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Magnetic Compass in Modern Maritime Navigation

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ABSTRACT: This article looks into the role of magnetic compass in providing the navigational safety of the ship. Existing requirements for the magnetic compass at the presence of satellite navigation are not economically justified. Therefore, a new rational requirement is proposed for the accuracy and frequency of deviation compensation work assuring the safety of navigation and cost-effectiveness. The proposed method has been verified by a lab experiment.

1 INTRODUCTION

The turn of the 21st century has witnessed a *scientific and technological revolution* in the global fleet. Entire classes of navigation equipment and systems have been withdrawn, e.g. *Loran A* and *Loran C*, *Decca*, *Omega and* radio direction finders.

A classical method of ship navigation at sea – *celestial navigation* – completely lost its former importance in the global fleet.

The satellite navigation systems GPS, DGPS, GLONAS, EGNOS have solved the problem of the discreteness of observation and continually raise their accuracy in comparison to the former satellite system *Transit*.

The widespread adoption of integrated navigation systems on ships, such as ARPA, VTS, AIS largely relieved navigators from routine work, and in the near future we may expect total elimination of laborious routine work with paper charts thanks to the implementation of ECDIS. All these achievements are the results of enormous progress of satellite and computer technology in recent years.

Rapid scientific and technological progress requires appropriate actions at legal, economic and education levels. The outdated regulatory inconsistencies with the technical realities of today lead to unreasonable financial costs of production, and have negative impact on scientific research and educational processes.

2 VOYAGE STAGES, NAVIGATIONAL TOOLS AND METHODS

The voyage of a modern ship can be roughly divided into three stages:
- limited port water area;
- coastal and offshore waters;
- oceanic route.

The first voyage phase is the most intense in terms of navigator's work because of the proximity of navigational dangers. Statistically, most navigational accidents occur in restricted waters of port and its vicinity. Navigation in this case relies mainly on v*isual and radar* observation.

The second phase, *coastal* navigation, uses all types of navigational equipment for ship's steering and control. Keeping the vessel on a given course is carried out with the aid of gyrocompass, while movement parameters are controlled by all available means, including RADAR and GPS.

The third, *oceanic* voyage phase is usually the least stressful, limited to keeping the vessel on the right track. This phase of navigation makes use of a gyrocompass, and gyrocompass errors are detected by using a magnetic compass. Satellite navigational systems GPS (DGPS), GLONASS, EGNOS allow at any time to monitor the position of the vessel with high accuracy.

3 MAIN TASKS OF MARINE NAVIGATION

The primary tasks of navigation are *precise* position fixing and *precise* keeping the vessel on a given course. These objectives are to be met quickly and *reliably*.

The accuracy of keeping the vessel on a set course in the oceanic voyage phase (the longest one) depends on the accuracy of gyrocompass and autopilot, as well as the accuracy of determining external factors (wind and drift, ice fields).

The most typical and common gyrocompasses of the twentieth century were *Course-4* and *Standard-14,* which had non-fixed axis of hydrostatic suspension of pickup. They had low speed test tracking system (4^0/s and 8^0/s, respectively).

The mean time between failures of the sensitive element [6, 7] was 12-15 thousand hours. The standard error was $m \approx 1^o$.

The presently widespread gyrocompass *Standard-20* is said to have a manufacturer's error [7] for speeds of 70 knots at latitudes up to 70^0 not higher than $0{,}4^0 \sec\varphi$. An improved performance tracking system (75^0/s) allows to reduce random errors of radar direction finding systems ARPA in stormy weather.

The gyrocompass uses microprocessor technology based on mathematical models in the form of differential equations. The microprocessor performs a calculation and compensation of speed deviation, as well as inertial deviations that occur when altering course or speed. The same or higher standards [6] are met by new gyrocompasses: SR-180MK1, Gyrostar-2, ГКУ-5, Meridian. The base system GM is built on the solution of gyrocompass SR-180 MK1 and magnetic compass. It is decelerated, that this the system [6] has the mean time between failure 40,000 hours.

The reliability and readiness of GPS and GLONASS systems is so high that it does not cause interruptions. Breaks in their operation are so short and rare that they do not have a significant impact on the operation of the vessel.

