A STUDY ON THE CORRECTION OF MAGNETIC COMPASS

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(1) Introduction

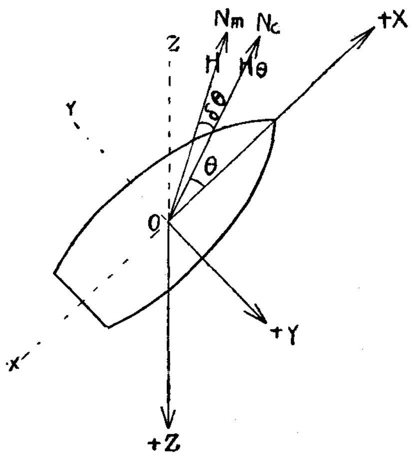
The writer proposed of a method to correct the magnetic compass by the observations of deviations of the compass and directive force of its needles on two or a single heading.

The methods generally followed necessitate keeping ship's head on four cardinal and intercardinal points by compass or magnetic bearing. However, this is a method to correct the compass by ascertaining the coefficients by keeping ship's head on any given two or a single heading.

(2) Method

§ 1. Formulae.

The formulae for this purpose can be as follows:



In figure (above), let X, Y and Z represent the respective axes of ship's fore and aft direction, athwartship direction and vertical direction.

The following Poisson's equation represents ship's magnetic field:

$$\left.\begin{aligned} X' &= X + aX + bY + cZ + P \\ Y' &= Y + dX + eY + fZ + Q \end{aligned}\right\} \cdots (1)$$

where: X′ and Y′ represent the respective components of ship's horizontal magnetic field. a, b, c, d, e and f are the constants induced by the effect of iron structures of ship, —viz. so-called Poisson's Coefficients.

P and Q represent the constants which induce ship's permanent magnetism.

Then let Nc denote Compass North,

Nm : Magnetic North,

H : Horizontal component of Earth's magnetic field,

Z : Vertical component of Earth's magnetic field,

I : Dip,

θ : Compass heading,

δ_θ : Deviation for θ,

and H_θ : Horizontal component of ship's magnetic field.

Then,

$$\begin{cases} X = H\cos(\theta+\delta_\theta) \\ Y = -H\sin(\theta+\delta_\theta) \end{cases} \qquad \begin{cases} X' = H_\theta\cos\theta \\ Y' = -H_\theta\sin\theta \end{cases}$$

and $Z = H\tan I$

Therefore Poisson's equation (1) becomes

$$\left.\begin{aligned} H_\theta\cos\theta &= (1+a)H\cos(\theta+\delta_\theta) - bH\sin(\theta+\delta_\theta) + cH\tan I + P \\ -H_\theta\sin\theta &= -(1+e)H\sin(\theta+\delta_\theta) + dH\cos(\theta+\delta_\theta) + fH\tan I + Q \end{aligned}\right\} \text{----} \quad (2)$$

Let

$$A_0 = \frac{1}{\lambda}\left(\frac{d-b}{2}\right), \qquad D_0 = \frac{1}{\lambda}\left(\frac{a-e}{2}\right)$$

$$B_\theta = \frac{1}{\lambda}\left(c\tan I + \frac{P}{H}\right), \qquad E_0 = \frac{1}{\lambda}\left(\frac{a+b}{2}\right)$$

$$C_\theta = \frac{1}{\lambda}\left(f\tan I + \frac{Q}{H}\right), \qquad \lambda = 1 + \frac{a+e}{2}$$

Here A_0, B_0, C_0, D_0 and E_0 are called the Exact Coefficients of Deviations, and λ horizontal shielding factor. Generally A_0 and E_0 are very small. Therefore, if A_0 and E_0 are assumed respectively zero, then b and d are regarded zero.

Therefore, (2) becomes

$$\left.\begin{aligned} \frac{H_\theta}{H}\cos\theta &= (1+a)\cos(\theta+\delta_\theta) + \lambda B_0 \\ -\frac{H_\theta}{H}\sin\theta &= -(1+e)\sin(\theta+\delta_\theta) + \lambda C_\theta \end{aligned}\right\} \text{----------------} \quad (3)$$

If a and e are expressed in D_0, (3) becomes

$$\left.\begin{aligned} B_0 &= \frac{H_\theta}{\lambda H}\cos\theta - (1+D_0)\cos(\theta+\delta_\theta) \\ C_0 &= -\frac{H_\theta}{\lambda H}\sin\theta + (1-D_0)\sin(\theta+\delta_\theta) \end{aligned}\right\} \text{----------------} \quad (4)$$

§ 2. Compensation on two headings.

