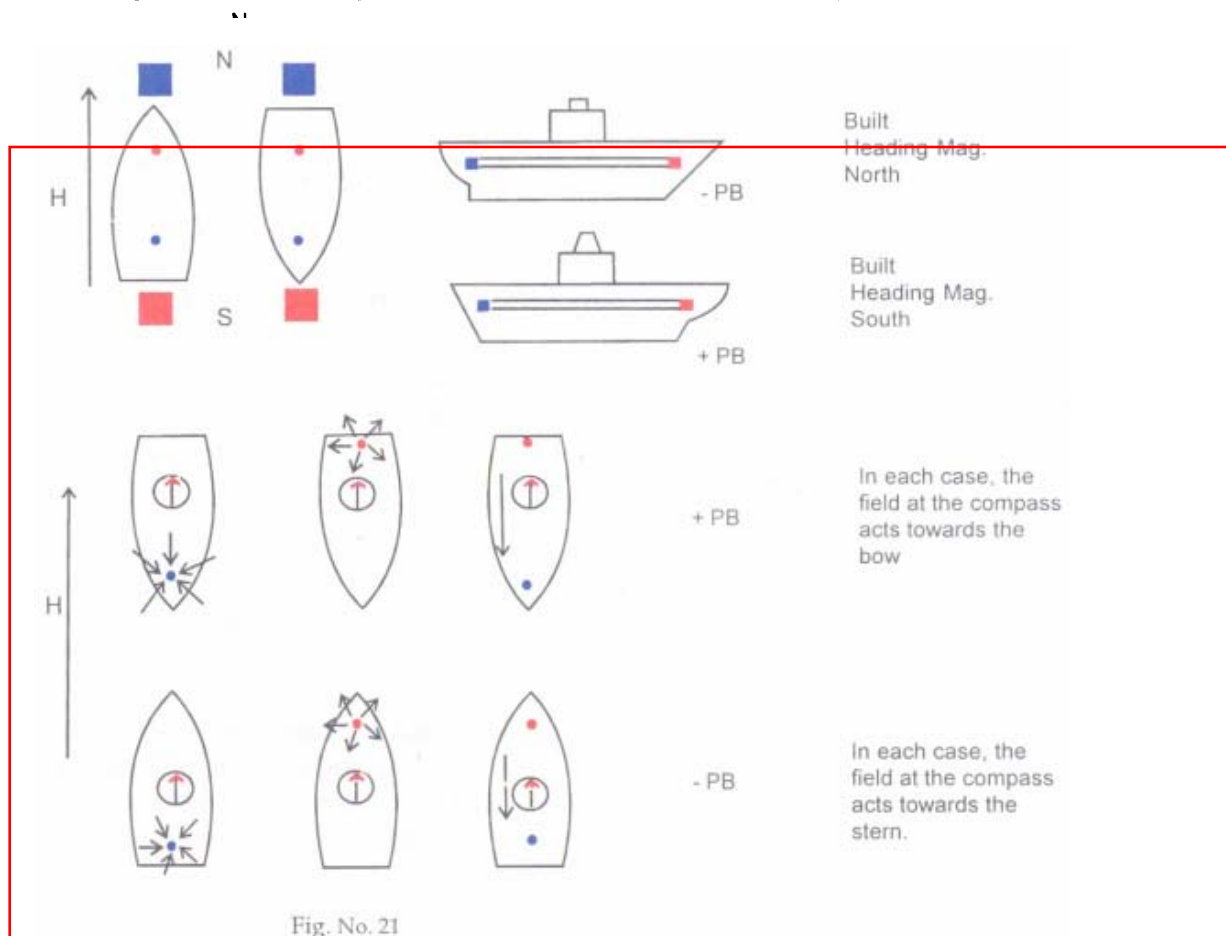
Westerly deviation on Easterly
Courses

and

Easterly deviation on Westerly
Courses

PERMANENT B (Due to Hard Iron)

A ship built on any Northerly heading (regardless of the hemisphere) will acquire a permanent red pole towards the bow and permanent blue pole towards the stern causing a field acting towards the stern at the compass and conversely, a ship built on any Southerly heading will acquire a permanent blue pole towards the bow and red pole towards the stern causing a field acting towards the bow at the compass.

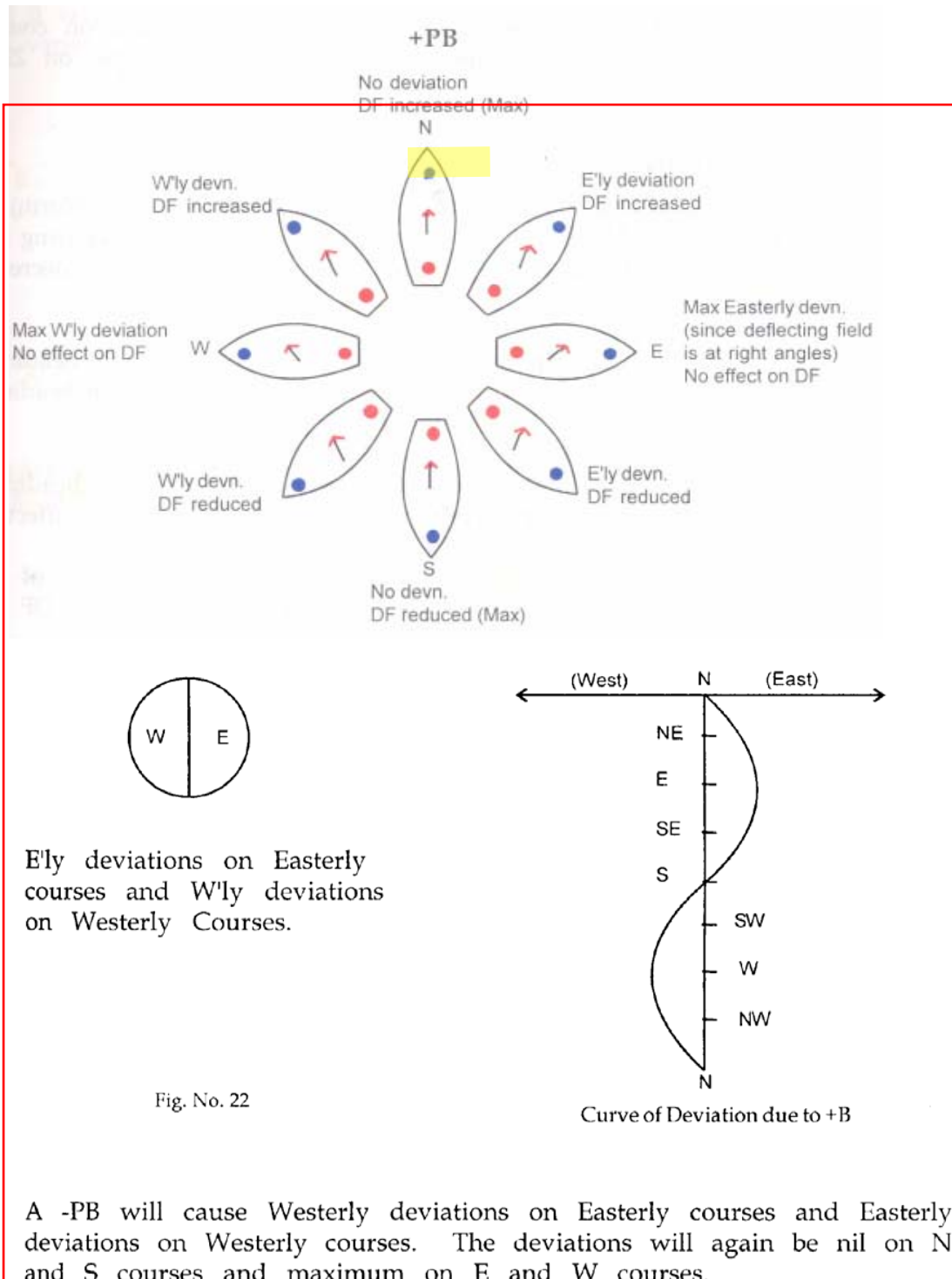


Recall, the force causing Permanent B i.e. P is constant. The value of the force does not change, either with latitude or the ship's head, but the deviation due to this force changes both with latitude and course.

Let us now examine how the deviation due to PB varies with change of course and with change of magnetic latitude of the ship.

- The force causing PB which is due to the ship's permanent magnetism is constant and is not affected by change of magnetic latitude or compass course.
- But the deviation it produces will change with latitude and the comp. course of the ship.

Change in deviation due to change in course



Effect of course on deviation due to PB:

1. Deviation ' δ ' due to PB is nil on course 000° , maximum on course 090° , nil on 180° and maximum and of the opposite name on 270° . Therefore PB δ varies as sin comp. co.
($\sin 0^\circ = 0$; $\sin 90^\circ = 1$; $\sin 180^\circ = 0$, $\sin 270^\circ = -1$).

Effect on Directive Force:

2. With a +B, the DF (field at the compass acting towards North) is increased on all Northerly headings, Maximum increase occurring on North. DF is reduced on all Southerly headings, Maximum decrease occurring on South.
3. Change in DF - Maximum change in DF occurs on the headings where δ is nil (N & S headings). No change in DF occurs on headings where δ is maximum (E & W headings).
4. Equal and opposite changes in DF occurs on opposite compass headings, so that the **Mean Directive Force** for all the headings remains unaffected.

A -PB will produce exactly the opposite effect as regards change of DF to those discussed above for a +PB. There will be increased DF on Southerly headings and decreased DF on Northerly headings.

Student is advised to verify the above statements regarding deviations and the DF for a ship with a -B by drawing a figure with the ship on the cardinal and intercardinal headings, with a red pole at the bow and a blue pole at the stern.

Effect of change of latitude on deviation due to PB:

We know that ' δ ' due to PB is maximum when heading East or West by compass because the deviating field then acts at right angles to the DF of the Earth, H.

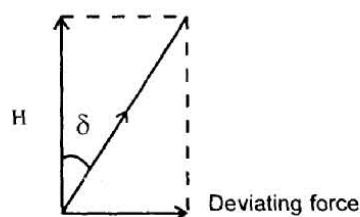


Fig. No. 23

Let us consider the ship at two places, (1) and (2) in widely different latitudes. Force P causing the deviation remains constant, but as the latitude of the ship changes, H also changes.

As can be seen from the figure if H (the D.F. of the Earth) is large the δ is small and if H is small the δ is large. i.e. deviation due to PB varies inversely as H

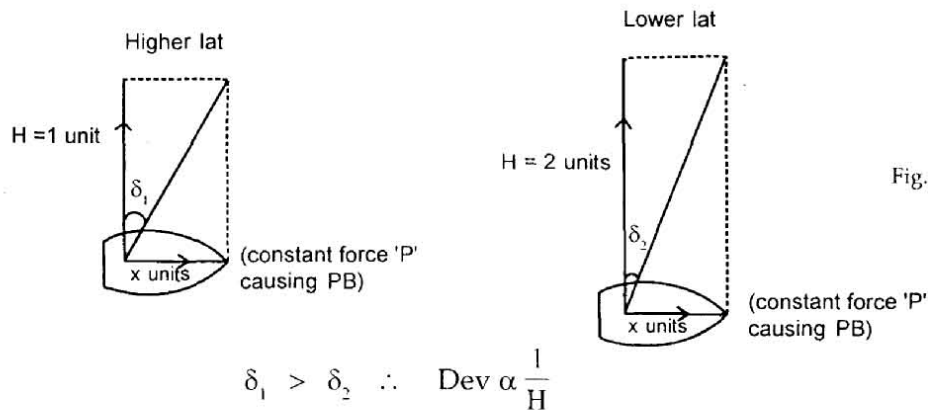


Fig. No. 24

We also know that ' δ ' due to PB varies directly as $\sin$ compass co. Combining both these, we may state

$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\sin \text{comp co}_2}{\sin \text{comp co}_1}$$

Also at any particular place, as H is unchanged,

Deviation due to PB = PB x $\sin$ compass co.

where PB is the value of coefficient PB.

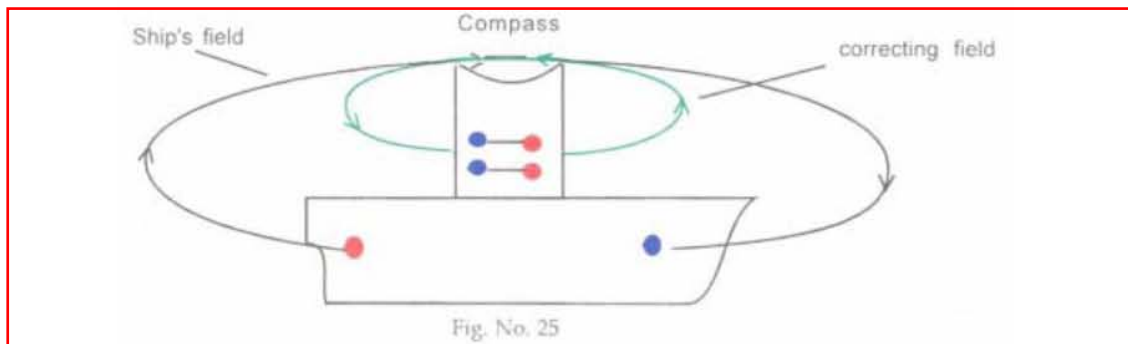
Correction:

The basic principle followed in correcting a compass is to cure *Like With Like*. The purpose being to ensure that the correction made holds good for all latitudes and all courses. The logic being that both PB δ and the correction provided by its corrector should vary in the same manner so that the deviation will remain corrected on all courses and at all latitudes.

F & A Corrector Magnets:

PB, which is caused by the ship's F & A, horizontal permanent magnetic field must therefore be corrected by using F & A permanent magnets, placed horizontally, such that they produce a permanent magnetic field at the compass, exactly equal to and opposite to that of the ship. When this is achieved, the field producing PB has been nullified and therefore PB has been eliminated. When the ship has a +PB, these magnets are placed with their red ends fore and if the ship has a -PB, they are placed with their blue ends fore.

+ PB



These F & A magnets are usually bar magnets of circular section 8" length, 3/8" or 3/16" diameter.

Slots are provided in the binnacle below the compass. They are placed 2 in each row side by side, at different levels. They are held in position by the doors of the binnacle when they are shut. They should not be nearer than twice their own length from the needle system so that they produce a uniform magnetic field around the compass. Normally the design of the binnacle ensures this.

Correction of each coefficient is carried out with the ship heading on a course on which that coefficient produces maximum deviation. Since PB produces maximum deviation when heading E or W, this correction is carried out with the ship heading E or W.

Example 1. Deviation due to hard iron is 10° E, when heading 090° (c), what will be the deviation on a course of 030°(c).

This dev is due to PB and since there is Easterly deviation on 090°(c), it indicates that the ship has a +PB

$$\frac{\delta_2}{\delta_1} = \frac{\sin \text{comp } \text{co}_2}{\sin \text{comp } \text{co}_1}$$

$$\frac{\delta_2}{+10} = \frac{\sin 30}{\sin 90} = \frac{1}{2}$$

$$\Rightarrow \delta_2 = +5^\circ = 5^\circ \text{E}$$

Example 2. Deviation due to coefficient PB is 5° W on 330° (c), find deviation on 150° (c).

$$\frac{\delta_2}{\delta_1} = \frac{\sin \text{comp } co_2}{\sin \text{comp } co_1}$$

$$\frac{\delta_2}{\delta_1} = \frac{\delta_2}{-5} = \frac{\sin 150^\circ}{\sin 330^\circ}$$

$$\delta_2 = -5 \times \frac{\sin 150^\circ}{\sin 330^\circ} = +5^\circ$$

$$\delta_2 = 5^\circ \text{ E}$$

Example 3. Deviation due to PB = 5° W on a certain course at a place where H = 15 A/m. What will be the deviation due to PB on the same course at a place where H = 30 A/m.

$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2}$$

$$\frac{\delta_2}{-5} = \frac{15}{30}$$

$$\delta_2 = -5 \times \frac{15}{30} = -2.5^\circ$$

$$\delta_2 = 2.5^\circ \text{ W}$$

Example 4. If deviation due to PB = 8° W, when heading 090° (c) at position (1); where H = 15 A/m, find deviation due to same when (a) on the same heading at position (2) where H = 20 A/m and (b) when heading 315° (c) at position (3) where H = 25 A/m

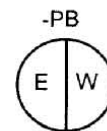
8° W due to PB when heading 090° (c) indicates -PB

(a) Same heading, but different H

$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \Rightarrow \frac{\delta_2}{-8} = \frac{15}{20}$$

$$\delta_2 = -8 \times \frac{15}{20} = -6^\circ$$

$$\delta_2 = 6^\circ \text{ W}$$



(b) Different headings and different H

$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\sin \text{comp } co_2}{\sin \text{comp } co_1}$$

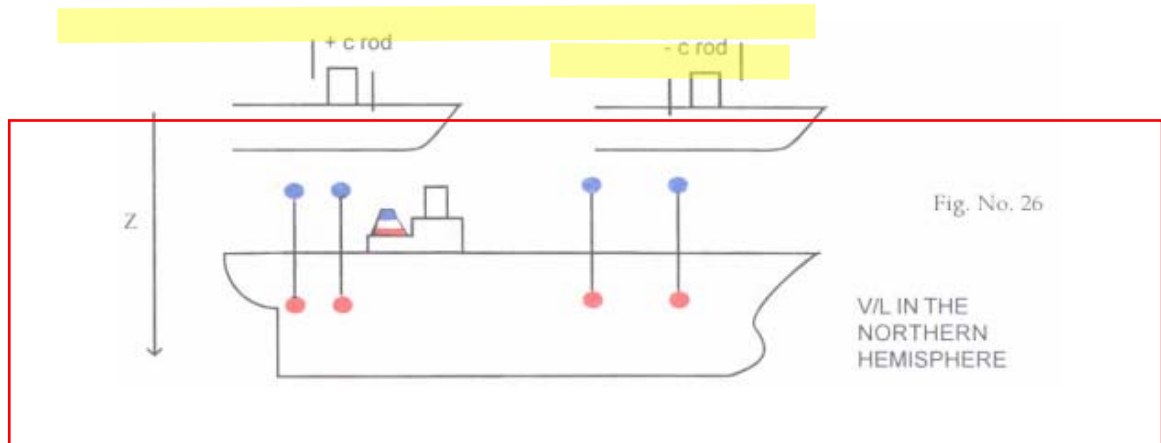
$$\frac{\delta_2}{-8} = \frac{15}{25} \times \frac{\sin 315^\circ}{\sin 090^\circ}$$

$$\delta_2 = -8 \times \frac{15}{25} \times \frac{\sin 315^\circ}{\sin 090^\circ} = +3.4^\circ$$

$$\delta_2 = 3.4^\circ \text{ E}$$

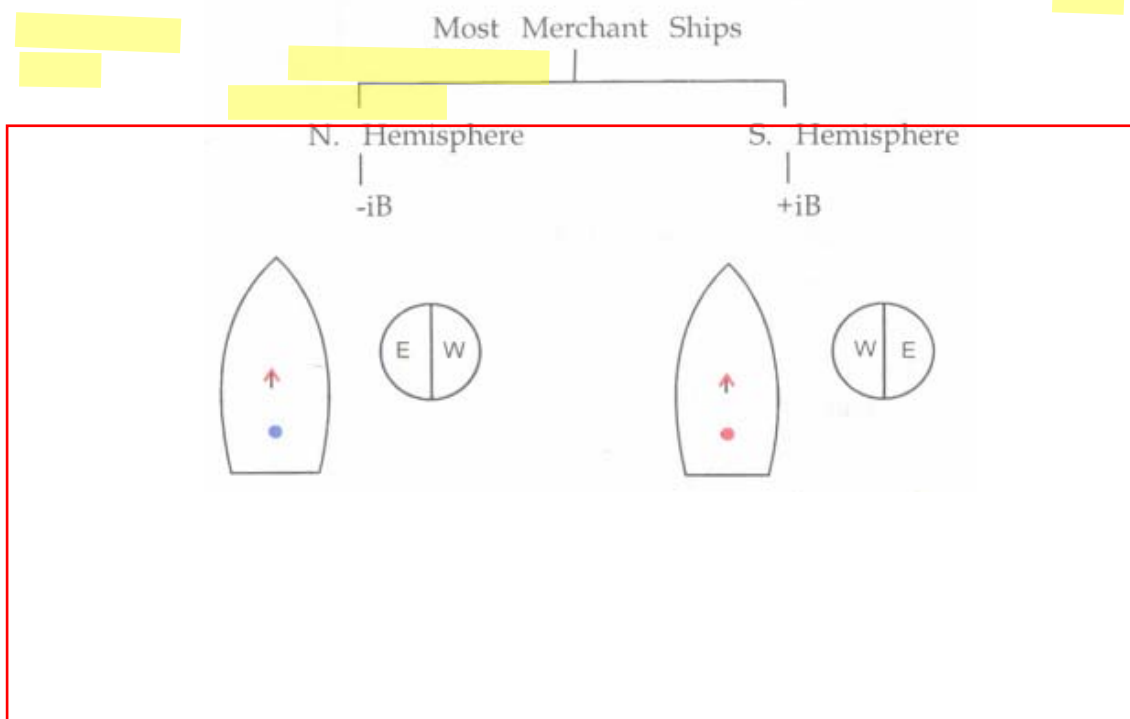
INDUCED B

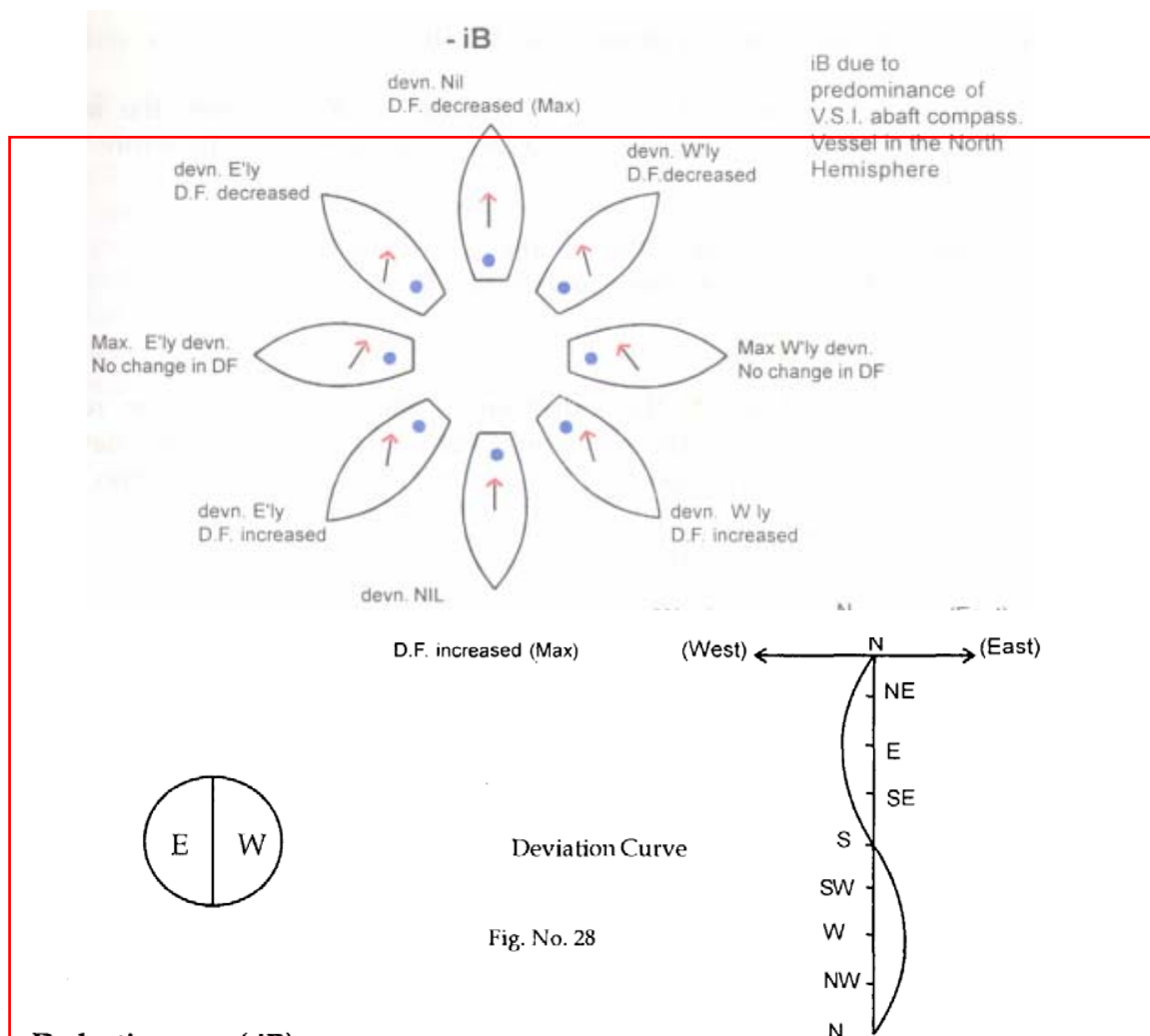
is caused by a horizontal fore and aft magnetic field at the compass due to the induced magnetism in the vertical soft iron, forward or abaft of the compass (i.e. due to c rod).



The above diagrams show how the vertical S.I. on a vessel in the Northern hemisphere will be induced, red pole at the bottom and blue pole at the top. Reverse polarity will be acquired by the same S.I. when the ship is in the Southern hemisphere. At the magnetic Equator there will be no induction in these vertical soft iron as Z is nil.

The construction of merchant ships is such that the compass is situated somewhat on a level with the top poles of the masts and funnel. They therefore cause a more horizontal field than the bottom poles of these vertical S.I. structures. As the funnel is the largest vertical S.I. on board and as it is normally situated close, abaft the compass, it normally produces the predominant effect at the compass. Thus, on most ships, in the North hemisphere, there is a predominance of blue abaft the compass causing a $-iB$ and in the South hemisphere there is a predominance of red abaft the compass causing a $+iB$.





Deductions: (-iB)

1. W'ly deviations on Easterly courses and E'ly deviations on Westerly courses.
2. Maximum deviation when heading E and W, nil when heading N and S.
3. DF decreases on all Northerly headings and is minimum on North.
4. DF increases on all Southerly headings and is maximum on South.
5. Mean DF for all headings however remains unchanged, as equal and opposite changes takes place on opposite compass headings.

Effect of course on deviation due to iB:

Like PB, we know δ due to iB is also maximum when heading East and West by compass because the disturbing blue pole or red pole acts at right angles to the compass needle. (Maximum deviation occurs, when disturbing force acts at 90° to the deflected needle). It is nil when heading N or S as the disturbing field acts in the direction of the needle. Therefore the δ due to iB varies directly as $\sin \text{comp. co.}$

$$\therefore iB \delta \propto \sin \text{comp co.}$$

Effect of Latitude on deviation due to iB :

The vertical S.I. is induced by Z. Therefore, as Z increases, the amount of induction and therefore the deviating field increases, therefore the δ also increases.

Conversely as Z decreases, the δ also decreases.
Therefore δ due to iB varies directly as Z.

$$\text{i.e. } iB \delta \propto Z$$

Further, if Z and therefore the induction in the vertical soft iron remains constant, the strength of the deviating field is constant. The deviation then will vary inversely as H like in the case of PB deviation.

$$\text{Therefore } iB \text{ deviation } \propto \frac{1}{H}$$

$$\left. \begin{array}{l} \propto Z \\ \propto \frac{1}{H} \end{array} \right\} \Rightarrow \propto \frac{Z}{H} \text{ i.e. } \propto \tan \text{ dip}$$

$$\text{deviation due to } iB \text{ varies } \left[\begin{array}{l} \text{directly as } Z \\ \text{inversely as } H \end{array} \right] \text{ i.e. directly as } \tan \text{ dip}$$

$$\delta \text{ due to } iB \propto \sin \text{ comp } \text{co}$$

$$\therefore \frac{\delta_2}{\delta_1} = \frac{\sin \text{co}_2}{\sin \text{co}_1} \times \frac{Z_2}{Z_1} \times \frac{H_1}{H_2} = \frac{\sin \text{co}_2}{\sin \text{co}_1} \times \frac{\tan \text{dip}_2}{\tan \text{dip}_1}$$

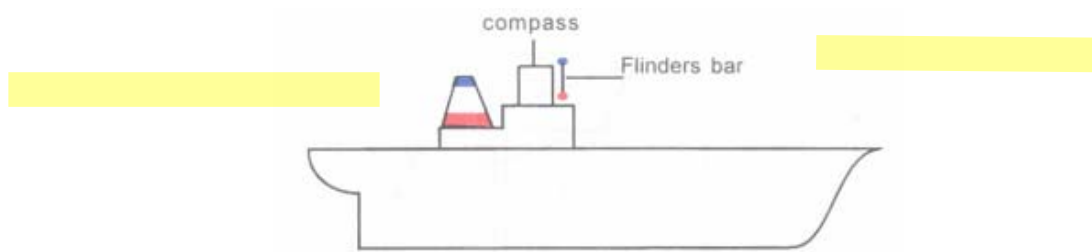
When solving problems, if the sign convention of the trigonometrical ratio sine is adhered to and the sign of Z or dip (+ve in Northern Hemisphere and -ve in S. hemisphere) are also adhered to, the answer obtained will be correct in value and sign.

When considering the two components of B i.e. induced B and Permanent B, we have to consider them separately as they do not vary together since deviation due to PB varies only directly as $\sin \text{co}$ and inversely as H, while deviation due to iB varies directly as $\sin \text{co}$, inversely as H and directly as Z.

When correcting the compass for PB and iB, they are also corrected individually, PB with permanent magnets and iB with the S.I. flinders bar.

Correction of Induced B:

Recall iB changes in sign according to the hemisphere the vessel is in. When correcting the compass, we apply the principle "*Like for Like*". Therefore iB caused by induced magnetism in Vertical soft iron should be corrected by an equal and opposite field produced by induced magnetism in V.S.I. This type of correction will hold good for all positions and headings. We therefore use a V.S.I in the form of **flinders bar**, to correct for iB . The value of the magnetism induced in the flinders bar will depend upon its length. Therefore the amount of correction can be varied by increasing or decreasing the length of the flinders bar used.



Flinders Bar:

The Flinders Bar is placed inside a brass case 610mm in length, attached to the compass binnacle. The S.I. bars of diameter 76mm (3") are supplied in the following lengths:

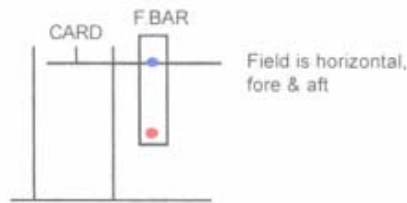
305 mm (12") - 1 bar ; 152 mm (6") - 1 bar; 76 mm (3") - 1 bar ; 38mm (1½") - 1bar; 19mm (¾") - 2 bars. Making total length of 610 mm (24").

Pieces of wood of the same dimensions are also provided. When the entire length of the flinders bar is not used for the correction, the wooden pieces are placed at the bottom of the brass case and the S.I. flinders bar placed over them, so that whatever the length of the flinders bar used, its effective top pole is in level with the compass card to produce a horizontal field at the compass.

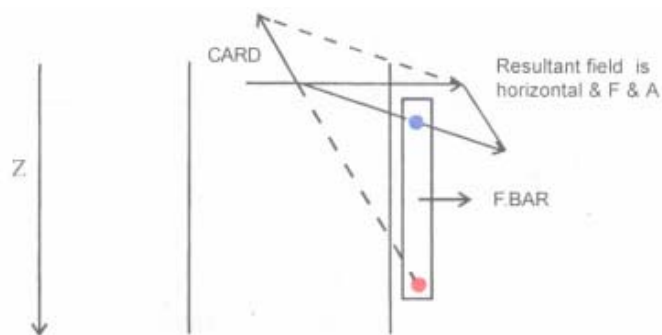
As in the usual case of a predominance of vertical S.I. abaft the compass, the flinders bar is placed forward of the compass. In the unlikely case of a predominance of vertical S.I. for'd of the compass the flinders bar would be placed abaft the compass.

If the length of the flinders bar used is large, then the top of the flinders bar should be slightly higher than the level of the compass card. This is due to the fact that the induced pole is not exactly at the end of the bar, but at a distance of about 1/12th of its length from the end.

In this case we consider that the lower pole is too far from the compass card to have any effect on it.



If the length of the flinders bar used is very short, the top of the bar is placed slightly lower than the level of the card. This is because in this case both induced poles of the bar will have an effect on the card and our intention is to have the resultant field in a horizontal and fore and aft direction.



Since we have corrected like with like, the correction will hold good for all positions as the induction in the ship's V.S.I causing the deviating field and the induction in the flinders bar causing the correcting field will vary together as the Z changes.

Question 1: In the Southern hemisphere, a ship has an iB of -2° , where do you place the flinders bar ?

Answer : In the Southern hemisphere, the ship's V.S.I. will have a red pole at the top. Since we have iB of -2° , the field at the compass acts towards the stern i.e. the red pole is forward of the compass. Therefore, place flinders bar aft of compass to correct -2° to provide a red pole at the top of the flinders bar, abaft the compass, to nullify the ship's red pole forward.

Question 2: In the Northern hemisphere, ship heading West, the deviation due to iB was $+3^\circ$, where should the flinder bar be placed ?

Answer : In the Northern hemisphere the ship's V.S.I will acquire 'blue' pole on top and deviation of $+3^\circ$ on Westerly heading indicates $-iB$. i.e. the blue pole is aft of the compass. Place the flinders bar forward of the compass to correct $+3^\circ$.

Example 1: Deviation due to iB is $5^\circ W$ on a certain course at a place where $H_1 = 15 \text{ A/m}$ and $Z_1 = 40 \text{ A/m}$. Find deviation due to iB on the same course at a position, where $H_2 = 30 \text{ A/m}$ & $Z_2 = -20 \text{ A/m}$.

$$\frac{\delta_2}{\delta_1} = \frac{Z_2}{Z_1} \times \frac{H_1}{H_2}$$

$$\frac{\delta_2}{-5} = \frac{-20}{40} \times \frac{15}{30}$$

$$\delta_2 = -5 \times \frac{-20}{40} \times \frac{15}{30} = +1.25^\circ$$

$$= 1.25^\circ E$$

Example 2: If deviation due to coefficient induced B is $5^\circ E$ when heading 210° (c), at position (1), where angle of dip is $+45^\circ$. Find the deviation when heading 330° (c) at position (2), where the angle of dip is $+30^\circ$.

$$\frac{\delta_2}{\delta_1} = \frac{\tan \text{dip}_2}{\tan \text{dip}_1} \times \frac{\sin \text{comp co}_2}{\sin \text{comp co}_1}$$

$$\frac{\delta_2}{+5} = \frac{\tan 30^\circ}{\tan 45^\circ} \times \frac{\sin 330^\circ}{\sin 210^\circ}$$

$$\delta_2 = +5 \times \frac{\tan 30^\circ}{\tan 45^\circ} \times \frac{\sin 330^\circ}{\sin 210^\circ}$$

$$\delta_2 = +2.887$$

$$\delta_2 = 2.9^\circ E$$

Example 3. If the deviation due to V.S.I is known to be $10^\circ W$, when the ship's head is $S 60^\circ W$ at a place where dip is $+30^\circ$, find the course upon which a deviation of $5^\circ W$ will appear due to the same cause, when dip is -60° .

$$\delta_1 = -10^\circ, \quad \text{co}_1 = 240^\circ, \quad \text{dip}_1 = +30^\circ$$

$$\delta_2 = -5^\circ, \quad \text{co}_2 = ?, \quad \text{dip}_2 = -60^\circ$$

$$\frac{\delta_2}{\delta_1} = \frac{\tan \text{dip}_2}{\tan \text{dip}_1} \times \frac{\sin \text{co}_2}{\sin \text{co}_1}$$

$$\frac{-5}{-10} = \frac{-\tan 60^\circ}{\tan 30^\circ} \times \frac{\sin \text{co}_2}{\sin 240^\circ}$$

$$\frac{1}{2} = \frac{-\tan 60^\circ}{\tan 30^\circ} \times \frac{\sin \text{co}_2}{\sin 240^\circ}$$

$$\Rightarrow \sin \text{co}_2 = \frac{1}{2} \times \frac{\tan 30^\circ}{-\tan 60^\circ} \times \sin 240^\circ$$

$$\text{co}_2 = 8.3^\circ$$

$$\text{New Course} = 008.3^\circ \text{ or } 171.7^\circ$$

Practice Exercise 1. (PB and iB) (Elementary)

1. The deviation due to V.S.I is known to be 5° E, with the vessel heading N 30° W at a place where dip is -60° . What will be the deviation due to the same cause when heading S 60° W, where dip is $+30^\circ$.

(Ans : 2.87° W)

2. A fore and aft magnet in the binnacle causes 5° E when heading 060° (c), where $H = 27$ A/m dip = 30° . Find the maximum deviation it causes, where $H = 24$ A/m, dip = -50° .

[Hint : Maximum deviation occurs, when the course is 90° or 270° (c)]

$$\text{Max. deviation} = +5 \times \frac{\sin 90}{\sin 60} = 5.8^\circ \text{ E on } 090^\circ \text{ (c) and } 5.8^\circ \text{ W on } 270^\circ \text{ (c)}$$

$$\frac{\text{Second place Max. deviation}}{5.8} = \frac{H_1}{H_2}$$

$$\frac{x}{5.8} = \frac{27}{24}$$

$$x = 6.52^\circ \text{ E on } 090^\circ \text{ (c) and } 6.52^\circ \text{ W on } 270^\circ \text{ (c).}$$

3. A flinders bar causes 5° E, when heading 060° (c), where $H = 27$ A/m, dip 30° . Find the maximum deviation it causes where $H = 24$ A/m, dip = -50° .

$$\frac{\delta_2}{\delta_1} = \frac{\sin \text{co}_2}{\sin \text{co}_1} \times \frac{\tan \text{dip}_2}{\tan \text{dip}_1}$$

$$\frac{\text{Max. deviation}}{+5} = \frac{\sin 90^\circ}{\sin 60^\circ} \times \frac{\tan \text{new dip}}{\tan \text{old dip}}$$

$$\text{Max } \delta \text{ on } 090^\circ \text{ (c)} = \frac{+5^\circ \times -\tan 50^\circ}{\sin 60^\circ \times \tan 30^\circ}$$

$$= -12^\circ \text{ i.e. } 12^\circ \text{ W on } 090^\circ \text{ (c) and } 12^\circ \text{ E on } 270^\circ \text{ (c)}$$

Note :- Easterly deviation has become Westerly, as hemispheres have changed.

TOTAL COEFFICIENT B

Total Coefficient B is obtained as $\frac{\delta \text{ on E} - \delta \text{ on W}}{2}$

Proof : (To be understood later, only after all the coefficients have been covered. However reproduced here for reference).

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

Deviation on North

$$\begin{aligned} &= A + B \sin 0^\circ + C \cos 0^\circ + D \sin 2(0^\circ) + E \cos 2(0^\circ) \\ &= A + C + E \quad \text{---- (1)} \end{aligned}$$

Deviation on NE

$$= A + B \sin 45^\circ + C \cos 45^\circ + D \sin (2 \times 45^\circ) + E \cos (2 \times 45^\circ)$$

$$= A + B \sin 45^\circ + C \cos 45^\circ + D \quad \text{---- (2)}$$

$$\text{Similarly Deviation on E} = A + B - E \quad \text{---- (3)}$$

$$\text{Deviation on SE} = A + B \sin 45^\circ - C \cos 45^\circ - D \quad \text{---- (4)}$$

$$\text{Deviation on S} = A - C + E \quad \text{---- (5)}$$

$$\text{Deviation on SW} = A - B \sin 45^\circ - C \cos 45^\circ + D \quad \text{---- (6)}$$

$$\text{Deviation on W} = A - B - E \quad \text{---- (7)}$$

$$\text{Deviation on NW} = A - B \sin 45^\circ + C \cos 45^\circ - D \quad \text{---- (8)}$$

From (3) and (7)

$$= \delta E - \delta W = (A + B - E) - (A - B - E) = 2B$$

$$\therefore B = \frac{\delta E - \delta W}{2}$$

$$\begin{aligned} \text{e.g. On East heading } \delta &= 10^\circ \text{ W} \\ \text{On West heading } \delta &= 6^\circ \text{ W} \end{aligned}$$

$$\text{Coefficient B} = \frac{(-)10 - (-6)}{2} = \frac{-10 + 6}{2} = \frac{-4}{2} = -2^\circ$$

$$\text{Coefficient B} = -2^\circ = 2^\circ \text{W}$$

Knowing total B at any location, there is no means of determining the individual values of PB and iB, the two components of total B. If it is necessary to obtain their separate values, we have to know the values of total B at two places with different H and Z values. It is then possible to obtain the values of PB and iB at both places, using simultaneous equations.

In practice, the correction of the compass is done at one place. Therefore after finding total B at that place, the adjuster uses an assessed value for iB and adjusts the flinders bar for correcting that value. An experienced compass adjuster is able to guess the iB value quite accurately by looking at the construction of the vessel and considering the location of the vertical S.I. on board and their proximity to the compass. The remaining amount of B is then considered as PB and corrected by horizontal, fore and aft permanent magnets. If the individual components of total B was correctly and separately corrected by flinders bar and F & A magnets, the correction will hold good for all places. However, if the correction of the separate components were not correct individually, the correction will not hold good for all places. Usually the compass adjusters are quite accurate.

If the vessel is on the magnetic equator, a better correction can be done, as all the existing deviation will be due to PB alone. Therefore it can be corrected by permanent magnets. This correction will hold good for PB at any place on any heading. Thereafter at any other place, if any deviation due to B is present, this will be totally due to iB and it can be corrected by using an appropriate amount of F/bar.

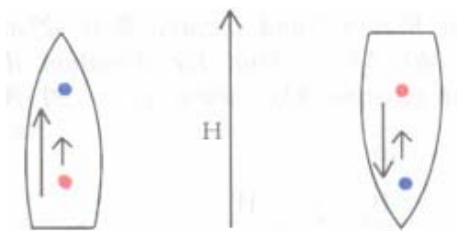
(Recapitulate)

- To split B into its components simultaneous equations are required for two places (two values of H and two values of Z)
- In practice, correction is done at one place. Experienced adjuster uses estimated value for iB and corrects - generally they are quite accurate.
- If the ship is at the magnetic equator - there is no iB , only PB is present - correct this with permanent magnets.

Thereafter, at any other place, whatever B is observed is due to iB alone as PB stands corrected.

EFFECT OF COEFFICIENT B ON DIRECTIVE FORCE

A F & A magnetic field at the compass due to the ship (combination of PB and iB), causes coefficient total B . If for example a vessel with $+B$ is swung on all headings, one will notice an increase in D/F , when heading North and loss in D/F when heading South. Conversely, a $-B$ will have the opposite effect. In other words, the D/F at the compass has a definite association with the sign of Coefficient B .



The field which causes Coefficient B causes an increase or decrease of DF when heading N as compared to that when heading S. (Correction of coefficient B, done by the **Deflector Method**, using comparison of D/F on N & S headings - will be dealt later).

It should be noted that the gain of D/F on certain headings is exactly balanced by the loss of D/F on the opposite headings (Refer sketches on PB and iB - Fig. 22 & 28). Therefore the fields which cause Coefficient 'B' have no effect on the **MEAN DF** at the compass position. The Mean D/F remains unaffected by Coefficient B.

(Recapitulate)

- Swing vessel with (+B) on all headings - notice increase in DF on N and decrease in DF on South and vice versa for (-B).
- D/F on N and S headings has a definite association with the sign of Coefficient B.
- Deflector method of compass correction uses this concept for the correction.
- Gain of D/F on certain headings is balanced by loss of DF on opposite headings. Therefore the Mean D/F remains unaffected.

Example 1. The following deviations were observed on an un-corrected compass. Calculate the value of coefficient B and the deviation due to coefficient B on a compass course of $330^{\circ}(c)$.

Hd by Compass	N	NE	E	SE	S	SW	W	NW
Deviation	6° W	$19\frac{1}{2}^{\circ}$ E	15° E	$1\frac{1}{2}^{\circ}$ W	4° E	$12\frac{1}{2}^{\circ}$ E	5° W	$22\frac{1}{2}^{\circ}$ W

$$\text{Coefficient B} = \frac{\delta E - \delta W}{2} = \frac{+15 - (-5)}{2} = \frac{15 + 5}{2} = +10^{\circ}$$

$$\text{Coefficient B} = + 10^{\circ}$$

$$\begin{aligned} \therefore \text{deviation due to B alone} &= B \sin \text{compass co.} \\ &= +10 \sin 330^{\circ} \\ &= -5^{\circ} \\ \text{Deviation} &= 5^{\circ} \text{ W} \end{aligned}$$

Example 2: Permanent B is +4° and induced B is -2° at a position (1), where H = 30 A/m and Z = 40 A/m. Find the deviation due to these coefficient when heading 250° (c) at position (2), where H = 20 A/m and Z = -30 A/m.

PB	iB
$\frac{PB_2}{PB_1} = \frac{H_1}{H_2}$	$\frac{iB_2}{iB_1} = \frac{Z_2}{Z_1} \times \frac{H_1}{H_2}$
$\frac{PB_2}{+4} = \frac{30}{20}$	$iB_2 = iB_1 \times \frac{Z_2}{Z_1} \times \frac{H_1}{H_2}$
$PB_2 = +4 \times \frac{30}{20}$	$iB_2 = -2 \times \frac{-30}{40} \times \frac{30}{20}$
$PB_2 = +6^\circ$	$iB_2 = +2.25^\circ$

$$\text{Coefficient B} = PB_2 + iB_2 = +8.25^\circ$$

$$\begin{aligned} \text{Deviation} &= B \sin \text{comp co} = 8.25^\circ \times \sin 250^\circ \\ &= 8.25 \times -0.9397 = -7.75^\circ \end{aligned}$$

$$\therefore \text{Deviation} = 7.75^\circ \text{ W}$$

Example 3: At a position A, on the magnetic equator, H = 30 A/m, the deviation on heading of 090° (c) was 4° W. At a position B, where (H = 20 A/m, dip +62°), the deviation on a heading of 090° (c) was 7° W. Find the value of PB and iB at the second position. Further, state how it should be corrected. (Assume Coefficients A, C, D & E are fully corrected)

The deviation on 090° (c) at magnetic equator indicates that PB = 4° W, since at the magnetic equator iB is zero, the coefficient is entirely due to PB.

$$\therefore PB_A = -4^\circ$$

To find PB at (B)

$$\begin{aligned} \frac{PB_B}{PB_A} &= \frac{H_A}{H_B} \\ \therefore PB_B &= -4 \times \frac{30}{20} = -6^\circ \end{aligned}$$

At position B, it is given that deviation is 7° W on 090° (c)

$$\therefore \text{Coefficient B i.e. total B} = -7^\circ$$

$$\text{but PB} = -6^\circ$$

$$\therefore iB = -1^\circ$$

(Correction:

- 1) PB of -6° indicates red pole for'd. With the ship heading East or West by compass, place F&A magnets, blue ends forward to correct 6° .
- 2) iB of -1° . In the Northern hemisphere the V.S.I will acquire blue pole at top. Since we have an iB of -1° , it indicates that the blue pole is aft of compass. With the ship heading East or West, place Flinders bar for'd of the compass to remove 1° deviation.

Example 4. At a place where $H = 40$ A/m and $Z = 20$ A/m, total B of $+3^\circ$ was observed. This was fully compensated by a F&A magnet in the binnacle. If induced B at that place was -3° , what deviation due to B is to be expected when heading 210° (c) at a second place, where $H = 15$ A/m and $Z = -30$ A/m.

Total B = PB and iB.

$$\begin{aligned} \text{At 1, Total B} &= +3^\circ \\ \text{induced B} &= -3^\circ \\ \therefore \text{PB of ship} &= +6^\circ \end{aligned}$$

Magnet corrected $+3^\circ$ i.e. magnet caused -3°

$\therefore$ Total PB of ship and magnet, after correction, since magnet is still there = $+6^\circ - 3^\circ = +3^\circ$

$$\text{PB (ship + magnet)} = +3^\circ \quad \text{iB} = -3^\circ$$

$$\begin{aligned} \frac{\text{PB}_2}{\text{PB}_1} &= \frac{H_1}{H_2} = \frac{40}{15} & \frac{\text{iB}_2}{\text{iB}_1} &= \frac{Z_2}{Z_1} \frac{H_1}{H_2} \\ \frac{x}{+3} &= \frac{40}{15} & \frac{x}{-3} &= \frac{-30}{20} \times \frac{40}{15} \\ x &= +3 \times \frac{40}{15} = 8^\circ & x &= +12^\circ \end{aligned}$$

$$\text{At 2, PB (ship + magnet)} = +8^\circ \quad \text{iB} = +12^\circ$$

$$\text{PB} = +8^\circ$$

$$\text{iB} = +12^\circ$$

$$\text{B} = +20^\circ$$

$$\begin{aligned} \text{Deviation} &= B \sin 210^\circ = 20^\circ \sin 210^\circ = -10^\circ \\ &= 10^\circ \text{ W} \end{aligned}$$

IMPORTANT NOTE

- 1) When working problems on splitting of B, C or Heeling Error, where permanent and induced components are present, it is best to start work with the **position**, where the **separate components** are required.
- 2) This rule **does not** hold good if one of the positions given is on the Magnetic Equator. In that case we start with the position on the Magnetic Equator.
- 3) In problems involving **correction** of compass, find PB and iB and PC and iC of ship alone.
- 4) In case the problem requires **adjustment or readjustment** of the **correctors**, we have to find PB, iB, PC, iC of ship and corrector together

Example 5:

Place L	H = 24 A/m	Z = 0,	deviation on East 2° W
M	H = 20 A/m	Z = 36 A/m,	deviation on East 1° E
N	H = 10 A/m	Z = -40 A/m,	find deviation on 090° (c)

Using the given data at L and M, we can obtain the separate values of PB and iB at M. We can then find their values at N.

