# THE MAGNETISM OF SHIPS

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During the nineteenth century various papers were published on the magnetism of ships, particulary by officers of the Compass Department of the British Admiralty. These papers showed that the magnetic characteristics at the compass position of a ship depended, to a very considerable extent, on the magnetic direction of her head while on the building slip. Some of the later papers indicated that these characteristics would be considerably modified if she were armour-plated with her head in a different direction but writers who followed after have in general ignored this warning, possibly considering that few ships were armour-plated and that the warning applied to no others.

It had long been apparent that the old explanation that the direction of the ship's magnetic field depended on the direction of the building slip did not fit modern conditions. A modified theory had to be evolved and it is the object of this paper to show how this new theory conforms with the facts.

While the ship is on the slip the hammering to which she is subjected will magnetise the horizontal plating of the hull in a north-south direction. The magnetic field so produced will affect the compass precisely as though there were two magnets at right angles to each other; one proportional to $-H \cos \zeta_s$ in the fore-and-aft direction; the other proportional to $H \sin \zeta_s$ in the athwartship.

H is the horizontal component of the earth's total magnetic force and $\zeta_s$ the direction of the building slip méasured clockwise from magnetic North.

Similarly the vertical plating will become magnetised and its force can also be resolved into two components, in this case horizontal and vertical. In the case of the fore-and-aft plating the horizontal component will be proportional to $-H \cos \zeta_s$ and in the case of the athwartship proportional to $H \sin \zeta_s$. The case of the vertical components will be discussed later.

The combined strength of the two horizontal ship's magnetic fields acting on the compass may by taken as :—

$-P_s \cos \zeta_s$ in a fore-and-aft direction.

$Q_s \sin \zeta_s$ in an athwartship direction.

After the ship has been launched a second magnetic condition will be superimposed on the first due to the hammering while fitting out with her head in a different direction. The horizontal components of this new field may be denoted by :—

$-P_f \cos \zeta_f$ and

$Q_f \sin \zeta_f$ where $\zeta_f$ is the direction of the fitting out berth.

During all the time that the ship is building, both on the slip and in the fitting out berth, the vertical plating will be subject to a magnetisation which, as before stated, will have a vertical component. The strenghth of this vertical component will be independent of the direction of the ship's head and in the northern hemisphere will always be *blue* upwards. With a ship of normal form there will be a preponderance of vertical plating abaft the compass while that at each side will be balanced. It follows, therefore, that we shall have a permanent *blue* pole abaft the compass and this will cause a semicircular deviation in addition to, and normally indistinguishable from, the semicircular deviation caused by the horizontal fore-and-aft permanent magnetism. For convenience we will call the strength of this field $P_z$ and its value will always be negative for ships built in the northern hemisphere.

Added to these the compass will be affected by the magnetism induced in the vertical *soft* iron equal to cZ, c also always having a negative value in the northern hemisphere.

The coefficients of semicircular deviation are :—

$$\bar{B} = \frac{P + cZ}{\lambda_2 H} \text{ and}$$

$$\bar{C} = \frac{Q + fZ}{\lambda_2 H}$$ f being normally zero for the symetrical ships we are considering.

P will be made up of three parts $P_z$, $-P_s \cos \zeta_s$ and $-P_f \cos \zeta_f$.

Q will be made up of two parts $Q_s \sin \zeta_s$ and $Q_f \sin \zeta_f$.

It follows that :—

$$\bar{B} = \frac{cZ + P_z - P_s \cos \zeta_s - P_f \cos \zeta_f}{\lambda_2 H}$$

$$\bar{C} = \frac{Q_s \sin \zeta_s + Q_f \sin \zeta_f}{\lambda_2 H}$$

or

$$cZ + P_z - P_s \cos \zeta_s - P_f \cos \zeta_f - \lambda_2 H\bar{B} = O$$

$$Q_s \sin \zeta_s + Q_f \sin \zeta_f - \lambda_2 H\bar{C} = O$$

For ships of a class cZ, $P_z$, $P_s$, $P_f$, $Q_s$ and $Q_f$ may be expected to be constant and if we analyse the data for *n* ships by the method of least squares we obtain the following :—

$$\Sigma\,(cZ + P_z - P_s \cos \zeta_s - P_f \cos \zeta_f - \lambda_2 H\bar{B})^2 = \text{a minimum.}$$

$$\Sigma\,(Q_s \sin \zeta_s + Q_f \sin \zeta_f - \lambda_2 H\bar{C})^2 = \text{a minimum.}$$

