Compensation of Magnetic Compass Deviation at Single Any Course

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ABSTRACT: The new method for compensation of deviation of magnetic compass at one any course is offered. The theoretical substantiation of a method is given, the analysis of accuracy is made, corresponding conclusions and recommendations are made. It allows to carry out a deviation's works without interruption from voyage.

1 INTRODUCTION.

The compensation of deviation of magnetic compass is usually carried out on the special aquatory equipped by leading line. The primary compensation of deviation is executed at an output of a vessel from building shipyard. All factors of deviation is determined and compensated in this case. The determination of residual deviation and calculation of the table is made after compensation of deviation. Such procedure can demand some hours of time. At annual deviation's works the compensation of the most inconstant factors of deviations B and C is made only. These factors on new building vessels can reach values $9^0 \div 12^0$. They are the most instable in storm conditions, at ice navigation, at knock about a quay on mooring, etc. As a rule, the table of deviation guarantees high reliability of the data up to the first heavy storm.

The most often used method for compensation of factors B and C is the method of Airy, which is carried out at 4 main magnetic courses. Accuracy of compensation depends on accuracy of supervision, on accuracy of operations by magnets - compensators, on hysteresis effects in the body of the vessel at maneuvering by means of course. After compensation of deviation the definition of residual deviation and calculation of the table is carried out.

Especially many problems are delivered at deviations maneuvers to large-capacity ships such as supertanker, big passenger ship, the big military ships and submarines etc.

Every time even the minimal program of deviation's work is connected to loss of operational time and an additional overhead charge. The problem of navigational safety is included in this case into the contradiction with economic problems. The radical decision of this question would be possible at presence of a method for destruction of deviation *without derivation of a vessel from the basic work*. Such statement of a question is possible only at presence of a method for destruction of deviation on one any course. The deviation's works at one course would allow as considerably to exclude influence of hysteresis effects on accuracy of deviation's works. Thus, the way of destruction of deviation on one any course is the most effective way to liquidate unproductive expenses of time.

2 THE DEVIATION OF MAGNETIC COMPASS AT CONTEMPORARY CONDITION.

At contemporary ships of symmetric design the constant factor of deviation A and the factor of deviation E depending from asymmetrical soft steel of the ship are in limits $0,2^0 \div 0,6^0$ and are characterized by extremely high stability [2]. The factor of deviation D after compensation by the help of without induction's sheet of a soft iron [1] does not exceed $0,25^0$ and as differs very high stability.

It can to tell, that the values of these three factors of deviation are situated at the same level as accuracy of supervision of courses and bearing. Howev-

er, according to rigid algorithm of Airy, these factors without any need are determined and recalculated anew for use in the new table of deviation [3].

All this operations can be qualified, as unproductive works with loss of time for measurements, processing and calculations.

Exact expression for deviation of a magnetic compass δ is implicit function from compass course KK and enters the name as:

$$Sin\delta = A\cos\delta + BSinKK + CCosKK + DSin(2KK + \delta) + ECos(2KK + \delta)$$

(1)

where:

$$A = \frac{d-b}{2\lambda}; \quad B = \frac{P+cZ}{\lambda H}; \quad C = \frac{Q+fZ}{\lambda H}; \quad D = \frac{a+e}{2\lambda}; \quad E = \frac{d+b}{2\lambda}$$

thus:

H - a horizontal component of force of terrestrial magnetism;

Z - a vertical component of force of terrestrial magnetism;

P, Q - longitudinal and cross-section magnetic forces from according hard ship's steel;

a,b,c,d,e,f - parameters of Poisson, describing constructions from soft ship's steel;

$$\lambda = 1 + \frac{a+e}{2}$$ - factor of shielding of a magnetic

compass.

Parameters of Poisson a, b, c, d, e, f and as factor λ, are functions of the sizes and forms of ship's soft steel, his remoteness from a compass and magnetic characteristics of a case material. All these characteristics are constant constructive parameters of a vessel, than high stability of factors A, D, E explains.