Place L is at Magnetic Equator, as $Z = 0$.

∴ Deviation 2° W at L on 090° (c) indicates, there is a -B and it is entirely due to PB alone.

Hence PB at L = -2°

$$\frac{PB_M}{PB_L} = \frac{H_L}{H_M}$$

$$\frac{PB_M}{-2} = \frac{24}{20}$$

$$PB_M = -2 \times \frac{24}{20} = -2.4^\circ$$

Total B at M = +1°

$$PB_M = -2.4^\circ$$

$$\therefore iB_M = +3.4^\circ$$

To find PB and iB at N

$$\frac{PB_N}{PB_M} = \frac{H_M}{H_N}; \quad \frac{iB_N}{iB_M} = \frac{Z_N}{Z_M} \times \frac{H_M}{H_N};$$

$$\frac{PB_N}{-2.4} = \frac{20}{10} \times \frac{2}{1} \quad \frac{iB_N}{+3.4} = \frac{-40}{60} \times \frac{20}{10}$$

$$PB_N = -4.8^0 \quad iB_N = -7.55^0$$

$$PB_N = -4.8^0$$

$$iB_N = -7.55^0$$

$$\text{Total } B_N = -12.35^0$$

$$\text{Deviation due to B at N on } 090^0 \text{ (c)}$$

$$= 12.35^0 \text{ W}$$

Example 6. At a position (1), where $H = 30 \text{ A/m}$, $\text{dip} = 55^0$, a total coefficient B of $+5^0$ was observed with no correctors in place. At position (2), where $H = 25 \text{ A/m}$, $\text{dip} = -64^0$ a total coefficient B of $+1.5^0$ was observed. What correction should be made at the second place with permanent magnets and what corrections should be made by means of F.Bar at place (2).

In this question, we have to split B into its two components, using simultaneous equations.

[Recall, since components are required at place (2), we should start our work from place (2)]

	H	DIP	B
(1).	30	55^0	$+5^0$
(2).	25	-64^0	$+1.5^0$

$\therefore$ Let x = PB at 2nd place.
and y = iB at 2nd place.

$$\text{Then } x + y = +1.5 \quad \text{----- (1)}$$

To find PB at position (1)

$$\frac{PB_1}{PB_2} = \frac{H_2}{H_1}; PB_1 = \frac{PB_2 \times H_2}{H_1} = \frac{x \times 25}{30} = \frac{5x}{6} = .83x$$

To find iB at position (1)

$$\frac{iB_1}{iB_2} = \frac{\tan \text{dip}_1}{\tan \text{dip}_2} = \frac{iB_1}{y} = \frac{\tan 55^0}{-\tan 64^0}$$

$$iB_1 = y \times \frac{\tan 55^\circ}{-\tan 64^\circ} = -0.7y$$

$$.83x - .7y = +5.00 \quad \text{----- (2)}$$

$$.83x + .83y = +1.24 \quad \text{----- (3) (multiplying equation(1) by 0.83)}$$

$$-1.53y = 3.76$$

$$y = \frac{-3.76}{1.53} = -2.46$$

$$y = -2.46$$

Substituting the value of y in equation (1)

$$x - 2.46 = 1.5$$

$$x = 1.5 + 2.46 = 3.96$$

$$PB \text{ at } (2) = +3.96^\circ$$

$$iB \text{ at } (2) = -2.46^\circ$$



Head the ship E or W and place F&A magnets Red end For'd to correct 3.96° and place flinders bar abaft the compass to correct 2.46° .

(iB is -ve = - 2.46). Since dip is -ve, ship is in the Southern hemisphere, the V.S.I will have red pole at top. Since, there is -ve iB $\Rightarrow$ red pole has to be ford of the compass. In other words there is predominance of V.S.I for'd of the compass. Correction - place V.S.I aft of compass.

Example 7. At place P ($H = 15$ A/m; $Z = 30$ A/m), deviation on 090° (c) = 12° W. This is allowed to remain un-corrected. At a place Q ($H = 22$ A/m, $Z = 15$ A/m), deviation on 090° (c) was 4° W. The compass was still not corrected. Find the deviation at a place R ($H = 20$ A/m, $Z = -25$ A/m), when heading 090° (c).

Given the value of B at P & Q, we first obtain the individual values of PB and iB at one of the places, P or Q, by simultaneous equations. We can then find their individual values at R.

	H	Z	B
P	15 A/m	+30 A/m	-12
Q	22 A/m	+15 A/m	-4
R	20 A/m	-25 A/m	?

Let PB at Q = x

and iB at Q = y

$$\text{Then, } x + y = -4^0 \quad \text{--- (1)}$$

At P:-

PB

iB

$$\frac{PB_P}{PB_Q} = \frac{H_Q}{H_P}, \quad PB_P = \frac{x \times 22}{15}$$

$$\therefore \frac{iB_P}{iB_Q} = \frac{Z_P}{Z_Q} \times \frac{H_Q}{H_P}$$

$$PB_P = 1.46x$$

$$\therefore iB_P = y \times \frac{30}{15} \times \frac{22}{15}$$

$$iB_P = 2.93y$$

$$\text{At P, } 1.46x + 2.93y = -12.0$$

$$1.46x + 1.46y = -5.84 \quad (\text{multiplying equation (1) by 1.46})$$

$$1.47y = -6.16$$

$$y = -4.19$$

Substituting y in equation (1)

$$x - 4.19 = -4$$

$$x = +0.19$$

$$x = \text{PB at Q} = +0.19^0$$

$$y = \text{iB at Q} = -4.19^0$$

$$\frac{PB_R}{PB_Q} = \frac{H_Q}{H_R}$$

$$\frac{iB_R}{iB_Q} = \frac{Z_R}{Z_Q} \times \frac{H_Q}{H_R}$$

$$PB_R = \frac{+0.19 \times 22}{20} = +0.21$$

$$iB_R = -4.19 \times \frac{-25}{15} \times \frac{22}{20}$$

$$PB_R = +0.21$$

$$iB_R = +7.68$$

$$\text{Total B} = +0.21 + 7.68$$

$$B = +7.89$$

So deviation at R on 090^0 (c) will be 7.89^0 E.

CORRECTORS IN PLACE

Example 8: At a place P ($H = 28$ A/m, $\text{dip} = 30^\circ$), coefficient B was observed to be $+1^\circ$ and was left uncorrected. On the magnetic equator ($H = 30$ A/m), B was found to be $+4^\circ$ and was corrected by F&A magnets. What Coefficient B may be expected at place Q ($H = 10$ A/m, $\text{dip} -60^\circ$) and how should it be corrected?

Since one of the places is on the magnetic equator, we start work from the magnetic equator.

Given, at Magnetic equator B is $+4^\circ \Rightarrow PB = +4^\circ$ (Blue pole of ship is for'd). It was corrected by F&A magnet. (i.e. red end of magnet was placed ford)

To find value of PB at P.

$$\frac{PB_p}{PB_{Eq}} = \frac{H_{Eq}}{H_p}; PB_p = +4 \times \frac{30}{28} = +4.3^\circ$$

$$\therefore PB \text{ at } P = +4.3^\circ$$

$$\text{Total } B \text{ at } P = +1^\circ$$

$$\therefore \text{Induced } B \text{ at } P = -3.3^\circ$$

(Since PB was fully corrected by the magnet at the magnetic equator, both PB of ship and magnet will change in the same manner, and once corrected like with like, it will remain corrected. In other words, at Q, coefficient B will be only due to iB as PB will be zero).

$$\frac{iB_Q}{iB_p} = \frac{\tan \text{dip}_Q}{\tan \text{dip}_p} = \frac{-\tan 60^\circ}{\tan 30^\circ}$$

$$iB_Q = \frac{-3.3 \times -\tan 60^\circ}{\tan 30^\circ} = \frac{-3.3 \times -1.7321}{1.5774} = +9.89^\circ$$

$$= 9.9^\circ \text{ E}$$

Since ship is in Southern hemisphere, the effective top pole will be red. Since $iB = +9.9^\circ$, it implies that there is predominance of V.S.I aft of compass, therefore F/B should be placed for'd of compass to correct $+9.9^\circ$ with the ship heading East or West.

Example 9 : At A ($H = 36$ A/m, $Z = 18$ A/m), a flinders bar forward of the compass corrects 2° , the remaining coefficient B, viz 5° , is corrected by fore and aft magnets, red end forward, leaving no deviation on any course. At B ($H = 24$ A/m, $Z = -30$ A/m), with the F & A magnet removed, coefficient B = $+2^\circ$. How should the compass have been corrected at A?

When comparing deviations at two places, it is essential that they are compared in the same condition. At place B, we are given the value of total B without the magnets. Therefore we must compare it with total B at place A also, without the magnets. Since the magnets were placed red ends for'd at place A they caused -5^0 , leaving no deviations. With the magnets removed, Coefficient B would have been $+5^0$. We can now solve for PB and iB at place A with only flinders bar in position.

	H	Z	B	
A	36	18	$+5^0$	(with flinders bar and no magnets)
B	24	-30	$+2^0$	(with flinders bar and no magnets)

Since we want corrections at A, start from A.

Let $PB_A = x$

iB_A with flinders bar = y

Then $x + y = +5^0$ ----- (1)

$$\frac{PB_B}{PB_A} = \frac{H_A}{H_B} = \frac{36}{24}$$

$$PB_B = x \times \frac{36}{24} = 1.5x$$

$$\frac{iB_B}{iB_A} = \frac{Z_B}{Z_A} \times \frac{H_A}{H_B}$$

$$iB_B = y \times \frac{-30}{18} \times \frac{36}{24}$$

$$iB_B = -2.5y$$

(of ship and flinders bar)

$$\begin{array}{rcl} 1.5x - 2.5y & = & +2.0 \quad \text{----- (2)} \\ 1.5x + 1.5y & = & +7.5 \quad \text{----- (1) \times 1.5} \\ \hline -4y & = & -5.5 \\ y & = & 1.36 \end{array}$$

Since y is iB of ship and flinders bar and as flinders bar for'd in Northern hemisphere causes $+2^0$, iB of ship alone = -0.64^0

Substituting y in equation (1), $x + 1.36^0 = 5^0$
 $x = 3.64^0$ (PB of ship)

At A, F&A magnets should have been placed red end for'd to correct 3.64^0 and flinders bar should have been placed ford to correct 0.64^0 .

Example 10. At place (1), where $H = 20 \text{ A/m}$, $Z = 40 \text{ A/m}$, a ship's compass is corrected and zero deviation obtained with Flinders Bar forward of the compass and fore and aft magnets inserted in the binnacle with red ends forward. At place (2), where $H = 30 \text{ A/m}$, $Z = 20 \text{ A/m}$, a coefficient B of $+2.5^\circ$ was observed. How should the correctors be readjusted at the second place?

Also state what would be the value of coefficient B at place (3), where $H = 20 \text{ A/m}$, $Z = -25 \text{ A/m}$, if the correctors were not readjusted.

(Since the adjustments required are at place (2), we must start from that place. As we are required to adjust the correctors we should find the value of PB of ship and magnet together and iB of ship and flinders bar together. As can be seen, the value of coefficient 'B' at place (1) with these correctors is nil and at place (2) total $B = +2.5^\circ$. Both values are with the correctors in place.

	H	Z	B (with correctors)
1	20	40	0°
2	30	20	$+2.5^\circ$
3	20	-25	?

Let PB of ship and magnet at place (2) = x

and iB of ship and Flinders bar at place (2) = y

$$\therefore x + y = +2.5^\circ \quad \text{----- (1)}$$

$$\frac{PB_1 \text{ (ship and corrector)}}{PB_2 \text{ (ship and corrector)}} = \frac{H_2}{H_1} ; \frac{PB_1}{x} = \frac{30}{20} ; PB_1 = \frac{30x}{20} = 1.5x$$

$$\frac{iB_1 \text{ (ship and corrector)}}{iB_2 \text{ (ship and corrector)}} = \frac{Z_1}{Z_2} \times \frac{H_2}{H_1} = \frac{40}{20} \times \frac{30}{20} ; iB_1 = 3y$$

$$1.5x + 3y = 0$$

$$\frac{1.5x + 1.5y = 3.75}{1.5y = -3.75} \quad \text{(multiplying equation (1) by 1.5)}$$

$$y = -2.5^\circ = iB \text{ of ship and flinders bar}$$

$$\text{Since } x - 2.5^\circ = +2.5^\circ$$

$$\therefore x = 5^\circ = \text{PB of ship and magnet.}$$

Since PB of ship and corrector is $+5^\circ$ at place (2), it means that it was not corrected properly at place (1).

The F&A magnets were placed red ends fore causing -PB, but despite their causing -PB, the residual PB is still +5° which means they are under correcting. Therefore raise the magnets closer to the card or insert more F&A magnets, red ends fore, to remove a further 5°.

$$y = -2.5^\circ$$

Ship is in North hemisphere. The effective top pole of V.S.I is blue. The flinders bar fore is therefore causing +iB. Despite this, the iB of ship and flinders bar together is -2.5°. Therefore the flinders bar is under compensating. The length of the flinders bar should therefore be increased to cause an additional correction of 2.5°.

The second part of the question is quite independent.

$$\frac{PB_3(\text{ship and corrector})}{PB_2(\text{ship and corrector})} = \frac{H_2}{H_3}; \quad \frac{x}{+5} = \frac{30}{20} \quad \therefore x = +7.5^\circ$$

$$\therefore PB_3 = +7.5^\circ$$

$$\frac{iB_3(\text{ship and corrector})}{iB_2(\text{ship and corrector})} = \frac{Z_3}{Z_2} \times \frac{H_2}{H_3}; \quad \frac{iB_3}{-2.5} = \frac{-25}{20} \times \frac{30}{20}$$

$$iB_3 = +4.7^\circ$$

$$\begin{aligned} \text{Total B (with correctors in place) at place (3)} \\ = 7.5^\circ + 4.7^\circ = +12.2^\circ \text{ E} \end{aligned}$$

Example 11: A vessel's compass was adjusted off River Clyde ($H = 12 \text{ A/m}$, $\text{dip} = 70^\circ$), the fore and aft magnets being placed with their red ends aft, and the F/B situated fore of the compass. On completion of adjustment no deviation was observed on any heading. Subsequently when off River Plate ($H = 28 \text{ A/m}$, $\text{dip} = -30^\circ$), the deviation on East was observed to be 5° E and on West it was 3° W . How should the correctors be readjusted to effect proper compensation of coefficient B at River Plate.

It is clear that the compass was not properly corrected at Clyde, otherwise the deviations would have remained nil at River Plate also.

Since adjustment is required at River Plate, we commence from here.

$$\begin{aligned} \text{Coefficient B at R. Plate} &= \frac{\delta E - \delta W}{2} = \frac{+5 - (-3)}{2} = \frac{+8}{2} \\ &= +4^\circ \end{aligned}$$

$$\begin{aligned} \text{Let PB (ship and corrector) at Plate} &= x^\circ \\ \text{and iB (ship and F/B) at Plate} &= y^\circ \\ x + y &= +4^\circ \end{aligned}$$

$$\frac{PB_{\text{clyde}} (\text{ship and magnet})}{PB_{\text{plate}} (\text{ship and magnet})} = \frac{H_{\text{plate}}}{H_{\text{clyde}}}$$

$$PB_{\text{clyde}} = x \times \frac{28}{12} = 2.3x \quad \text{----- (1)}$$

$$\frac{iB_{\text{clyde}} (\text{ship and F/B})}{iB_{\text{plate}} (\text{ship and F/B})} = \frac{\tan \text{dip}_{(\text{clyde})}}{\tan \text{dip}_{(\text{plate})}} = \frac{\tan 70^\circ}{-\tan 30^\circ} = \frac{2.747}{-.577} = -4.76$$

$$iB_{\text{clyde}} = -4.76y$$

$$2.3x - 4.76y = 0 \quad \text{----- (2)}$$

$$2.3x + 2.3y = 9.2 \quad (\text{multiplying equation (1) by 2.3})$$

$$-7.06y = -9.2$$

$$y = +1.3$$

$$x + 1.3^\circ = +4^\circ$$

$$x = 4 - 1.3 = 2.7^\circ(+) \quad (\text{PB of ship and magnet at Plate})$$

The corrector magnets are blue ends ford, i.e. they are causing +B. Since residual PB is +ve, they are over-correcting. Therefore lower the magnets in the binnacle or reduce the number of magnets to reduce the correction provided by them by 2.7° .

Residual iB = $+1.3^\circ$. Ship is in Southern latitude, the effective top pole of Flinders bar is red. The flinders bar for'd is causing -iB. Since value of iB is +ve, the flinders bar is under correcting. Therefore increase the length of the flinders bar to remove 1.3° of deviation.

Example 12: When adjusting compass off River Tyne, $H = 17 \text{ A/m}$, Dip 70° , coefficient B was found to be -7° . This was corrected by placing 300 mm of F/B ford of compass to remove 5° deviation and F&A magnets red ends aft 350 mm from the compass. The vessel was swung and no deviations were found on any heading. Later, when off Durban $H = 14 \text{ A/m}$, dip = -65° , deviation on East was 6° E and on West was 4° W . How would you correctly compensate PB and iB at Durban? Also state through what distance the magnets are to be shifted to achieve the above.

Ship at Tyne had a total B = -7°

Since F/B was placed forward (off R. Tyne in the N. hemisphere) to remove 5° deviation, it caused $+5^\circ$ (as blue pole of F/B would be for'd of compass)

$$iB \text{ of Flinders bar} = +5^\circ$$

The remaining -2^0 , was assumed to be due to -PB of 2^0 , which was corrected by F&A magnets blue ends for'd.

$$\text{PB of magnet} = +2^0$$

At Durban:

$$\text{Coefficient B with correctors in position} = \frac{\delta E - \delta W}{2} = \frac{6 - (-4)}{2} = \frac{10}{2} = +5^0$$

	H	DIP	B	
T	17	70^0	0^0	(with correctors)
D	14	-65^0	$+5^0$	(with correctors)

$$\text{At D, Let PB (ship and magnet)} = x^0$$

$$\text{and Let iB (ship and Flinders bar)} = y^0$$

$$\therefore x + y = +5^0 \quad \text{----- (1)}$$

$$\frac{\text{PB (ship and magnet)}_{\text{Tyne}}}{\text{PB (ship and magnet)}_{\text{Durban}}} = \frac{H_{\text{Durban}}}{H_{\text{Tyne}}}$$

$$\therefore \text{PB (ship and magnet)}_{\text{Tyne}} = x \times \frac{14}{17} = 0.82x$$

$$\frac{\text{iB (ship and F / B)}_{\text{Tyne}}}{\text{iB (ship and F / B)}_{\text{Durban}}} = \frac{\tan \text{dip}_{\text{Tyne}}}{\tan \text{dip}_{\text{Durban}}} = \frac{\tan 70^0}{-\tan 65^0}$$

$$\therefore \text{iB (ship and F / B)}_{\text{Tyne}} = y \times \frac{\tan 70^0}{-\tan 65^0} = -1.28y$$

$$0.82x - 1.28y = 0 \quad \text{----- (2)}$$

$$\frac{0.82x + .82y = 4.1}{- 2.10y = -4.1} \quad (\text{multiplying equation (1) by } 0.82)$$

$$y = +1.95^0 \quad (\text{iB of ship and flinders bar at D})$$

$$\text{Since } x + y = +5^0 \quad \text{----- (1)}$$

$$x = 3.05^0 \quad (\text{PB of ship and magnet at D})$$

$$\text{PB ship and corrector (Durban)} = +3.05^0$$

$$\text{iB ship and corrector (Durban)} = +1.95^0$$

We can now find the values of PB and iB of correctors alone at Durban.

Since we are required to correct the PB and iB, we must know, the values of PB and iB of the ship alone. What we have obtained are their values with the correctors. We will therefore now find the values of the correctors

alone at D and hence obtain the ships PB and iB.

$$\frac{\text{PB (magnet)}_{\text{Durban}}}{\text{PB (magnet)}_{\text{Tyne}}} = \frac{H_{\text{Tyne}}}{H_{\text{Durban}}} = \frac{\text{PB}_{\text{magnet}}}{2} = \frac{17}{14}$$

$$\therefore \text{PB (magnet)}_{\text{Durban}} = 2 \times \frac{17}{14} = 2.42^0$$

PB of magnet alone = +2.42⁰
(at Durban)

$$\frac{\text{iB of FB}_{\text{Durban}}}{\text{iB of FB}_{\text{Tyne}}} = \frac{\tan \text{dip}_{\text{Durban}}}{\tan \text{dip}_{\text{Tyne}}} = \frac{-\tan 65^0}{+\tan 70^0} = -.78$$

$$\text{iB (FB)}_{\text{Durban}} = +5 \times -.78 = -3.9^0$$

$\therefore$ iB of F/B alone = -3.9⁰
(at Durban)

PB of ship with magnet = +3.05⁰

PB of magnet at Durban = +2.42⁰

PB of ship alone at Durban = +0.63⁰

The magnet should cause -0.63⁰, but it is causing +2.42⁰. It should be reversed and if we reverse it at the same distance it will cause -2.42⁰. Therefore we have to reverse them as well as move them away.

Since the deviation caused by a magnet $\propto \frac{1}{\text{dist}^3}$

$$\frac{\text{dev}_1}{\text{dev}_2} = \frac{d_2^3}{d_1^3}$$

$$\frac{2.42}{0.63} = \frac{d_2^3}{350^3}$$

$$d_2^3 = 350^3 \times \frac{2.42}{.63}$$

$$d_2 = 350 \times \sqrt[3]{\frac{2.42}{.63}}$$

$$d_2 = 548\text{mm.}$$

The magnets should be reversed and shifted away (down) by 198 mm.

iB of ship and F/B = +1.95⁰

iB of F/B alone = -3.90⁰

iB of ship alone = +5.85⁰

F/B should cause -5.85⁰ and not -3.9⁰, it's length should be increased, as it is under compensating.

Example 13: During compass adjustment at a place, where $H = 18 \text{ A/m}$, $Z = 43 \text{ A/m}$ a vessel was found to have a Coefficient B of $+8^\circ$. This was corrected by placing an estimated length of FB fore of the compass to correct 4° and the residual B was corrected by fore and aft magnets. On the magnetic equator, where $H = 28 \text{ A/m}$, a Coefficient B of -3° was found to be present, which was corrected by adjusting the permanent magnets, and no deviation was found on E/W courses. What deviation may be expected when heading 246° (c) at a place where $H = 18 \text{ A/m}$, $Z = -57 \text{ A/m}$.

	H	Z	B	
(1)	18	43	+8	corrected with flinders bar causing 4° and F&A magnets
(2)	28	0	-3	corrected by adjusting magnet.
(3)	18	-57	δ	on 246° (c) ?

At magnetic equator PB of ship and magnet = -3°
(since no iB at equator)

$$\frac{\text{PB of ship and magnet place}_{(1)}}{\text{PB of ship and magnet at equator}} = \frac{\text{PB}_{(1)}}{-3} = \frac{28}{18}$$

$$\Rightarrow \text{PB}_{(1)} = -3 \times \frac{28}{18} = -4.66^\circ$$

Total B of ship and correctors at (1) = 0.0

PB of ship and magnet at (1) = -4.66°

$\therefore$ iB of ship and F/B at (1) = $+4.66^\circ$

At magnetic equator, since Coefficient B was fully corrected by adjusting magnets, it means that PB of ship has been fully corrected at magnetic equator, because at magnetic equator only PB appears. This correction will hold good for all latitudes as like has been corrected with like. Therefore any B appearing thereafter will be entirely due to iB.

$\therefore$ At place (3), only iB of ship and F/B will cause any deviation.

$$\frac{iB_3}{iB_1} = \frac{Z_3}{Z_1} \times \frac{H_1}{H_3}$$

$$iB_3 \text{ of ship and flinders bar} = +4.66 \times \frac{-57}{43} \times \frac{18}{18} = -6.2^\circ$$

Deviation on 246° (c) = B sin co.

$$= -6.2 \times \sin 246^\circ = +5.6^\circ = 5.6^\circ \text{ E}$$

Example 14: On a ship at place A in the N. hemisphere, the deviation of a well cited compass was $6^{\circ}W$ when heading $090^{\circ}(c)$. This was corrected by flinders bar placed forward of the compass correcting 4° , the remainder being corrected by F & A magnets.

Later, at place B in the S. hemisphere, the deviation when heading $090^{\circ}(c)$ was $6^{\circ}E$ with the correctors in the same position. On removing the magnets alone the deviation altered by 2.5° , and on removing the flinders bar alone it altered by 4° . The correctors were then replaced as before.

What alterations are necessary to the correctors to correctly compensate coefficient B at place B ?

$$\frac{\text{Effect of magnet at A}}{\text{Effect of magnet at B}} = \frac{2}{2.5} = \frac{H_B}{H_A}$$

$$\text{Similarly, } \frac{\text{Effect of F/B at A}}{\text{Effect of F/B at B}} = \frac{4}{4} = \frac{\tan \text{ dip at A (+)}}{\tan \text{ dip at B (-)}}$$

$$\text{Therefore, } \tan \text{ dip at A} = \tan \text{ dip at B}$$

$$(+ve, \text{ as N. Hemisphere}) \quad (-ve, \text{ as S. Hemisphere})$$

$$\text{At B, let PB (ship \& magnet) = } x$$

$$\& \text{ iB (ship \& F/B) = } y$$

$$\text{Then } x + y = + 6 \quad \dots\dots\dots(1)$$

$$\text{At A, PB (ship \& magnet) = } x \times \frac{H_B}{H_A} = x \times \frac{2}{2.5} = 0.8x$$

$$\text{iB (ship \& F / B) = } y \times \frac{\tan \text{ dip}_A}{\tan \text{ dip}_B} = y \times \frac{1}{-1} = -y$$

$$\therefore 0.8x - y = 0 \quad \dots\dots\dots(2)$$

$$0.8x + 0.8y = + 4.8 \quad \dots\dots\dots(1) \times 0.8$$

$$\hline -1.8y = -4.8$$

$$y = + 2.67$$

$$x + 2.67 = +6$$

$$x = +3.33$$

When heading East or West (compass), since the magnets are causing $+2.5^{\circ}$, reverse them and place them lower to correct 0.83° . Since F/B is causing negative effect, increase their length to increase the correction by 2.67° .

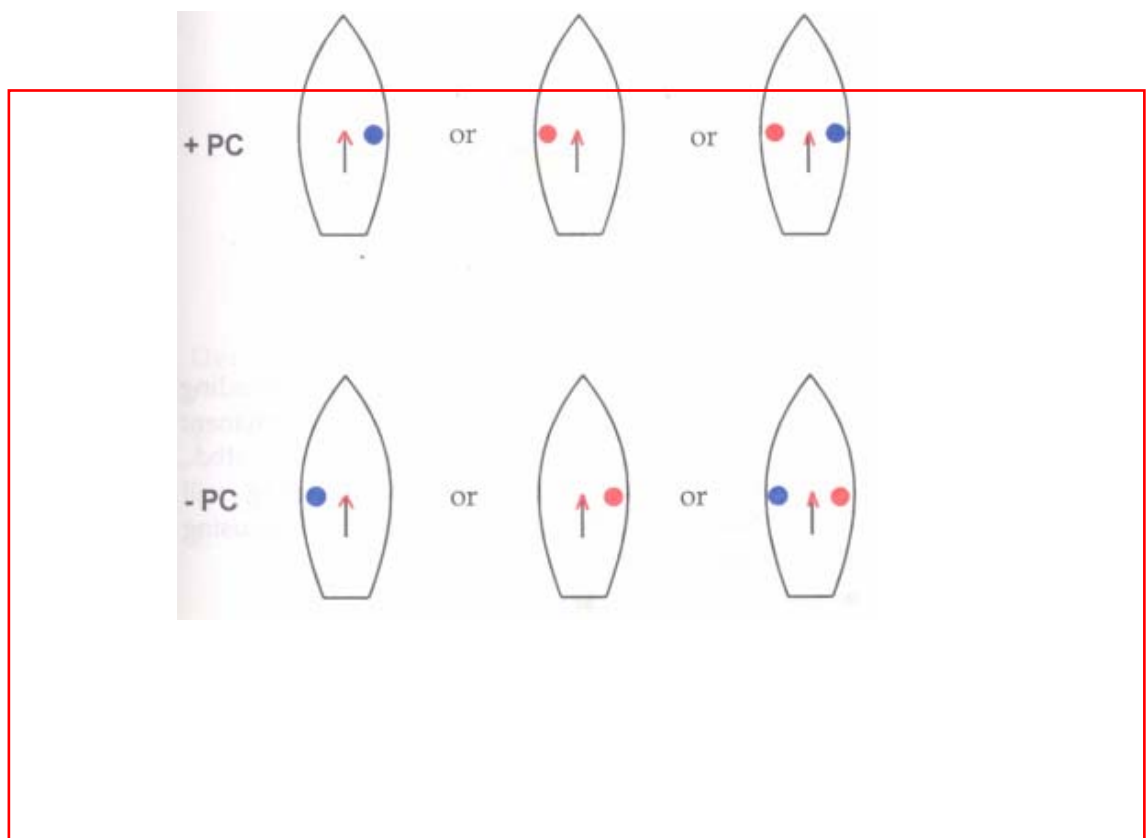
CHAPTER 6

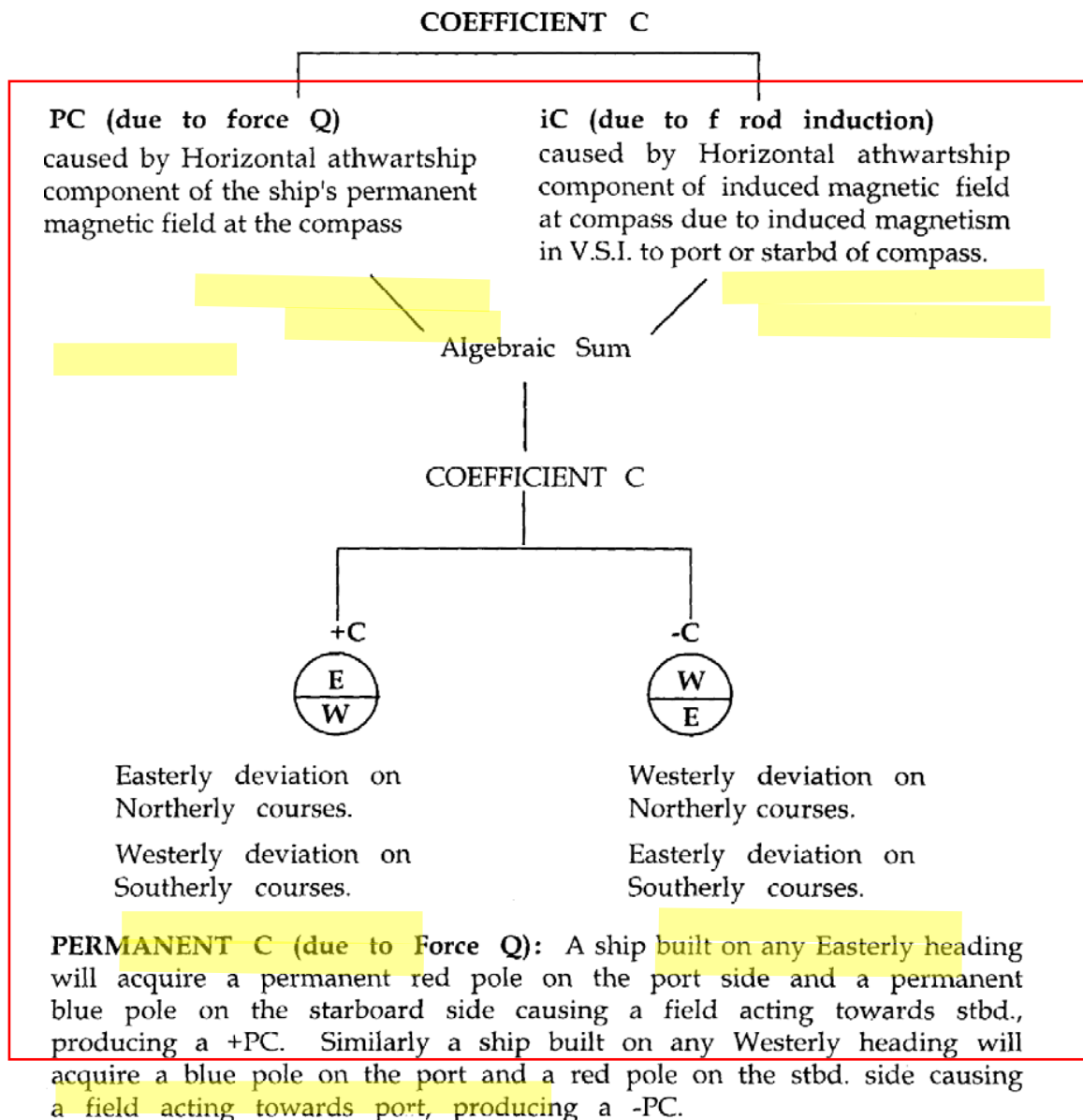
COEFFICIENT C

DEFINITION: Coefficient C is the maximum value of the semi-circular deviation which varies as the cosine of the compass co. and is caused by the horizontal athwartship component of the ship's magnetic field at the compass position. Coefficient C is the algebraic sum of Permanent C and induced C.

A +C is caused if the horizontal athwartship field at the compass acts towards starboard and a -C is caused if that field acts towards port.

There are therefore the following possibilities:-





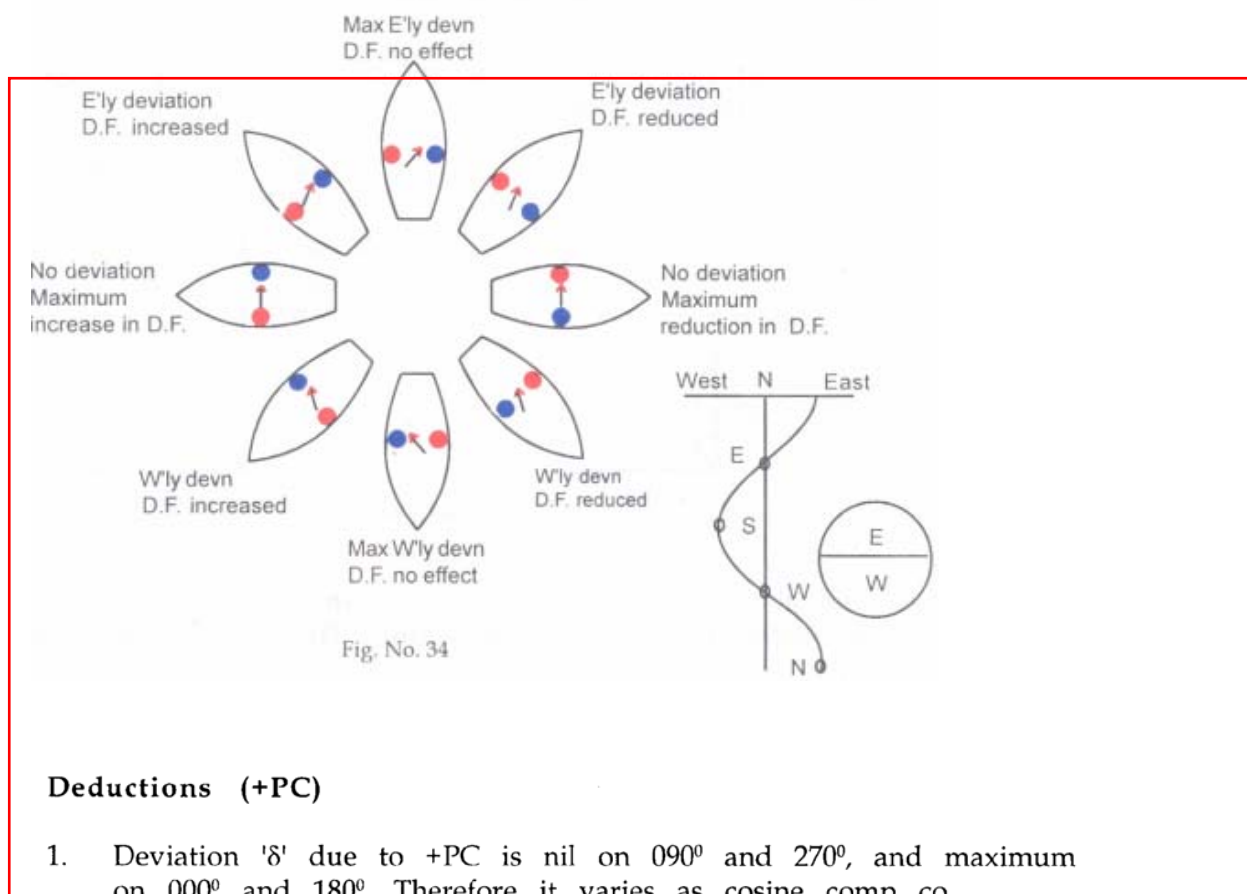
Recall the force causing PC (i.e. force Q) is constant. The value of this force does not change either with latitude or ship's head, but the deviation due to this force, changes with latitude and course.

(PC Recapitulate)

- Ship built on easterly heading, acquires a red pole on port side and blue pole on the starboard side (in any hemisphere), causing +PC

- Ship built on westerly heading, acquires a blue pole on port side and red pole on the starbd. side (in any hemisphere), causing -PC
- Force (Q) is constant but the deviation it causes varies with latitude and comp. co.

Change in deviation due to PC with change of course:



Deductions (+PC)

1. Deviation ' δ ' due to +PC is nil on 090° and 270° , and maximum on 000° and 180° . Therefore it varies as cosine comp co.
2. D.F (field at compass acting towards magnetic North) is decreased on all easterly headings. Maximum reduction on East. DF increases on all Westerly headings, maximum increase on W.
3. Maximum change in DF occurs on headings where ' δ ' is nil and maximum ' δ ' occurs where change in DF is nil.
4. Equal and opposite changes in DF occurs on opposite compass headings. Therefore Mean directive force for all headings remains unchanged.

(The above point no. 3 is very necessary in understanding the Deflector method correction of compass, later on.)

The student should now be able to draw a figure with the ship heading on the eight cardinal and intercardinal headings and establish that with a -PC also the deviation varies as the cosine of the comp co and also establish that the change in DF is exactly the reverse of the change with a +PC.

Effect of change in latitude : We know ' δ ' due to PC is maximum when heading $000^\circ/180^\circ$ by compass as the deviating force then acts at right angles to the compass needle.

We know that the force causing PC or Force (Q) is constant, but the value of H changes with latitude.

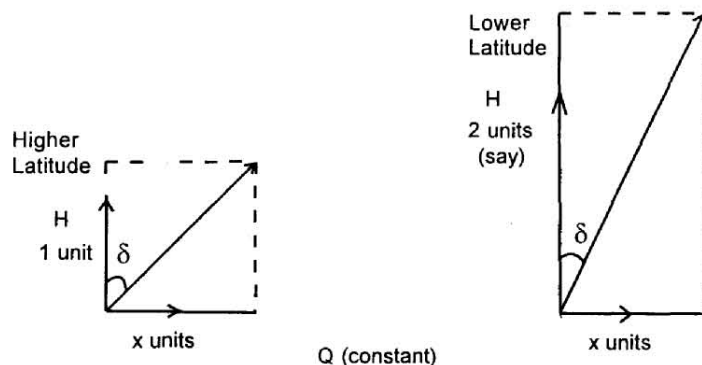


Fig. No. 35

From the above figures it can be seen that when H is large, the δ is small and when H is small, the δ is large. Therefore δ varies inversely as H
i.e. δ due to PC $\propto \frac{1}{H}$

Change of Course: We also know that δ due to PC varies directly as cosine compass co.

$$\Rightarrow \delta \propto \text{cosine comp. co.}$$

$$\therefore \frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\cos \text{comp co}_2}{\cos \text{comp co}_1}$$

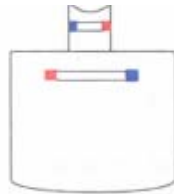
Also at any one place :-

$$\text{Deviation due to PC} = \text{PC} \times \text{cosine comp co}$$

Correction : The basic principle followed generally is to cure *like with like*. The purpose being to ensure that correction done holds good for all latitudes and all courses. The logic being that both PC and its correction should vary in the same manner so that we do not have to carry out fresh corrections frequently.

Athwartship Corrector Magnets (to correct force Q)

Similar magnets as used for PB i.e. 8" long, 3/8" or 3/16" dia, situated not nearer than twice their own length from the needle system, are placed with their axis athwartship and horizontal, below the compass card so as to produce a permanent athwartship magnetic field equal to but opposite in direction to the ship's magnetic field. Once the athwartship permanent field of the ship has been nullified by the permanent field of the magnet, the cause of coefficient PC has been eliminated i.e. PC has been corrected. This correction is made when heading N or S, the headings on which PC produces maximum deviation.



Example: If deviation due to PC = 8° W, when heading 000° at position (1), where H = 15 A/m, find deviation due to PC, at a place where H = 25 A/m, when on a course of 120°.

$$PC = 8^\circ \text{ W on } 000^\circ$$

$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\cos \text{comp } \phi_2}{\cos \text{comp } \phi_1}$$

$$\frac{\delta_2}{-8} = \frac{15}{25} \times \frac{\cos 120}{\cos 000}$$

$$\delta_2 = -8 \times \frac{15}{25} \times \frac{\cos 120}{\cos 000}$$

$$= +2.4^\circ$$

$$\therefore \delta \text{ due to PC} = 2.4^\circ \text{ E}$$

INDUCED C

Induced C is caused by a horizontal athwartship magnetic field at the compass due to induced magnetism in the Vertical Soft Iron to port or starboard of the compass. In other words it is due to 'f' rod.

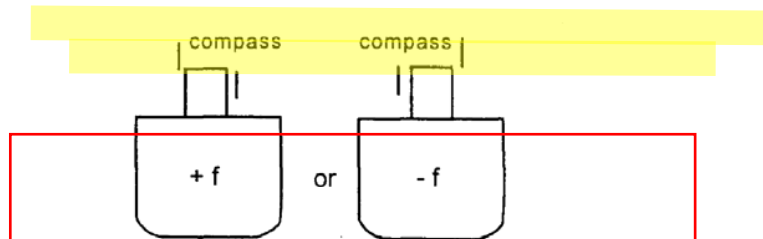
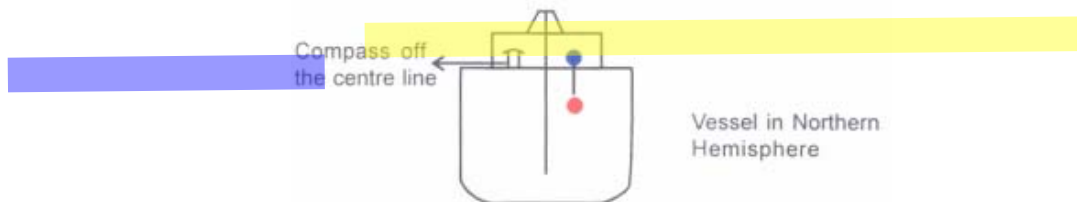


Fig. No. 36

In practice induced C does not exist at a well placed compass on a merchant ship, since the V.S.I to P and S of the ship's centre line is usually symmetrically placed (e.g. ventilators, samson posts etc.).

An iC may exist if the compass is placed off the centre line of the vessel e.g. Aircraft Carriers.



+ iC

Devn. Max Easterly
No change in DF

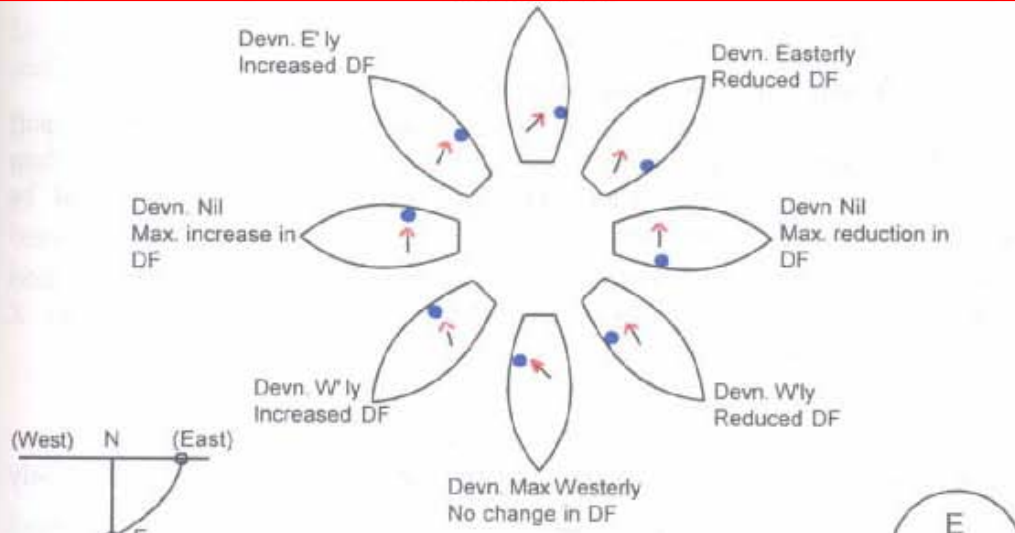
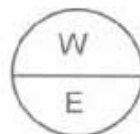
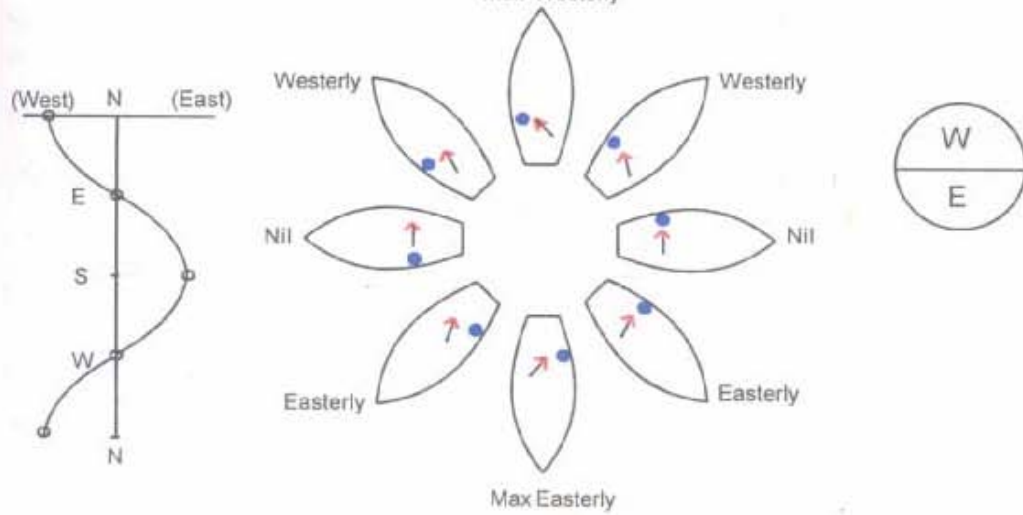


Fig. No. 38



- iC

Max Westerly



Effect of Course on deviation due to iC:

Since iC δ is nil on E and W courses, and maximum, but of opposite names on N and S courses, it varies directly as cosine comp. co.

$$\delta \text{ due to iC} \propto \cos. \text{ comp. co.}$$

Effect of Latitude on deviation due to iC:

The same ship will acquire no induced magnetism in her vertical soft iron at the magnetic equator, as the inducing force Z is nil, therefore iC will be zero. In the Southern Hemisphere, the same V.S.I. will be induced with red pole on top producing a -iC.

Since induction in vertical soft iron is due to Z, as Z increases, the induction and therefore the deviating force and deviation would increase. As Z decreases, the deviation would decrease. Therefore,

$$\delta \text{ due to iC} \propto Z.$$

If the deviating force remains unchanged, the deviation would vary inversely as H, as in the case of PC. Therefore deviation due to iC $\propto \frac{1}{H}$

Since deviation due to iC $\propto Z$ and $\propto \frac{1}{H}$

Deviation due to iC $\propto \frac{Z}{H}$ i.e. $\propto \tan \text{ dip}$.

$$\frac{\delta_2}{\delta_1} = \frac{Z_2}{Z_1} \times \frac{H_1}{H_2} \times \frac{\cos co_2}{\cos co_1}$$

$$\text{Also } \frac{\delta_2}{\delta_1} = \frac{\tan \text{ dip}_2}{\tan \text{ dip}_1} \times \frac{\cos co_2}{\cos co_1}$$

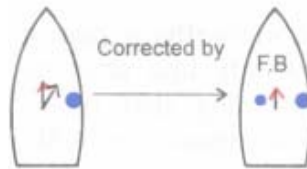
(Recapitulate +iC)

1. Deviation due to iC, Max but of opposite names on 000° and 180°.
2. Deviation due to iC, NIL on 090° and 270°.
3. Deviation due to iC $\propto \cos \text{ comp co}$.
4. DF increased on all Westerly headings.
5. DF reduced on all Easterly headings.
6. DF maximum on W and minimum on E.
7. On N/S, there is no change in DF.
8. Mean DF for all headings is unchanged as increase on various headings is balanced by a equal decrease on opposite headings.
9. Deviation due to iC $\propto Z$, $\propto \frac{1}{H}$ i.e $\propto \tan \text{ dip}$.