This can be done with a considerable accuracy for directive force on two headings, the only assumption being that the coefficients A_0 and E_0 are zero, which is generally true.

Two headings are available :

a) When a ship is moored alongside of a wharf or pier and afterward winded and moored on the opposite heading or another different heading.

b) When a ship is moored alongside of a wharf or pier, and before and afterward, when she is off them,—for instance entering or leaving harbor.

c) When a ship attained two of her courses at sea. (desirable in the harbor.)

The ship must not, in each case, be near another iron or steel ship or in the immediate vicinity of iron or steel structures on shore.

Now let θ_1 and θ_2 denote two respective ship's compass headings, $\delta_{\theta 1}$ and $\delta_{\theta 2}$ the corresponding deviations for two compass headings θ_1 and θ_2, n a reading shown on the scale when the North point of the compass card was deflected by 45° or 90° by deflector, on shore in a place free from local magnetic influences, and not greatly distant from the ship, $n\theta_1$ and $n\theta_2$ the respective readings shown on the scale for two compass headings θ_1 and θ_2 when the same point was deflected by the same angle by deflector on board the ship in the exact position of the compass needle, and $H_{\theta 1}$ and $H_{\theta 2}$ the respective ship's horizontal magnetic fields for two compass headings.

Then the equation (3) for each compass heading θ_1 and θ_2 becomes respectively,

$$\left.\begin{aligned} \frac{H_{\theta 1}}{H}\cos\theta_1 &= (1+a)\cos(\theta_1+\delta_{\theta 1}) + \lambda B_0 \\ \frac{H_{\theta 2}}{H}\cos\theta_2 &= (1+a)\cos(\theta_2+\delta_{\theta 2}) + \lambda B_0 \end{aligned}\right\} \quad \text{-------------} \quad (5)$$

$$\therefore \quad 1+a = \frac{\dfrac{H_{\theta 1}}{H}\cos\theta_1 - \dfrac{H_{\theta 2}}{H}\cos\theta_2}{\cos(\theta_1+\delta_{\theta 1}) - \cos(\theta_2+\delta_{\theta 2})} \quad \text{---------} \quad (6)$$

In like manner,

$$\left.\begin{aligned} -\frac{H_{\theta 1}}{H}\sin\theta_1 &= -(1+e)\sin(\theta_1+\delta_{\theta 1}) + \lambda C_0 \\ -\frac{H_{\theta 2}}{H}\sin\theta_2 &= -(1+e)\sin(\theta_2+\delta_{\theta 2}) + \lambda C_0 \end{aligned}\right\} \quad \text{-----------} \quad (7)$$

$$\therefore \quad 1+e = \frac{\dfrac{H_{\theta 1}}{H}\sin\theta_1 - \dfrac{H_{\theta 2}}{H}\sin\theta_2}{\sin(\theta_1+\delta_{\theta 1}) - \sin(\theta_2+\delta_{\theta 2})} \quad \text{---------} \quad (8)$$

λ and D_0 are given by

$$\lambda = 1 + \frac{a+e}{2} = \frac{1}{2}\left\{(1+a)+(1+e)\right\}$$

$$D_0 = \frac{1}{\lambda}\left(\frac{a-e}{2}\right) = \frac{1}{\lambda}\left\{\frac{(1+a)-(1+e)}{2}\right\}$$

and from (5) and (7),

$$B_0 = \frac{1}{2\lambda}\left[\left(\frac{H_{\theta 1}}{H}\cos\theta_1 + \frac{H_{\theta 2}}{H}\cos\theta_2\right) - (1+a)\left\{\cos(\theta_1+\delta_{\theta 1}) + \cos(\theta_2+\delta_{\theta 2})\right\}\right] \quad \text{---------} \quad (9)$$

$$C_0 = \frac{-1}{2\lambda}\left[\left(\frac{H_{\theta 1}}{H}\sin\theta_1 + \frac{H_{\theta 2}}{H}\sin\theta_2\right) - (1+e)\left\{\sin(\theta_1+\delta_{\theta 1}) + \sin(\theta_2+\delta_{\theta 2})\right\}\right] \quad \text{---------} \quad (10)$$

