ON THE VARIATION IN THE MAGNETIC MOMENT OF THE COMPENSATING MAGNETS, WITH A SIMPLIFIED METHOD OF OBSERVATION.

by

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In the manuals on magnetic compasses one seldom finds any details on the physical properties of the magnets. A gradual reduction in the magnetic moment of the compass needles is something which rarely occurs to such an extent as to detrimentally effect the compass as a navigational instrument. The same thing is not true, however, of the compensating magnets.

In the Bureau of Navigational Instruments we have had occasion to conduct several experiments on the magnetic moments of about fifty odd magnets belonging to different types of vessels.

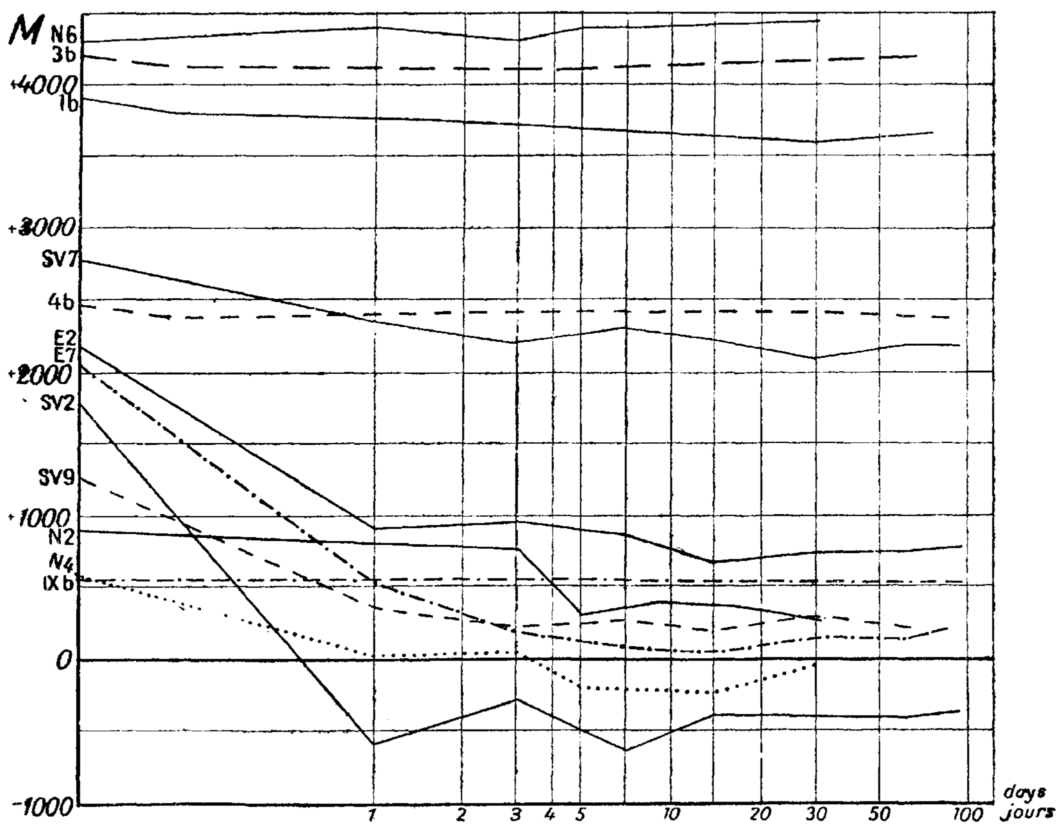

FIG. 1. — Variations on the magnetic moment of the six compensating magnets of different qualities.

The origin of this series of observations was a complaint lodged by a certain organisation reporting their compensating magnets as defective. We discovered immediately that the magnetic moments of some of these magnets were very small in comparison with their dimensions. Before proposing a re-magnetisation of these bar-magnets, however, we decided to make a series of observations on the change in the moment in order to form some conclusions regarding the quality of steel in the different bars.

The first series of observations was made simultaneously on 17 magnets. After being magnetised to saturation, their moments were determined by deflection. Thereupon the magnets were placed side by side without spacing with all their north poles turned to the same side. This constituted a magnetic field of comparatively great strength which should cause the moment of the bars of semi-soft steel to diminish quite rapidly. Such proved to be the case.