Correction of Induced C:

In a normal ship with a well placed compass, there is no iC , and as such, a correction is not required.

If the compass is badly placed, there may be an induced C present at the compass position. It should be corrected using the same principle as for induced B. Depending on the predominance of the ship's V.S.I. being to stbd. or port of the compass, the Flinders bar should be placed to port or stbd. of the binnacle, respectively.



Example 1 : In the Southern Hemisphere iC was $+2^\circ$, where should the FB be placed ?

In Southern Hemisphere, the effective top pole of any V.S.I. will be red. Since iC is $+2^\circ$, the red pole is to the port. Therefore there is predominance of V.S.I. to the port of the compass. The F/B should be placed on the starboard side.

Example 2 : In the Northern Hemisphere iC is $+5^\circ$, where should the F.Bar be placed ?

In Northern Hemisphere, the effective top pole of any V.S.I. will be blue. Since we have $+5^\circ$, the V.S.I. is predominant to starboard. Therefore to correct it, place the F/B to port of the compass.

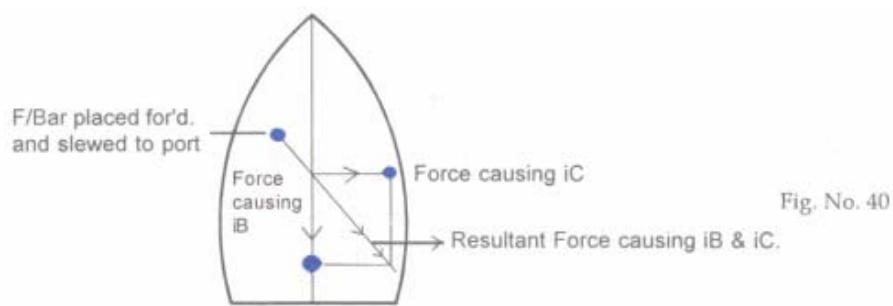
Normally a ship would definitely have an iB . If an iC is also present, they may be corrected by placing two flinders bars one in the F&A line i.e. fore or abaft to correct iB and the other in the athwartship line i.e. port or starboard of the compass to correct iC . In such a case it is more convenient to use one F/B to correct both iB and iC together. Generally iB is greater than iC . The flinders bar is therefore placed fore or abaft the compass as necessary to correct iB alone and then *slewed* from fore and aft line to port or starboard.

CORRECTING i_B & i_C TOGETHER (SLEWING OF FLINDERS BAR)

The following important considerations are to be borne in mind before correcting i_B and i_C together.

- (i) Hemisphere the V/L is in.
- (ii) The angle through which the single F.bar is to be slewed from F&A line.
- (iii) How much correction is required for the combined effect of i_B and i_C ?
- (iv) The Headings on which the correction should be made.

Let us imagine the ship to be in northern hemisphere. The effective poles of V.S.I both in the fore and aft line causing i_B and athwartship line causing i_C will be blue. Assuming that there is predominance of V.S.I abaft and to starboard of the compass, we will have two blue poles, one to starboard and one aft of compass due to ship's V.S.I.



As can be seen, the resultant of the forces causing i_B and i_C will act in a direction towards the starboard quarter. To nullify this resultant force, we need to place the F/B forward and to port, which will create a field opposite to that of the ship and both i_B and i_C will be corrected.

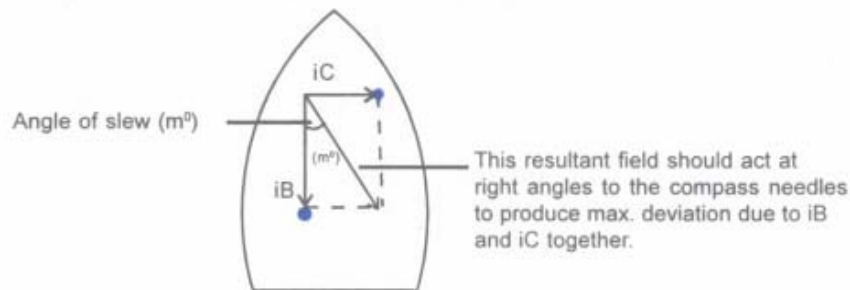
For the resultant to cause maximum deviation, the resultant should act at 90° to the needle.

The resultant of the two fields acts in a direction with respect to F&A center line such that the tangent of the angle from F&A line = $\frac{i_C}{i_B}$

The flinders bar should be placed on the opposite side of the compass slewed at an angle from F&A line such that tan angle of slew from F&A centre line = $\frac{i_C}{i_B}$

From the figure:

$$\text{Tan angle of slew from F\& A centre line} = \text{induced C} / \text{induced B}$$



Since deviations are proportional to the deviating forces, in the above figure, the field causing iB may be considered the value of iB and the field causing iC considered as the value of iC . If so, since iB and iC are the maximum deviations produced by them respectively, the maximum deviation produced by iB and iC together can be obtained as $\sqrt{iB^2 + iC^2}$

Since coefficients are always corrected on the heading on which they produce maximum deviations, it is now necessary to also find the headings on which the combination of iB and iC together will produce the maximum deviation so that the combined correction of iB and iC together can be affected by a single flinders bar on that heading.

Any deviating force produces a maximum deviation when that force acts at right angles to the compass needle. With the ship heading N (compass), in the above figure, the resultant field acts in a direction m° on the stbd-quarter i.e. m° to the axis of the compass needles. For the resultant field to act at right angles to the compass needles, the ship must swing $(90-m)^\circ$ to port when the field will act in a direction E (c). Therefore one of the headings on which the combined field will produce maximum deviation and therefore the heading on which this combined correction can be made is N $(90-m)^\circ$ W. If the ship swings 180° from that heading the resultant field will act exactly W (c), again producing maximum deviation, that is on S $(90-m)^\circ$ E.

The headings on which the combined correction is to be done is easily obtained by drawing a sketch of the ship heading N with the forces causing iB and iC and hence the resultant force causing the combined effect. Then obtain the angle of slew, m° as $\text{tan angle of slew} = iC/iB$. Thereafter, obtain one of the headings when the resultant force acts E or W compass. The other heading is obtained as this heading $\pm 180^\circ$.

Procedure to determine: Angle of Slew, the compass headings on which to carry out the combined correction and the **deviation** to be corrected on any of those headings by a single flinders bar.

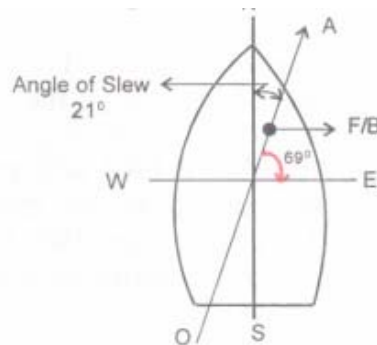
- (i) Determine whether F/B is to be placed forward or abaft the compass depending on the sign of iB and the hemisphere the vessel is in. The latter will decide the colour of the effective pole.
- (ii) Direction of slew can be decided by investigating the signs of iB and iC .
- (iii) If iB and iC are of the same name slew clockwise from the position found earlier.
If iB and iC are of opposite names slew anticlockwise.
- (iv) After determining the angle of **slew** and its placement, the ship should head in a direction such that the resultant of iB and iC forces is at right angles to the deflected needle, i.e. diagonal of the parallelogram in the figure should be E - W by compass to give maximum deviation.

The following method is pretty useful in determining the head on which the combined correction should be done:-

Place the ship initially heading N and draw N/S line and E/W line. Place the F/B at an angle of slew (already determined). For the purpose of illustration let angle of slew be 21° to starboard of F/A line from forward.

For the maximum deviation to occur OA line should coincide with the E/W line. For this force to act towards East, the OA line should rotate $90 - 21 = 69^\circ$ to right.

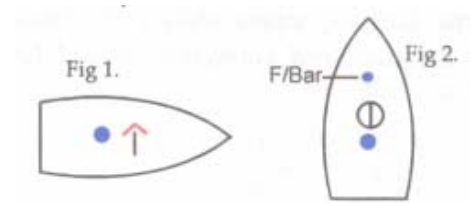
Therefore the vessel's head should turn to right by 69° or the vessel head should be $N 69^\circ E$ or $069^\circ (c)$. If the vessel turns through 180° from that direction, i.e. on a heading $249^\circ (c)$, that force will act towards W, causing max. deviation again. N



Therefore the combined correction can be made on $069^\circ (c)$ or $249^\circ (c)$.

- (v) As explained earlier, the deviation to be corrected on those headings, by the single flinders bar is the maximum deviation produced by iB and iC together, that is $\sqrt{iB^2 + iC^2}$.

Example 1: In northern hemisphere, $iB = -3$ and $iC = +2$ where should the F/B be placed?



In northern hemisphere the effective, top pole of any V.S.I is blue. Since $iB = -3^\circ$ (negative) effective blue pole must be aft. Figure (1). Therefore F/B should be initially placed ford.

Since iB and iC are of opposite names, slew the Flinders Bar anticlockwise.

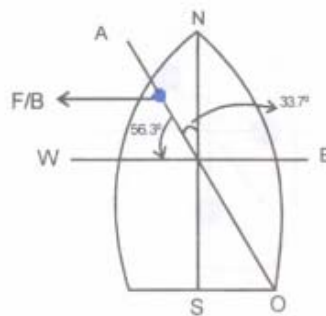
$$\tan m^\circ = \frac{2}{3} \quad \therefore m = 33.7^\circ$$

$\therefore$ **slew F/B** 33.7° to port from ford. (anti clockwise from F&A line).

Alternatively : Since iC is present, V.S.I is either to port or starbd, effective pole is blue, since vessel is in northern hemisphere and sign of iC is +ve. It indicates that the blue pole is to starbd. Therefore the Flinders Bar has to be port side.



Therefore the F/B should be slewed to port from ford



OA line should rotate $90 - 33.7 = 56.3$ to left

Ship's heading should be 56.3 to left of N. Therefore vessel must head N 56.3 W or S 56.3 E

Example 2 : If it is found that induced B = - 5° and induced C = - 2.5° at a place in north magnetic latitude, where should the Flinders bar be placed. State the headings on which the combined correction should be made and the deviation to be corrected on those headings.

$$\tan \text{ angle of slew} = \frac{iC}{iB} = \frac{2.5^\circ}{5^\circ} = \frac{1}{2}$$

$$\text{Angle of slew} = 26.5^\circ$$

$$\text{maximum deviation} = \sqrt{5^2 + 2.5^2} = 5.6^\circ$$

northern hemisphere $\Rightarrow$ blue pole effective

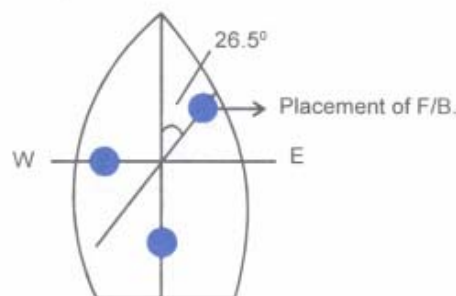
$iB = -5^\circ \Rightarrow$ Predominance of V.S.I. aft. of compass.

Place Flinders Bar fwd

$iC = -2.5^\circ \Rightarrow$ Predominance of V.S.I is to port.



F/B should be slewed to starboard from fwd.



Also, since iB and iC are of same sign, slew clockwise (slew to stbd from fwd).

Head should be N 63.5° E or S 63.5° W to correct 5.6° of deviation.

In practice, the brass case of the FB will be attached to the binacle at an angle of 26.5° to stbd. of for'd. direction. The ship is then headed 063.5° or 243.5° (c) and sufficient length of FB placed to correct 5.6° of deviation.

Example 3: On a ship in northern hemisphere with a F/B slewed 15° to port of F&A line from ford correcting for a maximum deviation of 6° , no deviation appears due to iB and iC on any course. Find values of and signs of induced B and induced C.

$$\tan m^\circ = \tan 15^\circ = \frac{\text{induced C}}{\text{induced B}} = .27$$

$$\text{Also } 6^\circ = \sqrt{\text{induced B}^2 + \text{induced C}^2}$$

$$iC = 0.27 \ iB.$$

$$\therefore 6 = \sqrt{iB^2 + (0.27iB)^2}$$

$$36 = iB^2 + .073 \ iB^2 = 1.073 \ iB^2$$

$$iB^2 = \frac{36}{1.073} = 33.55$$

$$iB = -5.8^\circ$$

$$36 = 33.55 + iC^2$$

$$iC = +1.6^\circ$$

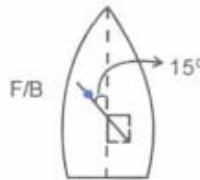
OR

$$iB = \max \delta \times \cos m^\circ$$

$$= 6 \times \cos 15 = -5.8^\circ$$

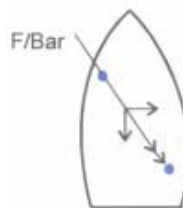
$$iC = \max \delta \times \sin m^\circ$$

$$= 6 \times \sin 15^\circ = +1.6^\circ$$



To determine sign

F/B to port of F & A line from ford means resultant of iB and iC acts towards starboard quarter



Since northern hemisphere, blue pole effective, hence blue is to starboard and aft.

$$\begin{aligned} \therefore \Rightarrow \quad iB &= -ve \\ iC &= +ve \\ iB &= -5.8^\circ \\ iC &= +1.6^\circ \end{aligned}$$

Example 4: In North latitude a F/B is ford and slewed $26\frac{1}{2}^{\circ}$ to port causing maximum deviation of 9° . What deviation will it cause on 000° C and 090° C.

$$\tan 26.5^{\circ} = 0.5$$

$$\frac{iC}{iB} = 0.5$$

$$iC = \frac{iB}{2}$$

$$9^{\circ} = \sqrt{iB^2 + \left(\frac{iB}{2}\right)^2}$$

$$= \sqrt{iB^2 + \frac{iB^2}{4}} ; \sqrt{\frac{5 iB^2}{4}} = 9^{\circ}$$

$$\frac{5iB^2}{4} = 81^{\circ}$$

$$iB^2 = \frac{324}{5} = 64.2$$

$$iB = 8^{\circ}$$

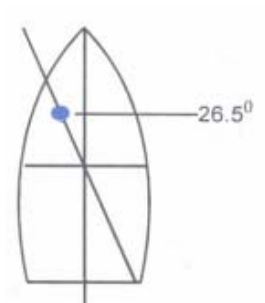
$$iC = 4^{\circ}$$

$$iB = \max \delta \cdot \cos m^{\circ}$$

$$= 9 \cdot \cos 26\frac{1}{2}^{\circ} = 8^{\circ}$$

$$iC = \max \delta \times \sin m^{\circ}$$

$$= 9 \cdot \sin 26\frac{1}{2}^{\circ} = 4^{\circ}$$



F/B is causing -iC

F/B is causing +iB.

$$\therefore iB \text{ of F/B} = +8^{\circ}$$

$$iC \text{ of F/B} = -4^{\circ}$$

$$\text{Deviation on } 090^{\circ} = +8 \sin 090^{\circ} - 4 \cos 090^{\circ} = +8^{\circ} \text{ or } 8^{\circ} \text{ E.}$$

$$\text{Deviation on } 000^{\circ} = +8 \sin 000^{\circ} - 4 \cos 000^{\circ} = -4^{\circ} \text{ or } 4^{\circ} \text{ W.}$$

CHARTER 7

HARD IRON DEVIATION

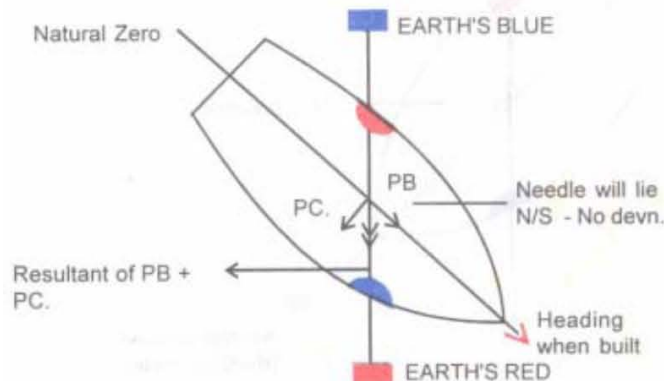
**Combination of
Permanent B and Permanent C
due to FORCE 'O'
HARD IRON
SHIP'S HEAD WHEN BUILT; NATURAL ZERO DIRECTION
NEUTRAL COURSES**

Recall force O is the resultant of forces P and Q or in other words, the resultant of the permanent magnetic field causing PB and PC. The combined deviation due to PB and PC together is known as Hard iron deviation.

A ship built heading North/South will acquire only PB and no PC will be present. Such a ship when heading North or South will have no deviation, because the permanent magnetic field of the ship due to H.I. lies along the compass N/S and hence no deviation is caused. Obviously such a vessel will have maximum deviation, when heading 90° to the right or left of this direction. i.e. 090° and 270° in this case.

Similarly a ship built heading E/W will acquire only PC and no PB will be present. Such a ship will have no deviation due to H.I. when heading E/W and maximum deviation when heading N/S.

A ship built on any other heading will acquire both PB and PC. In the building yard, the ship lies in one direction for a long period and therefore acquires permanent magnetism. The position and character (colour) of the permanent poles acquired by the H.I. will depend on the heading on which the ship was built. This heading is known as '*ship's head when building*'. The heading 180° away from ship's head when building is known as the "*Natural Zero direction*". These two directions together are called the "*Neutral Courses*".



Whenever the ship heads on any of the Neutral Courses, force 'O' (resultant of PB and PC) acts in the direction of the magnetic meridian and there will be no Hard Iron deviation. On these two headings, the total H.I. deviation (due to PB and PC together) is nil.

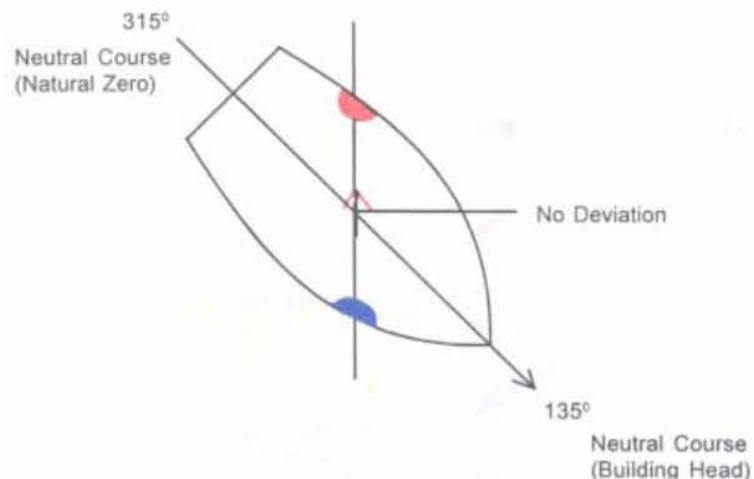
When heading on the neutral courses, the fields due to PB and PC together act exactly N or S (M), and there is no deviating force present. The H.I. deviation will be nil. There are two such Neutral Courses:

1. ship head when being built.
2. 180° away from the above heading, (Natural Zero).

(Recapitulate)

- Ship built heading N or S acquires PB only - no H.I. deviation when heading N/S.
- Ship built heading E or W acquires PC only - no H.I. deviation when heading E/W.
- Ship built on any other head will acquire both PC and PB (see fig no. 43). Together they will produce nil deviation when on the Neutral Courses, as the resultant of PB and PC lies along the Magnetic meridian.
- If given that deviation due to H. Iron is nil on a particular heading, two possibilities arise. That heading could either be:-
 - i) ship heading when built
 - or
 - ii) ship heading 180° from the above heading (Natural Zero)

It is worthwhile studying the pattern (i.e. types of deviation) that will be produced due to PB and PC together, if the ship is swung round 360° , starting from ship's head when building. Imagine ship built heading 135° .



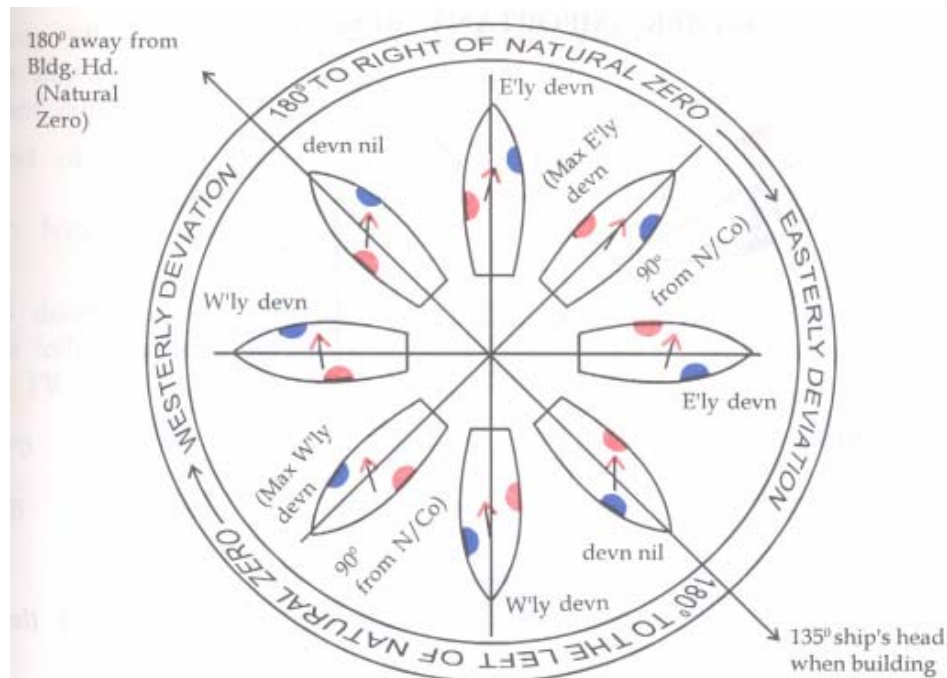


Fig. No. 45

Students should verify the result, by choosing any other ship's head when building and swinging the ship through 360°.

Results

1. Westerly deviation occurs on all courses 180° to the **LEFT** of Natural Zero.
2. Easterly deviation occurs on all courses 180° to the **RIGHT** of Natural Zero.
3. Maximum deviation occurs when heading 90° to right or left of the Neutral Courses.
4. No deviation on Neutral Courses.

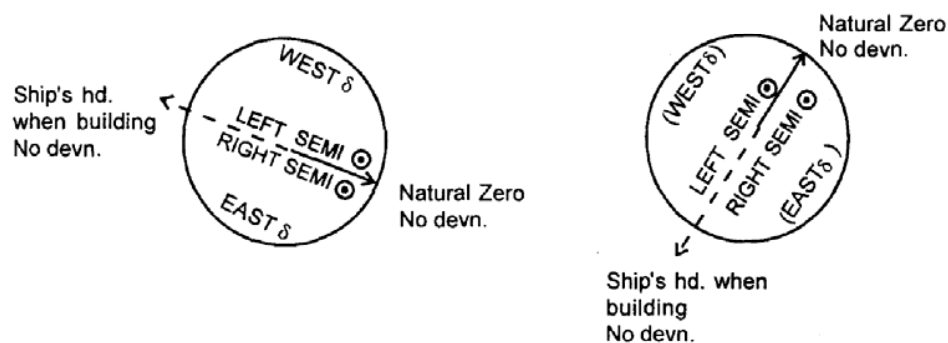
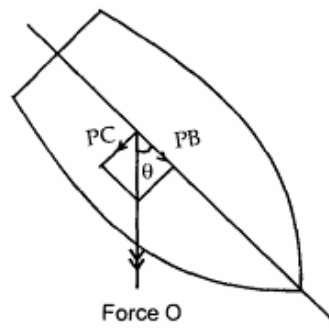
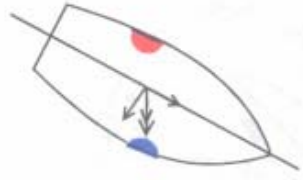


Fig. No. 46

The above results are very important when solving problems on H.I. deviation.

OTHER IMPORTANT RESULTS



$$\text{Max H.I. deviation} = \sqrt{PB^2 + PC^2}$$

From figure,

1. $\tan \theta = \frac{PC}{PB}$, where θ = Neutral Co. (Angle of Neutral Co. from the meridian)
2. Maximum H.I. $\delta = \sqrt{PB^2 + PC^2}$
3. On Natural Zero heading and reciprocal course, H.I. δ is nil. Maximum H.I. δ occurs when heading 90° away from Natural Zero direction and its reciprocal.

Therefore deviation due to H.I. $\propto \sin$ angle of ship's hd. from Natural Zero.

Hard Iron deviation on any heading = maximum deviation due to H.I. $\times \sin \angle$ of ship's head from Natural Zero.

We know from previous work that PB and PC both vary inversely as H, it follows that their resultant will also vary inversely as H, and therefore the deviation due to H.I. (combined deviation due to PB and PC) also varies in the same manner.

$$\text{Hard Iron deviation} \propto \frac{1}{H}$$

Force 'O', is constant, but the deviation due to 'O' changes with latitude and ship's head.

Therefore combining the effect of latitude and ship's head on H.I. δ , consider two places (1) and (2), we get

$$4. \frac{\text{Hard Iron } \delta_2}{\text{Hard Iron } \delta_1} = \frac{H_1}{H_2} \times \frac{\sin \angle_2 \text{ of ship head from Natural Zero}}{\sin \angle_1 \text{ of ship head from Natural Zero}}$$

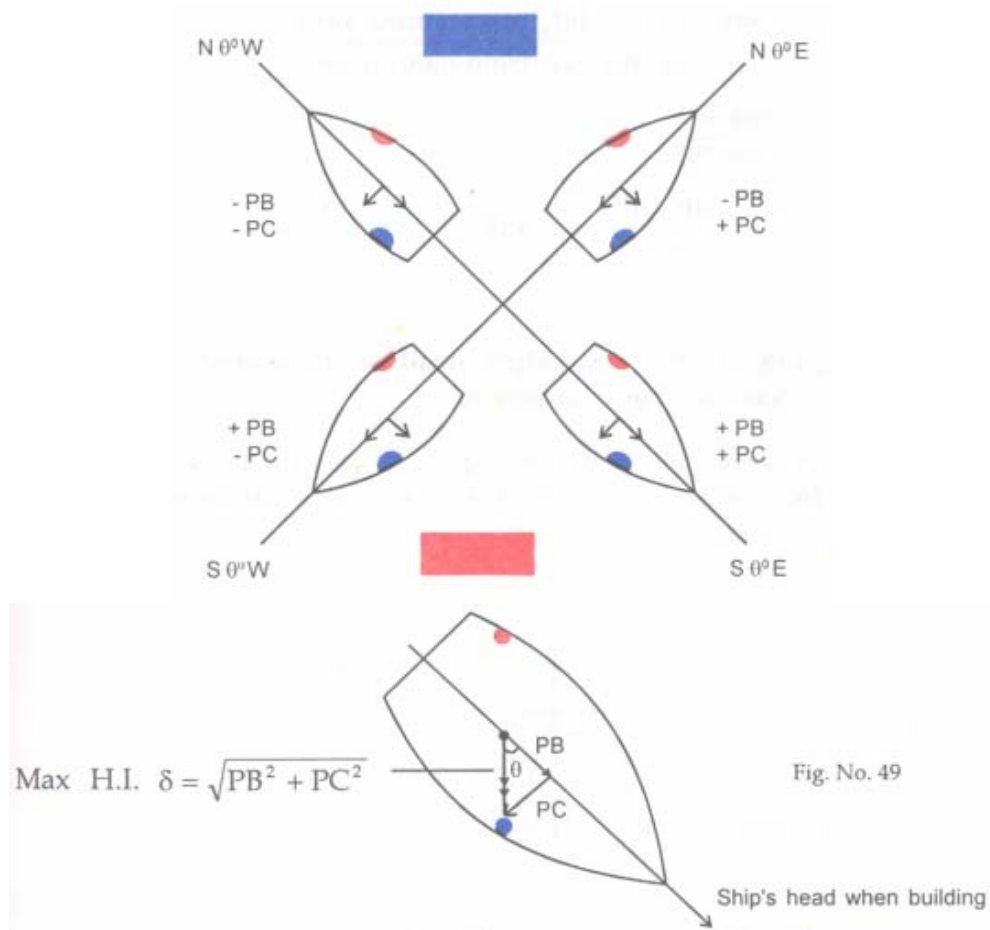
Given PB and PC , to determine the natural zero of a vessel, we first determine the ship's head when building. Natural zero is 180° away from ship's head when building.

First obtain the angle of the ship's head when building as:-

$$\tan \text{ Neutral Course} = \frac{PC}{PB}$$

To determine the quadrant in which the ship was heading when built, the following may be recalled from what you learned regarding the signing of PB and PC and ship's head when building.

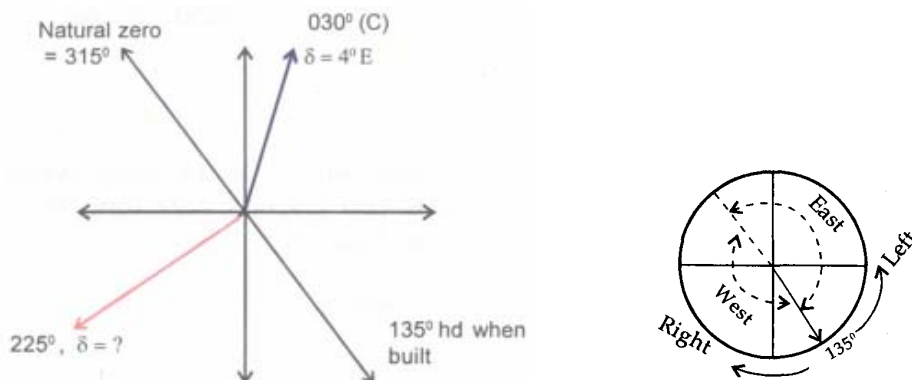
$+PB$	Southerly	$+PC$	Easterly
$-PB$	Northerly	$-PC$	Westerly.



$$PB = \text{Max H.I. } \delta \cos \text{ neutral co.}$$

$$PC = \text{Max H.I. } \delta \sin \text{ neutral co.}$$

Example 1: A vessel built on heading 135° has a hard iron deviation of 4° E, when heading 030° (c) at a place where $H = 10$ A/m. What hard iron deviation could be expected when heading 225° , where $H = 8$ A/m.



$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\sin \angle \text{ of ship hd}_2 \text{ from natural zero}}{\sin \angle \text{ of ship hd}_1 \text{ from natural zero}}$$

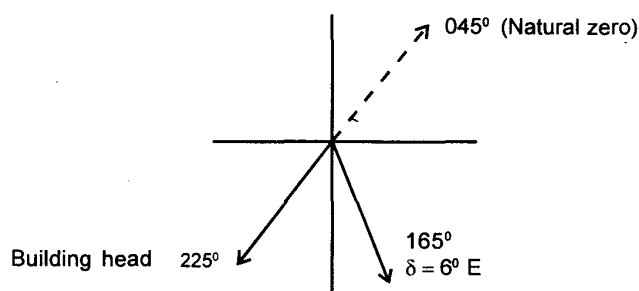
$$\frac{\delta_2}{+4} = \frac{10}{8} \times \frac{\sin 270^\circ}{\sin 75^\circ}$$

$$\delta_2 = +4 \times \frac{10}{8} \times \frac{\sin 270^\circ}{\sin 75^\circ} = -5.18^\circ$$

$$\delta_2 = 5.18^\circ \text{ W}$$

* The angles of each ship's head is measured clockwise from Natural Zero direction.

Example 2: A vessel built on heading 225° has a H.I. deviation of 6° E, when heading 165° , where $H = 10$ A/m. On what headings will the hard iron δ be 6° W, where $H = 7$ A/m.



$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\sin \angle \text{ of ship hd}_2 \text{ from natural zero}}{\sin \angle \text{ of ship hd}_1 \text{ from natural zero}}$$

$$\frac{6}{6} = \frac{10}{7} \times \frac{\sin \theta}{\sin 120^\circ} = \frac{10}{7} \times \frac{\sin \theta}{.866}$$

$$\begin{aligned}\sin \theta &= \frac{1 \times 7 \times .866}{10} \\ &= \frac{6.062}{10} = .606 \\ \theta &= 37.3^\circ\end{aligned}$$

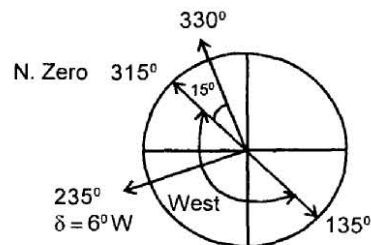
Since $\sin \theta = \sin (180 - \theta)$, there are two possibilities. Therefore, this angle can be from either of the neutral courses. Since deviation should be west, the course has to be to the left of natural zero and are

$$\begin{array}{rcl} 225 + 37.3 & = & 262.3^\circ \\ 045 - 37.3 & = & 007.7^\circ \end{array}$$

Example 3: The deviation due to hard iron on a course of 135° is nil, where $H = 12$ A/m. On a course of 235° at the same place, hard iron deviation = 6° W.

- What will be the hard iron δ on a course 330° , where $H = 8$ A/m.
- On what other course, will the same deviation occur?

Deviation nil due to hard iron when heading 135° indicates that this is one of the neutral courses and the other is 315° . Since δ on 235° is Westerly, the natural zero is 315° and not 135° .



$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\sin \angle \text{ of ship hd}_2 \text{ from natural zero}}{\sin \angle \text{ of ship hd}_1 \text{ from natural zero}}$$

$$\frac{\delta_2}{-6} = \frac{12}{8} \times \frac{\sin 15^\circ}{\sin 280^\circ}$$

$$\delta_2 = \frac{-6 \times 12}{8} \times \frac{\sin 15^\circ}{\sin 280^\circ} = +2.36^\circ$$

Since 330° is to the right of N/zero, the deviation will be East

- 2.36° E
- The other course is $135^\circ - 15^\circ = 120^\circ$.

Example 4

PB = - 8°, PC = - 6°, find deviation on N 20° E.

$$\tan N/Co = \frac{6}{8} = .75$$

$$\theta = 36.9^\circ$$

From previous theory (-B and -C) indicates, ship's head when building
= N 36.9° W = 323.1°. And Natural Zero direction 143.1°

$$\text{Maximum deviation} = \sqrt{6^2 + 8^2} = \sqrt{100}$$

$$= 10^\circ$$

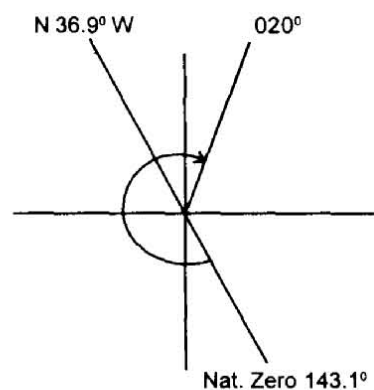
Deviation on 020°.

$$= \text{Maximum deviation} \times \sin \angle \text{ from N/Zero.}$$

$$= 10 \times \sin 236.9^\circ$$

$$= 10 \times \sin 236.9^\circ$$

$$= 10 \times 0.8377 = 8.38^\circ$$



Since Natural Zero is 143.1° and N 20° E is to its left, the deviation is West.

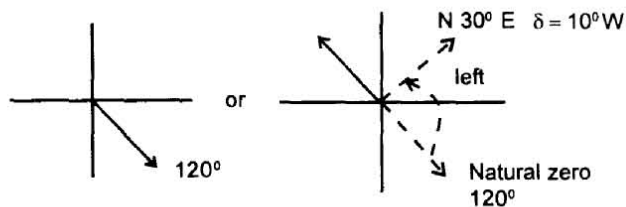
$$\text{Deviation} = 8.38^\circ \text{ W}$$

* This deviation could also have been obtained as PB sin co + PC cos co.

Example 5 : The maximum deviation due to H.I. is 10° W on a heading N 30° E by compass. What deviation due to the same cause will be experienced on West by compass.

Maximum deviation 10° W on 030° indicates that Neutral Courses are 030° ± 90° ⇒ 120° or 300°.

Since deviation on N 30° E is Westerly, Natural zero is 120° and not 300°.



$$\frac{\delta_2}{\delta_1} = \frac{H_1}{H_2} \times \frac{\sin \angle_2 \text{ from N. Zero}}{\sin \angle_1 \text{ from N. Zero}}$$

Since the place is same (H does not feature).

$$\frac{\delta_2}{\delta_1} = \frac{\sin \angle_2 \text{ from N. Zero}}{\sin \angle_1 \text{ from N. Zero}} = \frac{\sin 150^\circ}{\sin 270^\circ}$$

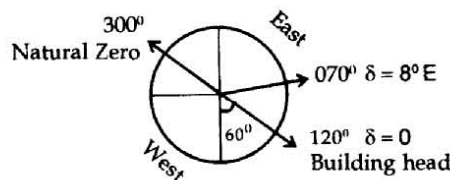
$$\delta_2 = -10 \times -0.5 = +5^\circ$$

Since course is west, which is to right of N/zero, deviation is Easterly.

Deviation = 5° E.

Example 6: The deviation due to H.I. is zero, when the ship is heading S 60° E by compass. When heading on a course of N 70° E by compass it is 8° E. Find maximum H.I. deviation. Also determine coefficients PB and PC. If deviation is 1° E, due to all causes on a heading West, find the value of induced B. Assume coefficients A and E are nil.

Heading 120° , deviation zero $\Rightarrow$ Neutral Courses are 120° or 300° . Since on 070° deviation is Easterly, Natural zero is 300° .



Let maximum deviation = x°

$$\frac{x}{8} = \frac{\sin \angle_2 \text{ from N.Zero (which should be } 90^\circ \text{ from N / Co.)}}{\sin \angle_1 \text{ from N.Zero}}$$

$$\frac{x}{8} = \frac{\sin 90^\circ}{\sin 130^\circ}$$

$$x = 8 \times \frac{\sin 90}{\sin 130} = 10.45^\circ$$

Max δ = 10.45° E when heading 030° (c)
or 10.45° W when heading 210° (c)

$$\begin{aligned} \text{ii) PB} &= \text{Maximum deviation} \times \cosine \text{ N/Co.} \\ &= 10.45 \times \cos 120^\circ \\ &= 10.45 \times \frac{1}{2} = 5.22^\circ \end{aligned}$$

$$\begin{aligned} PC &= 10.45 \times \sin 120^\circ \\ &= 10.45 \times \sin 0.866 = 9.05^\circ \end{aligned}$$

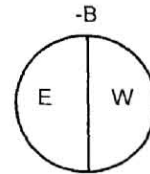
Since Building head is 120° , PB and PC both are +ve.

$$\begin{aligned} \therefore PB &= +5.22^\circ \\ PC &= +9.05^\circ \end{aligned}$$

Since on West, deviation is 1° E

$$\begin{aligned} \therefore \text{Coefficient } B &= -1^\circ \\ PB &= +5.22^\circ \end{aligned}$$

$$\therefore iB = -6.22^\circ$$



Example 7: The maximum H.I. deviation of 7° W appeared when heading 305° (c). Calculate the values of PB and PC.

Since the maximum H.I. deviation occurred on 305° , the neutral courses are 035° and 215° . On both these headings the H.I. deviation will be nil. Since H.I. deviation is the combination of PB deviation and PC deviation.

$$\begin{aligned} PB \sin 035 + PC \cos 035 &= 0 \\ \text{and } PB \sin 305 + PC \cos 305 &= -7 \end{aligned}$$

$$\begin{aligned} 0.574 PB + 0.819 PC &= 0 & \text{-----} & (1) \\ -0.819 PB + 0.574 PC &= -7 & \text{-----} & (2) \end{aligned}$$

Multiplying (1) by 0.819 and (2) by 0.574

$$\begin{aligned} 0.470 PB + 0.671 PC &= 0 \\ -0.470 PB + 0.329 PC &= -4.02 \\ \hline 1.000 PC &= -4.02 \end{aligned}$$

Substituting in (1)

$$.574 PB + 0.819 \times -4.02 = 0$$

$$.574 PB = +3.292$$

$$PB = +5.735^\circ$$

$$PB = +5.735^\circ \text{ and } PC = -4.02^\circ$$

A, B AND C

On all 8 (cardinal and inter cardinal) headings.

- (i) Mean of all deviations = Coefficient A. (Discussed already)
- (ii) Mean of all errors = Variation (provided coefficient A is zero)
- (iii) Mean of all compass bearings = Magnetic Bearing.

In case of (ii) above (All errors): Variation is a constant, and it will cause constant error on all headings. It will behave like coefficient A. If ship has no A, then mean of compass errors on all cardinal and inter cardinal headings will give variation, as shown below

Error = var + Deviation 5° E on one head

Error = var + Deviation 5° W on opp. head

$$\text{Mean of errors} = \frac{2\text{var}}{2} = \text{variation}$$

Example 1: Coefficients $A = -1^\circ$, $B = +3^\circ$, and $C = -4^\circ$. Find δ when

(i) heading 030° (c)

(ii) heading 300° (c)

$$\begin{aligned} \text{(i) } \delta &= A + B \sin \text{co} + C \cos \text{co.} \\ &= -1 + 3 \sin 30 + -4 \cos 30^\circ. \\ &= -1 + 3 \times .5 - 4 \times .866 \\ &= -1 + 1.5 - 3.464 \\ &= -2.96 \\ &= 2.96^\circ \text{ W} \end{aligned}$$

$$\begin{aligned} \text{(ii) } \delta &= A + B \sin \text{co} + C \cos \text{co.} \\ &= -1 + 3 \sin 300 + C \cos 300 \\ &= -1 + 3 \sin 300 - 4 \cos 300 \\ &= -1 + 3 \times -0.8666 - 4 \times 0.5 \\ &= -1 - 2.598 - 2 \\ &= -5.598 \\ &= -5.6^\circ \\ &= 5.6^\circ \text{ W.} \end{aligned}$$

Example 2 : During the course of a swing, through 360° , the following compass bearings of a planet were observed and true bearings calculated, as shown below. Find:

(i) Variation

(ii) Coefficient B and Coefficient C

Comp.Co.	N	NE	E	SE	S	SW	W	NW
Comp.Brg.	069	064	064	065	063	063½	071	077
T.Brg.	075	075½	076	076½	077	078	079	079½

	N	NE	E	SE	S	SW	W	NW	Total
i) Error:	6°E	11½°E	12°E	11½°E	14°E	14½°E	8°E	2½°E	= 80°E

$$\text{Variation} = \frac{80}{8} = 10^\circ \text{ E}$$

(ii) Deviation on East

Error on East:	12° E
Variation	10° E
Deviation	2° E

(iii) Deviation on West

Error on West:	8° E
Variation	10°E
Deviation	2° W

$$\text{Coefficient B} = \frac{\delta E - \delta W}{2} = \frac{2 - (-2)}{2} = +2$$

$$\text{Coefficient B} = +2^\circ$$

$$\text{Coefficient C} = \frac{\delta N - \delta S}{2} = \frac{-4 - 4}{2} = -4$$

$$\text{Coefficient C} = -4^\circ$$

The coefficients could also have been obtained as

$$\text{Coefficient B} = \frac{\text{Error on E} - \text{Error on W}}{2} = \frac{12 - 8}{2} = \frac{4}{2} = +2^\circ$$

$$\text{Coefficient C} = \frac{\text{Error on N} - \text{Error on S}}{2} = \frac{6 - 14}{2} = \frac{-8}{2} = -4^\circ$$

Example 3: During a swing through 360° , the following compass bearings were obtained of a distant object. Calculate the values of coefficients A, B and C and the deviations due to them when heading (a) 120° (c) and (b) 340° (c).

Comp. Hdg	N	NE	E	SE	S	SW	W	NW
Comp. Brg.	129°	133°	137°	135°	132°	128°	125°	121°

Hdg.	C. Brg.	M. Brg.	Deviation
N	129°	130°	1° E
NE	133°	130°	3° W
E	137°	130°	7° W
SE	135°	130°	5° W
S	132°	130°	2° W
SW	128°	130°	2° E
W	125°	130°	5° E
NW	<u>121°</u>	130°	9° E

$$\text{Mean} = \text{M. Brg.} = \frac{1040}{8} = 130^\circ$$

$$\text{Coefficient A} = \text{Mean of all deviations} = \frac{-17 + 17}{8} = \frac{0}{8} = 0^\circ$$

$$\text{Coefficient B} = \frac{\delta \text{ on E} - \delta \text{ on W}}{2} = \frac{-7 - 5}{2} = \frac{-12}{2} = -6^\circ$$

$$\text{Coefficient C} = \frac{\delta \text{ on N} - \delta \text{ on S}}{2} = \frac{1 - (-2)}{2} = \frac{+3}{2} = +1.5^\circ$$

$$\begin{aligned} \delta \text{ on } 120^\circ \text{ (c)} &= A + B \sin 120^\circ + C \cos 340^\circ \\ &= 0 - 6 \sin 120^\circ + 1.5 \cos 120^\circ \\ &= 0 - 5.19 - 0.75 = -5.94^\circ \\ &= 5.94^\circ \text{ W} \end{aligned}$$

$$\begin{aligned} \delta \text{ on } 340^\circ \text{ (c)} &= A + B \sin 340^\circ + C \cos 340^\circ \\ &= 0 - 6 \sin 340^\circ + 1.5 \cos 340^\circ \\ &= 0 + 2.05 + 1.41 = +3.46^\circ \\ &= 3.46^\circ \text{ E} \end{aligned}$$

B and C

Example 1: At a place, where $H = 18 \text{ A/m}$, $Z = +42 \text{ A/m}$, coefficient B was $+5^\circ$ and coefficient $C = 10^\circ$. These coefficients were corrected by permanent magnets and no flinders bar was used. On the magnetic equator, $H = 28 \text{ A/m}$, Coefficient B was found to be $+4.5^\circ$ and coefficient $C = +1^\circ$ with the correctors in place. How should the correctors have been placed at the original place and on what headings ?

Place 2 is situated at magnetic equator, therefore no induced B or induced C .

At (2) PB of ship and magnet = $+4.5^\circ$ PC ship + magnet = $+1^\circ$
To find PB ship and magnet @ (1) Similarly,

$$\frac{PB_1}{PB_2} = \frac{H_2}{H_1}; \quad \frac{PB_1}{+4.5} = \frac{28}{18}$$

$$\frac{PC_1}{+1} = \frac{28}{18}$$

$$PB_1 = \frac{4.5 \times 28}{18} = +7^\circ$$

$$PC_1 = +1 \times \frac{28}{18} = +1.55^\circ$$

PB_1 ship and magnet = $+7^\circ$
Magnet was causing = -5°

PC_1 ship and magnet = $+1.55^\circ$
Magnet was causing = -10°

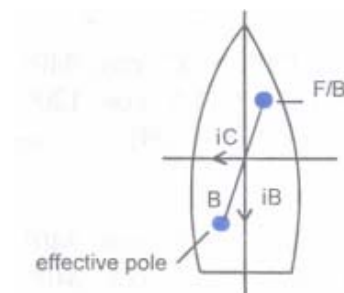
$\therefore PB$ of ship = $+12^\circ$
Coefficient B = $+5^\circ$
 $\therefore$ Induced B = -7°

$\therefore PC$ of ship = $+11.55^\circ$
Coefficient C = $+10^\circ$
Induced C = -1.55°

PB of ship is $+12^\circ$ - Place F&A magnets red end forward on heading East or West to remove 12° of deviation.

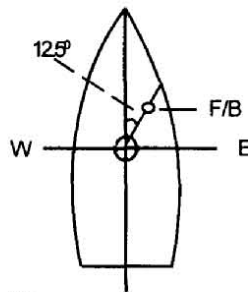
PC of ship is $+11.55^\circ$ - Place Athwartship magnets, red to starbd when heading North or South to remove 11.55° of deviation.

At place (1) ship is in the Northern hemisphere, effective pole of V.S.I is blue and we have iB of -7° and iC of -1.55° .



$$\tan \angle \text{ of slew} = \frac{iC}{iB} = \frac{-1.55}{-7} = .2214$$

$$\angle \text{ of slew} = 12.5^\circ$$



$$\text{Maximum deviation} = \sqrt{iB^2 + iC^2}$$

$$\sqrt{7^2 + (1.55)^2} = 7.2^\circ$$

Place flinders bar for'd and slew 12.5° to stbd, to correct 7.2° when heading N $77\frac{1}{2}^\circ$ E or S $77\frac{1}{2}^\circ$ W.

Example 2: A vessel was swung for compass correction at a place, where $H = 42$ A/m, $Z = +36$ A/m, coefficient B of $+2^\circ$ and coefficient C of $+4^\circ$ were corrected by permanent magnets only.

At a place where $H = 35$ A/m, $Z = 21$ A/m, with the correctors in place, a coefficient B of -1° and coefficient C of $+1/2^\circ$ was found. How should the correction have been done at the first place using permanent magnets and Flinders Bar.

At a place (1), after correction by magnets, total B and total C were nil.

