ON COMPASS TESTING IN SWEDEN, ESPECIALLY WITH REGARD TO THE DETECTION OF IRON IN COMPASS BOWLS.

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The testing of ships' compasses before they are placed in service on board vessels seems to be carried out on similar lines in various countries. During a recent journey, however, the present writer had occasion to note differences in technique in several countries, which are not sufficiently known. Although the various countries may have different requirements, and complete standardization is not a goal to be sought, it is hoped that the following lines on the methods used and the experience obtained in Sweden may be of some use.

Compasses are tested every fifth year for coast-trading vessels and every third year for vessels in farther traffic. For coast-trading vessels and other vessels below 100 tons gross register tonnage, there is a special certificate with less strict requirements than for other vessels.

The first part of the testing procedure is carried out in the rotating stand. Here the compass is rotated about a central axis. The lubbers-lines are checked and then the bowl is adjusted with one of the main lubbers-lines in the magnetic meridian.

The determination of the magnetic meridian has always been a tedious procedure, frequently to be carried out, on account of the often considerable perturbations at such high latitudes. Until recently a long needle in a special bowl was placed on the rotating stand, and on an opposite wall a movable mark was adjusted to the meridian as indicated by the needle. It has however proved feasible to simplify this procedure using another needle, viz. the ordinary deflection needle mounted in the sine deflection apparatus for liquid compasses. This apparatus has a fixed horizontal scale in degrees and minutes. The house of the needle is rotated by a micrometer screw until the needle points to the zero marks. The alidade rotates with the house of the needle, and when the needle shows zero, the alidade is read on the fixed circular scale. Suppose that the reading is 206° 15'.

A horizontal scale on white cardboard is now fixed on the wall opposite (north of) the rotating stand. The scale is graduated in degrees and subdivided to tenths of a minute. The long meridian needle is placed on the rotating stand and the magnetic meridian is determined. The cross-wires of the instrument tube being adjusted in the meridian plane, the tube is now directed towards the scale on the wall, and the scale is adjusted in the horizontal direction till the same number of minutes is read, viz. in the example chosen, 15'. The nearest degree below is then given the number 206° and the nearest degree above 207°.

Thus we possess two equivalent scales, one for the deflection-instrument and the other for the rotating stand. The meridian read on the former will always be valid for the latter, provided the variation in the meridian is always equal in both places. This should be tested for some time before the arrangement is used. If necessary or desired, a small torsion needle with a mirror may be placed sufficiently near the rotating stand. In such case, however, the torsion must be redetermined from time to time. This needle may also serve for determining magnetic moments as mentioned below.

The determination of magnetic moment is made by the sine method. There is, however, also a graduation on both sides of the zero mark of the needle, running to $\pm$ 20°, so that the instrument may also be used with the tangent method. This graduation and its numbering is in double degrees so that the mean of the two readings with poles reversed is obtained by simply adding the readings. It has been found that for general practical purposes both methods, tangent and sine, are equivalent within a few per-cent. The tangent method is of course more rapid and the instruments more simple. The needle is a single needle of 123 millimetres length. For great accuracy the needle should be replaced by a Kelvin multiple system (1), but we have found that even with a single needle the result is independent of the distance used, with a mean error of about 2 percent in the tangent and a half percent in the sine method.

For calculating the moment from readings according to the formula $M = 1/2\ H\ r^3\ F(\varphi)$, where $F(\varphi)$ denotes $\sin \varphi$ or tang φ, both logarithms and graphs on squared paper have been used. The best method has been found to be rectilinear nomograms. These are somewhat onerous to calculate, but once the calculation is made for one station, the results may be used for other stations with different horizontal intensity, by simply moving the *M* scale upwards or downwards. The same is the procedure when the horizontal field has changed perceptibly at a certain station.

The putting up of the compasses in two different stands being somewhat onerous, it is planned that the old deflection instrument will be superseded gradually by a modern very small needle and mirror, which may be read while the compass is on the rotating stand. The QHM instrument of La Cour for instance might no doubt be used for that purpose, although a more simple and rapid arrangement will suffice.