The moments of all the magnets were re-observed at successively increasing intervals, nearly in geometric progression; viz: 1, 2, 4, 8, 16, 31 and 51 days, the entire period embracing 114 days or nearly four months.

Even after the first day, two of the magnets changed poles, i.e. north for south and vice versa. Several days later, four other magnets followed the same course. It is evident that such bars are entirely inadmissible as compensating magnets. In fact, all the bars observed may be grouped in four categories, evidently depending upon the quality of steel of which they are made: very good, good, mediocre and poor.

The good steels show a change in the magnetic moment which is scarcely perceptible. The steels of the second category have changed perceptibly in the course of the first day, amounting to about 10 to 20%, after which they remain practically constant. The mediocre steels lose about 30% of their moment during the first few days, after which they remain passably constant. The last category includes the bars of rather soft steel which have reversed poles, which have suffered a violent or irregular reduction in moment, or which, in general, have changed their state while subject to a comparatively moderate environing field.

After this, the same sequence of observations was made on six magnets from another vessel. The results were almost identical.

In order to represent graphically the variations in the magnetic moment, we have made use of logarithmic paper, the magnetic moments being plotted as ordinates and the time elapsed as abscissae on the logarithmic scale. This was found useful because the variation is more intense immediately after saturation. For the same reason, the intervals of time have been chosen in such a manner that each, as far as possible, is approximately double the preceding.

After what we have said, it will be evident that the steels of the last two categories should never be considered acceptable for compensation magnets. Even the second category should be considered inadmissible, because modern steel for magnets has a quite satisfactory coercitivity and remanence, and the method of "artificial ageing" generally employed for magnetic steels makes the magnets very constant.

In order to confirm our opinion on this point, we subjected a series of modern magnets from a certain manufacturer to tests similar to those described above. These magnets were all of steel containing 15% cobalt and a small percentage of chromium; a steel which the manufacturer in question used ordinarily for the compasses and for the compensation magnets. The magnets had been artificially aged at the factory before delivery. No chemical analysis was made of the steel because we considered it more important to elaborate a test sufficiently simple, rapid and cheap which could be used for all compass compensation magnets. We shall return later to this question.