At (1) Let PB of ship and magnet = x

iB of ship = y

Then $x + y = 0$ ----- (1)

At place (2) PB of ship and magnet = $x \times \frac{H_1}{H_2} = x \times \frac{42}{35} = 1.2x$

and at (2) iB of ship = $y \times \frac{H_1}{H_2} \times \frac{Z_2}{Z_1} = y \times \frac{42}{35} \times \frac{21}{36} = 0.7y$

$1.2x + 0.7y = -1$ ----- (2)

$1.2x + 1.2y = 0$ ----- multiplying equation (1) by 1.2

$-0.5y = -1$

$y = +2$ ----- iB ship at (1)

$x + y = 0$

$\therefore x = \text{PB of ship and magnet at (1)} = -2^\circ$

PB of magnet alone at (1) = -2°

$\therefore \text{PB of ship alone} = 0$

Similarly

Let PC of ship and magnet at (1) = x

and iC of ship = y

$$\therefore x + y = 0$$

$$\text{PC of ship and magnet at (2)} = x \times \frac{H_1}{H_2} = x \times \frac{42}{35} = 1.2x$$

$$\text{iC of ship at (2)} = y \times \frac{H_1}{H_2} \times \frac{Z_2}{Z_1} = y \times \frac{42}{35} \times \frac{21}{36} = 0.7y$$

$$1.2x + 0.7y = +0.5$$

$$1.2x + 1.2y = 0$$

$$-0.5y = +0.5$$

$$y = -1$$

----- iC of ship at (1)

$$x - 1 = 0$$

$$x = \text{PC of ship and magnet at (1)} = +1^\circ$$

$$\text{PC of magnet alone at (1)} = -4^\circ$$

$$\therefore \text{PC of ship alone at (1)} = +5^\circ$$

No PB correction necessary as ship's PB is nil.

To correct PC, head ship N or S and place athwartship magnets red ends stbd, to remove 5° .

$$\tan \angle \text{ of slew} = \frac{iC}{iB} = \frac{1}{2}$$

$$\angle \text{ of slew} = 26\frac{1}{2}^\circ$$

Flinders bar to be placed abaft compass and slewed $26\frac{1}{2}^\circ$ to stbd

$$\begin{aligned} \text{Maximum deviation to be corrected} &= \sqrt{iB^2 + iC^2} \\ &= \sqrt{2^2 + (-1)^2} = 2.24^\circ \end{aligned}$$

Headings on which the correction can be done

$$= \text{N } 63\frac{1}{2}^\circ \text{ W or S } 63\frac{1}{2}^\circ \text{ E.}$$

Example 3: At position (1) ($H = 30 \text{ A/m}$, $Z = 40 \text{ A/m}$), coefficient B was calculated and found to be -3° and coefficient C was found to be -3° . The Flinders Bar was placed fo'rd to correct an estimated deviation of 2° due to V.S.I abaft the compass and the remaining deviation was corrected by fore and aft magnets. The deviation due to Coefficient 'C' was entirely corrected by permanent magnets.

At (2) ($H = 20 \text{ A/m}$, $Z = -30 \text{ A/m}$), the vessel was swung again and Coefficient B and C found to be $+2^\circ$ and -2° respectively. State how the correctors should be placed at position (2) and the amount of deviation they should correct.

At place (1): Total B = -3^0

F/B and magnets cause = $+3^0$

But F/B causes = $+2^0$

$\therefore$ Magnets cause = $+1^0$

$$\frac{PB_2 \text{ Magnet}}{PB_1 \text{ Magnet}} = \frac{H_1}{H_2}$$

$$PB_2 \text{ Magnet} = +1 \times \frac{30}{20} = +1.5^0$$

$$\therefore PB_2 \text{ Magnet} = +1.5^0$$

$$\frac{iB_2 \text{ F.B}}{iB_1 \text{ F.B}} = \frac{H_1}{H_2} \times \frac{Z_2}{Z_1}$$

$$iB_2 \text{ F.B} = +2 \times \frac{30}{20} \times \frac{-30}{40}$$
$$= -2.25^0$$

$$iB_2 \text{ of FB} = -2.25^0$$

$$PB_2 \text{ of magnets} = +1.5^0$$

$$\begin{array}{l} \text{Total B due to} \\ \text{magnet and F/B} \\ \text{at (2)} \end{array} = -0.75^0$$

$$\begin{array}{l} \text{Total B appearing} \\ \text{on the ship at (2)} \end{array} = +2^0$$

$$\begin{array}{l} \text{Total B of ship} \\ \text{alone at (2)} \end{array} = +2.75^0$$

$$\text{Let PB of ship at (2)} = x^0$$

$$iB \text{ of ship at (2)} = y^0$$

$$x + y = +2.75^0 \quad \text{--- (1)}$$

$$\frac{PB_1}{PB_2} = \frac{H_2}{H_1} = \frac{20}{30}$$

$$PB_1 = x \times \frac{20}{30} = .66x$$

Total C = -3^0

Magnets cause = $+3^0$

$$\frac{PC_2 \text{ Magnet}}{PC_1 \text{ Magnet}} = \frac{H_1}{H_2}$$

$$PC_2 \text{ Magnet} = +3 \times \frac{30}{20} = +4.5^0$$

$$PC_2 \text{ Magnet} = +4.5^0$$

$$\begin{array}{l} \text{Total C appearing} \\ \text{on ship at (2)} \end{array} = -2^0$$

$$PC \text{ of magnet at (2)} = +4.5^0$$

$$\therefore \begin{array}{l} \text{Total C of} \\ \text{ship alone at (2)} \end{array} = -6.5^0$$

$$\text{Let PC of ship at (2)} = x^0$$

$$\text{and } iC \text{ of ship at (2)} = y^0$$

$$x + y = -6.5^0 \quad \text{--- (1)}$$

$$\frac{PC_1}{PC_2} = \frac{20}{30}$$

$$PC_1 = x \times \frac{20}{30} = .66x$$

$$\frac{iB_1}{iB_2} = \frac{H_2}{H_1} \times \frac{Z_1}{Z_2}$$

$$\therefore iB_1 = \frac{20}{30} \times \frac{40}{-30} \times y$$

$$iB_1 = -0.89y$$

$$\frac{iC_1}{iC_2} = \frac{H_2}{H_1} \times \frac{Z_1}{Z_2}$$

$$\therefore iC_1 = \frac{20}{30} \times \frac{40}{-30} \times y$$

$$iC_1 = -0.89y$$

$$.66x - .89y = -3^0 \quad \text{-----(2)}$$

$$\frac{.66x + .66y = 1.815^0 \quad \text{-----(1)} \times 0.66}{-1.55y = -4.815^0}$$

$$y = +3.126^0$$

$$y = +3.13^0$$

$$\therefore x = -0.38^0$$

$$.66x - .89y = -3^0 \quad \text{--- (2)}$$

$$\frac{.66x + .66y = -4.29^0 \quad \text{--- (1)} \times 0.66}{-1.55y = 1.29^0}$$

$$y = -0.83^0$$

$$x = -5.67^0$$

$$\therefore \text{PB ship at (2)} = -0.38^0$$

$$\text{iB ship at (2)} = +3.13^0$$

$$\text{PC ship at (2)} = -5.67^0$$

$$\text{iC ship at (2)} = -0.83^0$$

$$\tan \angle \text{ of slew: } \frac{iC}{iB} = \frac{.83}{3.13} = 0.2652$$

$$\theta = 15^0 \text{ approx.}$$

$$\text{Maximum deviation due to iB and iC} = \sqrt{iB^2 + iC^2}$$

$$= \sqrt{(3.13)^2 + (.83)^2} = \sqrt{9.79 + .69} = \sqrt{10.48} = 3.2^0$$

Since vessel is situated in Southern hemisphere, the effective pole is red, and as we have

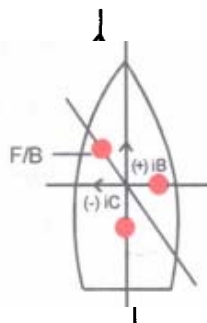
$$iB = +3.13^0$$

$$iC = -0.83^0$$

iB +ve $\Rightarrow$ field acting towards bow, i.e. red pole will be aft.

Similarly since iC is -ve, red pole is starbd.

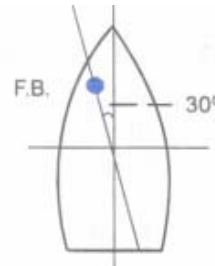
$\therefore$ Place flinders bar for'd and slew 15^0 to port to correct 3.2^0 when heading N 75^0 W or S 75^0 E.



Permanent B = -0.38^0 Place F/A magnet - blue ends ford when heading E or W, to correct 0.38^0 .

Permanent C = -5.66^0 . Place Ath magnet - blue ends to starbd when heading N or S, to correct -5.66^0 .

Example 4 : At position A, a F/B placed fore'd and slewed 30° to port was known to correct a maximum deviation of 8° . The vessel was swung and no deviations were found on the cardinal points. At position 'B' the following deviations were observed :- On North 3° E, on South 1° W, on East 1° W, and on West 3° E. State what corrections should be made by permanent magnets and by Flinders Bar at place B.



$$A : H = 16 \text{ A/m}, Z = +32 \text{ A/m}$$

$$B : H = 20 \text{ A/m}, Z = -40 \text{ A/m}$$

Since no deviations were found at A, on N/S or E/W with the flinders bar in position, total B of ship and flinders bar and total C of ship and flinders bar were nil.

To find iB and iC of F/B at A.

$$\tan m^\circ = \frac{iC}{iB}; \tan 30^\circ = 0.5774 = \frac{1}{\sqrt{3}}$$

$$\therefore iB = \sqrt{3} iC$$

Also, the maximum deviation caused by F/B due to its iB & iC effects, is 8° .

$$\therefore \sqrt{iB^2 + iC^2} = 8 \text{ (of flinders bar)}$$

$$iB = \sqrt{3} iC$$

$$\therefore 8 = \sqrt{iC^2 + (\sqrt{3} iC)^2} = \sqrt{iC^2 + 3 iC^2} = 2 iC$$

$$iC = 4^\circ$$

$$iB = \sqrt{3} \times 4^\circ$$

$$= 6.93^\circ$$

or

$$iB = \text{Maximum } \delta \cos \angle \text{ of slew}$$

$$= 8 \times \cos 30^\circ = 6.93^\circ$$

$$iC = \text{Maximum } \delta \sin \angle \text{ of slew}$$

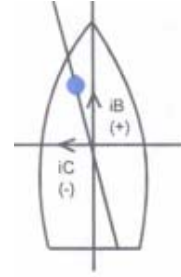
$$= 8 \times \sin 30^\circ = 4^\circ$$

Effective pole at A is blue $\Rightarrow iB$ is +ve.
 iC is -ve

$$\therefore iB \text{ of F/B} = +6.93^\circ$$

$$iC \text{ of F/B} = -4^\circ$$

we conclude total B of ship was -6.93^0
and total C of ship was $+4.00^0$ } at A



To find effect of F/B at B.

$$\frac{iB_2}{iB_1} = \frac{Z_2}{Z_1} \times \frac{H_1}{H_2} = \frac{-40}{32} \times \frac{16}{20} = -1$$

$$iB_2 = 6.93 \times -1 = -6.93^0 \quad \text{----- } iB \text{ of Flinders bar at B.}$$

$$\frac{iC_2}{iC_1} = \frac{-40}{32} \times \frac{16}{20} = -1$$

$$\therefore iC_2 = -4 \times -1 = 4^0 \quad \text{----- } iC \text{ of Flinders bar at B.}$$

$$\text{Total B at place 'B' including F/B} = \frac{-1-3}{2} = -2^0$$

$$\text{But F/B causes} = -6.93^0$$

$$\therefore \text{Total B of ship alone} = +4.93^0$$

$$\text{Total C at place 'B' with F/B} = \frac{3-(-1)}{2} = +2^0$$

$$\text{But Flinders bar causes } +4^0$$

$$\therefore \text{Total C of ship alone} = -2^0$$

$$\text{At place B, B of ship} = +4.93^0$$

$$\text{C of ship} = -2^0$$

$$\begin{aligned} \text{At place B, let PB} &= x^0 \\ \text{and } iB &= y^0 \end{aligned}$$

$$\begin{aligned} \text{At B, let PC} &= x^0 \\ \text{At B, let } iC &= y^0 \end{aligned}$$

$$x + y = +4.93^0 \quad \text{--- (1)}$$

$$x + y = -2^0 \quad \text{--- (1)}$$

$$\frac{PB_1}{x} = \frac{H_2}{H_1} = \frac{20}{16} = 1.25$$

Similarly,

$$PB_1 = 1.25x$$

$$PC_1 = 1.25x$$

$$\frac{iB_1}{y} = \frac{Z_1}{Z_2} \times \frac{H_2}{H_1} = \frac{32}{-40} \times \frac{20}{16}$$

$$iB_1 = -1y$$

$$\begin{aligned} \text{Similarly,} \\ iC_1 &= -y^0 \end{aligned}$$

$$iB_1 = -y^0$$

$$\therefore 1.25x - y = -6.93^0$$

$$\therefore 1.25x - y = +4^0$$

$$1.25x - y = -6.93^0 \quad \text{----- (2)}$$

$$1.25x + 1.25y = +6.16 \quad \text{----- (1) } \times 1.25$$

$$\hline -2.25y = -13.09$$

$$y = +5.8^0$$

$$\therefore x = -0.87^0$$

$$\text{PB of ship} = -0.87^0$$

$$\text{iB of ship} = +5.8^0$$

$$1.25x - y^0 = +4 \quad \text{--- (2)}$$

$$1.25x + 1.25y = -2.5 \quad \text{---- (1) } \times 1.25$$

$$\hline -2.25y = 6.5$$

$$y = -2.9^0$$

$$\therefore x = +0.9^0$$

$$\text{PC of ship} = +0.9^0$$

$$\text{iC of ship} = -2.9^0$$

Southern hemisphere

Effective pole will be red

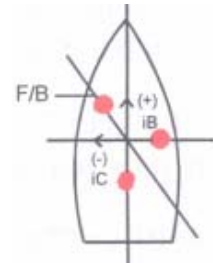
since iB is +ve $\Rightarrow$ red pole is aft

since iC is -ve $\Rightarrow$ red pole is to starbd.

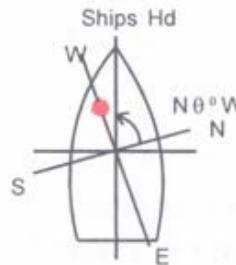
$\therefore$ F/B should be placed for'd and slewed to port

$$\tan \angle \text{ slew: } \frac{2.9}{5.8} = \frac{1}{2} = .5$$

$$m^0 = 26\frac{1}{2}^0$$



$$\begin{aligned} \text{Maximum deviation} &= \sqrt{(5.8)^2 + (-2.9)^2} \\ &= 6.48^0 \end{aligned}$$



$\therefore$ Correct iB and iC by placing flinders bar ford and slewing to port by $26\frac{1}{2}^0$ to correct 6.48^0 when heading on N $63\frac{1}{2}$ W or S $63\frac{1}{2}$ E.

Permanent Magnets:

Place F&A magnets Blue ends ford to correct 0.87^0 when heading E or W.

Place athw. magnets Red ends to starbd to correct 0.9^0 when heading N or S.

EXERCISE I

(Coefficients B & C)

1. At place A ($H = 8.5 \text{ A/m}$) coef. PB = $+4^\circ$ and coef. PC = $+5^\circ$. Find the values of these coefficients at place B ($H = 15 \text{ A/m}$).
2. At P ($H = 24 \text{ A/m}$), the deviation due to PB was 7° E when heading 280° (C) . Calculate the value of coef PB at P and at Q ($H = 30 \text{ A/m}$).
3. At A ($H = 24 \text{ A/m}$) the deviation due to PC when heading 320° (C) was 7° W . Calculate the deviation due to the same cause when heading 210° (C) at B ($H = 16 \text{ A/m}$).
4. At M ($H = 20 \text{ A/m}$, $Z = 24 \text{ A/m}$) coef. iB was -3° . Find the value of iB at N ($H = 24 \text{ A/m}$, $Z = 30 \text{ A/m}$).
5. At P ($H = 22 \text{ A/m}$, $\text{dip} = -40^\circ$) the deviation due to iB was 4° W when heading 270° (C) . Find the deviation due to the same cause at Q ($H = 30 \text{ A/m}$, $\text{dip} = 55^\circ$) when heading 140° (C) .
6. The deviation due to iC when heading 180° (C) at A ($H = 28 \text{ A/m}$, $Z = -16 \text{ A/m}$) was 5° E . Calculate the value of coef. iC at B ($H = 21 \text{ A/m}$, $Z = 18 \text{ A/m}$).
7. At R ($\text{dip} = 63^\circ$) the deviation due to iC was 2° E when heading 250° (C) . Calculate the deviation due to iC at S ($\text{dip} = -34^\circ$) when heading 140° (C) and at T ($\text{dip} = 47^\circ$) when heading 310° (C) .
8. When heading N, the deviation was 10° E and when heading $N 30^\circ \text{ E}$, the deviation was 10° E . If A, D and E are nil, calculate coef. B.
9. If the deviation on W is 2° W and on 065° it was nil, find coef. C assuming A, D and E are nil.
10. The flinders bar causes a maximum deflection of 3° where $\text{dip} = 30^\circ$. What deflection will it cause when heading 210° where $\text{dip} = 60^\circ$?
11. An athwartship magnet corrects for 10° when heading 000° (C) . How much will it correct when heading 310° (C) ?

12. A fore and aft magnet placed 24 cms from the card deflects it 3° when heading 045° (C). At what distance should it be placed to correct a coef. PB of 8° ?
13. The following deviations were noted on the cardinal headings: N: 12° W, E: 4° E, S: 4° W, W: 6° E. Calculate the values of coefs. B and C and the total deviation due to them when heading 142° (C).
14. When heading 050° (C), the combined deviation due to B and C was 4° E and when heading 310° (C), it was 8° W. Find the values of coefs. B and C.
15. PB was $+8^\circ$ and iB was -4° where $H = 30\text{A/m}$ and $Z = 40\text{A/m}$. Find the total deviation due to them when heading 255° (C), where $H = 20\text{A/m}$ and $Z = -30\text{A/m}$.
16. At A on the magnetic equator ($H = 15\text{A/m}$) the deviation when heading 090° was 6° W. At B ($H = 10\text{A/m}$, dip = 65°) the deviation when heading 270° was 8° E. Assuming A and E are nil, find the values of PB and iB at position B.
17. At P ($H = 38\text{A/m}$, $Z = 19\text{A/m}$), total B was $+4^\circ$ and induced B was -4° . Coef. B was corrected there by F & A magnets alone. What deviation can be expected at Q ($H = 15\text{A/m}$, $Z = -30\text{A/m}$), when heading 240° (C), with the magnets in the same position? Assume all other coefs. are nil.
18. Total B is nil and PB is -5° at L ($H = 20\text{A/m}$, $Z = 45\text{A/m}$). What deviation would coef. B cause at M ($H = 30\text{A/m}$, $Z = -10\text{A/m}$) when heading 270° (C)?
19. At A ($H = 18.5\text{A/m}$, $Z = -57\text{A/m}$) the deviation on E was 4° W and on W it was 6° E. At B ($H = 37.5\text{A/m}$, $Z = +24\text{A/m}$) the deviation on E was 4° W and on W it was 6° E. What is the value of PB and iB at A?
20. At P ($H = 30\text{A/m}$, dip = $+49^\circ$), coef. B was $+7.5^\circ$ and at Q ($H = 25\text{A/m}$, dip = -64°). Coef. B was $+13^\circ$. Calculate PB and iB at P.
21. At position 1, ($H = 15\text{A/m}$, $Z = -29\text{A/m}$) coef. B was nil. At position 2, ($H = 27\text{A/m}$, $Z = 0$) coef. B was -8° . Calculate the value of coef. B at position 3 ($H = 28\text{A/m}$, $Z = -20\text{A/m}$).
22. At A ($H = 16\text{A/m}$, dip = 74°) coef. B was corrected with fore and aft magnets red ends for'd and flinders bar for'd of compass. At B ($H = 25\text{A/m}$, dip = 52°) coef. B was $+5^\circ$ with the correctors in the same position. How would you adjust the correction at B?

23. At P ($H = 20A/m$, $Z = -32.4A/m$) coef. B was corrected with fore and aft magnets red ends aft and flinders bar for'd of compass. At Q ($H = 32A/m$, $Z = 20A/m$) coef. B was -20° . Readjust the correctors at Q.
24. At A ($H = 30A/m$, $dip = 55^\circ$) total B was $+6^\circ$ and at B ($H = 25A/m$, $dip = -64^\circ$), total B was $+2^\circ$. How would you correct coef. B at place B?
25. At P ($H = 20A/m$, $Z = 40A/m$), coef. B was -12° . At Q ($H = 30A/m$, $Z = 10A/m$) coef. B was -4° . How would you correct coef. B at Q. If the correction was not carried out at Q, what would be the value of coef. B at R ($H = 25A/m$, $Z = -30A/m$).
26. At P ($H = 36A/m$, $dip = 30^\circ$) coef. B was $+1^\circ$. At Q ($H = 40A/m$, $dip = \text{nil}$) coef. B was $+5^\circ$ which was corrected by F & A magnets. What would be the value of B at R ($H = 15A/m$, $dip = -60^\circ$) ? How would you correct it?
27. At P ($H = 18A/m$, $Z = 9A/m$), the flinders bar is placed for'd to correct 2° and the remaining coef. B of 5° is corrected by F & A magnets red ends for'd. At Q ($H = 12A/m$, $Z = -15A/m$), the magnets were removed and a coef. B of $+2^\circ$ was observed. How should the compass have been corrected at P?
28. At A ($H = 36A/m$, $dip = 32^\circ$), F & A magnets were placed red ends for'd correcting 6° and flinders bar was placed for'd correcting 3° . With the correctors in position, coef. B was $+1^\circ$. At B, ($H = 18A/m$, $dip = 68^\circ$) coef. B was $+5^\circ$ with the correctors in the same position. What would be the value of coef. B of the ship alone at C on the magnetic equator ($H = 33A/m$)?
29. At X ($H = 17.3A/m$, $Z = 32A/m$), the entire coef. B of 4° was corrected by flinders bar placed for'd. At Y ($H = 26A/m$, $Z = -8A/m$), coef. B was -12° . How should coef. B be corrected at Y?
30. In the Southern Hemisphere, iB was -5° and iC was $+2^\circ$. How are they to be corrected by a single flinders bar? On what headings would this correction be made and what deviation is to be corrected on those headings?
31. In N. latitude, iB is -2° and iC is $+1.5^\circ$. How would you correct them?
32. In the S. hemisphere a flinders bar placed aft and slewed 15° to stbd corrects iB and iC , the maximum combined deviation of which was 8° . What are the values of the ship's iB and iC ?

33. At P ($H = 39\text{A/m}$, $Z = 10\text{A/m}$) coef. B was corrected with F & A magnets red aft and flinders bar for'd of the compass. At Q ($H = 26\text{A/m}$, $Z = -35\text{A/m}$) coef. B was $+6^\circ$ with the correctors in position. How should the correctors be re-adjusted at Q?
34. At A ($H = 16\text{A/m}$, $\text{dip} = 74^\circ$), coef. B was corrected with F & A magnets red for'd and flinders bar for'd of the compass. At B, ($H = 25\text{A/m}$, $\text{dip} = 52^\circ$) coef. B was $+5^\circ$. How would you adjust the correctors at B?
35. At X ($H = 15\text{A/m}$, $Z = 22\text{A/m}$) coef. B was $+2^\circ$ and coef. C was $+6^\circ$. Both coefficients were corrected by magnets alone. The ship then proceeded to Y ($H = 30\text{A/m}$, $Z = 0$) and with the magnets in position, coef. B was $+3^\circ$ and coef. C was -1° . How should the compass have been corrected at X?
36. With an athwartship magnet 30 cms below the card, the deviation when heading 230° (C) was 3° E. When the magnet is removed the deviation was 1° W. The vessel was then headed S and a deviation of 4° W was observed. If A and E are nil, at what distance should the magnet be replaced?
37. When heading 320° (C), the deviation was 2° W. A, iB, C, D & E are nil. The ship was then headed E and a F & A magnet placed 35 cms below the card. The deviation then was 5° E. How would you place the magnet to compensate PB?
38. At A ($H = 28\text{A/m}$, $Z = 12\text{A/m}$) the deviation on E was 6° E and on W it was 4° W. This was corrected by placing flinders bar for'd to correct an assumed iB of 2° and the remainder was corrected by F & A magnets. On arrival at B ($H = 20\text{A/m}$, $Z = -20\text{A/m}$) coef. B was found to be -4.8° . How should coef. B have been corrected at A?
39. The maximum hard iron deviation is 8° E when heading 040° (C). Calculate the deviation due to the same cause when heading 270° (C).
40. A vessel built heading 120° (C) has a H.I. deviation of 9° E when heading 045° (C) where $H = 16\text{ A/m}$. What is the value of the maximum deviation and on what courses will the deviation be 4° W where $H = 24\text{ A/m}$?
41. If $PB = +6^\circ$ and $PC = +4^\circ$, calculate her building head. What will be the maximum deviations and the headings on which they occur?

42. The H.I. deviation is nil when heading 120° (C) and 6° E when heading 070° (C). Calculate the value of PB and PC.
43. A compass had a maximum H.I. deviation of 8° W when heading 070° (C). Calculate the values of PB and PC, the ship's head when building and the H.I. deviation when heading 220° (C).
44. A vessel had maximum easterly H.I. deviation when heading 315° (C) at place A where $H = 20$ A/m. When heading 012° (C) at the same place, the H.I. deviation was 6° E.
- Find
- 1) Her building head
 - 2) Signs and values of the coefficients causing the above deviations at A.
 - 3) The maximum H.I. deviation at A.
 - 4) Maximum H.I. deviation at B ($H = 30$ A/m)
 - 5) The courses on which the H.I. deviation will be 3° E at B.
45. The deviation due to permanent magnetism is nil when heading 295° (C) and 10° W when heading 177° (C). What deviation may be expected due to the same cause when heading 245° (C).

CHAPTER 8

COEFFICIENT D

DEFINITION: Coefficient D is the maximum value of the quadrantal deviation which varies as the sine of twice the compass course and is caused by a horizontal field at the compass position due to induced magnetism in horizontal soft iron situated symmetrically about a fore and aft line through the compass.

The soft iron may be F & A or athwartship. Being horizontal they are induced by the horizontal force of the Earth.

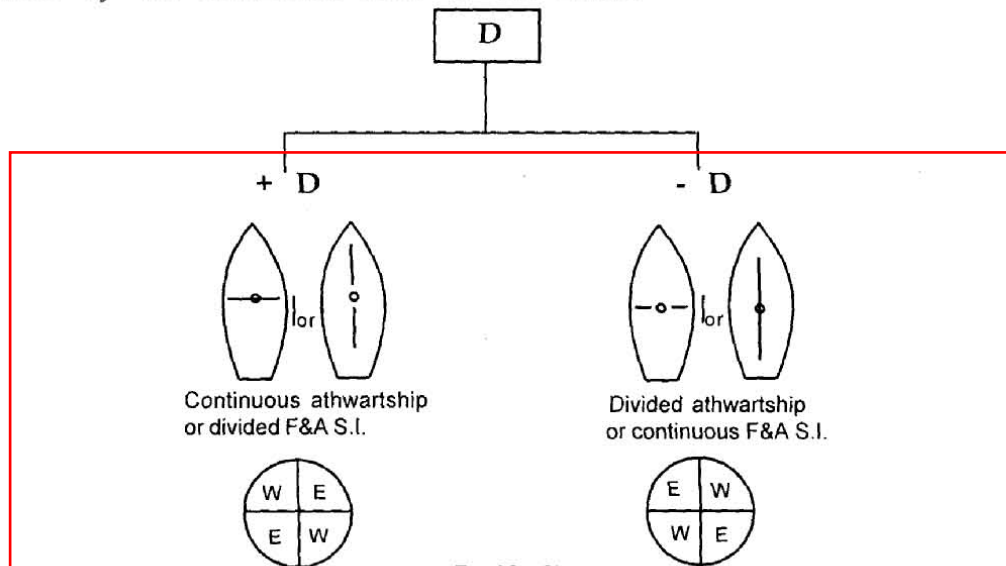


Fig. No. 50

On most merchant ships, the transverse beams (-e rods) and F & A girders (-a rods) are the structures that produce coefficient 'D' at the compass. The number of transverse beams are normally much larger than the number of girders. Further, the poles formed towards the end of the beams are closer to the compass than those of the girders. Therefore most merchant ships have a + D at the compass position.

(Recapitulate)

- merchant ships (Transverse beams > F/A continuous girders)
- Poles of beams closer than those that of girders
- merchant ships normally have + D.

Coefficient D causes deviations of one name over continuous opposite quarters of the ship's heading and of the other name over the other two continuous opposite quarters of the ship's heading. The deviation due to D will be nil on the cardinal headings and maximum on the inter cardinal headings. Since $\sin \theta$ is nil when θ is 0° or 180° and maximum when θ is 90° or 270° , it can be stated that deviation due to D varies as the sine of twice the compass course.

+D

Continuous Athwartship S.I.

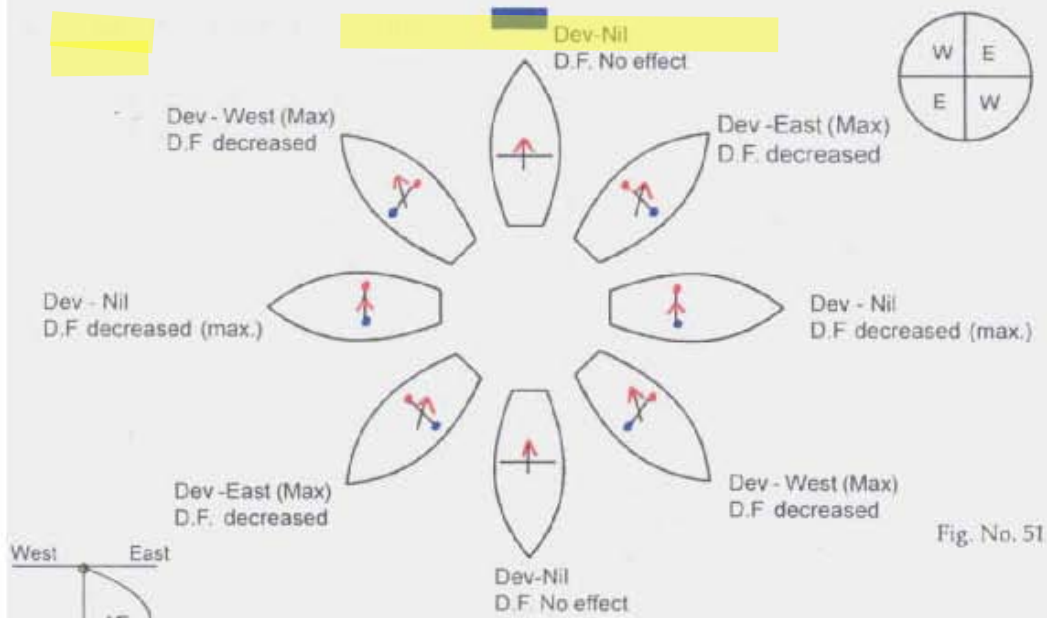


Fig. No. 51

The mean DF at the compass position is reduced.

Divided F&A S.I.

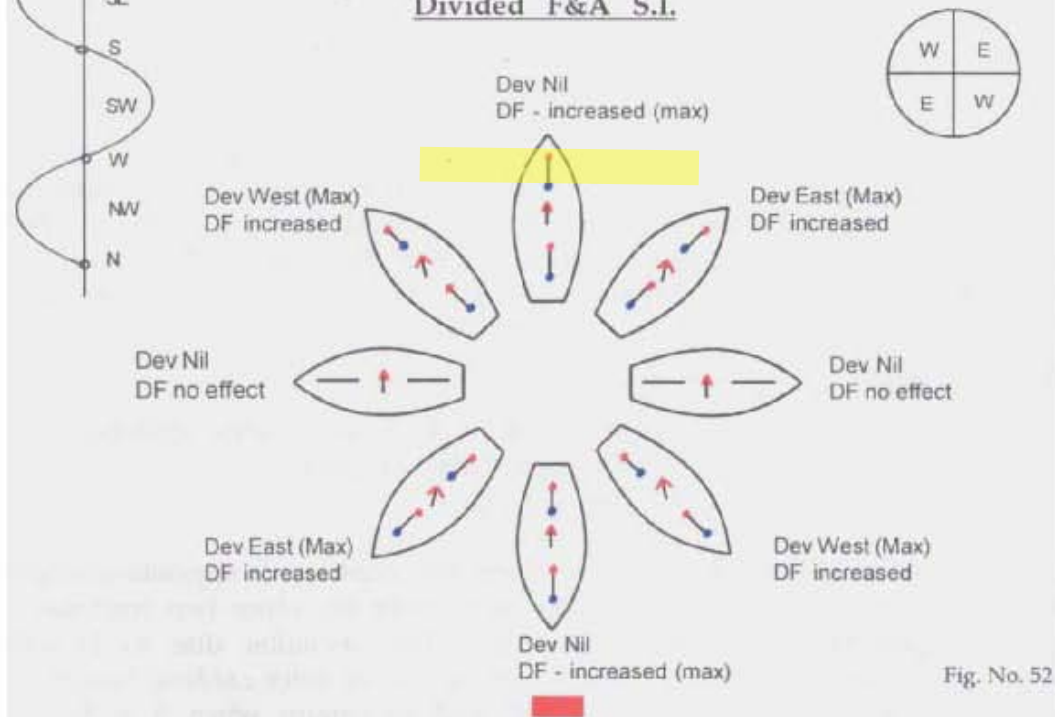
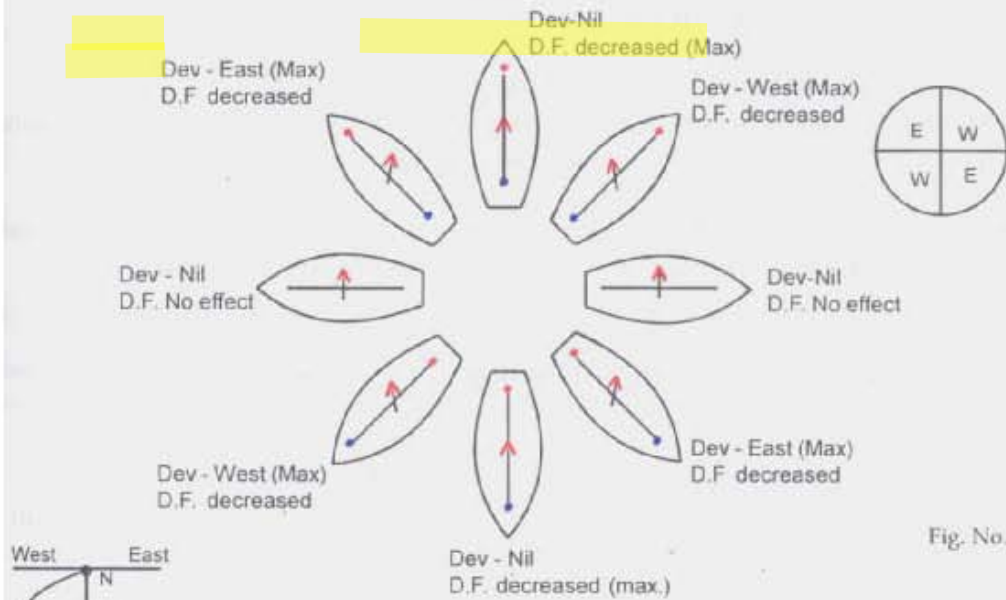


Fig. No. 52

The mean DF at the compass position is increased.

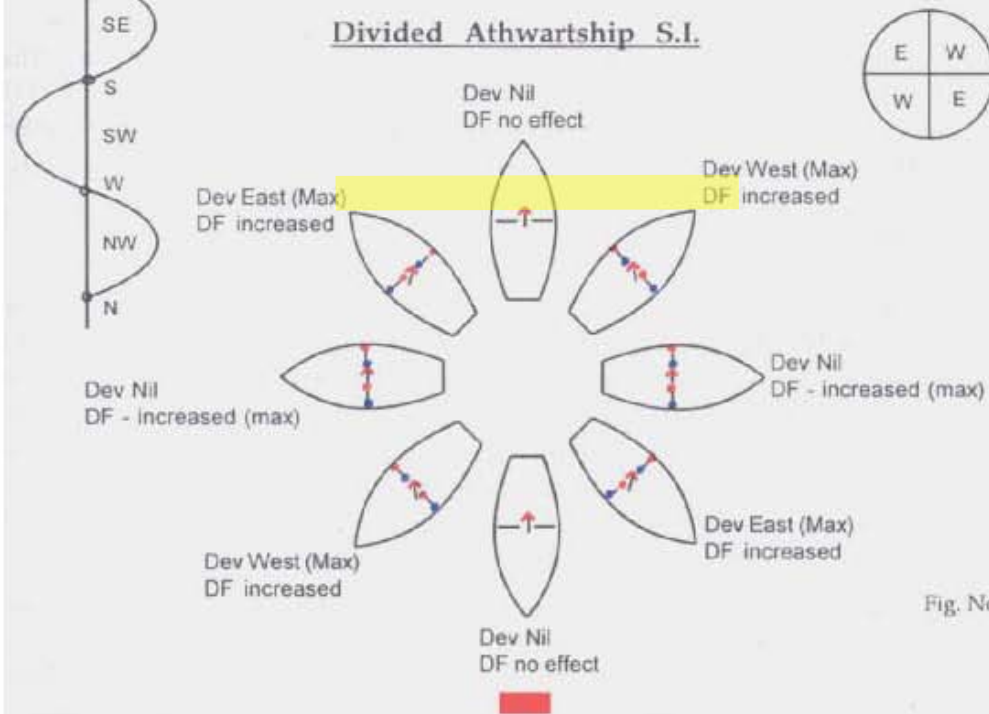
-D

Continuous F&A S.I.



The mean DF at the compass position is reduced.

Divided Athwartship S.I.



The mean DF at the compass position is increased.

Study of DF due to coefficient D

+D caused by athwartships CONTINUOUS Soft Iron.

The DF is reduced on all headings except NORTH and SOUTH. Therefore Mean DF at the compass is reduced.

+D caused by DIVIDED Fore and Aft S.I.

The DF is increased on all headings, except EAST and WEST. Therefore the Mean DF at the compass is increased.

Identification of +D: Whether due to divided F&A or continuous athwartship S.I., the DF on N & S is greater than DF on E & W.

-D caused by DIVIDED athwartship Soft Iron.

The DF is increased on all headings, except N/S. Therefore Mean DF at the compass position is increased.

-D caused by CONTINUOUS Fore and Aft Soft Iron.

The DF is reduced on all headings, except E/W. Therefore Mean DF at the compass position is reduced.

Identification of -D : Whether due to divided athwartship or continuous F&A S.I., the DF on East and West is greater than DF on North and South.

In all cases, continuous soft iron reduces the mean DF at the compass, while any divided S.I. increases it. Also, greater DF on N and S than on E and W indicates a +D and conversely, greater DF on E and W than on N and S indicates a -D.

Effect of latitude:

We know that all horizontal soft irons are magnetised by the earth's horizontal force. At the poles, H is zero, therefore there is no induction by H. As H increases from zero at the pole to maximum at the equator, the induction in the horizontal S.I. also increases in the same proportion. At the equator, where H is maximum, the induction in the horizontal soft iron is also maximum. Therefore we can say that any increase in the earth's horizontal force H, causes a proportionate increase in the induction in the ship's horizontal S.I. (the disturbing force causing coefficient D say F).

Since the directive force at the compass is H itself, an increase in H causes an increase in the directive force at the compass and also a corresponding increase in the disturbing force, F. As the directive force and the disturbing force increase together proportionately or decrease together proportionately, when H increases or decreases respectively, the deviation due to D remains unchanged. Therefore deviation due to D is unaffected by change of magnetic latitude.

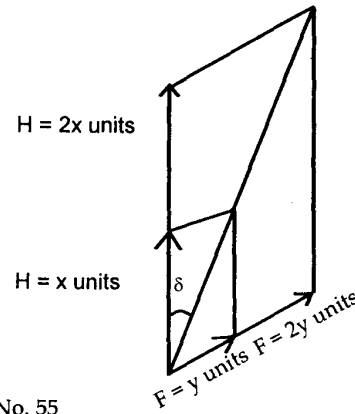
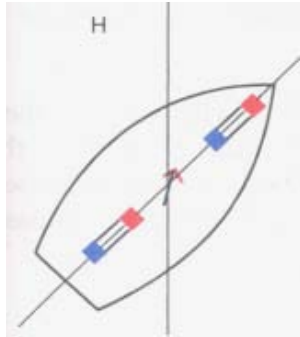


Fig. No. 55

Effect of Change of Course:

Deviation due to coefficient D varies directly as the sine of twice the compass course.

$$\therefore \delta \text{ due to } D = D \times \sin 2 \text{ comp.co.}$$

$$\text{and } \frac{\delta_2}{\delta_1} = \frac{\sin 2 \text{ comp.co}_2}{\sin 2 \text{ comp.co}_1}$$

The value of Coefficient D is obtained as

$$\text{COEFFICIENT } D = \frac{\delta \text{ on NE} - \delta \text{ on SE} + \delta \text{ on SW} - \delta \text{ on NW}}{4}$$

Correction of coefficient D:

Normally, on a vessel, a +D is present. This is because, on a merchant ship there is a predominance of continuous athwartship beams causing a +D and only a few F & A girders causing a -D. The beams being very much larger in number and their poles being closer to the compass, the transverse beams have more of an effect than the continuous F&A girders.

Coefficient D is therefore generally caused by the excess of continuous transverse Soft Iron (i.e. -e rod, producing a +D effect) over continuous F&A Soft Iron (i.e. -a rod, producing -D effect), that is due to the predominance of +D over -D. Therefore, we normally have a +D on the ship.

If a +D is present, it must be corrected by providing -D effect of the same value by placing divided athwartship S.I., so that the -D caused by the correctors will nullify the +D of the ship in all latitudes and on all courses. This is done by providing two S.I. spheres (divided athwartships) placed one on either sides of the compass in the athwartship plane. This correction is carried out with the ship heading on any one of the intercardinal headings, where the deviation due to D is maximum.

In the unlikely event of the ship having a $-D$, the spheres would have to be placed, one forward and the other abaft the compass, to produce a $+D$.

The spheres are placed on brackets attached to the binnacle, so that their centres are in the same plane as the plane of the needle system of the compass. The amount of correction provided by the spheres can be increased or decreased by shifting them closer or further away from the compass, on their brackets.

(Recapitulate)

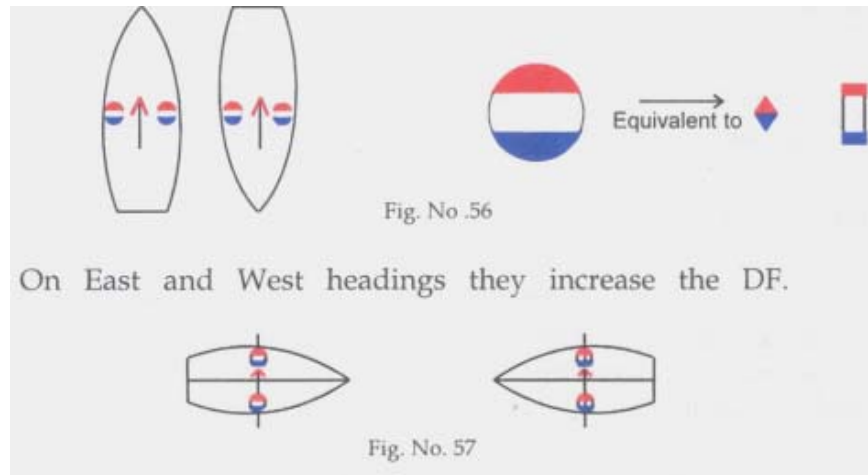
- Normally a $+D$ is present, as on merchant ships, continuous transverse beams are predominant and their poles are closer than those of F&A girders.
- $\therefore +D$ is caused by excess of transverse beams over continuous F&A girders (-e rod causing $+D > -a$ rod causing $-D$).
- Corrected by Soft Iron Spheres placed athwartship (divided, athwartship soft iron), which will cause $-D$.
- Correction done on intercardinal headings, where coefficient D produces maximum deviation.

Spheres are chosen for the following reasons:

- i) The magnetism in any material exists on the outer surface of the material and not within it. Therefore, the greater the surface area, the greater is the magnetism in a magnetic material. Volume for volume, a sphere has the largest surface area over all other geometric shapes.
- ii) The sphere is the most regular of all geometric shapes. Hence correction by them will be most uniform on all headings.
- (iii) It is important that the centres of the spheres are in level with the compass needles.
- (iv) If a $-D$ is present, the spheres are to be placed F&A of the compass.

MORE THEORY ABOUT THE S.I. SPHERES

1. The divided S.I. (spheres) in addition to correcting Coefficient D, also provides the very desirable effect of increasing the mean DF at the compass position. (Refer fig. no. 52 & 54 for coefficients +D and -D caused by divided S.I.). This is an advantage as, for the same disturbing field, the deviations would be lesser if the directive force is larger.
2. On N/S headings, the athwartship spheres decrease the DF.



However, it should be noted that when on N and S headings, if the spheres are considered as bar magnets, they are *Broad Side on* to the compass needle while when on E or W headings they are *End on* to the compass needle.

Since the field due to a magnet in the *End on* position is **double** than that in the *Broad Side on* position, at the same distance, it is clear that on East/West heading the increase in DF is 2 times the decrease in DF they cause when heading North/South. Thus the mean DF at the compass is increased.

Example 1: Given deviation on NE 4° E, SE 7° W, SW 2° W, and NW 2° E. Find Coefficient D

$$\begin{aligned}
 D &= \frac{\delta \text{ on NE} - \delta \text{ on SE} + \delta \text{ on SW} - \delta \text{ on NW}}{4} \\
 &= \frac{+4 - (-7) - 2 - 2}{4} = \frac{+7}{4} = 1.75 \\
 \therefore \text{Coefficient D} &= +1.75^{\circ}
 \end{aligned}$$

Example 2: At a place A ($H = 20$ A/m, $Z = 40$ A/m), the deviation due to coefficient D was observed to be 5° W, when heading 020° (c). Find deviation due to the same cause at place B ($H = 18$ A/m, $Z = 30$ A/m) when heading 165° (c).

Coefficient D is independent of latitude and hemisphere

$$\frac{\delta_2}{\delta_1} = \frac{\sin 2 \text{ comp. co}_2}{\sin 2 \text{ comp. co}_1}$$

$$\frac{\delta_2}{-5} = \frac{\sin 330^\circ}{\sin 40^\circ}$$

$$\delta_2 = -5 \times \frac{\sin 330^\circ}{\sin 40^\circ} = +3.9^\circ$$

Deviation = 3.9° E

Example 3: Coefficient B = $+10^\circ$, Coefficient C = -6° , Coefficient A and E are nil. The deviation on 030° (c) was $3\frac{1}{2}^\circ$ E.

- (i) What is the value of coefficient D.
(ii) What total deviation may be expected when heading 310° (c).

$$\begin{aligned} \text{(i)} \quad \delta &= B \sin \text{co} + C \cos \text{co} + D \sin 2 \text{ co} \\ +3.5 &= 10 \sin 30 - 6 \cos 30^\circ + D \sin 60^\circ \\ +3.5 &= 5 - 5.196 + .866 D \\ D &= +4.26^\circ \end{aligned}$$

$$\begin{aligned} \text{(ii)} \quad \delta \text{ on } 310^\circ \text{ (c)} &= B \sin \text{co} + C \cos \text{co} + D \sin 2 \text{ co} \\ &= 10 \sin 310 - 6 \cos 310^\circ + 4.26 \sin 620 \\ &= -7.66 - 3.8568 - 4.1953 \\ &= -7.66 - 3.86 - 4.2 = -15.72^\circ \\ &= 15.72^\circ \text{ W} \end{aligned}$$

Example 4: Deviation on $000^\circ = 5^\circ$ W, on $315^\circ = 4.7^\circ$ W, and on $270^\circ = 4^\circ$ E, where $H = 24$ A/m. Calculate the deviation on 250° (c), where $H = 16$ A/m. Coefficients A, E and induced C negligible. Induced B is corrected.

On 000° (c) deviation 5° W $\Rightarrow$ Coefficient C = -5°
On 270° (c) deviation 4° E $\Rightarrow$ Coefficient B = -4°
On 315° (c) deviation 4.7° W $\Rightarrow$ **Does not mean that coefficient D is 4.7° as coefficient B and C are also producing deviations on that heading.**

On 315° (c), we have

$$\begin{aligned}
 -4.7^\circ &= B \sin 315^\circ + C \cos 315^\circ + D \sin 630^\circ \\
 -4.7^\circ &= -4 \sin 315^\circ + (-5) \cos 315^\circ + D \sin 630^\circ \\
 -4.7^\circ &= 2.828 - 3.535 - D \\
 D &= +4.7 + 2.828 - 3.535 \\
 D &= +3.99^\circ
 \end{aligned}$$

At place (2), $B = -4 \times \frac{H_1}{H_2} = -4 \times \frac{24}{16} = -6^\circ$

$$C = -5 \times \frac{24}{16} = -7.5^\circ$$

And $D = +3.99^\circ$

Deviation on 250° (c) at place (2)

$$\begin{aligned}
 &= B \sin co + C \cos co + D \sin 2 co \\
 &= -6 \sin 250^\circ - 7.5 \cos 250^\circ + 3.99 \sin 500^\circ \\
 &= 5.638 + 2.565 + 2.5648 \\
 &= +10.76^\circ \\
 &= 10.8^\circ \text{ E.}
 \end{aligned}$$

Example 5: At a place ($H = 15 \text{ A/m}$, $Z = 24 \text{ A/m}$) the following deviations were observed. On $N = 1.5^\circ \text{ W}$, on $NE = 0.5^\circ \text{ E}$, and on $East = 2^\circ \text{ E}$. Assume no A & E . What deviation could be expected at another place ($H = 10 \text{ A/m}$, $Z = +24 \text{ A/m}$) on a course of 105° (c).