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(1) Cf. W. ULLRICH : *Über die Prüfung der Schiffskompasse.* Der Seewart 6, 40-44 (1937).

The most complicated branch of compass testing during later years has proved to be the detection of iron in bowls and rings. The Swedish regulations state that the metal parts of a compass shall be practically free from iron. The method used till last summer was the deviation method used in several countries. The bowl was rotated 45°, 90°, 135° etc., and the compass reading was checked by the reading on the instrument scale in order to find out if there was a perceptible deviation from local iron admixtures in the bowl or rings. A deviation amounting to half a degree was considered of no importance.

By and by, however, evidence accumulated which showed more and more clearly that compasses had been passed according to this method, although there was evidently iron in the bowl, rings, gimbals or screws. And it was found also that, in some cases, the iron in such compasses which had been passed with the old method was enough to make the compass useless for navigation. Investigations along this line were carried out some twenty years ago with considerable zeal and ingenuity by the late Otto Wedin, B.A., compass surveyor at the Stockholm branch office.

The following example may be cited. Another department of the Hydrographic Office had bought a compass and tested it. They found it without fault except for a collimation error, viz. a constant error of a couple of degrees, indicating that the needles were not in line with the north to south axis of the card. Inspection showed that the needles were actually parallel to this axis, and the case was submitted to Mr. Wedin. He took the rose out and put it into another bowl. There the card had no collimation error. After a couple of days the owners of the compass were invited to the compass surveyor. He showed them their card in the latter bowl, and he showed also that now it had a collimation error of the same value as it had before in the original bowl. In order to obtain that, he had placed four small iron coins in different positions around the rim of the glass. When these coins were taken away the collimation error was again nil.

Now the original bowl was tested with a small testing needle and was found to contain iron. This iron no doubt had by its peculiar distribution produced the appearance of a collimation error.

The above case is relatively harmless in its effects. The following case is more serious. Several years ago, the master of a Swedish vessel sent to the Compass Department a liquid compass. The compass had been tested and certified by the Department and had been in use for navigation on board the same vessel, till suddenly on beginning a voyage the compass had ceased to function, the card pointing persistently towards the same side of the bowl. The bowl was emptied and searched with a testing needle and found to contain a considerable amount of iron.

It was found that before latest voyage the vessel had been lying moored for some time alongside a wharf, and it was thought that during that time the iron in the bowl had received induction from external permanent magnetic masses or electromagnets.

From these and other experiences it had become evident to the Compass Department that the deviation method was unsatisfactory for detecting iron in bowls. Other methods were investigated, which would not necessitate the opening and emptying of every compass bowl. A vertical or inclination needle was found too insensitive. Another arrangement was to mount the compass on a rotating stand and to place a small needle on a fixed stand as near the bowl as possible. Then the bowl was rotated so slowly that the card could be expected to stand still and the small needle would then show deviation if any iron admixture in the bowl passed near either of its poles. It was found, however, that the card always made small motions which deflected the small needle, although when the bowl was emptied it was found to be free from iron.

Enough experience had finally been gathered to show that navigation could not be safeguarded from these dangers without emptying the bowls and searching them with a testing-needle. The Hydrographic Office decided they did not want to be responsible for disasters which might ensue from iron in compasses undetected by the older methods, and new regulations were issued for iron testing.

From 1 August 1938, every dry card compass was tested with the card taken out. The bowl of every liquid compass which needed repairs should be delivered to the local branch testing office before filling the compass. The same was to be the case with all new compasses. After testing a compass in this way a stamp was to be made on the bowl, on each ring and on the larger screws, especially the filling screw. Thus a bowl etc., once tested for iron, would never again need testing in the same manner. Each branch office had its own stamp differing from those of the others.