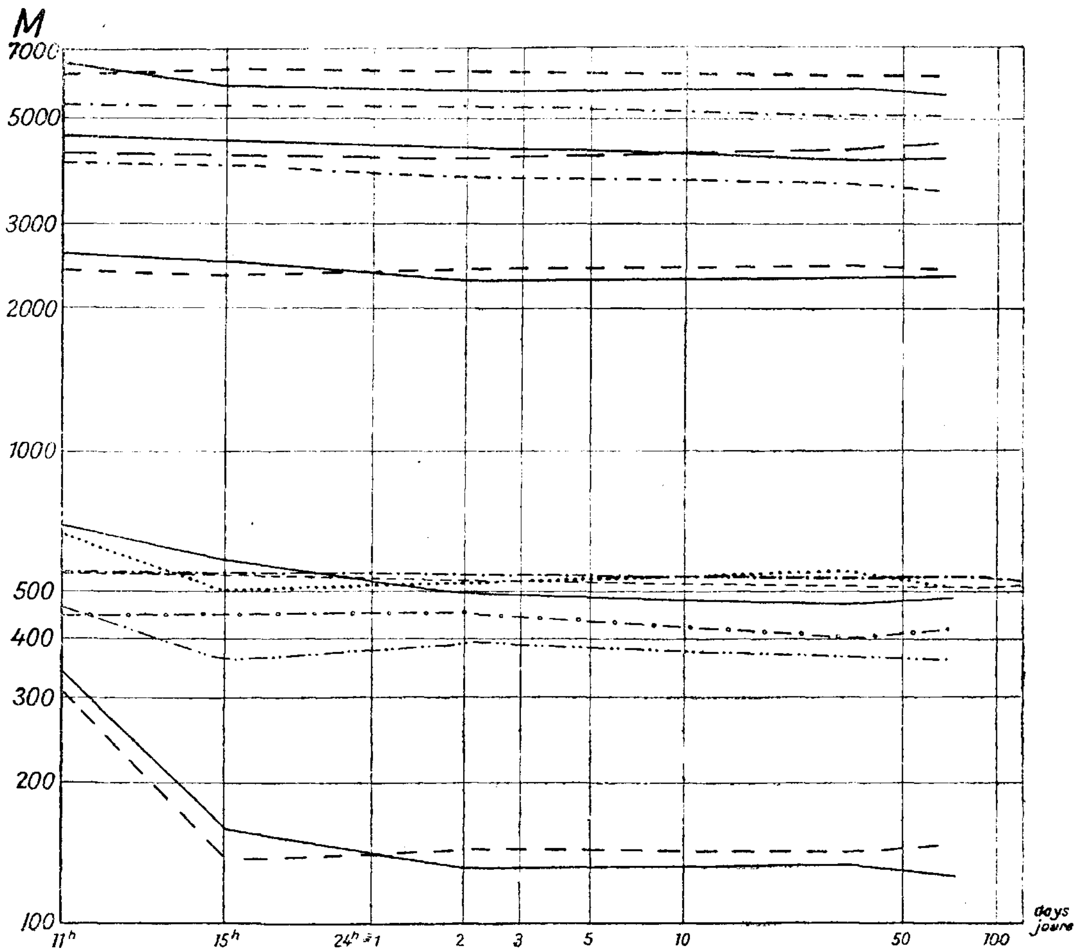

FIG. 2. — Variations in the magnetic moment of the sixteen bar-magnets of good steel.

The experiments with the artificially aged bar-magnets of cobalt-chrome steel embraced sixteen bars and two systems composed of magnets for liquid compasses. Their lengths varied from twenty to four centimetres and their magnetic moments from 7000 to 130 C. G. S. The ratio of length of diameter, which is an important parameter for magnets, varied from 25 for the strongest and longest magnets to 10 for the shortest and weakest.

These magnets being all of good steel, it was not considered necessary to saturate them again. We used them in the state in which they were received from the factory, and each couple of equal bars was placed with north pole to north pole. The moment was obtained immediately after unpacking, then after four hours, and subsequently after two days, one month and three and one half months — all intervals being measured from the time of dismantling. During the entire time, the magnets were placed parallel one to the other and at a distance of 20 mm. between the axes of neighbouring magnets, that is, at the minimum distance existing between the compensation magnets when placed in the compass binnacle aboard ship. Nevertheless the best modern magnets showed the same constancy in the two cases.

In the course of the first four hours, there was a reduction in the moment of the weakest magnets; i.e. those having a moment less than 700 C.G.S., a length under 9 centimetres and a ratio of length to diameter varying between 25 and 10. This reduction was of several percent for the strongest magnets and 50% (from 300 to 150 C.G.S. units) for the weakest (length 4 centimetres, length/ dia - 10). Even for some of the magnets in this weakest group, there was little appreciable difference in the moment between the armed state and the disarmed state.

The two series of observations which we have just described permit us to draw several practical conclusions.

1) — That the compensation magnets of the first class of steel have a practically perfect permanence.

2) — That there are in service aboard ship a relatively large number or bar-magnets of insufficient permanence.

In order to avoid ill-founded conclusions, we have conducted a third series of observations on five compensation magnets belonging to a different organisation. In the depots of this firm, the magnets when not in service are armed, in pairs, north pole against north pole. In order to study the variation in magnetic moment immediately after disarming, the observations on the moments were made every fifteen minutes. After disarming, the bars were placed as in the preceding series, that is parallel to each other at a minimum distance of 20 mm. from each other and with the north poles in the same direction. The results are shown in fig. 3 by the continuous curves. As before, the reduction in the moment was greater, in general, for the weakest magnets, or in round numbers :

Magnetic Moment C.G.S.	4900	3200	1800	1200	800
Reduction in percent. ..	4	8	1	20	15

After the first hour, the magnets did not change during the next four days.

It is evident that here a part of the relation in question may be due to the effect of the different qualities of steel; nevertheless, the similarly between this relation and that found in the preceding series is interesting.

The conclusion to be drawn from this last series of observations appears to be that the magnets should not be stored in pairs but in a magnetic field of about the same strength as that to which the magnets would be subjected in the compass binnacle, or, what amounts to the same thing, in a field similar to that in which the magnets were placed during the series of experiments just described.