On 000° (c) deviation $1.5^\circ \text{ W} \Rightarrow$ Coefficient $C = -1.5^\circ$

On 090° (c) deviation $2.0^\circ \text{ E} \Rightarrow$ Coefficient $B = +2^\circ$

On 045° (c) deviation $0.5^\circ \text{ E} \Rightarrow$ **Does not mean that coefficient D is 0.5° , as δ due to B and C are also present.**

To find Coefficient D at place (1).

$$\begin{aligned}
 \delta \text{ on NE} &= 0.5 = B \sin 045^\circ + C \cos 045^\circ + D \sin 090^\circ \\
 0.5 &= 2 \times 0.707 - 1.5 \times 0.707 + D \\
 0.5 &= 1.41 - 1.06 + D \\
 D &= 0.5 + 1.06 - 1.41 \\
 D &= +0.15^\circ
 \end{aligned}$$

Since Z is same at both places, iB and iC (if present) will only vary inversely as H . i.e. total B and total C will vary inversely as H .

Therefore if we use $\frac{H_1}{H_2}$, we will obtain the values of total B (PB and iB) and total C (PC and iC) at the 2^{nd} place.

At place 2 :

$$B = 2 \times \frac{H_1}{H_2} = \frac{+2 \times 15}{10} = +3^\circ$$

$$C = -1.5 \times \frac{15}{10} = \frac{-9}{4} = -2.25^\circ$$

$$D = +0.15^\circ \text{ (unchanged)}$$

Deviation on 105°

$$\begin{aligned} &= B \sin 105 + C \cos 105^\circ + D \sin 210^\circ \\ &= 3 \times 0.9659 - 2.25 \times -0.2588 + 0.15 \times -0.5 \\ &= 2.898 + .5823 - .075 \\ &= +3.4^\circ \\ &= 3.4^\circ \text{ E} \end{aligned}$$

Example 6: Coefficient $B = +4^\circ$, $C = +4^\circ$, $D = +3^\circ$, induced $B = -3^\circ$ ($H = 20 \text{ A/m}$, $Z = 10 \text{ A/m}$). Calculate the deviation on 030° (c), where ($H = 10 \text{ A/m}$, $Z = -25 \text{ A/m}$).

Place (1)

$$\text{Total } B = +4^\circ$$

$$iB = -3^\circ$$

$$PB = +7^\circ$$

$$C = +4^\circ$$

Place (2)

$$\frac{PB_2}{PB_1} = \frac{H_1}{H_2}; \frac{PB_2}{7} = \frac{20}{10}$$

$$= PB_2 = +14^\circ$$

$$\frac{iB_2}{iB_1} = \frac{H_1}{H_2} \times \frac{Z_2}{Z_1}$$

$$iB_2 = -3 \times \frac{20}{10} \times \frac{-25}{10}$$

$$iB_2 = +15^\circ$$

$$PB_2 = +14^\circ$$

$$\text{Total } B = 29^\circ$$

$$PC_2 = 4 \times \frac{20}{10} = 8^\circ$$

$$\begin{aligned} \delta 030^\circ C &= B \sin 30 + C \cos 30 + D \sin (2 \times 30^\circ) \\ &= +29^\circ \sin 30 + 8 \cos 30 + 3 \sin 60 \\ &= +14.5 + 6.93 + 2.6 \\ &= +24.03 \\ &= 24.03^\circ \text{ E} \end{aligned}$$

Example 7: At a place where dip is $+ 30^\circ$, a flinders bar forward of the compass is correcting a maximum deviation due to V.S.I of 4° and athwartship spheres are correcting a maximum deviation of 4° . What deviation would be corrected by these correctors on a course of $315^\circ(c)$, where dip is $+ 70^\circ$.

FB ford in Northern hemisphere $\Rightarrow$ it is causing $+ iB$ and it will vary as $\tan$ dip.

$$\frac{\delta_2}{\delta_1} = \frac{\delta_2}{+4} = \frac{\tan 70}{\tan 30} = \frac{2.7475}{.5774}$$

$$\begin{aligned}\delta_2 &= +4 \times 4.7858 \\ &= +19.03^\circ\end{aligned}$$

$$\begin{aligned}\text{Deviation on } 315^\circ (c) &= 19.03 \times \sin 315^\circ \\ &= 19.03 \times -.7071 \\ &= -13.46^\circ\end{aligned}$$

$\therefore$ it corrects for $+13.46^\circ$.

Spheres athwartships cause $-D$, and does not change with latitude but only with comp.co.

$$\begin{aligned}&= -4 \sin 2 (315^\circ) \\ &= -4 \times \sin 630^\circ \\ &= -4 \times \sin 270 \\ &= +4^\circ \\ \therefore \text{ They correct for } -4^\circ.\end{aligned}$$

$$\begin{aligned}&- 13.46 \\ &+ 4.00\end{aligned}$$

$$\text{Net cause of correctors} = - 9.46^\circ (W)$$

Together, they are correcting a deviation of 9.46° E (as they are causing -9.46°).

Example 8: During a swing through 360° , the following deviations were observed on inter-cardinal headings: NE: 5° E, SE: 2° W, SW: 1° E, NW: 4° W. The spheres were then placed on their brackets, 40 cms apart and equidistant from the compass. A further swing of 360° was done and the following deviations observed on the inter cardinal headings.

NE: 3° E, SE: 1° W, SW: 0.5° E, NW: 2° W. How should the spheres be readjusted.

Original value of Coefficient D (without spheres)

$$= \frac{\delta \text{ on NE} - \delta \text{ on SE} + \delta \text{ on SW} - \delta \text{ NW}}{4}$$

$$= \frac{+5 + 2 + 1 + 4}{4} = \frac{12}{4} = 3^0 \text{ E}$$

Coefficient D of ship alone = $+3^0$

Similarly D of ship and spheres together

$$= \frac{+3 - (-1) + 0.5 - (-2)}{4} = \frac{6.5}{4} = +1.6^0$$

Coefficient D of ship alone = $+3^0$

Coefficient D of ship and spheres = $+1.6^0$

$\therefore$ D of spheres alone = (-1.4^0)

The spheres are under correcting, placed 40 cms apart. They are causing -D of 1.4^0 , while they should cause a -D of 3^0 . The effect of the corrector varies inversely as the cube of its distance from the compass.

$$\delta_1 \rightarrow -1.4^0 ; \text{dist } d_1 = 40 \text{ cms}$$

$$\delta_2 \rightarrow -3^0 ; \text{dist } d_2 = ?$$

$$\frac{\delta_1}{\delta_2} = \frac{d_2^3}{d_1^3} \Rightarrow d_2^3 = (40)^3 \times \frac{1.4}{3}$$

$$d_2 = 40 \times \sqrt[3]{\frac{1.4}{3}} = 31 \text{ cms.}$$

Move spheres closer till they are 31 cms apart.

Example 9 : During a swing through 360^0 , the following deviations were observed on intercardinal headings. NE: 2.5^0 E, SE: 1^0 W, SW: 0.5^0 E, NW: 2^0 W. Spheres were then placed athwartships 20cms apart. Coefficients B and C were properly corrected and the deviation on NE was then found to be 0.5^0 W. How should the spheres be readjusted? Assume A is nil.

$$\begin{aligned} \text{Coefficient D (without spheres)} &= \frac{\delta \text{ NE} - \delta \text{ SE} + \delta \text{ SW} - \delta \text{ NW}}{4} \\ &= \frac{2.5 - (-1) + 0.5 - (-2)}{4} = \frac{6}{4} = +1.5 \end{aligned}$$

When heading 045^0 , the deviation would be due to B, C and D. Since B and C have been properly corrected any deviation on NE, thereafter, is only due to D.

$$\begin{aligned}
 \therefore D \text{ of ship and spheres} &= -0.5^0 \\
 \text{But } D \text{ of ship alone} &= +1.5^0 \\
 \therefore D \text{ of spheres} &= -2^0
 \end{aligned}$$

The spheres are therefore over compensating. They should have caused a -D of 1.5^0 . Instead they are causing a -D of 2^0 . They should therefore be moved out.

$$\delta_1 = 2^0 \quad d_1 = 20 \text{ cms.}$$

$$\delta_2 = 1.5^0 \quad d_2 = ?$$

$$\frac{d_2^3}{d_1^3} = \frac{\delta_1}{\delta_2}$$

$$d_2^3 = 20^3 \times \frac{2}{1.5}$$

$$d_2 = 20 \sqrt[3]{\frac{2}{1.5}} = 22.01 \text{ cms.}$$

Move the spheres out till they are 22 cms apart.

Example 10: A vessel was swung and the following deviations were observed. NE 6^0 E, SE 3^0 E, SW 4^0 E, NW 7^0 W. The spheres were then secured in place in the athwartship line with their centres 60 cms apart. The deviation on NE was then observed to be 3.5^0 E. What alteration should be made in the position of the spheres to correct for Coefficient D? Assume A & E nil. Also state the residual deviations on the inter cardinal headings after the spheres have been correctly positioned.

Coefficient D (without spheres)

$$\begin{aligned}
 &= \frac{\delta \text{ on NE} - \delta \text{ on SE} + \delta \text{ on SW} - \delta \text{ on NW}}{4} \\
 &= \frac{6 - 3 + 4 - (-7)}{4} \\
 &= \frac{14}{4} = +3.5^0
 \end{aligned}$$

On NE, without spheres, deviation was 6^0 E.

On NE, with spheres, deviation is 3.5^0 E.

$\therefore$ spheres cause -2.5^0 , when placed 60 cms apart.

On NE, spheres have caused a -D of 2.5^0 i.e. 2.5^0 W. We can say that this 2.5^0 W is solely due to spheres, because no other changes have been made and vessel has not changed latitude either.

But they should cause -3.5° to correct the $+3.5^\circ$ (D of ship)

$$\frac{d_2^3}{d_1^3} = \frac{\delta_1}{\delta_2}$$

$$d_2^3 = \frac{60^3 \times 2.5}{3.5} \Rightarrow d_2 = 53.63 \text{ cms.}$$

Move the spheres closer, till they are 53.63 cms apart. They should then correctly compensate a +D of 3.5° .

By correctly positioning the spheres athwartships we have introduced a -D of 3.5° . A -D gives Westerly deviation on NE and SW and Easterly deviations on SE and NW. Therefore if these effects are applied to the original deviations, we obtain the residual deviations after the spheres are correctly positioned.

Deviations without spheres	Effect of placing spheres correctly	Deviations after spheres are correctly placed.
NE 6° E	3.5° W	2.5° E
SE 3° E	3.5° E	6.5° E
SW 4° E	3.5° W	0.5° E
NW 7° W	3.5° E	3.5° W

Example 11: With no spheres in position the deviation on NE was 2° W. Spheres were then placed athwartship 60 cms. apart and the following deviations were observed:-

NE: 10° W, SE: 1° E, SW: 2° E, NW: 6° W.

How should the spheres be moved to correct Coefficient D. What are the residual deviations after correcting Coefficient D.

$$\text{D of ship and spheres} = \frac{-10 - 1 + 2 - (-6)}{4} = -0.75^\circ$$

$$= 0.75^\circ \text{ W}$$

δ on NE : 2° W (effect of B, C & D)

δ on NE with spheres 10° W (effect of B,C,D and spheres)

$\therefore$ effect of spheres on NE : 8° W

$\therefore$ D of spheres = 8° W = -8°

D of ship and spheres = -0.75°

$\therefore$ D of ship alone = $+7.25^\circ$

Spheres are causing 8° W, they should cause 7.25° W. $\therefore$ they are over correcting. They should be moved outwards.

$$d_2^3 = \frac{60' \times 8}{7.25} = 62 \text{ cms. (Move outwards.)}$$

By moving the spheres outwards, we have reduced the D of spheres from -8^0 to -7.25^0 i.e. by moving the spheres, we have introduced a +D affect of .75. A +D will provide Easterly deviations on NE and SW and Westerly deviations on SE and NW.

Hdg.	Deviation with spheres in original position	Effect of shifting spheres	Residual deviation after shifting spheres.
NE	10^0 W	0.75^0 E	9.25^0 W
SE	1^0 E	0.75^0 W	0.25^0 E
SW	2^0 E	0.75^0 E	2.75^0 E
NW	6^0 W	0.75^0 W	6.75^0 W

The residual deviations are being caused by B and C. However, it will be seen that if we calculate D, using the residual deviations on the intercardinal headings, we obtain the value of D as nil.

CHAPTER 9

COEFFICIENT E

DEFINITION: Coefficient E is the maximum value of the quadrantal deviation which varies as the cosine of twice the compass course and is caused by a horizontal field at the compass position due to induced magnetism in horizontal S.I. situated symmetrically about a 45° line through the compass position.

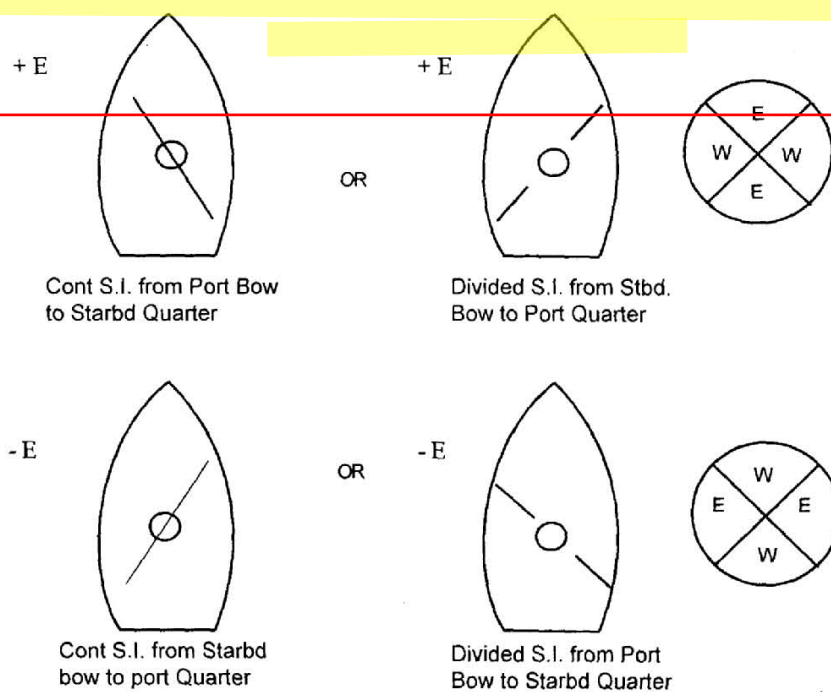


Fig. No. 58

In terms of rods, coefficient E is caused by b and d rods of the same name.

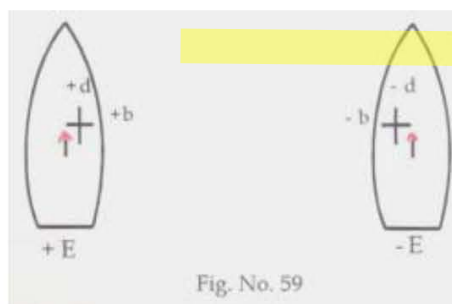
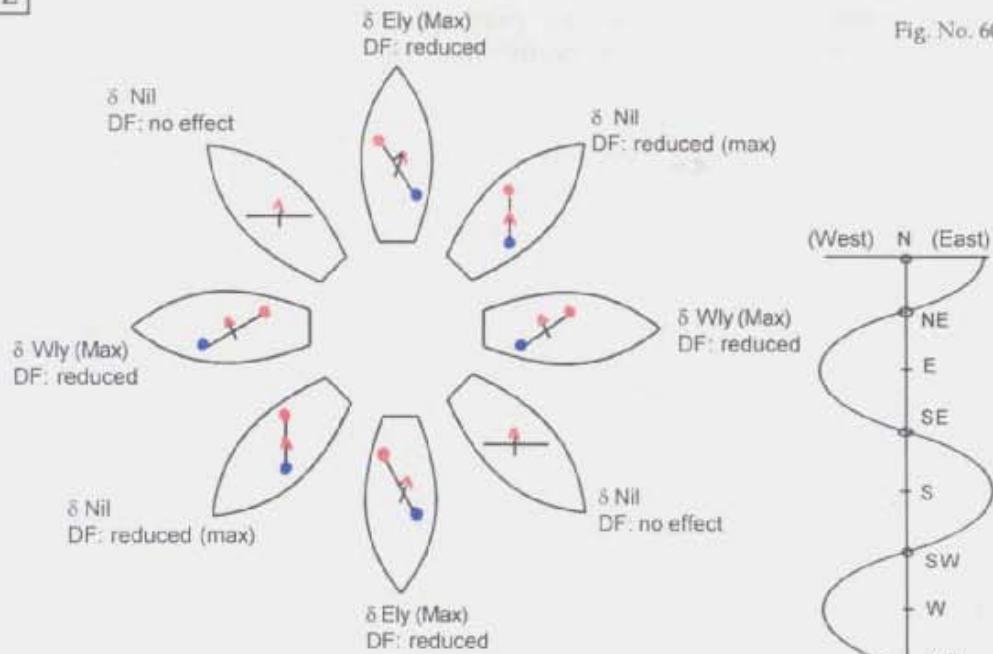


Fig. No. 59

+ E

Fig. No. 60



The mean DF at the compass position is reduced.

+E

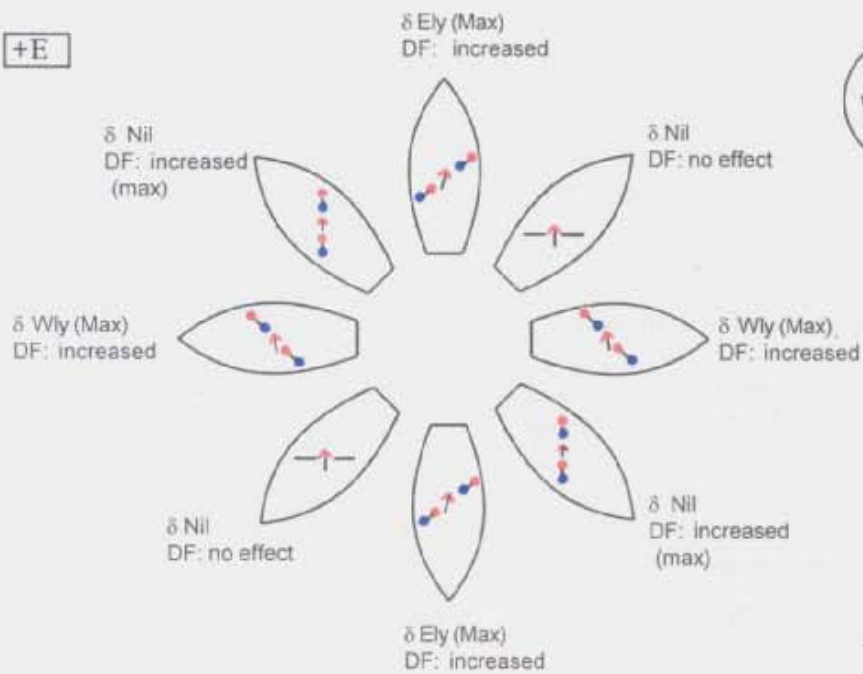
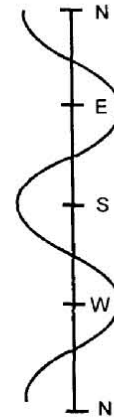
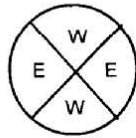


Fig. No. 61

The Mean DF at the compass is increased.

It is suggested that the student draws similar figures for a -E caused by continuous S.I. stbd. bow to port quarter or divided S.I. port bow to stbd. quarter. He should verify that the deviations produced are as below.



Both the above arrangements, (continuous S.I., port bow to stbd. quarter and divided S.I., stbd. bow to port quarter produce the same pattern of deviations with change of ship's head. But continuous S.I. reduces the mean DF while divided S.I. increases it. However, both arrangements give greater DF on NW and SE as compared to those on NE and SW. Conversely, if the DF on NE and SW is greater than the DF on NW and SE, it indicates existence of a -E.

Coefficient E causes deviations of one name over continuous opposite quarters of the ship's heading and of the other name over the other two continuous opposite quarters of the ship's heading. Deviation due to E is nil on the inter-cardinal headings and maximum on the cardinal headings. Therefore, deviation due to E varies directly as the cosine of twice the compass course.

Effect of Latitude and Change of Course:

The same arguments apply as they do for coefficient D. Since the Horizontal S.I. is induced by H, the amount of induction in them, i.e. the disturbing field, as well as the directive force, H increase and decrease together, the deviation due to Coefficient E is therefore independent of latitude. Therefore, the deviation due to E varies only directly as the cosine of twice the compass course.

$$\text{Coefficient } E = \frac{\delta \text{ on N} - \delta \text{ on E} + \delta \text{ on S} - \delta \text{ on W}}{4}$$

$$\delta \text{ due to E} = E \times \cosine 2 \text{ comp. course}$$

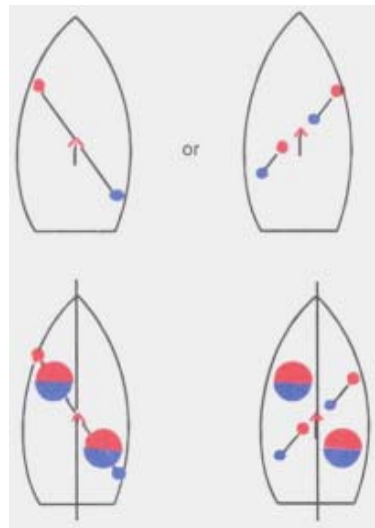
$$\text{and } \frac{\delta_2}{\delta_1} = \frac{\cos 2 \text{ comp. } co_2}{\cos 2 \text{ comp. } co_1}$$

Correction of Coefficient E:

On a normal merchant ship, an arrangement of S.I. running diagonally is seldom present. Therefore coefficient E will normally be absent on merchant ships. However if it is present, correction is done by S.I. spheres as for Coefficient D, but placed diagonally.

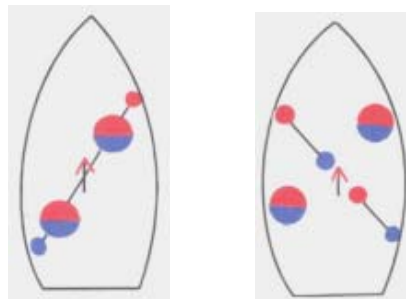
If a +E is present at the compass, a -E can be introduced by the spheres placed at an angle of 45° (port bow and stbd. quarter (note: divided S.I. port bow to stbd. quarter produces a -E). By moving the spheres in or out, the correction they provide can be varied till they exactly nullify the +E of the ship.

+E



-E

If a -E is present, a +E is created by placing the S.I. spheres on starboard bow and port quarter.



CORRECTION OF D & E TOGETHER

When both D and E are present, both of them are corrected by a single set of spheres slewed to some intermediate angle M^0 from the position they correct D alone. Angle of slew M^0 is found from the relationship.

$$\begin{aligned}\tan 2 M &= \frac{E}{D} \\ \tan \text{ twice angle of slew} &= \frac{E}{D}\end{aligned}$$

The spheres are initially placed in the direction necessary to correct the D of the ship. (Athwartships to correct +D and F&A to correct -D). They are then slewed through the angle M. The direction of slew is obtained in a similar manner to that of the flinders bar. If both D and E are of the same signs, slew the spheres clockwise and if they are of opposite signs, slew them anticlockwise.

Maximum deviation due to D and E

The maximum deviation due to D and E together is obtained as $\sqrt{D^2 + E^2}$. It can be proved mathematically that maximum deviation due to D and E together occurs when the spheres in the slewed position lie in the NE/SW or NW/SE direction from the compass.

The reason for this is that any horizontal soft iron will produce maximum deviation when they lie in a NE/SW or NW/SE direction.

(Recapitulate)

1. **Maximum Deviation** due to D and E together = $\sqrt{D^2 + E^2}$
and occurs when spheres lie NE/SW, NW/SE direction from compass.
2. $\tan 2 M = \frac{E}{D}$ (Angle M is the angle from the position where spheres correct D alone. From athwartships if D is +ve, and from F&A line when D is -ve.)
3. Maximum deviation occurs when the slewed spheres are in the NE/SW or NW/SE line.

Procedure for Slewing:

To correct a +D, the brackets for the spheres have to be placed athwartships. To correct a -D, the brackets have to be placed F&A. Similarly, to correct a +E, they should be placed port bow and stbd. quarter and to correct a -E they should be placed stbd. bow and port quarter.

When a + or - D is present and a + or - E is present, the bracket for the spheres have to be at an intermediate position such that the spheres would correct both the D and the E that is present.

Thumb Rule

- (i) If D and E are of the **same** signs, slew **clockwise**, from the position the spheres correct coefficient D.

If D and E are of **opposite** signs, slew **anti-clockwise** from the position the spheres correct coefficient D.

- (ii) **To determine course on which to correct the combined effect.**

All coefficients are corrected on the heading on which they produce maximum deviations. On those headings the correctors are also providing maximum correction. Therefore find one heading on which the spheres will lie either in the NE/SW direction or in the SE/NW direction. Then find the other three headings by adding or subtracting 90° successively. The combined correction can be done on any of those four headings.

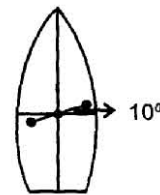
Slewing of spheres: (D & E together)

Example: If coefficient D was $+5.5^\circ$ and coefficient E was -2° , where are the spheres to be positioned, what are the headings on which the combined correction should be done and what is the maximum deviation due to D & E together which the spheres should correct?

$$\tan 2M = \frac{E}{D} = \frac{2}{5.5} = .3636$$

$$2M = 20^\circ$$

$$M = 10^\circ$$



Since D is +ve, place the spheres athwartships and slew 10° anticlockwise as D and E are of opposite signs, (stbd sphere for'd and port sphere aft). When heading North, with the spheres slewed, they are lying 10° to the North of E and 10° to the South of W. To bring them in the NE - SW direction from the compass, the ship must swing 35° to port i.e. head N 35° W or 325° . Once we obtain one of the headings, we

may obtain the other three headings when the spheres will be in the NE - SW or SE - NW directions from the compass by successively adding or subtracting 90° to the heading initially found. In this example they will be 235° , 145° and 055° in addition to 325° , the heading initially found. The maximum deviation due to D and E combined would be $\sqrt{5.5^2 + 2^2} = 5.85^\circ$ which is the deviation the slewed spheres should correct when on one of the above headings.

Example 1. How should S.I. spheres be placed on the binnacle to correct a combination of $D = +2^\circ$ and $E = -3^\circ$. State the maximum deviation they should correct and on what headings?

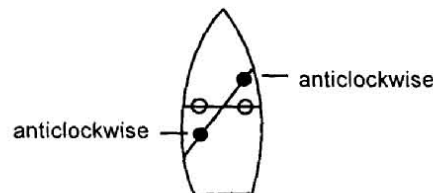
$$\tan 2M = \frac{3}{2} = 1.5$$

$$2M = 56.3^\circ$$

$$\therefore M = 28.15^\circ \text{ say } 28^\circ$$

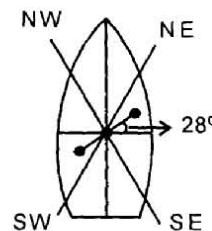
Angle of slew 28°

As D is +ve, the spheres should initially be athwartship and since D and E are of opposite signs, slew anticlockwise. Spheres must be slewed 28° , from athwartship, starbd. sphere for'd and port sphere abaft the beam.



$$\text{Maximum deviation } \sqrt{D^2 + E^2} = \sqrt{2^2 + 3^2} = \sqrt{13} = 3.6^\circ$$

$$\text{amount to be corrected} = 3.6^\circ$$



To bring spheres in NE - SW direction, she must swing 17° to Port.

$\therefore$ one of the headings is $N 17^\circ W = 343^\circ$.

The other headings on which the correction can be made are 253° , 163° and 073° .

Example 2. There was no quadrantal deviation with the spheres placed 15° from the F & A line, fore sphere to starbd. and correcting for a maximum deviation of 6° . Find values of D and E.

$$\tan 2M = \frac{E}{D}$$

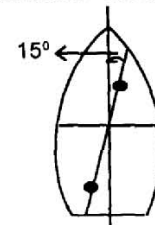
$$\text{maximum Deviation} = \sqrt{D^2 + E^2}$$

Since the spheres are F&A, the ship's D is -ve. Also since they are slewed clockwise the ship's E is also negative.

$$\tan 2 \times 15^\circ = \tan 30^\circ = \frac{E}{D}$$

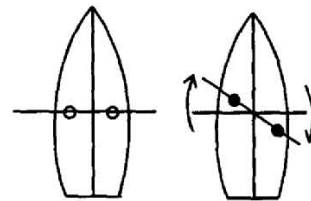
$$D = \text{Maximum } \delta \cos 30^\circ = -5.2^\circ$$

$$E = \text{Maximum } \delta \sin 30^\circ = -3^\circ$$



Example 3. There was no deviation due to D and E on any course with S.I. spheres in position slewed 15° from the athw line, port sphere fore. Coefficient D was known to be $+6^\circ$. Find value of E and the maximum deviation D and E together cause.

D is +ve



Since spheres are slewed clockwise, Coefficient E must also be +ve.

$$\tan 2M = \tan 30^\circ = \frac{E}{D}$$

$$\therefore E = D \tan 30^\circ = 6 \cdot \tan 30^\circ = 3.46^\circ$$

$$E = +3.46^\circ$$

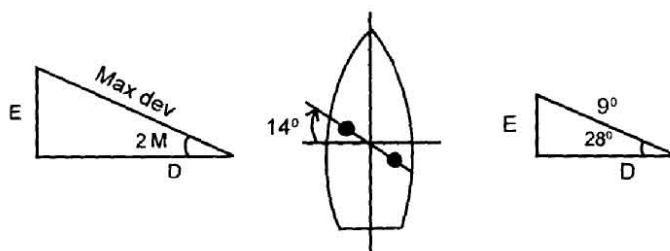
$$\text{Maximum deviation} = \sqrt{3.46^2 + 6^2} = 6.92^\circ$$

Example 4: The two spheres on a compass are known to be correcting a maximum quadrantal deviation of 9° when slewed 14° from the athwartship line, port sphere forward. A swing for deviations gave the following results :-

N	2.5° E	S	1.0° W
NE	0.5° E	SW	2.5° E
E	2.0° W	W	0.5° W
SE	1.0° E	NW	2.0° W

What alteration if any should be made in the position of the spheres, to correctly compensate for the quadrantal deviations?

Spheres are correcting maximum deviation of 9° , when slewed 14° from the athw line $\Rightarrow$ spheres are causing $-D$ and $-E$.



$$\tan 28^\circ = \frac{E}{D} \quad \text{-----} \quad (1)$$

$$\text{From figure } \frac{E}{9} = \sin 28^\circ, E = 9 \sin 28^\circ = 9 \times .4695 = 4.225^\circ$$

$$\frac{D}{9} = \cos 28^\circ, D = 9 \cos 28^\circ = 9 \times .8829 = 7.946^\circ$$

$$E \text{ of spheres} = -4.225^\circ$$

$$D \text{ of spheres} = -7.947^\circ$$

$$D \text{ of ship and spheres} = \frac{+0.5 - 1^\circ + 2.5^\circ - (-2)^\circ}{4} = +1^\circ$$

$$D \text{ of ship and spheres} = +1^\circ$$

$$E \text{ of ship and spheres} = \frac{\delta N - \delta E + \delta S - \delta W}{4} = \frac{2.5 - (-2) - 1 - (-.5)}{4} = 1^\circ$$

$$E \text{ of ship and spheres} = +1^\circ$$

$$D \text{ of ship and spheres} = +1^\circ \quad E \text{ of ship and sphere} = +1^\circ$$

$$D \text{ of spheres alone} = -7.947^\circ \quad E \text{ of spheres alone} = -4.225^\circ$$

∴ D of ship alone +8.947° E of ship alone +5.225°

$$\tan 2M = \frac{5.225}{8.947} = 0.584 = 30.3^\circ$$

$$\therefore M = 15^\circ$$

$$\text{Maximum deviation} = \sqrt{5.225^2 + 8.947^2} = 10.36^\circ$$

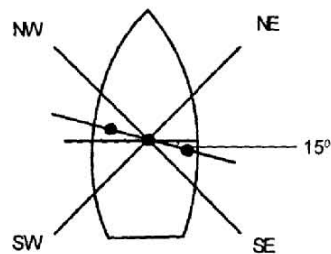
$$\text{Maximum deviation} = 10.36^\circ$$



Since the ship's D and E are +ve.

Place the spheres athwartships and slew clockwise through 15° to correct 10.36° .

To determine headings



To bring the spheres in NW-SE line, the ship must swing 30° to stbd., i.e. we have to head 030° . The other headings on which the correction can be made are 120° , 210° and 300° .

Example 5: Vessel was swung with spheres placed at a distance of 30 cms apart and slewed 8° from the athw. line, starbd sphere fwd. It is known that these spheres correct a maximum quadrantal deviation of 10° when placed 30 cms apart. In this condition coefficient D was found to be -2° and coefficient E = -1° . How would you make a correct adjustment for quadrantal deviation?

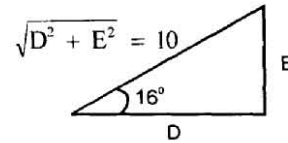
$$M = 8^\circ$$

$$\therefore 2 M = 16^\circ$$

$$\frac{D}{10} = \cos 16^\circ$$

$$D = 10 \cos 16^\circ = 10 \times .9613 = 9.613^\circ$$

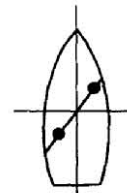
$$E = 10 \sin 16^\circ = 10 \times .2756 = 2.756^\circ$$



Since the spheres are athwartships, and slewed anticlockwise, the spheres would cause -D and +E.

$$\therefore D \text{ of spheres} = -9.61^\circ$$

$$\text{and } E \text{ of spheres} = +2.76^\circ$$



D of ship and spheres = -2°	E of ship and spheres = -1°
D of spheres alone = -9.61°	E of spheres = $+2.76^\circ$
D of ship alone = $+7.61^\circ$	E of ship alone = -3.76°

$$\tan 2 M = \frac{3.76}{7.61} = 26^\circ 20'$$

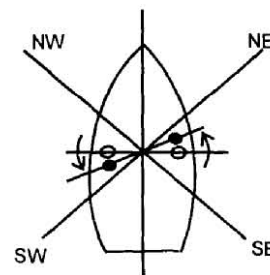
$$M = 13^\circ - 10', \text{ say } 13^\circ$$

Since D is +ve and E is -ve, place the spheres athwartship and slew anticlockwise through 13° i.e. starbd sphere fwd from athw line.

$$\text{Max. deviation} = \sqrt{D^2 + E^2} = \sqrt{(7.61)^2 + (3.76)^2} = 8.6^\circ$$

$$\frac{d_2^3}{d_1^3} = \frac{\delta_1}{\delta_2} \quad \therefore d_2^3 = 30^3 \times \frac{10}{8.6}$$

$$\therefore d_2 = 31.5 \text{ cms.}$$



The spheres should be placed 31.5 cms. apart.

$$\text{Headings } N 32^\circ W = 328^\circ$$

Headings on which correction can be made are 328° , 238° , 148° or 058°

EXERCISE II

(Coefficients D & E)

1. At A ($H = 20$ A/m, $Z = -30$ A/m) the deviation due to D was 6° E when heading 110° (C). Find the value of coef. D. Also find the deviation due to the same cause when heading 030° at B ($H = 24$ A/m, $Z = 18$ A/m).
2. At P, in the N. hemisphere, coef. E was -2° . Find the deviation due to E at Q in the S. hemisphere when heading 300° (C).
3. Coef. B was $+7^\circ$ and coef. C was -6° . The deviation on 330° (C) was 10° W. Find the value to Coef. D assuming A and E are nil.
4. During a swing through 90° , the following deviations were observed: N(C): 5° W, NE(C): 2° E, E(C): 2° E. If coefs. A and E are nil, calculate the value of coef. D and the total deviation when heading 330° (C).
5. The following deviations were observed:
S(C): 4° E, SW(C): 2° E, W(C): 2° W. Coefs. A and E are nil.
Calculate the deviation when heading 340° (C).
6. Coef. D was $+6^\circ$ and Coef. E was -1.5° . What is the maximum deviation they will together cause and on what headings will it occur?
7. With the spheres athwartships, 36 cms apart, correcting 6° of deviation, the following deviations were observed:

Comp.hd:	N	NE	E	SE	S	SW	W	NW
Deviation:	6° W	1° W	5° E	3° E	1° E	3° E	0°	5° W

Calculate the values of coefs. D & E. How would you adjust the spheres to correct for both?

What are the headings on which the combined correction may be carried out and what deviation should the spheres correct on those headings?
8. The following deviations were observed on the intercardinal headings: NE: 5° E, SE: 2° W, SW: 1° E and NW: 4° W. The spheres were then placed 36 cms. apart and coefs. B & C were corrected, coef. A was nil. Thereafter, the deviation on NE was found to be 1° W. How would you re-adjust the spheres?
9. The following deviations were observed on the intercardinal headings: NE: 16° E, SE: 6° W, SW: 5° E, NW: 21° W. Spheres were then placed

40 cms apart and the deviation on NW was found to be 12° W. How should the spheres be adjusted and what would be the deviations on the intercardinal headings after the adjustment?

10. The deviation was observed to be 3° W when heading NE. Spheres were then placed 38 cms apart and the following deviations were observed: NE 12° W, SE 1° E, SW 3° E and NW 5° W. How would you re-adjusted the spheres and what residual deviations would you expect on the intercardinal headings?
11. If D & E were fully corrected by spheres placed athwartships and slewed 8° clockwise causing a maximum correction of 7° , calculate coefs. D and E of the ship.
12. Coefs. D and E were correctly compensated by spheres placed athwartships and slewed 10° , stbd. sphere for'd. If coef. D was $+5^{\circ}$, calculate the value of coef. E, the maximum correction provided by the spheres and the headings on which the combined correction may have been done.
13. Coefs. D and E are fully corrected by spheres placed athwartships 35 cms apart and slewed $17\frac{1}{2}^{\circ}$, port sphere for'd. Later, due to structural alterations to the ship, the value of D increased to 1.5 times its original value and that of E reduced to 0.6 of its original value. How are the spheres to be adjusted?

EXERCISE III

(All coefficients)

- During a swing through 360° , the following compass bearings were obtained of a distant object. Calculate the various coefficients and the total deviation when heading $120^\circ(\text{C})$ and $340^\circ(\text{C})$.

C.Hdg.	N	NE	E	SE	S	SW	W	NW
C. Brg.	129°	133°	137°	135°	132°	128°	125°	121°

- The following errors were obtained during a full swing.

C.Hdg.	N	NE	E	SE	S	SW	W	NW
Error	12° E	7° E	8° W	18° W	12° W	1° E	8° E	10° E

Calculate the coefficients and the deviation when heading $113^\circ(\text{C})$.

- During a swing through 360° , the following compass bearings were observed and true bearings calculated of a star. Calculate the value of variation at that place, assuming coef. A is nil. Calculate the errors and deviations on the eight headings.

	N	NE	E	SE	S	SW	W	NW
T.Brg:	276°	276°	276.5°	277°	277.5°	278°	278.5°	279°
C.Brg:	281°	284°	279.5°	274°	270.5°	274°	278.5°	285°

Calculate the various coefficients: 1) using the errors and 2) using the deviations. Calculate the error of the compass when heading $230^\circ (\text{C})$.

- At P ($H = 15\text{A/m}$, $Z = 20\text{A/m}$), the following deviations were observed:

C.Hdg.	N	NE	E	SE	S	SW	W	NW
Deviation	5° E	3.5° E	0°	3.5° W	5° W	3.5° W	0° W	3.5° E

At Q ($H = 15\text{A/m}$, $Z = -20\text{A/m}$), the deviations were as follows:

C.Hdg.	N	NE	E	SE	S	SW	W	NW
Deviation	0°	3.5° E	5° E	3.5° E	0°	3.5° W	5° W	3.5° W

How would you correct the compass at Q.

- At position 1, ($H = 18 \text{ A/m}$, $Z = 36 \text{ A/m}$) a compass was corrected with flinders bar for'd, F & A magnets red for'd, athwartship magnets red to stbd. and spheres athwartships. At position 2, the following deviations were observed. ($H = 18\text{A/m}$, $Z = -24\text{A/m}$).

C.Hdg.	N	NE	E	SE	S	SW	W	NW
Deviation	Nil	3.5° E	5° E	3.5° E	Nil	3.5° W	5° W	3.5° W

What adjustments are necessary to the correctors at position 2?

CHAPTER 10

HEELING ERROR

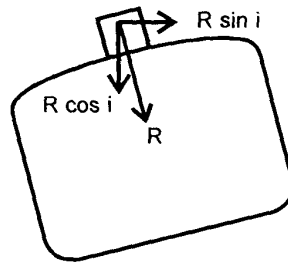
With the knowledge of Coefficients A, B, C, D and E and the measures for their correction, we can ensure that the compass does not have any deviation on any heading in any latitude, provided the ship is **UPRIGHT**. When the ship heels, however, certain effects can result in the compass being deviated.

DEFINITION

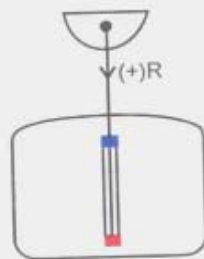
Heeling Error is the difference in deviation between that when the ship is upright and that when heeled on the same course. Thus if the deviation was 5° E when upright and 7° E when heeled, the heeling error is 2° E.

CAUSE OF HEELING ERROR

When a ship heels, the compass being gimballed remains horizontal. A magnetic field acting vertically at the compass position will cause no deviation when ship is upright. But when the ship heels this field acts at an oblique angle. The horizontal component of this oblique field will cause a deviation (called Heeling Error).

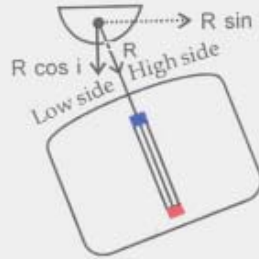


i = angle of heel



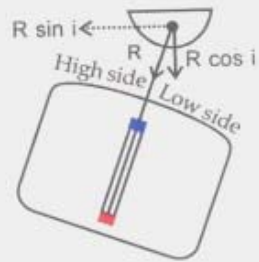
Upright

No deflecting force



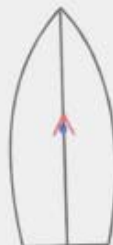
Port Heel

Deflecting force to High Side



Starbd heel

Deflecting force to High Side



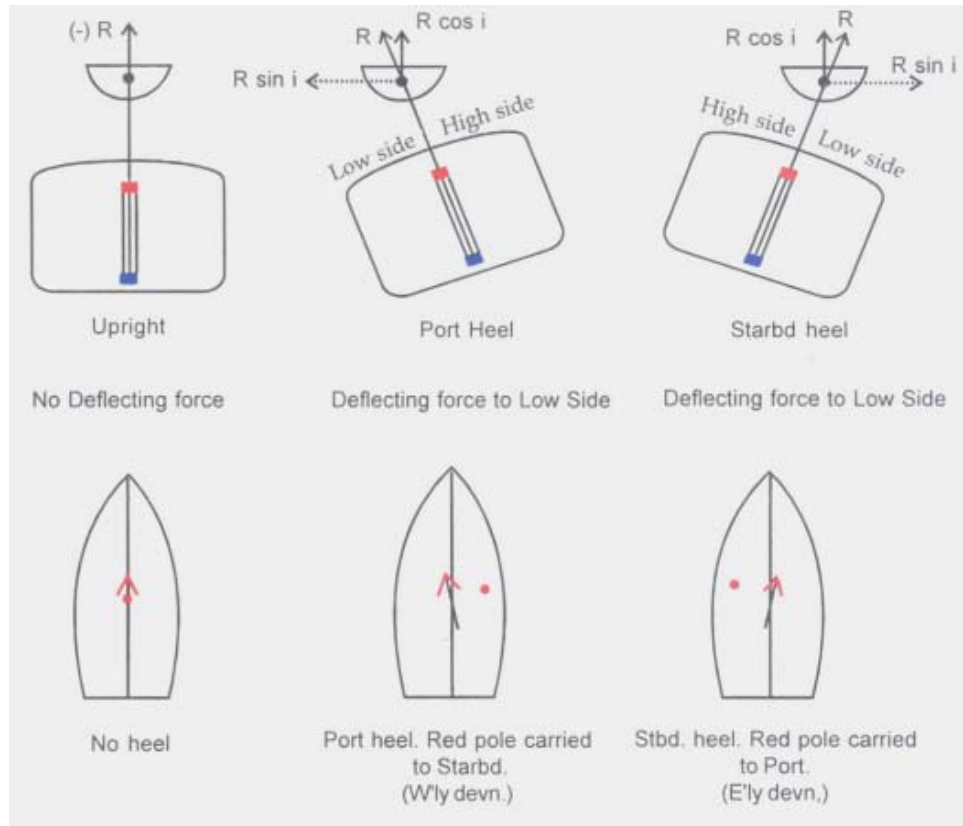
No heel
No devn.



Port heel. Blue pole
carried to Starbd.
(E'ly devn.)



Starbd heel. Blue pole
carried to Port.
(W'y devn.)



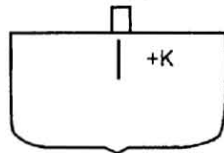
A blue predominating below the compass causes a heeling error to the high side and a red predominating below the compass causes a heeling error to the low side when the vessel heels. Therefore when a vessel is rolling, it causes an oscillation of the compass card, which makes steering difficult. Rolling makes the card swing from one side to the other side, resulting in a very unsteady compass.

The total heeling error is composed of :-

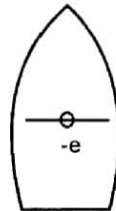
- Permanent heeling error and
- Induced heeling errors

PRINCIPAL CAUSES

1. **Permanent H/E** due to force R, the vertical component of the ship's permanent magnetic field at the compass position.
2. **Induced H/E**
 - (i) **k rod Heeling Error:**
caused due to induced magnetism in the vertical soft iron, above or below the compass, e.g. pillars, induced by Z.

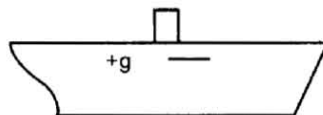


- (ii) **e rod Heeling Error:**
caused due to induced magnetism in horizontal athwartship soft iron, induced by Z. Generally, these are the soft iron which give rise to coefficient D.

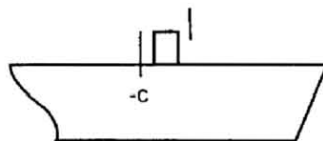


Other causes of heeling error are also due to induced magnetism but usually have very insignificant effect. They are:

- (i) **g rod Heeling Error** : caused due to induced magnetism in F & A horizontal soft iron terminating below the compass, induced by H.



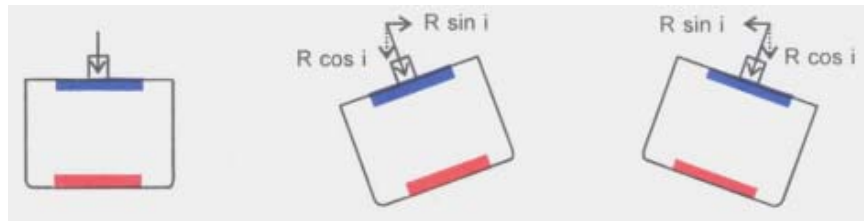
- (ii) **c rod Heeling Error:** caused due to induced magnetism in vertical soft iron forward or abaft the compass, induced by H.



Let us now discuss each of the above in some detail.

PERMANENT HEELING ERROR

It is caused by the vertical component of vessel's permanent magnetism, Force R . Whether Force R is +ve or -ve will depend upon which hemisphere the ship was built in. Ships can have either a blue deck and red keel, if built in the N. Hemisphere or red deck and blue keel, if built in the S. Hemisphere.



If blue predominates below the compass, the compass swings to the high side, whether the vessel heels to port or starboard.

Opposite will be the case, when red predominates below the compass.

Effect of Heel :

It can be seen from the figure that as the angle of heel (i) increases, deviating force $R \sin i$ increases. (sin of an angle increases from 0° to 90°)

$$\therefore \text{PHE} \propto \sin i$$

(for small angles of heel) $\text{PHE} \propto i$

When on a steady course, equal heel to starboard and heel to port will cause opposite heeling errors of equal magnitude.

By Convention

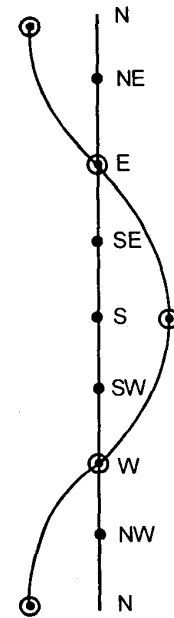
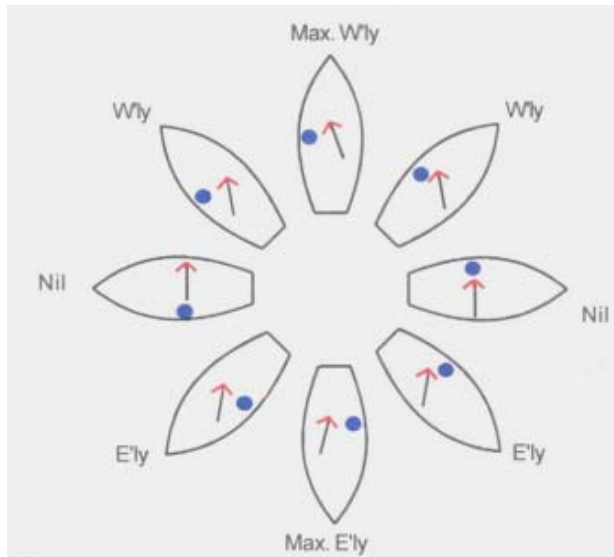
Starboard Heel are +ve

and Port Heel are -ve

Effect of ship's head:

In a ship with a permanent blue predominating below the compass, and with a constant heel to starboard, the blue pole will be carried to port of the compass. The compass being on gimbals remains horizontal. Let us study the pattern of deviations as the ship's head changes, the heel remaining unchanged.