Taking into consideration this circumstance, factors of deviation A, D, E usually consider constant and at performance of annual procedural works these factors do not adjust. In this case the problem of annual deviation's works is reduced to indemnification of factors B and C and to calculation of the new table of deviation. Such operations at annual deviation's works are the established practice already for a long time.

The last ministry's instruction of Russia "Recommendations to navigation's service" of 1989 year do not define the time of actuality for a table of deviation. Only the level of accuracy according to requirements of IMO is formulated at this instruction. At the same time "Recommendations to navigation's service for a ships of a fishing fleet" contains record about the maximal 1 year interval of actuality of the deviation's table. These departmental distinctions emphasize complexity and a urgency of this problem.

Progress in development of satellite systems of navigation and gyrocompasses has led to that magnetic compasses on sea vessels basically carry out reserving and monitoring function. Unproductive expenses of time for deviation's works stimulates a negative attitude of ship-owners and captains of ships.

Modern market conditions demand optimization of production and the proved time expenses. It is natural, that such optimization should be made in view of safety of navigation.

3 PRECONDITIONS TO DESTRUCTION OF DEVIATION WITHOUT INTERRUPTION OF VOYAGE.

If the factors of deviation A, D, E are small and constant, there is no need to spend time for determination of these factors anew. It is necessary to take into account their values from the previous table.

The same logic can be continued further. Factors B and C at carrying out of deviation's work can be not destroyed up to zero, and to restore their former residual tabulated values [4].

Such step gives the basis to consider, that after restoration of factors B and C all factors of deviation correspond(meet) to values of the old table of deviation and to expect the new table there is no necessity.

Validity of the former table in this case can be prolonged for one year. All deviation's works will be reduced in this case only to restoration of factors B and C without expenses of time for 8 courses for determination and calculation of all five factors. Also there is not necessity for calculation of new deviation's table . Such actualization of the former table of deviation can be made during 4÷5 years.

However the determination of factors B and C for the purpose of their return to former tabulated values demands not less than two equations, that is, at least, two courses. Otherwise it means, that compensation of two factors B and C at one course is impossible.

It is possible to notice, however, that in navigating practice exists essentially various two ways of determination of deviation. The first way bases on use of navigating measurements. The second way bases on physical measurements of magnetic forces with the subsequent calculation on this basis of deviation's factors.

Simultaneous use of these two essentially various methods allows to receive the missing information for the determination of a task in view on destruction of two factors deviations B and C at one course.

4 DETERMINATION OF FACTORS B AND C AT ONE ANY COURSE.

The set *of navigating* ways and means for determination of deviation of a magnetic compass on an any course of a vessel is known. For this purpose it is possible to use a terrestrial leading line, celestial object, remote reference points, systems AIS and gyrocompasses. The deviation of a magnetic compass δ determined by navigating way can be written down as implicit function of compass course KK as expression 1.

Taking into account, that in terms of 1 set sizes are deviation δ (measured by navigating way), compass course KK, and as factors A, D and E (from the previous table), the expressi0n 1 can be copied to more compact kind:

$$B \sin KK + C \cos KK = \Delta_1 \tag{2}$$

where:

$$\Delta_1 = \sin \delta - A \cos \delta - D \sin(2KK + \delta) - E \cos(2KK + \delta) \tag{3}$$

Thus, the equation 2 connects two unknown factors of deviation B and C by means of measurement of deviation δ.