The type of needle to be used was the subject of a special investigation. A series of different needles were tried, and their weight, magnetic moment, moment of inertia and other properties determined. The best needles were found to be a short flat needle of rhombic form and a relatively short prismatic needle of uniformly quadratic transverse section and somewhat pointed towards the ends. Practical test showed that the latter was about three times more sensitive then the former.

The only kind of iron admixture which may be detected in this way is soft or relatively soft iron. It may be surmised that during the welding process perhaps even hard iron may enter into the said state. We do not know this at present. If there is an iron admixture with such a high coercivity that it does not answer to the testing needle at a distance of some millimetres, then we may suppose that it will be relatively harmless because it will not come later under the action of other fields as strong as that of the testing needle. This will be evident because the compass needles, and the compensation magnets or other external sources will be tens or hundreds of times more distant than the pole of the testing needle.

Theoretically the action of the testing needle may be sketched as follows. One pole, $+$ P, of the testing needle acts on a local iron admixture and engenders there by induction an opposite pole, — p, at a distance r. The induction will vary inversely with the square of the distance, say $\times \frac{P}{r^2}$ according to a law $=$ const. We will not consider more than this one induced pole p, for reasons shown below, although there must of course appear at least one more pole, $+$ p, farther away. But we cannot treat that case without knowing the extent of the iron admixture, which we cannot ascertain. Now the induced pole, — p, will react on the pole P inversely as the square of the distance, say, discarding signs, according to the law, const. $\times \frac{p}{r^2}$, or, as $p =$ const. $\times \frac{P}{r^2}$, the field acting at the pole P will be proportional to $\frac{P}{r^4}$.

The needle will now react mechanically to this field at P by swinging P towards p. The reaction will be quicker if the moment of inertia of the needle is small. Thus the testing needle should have as large a magnetic moment and as small a moment of inertia as possible. This will explain, why the square — parallelepipedic needle was found most successful. Its constants were the following : length 76 millimetres, weight 2,7 grams, magnetic moment 100 C.G.S.

Supposing that the reactive field strength at the original pole varies inversely as the fourth power of the distance, we may consider the other induced pole $+$ p at an assumed distance $r_1 = 2r$. The field of this pole at P will be of the opposite sign, and proportional to $\frac{P}{r_1^4} = \frac{P}{16\,r^4}$. In this case the reactive field component from $+$ p will be 16 times weaker than the reactive field from the nearest pole — p. Thus we may in most cases treat the problem as if there were only one single induced pole. We will find below that this theoretical conclusion is supported by empirical facts.

Now consider one of the ordinary poles in the compass rose itself; its strength, say, is 10 P, which ought to be pretty high. If its distance from the same iron admixture in the bowl is 30 millimetres, the reactive field will be proportional to $\frac{10\,P}{30^4}$, while the reactive field of the testing needle with one pole at the distance 3 millimetres is proportional to $\frac{P}{3^4}$. The proportion between these two fields is $\frac{10\,P}{30^4} : \frac{P}{3^4} = 1 : 1000$. Thus the reactive field on the said compass pole of the card is only one thousandth of the reactive field on the pole of the testing needle. This may explain why the deviation method is so insensitive in detecting iron admixture as compared with the testing needle.

In order to test the above theoretical considerations some experiments have been carried out with the testing needle. Soft iron wire was cut up into portions of different weight, viz. 0,02; 0,03; 1,0 and 50 grams, and compressed by aid of a pair of thongs into a fairly compact form. The different samples were approached to one of the poles of the needle, and the distance was recorded when the needle showed a perceptible deflection. The mean values were :

Weight of soft iron.... :	0.1	0.3	1.0	3.0	5.0 grams
Deflection at distance .... :	13.8	18.0	23.8	31.6	36.1 millimetres

Calling the weight W, and the distance d, the theoretical formula will be :

$$W = \text{const.} \times d^4$$

The above empirical values give the formula :

$$W = \frac{1}{69000} \times d^{3,94}.$$

We find that the reaction follows practically exactly the theoretical formula. The values are derived from four different testing needles.