In order to determine whether or not this rather vague condition is satisfactory, we have submitted one of the magnets of the last series to a new test. The bar was re-magnetised to saturation, then placed between two bars of about 2000 C.G.S. parallel and at distances between axes of about 20 mm. There was observed a reduction in the magnetic moment of about 25% during the first quarter of an hour, then a reduction of about 3% during the next two hours. After that the moment remained approximately constant during the next four days.

Now the field was tripled in intensity and the neighbouring bars exchanged for two others of the same length and with a magnetic moment of about 6000 C.G.S. Such a moment is reached with certain magnets in practice in compensation. Fig. 3 shows the curve (dotted curve to the right) with a sharp reduction of the magnetic moment of about 40% during the course of the first three hours. After a week the moment has been reduced by another 10%, i.e. the quasi-constant moment of the magnet in the first weak field is twice as great as in the second stronger field, which, none the less, has an intensity in no way excessive from the point of view of practical compensation.

We might show by a simple calculation that if a series of these magnets were used, for instance, for the compensation of the co-efficient *B* or *C*, the deviation might change by several degrees in the course of the first few hours.

It then becomes necessary to seek some method which will be rapid and simple and within reach of all for the purpose of determining the quality of steel in the magnets. In the first place the series of observations should be made as short as possible. To judge the series of observations which we have mentioned above, it would seem that a series of observations embracing a period of seven days should be sufficient to determine the degree of per-

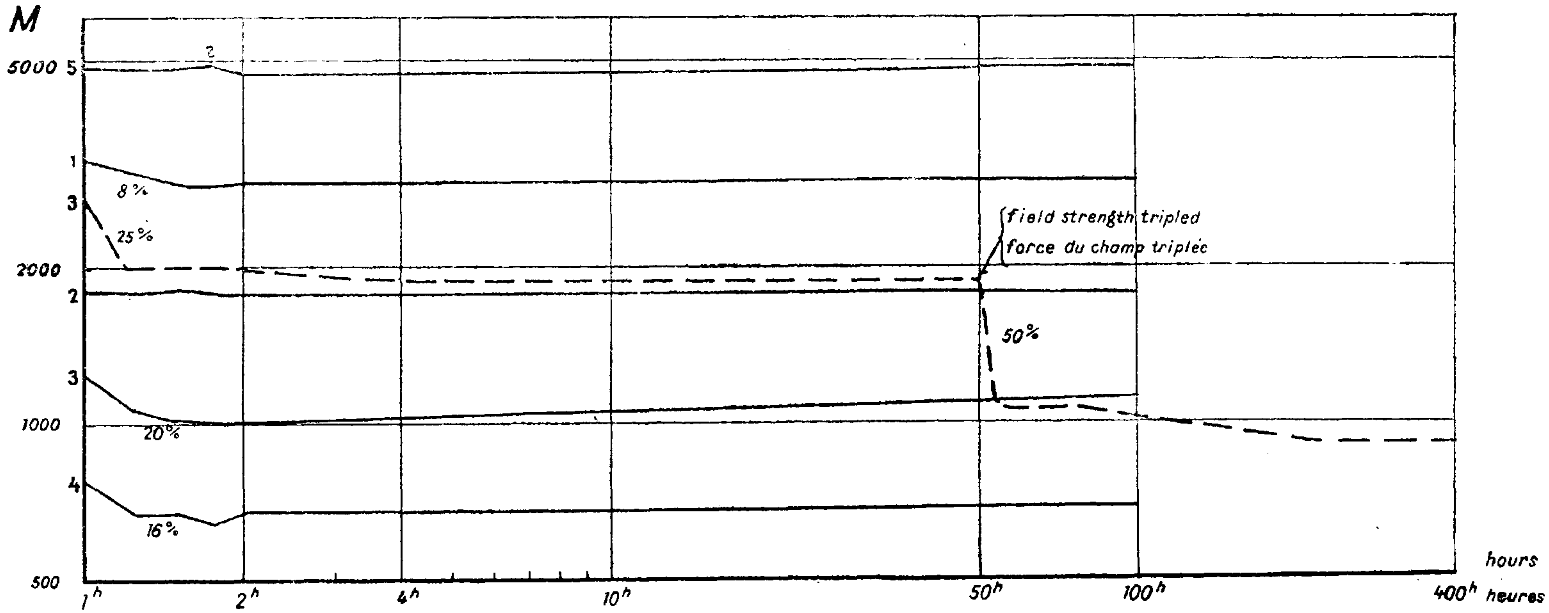

FIG. 3. — Variations in the moment after disarming and after subjection to a strong field (curve 3 broken lines).

manence of the magnet and to separate the good steel from the poor. In the physical treatises, we find that it is recommended to employ the Brinnel test of mechanical hardness of the steel to determine the magnetic hardness. We have not had occasion to undertake any experiments along these lines, but an old manufacturer of compasses possessing considerable experience told us that he had not found the Brinnel test for mechanical hardness of any great value in determining the degree of magnetic hardness.