As the second missing equation can be used equation of total ship's magnetically force of compass H_K. It is known [2], that the value of measured force H_K looks like:

$$H_K = \lambda H[\cos \delta + A \sin \delta + B \cos KK - C \sin KK + D \cos(2KK + \delta) - E \sin(2KK + \delta)] \tag{4}$$

Expression 4 can be copied to more compact kind:

$$B \cos KK - C \sin KK = \Delta_2 \tag{5}$$

where

$$\Delta_2 = \frac{H_k}{\lambda H} - \cos \delta - A \sin \delta - D \cos(2KK + \delta) + E \sin(2KK + \delta) \tag{6}$$

Thus, the system of two equations 2 and 5 at two unknown factors B and C is received:

$$B \sin KK + C \cos KK = \Delta_1$$
$$B \cos KK - C \sin KK = \Delta_2 \tag{7}$$

The solution of this system of the equations gives:

$$B = \Delta_1 \sin KK + \Delta_2 \cos KK$$
$$C = \Delta_1 \cos KK - \Delta_2 \sin KK \tag{8}$$

At essential changes of these factors they must be restoring by means of regulators B and C of compass before former table's values. For restoration of former values of factors B and C the value of correction ΔB and ΔC is calculated under formulas:

$$\Delta B = B_T - B$$
$$\Delta C = C_T - C \tag{9}$$

where B_T and C_T - values of factors B and C from the table of deviation.

If factors of correction ΔB and ΔC are positive, readout of each regulator increases before the corresponding value and on the contrary.

Thus, joint application of navigating and physical measurements allows to solve a problem which all time was considered insoluble.

Both factors B and C depend from correction a component Δ_1 and Δ_2. Navigating component Δ_1, apparently from expression 4, depends on accuracy of definition of deviation δ and from accuracy of tabulated factors A, D, E. Correction component Δ_2, apparently from expression 7, demands knowledge of exact values of resulting compass force H_k, a horizontal component of terrestrial magnetism H, factor λ, and as deviation δ and factors A, D, E. Except for accuracy of the navigating data the exact data of physical measurements here are required. Accuracy of attitude H_k/H can be provided with use of the same deflector for measurements on coast and on a vessel.

Accuracy of factor λ in usual circumstances never represented special interest. In this case of accuracy of knowledge of this factor are demanded much.

The situation is facilitated by that it needs to be determined accuracy once as his stability as is extremely high as stability of factors A, D, E.

Believing, that deviations are characterized by rather small angles, that usually corresponds to the validity, both settlement components Δ_1 and Δ_2 at high accuracy can be simplified to a kind:

$$\Delta_1 = \delta - A - D \sin 2KK - E \cos 2KK$$
$$\Delta_2 = \frac{H_k}{\lambda H} - 1 - D \cos 2KK + E \sin 2KK \tag{10}$$

In view of these simplifications the correction ΔB and ΔC will become:

$$\Delta B = (\delta - A + E) \sin KK + \left[\frac{H_k}{\lambda H} - 1 - D\right] \cos KK$$
$$\Delta C = (\delta - A - E) \cos KK - \left[\frac{H_k}{\lambda H} - 1 + D\right] \sin KK \tag{11}$$

Final record of factor ΔB and ΔC can be submitted as:

$$\Delta B = (\delta - M) \sin KK + \left[\frac{H_k}{\lambda H} - N\right] \cos KK$$
$$\Delta C = (\delta - U) \cos KK - \left[\frac{H_k}{\lambda H} - V\right] \sin KK \tag{12}$$

where:

$$M = A - E;$$
$$N = 1 + D;$$
$$U = A + E;$$
$$V = 1 - D.$$

Factors M, N, U, V it is necessary to calculate at once after full indemnification of deviation and calculation of the table of residual deviation. Formulas 12 and value of factors M, N, U, V are used at the further annual procedural works on compensation of deviations factors B and C.

Substitution of these numerical values in beforehand prepared formulas allows to calculate quickly values of correction's factors ΔB and ΔC and to enter them with the help of corresponding regulators.

Application of such method directly at a cargo mooring, as a rule, is not expedient owing to presence on a mooring and in designs of a mooring of the big iron weights, and as positions of ship iron not in a marching way.