From the above formula or a graph constructed from the observed data, the value W for an observed value d may be derived. Thus observing the maximum distance, within which a certain iron particle begins to attract the needle, we may, if the expression is allowed, " weigh " even an iron admixture, if it is evenly distributed within a piece of metal. This has been attempted with samples of metal, containing a known percentage of iron and the results have agreed fairly well with expectations.

For use in testing compasses, the needle is mounted on a small metal stand, consisting of a circular foot-plate upon which is fixed a vertical metal pipe. Within that pipe slides another metal pipe or rod with some friction, and the latter supports the point on which the needle swings. For obtaining high sensitivity, it is of course essential that the point should be of high quality and is always carefully used, and, if necessary, reground.

It is possible to obtain a higher sensitivity for special purposes. When used for testing, the needle will be subject to two fields, viz. the earth's field and the reaction field on the iron admixture. The needle will be deflected by the resultant of these two fields of forces. If the earth's horizontal force is annulled, the needle will be deflected only by the reaction field.

We may thus place a magnet bar on the table below the needle with red pole to the north and blue pole to the south. If the magnet is of the proper moment, it will annul the earth-field and the magnet will be astatic, i.e. it will take any position of rest. We may adjust the height of the stand till this condition is obtained. To ascertain the proper height of the stand we may also place the bar magnet east and west and adjust the height till the needle is deflected 45° and then alter the position of the bar, red pole north and blue south. The former procedure seems to be more rapid.

There may, of course, be iron also in the binnacle or pelorus, but this generally comes within the domain of the adjuster, and such iron is always farther away from the card. Occasionally it may be found that the cylindrical lower border of the binnacle cap is strengthened by a ring, which consists of a steel wire sheathed with brass. This may be ascertained with a small pocket compass, which is a useful accessory for an adjuster. Especially is this the case, when deviating airplanes built on a steel skeleton, which often contains a collection of magnetic poles violating almost every accepted law of magnetism.

It should be remembered also that the material used for varnishing the bowl may contain iron. We have had one such case, when a gimbal ring was sent from the maker to a branch office in order to replace a condemned ring. The new ring had been tested at another branch office and stamped in its unvarnished state. On receipt of this ring at the other branch office it was also tested there and found to contain a fair amount of iron. It then went to the head office, where some of the dull black varnish was scraped off. "Weighing" the sample magnetically with the testing needle as described above, it was found that about half of its weight was pure iron.

When this method of iron-testing was put into practice, it was foreseen that difficulties of a practical order might arise. It seems that these have been over-estimated. The branch offices were instructed to disturb the feelings of navigators and compass-firms as little as possible, to explain the new methods carefully and try to bridge over difficulties. The manner in which the innovation was received seems to justify a high opinion of the nautical circles interested. The gradual introduction of the new rules also proved fortunate. Now it is evident, that after three or five years on board, most compasses need supervision by the compass-maker, and there are relatively few compasses which must be opened *only* for the purpose of iron-testing. If they go to the compass-maker for repairs the bowls are tested for iron by our branch office before they are put together again. Bowls and rings for new compasses are sent to the branch office from the maker before they are varnished. A considerable number of bowls and rings may thus be tested at the same time and stamped.

After three or five years, respectively, every compass in use will have been tested and stamped, and only new instruments will have to be tested, unless one branch office is interested in checking the result of another. Evidently every branch office will not act according to quite the same standard, and this is the reason why all offices have different stamps. This will, by and by, we believe, work towards the decrease of differences.

Some mention may perhaps be made of the results of the period of testing elapsed up till now, i.e. nearly one year. The date does not embrace all the branch offices but the choice has been made without prejudice. Of 632 compasses tested, iron has been found in 98. Of these certain parts have been renewed, as rings, screws or gimbals, in 45 compasses and 53 have been rejected as unfit for navigation.