PERMANENT H/E



$\therefore$ PHE varies as $\cos$ comp. co.

i.e. $\text{PHE} \propto \cos \text{ comp. co.}$

Imagine the ship heading N/S and heeled, the blue pole shifts, and deviates the N end of the needle. While heading East - West the blue pole acts exactly in line with the axis of the needle and the needle does not experience any deviating force.

Recall, the behaviour of deviations as similar to those due to Coefficient C, which also varies as cosine comp co.

Effect of Latitude:

The ability of the compass to point N/S or to be in the magnetic meridian depends on H of the earth. The deviating force due to heeling is $R \sin i$.

Therefore when H is small, the same ' $R \sin i$ ' will cause more deviation than when H is large. In other words smaller the H, greater the H/E.

Graphically

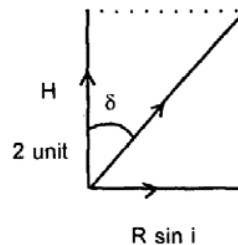
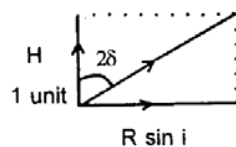


Fig. No. 68

$$\therefore \text{PHE} \propto \frac{1}{H}$$

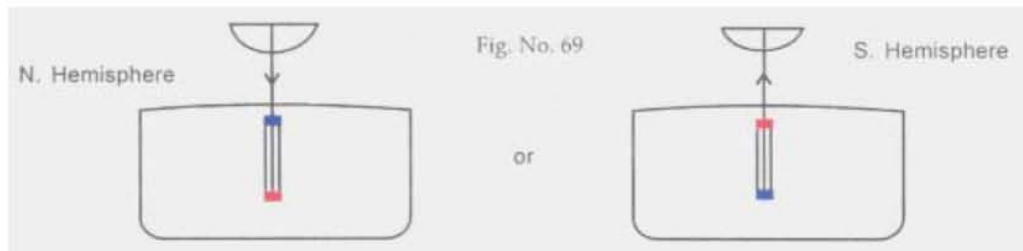
Since $PHE \propto \cos \text{comp. co.}, \propto i$ and $\propto \frac{1}{H}$

comparing H/E at two places (1) and (2), we have

$$\frac{PHE_2}{PHE_1} = \frac{i_2 \times \cos \text{comp co}_2 \times H_1}{i_1 \times \cos \text{comp co}_1 \times H_2}$$

2. INDUCED H/E

- (a) **k rod H/E :** There is considerable amount of vertical soft iron in the ship, below the compass, such as pillars etc. These soft irons can be considered to be a single piece of soft iron below the compass and will acquire blue pole on top when the ship is in the N. Hemisphere or red pole on top when the ship is in the S. Hemisphere, due to induction by Z , the Earth's vertical force.



If the ship is heeled, it will produce deviations in the similar manner as for Permanent heeling error, i.e. the deflecting force will act towards the high side, with a blue predominating below the compass and to the low side with a red predominating under the compass.

We must however recall, that unlike force R , the strength of the blue pole and its effect in producing heeling error is not constant, as it will vary with Z , the force which induces magnetism in the k rod. Thus k rod Heeling error will vary directly as Z .

Further, as in the case of PHE, when the directive force H is large, the k rod H/E will be small and when H is small, the deviation due to k rod H/E will increase. In other words, k rod H/E varies inversely as H .

As regards the change of H/E with change of course, and the change of the angle of heel, the same arguments hold good as for PHE.

Therefore k rod $H/E \propto \cos \text{comp co.}$
 $\propto i$
 $\propto Z$
 $\propto \frac{1}{H}$

Combining these, we have

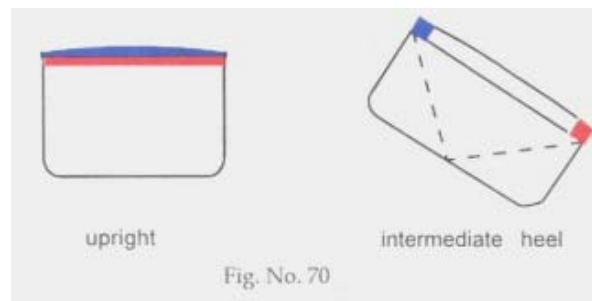
$$\frac{k \text{ rod } H / E_2}{k \text{ rod } H / E_1} = \frac{\cos \text{comp } \cos_2}{\cos \text{comp } \cos_1} \times \frac{i_2}{i_1} \times \frac{Z_2}{Z_1} \times \frac{H_1}{H_2}$$

Also, as $k \text{ rod } H/E$ varies directly as Z and inversely as H , we may say it varies directly as $\frac{Z}{H}$ i.e.- directly as $\tan \text{ dip}$.

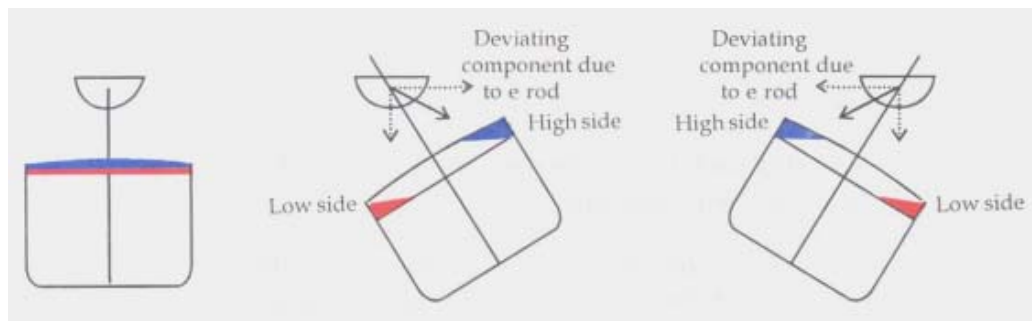
$$\therefore \frac{k \text{ rod } H / E_2}{k \text{ rod } H / E_1} = \frac{\cos \text{comp } \cos_2}{\cos \text{comp } \cos_1} \times \frac{i_2}{i_1} \times \frac{\tan \text{ dip}_2}{\tan \text{ dip}_1}$$

When doing calculations using the above, care must be exercised in sign convention for Z and dip , both of which are positive in the N. Hemisphere and negative in the S. Hemisphere. Also as stated earlier, starboard heels are positive and port heels are negative.

(b) $e \text{ rod } H/E$, due to induction by Z in horizontal athwartship soft iron:



When the ship is upright, these horizontal soft irons are only induced by H causing coefficient D . However, when the ship heels, the beams develop vertical component which get induced by Z as well.



The field due to e rod induction will cause deviation as follows:-

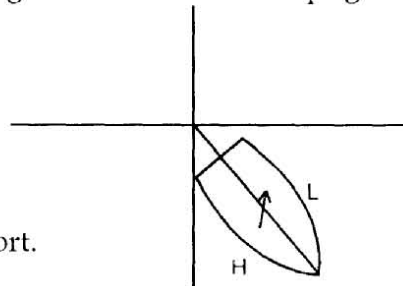
In the Northern hemisphere, the continuous athwartship beams (-e rod) will be induced by Z with a blue pole at the top end and a red pole at the bottom end causing a deviation to **high side** on both **Port & Starbd** heels.

In the Southern hemisphere, the continuous athwartship beams (-e rod) will cause deviation to **low side** on both **Port & Starbd** heels as their top ends will be red and bottom ends blue due to induction by -Z. As the angle of heel increases, the athwartship soft irons become more vertical and induction in them by Z also increases. Thus e rod H/E also varies directly as i. Obviously, as Z increases, the amount of induction increases and the heeling error thus produced increases. Thus e rod heeling error varies directly as Z. As with k rod H/E, e rod H/E will also vary inversely as H and directly as cosine of the compass course. Thus e rod H/E varies exactly as k rod H/E with change of course, H, Z and i. It should also be noted that both e rod and k rod heeling errors occur to the same side, i.e. to the high side in the N. Hemisphere and to the low side in the S. Hemisphere. Therefore in calculations we need not distinguish between them. They may be combined together as induced H/E.

$$\begin{aligned}\therefore \frac{iH/E_2}{iH/E_1} &= \frac{\cos \text{comp } co_2}{\cos \text{comp } co_1} \times \frac{i_2}{i_1} \times \frac{Z_2}{Z_1} \times \frac{H_1}{H_2} \\ &= \frac{\cos \text{comp } co_2}{\cos \text{comp } co_1} \times \frac{i_2}{i_1} \times \frac{\tan \text{dip}_2}{\tan \text{dip}_1}\end{aligned}$$

High Side/Low Side:

To sort out whether the heeling error will be to **East** or **West**, it is always easier to sort out by making a simple diagram which will help greatly.



In the diagram, the ship is heeled to port.

Label High side (H) and Low side (L) on the diagram and observe which side the north end will deviate.

However, if we adhere to the sign convention for the side of the heel, Z, dip and of course the cosine of the ship's head, the heeling error calculated will be not only correct in amount but also in name.

Example 1. When heading 310° by compass and heeled 10° to Port, the deviation due to H/E was 5° E. What will be the deviation due to H/E when heeled 7° to starbd and ship heading 215° (c).

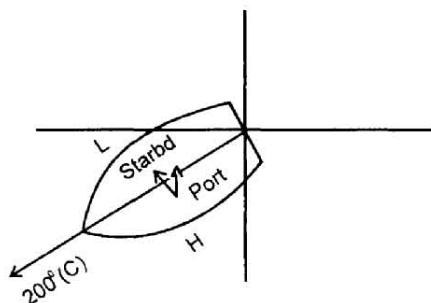
Since H and Z have not changed, both PHE and iHE i.e. the total H/E will vary only directly as the angle of heel, i and directly as cos comp co.

$$\frac{H/E_2}{H/E_1} = \frac{i_2}{i_1} \times \frac{\cos \text{comp } co_2}{\cos \text{comp } co_1}$$

$$H/E_2 = +5 \times \frac{+7}{-10} \times \frac{\cos 215^\circ}{\cos 310^\circ} = +4.46^\circ$$

$$= 4.46^\circ \text{ E}$$

Example 2. On a Course of 200° (c), heeled 4° to starbd, heeling error is 3° to the low side. Find the H/E on 300° (c), heeled 6° to port.



From the diagram it is clear that since the north end of the compass has deviated to the low side, the Heeling error is Westerly i.e. -3°

$$\frac{H/E_2}{H/E_1} = \frac{i_2}{i_1} \times \frac{\cos \text{comp } co_2}{\cos \text{comp } co_1}$$

$$\therefore \frac{H/E_2}{H/E_1} = \frac{-6}{+4} \times \frac{\cos 300^\circ}{\cos 200^\circ}$$

$$H/E_2 = -3 \times \frac{-6}{4} \times \frac{\cos 300}{\cos 200} = -2.39^\circ$$

$$H/E_2 = 2.39^\circ \text{ W}$$

Example 3: A vessel when steering 046° (c) and upright had no deviation on the compass, but when heeled 10° to starbd, the deviation was 12° E. The variation in this position is 15° W. Find the compass course to steer to make good a course of 303° , with a heel of 7° to port.

Since the 2nd compass co. is not known, we use the Magnetic co. as a first approximation.

True co. to steer 303°

Variation 15° W

Magnetic co. 318° (M)

$co_1 = 046^{\circ}$ (c) $co_2 = 318^{\circ}$ (approx.)

$i_1 = +10^{\circ}$ $i_2 = -7^{\circ}$

$H/E_1 = +12^{\circ}$ $H/E_2 = ?$

$$\frac{H/E_2}{H/E_1} = \frac{i_2}{i_1} \times \frac{\cos co_2}{\cos co_1}$$

$$\frac{H/E_2}{12} = \frac{-7}{10} \times \frac{\cos 318^{\circ}}{\cos 046^{\circ}}$$

$$H/E_2 = +12 \times \frac{-7}{10} \times \frac{\cos 318^{\circ}}{\cos 046^{\circ}} = -8.98^{\circ}$$

Approx. $= 9^{\circ}$ W

Approximate Deviation $= 9^{\circ}$ W

Magnetic co. 318° (m)

Comp. co. 327° (c)

Repeating again

$$\frac{H/E_2}{H/E_1} = \frac{-7}{10} \times \frac{\cos 327^{\circ}}{\cos 046^{\circ}}$$

$$H/E_2 = 12 \times \frac{-7}{10} \times \frac{\cos 327^{\circ}}{\cos 046^{\circ}} = -10.1^{\circ}$$

deviation $= 10.1^{\circ}$ W

Mag. Co. $= 318^{\circ}$ (m)

comp co to steer: 328.1° (c)

Example 4.

Coefficient A = +1°, Coefficient B = -7°, Coefficient C = -12°, Coefficient D = +6°, Coefficient E = +2°. When heeled 16° to starbd, the deviation on 330° (c) was 3° W.

(a) Find deviation on 038° (c), when heeled 10° to Port

(b) Will the deviation be to the high side or low side.

Deviation when upright on 330° (c).

$$\begin{aligned} & A + B \sin co + C \cos co + D \sin 2co + E \cos 2co. \\ = & +1 -7 \sin 330^\circ -12 \cos 330^\circ +6 \sin 660^\circ +2 \cos 660^\circ \\ = & 1 + 3.5 - 10.39 - 5.19 + 1 \\ = & -10.08^\circ \end{aligned}$$

$$\text{Deviation on } 330^\circ \text{ when upright} = -10.08^\circ$$

$$\text{Deviation on } 330^\circ \text{ when heeled} = -3^\circ$$

$$\text{Deviation due to H/E} = +7.08^\circ$$

$$Co_1 = 330^\circ \quad Co_2 = 038^\circ$$

$$i_1 = +16^\circ \quad i_2 = -10^\circ$$

$$H/E_1 = +7.08^\circ \quad H/E_2 = ?$$

$$\frac{H/E_2}{+7.08} = \frac{-10}{16} \times \frac{\cos 038^\circ}{\cos 330^\circ}$$

$$\begin{aligned} H/E_2 &= +7.08 \times \frac{-10}{16} \times \frac{\cos 038^\circ}{\cos 330^\circ} \\ &= -4.02^\circ \end{aligned}$$

To find deviation due to coefficients on 038° (c)

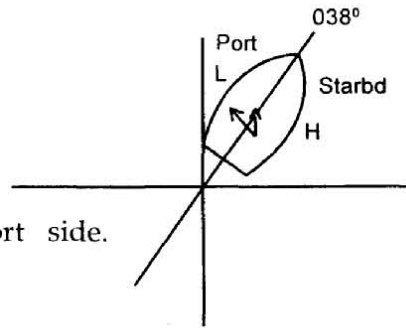
$$\begin{aligned} & = A + B \sin 038^\circ + C \cos 038^\circ + D \sin 076^\circ + E \cos 076^\circ \\ & = 1 -7 \sin 038^\circ -12 \cos 038^\circ + 6 \sin 076^\circ + 2 \cos 076^\circ \\ & = 1 - 4.31 - 9.456 + 5.82 + 0.484 \\ & = -6.462^\circ \end{aligned}$$

Total Deviation on 038° when heeled

$$= -6.462^\circ - 4.02^\circ$$

$$= -10.48^\circ$$

$$= 10.5^\circ \text{ W}$$



Since deviation is Westerly, it is to Port side.

Since vessel is heeled to Port.

$\therefore$ Deviation is to Low side.

Example 5: A ship with a list of 8° to starbd is swung through 90° and the following deviations were found.

S : 6° E; SE : 5° E; E : 7° E. What will be the deviation on N 30° E. Assume no A and E.

Heading East, δ of 7° E $\Rightarrow$ Coefficient B = $+7^\circ$

Heading South, δ of 6° E $\Rightarrow$ Combination of Coefficient C and H/E, which means when heading South its value will be -6° .

Since list has remained unchanged, the deviation due to coefficient C and H/E would vary together directly as $\cos$ comp. co.

Since δ on SE was 5° E,

$$+5 = B \sin co + (C + H/E) \cos co + D \sin 2 co.$$

$$+5 = 7 \sin 135^\circ + (C + H/E) \cos 135^\circ + D \sin 270^\circ.$$

$$+5 = 7 \sin 135^\circ - 6 \cos 135^\circ - D.$$

$$+5 = 4.95 + 4.24 - D$$

$$D = +4.2^\circ$$

Deviation on 030° .

$$B \sin co + (C + H/E) \cos co + D \sin 2 co$$

$$= +7 \sin 30^\circ + (-6) \cos 30^\circ + 4.2 \sin 60^\circ.$$

$$= 7 \times .5 - 6 \times .866 + 4.2 \times .866$$

$$= 3.5 - 5.2 + 3.6 = 1.9^\circ \text{ E}$$

Example 6. At position A ($H = 24$ A/m, $Z = 40$ A/m). H/E was observed to be 4° E, when heeled 8° to port. This error was corrected by vertical magnets placed 20 cms below the needle. At position B, ($H = 20$ A/m, $Z = -30$ A/m), the heeling error was 5° W, when heeled 5° to port on the same heading. What alteration should be made in the position of the corrector magnets?

Since H/E of 4° E is corrected by magnets, the magnets cause -4° .

To find the effect of magnet at B.

$$\frac{H/E \text{ magnet}_2}{H/E \text{ magnet}_1} = \frac{H_1}{H_2} \times \frac{i_2}{i_1}$$

$$H/E \text{ mag}_2 = -4 \times \frac{24}{20} \times \frac{-5}{-8} = -3^\circ$$

Magnets cause -3° at position B.

Total H/E including magnets = -5°

$\therefore$ Ship's H/E alone = -2°

Magnets must therefore cause $+2^\circ$ and not -3° , as it is presently causing. The magnets should therefore be reversed end for end.

$$\delta_1 = 3^\circ \quad \text{dist. } d_1 = 20 \text{ cms}$$

$$\delta_2 = 2^\circ \quad \text{dist. } d_2 = ?$$

$$\frac{d_2^3}{d_1^3} = \frac{\delta_1}{\delta_2}$$

$$d_2^3 = 20^3 \times \frac{3}{2}$$

$$\therefore d_2 = 20 \times \sqrt[3]{\frac{3}{2}} = 22.87 \text{ cms.}$$

Note : The original H/E, is the combination of Permanent H/E and induced H/E and its value is 4° E. The magnet causes -4° . The combination of Permanent and induced was corrected by Permanent magnets. Therefore the error cannot remain corrected for all latitudes, since we have not corrected like for like. At the 2nd position, the H/E has re-appeared (due to Permanent H/E, and induced H/E and the magnets). The effect by magnets alone is known to be -3° . Ship's H/E due to Permanent H/E and induced H/E = -2° . It has to be corrected by reversing the magnet end for end and lowering it by 2.9 cms.

Example 7. The following observations and adjustments were made at a well placed compass.

Place 1. (H: 30 A/m, Z: 24 A/m) Ship's head 000° (c), vessel upright, deviation was 2° E.

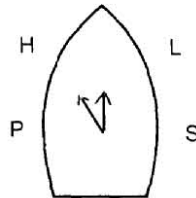
At the same place and the same heading but heeled 6° to starbd, deviation observed was 3° W. The whole of the heeling error was now removed by a single vertical magnet situated 40 cms below the compass needle.

At place 2, (H = 20 A/m, Z = -30 A/m) ship's head 295° (c), with 3° port heel, a deviation of 3° W was observed. What alteration should be made in the position of the corrector. Assume no A and E and iC. Coefficient B and D have been properly corrected.

Ship upright deviation = $+2^\circ$ (due to coefficient C)

heeled 6° (S), deviation = -3° (due to coefficient C + H/E (PHE + possibly H/E due induced magnetism))

$\therefore$ Heeling Error = -5°



(Since on heading 000° , when heeled to stbd, high side is to port and it is giving Westerly deviation. Attraction is to high side, which indicates a blue pole is beneath the compass. Magnet must therefore have been kept red end up). Since the whole of H/E was fully removed by magnet, it implies that the magnet causes $+5^\circ$.

Now, that H/E (PHE + induced H/E if any) has been removed by the vertical magnet causing $+5^\circ$. The remaining deviation would be $+2^\circ$ due to coefficient C.

At position 1, we have magnet causing $+5^\circ$ and Coefficient C causing $+2^\circ$.

At place 2, a deviation of 3° W has appeared. This would be caused due to [Coefficient C, H/E (PHE $\pm$ induced if any) and permanent vertical magnet].

We know value of coefficient C at place 1

$\therefore$ effect of C at place 2 will be

$$\frac{PC_2}{PC_1} = \frac{H_1}{H_2} \times \frac{\cos \alpha_2}{\cos \alpha_1}$$

$$PC_2 = +2 \times \frac{30}{20} \times \frac{\cos 295^\circ}{\cos 000^\circ}$$

$$= +1.27^\circ$$

Effect of H/E corrector magnet alone at place 2:

$$\frac{H/E \text{ magnet}_2}{H/E \text{ magnet}_1} = \frac{i_2}{i_1} \times \frac{H_1}{H_2} \times \frac{\cos \alpha_2}{\cos \alpha_1}$$

$$H/E \text{ magnet}_2 = +5 \times \frac{-3}{6} \times \frac{30}{20} \times \frac{\cos 295^\circ}{\cos 0^\circ}$$

$$= -1.58^\circ$$

$$\text{Total effect of C and Vertical magnet} = +1.27^\circ - 1.58^\circ$$

$$= -0.31^\circ$$

But deviation due to C, H/E of ship (PHE $\pm$ induced if any) and H/E of Magnet = -3°

$$\text{But C and Magnet} = -0.31^\circ$$

$$\therefore \text{H/E of ship (PHE } \pm \text{ induced if any)} = -2.69^\circ$$

The magnet is causing -1.58° . It in fact should cause $+2.69^\circ$ instead.

Magnet therefore must be reversed.

$$\begin{array}{ll} \delta_1 = 1.58^\circ & \text{dist } d_1 = 40 \text{ cms} \\ \delta_2 = 2.69^\circ & \text{dist } d_2 = ? \end{array}$$

$$d_2^3 = \frac{40^3 \times 1.58}{2.69}$$

$$= 33.497 = 33.5 \text{ cms.}$$

Invert the magnet and move it up till it is 33.5 cms below the compass.

Example 8: At position (1) $H = 20$ A/m, $Z = 30$ A/m, when heading 000° (c), the H/E was observed to be 2° W, when heeled 6° to starbd. This was corrected by vertical magnets in the heeling error bucket. At position (2), where $H = 40$ A/m, $Z = 0$, when heading 180° (c), the H/E was observed to be 4° E, when heeled 8° to port. This was again removed by adjusting the H/E magnet. What heeling error is to be expected at position 3. $H = 20$ A/m, $Z = -30$ A/m, when heading 000° (c) and heeled 6° to port.

In this question, we have to split the total H/E into its components, permanent and induced heeling error. Since one of the places is at magnetic equator, we should start the work from the magnetic equator, like in coefficient B problems.

At (2) magnetic equator, there is no induced H/E.

At (2) H/E (PHE of ship + magnet) = $+4^\circ$.

We can find PHE (ship and magnet) at place (1).

$$\begin{aligned}\frac{\text{PHE}_1}{\text{PHE}_2} &= \frac{i_1}{i_2} \times \frac{H_2}{H_1} \times \frac{\cos \phi_1}{\cos \phi_2} \\ \text{PHE}_1 &= +4 \times \frac{6}{-8} \times \frac{40}{20} \times \frac{\cos 000^\circ}{\cos 180^\circ} \\ &= +4 \times \frac{6}{-8} \times \frac{40}{20} \times \frac{1}{-1} = +6^\circ\end{aligned}$$

H/E at (1) due to (PHE ship + magnet) = $+6^\circ$

Total Heeling Error at (1), (PHE + induced H/E + magnet) = 0
(as total H/E was made nil when it was corrected by magnets)

$\therefore$ Induced H/E at (1) = -6°

Since the magnet is readjusted at place (2) at the magnetic equator, and as there is no induced magnetism there, the entire PHE must have been corrected by the magnet. Since method adopted is *like for like*, that correction would remain in order for all latitudes and courses.

$\therefore$ H/E appearing in position (3) will be due to induced H/E only.

To find H/E at place (3)

$$\begin{aligned}\frac{iH/E_3}{iH/E_1} &= \frac{i_3}{i_1} \times \frac{Z_3}{H_3} \times \frac{H_1}{Z_1} \times \frac{\cos 000^\circ}{\cos 000^\circ} \\ iH/E_3 &= -6 \times \frac{-6}{+6} \times \frac{-30}{20} \times \frac{20}{30} \times \frac{1}{1} = -6\end{aligned}$$

$\therefore$ Heeling Error at place (3) = 6° W.

Example 9: At A ($H = 20$ A/m, $Z = 40$ A/m), the H/E when heading 150° (c) and heeled 5° to port was 5° E.

At B ($H = 30$ A/m, $Z = 15$ A/m), the H/E, when heading 300° (c), heeled 10° to port was 5° W.

At C ($H = 30$ A/m, $Z = -35$ A/m), find deviation due to H/E when heading 045° (c), heeled 15° to starbd.

[Since none of the places is at magnetic equator we have to split H/E into its components using the method of simultaneous equations. **In this case it is important that comparison should be made for same heading and same list in each case.**]

To find H/E at A on 045° (c) and heel 15° to starbd.

$$\frac{H/E_2}{H/E_1} = \frac{i_2}{i_1} \times \frac{\cos \phi_2}{\cos \phi_1}$$

$$\therefore H/E_2 = +5 \times \frac{15}{-5} \times \frac{\cos 45^\circ}{\cos 150^\circ}$$

$$= +12.25^\circ$$

Similarly, to find H/E at B on 045° (c) and heel 15° to starbd

$$\frac{H/E_2}{H/E_1} = \frac{i_2}{i_1} \times \frac{\cos \phi_2}{\cos \phi_1}$$

$$\therefore H/E_2 = -5 \times \frac{15}{-10} \times \frac{\cos 45^\circ}{\cos 300^\circ}$$

$$= +10.6^\circ$$

We can now split H/E either at A or B.

Choosing B in this case

$$\begin{aligned} \text{Let PHE at B} &= x \\ \text{and induced H/E at B} &= y \\ \text{At B, } x + y &= +10.6 \quad \text{----- (1)} \end{aligned}$$

$$\frac{PHE_A}{PHE_B} = \frac{H_B}{H_A}$$

$$PHE \text{ at A} = x \times \frac{30}{20} = 1.5x$$

$$\frac{\text{Induced H / E}_A}{\text{Induced H / E}_B} = \frac{Z_A}{H_A} \times \frac{H_B}{Z_B}$$

$$\therefore \text{Induced H / E at A} = y \times \frac{40}{20} \times \frac{30}{15}$$

$$= 4y$$

$$\therefore 1.5x + 4y = 12.25^0 \quad \text{----- (2)}$$

$$1.5x + 1.5y = 15.9^0 \quad \text{----- (1) } \times 1.5$$

$$2.5y = -3.65$$

$$y = \frac{-3.65}{2.5} = -1.46^0$$

y = induced H/E at B

Substituting value of y in equation (1)

$$x = \text{PHE at B}$$

$$= 12.06^0$$

To find PHE at C

$$\frac{\text{PHE}_C}{\text{PHE}_B} = \frac{H_B}{H_C}$$

$$\text{PHE}_C = 12.06^0 \times \frac{30}{30} = +12.06$$

To find Induced H/E at C

$$\frac{\text{Ind. H/E}_C}{\text{Ind. H/E}_B} = \frac{Z_C}{H_C} \times \frac{H_B}{Z_B}$$

$$\text{ind. H/E}_C = -1.46^0 \times \frac{-35}{30} \times \frac{30}{15}$$

$$= +3.4^0$$

$$\therefore \text{Total H/E} = 12.06^0 + 3.4^0 = 15.46^0 \text{ E}$$

It must be pointed out that although H/E may be estimated for position (3), this type of problem is only theoretical. The entire H/E is corrected by Permanent magnets alone, so that, unlike Coefficients B and C, a knowledge of separating the components of H/E is not necessary for its correction unlike that in the case of B and C, where a knowledge of iB and iC could help in positioning of the F/B.

Example 10 A vessel had its coefficients A, B, D and E fully corrected. When heading 060° (c) and heeled 5° to starboard, the deviation was observed to be 4° E, when heading 150° (c) and heeled 10° to port the deviation was observed to be 12° E. Find the value of Coefficient C and state what H/E is to be expected when heading 240° (c), heeled 2.5° to port. Also state the total deviation.

060° (c) heeled 5° starbd, deviation = $+4^\circ$ (This is due to C and H/E)

150° (c) heeled 10° port, deviation = $+12^\circ$ (This is due to C and H/E)

240° (c) heeled 2.5° port, deviation = ?

We know that deviation due to Coefficient C varies as cos comp. co. We also know that deviation due to H/E varies as cos comp. co. and heel.

Let us start with the course of 060° (c)

The deviation obtained is the sum of deviations due to Coefficient C and H/E

$$\begin{aligned} \text{(case 1) } \delta &= C \cos co + H/E_1 = +4 \\ &0.5 C + H/E_1 = +4 \quad \text{--- (1)} \end{aligned}$$

Let us obtain H/E_2 on 150° (c) and 10° heel to port.

$$\frac{H/E_2}{H/E_1} = \frac{i_2}{i_1} \times \frac{\cos co_2}{\cos co_1}$$

$$H/E_2 = H/E_1 \times \frac{-10}{+5} \times \frac{\cos 150^\circ}{\cos 60^\circ} = H/E_1 \times -2 \times \frac{\cos 150^\circ}{\cos 60^\circ}$$

$$H/E_2 = +3.466 H/E_1$$

$\therefore$ Deviation on 150° (c) with 10° port heel will be

$$\begin{aligned} C \cos 150^\circ + H/E_2 &= +12 \\ -.8666 C + 3.466 H/E_1 &= +12 \quad \text{--- (2)} \end{aligned}$$

Solving (1) and (2)

$$1.733C + 3.466H/E_1 = +13.864 \quad \text{----- (1) X 3.466}$$

$$\underline{-.866C + 3.466H/E_1 = +12.000} \quad \text{----- (2)}$$

$$2.599C = 1.864$$

$$C = \frac{1.864}{2.6}$$

$$= +0.71^0$$

Substituting

$$.5C + H/E_1 = +4$$

$$.355 + H/E_1 = +4$$

$$H/E_1 = 3.645^0$$

To find H/E_3

$$\frac{H/E_3}{H/E_1} = \frac{i_3}{i_1} \times \frac{\cos \alpha_3}{\cos \alpha_1}$$

$$H/E_3 = +3.645 \times \frac{-2.5}{+5} \times \frac{\cos 240^0}{\cos 60^0}$$

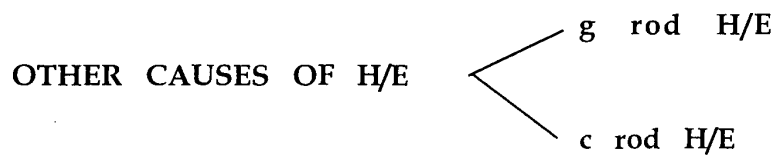
$$= 3.645 \times \frac{-1}{2} \times \frac{-0.5}{0.5}$$

$$= +1.822^0$$

$$\begin{array}{ll} \text{Coefficient } C & = +0.71^0 \\ H/E_3 & = +1.822^0 \end{array}$$

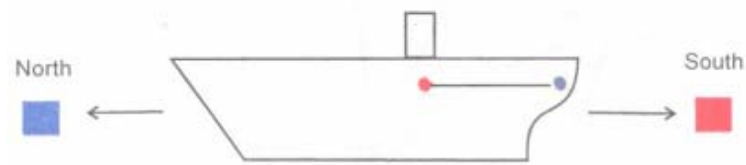
$$\begin{aligned} \text{Deviation due to coefficient } C \text{ on } 240^0 (c) &= C \cos 240^0 \\ &= 0.71 \times \cos 240 \\ &= -0.355^0 \end{aligned}$$

$$\begin{array}{ll} \text{Deviation due to } C & = -0.355 \\ \text{Deviation due to } H/E & = \underline{+1.822} \\ \therefore \text{ Final deviation} & = +1.467^0 \end{array}$$

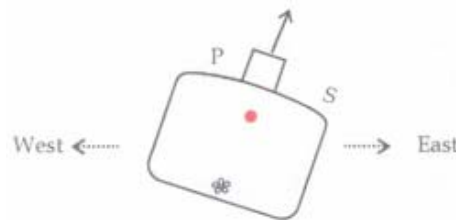


1. g rod Heeling Error :

g rod is fore and aft horizontal soft iron terminating below compass, it is induced by H with its effective pole below the compass. If heading North, the g rod will acquire polarity as shown in the figure. In the upright condition, it causes no error, but when heeled, it will contribute to H/E.



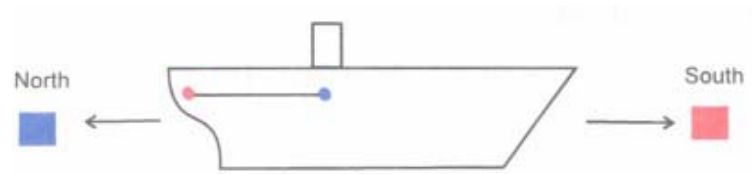
As shown in the figure, if heeled to stbd., the g rod H/E is easterly. In the following explanation, we shall maintain a constant heel to stbd.



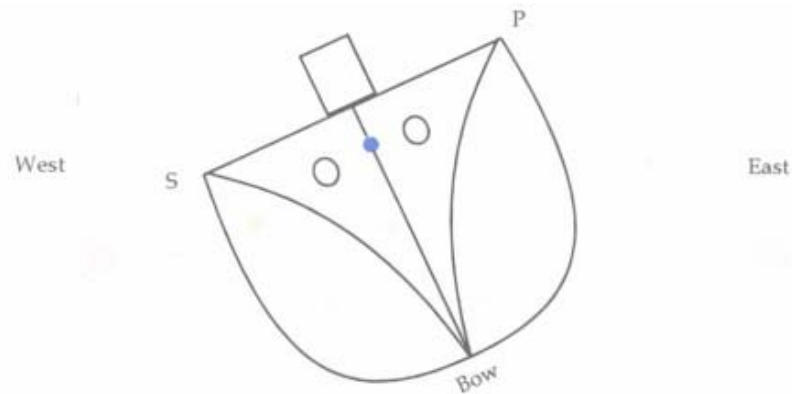
[Heading North & heeled to starboard]

Looking towards North i.e. from astern, there is red pole below the compass and this pole comes out to the high side, and the compass needle will be repelled to the low side, causing a Easterly deviation.

Heading south



Heading South, induction by H causes blue pole below the compass.



[Heading South & heeled to starboard]

Heading South, and heeled to starboard, the blue pole moves to high side and the compass needle is attracted towards the high side, causing a Easterly deviation.

We find that, on both N and S headings, deviation observed is Easterly.

This is unlike all other causes of H/E discussed earlier, where H/E on N & S headings were of opposite names, provided the direction of heel is unchanged.

If heeled to Port, Westerly deviation would be caused on both N & S headings.

When heading East/West, the g rod is in the neutral position with respect to H which runs North/South and therefore receives no induction and therefore no H/E is caused.

We can thus summarise as:

- (a) 1. Maximum induction when heading N/S.
 2. No induction when heading E/W.
 3. $H/E \propto \cos \text{ comp co.}$
- (b) If induction remains constant.
- (i) On E/W : δ is Nil, as the pole below the compass acts in line with the needle when the ship heels.



- (ii) On N/S : δ is maximum, as the pole below the compass acts at right angles to the needle when the vessel heels.



- (iii) $g \text{ rod } H/E$ is same both in value and name on opposite headings provided the heel is of same amount and to the same side.

$\therefore H/E$ due to $g \text{ rod} \propto \cos \text{ comp co.}$ due to the amount of induction and again $\propto \cos \text{ comp co.}$ due to the position of the disturbing pole with respect to the needle, when the ship heels.

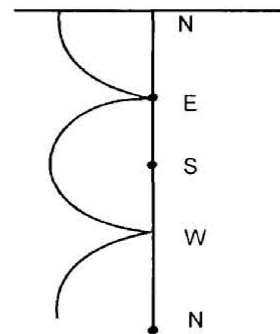
Thus H/E due to $g \text{ rod} \propto \text{twice as } \cos \text{ comp co.}$

i.e. $g \text{ rod } H/E \propto \text{as } \cos^2 \text{ comp co}$

and $\propto \text{angle of heel (i)}$

$$\frac{g \text{ rod } H/E_2}{g \text{ rod } H/E_1} = \frac{i_2}{i_1} \times \frac{\cos^2 \text{ co}_2}{\cos^2 \text{ co}_1}$$

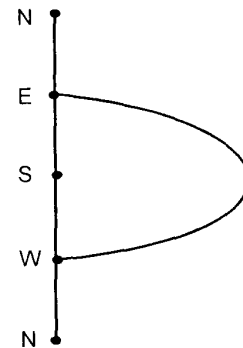
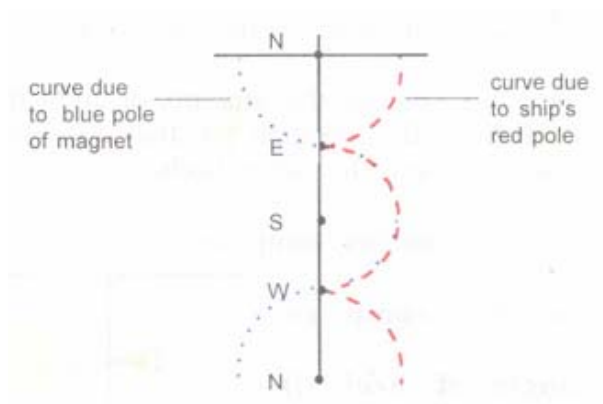
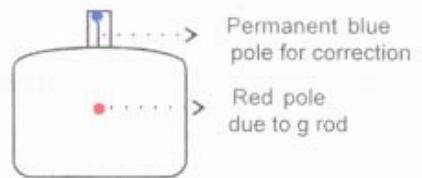
Fig. No. 76



Mathematically also, it may be seen that, since $\cos^2$ is positive for all 360° , the name of the deviation due to $g \text{ rod } H/E$ remains the same for all 360° of compass headings provided the heel remains to the same side.

Since the DF and the disturbing force i.e. H and induction in $g \text{ rod}$ due to H vary in the same proportion, change of latitude does not affect H/E due to $g \text{ rod}$.

g rods are usually not present on ships, as girders normally run continuous and do not terminate below the compass as g rods do. Therefore g rod H/E is usually not present and correction for g rod effect is generally not made. However, if an attempt was to be made to correct it by using Permanent magnets, the error can be made nil on one semicircle of headings, but will be doubled on the opposite semicircle.

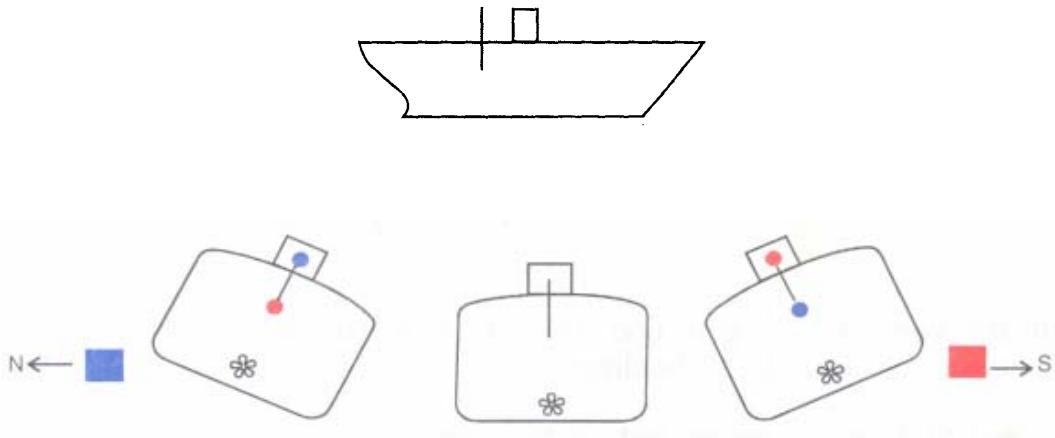


If corrected by permanent magnets, the combined effect of g rod and magnet on one semicircle of headings - NIL, DOUBLE on opposite semicircle.

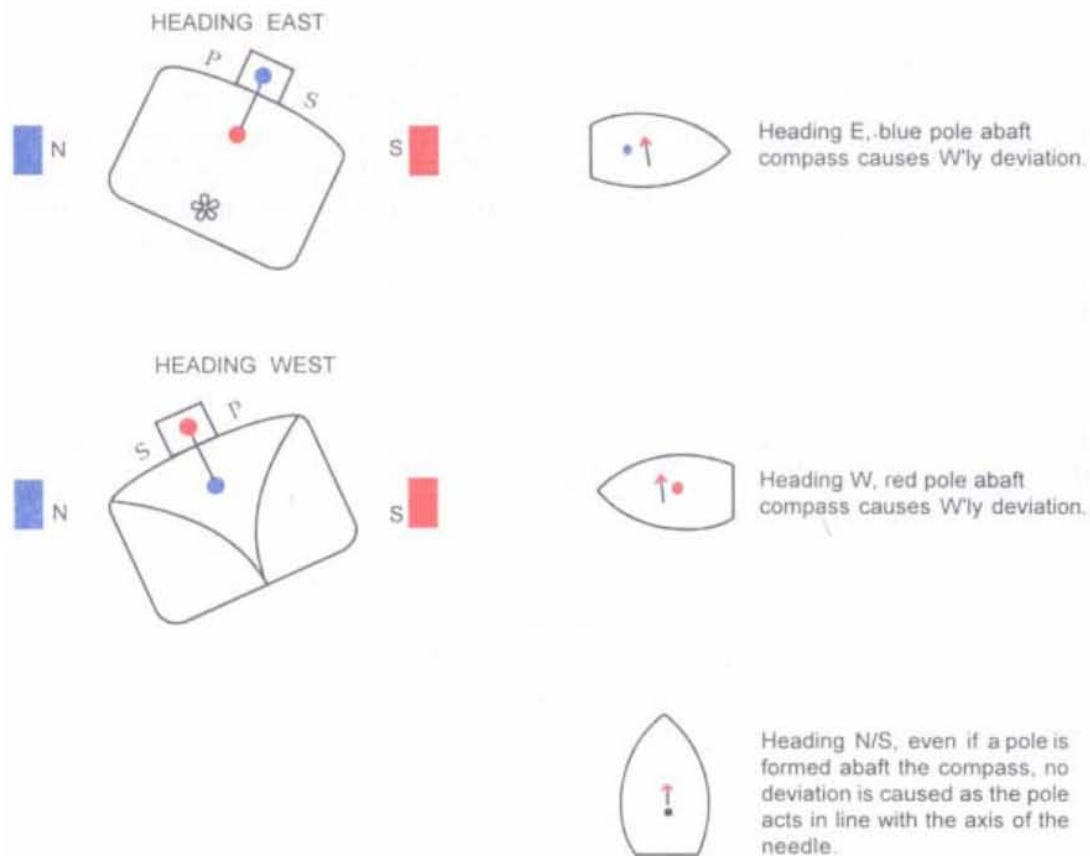
2. c rod Heeling Error :

c rod is vertical soft iron for'd or abaft of compass. When upright, c rod is not induced by H, but only by Z, which causes iB. However when heeled, the vertical soft iron develops a horizontal component which will be induced by H. When the vessel is heading N/S and heels, the c rod will not acquire any induction by H, as it is in the neutral position with respect to H which runs N-S. However, when heading E/W, the vertical soft iron will lie in such a manner that it will be induced by H.

Let us take the normal case of a predominance of vertical soft iron abaft the compass.



From the above figures, it will be seen that when heading East, if the vessel heels to starbd, the effective pole is blue. On the same heading when heeled to port, the effective pole is red.



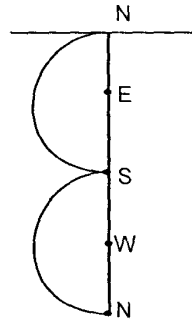
[If the vessel had a port heel, instead of starbd, we will have Easterly deviation on E and W headings].

C rod H/E is maximum and of the same name on E and W courses, nil on N and S courses.

We therefore summarise :

1. H/E due to c rod $\propto$ twice as sin comp co., once because on E - W headings the induced pole abaft the compass acts at right angles to the needle producing maximum deviation, but on N - S headings it acts in line with the needle, producing nil deviation. It again varies as sin of comp. co. since induction in the c rod when the vessel heels is maximum when heading E or W as its horizontal component lies N/S and nil when heading N or S as its horizontal component lies E/W (in the neutral position with respect to the Earth's horizontal force, H).

Therefore, **c rod H/E** $\propto \sin^2 \text{ comp. co.}$



2. **H/E due to c rod $\propto i$**

Since greater the angle of heel, greater is the horizontal component of the c rod and therefore greater the induction in it by H.

Since c rod H/E $\propto \sin^2 \text{ comp. co.}$ and as $\sin^2$ of any angle is always positive, the name of c rod H/E remains unchanged with change in the semicircle of heading, provided the direction of heel is unchanged.

$$\therefore \frac{\text{c rod H/E}_2}{\text{c rod H/E}_1} = \frac{\sin^2 \text{ comp co}_2}{\sin^2 \text{ comp co}_1} \times \frac{i_2}{i_1}$$

Like g rod H/E, c rod H/E is also independent of magnetic latitude, as the directive force and the disturbing force due to induction by H vary together.

H/E due to c rod is automatically corrected when the flinders bar is placed to correct iB because when the vessel heels, the flinders bar is also induced by H causing the same pole for'd of the compass as created in the ship's c rod abaft the compass. If the c rod heels, so does the flinders bar. Since flinders bar is generally placed by estimation - there is a likelihood of experiencing heeling error due to c rod, if iB correction is not accurate. If such an effect is present, it is normally very small and negligible, but it has the effect of causing an unsteady compass on Easterly/Westerly headings when the vessel rolls.

c rod effect is the only cause of H/E on E - W headings. It produces maximum H/E on E and W headings and nil on N and S headings. All the other causes of H/E produces maximum H/E on N and S headings and nil on E and W headings.

CORRECTION OF HEELING ERROR

As we already know that H/E is mainly due to two causes :-

1. Permanent Magnetism (force R)
2. Induced Magnetism (k rod and e rod)

Strictly speaking "*like cures like*" principle is the one that results in no deviation on any course and in any latitude. However in the case of H/E correction, this principle is not adhered to. It is not practicable to compensate separately for the effects of the permanent and induced magnetism of the ship. The reasons are :-

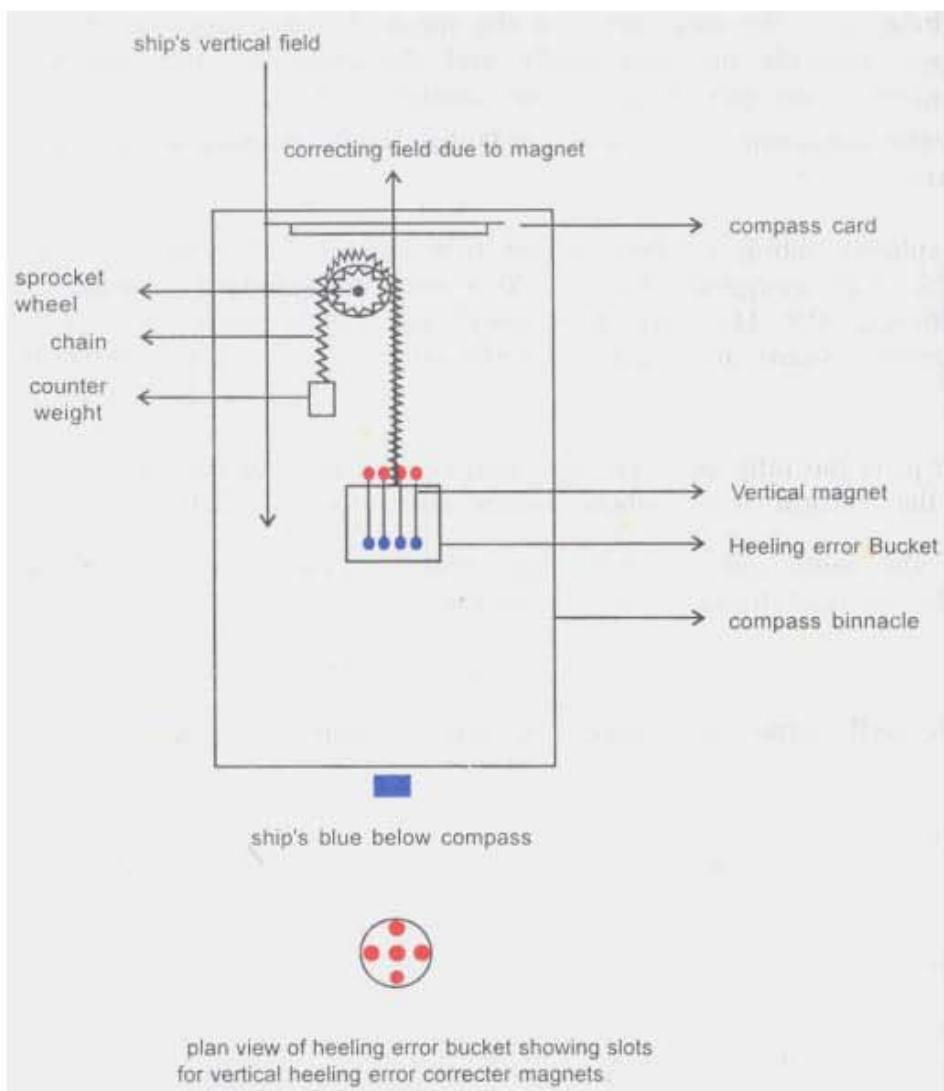
That soft iron correctors would be inconveniently large and also the proximity of both permanent and induced correctors would cause serious interaction which may become unmanageable.