The determination of the elements of the curve of hysteresis, i.e. the coercitivity and the remanence, requires an apparatus which is rather complicated. There remains, therefore, the determination of the variation of the moment in two fields, or strictly speaking, in passing from one field to another. We shall consider the question here from a strictly practical standpoint.

Let us return therefore to the series of seven days. We have determined, therefore, the moment for two and five hours, then for one, three and seven days since the start; i.e. the successive intervals are: 3 hours, 1 day, 2 days, four days.

The observation of two deflections (E and W) with the aid of the tangent method and the deduction of the moment by means of a nomogram or diagram does not require more than one or two minutes and the total series of observations for one magnet does not require more than ten minutes to one quarter of an hour. We have completed such a series for four of the worst magnets of the first series of which we have spoken previously. First the bars were magnetised as strongly as possible with the aid of a powerful electro-magnet; and it was this process which we have designated in the preceding by the somewhat inexact term of " magnetisation to saturation ". While in this state of remagnetisation, the magnet is armed with the aid of another magnet equally strong, then the two bars are separated and the magnetic moment is determined for the magnet in question. After this the magnet is not armed again but is placed parallel between two bar magnets of good steel having moments of 4000 to 6000 C.G.S., north pole placed against the north pole of the magnet under observation. Then the test series of seven days is commenced. The results are shown in fig. 4. We see that after two hours the moment is almost zero for the three magnets, one of them having changed poles and the fourth having lost about two thirds of its initial moment. After three hours more, one of the other magnets changed poles. Finally all five of the magnets remained appreciably constant except bar N° 2 which has a sharper curve than the others.

Comparing the results of this series with those of the first series, we find that the reduction in the magnetic moment has generally been greater in the first case than in the last, although certain steels have diminished their moments in approximately the same proportion in the two cases. This leads us to suppose that the study of such a characteristic curve consisting of six observations should well suffice for the determination of the quality of the magnet. It appears probable that we could allow a diminution of about

30% for a passable steel magnet (see fig. 5, curve SV7) and about 10% for a high grade magnet.

A difficulty may however arise here. As we have already seen the best steels for magnets are, after magnetisation, artificially aged by a thermal process, or otherwise, which has diminished their intensity and their moment to a point where they are most stable. There is no need to disturb this inner balance, but one should not subject such a magnet to a field which is too strong. We have found that the magnetisation, by rubbing against the poles of the electro-magnets of which we made use, had no influence on those magnets or high quality steel. These magnets are practically insensitive to all the fields which come into question here. The electro-magnet in question was fed by an ordinary lighting current of 220 volts and the number of turns on each branch of the magnet was several hundreds.

It is evident that with such a procedure as we have proposed, and which is much less accurate than the more scientific methods employed in the science of electromagnetism, we should not be able to reach a determination of the effects of the spontaneous internal variations of state which occur sometimes in magnetic steels. These require tests lasting a month or more. In the longest series which we have studied in the preceding, we have not found any effects which might be attributed to such changes independent of the external field.

For the rest, we were interested in developing a method which did not require elaborate or costly apparatus. It appeared probable that we might arrive at results having some practical value by the means described above.

It even seemed possible that we might make use of a still more simplified method. Studying the curves of the different magnets in fig. 3, we find that a bar like N° 3, being armed and then disarmed and placed parallel between two other equally strong magnets at a distance of 20 mm. (curve of plane dashes) has lost 20% of its moment after an hour. This is a bad steel in accordance with what we have found in the preceding by the study of the dotted curve N° 3. From other tests we have found that a passable magnet under the same conditions will change its moment up to 10%, while a magnet of high quality steel will only change its moment about five percent. This last test is more rapid, but is also somewhat summary and doubtless requires more circumspection. We believe, nevertheless, that with some experience it will produce results which are useful.