By differentiating these relations with respect to $(cZ + P_z)$, $P_s$, $P_f$, $Q_s$ and $Q_f$ we obtain the following five "normal" equations which give the required best estimates when solved as simultaneous equations :—

$$n\,(cZ + P_z) - [\cos \zeta_s]\,P_s - [\cos \zeta_f]\,P_f - [\bar{B}]\,\lambda_2 H = O$$

$$-[\cos \zeta_s]\,(cZ + P_z) + [\cos^2 \zeta_s]\,P_s + [\cos \zeta_s \cos \zeta_f]\,P_f + [B \cos \zeta_s]\,\lambda_2 H = O$$

$$-[\cos \zeta_f]\,(cZ + P_z) + [\cos \zeta_s \cos \zeta_f]\,P_s + [\cos^2 \zeta_f]\,P_f + [B \cos \zeta_f]\,\lambda_2 H = O$$

$$[\sin^2 \zeta_s]\,Q_s + [\sin \zeta_s \sin \zeta_f]\,Q_f - [C \sin \zeta_s]\,\lambda_2 H = O$$

$$[\sin \zeta_s \sin \zeta_f]\,Q_s + [\sin^2 \zeta_f]\,Q_f - [C \sin \zeta_f]\,\lambda_2 H = O$$

Square brackets are used in the customary sense, to indicate that the expression which they contain is to be evaluated for all the different individual cases and summed.

To test the theory expounded above the constants for the eight F-class destroyers and for four of the five *Leander* class cruisers were calculated. The report of the initial swing of each ship was consulted and the deviation caused on the cardinal points by the correctors used on that occasion found by experiment. From these deviations with their signs changed the approximate coefficients B and C were obtained. These values will not be strictly accurate owing to variation in the strength of magnets. The error will not, however, be great. The following table gives the data for the ships concerned :—

| Ship | B | C | $\zeta_s$ | $\zeta_f$ |
|---|---|---|---|---|
| Destroyers. | | | | |
| *Fearless* | —59° | —15° | N. 68° W. | S. 85° W. |
| *Foreseight* | —52° | —13° | | |
| *Fame* | —61° | —7° | N. 34° E. | N. 83° W. |
| *Firedrake* | —58° | —4° | | |
| *Fortune* | —50° | +14° | N. 7° W. | N. 50° E. |
| *Foxhound* | —43° | +10° | | |
| *Fury* | —36° | +12° | S. 69° E. | N. 31° E. |
| *Forester* | —32° | +13° | | |
| Cruisers. | | | | |
| *Leander* | —30° | —3° | N. 41° E. | S. 2° E. |
| *Orion* | —34° | +1° | | |
| *Achilles* | —54° | —26° | S. 81° W. | N. 68° W. |
| *Ajax* | —58° | —17° | N. 37° E. | N. 83° W. |

The exact coefficients $\bar{B}$ and $\bar{C}$ were obtained from the approximate by the formulae :—

$B = \sin B\ (1 + 1/2 \sin D + 1/12 \text{ versin } B - 1/4 \text{ versin } C) + 1/2 \sin C \sin E.$

$C = \sin C\ (1 - 1/2 \sin D - 1/4 \text{ versin } B + 1/12 \text{ versin } C) + 1/2 \sin B \sin E.$

Since the spheres were correctly placed and the ships magnetically symetrical D and E were zero.

The following table shows the values of the constants for the eight F-class destroyers and for the four *Leander*-class cruisers. H.M.S. *Neptune* was not included in the calculation as she was moved while fitting out so that her guns and machinery were hoisted in when her head was on a very different direction to that for the remainder of the time.

| | F-class | | *Leander*-class |
|---|---|---|---|
| $\lambda_2$ | ·95 | | ·90 |
| c | —0.12 | | —0.08 |
| H | | 0.18 | |
| Z | | 0.45 | |
| $P_s$ | +0.019 | | +0.006 |
| $Q_s$ | +0.017 | | +0.007 |
| $P_f$ | —0.041 | | +0.041 |
| $Q_f$ | +0.030 | | +0.053 |
| $P_z + cZ$ | —0.137 | | —0.124 |
| $P_z$ | —0.083 | | —0.088 |

Several interesting facts about these figures will be noted.