Both effects are therefore corrected by vertical, permanent magnets, placed below the compass card.

As the ship changes her latitude, the k rod and e rod effects will vary due to change in Z. The effect of permanent magnets (used for correction) will remain unchanged. Hence H/E will reappear when the latitude changes. The correction will therefore hold good only for a particular latitude, but for all courses and all heels in that latitude.

The correction is achieved practically by means of permanent magnets set vertically in a H/E bucket, which can be raised or lowered, in the binnacle, under the compass card. The amount of correction may be varied by increasing or decreasing the number of magnets or by raising or lowering the H/E bucket.

It is preferable to use more number of magnets at a greater distance below the card than a single magnet placed close under the card as the former provides a more uniform field. Whatever the number of magnets used, they must be placed symmetrically in the bucket.



The direction in which a compass needle, at the compass position, will lie depends on the directive force acting towards magnetic north, at that position and on the disturbing force there.

Lambda: λ_1 is the ratio between the mean directive force at the compass position, towards magnetic north, and the directive force ashore, before the spheres are placed to correct coefficient D.

λ_2 is the same ratio after coefficient D has been correctly compensated by the spheres.

The spheres acting as divided soft iron increase the mean directive force. Thus λ_2 is always greater than λ_1 . At a well sited standard compass, λ_2 would be around 0.9. However it is never equal to or greater than 1.0 as the continuous beams and girders on the ship do cause a loss in the directive force.

(Mu): μ , is the ratio between the mean vertical force at the compass position and the vertical force ashore before correction of heeling error.

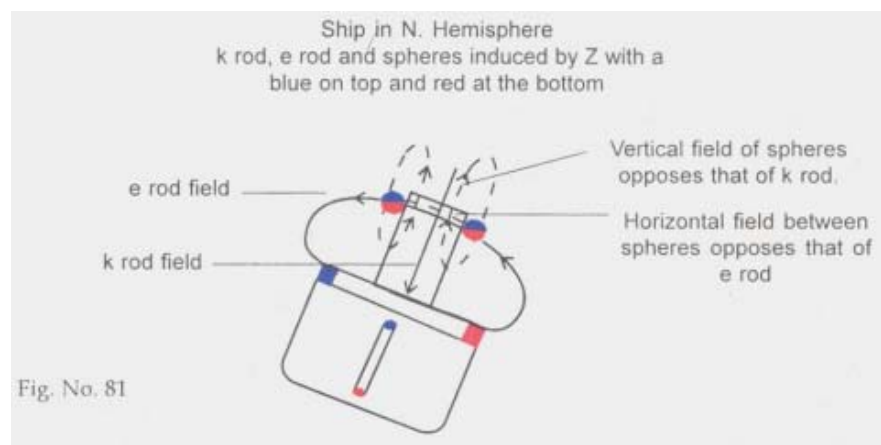
μ_2 is the same ratio after heeling error has been correctly compensated by the vertical heeling error corrector magnets.

(At a well corrected compass, λ_2 will be equal to μ_2)

THEORY OF HEELING ERROR CORRECTION

The forces which cause heeling error are the vertical fields, due to the ship, at the compass position. The vertical fields acting at the compass are Z, force R, k rod effect and e rod effect which also produces heeling error when the ship heels. Of these, Z, the vertical force of the Earth does not produce any heeling error as it always acts vertically, even if the ship heels and therefore does not cause any deviation. If we can nullify force R, k rod and e rod effects, heeling error would be eliminated. We have to therefore devise a method of nullifying these three forces.

However, before proceeding to correct heeling error, the flinders bar and spheres should be positioned correctly. The flinders bar should be in position as it automatically eliminates c rod H/E. The spheres should also be in position as they partly compensate for the k rod and e rod fields causing H/E. If the entire H/E was corrected by vertical magnets and the spheres placed later, we would be overcompensating for heeling error.



One method of correcting heeling error would be to head the ship N or S by the compass we are correcting. While holding that heading, using the gyro compass, heel the ship. If the card of the compass we are correcting deviates to the high or low side, it is evident that heeling error due to blue or red pole respectively predominating below the compass exists. This can then be corrected by placing vertical magnets and adjusting them till the compass card indicates the original heading. This method is not used practically, as it is time consuming and cumbersome. Instead, as stated earlier, we assess and eliminate any vertical field due to the ship, acting at the compass. For this, we do not have to heel the ship. Heeling error correction is therefore practically carried out with the ship upright. To assess and eliminate the vertical fields of the ship at the compass position we use an instrument called the Vertical Force Instrument. The instrument and its use in correcting heeling error is described in the next chapter.

EXERCISE IV (Heeling Error)

1. If the PHE was 4° E when heading 215° (C) and heeled 3° (S) at A ($H = 30$ A/m, $Z = 20$ A/m) find the PHE at B ($H = 24$ A/m, $Z = -30$ A/m) when heading 040° (S) and heeled 5° (P).
2. If iHE was 3° W at P ($H = 22$ A/m, $Z = -20$ A/m) when heading 165° (C) and heeled 4° to port, what will iHE be at Q ($H = 28$ A/m, $Z = 18$ A/m) when heading 070° (C) and heeled 6° to stbd.
3. If PHE was 4° W and iHE was 4° W at L ($H = 24$ A/m, dip = 35°) when heeled 6° (S) on a course of 040° (C), find the total HE at M ($H = 18$ A/m, dip = -50°) when heading 300° (C) and heeled 5° (S).
4. The deviation due to heeling error is 5° W when heading 140° (C) and heeled 6° to stbd. What will be the heeling error when heading 070° (C) and heeled 3° to port.
5. At P ($H = 24$ A/m, $Z = 30$ A/m) the heeling error was 5° E when heeled 6° to port. This was corrected by magnets placed 30 cms below the card. Later, at Q ($H = 20$ A/m, $Z = -24$ A/m), the heeling error on the same heading as 5° W when heeled 3° to port. How would you alter the corrector magnets.
6. On a heading 070° (C) and heeled 3° (S), the total deviation was 5° W. Coef. B = -4° , Coef. C = $+3^{\circ}$. A, D and E are nil. What total deviation may be expected when heading 130° (C) and heeled 5° (P).
7. At position 1, ($H = 20$ A/m, $Z = 24$ A/m), course 000° (C), heel 4° (P), the deviation was 5° E. At position 2, ($H = 16$ A/m, $Z = -30$ A/m), course 180° (C), heel 6° (S), the deviation was 6° E. Assuming all deviations were produced by permanent magnetism, what corrections should have been made at position 1 by vertical magnets and horizontal magnets?
8. With a constant heel of 6° to stbd. the following deviations were observed: S: 10° E, SW: 1° W, W: 14° W. What deviation may be expected when heading 158° (C), with the same heel. Coefs. A and E are nil.
9. Coefs. A and E are nil. B = $+5^{\circ}$, C = -4° , D = $+3^{\circ}$. When heading 030° and heeled 6° (S), the deviation was 4° W. What will be the deviation when heading 240° (C) and heeled 4° (P)?
10. At P ($H = 16$ A/m, $Z = 30$ A/m), the heeling error was 4° W when heading N and heeled 4° (S). This was corrected by vertical magnets. At Q ($H = 32$ A/m, $Z = \text{nil}$) when heading S(C) and heeled 2° (P) the heeling error was 2° E. This was removed by adjusting the magnets. What heeling error would you expect at R ($H = 16$ A/m, $Z = -15$ A/m) when heading N and heeled 3° (P)?

11. At A ($H = 30\text{A/m}$, $Z = \text{nil}$) course 000° , the deviation when upright was nil and when heeled 3° (P) it was 5° W. This was corrected by vertical magnets. At B ($H = 15\text{A/m}$, $Z = -20\text{A/m}$), the deviation on the same course when upright was nil and when heeled 3° (S) the deviation was 10° W. How would you correct the heeling error at B?
12. At P ($H = 20\text{ A/m}$, $\text{dip} = 49^\circ$) the deviation when upright was 5° E and when heeled 6° (S), it was 2° W. The heeling error was corrected by vertical magnets 36 cms. below the card. At Q ($H = 20\text{ A/m}$, $\text{dip} = -57^\circ$) the deviation on the same course when upright was 4° W and when heeled 6° (S) it was 8° E. How would you adjust the vertical magnets?
13. At P ($H = 10\text{A/m}$, $Z = 30\text{A/m}$) the heeling error of 5° E was corrected by vertical magnets. At the magnetic equator, ($H = 25\text{A/m}$) the heeling error on the same course and heel was 1° W. The vertical magnets were adjusted to correct it. What heeling error may be expected at R ($H = 16.7\text{A/m}$, $Z = -33.3\text{A/m}$) on the same course and heel?
14. At A ($H = 12\text{A/m}$, $Z = 30\text{A/m}$) the heeling error was 3° W when heading 320° (C) and heeled 5° (S). This was corrected by vertical magnets. At B ($H = 18\text{A/m}$, $Z = \text{nil}$) the heeling error was 1.5° W when heeled 3° (S) and heading 170° (C). This was corrected by adjusting the H/E magnets. What heeling error may be expected at C ($H = 12\text{A/m}$, $Z = -30\text{A/m}$) when heading 030° (C) and heeled 4° (P).
15. At P ($H = 27\text{A/m}$, $Z = 36\text{A/m}$), Course 025° (C), heeled 5° (P), the heeling error 5° W. At Q ($H = 45\text{A/m}$, $Z = 18\text{A/m}$) course 350° (C), heeled 4° (S) the heeling error was 2° E. Find the heeling error at R ($H = 30\text{A/m}$, $Z = -36\text{A/m}$) on a course of 150° (C) and heeled 3° (S).
16. A vessel has no deviation on any course when upright. When heading 310° (C) and heeled 3° (P) the deviation is 3° (W). Calculate the deviation and the compass course to steer to make good 180° (T) with a heel of 6° (S). Variation 14° (W).
17. At A ($H = 22\text{A/m}$, $\text{dip} = 70^\circ$) when heading north and upright, the deviation was 2° E and when heeled 4° (S) the deviation was 3° W. The heeling error was corrected by a single magnet 30 cms. below the card. At B ($H = 28\text{A/m}$, $\text{dip} = -30^\circ$), when heading 295° and heeled 2° (P), the deviation was 3° W. Assuming no magnet is to be placed closer than 22 cms from the card, how would you correct the heeling error at B? A, B, D & E are nil.

CHAPTER 11

VERTICAL FORCE INSTRUMENT

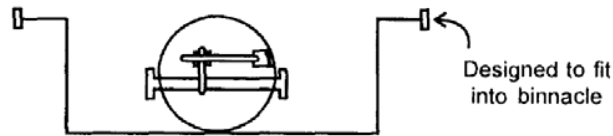


Fig. No. 82

DESCRIPTION

The instrument essentially consists of a magnetic needle mounted on a knife edge support, pivoted horizontally a little above its c.g. so that in the absence of any magnetic field, it would lie horizontal. In the presence of any vertical magnetic field, it would obviously be tilted. Therefore, when aligned in the plane of the magnetic meridian, it assumes the direction of the earth's total field at that place. It will lie at an angle corresponding to the angle of dip at that place. In the northern hemisphere the red end of the needle will tilt downwards and in southern hemisphere it will tilt upwards. The needle is graduated uniformly on either side of the pivot and is provided with a sliding aluminium weight which can be moved till it balances the effect of vertical force Z , so that the needle is horizontal. At either end of the needle and fixed to the case are two strips of high conductivity copper, shaped so as to be as near as possible to the ends of the magnetic needle. These carry graduated scales and tend to damp the vibration of the needle, by electromagnetic induction.

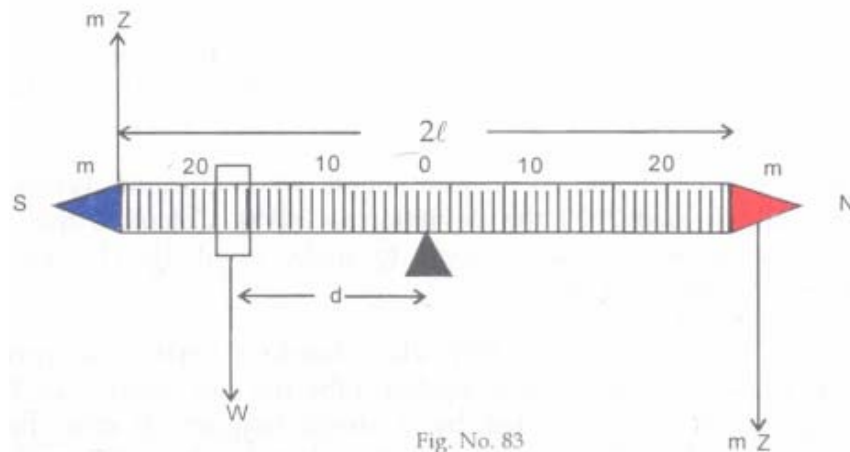


Fig. No. 83

Let the pole strength of the needle = m .

clockwise moments = $m \times l \times Z + m \times l \times Z$

anti-clockwise moments = $w \times d$

$$2mlZ = w \times d \quad (\text{when the needle is horizontal})$$

$$MZ = w \times d$$

Where M = Magnetic moment

Z = Earth's Vertical Force

w = rider wt.

d = distance between rider and pivot

For the same instrument, M is constant, and w (rider wt.) is also constant.

$$\therefore d \propto Z$$

$\therefore$ for different latitudes, using same instrument, we have

$$\begin{aligned} d_1 &\propto Z_1 \\ d_2 &\propto Z_2 \end{aligned}$$

$$\therefore \frac{Z_1}{Z_2} = \frac{d_1}{d_2}$$

$$\frac{Z_{\text{aboard}}}{Z_{\text{ashore}}} = \frac{d_1}{d} = \mu \quad (\text{by definition})$$

$\therefore \mu$ = ratio between scale reading on board ship to scale reading ashore.

PROCEDURE [USE OF V.F.I TO CORRECT H/E]

1. Place the instrument ashore where it is free from local disturbing magnetic fields, at least 1 metre above the ground, with the needle lying in the magnetic meridian.
2. Place the rider weight on the high end and slide it till the needle is horizontal. The dipping couple acting on the needle due to Z has then been nullified by the rider weight acting at 'n' divisions from the pivot. Note the reading, say 'n'.

If we now take the instrument to the compass position on the ship, with the rider weight at the same position, on a wooden ship, the needle will still remain horizontal. However, we know that, on a steel ship, besides Z , force R and induced magnetism due to k rod and also if heeled, the effect of induced magnetism due to transverse beams (i.e. e rod effect) are also present. Therefore the needle of the V.F.I, when placed at the compass position on the ship, in the direction of the magnetic meridian, will tilt, one or other end up, depending upon the nature

of force R and k rod effect. If the V.F.I needle is now made horizontal by placing the vertical heeling error corrector magnets, force R and k rod effects would be eliminated. However, since H/E correction is carried out with the ship upright, e rod induction by Z is absent. When the ship heels later, induction by Z in the athwartship horizontal soft iron will produce some H/E. Since λ_2 is a measure of the effect of horizontal soft iron on board, as modified by the spheres, the effect of horizontal soft iron (e rod) in producing heeling error is allowed for by multiplying the shore reading of the V.F.I i.e. 'n' by the λ_2 to obtain 'n₁'

$$n_1 = n \times \lambda_2$$

Since λ_2 is used in this manner; it is also called the "**Ship's Multiplier**".

3. Reset the rider weight at n_1 divisions. The instrument is now ready for use on board.
4. Before correcting for H/E, ensure F/B and spheres are correctly positioned. If they are not in position, the H/E will be over corrected, when the S.I. correctors are placed after heeling error correction.
5. Head the ship East - West so that any g rod present on the ship is in the neutral position with respect to the Earth's H and therefore receives no induction. If the g rod is induced, it will also produce a vertical field which will affect the vertical force instrument. However, as stated earlier, we deliberately refrain from correcting g rod H/E.

However, if g rod is not present, the heading is immaterial.

6. Unship the compass bowl. Place the V.F.I in the position normally occupied by the compass needle system, with the needle of the V.F.I lying in the magnetic meridian, red end towards North.

If any vertical field due to the ship is present the V.F.I. needle will lie at an angle to the horizontal.

7. Insert vertical magnets or adjust them if they are already present in the heeling error bucket beneath the compass, until the needle of the instrument is horizontal. When this is achieved, the ship's vertical field causing H/E has been nullified, that is, H/E has been corrected.

Recall that, the **correction for H/E holds good for only that latitude in which the correction was made.**

Example 1: The V.F.I was levelled ashore off place (1) $H = 30$ A/m, $Z = 20$ A/m, with sliding wt. at 20 divisions from the centre. If $\lambda_2 = 0.85$, calculate setting of the instrument for correction of H/E on board at place (2) $H = 36$ A/m, $Z = -15$ A/m.



Place (1), Since Z is +ve, N end will dip down.

$\therefore$ wt. must be 20 divisions from centre on the South arm.

$$Z_1 = 20 \quad Z_2 = -15$$

$$d_1 = 20 \quad d_2 = ?$$

$$\frac{Z_1}{Z_2} = \frac{d_1}{d_2} ; \frac{20}{-15} = \frac{20}{d_2}$$

$$d_2 = -15$$

Since d_2 is -ve, the rider weight is to be placed on the other arm of the V.F.I. needle. Also by logic, in Southern latitude, the blue end will dip down. Therefore the weight has to be shifted to the red arm.

$\therefore$ the wt. must be placed on the red arm.

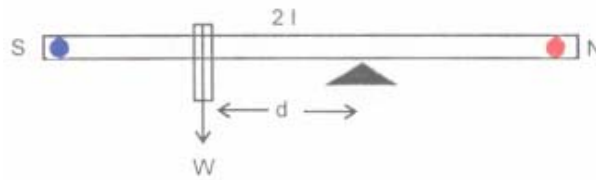
$\therefore$ Dist. for correction of H/E = $n \times \lambda_2$

$$= -15 \times .85$$

$$= -12.75$$

i.e. 12.75 divisions from the centre on the red arm.

Example 2: What is the Magnetic Moment of a V.F.I. if the rider wt. of 80 mg must be set at 2.2 cms. from the fulcrum when the instrument is used to adjust, heeling error at the compass position on board a ship, where $H = 20 \text{ A/m}$, $\text{dip} = 71^\circ$; ship's multiplier = 0.88



$$\text{We know } M \times Z_1 = w \times d$$

$$\begin{aligned} \text{where } Z_1 &= \lambda_2 \cdot Z \\ &= .88 \times Z \end{aligned}$$

$$Z = 20 \tan 71^\circ$$

$$\therefore Z_1 = .88 \times 20 \times \tan 71^\circ$$

$$M \times .88 \times 20 \times \tan 71^\circ = \frac{80}{1000} \times g \times 2.2$$

$$M = \frac{80 \times 981 \times 2.2}{1000 \times 0.88 \times 20 \times \tan 71^\circ}$$

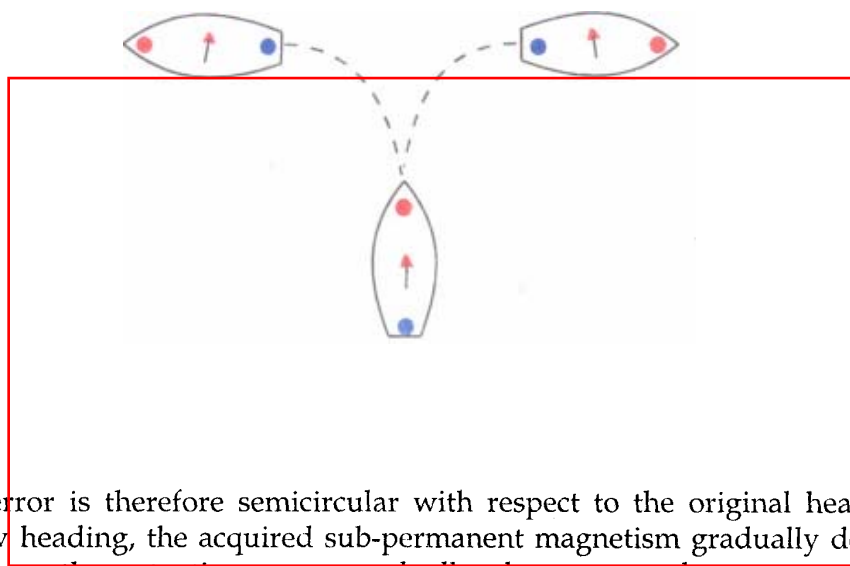
$$= 3.4 \times 10^{-5} \text{ wm.}$$

CHAPTER 12

GAUSSIN AND RETENTIVE ERRORS

RETENTIVE ERROR

A vessel on steady course for a considerable period acquires a certain amount of sub-permanent magnetism, in her structure, with a red pole to the northward of the compass and a blue pole to the southward of the compass due to the vibration, pounding etc. Though the vessel alters course thereafter, these poles are retained for a few hours, during which period they gradually decay. This retained sub-permanent magnetism will cause westerly deviations on any new course upto 180° to the right of the original heading, as the red pole will then be carried to the east and the blue pole to the west of the compass. It will cause an easterly deviation on any new course upto 180° to the left of the original heading as the red pole will then be carried to the west and the blue pole to the east of the compass.



Retentive error is therefore semicircular with respect to the original heading. On the new heading, the acquired sub-permanent magnetism gradually decays and therefore the retentive error gradually decreases and ceases to exist after a few hours. Therefore, when the vessel alters course after steering a steady course for a considerable period, the compass error should be checked frequently, over the next six hours or so, as the retentive error gradually reduces over that period.

GAUSSIN ERROR

When a vessel alters course rapidly, the different parts of the ship's structure cut the Earth's magnetic field at varying rates. This sets up an EMF and therefore an electric current in the ship's hull. This current sets up a magnetic field of its own, which according to Lenz's law will act in a direction opposite to that of the ship's swing which caused it. There is also a short lag in the shift of the induced poles in the ship's S.I. structures, because of hysteresis. Due to both these effects, while the ship swings to starboard the compass deviates to the west. If the ship swings to port, the compass will deviate to the east. The name of the deviation remains the same for all 360° of the ship's swing provided the direction of swing remains the same, but the amount of the deviation will increase and decrease quadrantly due to the unsymmetrical shape of the ship. Thus, a rapid swing to starboard produces a -A and -F, while a rapid swing to port produces a +A and +E. This error is present only while the ship is swinging and ceases to exist within a couple of minutes of the ship steadying on her next course. Bearings observed while the ship is swinging should not, therefore, be relied upon.

CHAPTER 13

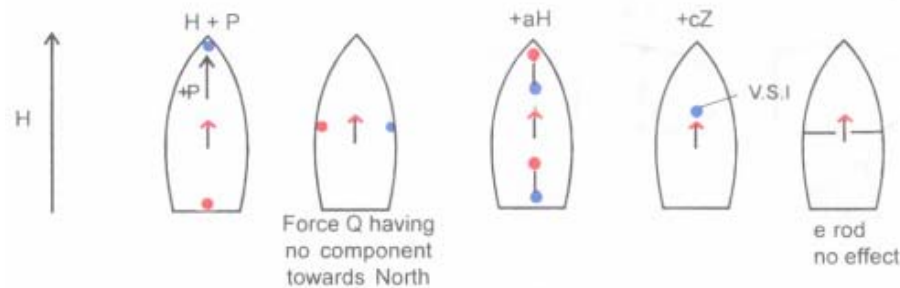
DIRECTIVE FORCE

The force which enables the compass needle to point towards magnetic north is called the directive force, D.F. This force is the earth's horizontal force H , as modified by the horizontal component of the ship's magnetic field at the compass position.

The DF on the various headings would be affected by Force P , Force Q , vertical soft iron (c rod), fore and aft soft iron (a rod) and athwartship soft iron (e rod).

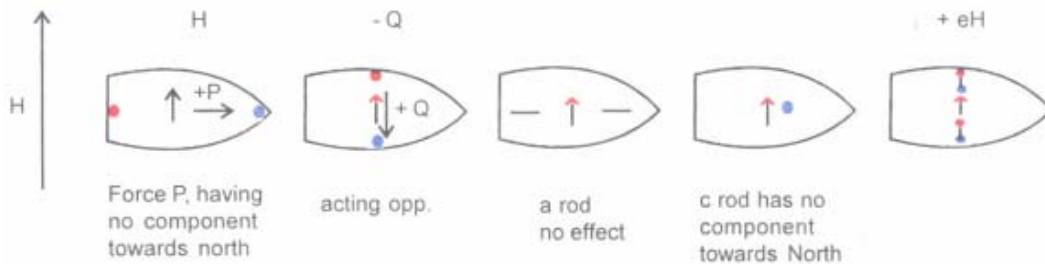
Let us consider the D.F. values on 4 cardinal headings. Further, assume the ship to be in Northern hemisphere with $+P$, $+Q$, $+a$ rod $+c$ rod and $+e$ rod.

On North



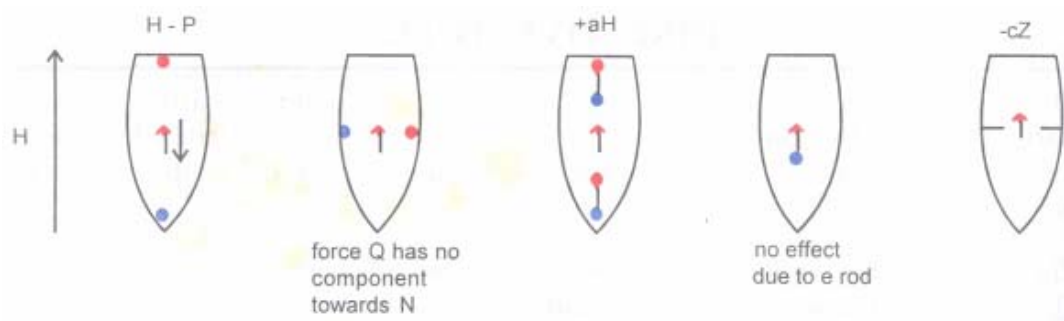
On North $\underline{H + P + aH + cZ}$ - - - (1)

On East



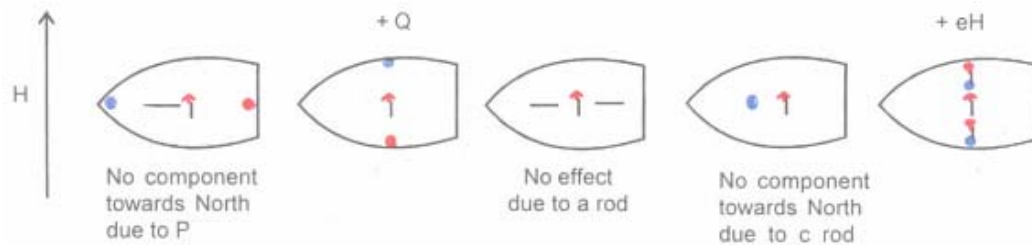
On East $\underline{H - Q + eH}$ - - - (2)

On south



On south $H - P + aH - cZ$ ---- (3)

On West



On West $\underline{H + Q + eH}$ -- (4)

$$\begin{aligned}
 \text{Mean DF} &= \frac{(1) + (2) + (3) + (4)}{4} \\
 &= \frac{H + P + aH + cZ + H - Q + eH + H - P + aH - cZ + H + Q + eH}{4} \\
 &= \frac{4H + 2aH + 2eH}{4} \\
 \text{Mean DF} &= H + \left(\frac{a+e}{2}\right)H
 \end{aligned}$$

At a badly placed compass, b, d and f rods may also have some effect but this effect is being ignored.

The ratio λ (LAMBDA) is the ratio of mean DF at the compass position towards magnetic North to the DF of the earth, ashore, at that place.

$$\begin{aligned}\lambda &= \frac{\text{Mean DF at compass}}{H} \\ &= \frac{H + \left(\frac{a+e}{2}\right)H}{H} \\ \lambda &= 1 + \left(\frac{a+e}{2}\right)\end{aligned}$$

Since values of a and e rods (F and A continuous and athwartship continuous soft iron) are generally both negative on a normal ship.

$$\lambda = 1 + (\text{negative quantity})$$

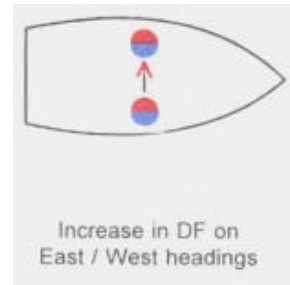
$\therefore \lambda$ is generally < 1 on a ship.

We know from our previous work that Coefficient D is usually caused by a combination of -a and -e rods on the ship. The -a rod causes a -D and the -e rod causes a +D. In the usual case, the -e rod predominates causing a +D at the compass. This effect i.e. Coefficient D is corrected by placing divided soft iron athwartship of the compass in the form of spheres. The athwartship spheres act as +e and -a rods. The spheres, athwartships increases the -a (-D) and reduces the -e (+D) effects at the compass till they are numerically equal so that coefficient D is fully corrected. (Refer to correction of Coefficient D). The rods after correction are known as a_2 and e_2 and are numerically equal to each other.

Therefore after D has been corrected i.e. spheres have been placed correctly, if we again measure the mean DF at the compass to obtain the ratio λ_2 (LAMBDA₂)

$$\begin{aligned}\lambda_2 &= \frac{H + \left(\frac{a_2 + e_2}{2}\right)H}{H} \\ \therefore a_2 &= e_2 \\ \therefore \lambda_2 &= 1 + e_2\end{aligned}$$

It is important to note that a and e rods of a ship are usually -ve, and therefore as already stated λ_1 is less than 1. But after the spheres, are correctly positioned the value is increased, and is then referred to as λ_2



On E - W headings, the spheres are in the *end on* position with respect to the compass needle while on N/S headings they are in the *broadside on* position. As the effect in the *end on* position is double that in the *broadside on* position, the increase in DF on E and W headings is double that of loss in DF on N and S headings.

Therefore ultimately, the placement of spheres cause an increase in DF. λ_2 is therefore greater than λ_1 . However even then, its value remains less than H. λ_2 may have a value as high as 0.95 at the compass position.

λ_2 will remain constant for a particular ship in any part of the world, since the force inducing the a and e rods and the DF at the compass are both due to H, and therefore will vary together.

It should be noted that Coefficient A has no effect on the DF on any heading as the deviating force causing Coefficient A acts exactly E or W with no N - S component. Coefficients PB, iB, PC and iC while increasing and decreasing the DF on opposite headings, do not affect the mean DF, λ . Coefficients D and E caused due to induced magnetism in horizontal Soft Iron do affect the mean DF, λ .

CHAPTER 14

HORIZONTAL VIBRATING NEEDLE

To find λ_1 or λ_2

HORIZONTAL VIBRATING NEEDLE (OSCILLATING NEEDLE)

A magnetic needle about 75 mm long and 12.5 mm broad at its centre is used as an oscillating needle. It is fitted with a jewel cap, and pivot of similar construction as described for the compass card, so that the needle can oscillate in the horizontal plane

It is suspended in a circular wooden frame provided for the purpose. For use on board, it is placed in the same position as the compass after removing the bowl.

The needle is deflected about 40° and allowed to oscillate. An oscillation consists of the movement of the needle from one extreme to the other extreme and then back again to the original extreme position. The mean time for 10 oscillations is determined ashore. Observations are then made on board on 4 or more equidistant magnetic headings, and the value of λ determined. If this type of needle is not available, a dry card compass may be used instead.

The period of oscillation of a magnetic needle in seconds :

$$T = 2\pi \sqrt{\frac{I}{MH}}$$

Where I is the moment of inertia of the oscillating needle
 M is the magnetic moment of the needle
 H the field in which the oscillation occur.

$$\therefore T^2 = 4\pi^2 \times \frac{I}{MH}$$

$$\therefore H \propto \frac{1}{T^2} \text{ (As } 4, \pi^2, I \text{ and } M \text{ constant)}$$

- The faster the needle oscillates, the stronger must be the strength of the field.

$$\frac{H \text{ on board}}{H \text{ ashore}} = \frac{T^2 \text{ ashore}}{T^2 \text{ on board}}$$

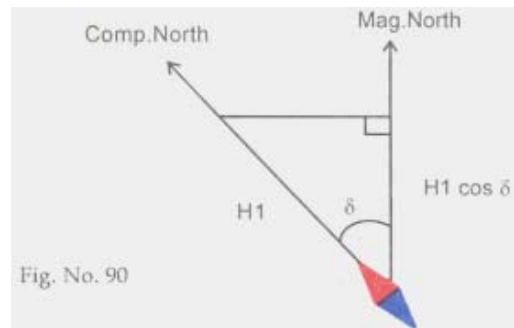
Also $T \propto \frac{1}{n}$ where n is the number of oscillations in a certain period.

$$\therefore \frac{H \text{ on board}}{H \text{ ashore}} = \frac{n^2 \text{ on board}}{n^2 \text{ ashore}}$$

When the needle is oscillated at the compass position, it will oscillate about compass North. Thus the field being compared will be that acting towards compass North. However λ is the ratio of the field towards magnetic North on board, as compared to the Earth's field. To reduce H_1 the field towards compass North to that acting towards magnetic North, we can multiply H_1 by the cosine of the deviation on that heading.

H_E = Horizontal component of Earth's field, ashore

H_1 = Horizontal component, on board, in the direction of the compass north.



The component of H_1 along the magnetic meridian = $H_1 \cos \delta$

$\therefore H_1 \cos \delta$ is the DF at the compass, on board.

Mean DF on board = Mean of $H_1 \cos \delta$ on any number of equidistant magnetic headings.

After having obtained the ratio of the DF on board to DF ashore on the four cardinal headings, it is possible to deduce the signs of the Coefficients e.g. if DF on North < DF on South $\Rightarrow$ the ship's F&A field acts towards the stern, implying a -B. Similarly if DF on East is less than DF on West, it indicates a field acting towards stbd. implying a +C. Also if mean DF on N & S is less than mean DF on E & W, it implies a -D.

Example 1: With the flinders bar correctly positioned and the spheres in an approximate position athwartships, the following readings were recorded. Ashore, the mean time for 10 oscillations was found to be 20 seconds. On board, the following readings were recorded. Calculate the values of λ and state how the horizontal magnets are to be placed and the spheres adjusted.

Mag.Co..	Comp.Co.	Deviation	Mean time for (10 oscillations)
N	003°	3° W	22
E	091°	1° W	19
S	178°	2° E	17
W	269°	1° E	25

Find the value of λ_2 and the signs of coefficients B, C and D.

$$\lambda_2 = \frac{H_B}{H_S} = \frac{T_S^2}{T_B^2} \cos \delta$$

$$\lambda_2 \text{ N Mag.} = \frac{H_B}{H_S} = \frac{20^2}{22^2} \times \cos 3^\circ = 0.825$$

$$\lambda_2 \text{ E Mag.} = \frac{H_B}{H_S} = \frac{20^2}{19^2} \times \cos 1^\circ = 1.108$$

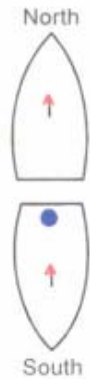
$$\lambda_2 \text{ S Mag.} = \frac{H_B}{H_S} = \frac{20^2}{17^2} \times \cos 2^\circ = 1.383$$

$$\lambda_2 \text{ W Mag.} = \frac{H_B}{H_S} = \frac{20^2}{25^2} \times \cos 1^\circ = 0.640$$

3.956

$$\text{Mean} = \lambda_2 = \frac{3.956}{4} = 0.989$$

Coefficient B N $\longrightarrow$ 0.825
 S $\longrightarrow$ 1.383



Since field is stronger, when heading south.
 Blue pole is aft $\Rightarrow$ -B

Coefficient -B is present $\therefore$ Place F/A magnets red ends aft.

Coefficient C E $\longrightarrow$ 1.108
 W $\longrightarrow$ 0.640



D/F is more on East $\Rightarrow$ Blue pole is to Port, $\therefore$ a -C is present.

Coefficient -C is present $\therefore$ Place athwartship magnets red ends to port.

Coefficient D	N	0.825	}	----- 1.104 Mean
	S	1.383		
	E	1.108	}	----- 0.874 Mean
	W	0.640		

Mean DF on N - S is more than that on E - W $\Rightarrow$ +D is present

Ship has +D $\therefore$ Correct by moving the athwartships spheres inwards to cause more -D effect.

(It is advantageous to site the standard compass at a position, where λ_2 has maximum value, as the compass would then be steadiest, and also will have least deviations.)

Example 2: With the flinders bar correctly positioned but no spheres or horizontal magnets, the following observations were noted using an oscillating needle.

Mag.Hdg.	Comp.Hdg.	Deviation	No. of oscillations in a minute
000°	005°	5° W	11
090°	092°	2° W	9
180°	176°	4° E	5
270°	267°	3° E	8
		ASHORE	10

Calculate the value of λ and state how the horizontal magnets and spheres are to placed.

$$\lambda N = \frac{H_B}{H_S} = \frac{N_B^2}{N_S^2} \times \cos \delta = \frac{11^2}{10^2} \times \cos 5^\circ = 1.205$$

$$\lambda E = \frac{H_B}{H_S} = \frac{N_B^2}{N_S^2} \times \cos \delta = \frac{9^2}{10^2} \times \cos 2^\circ = 0.810$$

$$\lambda S = \frac{H_B}{H_S} = \frac{N_B^2}{N_S^2} \times \cos \delta = \frac{5^2}{10^2} \times \cos 4^\circ = 0.249$$

$$\lambda W = \frac{H_B}{H_S} = \frac{N_B^2}{N_S^2} \times \cos \delta = \frac{8^2}{10^2} \times \cos 3^\circ = \frac{0.639}{2.903}$$

$$\lambda = \frac{2.903}{4} = 0.726$$

- a) DF on N > DF on S $\Rightarrow$ +B.

Place F & A magnets, red ends for'd.

- b) DF on E > DF on W $\Rightarrow$ -C.

Place athwartship magnets, red ends to port.

- c) Mean DF on N & S > Mean DF on E and W.

$\Rightarrow$ +D Place the spheres athwartships.

CHAPTER 15

KELVIN DEFLECTOR

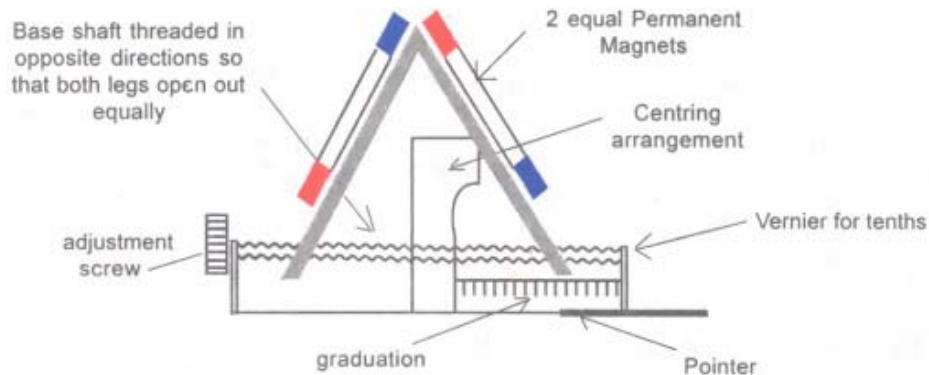
This is an instrument used for correction of the compass, when more direct methods are not available due to either poor visibility or non availability of suitable land marks, or simply that some compass adjuster prefers this method. The results are, at best, more practical, but not very accurate.

PRINCIPLE

If the DF is equal on all compass headings, then no deviations will exist, as there will be no disturbing force.

The deflector compares the DF on different headings. These directive forces are then equalised on all headings by using Permanent magnets and soft iron correctors, so that theoretically there is no deviation on any heading. **This instrument only compares DFs and does not measure them.**

DESCRIPTION



It consists of two equal permanent magnets hinged with their unlike poles together. The two unlike poles nullify each other, while the two poles below can open out in scissor fashion. This arrangement allows the combination to act as a single magnet of a variable length and therefore of variable magnetic moment ($2 \ell \phi_{wb} / m$). This can be achieved by turning the screw, having a vernier arrangement as well. The direction of the magnetic axis of the equivalent magnet is indicated by a pointer on the base of the instrument. There is a centre pin designed to fit into the centre brass boss of the plate glass cover of the compass bowl. It is very important to centre the instrument over the compass bowl. The Kelvin Deflector is capable of rotating on the bowl like an ordinary azimuth measuring device. There is further, an arrangement to house auxiliary magnets to assist the existing pair of magnets, in case the magnetic moment is to be increased. As the poles move apart, a pointer moves along a graduated scale which indicates arbitrary units of force.

When the Kelvin Deflector is placed over the compass card with its blue end (pointer end) over the North point (red end) of the compass card and then turned in azimuth, the blue pole of the Deflector attracts the compass North which tends to follow the pointer end of the deflector.

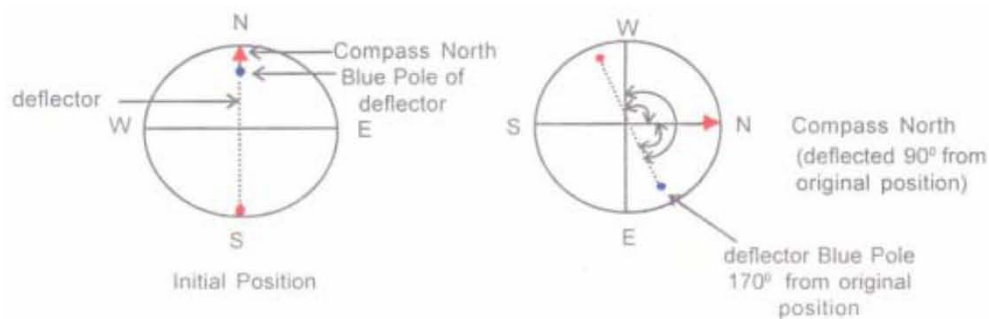
PROCEDURE FOR CORRECTION OF COMPASS

1. Place the flinders bar to correct iB , the spheres to correct an estimated Coefficient D and correct the heeling error.
2. Head the ship north by the compass, to be corrected. Maintain this heading by steering the corresponding course by another compass.
3. Place the Deflector over the compass with its pointer, (blue end) over the north point of the compass card.
4. Open out the scissor magnets and rotate the Deflector slowly clockwise by 170° . Adjust the deflector screw till the compass card is deflected exactly 90° . (The North point of the card should be against the athwartship lubber line).

In this position the compass card would have deflected by 90° , and the pointer of the deflector would be on 080° on the compass card. This 90° deflection is known as **normal deflection**. If the verge ring of the compass bowl is graduated from 0° to 360° as is usually the case, the deflector can be rotated through 170° using those graduations.

These angles are chosen for the following reasons:-

- i) More accurate results are obtained when the needle is deflected 90° i.e. perpendicular to the original direction.
- ii) Angle between compass needle and pointer is kept at 80° , so that its field acts almost perpendicular to the needle system of the compass, thus providing maximum deflecting couple. If that angle is made exactly 90° , the deflector field will be acting exactly southward, only reducing the DF at the compass and not providing any deflecting force. The compass card will then just fly back and point North.



5. When the above is achieved, note the reading. This gives deflector reading when heading north.
6. Now repeat the same process, with ship heading East, South and West successively, ensuring that the pointer end of the Deflector is placed over the north point of the compass card, turned through 170° and adjusted till the north point of the compass card is deflected exactly 90° from its original position, on each occasion.

The larger the reading on the graduated scale (i.e. length of the magnet), the larger is the DF on that heading, as a larger force had to be used to deflect the compass card through the same 90° angle.

Advantages:

1. Requires no external visual bearings, therefore ideal in poor visibility.
2. Not sensitive to ship's turning circle, drift due to current etc.
3. It is done more quickly than other methods.

Disadvantages:

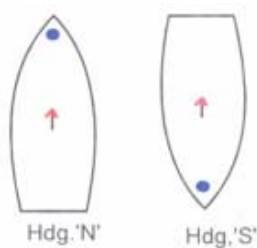
1. Not as accurate as analysis or tentative methods.
2. No table of deviations available after the correction i.e. no deviation card to refer to.
3. Exact value of coefficients not known.
4. Alternate compass essential for steering.

Example 1 : With the flinders bar correctly compensating iB and the spheres in an approximate position athwartships, the following readings were obtained using a Kelvin Deflector.

N	→	26	} Mean 23
S	→	20	
E	→	18	} Mean 21
W	→	24	

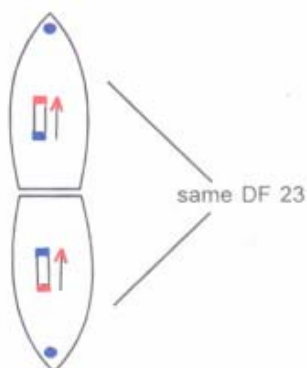
State how you would correct PB and PC and how you would adjust the spheres to correctly compensate Coefficient D.

Heading North
South



The DF on North is $>$ DF on South. This indicates there is an attraction towards the Bow, due to blue pole located forward. i.e. $+B$.

Set the deflector to the mean of N and S readings $\left(\frac{26+20}{2}\right)=23$. With the ship heading



N or S, place the deflector over the compass with its pointer over the N point of the card and turn it through the same 170° . Place F & A magnets, red ends forward and adjust them till the compass card shows exactly 90° deflection.

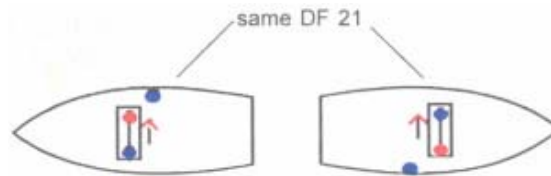
The DF on N and S have now been equalised and PB has therefore been corrected, as the F and A field of the ship has been eliminated.

Heading East
West

The DF on West is $>$ DF on East. There is attraction to starb'd. This indicates there is a blue pole to starbd i.e. $+PC$.



Set the Kelvin deflector to the mean of E and W readings $\left(\frac{18+24}{2}\right)=21$



With the ship heading E or W, place the deflector over the compass with its pointer over the N point of the card and turn it through 170° . Place athwartship magnets red ends to stbd. and adjust them till the compass card shows exactly 90° deflection. The DF on E and W have now been equalised and PC has therefore been corrected.

Mean on N/S is 23

Mean on E/W is 21

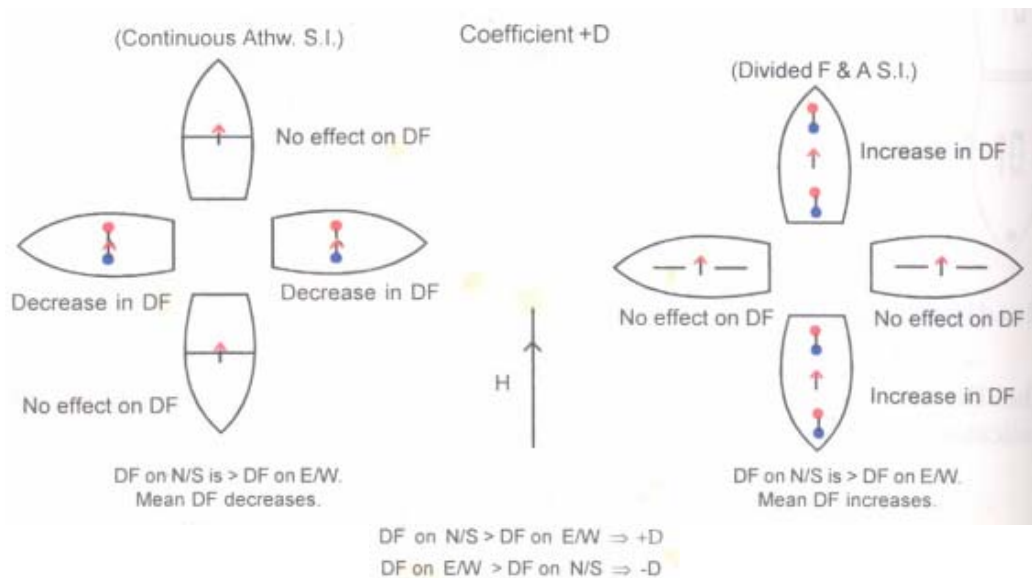
Mean of Means is 22

DF on N/S is $>$ DF on E/W indicating a +D.

Since spheres are in position already and are placed athwartships, they cause -D. They are therefore under compensating.

Set the Kelvin Deflector to the mean of means reading of 22. With the ship on any of the four cardinal headings, place the Kelvin Deflector with its pointer over the N point of the card and turn it through 170° . Move the spheres in till the compass card shows exactly 90° deflection.

Since DF on N & S has been made equal to that on E & W, Coefficient D has been corrected.



(The above method assumes no A & E or iC are present. iB has been corrected by estimation, placing F/B say ford.)

Example 2: Using a Kelvin Deflector, the following readings were obtained on board. N: 16, E: 24, S: 18, W: 18.