With regard to the apparatus necessary for the making a determination of the magnetic moment, the apparatus usually employed may permit of certain simplifications. Evidently it is not necessary to know the magnetic moment; it will suffice to determine the variation as a percentage. Let us admit, as may be done for the actual practical needs, that the change in the moment is proportional to the change in the deflection in the "tangent" apparatus, it will suffice to determine the deflection and to study its variation in percentages. Thus we may make use of a very simple apparatus. We take a board about 70 cm. in length and draw on it in pencil a longitudinal axis. At one of the extremities of the axis, we rigidly secure to the board, a compass having a well pointed needle and with the degrees graduated on the board. The diameter of the compass should not exceed ten cm. which will give about 1 mm. of length for each degree of the circular scale. Thus, with a little experience we are able to read to within a tenth of a degree.

Such compasses are easily found in the trade and also in stores dealing with second hand articles.

Giving the axis of the board an east-west orientation, it should be rigidly secured to a table or other solid support. Several fixed distances are measured along the axis, such as, for instance, 30, 40 and 50 cm. from the origin at the centre of the compass and opposite these points are marked the number of centimetres. The greatest distances will be for the strongest magnets and the lesser distances for the weaker magnets. It is essential to keep the deflection rather large; for instance a deflection not exceeding about 6°. With an error of 0.2° in the reading of the deflection angle (E and W) this will give an uncertainty of about 5% in the magnetic moment with a deflection of six degrees, which is sufficient in practice.

Although a deflection of six degrees may suffice, one should not on that account be required to choose a lesser distance than demanded for the purpose, because an error in the distance is much more serious at shorter distances than at greater distances. The distance enters into the formula as the third power :

$$M = \frac{H}{2} r^3 \tan \varphi$$

In order to solve this equation, resort must be had to logarithmic calculations. This may be avoided by calculating in advance, for a certain value of the distance r, the values of the moment M corresponding to certain values of the deflection. Thereupon a diagram is constructed on millimeter square paper with the value of φ as abscissa and M as ordinate. Thus, for instance, we may construct four curves, i.e. for r equal 30, 40, 50 and 60 centimetres. These curves are almost straight lines and a few points will suffice to determine the curve, especially in the lower part. A nomogram is still more useful but its construction requires much more calculation.

In order to give an example, we have treated three magnets of the first series according to the method we have just proposed. The compass which was secured to the board by four screws had a diameter of only 68 mm. (diameter less than the circular scale). After having separated the magnets one by one from their armed position, we found the following values :

N:o	r						M	
SV 6	50	+	4,7°	—	5,2°	4,9°	770	CGS
SV 2	50	+	7,1	—	6,9°	7,°	1090	
E 4	50	+	4,7	—	4,9°	4,8°	750	

After that, the magnets were replaced parallel between the bar-magnets of good steel, north pole to north pole and at a distance of 20 mm. from each other. After one hour, we found :

SV 6	50	+	2,2	—	2,5	2,4	375
SV 2	50	++	2,0	—	2,2	2,1	330
E 4	50	+	3,1	—	3,1	3,1	480

Comparing the moments for a certain magnet, we find that the first has diminished to 51, the second to 70 and the third to 36%. We find then that the simplified method gives results which are quite satisfactory.

This requires only that we make use, for the same magnet, of the same distance for the two observations. We may note also the sign of the deflection : positive, for instance, when the red pole of the magnet repels the north pole of the compass needle. This precaution is not entirely unnecessary, because we have found magnets in which the polarity became inverted.

We believe, therefore, that we can specify a simple procedure, namely:

1° — A tangential deflector improvised as described above.

2° — Arming the magnets with magnets of good steel during two or three hours.

3° — Deflection.

4° — Disarming the magnets as described, for one hour.

5° — Deflection.

6° — Calculation of the change in the angle of deflection in percent.

This procedure subjects the magnets to fields which are sufficiently moderate so that no disturbance is caused to the internal balance in the case of good steels.

With regard to the changes which are admissible, the values given in the preceding (see page) may be used as a provisional guide, which may be modified subsequently according to the experience of each observer.