(a) The very close approximation of $P_s$ and $Q_s$ to each other in each case indicates the accuracy of the old theory when one is only concerned with the bare hull of a vessel as launched.

(b) The very large value of $P_z$ compared with those for $P_s$ and $P_f$. It had been realised in the Compass Department for some time that this could be the only explanation of the fact that for a great many years all of His Majesty's ships had required magnets *blue* forward to correct their standard compasses irrespective of the directions in which they were built (*).

(c) $P_f$ and $Q_f$ are considerably greater than $P_s$ and $Q_s$ showing that the direction of the fitting out berth has more effect than that of the slip.

(d) The negative value of $P_f$ for the destroyers is, at first sight, surprising. It may be accounted for by the fact that, in a destroyer, much of the fitting out work consists in the erection of the boilers and engines abaft the compass to which they are comparatively close. On the other hand in cruisers these items are further away while more of the bridge work remains to be built after launching. This would also account for the greater ratio of $P_f$ and $Q_f$ to $P_s$ and $Q_s$ in the case of the cruisers than in that of the destroyers.

From these most probable values of the constants new values for $\bar{B}$ and $\bar{C}$ were calculated and compares with those observed.

| Ship | Observed $\bar{B}$ | Calculated $\bar{B}$ | Difference | Observed $\bar{C}$ | Calculated $\bar{C}$· | Difference |
|---|---|---|---|---|---|---|
| *Fearless* .......... | —0.884 | —0.866 | 0.018 | —0.251 | —0.264 | 0.013 |
| *Foresight* ......... | —0.808 | —0.866 | 0.058 | —0.204 | —0.264 | 0.060 |
| *Fame* ............ | —0.910 | —0.865 | 0.045 | —0.106 | —0.116 | 0.010 |
| *Firedrake* ........ | —0.880 | —0.865 | 0.015 | —0.062 | —0.116 | 0.056 |
| *Fortune* .......... | —0.783 | —0.757 | 0.026 | +0.221 | +0.120 | 0.101 |
| *Foxhound* ........ | —0.694 | —0.757 | 0.063 | +0.162 | +0.120 | 0.042 |
| *Fury* ............ | —0.594 | —0.556 | 0.038 | +0.198 | +0.181 | 0.017 |
| *Forester* .......... | —0.533 | —0.556 | 0.023 | +0.217 | +0.181 | 0.036 |
| *Leander* .......... | —0.505 | —0.540 | 0.035 | —0.051 | +0.039 | 0.090 |
| *Orion* ............ | —0.567 | —0.540 | 0.027 | +0.017 | +0.039 | 0.022 |
| *Achilles* .......... | —0.816 | —0.855 | 0.039 | —0.397 | —0.348 | 0.049 |
| *Ajax* ............ | —0.872 | —0.825 | 0.047 | —0.259 | —0.302 | 0.043 |

(*) During the second Great War this fact was no longer correct owing to the disturbance of the magnetic conditions of ships by degaussing operations.

If the differences between the observed and calculated values of $\bar{B}$ are examined it will be noted that they never exceed 10% of $\bar{B}$ and that the largest does not exceed the mean difference between yard sisters. When it is realised that these differences include the errors due to the faulty estimation of $\bar{B}$ owing to variation in magnet strengths, magnetisation of plates prior to their being put on board and differences in yard practice concerning the advancement of the ship before launching the results may be taken as very satisfactory.

The differences between the observed and calculated values for $\bar{C}$ are about the same though as $\bar{C}$ is smaller than $\bar{B}$ the percentage error is higher. The largest error, that for H.M.S. *Fortune,* is more than double the mean. This is probably accounted for by the fact that this ship lay close to S.S. *Queen Mary* while fitting out and the immense hull of the latter ship must have distorted the local magnetic field considerably.