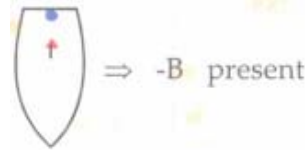
a) Assume no correctors to be in position. State how they should be placed and name the signs of coefficients they would correct.

b) If the compass was deflected ashore and Deflector reading of 24 was obtained, calculate the approximate value of λ .

N $\longrightarrow$ 16
S $\longrightarrow$ 18 } Mean 17

E $\longrightarrow$ 24
W $\longrightarrow$ 18 } Mean 21

1. DF on South > DF on North



Head the ship N or S.

With the Kelvin Deflector set to read 17 and turned through 170° , achieve 90° deflection, by placing F&A magnets red ends aft.

2. DF on East > DF on West



Head the ship E or W.

With the Kelvin Deflector set to read 21 and turned through 170° , achieve 90° deflection, by placing athw. magnets red ends to port.

3. Mean DF on E - W is > Mean DF on N - S $\Rightarrow$ Coefficient -D is present.

Since -D is present with no spheres in position, it means ship has either continuous F & A or divided athwartship S.I on the ship.

Head the ship N, E, S or W.

With the Kelvin Deflector set to a reading of $\frac{17+21}{2} = 19$, and turned through 170° , place spheres F & A and adjust their distance to achieve 90° deflection.

b) Approximate $\lambda \Rightarrow$

$$\text{Mean deflector reading on board} = \frac{16+18+24+18}{4} = 19$$

Deflector reading ashore = 24

$$\therefore \frac{H_B}{H_S} = \frac{19}{24} = 0.79$$

Approx. $\lambda = 0.79$

CHAPTER 16

DEVIASCOPE DEFLECTOR

It is a bar magnet used for correcting the compass in a manner similar to that when using the Kelvin Deflector.

To correct the compass using the deviascope deflector, on each of the four cardinal headings we keep the magnet over the compass and turn it through 90° on each occasion. For the same deflecting force we note the corresponding deflections of the compass card. The larger the deflection the smaller is the directive force at the compass position on that heading and vice versa.

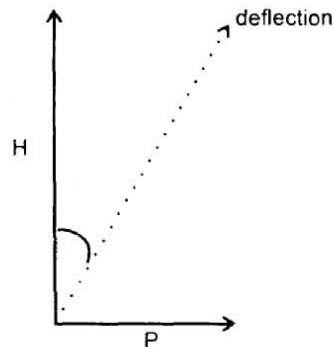


Fig. No. 93

Flinders bar and the spheres must be in approximate positions before commencing.

Example 1: With the flinders bar fore and spheres athwartship at an approximate position, the following deflections were noted using a deviascope deflector. How would you place the correctors?

Comp Co.	Deflection
000 ^o	20 ^o
090 ^o	16 ^o
180 ^o	14 ^o
270 ^o	22 ^o

Comparing the deflections on N and S headings, we find a larger deflection on N i.e. the directive force is lesser on N and greater on S i.e., we have a -B.

With the ship heading N or S, and the deflector magnet turned through 90° insert fore and aft magnets with blue ends fore, until the compass deflects to the mean of 20° (on N) and 14° (on S) i.e. until the compass deflection is 17° .

We compare the deflections on E and W headings. We find a larger deflection on W than on E i.e. smaller DF on W and larger DF on E i.e. we have a -C.

With the ship heading E or W and the deflector magnet turned through 90° insert athwartship magnets with red ends to port until the compass deflects to the mean value between 16° and 22° i.e. 19° .

We now compare the mean deflection N and S with that on E and W. Mean on N&S is 17° and that on E&W is 19° . The DF on N&S > the DF on E&W. We therefore have a +D.

This means the spheres athwartships are under correcting. Therefore they have to be brought closer till the deflection reaches the mean between 17° (the mean between N and S) and 19° (the mean between E and W) i.e. deflection should be 18° with the deflector magnet turned through 90° . This correction is to be done with the ship heading on any of the four cardinal headings.

We have thus corrected the compass for deviations due to coefficients B, C and D.

EXERCISE V

(V.F.I., I, Kelvin Deflector, Deviascope Deflector)

1. The shore reading of the V.F.I. is 20 divisions on the red arm, when the instrument was balanced. If the ship's multiplier is 0.8, where is the weight to be placed to correct heeling error?
2. The V.F.I. is balanced ashore with the weight placed at 15 divisions on the south arm where $H = 24$ A/m, $Z = 18$ A/m. Where should the weight be placed to correct the H/E where $H = 15$ A/m, $Z = 24$ A/m, $\lambda_2 = 0.9$.
3. With the flinders bar correctly positioned and the spheres in an approximate position athwartships, the following readings were obtained with an oscillating needle.

Mag. Hdg.	Comp. Hdg.	Time for 5 oscillations
000°	356°	26 secs
090°	096°	25 secs
180°	185°	19 secs
270°	264°	22 secs
Ashore		20 secs

Calculate the value of λ . State the signs of coefs. B, C and D and state how the horizontal magnets are to be placed and the spheres adjusted.

4. With flinders bar correctly positioned and spheres in an approximate position athwartships, the following readings were obtained with an oscillating needle.

Comp.Co.	Mag.Co.	No. of Oscillations in 2 mins.
006°	N	15
086°	E	13
174°	S	12
274°	W	11
Ashore		14

Calculate the value of λ and state how the Horizontal Magnets are to be placed and the spheres adjusted.

5. With the flinders bar correctly positioned and the spheres athwartships in an approximate position the following observations were made with an oscillating needle:

Mag.Hdg.	Comp.Hdg.	No. of Oscillations	Time taken in seconds
N	355 ⁰	7	26
E	086 ⁰	8	24
S	187 ⁰	6	22
W	264 ⁰	10	39
	Ashore	9	30

State the value of λ , the signs of Coefficients B, C and D and how the corrector magnets are to be placed and the spheres adjusted.

6. With the flinders bar correctly positioned, the following readings were obtained with a Kelvin deflector.

Comp.Hd.	N	E	S	W
Deflector reading	29	27	35	33

How would you correct B, C and D?

If the deflector reading for the same compass ashore was 34, find the approximate value of λ .

7. With the flinders bar correctly positioned, spheres athwartships, F&A magnets red for'd, athw. magnets red to port, the following Kelvin deflector readings were obtained for 90 deflection of the card.

Comp. Hdg.	:	000 ⁰	090 ⁰	180 ⁰	270 ⁰
Deflector reading	:	34.6	29.5	27.6	35.7

How would you adjust the correctors?

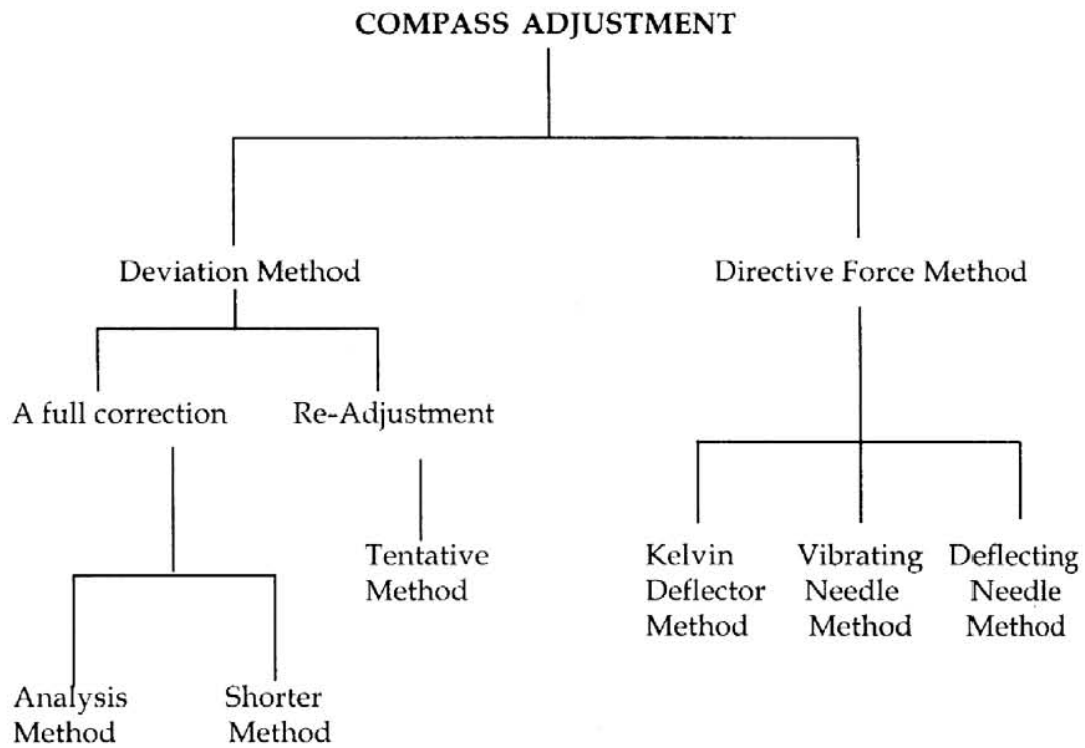
8. The following deflections were obtained when a Deviascope deflector was placed over the compass and turned through 90⁰

Comp. Hdg.	N	E	S	W
Deflection	40 ⁰	55 ⁰	54 ⁰	43 ⁰

How would you correct coefs. B, C and D if iB is nil?

CHAPTER 17

COMPASS ADJUSTMENT AND CORRECTION



COMPASS CORRECTION

The practical compass correction may be achieved by several methods. Each has its own advantages. Some of the popular methods of correction are being discussed here. However, before the actual correction, it has to be understood, in what order the correctors are to be placed. It is necessary to follow a definite order of placing the correctors so that the corrections done earlier are not disturbed by other corrections made thereafter.

ORDER OF PLACING THE CORRECTORS AND THE UNDERLYING REASONS

It is essential that the following order of placing the correctors be adhered to, for the reasons indicated:

1. The soft iron correctors - The flinders bar followed by spheres.
2. Heeling error corrector magnets.
3. The horizontal magnets to correct PB and PC, the larger coefficient first.

Though the main dimension of the flinders bar is vertical, it also has small horizontal fore and aft and athwartship dimensions, both these produce a +D effect. When the spheres are placed later, they correct this effect together with the D of the ship.

The soft iron correctors should be in position before correcting heeling error as:-

- a) The flinders bar when placed correctly also corrects the c rod H/E.
- b) The spheres placed athwartships partly compensates the k rod and e rod H/E. If they are placed after the H/E is fully corrected by vertical magnets the H/E would be over corrected.
- c) The spheres have to be in position for obtaining λ_2 which is necessary for H/E correction.

The spheres should be in position before correction of PB and PC because :-

- a) The spheres increase the mean directive force at the compass and therefore the calculation of coefficients PB and PC and their correction will be more accurate.
- b) The horizontal permanent corrector magnets will induce some magnetism in the soft iron spheres, causing fore and aft and athwartship fields at the compass. When the magnets are placed after the spheres, they correct these effects as well as forces P and Q causing PB and PC respectively.

The heeling error corrector magnets should be positioned before correction of PB and PC because :-

- a) With the heeling error corrected, even if the ship is rolling, the compass will be steady enabling more accurate bearings and therefore more accurate calculation of the coefficients. Thus correction of PB and PC will be more accurate.
- b) When the vertical heeling error corrector magnets are placed, they induce some magnetism in the vertical soft iron flinders bar, causing a pole for'd of the compass, which will produce a PB. When the fore and aft magnets are placed later, they correct for this effect in addition to force P causing PB.

Of PB and PC the larger coefficient should be corrected first. Recall that force P which causes PB or force Q which causes PC also causes maximum change of directive force on the headings on which the PC or PB respectively produce maximum deviation. If for example, Coefficient B was very large, there is a large force P in the fore and aft direction. This will cause a large change in the directive force on N and S headings. Calculation of Coefficient C by obtaining deviation on those headings will therefore be unreliable and correction of Coefficient C will not be accurate.

If the large PB is corrected first by obtaining deviations on E and W headings where changes in directive force is due to force Q (which is small - as Coefficient C is small) a more accurate correction of PB will result. Later when correcting PC on N or S headings, there will be no reduction in the directive force on any of those headings as the correction of PB earlier has nullified force P.

METHODS OF CORRECTING THE COMPASS

There are two methods by which the compass can be corrected:

By ascertaining the deviations, analysing the coefficients and then correcting them (Deviation method) or by comparison and equalisation of directive forces on all headings (Directive force method).

THE DEVIATION METHOD

There are two situations here:

1. When a full correction of the compass is required

or

2. A previously corrected compass is being re-adjusted.

In the case of (1) above, two methods can be used: The **ANALYSIS METHOD** or The **SHORTER METHOD**.

In the case of (2) above, a full scale correction is not necessary but a readjustment of the existing correctors is required (The **TENTATIVE METHOD**). In any case, a full correction is also possible using any of the other methods mentioned above.

1. THE ANALYSIS METHOD: The basic principle of this method of correction is, observation of deviations on various headings, analysing the coefficients and then making corrections for these by placing soft iron correctors and the permanent magnets. Re-swinging the ship to check for any large deviations left un-corrected and finally leaving only small amounts of deviations that could represent coefficients A & E.

The order of correction will be as per details above so we will stick to the same order of correction.

a. Induced B: It is hard to calculate the exact amount of Flinders bar that will be necessary, and only experience can guide the adjuster in this regard. Hence, as a general rule, sufficient Flinders bar is placed forward to correct a deviation of 3 to 4 degrees when heading E or W (compass). Here, it will be worthwhile to note that most merchant ships have a -ve iB (in the N. hemisphere) as the compass is mounted forward of the mast and the funnel. If the funnel or mast is mounted forward of the compass, the vessel will have +ve induced B (in the N hemisphere), the Flinders bar would then have to be placed abaft the compass. Again, the value of 3 to 4 degrees is based on normal distance of the funnel and the mast from the compass. This value will have to be adjusted either way depending upon whether the distance is lesser or greater than the normal.

b. Coefficient D: Coefficient D is to be corrected next. Observe the bearing of any distant object on any four or more equidistant headings. The mean of these would be the magnetic bearing of that object from the ship. Now steady the vessel on all of the intercardinal points (NE, SE, SW & NW) by compass. Observe the bearing of the same distant object, calculate the deviations on those headings, and hence calculate the value of coefficient D. When the vessel is on the last of the intercardinal points, correct the coefficient D as calculated by placing the soft iron spheres on their mounting brackets. It may be noted that most merchant vessels would have +D (For which the spheres have to be placed athwartships.)

c. The ship is now steadied on each of the four cardinal magnetic headings and the value of λ_2 is calculated as described earlier.

d. Heeling Error: Next to be corrected is the heeling error. The instrument used for this is the Vertical Force Instrument (V.F.I). Before bringing the V.F.I on board it should have been balanced ashore and the reading of the rider weight position noted ashore. This reading is multiplied by the ship's multiplier (λ_3), the rider weight is set to this value. The vessel is steadied on either E or W (magnetic), the compass bowl is removed from its position, the V.F.I is mounted in its place so that the position occupied by the V.F.I would be as close to the position of the compass card. The vertical magnets are inserted in the H/E bucket which is raised or lowered as necessary till the V.F.I needle is horizontal. As stated earlier, the larger of coefficients PB or PC is to be corrected next.

e. Permanent B: is corrected by permanent fore & aft magnets. Obtain the compass bearings of the distant object when heading E and W. By comparing them with its magnetic bearing - obtained earlier, ascertain the deviations on E and W. Calculate the value of PB (iB has already been corrected). When heading E or W, correct the coefficient by inserting F & A magnets, when heading E or W (compass).

f. Permanent C: is corrected by calculating deviation on N & S compass headings, calculating the value of Permanent C and then correcting it by inserting athwartships magnets when heading N or S (compass).

At this stage all coefficients other than coefficient A, coefficient induced C and coefficient E have been corrected. Induced C and coefficient E are rare on conventional merchant ships, hence any remaining deviation can be assumed to be either due to improper correction of any of the already corrected coefficients or due to coefficient A. The vessel therefore should now be swung very slowly, deviations noted on at least 8 equidistant points (cardinal & intercardinal headings) to ensure that all coefficients have been correctly compensated.

Finally record a table of deviations remaining uncorrected, note down the

place (latitude & longitude), date, time, position of all permanent magnets (fore & aft, athwartships & heeling error) together with the directions they face (Red forward, Blue to stbd., Blue upwards etc.), position of the heeling error bucket, length of the Flinders bar used, scale position of the S.I. spheres (the bracket mounting the spheres has graduated markings on its side) and the value of variation used to carry out the adjustment. A brief report as to how the correction was carried out would be a big help for future adjustment, should it become necessary.

It should be noted that, when placing the spheres, the F&A and the athwartship magnets, we correct the value of the coefficient and not the deviation observed on each heading on which the corrections are made.

2. THE SHORTER METHOD: As can be seen from the details of adjustment given in the analysis method, it is a rather lengthy and time consuming method. Equally accurate results can be obtained using the 'Shorter Method' of correction.

Here again the order of correction will remain just the same. Time will however be saved by reducing the several swings of the vessel.

a. induced B: It is to be corrected by flinders bar, when heading E or W for an assumed value of induced B exactly as in the analysis method.

b. Coefficient D: Mount the spheres on athwartship brackets and leave them at the maximum outward position.

c. Heeling Error: Same as under analysis method. If the value of the ship's multiplier is not known, the rider weight is to be left in the same position as was levelled ashore, but when correcting heeling error it is slightly overcompensated by inserting the vertical magnets so that the N end of the V.F.I needle is slightly above the horizontal in northern hemisphere. It should be slightly below the horizontal in the southern hemisphere.

Of coefficients PB and PC, the larger coefficients to be corrected first.

d. Coefficient Permanent B: Steady the vessel on E by compass, calculate the deviation and correct ALL the deviation on this head by fore and aft magnets.

e. Coefficient Permanent C: Steady the vessel on N by compass, calculate the deviation and correct ALL the deviation on this head by inserting athwartship magnets.

f. Coefficient D: Steady the vessel on NE by compass, calculate the deviation and correct ALL the deviation on this head by adjusting the position of the soft iron spheres (recall the spheres were placed in their maximum outward position earlier, now these will have to be brought inwards, both by the same amount.)

g. Fine tuning coefficients B, C & D: Steady the vessel on W by compass, calculate the deviation, correct only the half of this value by adjusting the fore & aft magnets.

Now steady the vessel on S by compass, calculate the deviation, correct only the half of this value by adjusting the athwartship magnets.

Next steady the vessel on SW by compass, calculate the deviation, correct only the half of this value by adjusting the soft iron spheres.

A final swing is then made to obtain residual deviations on the eight headings and to make records to complete the adjustment.

3. THE TENTATIVE METHOD: The tentative method is used in the case of a vessel which is at least one year old in which the magnetism has stabilized. It is a method to only readjust an earlier well done correction. In case the vessel has gone through major structural changes, has had a major fire, has grounded, or suffered a serious collision damage, the magnetic signature of the vessel would have altered considerably. This method therefore CANNOT be used in such cases. It would not give satisfactory results if the deviations before this adjustment have been large.

a. Induced B: Flinders bar is left at its original length and position, unless reasons are there to justify changing its length. It is tested however for residual magnetism by reversing it end for end and noting any deviation of the compass card it may cause. This test is done on an E or W heading.

b. Coefficient D: The spheres are tested by rotating them on their brackets and if no permanent magnetism is found in these, the spheres are left at their original position.

c. Heeling Error: The heeling error is next corrected using the V.F.I on E or W magnetic head. The ship's multiplier is assumed to be about 0.9. Alternatively, the rider weight is left in the same position as was levelled ashore, and the heeling error slightly overcompensated by having the N end of V.F.I slightly above the horizontal when adjusting the H/E magnets in northern hemisphere.

d. Permanent B: The vessel is now steadied on E or W by compass and the deviation on this heading is corrected in full by adjusting the fore and aft magnets.

e. Permanent C: The vessel is now steadied on N or S by the compass and the deviation on this heading is corrected in full by adjusting the athwartship magnets.

f. **Coefficient D:** The vessel is now steadied on NE or any other intercardinal heading by the compass and the deviation on this heading is corrected in full by adjusting the position of the soft iron spheres.

g. **Finer adjustment of Perm. B:** The vessel is steadied on opposite headings as under (d) above and half the deviation is removed by readjusting the fore and aft magnets.

h. **Finer adjustment of Perm. C:** The vessel is steadied on opposite headings as under (e) above and half the deviation is removed by readjusting the athwartship magnets.

i. **Finer adjustment of Coefficient D:** The vessel is steadied on one of the quadrantal headings and half the deviation is corrected by readjusting the soft iron spheres.

Like in the other cases, now a final SLOW swing is made to record the residual deviations and position of all correctors and other details that may be necessary as per the final paragraph under the Analysis method. Though the "Shorter Method" and the "Tentative Method" appear similar, a careful study will indicate differences between them.

PRECAUTIONS TO BE OBSERVED WHEN SWINGING THE VESSEL

If an accurate adjustment of the compass is desired, efforts should be made by the persons responsible, to ensure that necessary precautions are adhered to in FULL to achieve this.

1. The vessel should be in a seagoing condition, that is, all derricks, cranes, davits etc. should be stowed and secured. Since anchors are masses of steel, the anchors should be housed and secured.
2. The vessel must be upright and have her normal seagoing, or close to normal seagoing trim.
3. Before bringing the compass on board, test it ashore for excessive friction by deflecting the compass to one side by few degrees (using a hand held magnet) and letting it come to rest after the removal of the magnet. Note the head and repeat the same procedure by swinging the card to the other side and noting the head again once the card settles. The above test is to be repeated several times and the readings should be consistent. If the readings are different, there is excessive friction at the pivot and such a compass should be sent ashore for repairs/testing by the maker.
4. The accuracy of the lubber line should be checked to ensure that it is parallel to the ship's fore and aft line.
5. The azimuth mirror must be checked for accuracy by taking the bearing of an object with 'arrow up' and then with 'arrow down'. An accurate azimuth mirror will show the same bearings.
6. Remove all metal objects howsoever small, from the vicinity of the compass.
7. All persons who are required to be near the compass when the adjustments are being made should ensure that there are no magnetic material, like keys, etc. on their person.
8. As a ship is a large steel object, there must be no vessel within 3 to 4 cables.
9. Test the Flinders bar - note the compass head (preferably when heading east or west as the Flinders bar causes maximum effect on these headings) and hold the vessel steady by the steering compass or by the gyro compass. Now invert the bar, the heading by the compass must not change. Test by reversing a few times and there must be no change in the compass heading. If the readings change, there is residual magnetism in the bar and it must be de-magnetised as explained later.

10. The soft iron spheres are tested by rotating them after slacking the mounting nuts. If the compass heading changes as the spheres are rotated, the spheres have residual magnetism and must be demagnetised.

To demagnetise the Flinders bar or the soft iron spheres, they must be heated to 'Red Hot' and then allowed to cool slowly. Test them in position again and if retained magnetism is still found, the process of heating and slowly cooling is to be repeated again till no deflections of the compass is achieved, when the spheres are rotated.

If only slight magnetism is found to remain in the spheres, it can be got rid of by rolling them on the deck.

OCCASSIONS WHEN A FULL CORRECTION IS NECESSARY

1. When the compass is first installed.
2. After the ship has undergone large structural alterations or repairs whereby her permanent magnetic characteristics have altered.
3. When alterations have been made in any electrical apparatus or magnetic material in the vicinity of the compass.
4. After the ship has been struck by lightning so as to materially alter her magnetic condition.
5. After a major fire on board which could alter her magnetic characteristics.
6. After collision or stranding.

OCCASSIONS WHEN AN ADJUSTMENT IS NECESSARY

1. Three to six months after the first correction, due to the likelihood of changes having taken place, during that period, in her permanent magnetism.
2. Once every year as a routine.
3. After carriage and discharging of cargoes of a magnetic nature.
4. After loading or disloading by electromagnets.
5. When the ship re-enters service after being laid up for some period.

Each magnetic compass is to be properly adjusted and a curve or table of residual deviations is to be available at all times.

CHAPTER 18

CARRIAGE AND PERFORMANCE STANDARDS

PROVISION OF MAGNETIC COMPASSES ON SHIPS

Regulation 12, Chapter V of SOLAS requires all ships of 150 gross tons and over to be fitted with

- 1) a standard magnetic compass unless exempted by the Administration due to the nature of her voyages and proximity to land. If such exemption is granted, she must be fitted with a steering magnetic compass.

and

- 2) a steering magnetic compass unless heading information provided by the standard compass is available at the main steering position. The transmitting image of the standard compass of at least 15° to each side of the lubber line should be clearly readable, for steering purposes, both in daylight and artificial light.

A spare magnetic compass, interchangeable with the standard compass shall be carried unless a steering magnetic compass or a gyro compass is fitted.

PERFORMANCE STANDARDS

Compass Card:

The card should be graduated in 360 single degrees, clockwise from 000° for North. A numerical indication should be provided every 10°. The cardinal points should be indicated by capital letters - N, E, S, and W. The north point may instead be indicated by an emblem.

The directional error of the card composed of graduation inaccuracies, eccentricity of the card, and misalignment of the card with the magnetic needle system shall not exceed 0.5°.

The card of the steering compass should be clearly readable at a distance of 1.4 m in both daylight and artificial light. The use of a magnifying glass is permitted.

Material:

The magnets of the compass card and the corrector magnets should have a coercivity of at least 11.2 k A/m. The material of the soft iron correctors should have a low remanence and coercivity. All other material used in the magnetic compass and binacle should be non-magnetic.

Performance:

The compass should operate satisfactorily under operational and environmental conditions to be experienced.

Constructional Errors:

With the compass rotating at a uniform speed of 1.5° per second, at a temperature of $20^{\circ} \pm 3^{\circ}$ C, the deflection of the card should not exceed $\left(\frac{54}{H}\right)^{\circ}$ where H is the flux density of the horizontal field in micro Tesla.

The error due to friction should not exceed $\left(\frac{3}{H}\right)^{\circ}$ at a temperature of $20^{\circ} \pm 3^{\circ}$ C, where H is as defined above.

After a deflection of 40°, the half period of the card should be at least 12 seconds where the horizontal magnetic field is 18 micro Tesla.

After a deflection of 90°, the card should return finally to within 1° of the magnetic meridian within 60 seconds.

Corrective Devices:

The binnacle should be provided with devices for correcting the semicircular and quadrantal deviations due to the components of the ship's permanent and induced magnetism in horizontal and vertical soft iron, as well as for correction of heeling error.

Construction:

Primary and emergency illumination should be provided for the card together with facility for dimming.

No electrical power should be necessary for operating the compass, other than for illumination.

When electrical reproduction of the standard compass is made available at the steering position, the transmitting system should be provided with primary and emergency power supply.

The compasses should be gimbal suspended so that the verge ring remains horizontal when the binnacle is tilted upto 40° in any direction. They should not be dislodged under any sea or weather condition.

The material used for manufacturing the compasses should be of sufficient strength. The compass should be installed so that they are easily accessible for correction and maintenance.

Positioning:

The compass should, when practicable, be installed on the ship's F&A centerline. The main lubber mark should indicate the ship's head with an accuracy of at least 0.5° .

The standard compass should be so positioned that the view from the site is as uninterrupted as possible for taking terrestrial and celestial bearings.

The compasses should be installed as far away as possible from any magnetic material. The minimum distance of the standard compass from ship's structures of magnetic material should be to the satisfaction of the Administration. As a general guide line, the following are the desirable minimum distances from the standard compass.

- a) Uninterrupted fixed magnetic material: 1.5 m in ships of length upto 30 m, increasing linearly to 3 m in ships of length 84 m and above.
- b) Movable magnetic material such as steel door, ends of fixed magnetic material such as pillars, beams, bulkheads etc., and large structures of magnetic material with variable magnetic fields such as the funnel: 2 m for ships upto 30 m in length, increasing linearly to 4 m in ships of length 120 m and over.

On a ship exempted from carrying a standard compass, the above are the minimum distances from the steering compass also. When a steering compass is provided in addition to a standard compass, the minimum desirable distances for the steering compass may be reduced to 65% of the distances stated above, provided that no distance is less than 1 m. The distance of the magnetic compasses from any electrical or magnetic equipment should be at least equal to the safe distance specified for the equipment.

THEORY QUESTIONS

1. The ship's induced magnetism may be represented by soft iron rods. Make a table of the S.I. rods. Indicate which rods may produce coefs. A, iB, iC, D & E.
2. What is 1) a real A and 2) an apparent A?
List the causes for an apparent A. How is coef. A dealt with when correcting the compass. Does deviation due to A change with magnetic latitude? Explain why.
3. With the help of a figure show how a particular arrangement of soft iron around the compass may produce a constant deviation on all headings.
4. Discuss the cause and correction of the components of coef. B. Explain how the deviation due to each component varies with change of course and change of latitude.
5. With the help of figures explain the cause and correction of the components of coef. C. How does deviation due to each of them vary with change of course and change of latitude.
6. How is coef. D caused? Does deviation due to D vary with change of course, change of latitude? Explain. How is it corrected?
7. What is the cause of coef. E? Why is E not usually present at a ship's compass? Does deviation due to E vary with change of course, change of latitude? If both D and E are present, how are they corrected?
8. How and why does deviation due to permanent magnetism vary with change of latitude? Why is deviation due to induced magnetism in horizontal S.I. unaffected by change in latitude?
9. Derive expressions to determine the value of each coefficient using deviations on the cardinal and intercardinal headings.
10. Justify the statement, "If a compass is corrected 'like with like', the correction will hold good for all latitudes". Use coefs. PB, iB and D to illustrate your answer.
11. Discuss the statement "A rapid swing of the ship causes an A and an E".
12. a) If a ship has a -PB and +PC, in which quadrant was she heading when built?
b) If DF on N > DF on S what coef. is present and what is its sign?

- c) If DF on E > DF on W, what coef. and its sign is indicated?
 - d) If DF on N = DF on S and DF on E = DF on W, does it indicate that DF on all headings are equal? If not what coef. is to be corrected?
13. Define λ and μ . Do coefs. A, PB, iB, PC, iC and D affect the value of λ ? Explain.
 14. What is the effect of the corrector magnets, flinders bar and S.I. spheres on the value of λ ? Explain with the help of diagrams.
 15. What are the three main causes of heeling error? How does the error due to each of them vary with change of latitude, course and heel?
 16. With the help of figures, show how the heeling error due to g rod varies with change of course. If present, why is it left uncorrected?
 17. What is the cause of H/E when heading E/W? With the help of figures, show how this error will vary with change of course? What is the relation between correction of iB and this heeling error?
 18. A vessel built in Japan had her compass corrected there for heeling error. What changes in H/E would you expect on a voyage to New Zealand and what adjustment may have to be made by you, on the voyage?
 19. Describe the Vertical Force Instrument and how heeling error is corrected using it. Will this correction hold good for all latitudes? Why? On what headings is this correction made? Why?
 20. With the help of figures, show how the S.I. spheres partly correct for k rod and e rod heeling errors.
 21. a) Why is the rule 'like corrects like' not applied when correcting H/E?
b) What is the ship's multiplier? Why is the shore reading of the V.F.I. multiplied by this when correcting H/E?
 22. How is 1) Gaussin error and 2) Retentive error caused? List the differences in deviation caused by each. What precautions are necessary when either of them may be present?
 23. List the preparations and precautions necessary for swinging the ship for compass adjustments.

24. Describe the Kelvin Deflector. State the principle and procedure of compass correction using the Kelvin Deflector. What are the advantages and disadvantages of such correction?
25. State the sequence of placing the correctors and the reasons for the same.
26. List the occasions:
 - 1) when a full correction of the compass is necessary, and
 - 2) when a tentative adjustment is necessary.
27. As per IMO's performance standards for magnetic compasses, what are the requirements regarding its positioning?
28. What are the performance standards required for a compass card, its constructional errors and the construction of a magnetic compass?
29. How many magnetic compasses are to be provided on ships of 150 tons or over?
30. Describe the analysis method of compass correction.
31. Describe the tentative method of adjustment.
32. What coefficients if any, together with their signs are caused, if the following rods are present at a magnetic compass.
 - (i) $-b = +d$ (ii) $-e > -a$ (iii) $+b = +d$
 - (iv) $+f$ in the S. Hemisphere (v) $+e = +a$
 - (vi) $-c$ in N. Hemisphere

FORMULAE

1. Mag. bearing $\sim$ Comp. brg. = deviation, δ .
2. True brg. $\sim$ Comp. brg. = Error.
3. The mean of compass bearings of a distant terrestrial object on at least four (preferably eight) equidistant headings = The magnetic bearing of the object - assuming Coeff. A is nil.
4. Mean of errors on at least four (preferably eight) equidistant headings = variation - assuming Coef. A is nil.
5. Error $\sim$ variation = deviation.

Easterly deviations are +ve and westerly deviations are -ve.

Coefficients are +ve if they produce +ve deviations on headings between 000° and 045° (C).

They are -ve if they produce -ve deviations on headings between 000° and 045° (C).

6. Coef. A = Mean of deviation on at least four (preferably eight) equidistant headings.

$$\text{i.e. Coef. A} = \frac{\delta \text{ on N} + \delta \text{ on NE} + \delta \text{ on E} + \delta \text{ on SE} + \delta \text{ on S} + \delta \text{ on SW} + \delta \text{ on W} + \delta \text{ on NW}}{8}$$

$$7. \text{ Coef. B} = \frac{\delta \text{ on E} - \delta \text{ on W}}{2} = \frac{\text{Error on E} - \text{Error on W}}{2}$$

$$8. \text{ Coef. C} = \frac{\delta \text{ on N} - \delta \text{ on S}}{2} = \frac{\text{Error on N} - \text{Error on S}}{2}$$

$$9. \text{ Coef. D} = \frac{\delta \text{ on NE} - \delta \text{ on SE} + \delta \text{ on SW} - \delta \text{ on NW}}{4}$$

$$= \frac{\text{Error on NE} - \text{Error on SE} + \text{Error on SW} - \text{Error on NW}}{4}$$

$$10. \text{ Coef. E} = \frac{\delta \text{ on N} - \delta \text{ on E} + \delta \text{ on S} - \delta \text{ on W}}{4}$$

$$= \frac{\text{Error on N} - \text{Error on E} + \text{Error on S} - \text{Error on W}}{4}$$

11. With the ship upright, total δ on any comp. co.

$$= A + B \sin \text{co.} + C \cos \text{co.} + D \sin 2 \text{co.} + E \cos 2 \text{co.}$$

12. δ due to A is unaffected by change of course, H or Z.

13. δ due to PB $\propto \sin \text{comp. co.}$ δ due to iB $\propto \sin \text{comp. co.}$

$$\propto \frac{1}{H} \qquad \qquad \qquad \propto \frac{1}{H}$$

$$\qquad \qquad \qquad \propto Z$$

$$\frac{PB_2}{PB_1} = \frac{H_1}{H_2} \qquad \qquad \frac{iB_2}{iB_1} = \frac{H_1}{H_2} \times \frac{Z_2}{Z_1} = \frac{\tan \text{dip}_2}{\tan \text{dip}_1}$$

$$\therefore \frac{PB \delta_2}{PB \delta_1} = \frac{\sin \text{co}_2}{\sin \text{co}_1} \times \frac{H_1}{H_2} \qquad \therefore \frac{iB \delta_2}{iB \delta_1} = \frac{\sin \text{co}_2}{\sin \text{co}_1} \times \frac{H_1}{H_2} \times \frac{Z_2}{Z_1}$$

$$= \frac{\sin \text{co}_2}{\sin \text{co}_1} \times \frac{\tan \text{dip}_2}{\tan \text{dip}_1}$$

Note: Z and dip are both +ve in N. Hemisphere and both -ve in S. Hemisphere.

At one location (when H and Z are unchanged)

δ due to Total B $\propto \sin \text{comp. co.}$

$$\therefore \delta \text{ due to B} = B \sin \text{comp. co.}$$

$$\text{and } \frac{B \delta_2}{B \delta_1} = \frac{\sin \text{co}_2}{\sin \text{co}_1}$$

14) δ due to PC $\propto \cos \text{comp. co.}$

δ due to iC $\propto \cos \text{comp. co.}$

$$\propto \frac{1}{H} \qquad \qquad \qquad \propto \frac{1}{H}$$

$$\qquad \qquad \qquad \propto Z$$

$$\frac{PC_2}{PC_1} = \frac{H_1}{H_2} \qquad \qquad \frac{iC_2}{iC_1} = \frac{H_1}{H_2} \times \frac{Z_2}{Z_1} = \frac{\tan \text{dip}_2}{\tan \text{dip}_1}$$

$$\frac{PC \delta_2}{PC \delta_1} = \frac{\cos \text{co}_2}{\cos \text{co}_1} \times \frac{H_1}{H_2} \qquad \frac{iC \delta_2}{iC \delta_1} = \frac{\cos \text{co}_2}{\cos \text{co}_1} \times \frac{H_1}{H_2} \times \frac{Z_2}{Z_1}$$

$$= \frac{\cos \text{co}_2}{\cos \text{co}_1} \times \frac{\tan \text{dip}_2}{\tan \text{dip}_1}$$

At one location (when H and Z are unchanged)

δ due to Total C $\propto$ cos comp. co.

$\therefore \delta$ due to C = C . cos co.

and $\frac{C \delta_2}{C \delta_1} = \frac{\cos co_2}{\cos co_1}$

15) $\tan \angle$ of slew of flinders bar = $\frac{iC}{iB}$

Max δ due to iB and iC together = $\sqrt{iB^2 + iC^2}$

16) H.I. $\delta \propto \sin$ angle of ship's hd. from Natural Zero
 $\propto \frac{1}{H}$

$\frac{H.I. \delta_2}{H.I. \delta_1} = \frac{\sin \text{angle}_2 \text{ from natural zero}}{\sin \text{angle}_1 \text{ from natural zero}} \times \frac{H_1}{H_2}$

$\tan \text{neutral co.} = \frac{PC}{PB}$

Max H.I. $\delta = \sqrt{PB^2 + PC^2}$

PB = Max H.I. $\delta \times \cos \text{neutral co.}$

PC = Max H.I. $\delta \times \sin \text{neutral co.}$

Bldg. head is S'ly if PB is +ve and N'ly if PB is -ve.

Bldg. head is E'ly if PC is +ve and W'ly if PC is -ve.

17) δ due to D $\propto \sin 2$ comp. co.

$\therefore \delta$ due to D = D $\sin 2$ comp. co.

and $\frac{D \delta_2}{D \delta_1} = \frac{\sin 2 co_2}{\sin 2 co_1}$

18) δ due to E $\propto \cos 2$ comp. co.

$\therefore \delta$ due to E = E $\cos 2$ comp. co.

and $\frac{E \delta_2}{E \delta_1} = \frac{\cos 2 co_2}{\cos 2 co_1}$

$$\tan \text{ twice angle of slew of spheres} = \frac{E}{D}$$

$$\text{Max } \delta \text{ due to D and E together} = \sqrt{D^2 + E^2}$$

$$19) \text{ PHE} \propto \cos \text{ comp. co.}$$

$$\propto \frac{1}{H}$$

$$\propto i$$

$$\text{iHE} \propto \cos \text{ comp. co.}$$

$$\propto \frac{1}{H}$$

$$\propto Z$$

$$\propto i$$

$$\therefore \frac{\text{PHE}_2}{\text{PHE}_1} = \frac{\cos \text{co}_2}{\cos \text{co}_1} \times \frac{H_1}{H_2} \times \frac{i_2}{i_1} \quad \therefore \frac{\text{iHE}_2}{\text{iHE}_1} = \frac{\cos \text{co}_2}{\cos \text{co}_1} \times \frac{H_1}{H_2} \times \frac{Z_2}{Z_1} \times \frac{i_2}{i_1}$$

$$= \frac{\cos \text{co}_2}{\cos \text{co}_1} \times \frac{\tan \text{dip}_2}{\tan \text{dip}_1} \times \frac{i_2}{i_1}$$

At one location, (when H and Z are unchanged)

$$\text{Total HE} \propto \cos \text{co.}$$

$$\propto i$$

$$\therefore \frac{\text{HE}_2}{\text{HE}_1} = \frac{\cos \text{co}_2}{\cos \text{co}_1} \times \frac{i_2}{i_1}$$

$$20) \lambda = \frac{\text{Mean DF towards mag. N onboard}}{\text{DF towards mag. N ashore}}$$

$$\text{i.e. mean of } \frac{\text{DF}_B}{\text{DF}_S} = \frac{T_S^2}{T_B^2} \times \cos \delta = \frac{n_B^2}{n_S^2} \times \cos \delta$$

$$21) \text{ DF on N} > \text{DF on S} \Rightarrow \text{B is +ve}$$

$$\text{DF on W} > \text{DF on E} \Rightarrow \text{C is +ve}$$

$$\text{DF on N \& S} > \text{DF on E \& W} \Rightarrow \text{D is +ve.}$$

$$\text{DF on SE \& NW} > \text{DF on NE \& SW} \Rightarrow \text{E is +ve.}$$

22) Scale reading of V.F.I for correcting H/E = shore reading $\times \lambda_2$

Scale reading $\propto Z$

$$\therefore \frac{\text{scale reading}_2}{\text{scale reading}_1} = \frac{Z_2}{Z_1}$$

23) Effect of correctors $\propto \frac{1}{d^3}$

$$\therefore \frac{d_2^3}{d_1^3} = \frac{\delta_1}{\delta_2}$$

ANSWERS TO EXERCISES

EXERCISE I (Coefficients B & C)

1. $PB = +2.27^0$
 $PC = +2.83^0$
2. -7.11^0 at P
 -5.69^0 at Q
3. 11.87^0 E
4. -3.13^0
5. 4.38^0 W
6. $+7.5^0$ (Deviation due to iC is W'ly on 180^0 . $\therefore$ Coeff. iC is +ve)
7. At S 1.54^0 W, at T 2.05^0 W
8. $+2.68^0$
9. -4.29^0
10. 4.5^0
11. 6.4^0
12. 19.4 cms.
13. $B = -1^0$, $C = -4^0$,
 $\delta = 2.54^0$ E
14. $B = +7.83^0$, $C = -3.11^0$
15. 15.94^0 W
16. $PB = -9^0$, $iB = +1^0$
17. 22.7^0 (W)
18. 4.07^0 E
19. $PB = -8.6^0$, $iB = +3.6^0$
20. $PB = +8.8^0$, $iB = -1.3^0$
21. -2.4^0

22. Raise the magnets to increase the correction by $11\frac{3}{4}^{\circ}$. Increase length of flinders bar to increase the correction by $6\frac{3}{4}^{\circ}$.
23. Raise the magnets to increase the correction by 12.4° . Increase length of flinders bar to increase correction by 7.6° .
24. Place F&A magnets red ends for'd to correct 4.84° and flinders bar abaft compass to correct 2.84° when heading E or W.
25. Place F&A magnets blue ends for'd to correct 2.7° and flinders bar for'd of compass to correct 1.3° when heading E or W.
Coef. B at Q = $+1.6^{\circ}$
26. $+13.7^{\circ}$. Place flinders bar for'd to correct 13.7° when heading E or W.
27. The F&A magnets placed red ends for'd to correct $+3.6^{\circ}$ and flinders bar for'd to correct -0.6° when heading E.
28. $+5.97^{\circ}$
29. Place F&A magnets red aft to correct 9.6° and flinders bar aft to correct 1.7° when heading E or W.
30. Flinders bar to be placed slewed 21.8° to stbd. from aft, to correct 5.39° when heading 111.8° (C) or 291.8° (C).
31. Place flinders bar for'd and slewed 37° to port to correct 2.5° when heading 127° or 307° (C).
32. $iB = -7.73^{\circ}$, $iC = +2.07^{\circ}$.
33. When heading E or W, lower magnets to alter correction by $1\frac{3}{4}^{\circ}$ and increase length of flinders bar to alter correction by $4\frac{3}{4}^{\circ}$.
34. When heading E or W, raise magnets to alter deviation by $11\frac{3}{4}^{\circ}$ (11.69°) and increase length of flinders bar to alter deviation by $6\frac{3}{4}^{\circ}$ (6.69°).
35. Place F&A magnets red for'd to correct 8° , athwartship magnets red stbd. to correct 4° . Since iB is -6° and iC $+2^{\circ}$, place flinders bar slewed $18\frac{1}{2}^{\circ}$ to port form for'd to correct 6.3° when heading 108.5° (C) or 288.5° (C).
36. Replace magnet 34.8 cms below the card.
37. Reverse the magnet and reduce the distance to 29.7 cms.
38. Place flinders bar for'd to correct 0.7° instead of 2° and F&A magnets red ends for'd to correct 5.7° instead of 7° .
39. 5.14° W
40. Max. δ : 6.21°
Courses : 260° (C) and 160° (C)
41. Bldg. Hd. : $146^{\circ} 19'$
Max δ : 7.21° E on $056^{\circ} 19'$ (C)
 7.21° W on $236^{\circ} 19'$ (C)
42. PB = $+3.92^{\circ}$
PC = $+6.78^{\circ}$
43. PB = -7.52°
PC = -2.74°
Bldg. Hd. = 340° (C)
 δ = 6.93° E

44. 1) Bldg. Hd. 045^0 (C)
 2) PB = 7.8^0 PC = $+7.8^0$
 3) Max. δ at A 11.02^0
 4) Max. δ at B 7.35^0
 5) Hdgs: 249.1^0 (C) 020.9^0 (C)

45. 8.7^0 W.

EXERCISE II (Coefficients D & E)

1. D = -9.33^0
 δ = 8.08^0 W
2. 1^0 E
3. $+1.5^0$
4. Coef. D = $+4.12^0$
 δ on 330^0 (C) = 8.9^0 W
5. 4.82^0 W
6. 6.18^0 on 052^0 , 142^0 , 232^0 , 322^0
7. D = $+7^0$, E = -2.5^0
 Slew spheres 9.8^0 from athwartships, anticlockwise and place them 33.5 cms apart to correct 7.43^0 , when heading 054.8^0 , 144.8^0 , 234.8^0 or 324.8^0 (C).
8. Increase distance between spheres till they are 39.6 cms apart.
9. Move in spheres till they are 36.3 cms. apart.
 Residual deviations: NE 4^0 E, SE 6^0 E, SW 7^0 W, NW 9^0 W.
10. Move spheres out till they are 39.9 cms apart.
 Residual deviations: NE 10.75^0 W, SE 0.25^0 W, SW 4.25^0 E, NW 6.25^0 W
11. D = $+6.73^0$, E = $+1.93^0$
12. E = -1.82^0 , Max. corn: 5.32^0
 Hdgs. 055^0 , 145^0 , 235^0 or 325^0 (C)
13. Reduce angle of slew to 7.8^0 and

move the spheres in till they are 32.3 cms. apart.

EXERCISE III (All Coefficients)

1. A = nil, B = -6^0 , C = $+1.5^0$,
 D = -1.25^0 , E = $+0.25^0$.
 δ on 120^0 (C) = 5^0 W,
 δ on 340^0 (C) = 4.45^0 E
2. Ans: A = 0, B = -8^0 , C = $+12^0$,
 D = $+4^0$, E = 0.
 Deviation on 113^0 (C) = 14.9^0 W
3. Variation = 1^0 W
 Errors : N 5^0 W, NE 8^0 W,
 E 3^0 W, SE 3^0 E, S 7^0 E, SW
 4^0 E, W nil, NW 6^0 W.
 Deviations: N 4^0 W, NE 7^0 W,
 E 2^0 W, SE 4^0 E, S 8^0 E, SW 5^0 E,
 W 1^0 E, NW 5^0 W.
 Coefs: B = -1.5^0 , C = -6^0 ,
 D = -0.25^0 , E = $+1.25^0$.
 Error = 3.54^0 E.
4. Place F&A magnets red for'd to correct 2.5^0 , Athwartships magnets red to stbd. to correct 2.5^0 .
 Flinders bar slewed 45^0 to port from for'd to correct 3.54^0 when heading 135^0 or 315^0 (C).
5. Raise F&A magnets to correct a further 3^0 . Increase length of flinders bar to correct a further 2^0 - Both corrections on E or W hdg. Leave other correctors in the same position.

EXERCISE IV (Heeling Error)

1. 7.79° E
2. 1.13° E
3. 0.8° E
4. 1.12° W
5. Reverse the magnets and lower them till they are 34.3 cms from the card.
6. 12.1° W
7. Place vertical magnets, red end up to correct 3.92° and athwartships magnets red to stbd. to correct 1.08° when heading N or S.
8. 13.25° E
9. 1.9° W
10. 3° W
11. Remove the magnets.
12. Reverse the magnets and increase their distance to 40.27 cms.
13. 1.66° W
14. 2.64° W
15. 0.18° W
16. $\delta = 8.6^{\circ}$ W
Comp. Co.: 202.6°
17. Place two magnets, 25.1 cms below the card, blue ends up.

EXERCISE V

(V.F.I., λ , Kelvin Deflector,
Deviascope Deflector)

1. 16 divisions on the red arm.
2. 18 divisions on the north arm.
3. $\lambda = 0.788$
-B: Place F&A magnets red aft
+C: Place athw. magnets red to stbd.
+D: Move spheres in
4. $\lambda = 0.837$
+B: Place F&A magnets red for'd
-C: Place athw. magnets red to port.
+D: Move spheres in
5. $\lambda = 0.895$
-B: Place F&A magnets red aft
-C: Place athw. magnets red to port.
-D: Move spheres out
6. -B: Place F&A magnets red aft
+C: Place athw. magnets red to stbd.
+D: Place spheres athwartships
 $\lambda = 0.912$
7. Shift F&A magnets up
Shift athwartship magnets down
Move spheres outwards
8. Place F&A magnets red for'd
Place athw. magnets red to stbd.
Place spheres athwartships.