We have endeavoured in the above to give an outline of the results of our research, which are of a practical rather than a scientific order. It would be interesting to learn of the experience in this connection which has been obtained in other countries. * Possibly we may find in this some explanation of the causes for the inconsistencies found in the curves of deviations which are the basis of complaints by navigators from time to time. We have endeavoured in another article to point out one of the other causes for these inconsistencies, aside from the semi-permanent magnetism of the vessel, i.e. the ferrous impurities in the metal of the compass case.

* The Directing Committee will be glad to publish any other articles received on this subject in subsequent numbers of the Hydrographic Review.

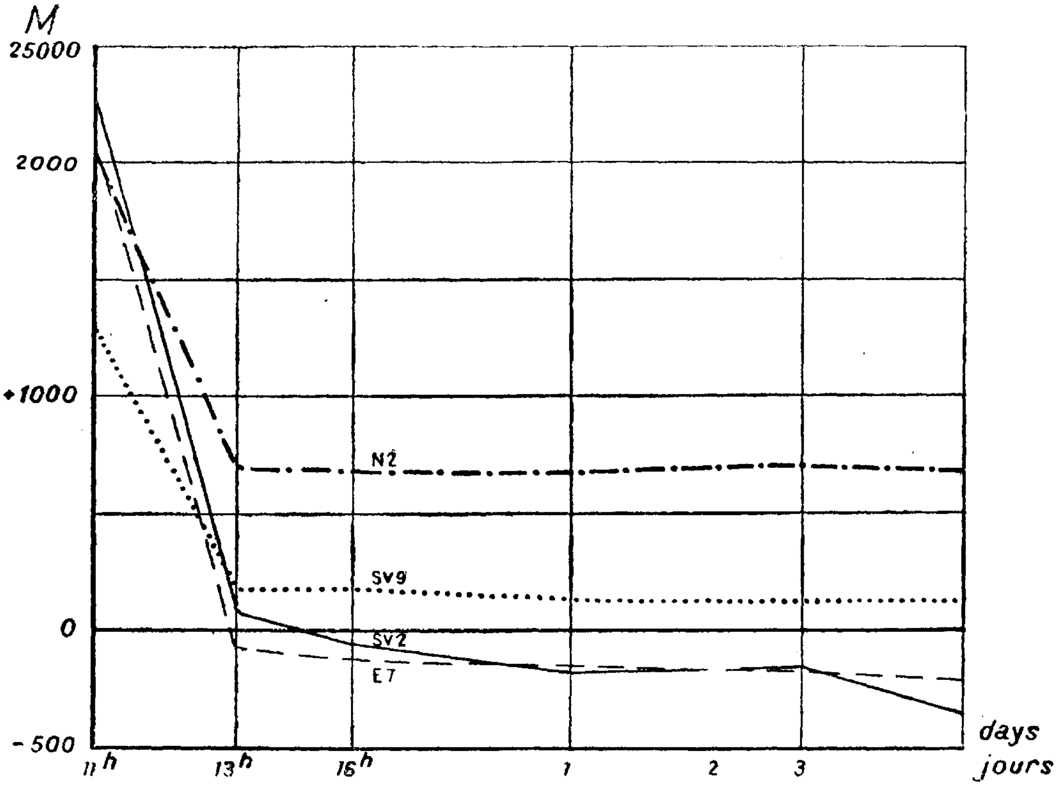

FIG. 4. — Simplified method of observation during seven days.

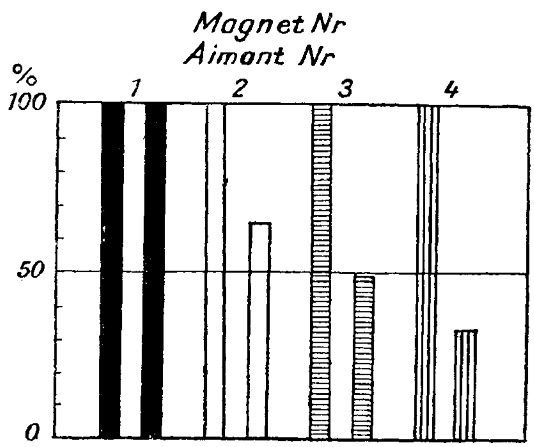

FIG. 5. — The simplest method : two observations of the moment at intervals of one hour.