Then since $\frac{H_\theta}{H}=\frac{n_\theta}{n}$, (9) and (10) can be written

$$B_0=\frac{1}{2\lambda}\left[\left(\frac{n_{\theta 1}}{n}\cos\theta_1+\frac{n_{\theta 2}}{n}\cos\theta_2\right)-(1+a)\left\{\cos(\theta_1+\delta_{\theta 1})+\cos(\theta_2+\delta_{\theta 2})\right\}\right] \quad (11)$$

$$C_0=\frac{-1}{2\lambda}\left[\left(\frac{n_{\theta 1}}{n}\sin\theta_1+\frac{n_{\theta 2}}{n}\sin\theta_2\right)-(1+e)\left\{\sin(\theta_1+\delta_{\theta 1})+\sin(\theta_2+\delta_{\theta 2})\right\}\right] \quad (12)$$

Substituting the values of λ, $(1+a)$ and $(1+e)$ into the equations (11) and (12), B_0 and C_0 can be obtained.

Now if the approximate coefficients are expressed by A, B, C, D, E; and the deviation δ_θ for compass heading θ, in degrees,

$$\delta_\theta=A+B\sin\theta+C\cos\theta+D\sin 2\theta+E\cos 2\theta \quad (13)$$

Then the relation between the exact coefficients and approximate coefficients is as follows:

$$\left.\begin{array}{lll} A_0=\sin A, & B_0\fallingdotseq\sin B, & C_0\fallingdotseq\sin C \\ D_0\fallingdotseq\sin D, & E_0\fallingdotseq\sin E, & E_0=\sin E-\sin A\sin D \end{array}\right\} \quad (14)$$

Now since A_0 and E_0 are respectively zero, A and E accordingly become zero.

Therefore (13) can be written

$$\delta_\theta=B\sin\theta+C\cos\theta+D\,\mathrm{sind}\,2\theta \quad (15)$$

From (14) it follows that

$$B\fallingdotseq B_0\times 57^\circ.3,\quad C\fallingdotseq C_0\times 57^\circ.3,\quad D\fallingdotseq D_0\times 57^\circ.3$$

So that, $B\sin\theta_2\fallingdotseq B_0\sin\theta_2\times 57^\circ.3$ is the amount to be corrected by fore and aft magnets for ship's compass heading θ_2.

$C\cos\theta_2\fallingdotseq C_0\cos\theta_2\times 57^\circ.3$ is the amount to be corrected by athwartship magnets for ship's compass heading θ_2.

$D\sin 2\theta_2\fallingdotseq D_0\sin 2\theta_2\times 57^\circ.3$ is the amount to be corrected by iron spheres for ship's compass heading θ_2.

Example:

When the following data in a certain ship are observed, the compensation on 2nd heading is required.

$\theta_1=45^\circ 45'$	$\delta_{\theta 1}=12^\circ 15'$ E
$\theta_2=245^\circ$	$\delta_{\theta 2}=7^\circ 00'$W
$n_{\theta 1}=22.7$	$n_{\theta 2}=9.1$
$n=17.8$	

Using the equations (6), (8), (11) and (12), the following values are obtained:

$1+a=1.043 \quad \lambda=0.927 \quad D_0=+0.125 \quad C_0=-0.2445.$

$1+e=0.811 \qquad B_0=+0.365$

Then the amounts to be corrected on ship's compass heading 245° are,

$B \sin \theta_2 \fallingdotseq B_0 \sin \theta_2 \times 57.°3 \fallingdotseq -18.°9$

$C \cos \theta_2 \fallingdotseq C_0 \cos \theta_2 \times 57.°3 \fallingdotseq +5.9$

$D \sin 2\theta_2 \fallingdotseq D_2 \sin 2\theta_2 \times 57.°3 \fallingdotseq +5.5$

Then of these values, $-18.°9$ due to B_0 is to be compensated by fore and aft magnets, $+5.°9$ due to C_0 by athwartship magnets and $+5.°5$ due to D_0 by iron spheres.