The method is the most expedient for applying at an output of a vessel from port when it is situated on leading line. Such operation can be executed by deviator so as ship's navigator. For performance of works it is required no more than 10 minutes. In this case disappears necessity of special aquatory and additional time for deviation's work.

All this process can be named as a process of restoration or process of actualization of the former table of deviation. The most important in all it is that this actualization can be made on one any course without interruption of voyage.

5 THE ANALYSIS OF ACCURACY OF A METHOD

It is obvious, that accuracy of restoration of the table of deviation depends on accuracy of determination of proof values ΔB and ΔC. They, in turn, depend on accuracy of measurement of deviation δ, from accuracy of the information about tensions of magnetic fields H_K and H, and as from accuracy of factor λ.

Regular error of actualization of deviation's table. For an estimation of a regular error of restoration of the table of deviation it is necessary to execute differentiation of expressions (11) therefore it turns out:

$$d\Delta B = d\delta \cdot \sin KK + \left[\frac{\lambda H dH_k - HH_k d\lambda - \lambda H_k dH}{\lambda^2 H^2} \right] \cdot \cos KK$$
$$d\Delta C = d\delta \cdot \cos KK - \left[\frac{\lambda H dH_k - HH_k d\lambda - \lambda H_k dH}{\lambda^2 H^2} \right] \cdot \sin KK \tag{13}$$

Believing, that measurement of force H on coast and force H_K on a vessel was made by means of the same deflector and by the same observatory these measurements can be qualify as the same accuracy.

$$dH = dH_k$$

In this case expression (13) corresponds to a kind:

$$d\Delta B = d\delta \sin KK + \left[\frac{(H - H_k)dH}{\lambda H^2} - \frac{H_k d\lambda}{H\lambda^2} \right] \cdot \cos KK$$
$$d\Delta C = d\delta \cdot \cos KK - \left[\frac{(H - H_k)dH}{\lambda H^2} - \frac{H_k d\lambda}{H\lambda^2} \right] \cdot \sin KK \tag{14}$$

Apparently from expression (14), accuracy of restoration of the table of deviation depends on accuracy of a navigating component of measurements $d\delta$, a technical component of measurements dH, and also an information component $d\lambda$.

For estimating calculations it is possible to count that $H \approx H_K$, $\lambda \approx 1$. In view of told, for an estimation of accuracy as a first approximation expression (14) can be simplified to a kind:

$$d\Delta B = d\delta \cdot \sin KK - d\lambda \cos KK$$
$$d\Delta C = d\delta \cdot \cos KK + d\lambda \cdot \sin KK \tag{15}$$

From this expression it is visible, that the main factors of regular errors are accuracy of navigating supervision and accuracy of knowledge of factor λ. The regular error of determination of deviation at leading line is extremely small. In this connection the basic role belongs to a component depending on factor λ. For maintenance of accuracy at a level $0,5^0$ relative error of factor λ should not exceed 0,8 %. Such requirement is high enough, but quite real. Determination of factor λ is carried out by measurement of compass force H_k on four main and four intermediate course's with the subsequent calculation under the formula:

$$\lambda = \frac{\sum_{1}^{8} H_k}{8H}$$

The requirements of Register to accuracy of compensation of deviation is $\delta \leq 3^0$. The relative *methodical* error of determination of factor λ will be not worse, than 0,12 % . Such accuracy is more than sufficient.

Exact value of factor λ should be determined at descent of a vessel to water. The information on factors A, D, E and as about factor λ it should be kept carefully on a vessel before the next complex check and compensation of deviation. At capital reconstruction of a vessel, replacement of the engine these factors should be determined anew.