It may evidently be said that not every compass or part rejected may have been unfit for navigation. This is certainly true. If the testing official finds traces of iron, which he considers to be without importance on account of its minute quantity or position with regard to the needle system, he may stamp the compass and give it a certificate, stating however " traces of iron in the glass ring ", or otherwise as the case may be. It may be said, however, that if iron in perceptible quantities is found in a compass, we cannot foretell to what extent it may come into play under certain circumstances. in a bowl used for a dry card with its feeble moment and central needle system, a certain iron quantity may be innocuous, and with a strong needle system with a magnetic moment of several thousand C.G.S. units, the same iron quantity may be dangerous. If we find an error in a ship's sidelight, we may determine exactly how it will affect the light-range or the light-sector limits, but this is not the case with iron in the compasses.

It has been found that with the testing needle in the undiminished earth-field the results are such that there is no difficulty for a careful compass-maker to obtain metal at a reasonable price, which will stand the actual tests. It has also been found that during the past year the iron in new compasses has grown better, that is, makers have grown more careful. The greatest difficulty seems to be with screws and gimbals, but fortunately these may be replaced. The bolt metal from which these parts are made seems generally to be less free from iron than foundered metal. Iron has been found in compasses from all countries delivering compasses to Swedish vessels, but especially in compasses from the years about the end of the great war, as has been pointed out by Captain Ullrich in the paper mentioned above.

Some concluding words may be said regarding the case of iron admixture, mentioned on page 65 During a recent journey to other Scandinavian countries I had occasion to show the compass in question to our colleagues. In the first country, where the compass was tested on the rotating stand, a slight semicircular deviation was found amounting to half a degree at a maximum. This compass would accordingly have been given a certificate here, as had been done earlier in Sweden. When the compass was disassembled, iron was found in the bowl with the aid of the testing needle. In the next country the rotating stand showed a very irregular deviation, maximum 1 1/4 degree. Consequently it would have been rejected. On disassembling the compass, the testing needle showed a strong deflection opposite a point in the bowl, answering to the maximum deviation observed.

Thus the compass had in one place shown a regular semi-circular deviation amounting to half a degree, and two days later in another place an isolated maximum deviation of 1 1/4 degree. Some years earlier it had on one occasion been completely useless for navigation.

The explanation seems to be the following. Before being tested in the first place the compass had gone by railway with the card mounted in the bowl, thus swinging freely. Between the first and the second test, the card had been packed at the bottom of the bowl, thus giving a steadily growing induction to a certain iron admixture. Accordingly it may be surmised that the iron in the bowl was not quite soft, that it had originally been tested when taken directly from the maker, but when the vessel had later been lying moored for some time, an intensive induction of poles had been produced. Probably some strong admixtures of iron had by chance been occupying favourable positions near the poles of the magnet system. What seems to have occurred later we have already mentioned. The compass was made by an old Swedish firm well-known for its workmanship.

It is to be regretted that in this respect the present regulations in Sweden put difficulties in the way of importing foreign compasses of well-known makers. Shipowners have in general proved disinclined to buying foreign compasses without a Swedish certificate, and as this involves taking out the card for testing and stamping the metal parts, the price will be augmented by the repairer's fee for disassembling the compass and assembling it. Measures are however considered, which may make it possible to overcome this difficulty.

In the light of the experience described above it will be understood that the Swedish testing department will hardly be able to revert to the older method of testing for iron.

From investigations carried out by this department during the last two decades, it seems probable that such shifts in the deviation curves, of which masters of vessels not infrequently complain, may be caused at least in part by iron in the compass bowls, and also, as I hope to show in another article, in part by compensation magnets of unsatisfactory quality. Thus, in cases where deviation curves are shifting considerably from time to time adjusters would probably do well to advise the masters to have these two possible causes investigated, as they may easily be remedied, whereas errors arising from semi-permanent magnetism in the vessel can as a rule be remedied only by frequent swinging of the ship or occasional azimuth observations.