§ 3. Compensation on one heading

Should it not be possible to take observations for directive force on two headings, the compass can be corrected with tolerable accuracy from observations on one heading only. Center the compass accurately, place the spheres by estimate, and then compensate the heeling error regardless of the fact that the ship may not be heading near East or West.

Next, record the compass heading of the ship by compass to be corrected. And observe and record the magnetic heading obtainable by means of a chart, or an azimuth of the sun, or of a distant object of known magnetic bearing, or by a single set of reciprocal bearings.

Let θ denote ship's compass heading,

δ_θ : deviation for θ

n : a reading shown on the scale when the North point of the compass card was deflected by 45° or 90° by deflector, on shore in a place free from local magnetic influences, and not greatly distant from the ship

n_θ : a reading shown on the scale for ship's compass heading θ when the same point was deflected by the same angle by deflector on board the ship in the exact position of the compass needle

And then using the equation (4), B_0 and C_0 are obtained as follows:

$$\left.\begin{aligned} B_0 &= \frac{1}{\lambda}\frac{n_\theta}{n}\cos\theta-(1+D_0)\cos(\theta+\delta_\theta) \\ C_0 &= \frac{-1}{\lambda}\frac{n_\theta}{n}\sin\theta+(1-D_0)\sin(\theta+\delta_\theta) \end{aligned}\right\} \quad \text{- - - - - - - - - - - - -} \quad (16)$$

In this event the quadrantal spheres must be placed by estimate and values of λ and D_0 assumed; the value of λ, being generally 0.70 to 0.95 average, may be assumed as approximately 0.9 when λ cannot be observed. In the same manner as in the compensation on two headings, B_0, C_0 and D_0 can be expressed by B, C and D, and the deviation may be compensated on any compass heading as desired. Viz.—

Let $D \sin 2\theta \fallingdotseq D_0 \sin 2\theta \times 57.^\circ 3$ be the amount to have been compensated by iron spheres assuming the values of D_0, and then $B \sin\theta \fallingdotseq B_0 \sin\theta \times 57.^\circ 3$ is the amount to be compensated by fore and aft magnets, and $C \cos\theta \fallingdotseq C_0 \cos\theta \times 57.^\circ 3$ the amount to be compensated by athwartship magnets.

Example:

From data for standard compass of a similar ship, assumed: And estimated that the deviation due to D_0 has been compensated by iron spheres. It is then found that:

$$\theta = 21^\circ \qquad \delta_\theta = 5^\circ 10' W$$

$$n = 25.3 \qquad n_\theta = 14.8$$

Compensate on ship's compass heading 21.°

Using (16), the following values are obtained:

$$B_0 = -0.35. \qquad C_0 = +0.04$$

Therefore the amount to be compensated on compass heading are,

$$B \sin\theta \fallingdotseq B_0 \sin\theta \times 57.^\circ 3 \fallingdotseq -7.^\circ 2$$

$$C \cos\theta \fallingdotseq C_0 \cos\theta \times 57.3 \fallingdotseq +2.1$$

Of these values, $-7.^\circ 2$ is to be compensated by fore and aft magnets, and $+2.^\circ 1$ by athwartship magnets.

In such cases as described above in the compensations on two or a single heading, the computed values of these portions $B \sin\theta + C \cos\theta$ may differ appreciably from the actual values of δ_θ; this is due to the reason that the relation between the Approximate and Exact Coefficients of Deviations in (13) has been required approximately.

§ 4. Analysis of Coefficient B_0

As the analysis of coefficient B_0 was described in the previous report by the writer, this subjest is herein omitted.

(3) Conclusion

The writer considers that this may be good enough to adopt as a method to correct the compass on two or a single heading in taking advantage of the time when a ship is being moored or lying in the harbor.

As the coeffieients A_0 and E_0 are supposed zero and the formulae used in computations are obtained approximately, this cannot be called an absolutely perfect method. However, the writer believes that this is well adopted for the practical use of magnetic compass correction, and navigators are earnestly requested to pay attention to this work and to try this method at sea.

(水產科學研究所業績 第88號)