Casual errors of actualization of the table of deviation. Influence of casual errors of supervision and measurements is estimated by the help of standard error under the formula:

$$m_x = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 \cdot m_{X_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 \cdot m_{X_2}^2 + \dots + \left(\frac{\partial f}{\partial x_n}\right)^2 \cdot m_{X_n}^2}$$

Using as function f expressions (11), we shall receive standard errors of the proof data ΔB and ΔC as:

$$m_{\Delta B} = \sqrt{m_\delta^2 \sin^2 KK + \left[\frac{m_{H_k}^2}{\lambda^2 H^2} + \frac{H_k^2 m_H^2}{\lambda^2 H^4} + \frac{H_k^2 m_\lambda^2}{\lambda^4 H^2}\right]\cos^2 KK}$$

$$m_{\Delta C} = \sqrt{m_\delta^2 \cos^2 KK + \left[\frac{m_{H_k}^2}{\lambda^2 H^2} + \frac{H_k^2 m_H^2}{\lambda^2 H^4} + \frac{H_k^2 m_\lambda^2}{\lambda^4 H^2}\right]\sin^2 KK} \qquad (16)$$

For estimated calculations it is possible to accept $H_k \approx H; \lambda \approx 1;$. At such assumptions of expression (16) become simpler to a kind:

$$m_{\Delta B} = \sqrt{m_\delta^2 \sin^2 KK + \left[\left(\frac{m_{H_k}}{H_k}\right)^2 + \left(\frac{m_H}{H}\right)^2 + (m_\lambda)^2\right]\cos^2 KK}$$

$$m_{\Delta C} = \sqrt{m_\delta^2 \cos^2 KK + \left[\left(\frac{m_{H_k}}{H_k}\right)^2 + \left(\frac{m_H}{H}\right)^2 + (m_\lambda)^2\right]\sin^2 KK} \qquad (17)$$

From these expressions it is visible, that casual errors of compensation of factors *B* and *C* depend on relative errors of all three factors – navigating, technical and information.

At standard error of deviation at the level $m_\delta = 0,5^0$, at relative accuracy of magnetic forces at the level of 1 % and at relative accuracy of factor λ also at the level of 1 % a standard errors ΔB and ΔC is not lower 1^0. Schedule of standard errors $m_{\Delta B}$ and $m_{\Delta C}$ for such initial data is submitted in figure 1.
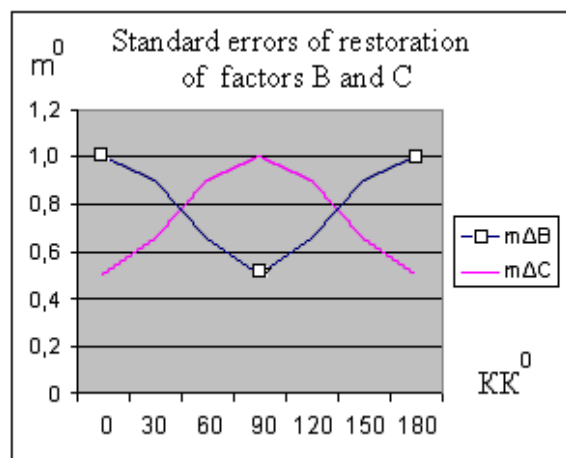

Fig. 1 The standard errors and depending from compass course at $m_{\Delta B}$ $m_{\Delta C}$ $m_\delta = 0,5^0$ and

$$\frac{m_H}{H} = \frac{m_{H_k}}{H_k} = \frac{m_\lambda}{\lambda} = 0,01$$

From figure it is visible, that casual errors of restoration of factors B and C are in limits $0,5^0 \div 1,0^0$.

The additional errors from instability of factors *A, D* and *E* are small, and stability of them is very high. Such accuracy of actualization of deviation's table is quite sufficient.

Not always the innovation gives a prize without by-effects and additional expenses. This case just does not entail any additional questions and problems.

6 THE CONCLUSION

1 The offered method for compensation of deviation of a magnetic compass on one any course of a vessel is essentially new method allowing to reduce a routine work of a vessel, connected with financial expenses.
2 The method differs exclusive simplicity. It can be applied by navigators in conditions of voyage.
3 For introduction of a method in practice of navigation it should find reflection in corresponding program of educational institutions.

THE LITERATURE

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