Modern gyrocompasses, even those with electronic and computer components, are not the most reliable navigation devices. A survey of 212 skippers showed that each of them at least once was returning to port using only a magnetic compass while the gyrocompass was broken.

The magnetic compass is a highly reliable and cheap indicator of ship's course. It is a very good solution to the problem of gyrocompass monitoring and its back-up device.

4 CONTROL AND BACKUP FUNCTIONS OF MODERN MAGNETIC COMPASS

The control of technical condition and accuracy of a gyrocompass can be done by comparing the courses from two gyros, but such redundancy is expensive and relies on power supply. A combination of a gyrocompass and a magnetic compass much more effectively and in all circumstances guarantees that the destination will be reached in due time. Statistics show that the mean time between failures (MTBF) of today's gyrocompass is 3000 ÷ 4000 hours and for this reason the question of redundancy is topical.

Positive indicators of quality gyro- and magnetic compasses are shown in Table 1 in green and the negative indicators are in red. The *gyrocompass + magnetic compass* set allows to combine good indicators of the two compasses.

High precision of the gyrocompass is used in regular situations, while high reliability and autonomy of the magnetic compass come to the fore in case of gyrocompass failure.

Table 1. Main indicators of the quality of modern gyro and magnetic compasses

Indicators	View of compass	
of compass quality	Gyrocompass	Magnetic compass
1. Accuracy [0]	$0.5^0 \div 0.8^0$	1.2^0 to 1.3^0
2. Reliability [h]	3000 ÷ 4000	No statistics
3. The autonomy	Online	Offline
4. The value [$]	20,000-40,000	2.000-3.000
5. Requirements to service	Service rules	The annual compensation of deviation

Today the magnetic compass and gyro are usually combined within an integrated navigation system, allowing to maximize the advantages of either device, bypassing their shortcomings. In such systems, comparison of data is carried out automatically. The sound and light signals inform the user about a difference of true courses from the permissible value.

An example of such system is *Naviwarn* from Plath. The system's warning beep can be immediately shut off and the signal light turns off automatically once the fault is corrected. The system Naviwarn, based on the gyrocompass Navigat-X, can use the magnetic compass *Jupiter*, *Mars* and *Neptun*. Such system is the same in the gyrocompass *Standard-20*. *Naviwarn* Gyromagnetic sets and systems are typically found on high-end vessels or navy ships, while the rank and file seafarers usually do not have opportunities to use such systems.

Both functions of a magnetic compass (control and backup) are essential in terms of ensuring the safety of navigation and of economy. To properly secure the backup function, regulatory requirements for the annual compensation of the magnetic compass deviation were established in the previous century. The accuracy requirements for deviation were established at the level of ± 3^0 for the master compass and ± 5^0 for a steering compass. In those days, the magnetic compass was not qualified as a spare indicator of the course and such high demands were understandable.

Although the current status of the magnetic compass on board has fallen, as it is now regarded as a reserve compass, the requirements have remained.

The time and cost of compass adjustment are quite substantial, especially for large-tonnage vessels. Compass adjustment must be executed every year. It is appropriate to take a look at the effectiveness of relevant requirements and costs under the new conditions.

5 ANALYSIS OF THE COST EFFECTIVENESS OF DEVIATION ADJUSTMENT

Modern satellite systems have increased the reliability of navigation and, as a consequence, the role of magnetic compass has decreased. In this context, it becomes relevant to ask how costs associated with a magnetic compass can be lowered. Above all, it is necessary to reduce the time spent on the determination of deviation.

According to the requirements of classification societies the table of deviation is legitimate during one year after deviation adjustment. However, while navigating in ice or in stormy conditions the deviation can change after a few days of sailing. A one-year term does not guarantee compass accuracy in all circumstances.

The reduced role and importance of the magnetic compass inadvertently reflects its use on vessels. At the same time, the regulations do not provide for any exemptions to quality of service of magnetic compasses, including the quality of deviation adjustment.

It is known that if high cost of service does not increase efficiency, people tend to avoid such costs by hook or by crook. This is what is happening now in the global fleet in reference to deviation compensation. Pleskacz in his study based on observations of 35 vessels from 17 countries around the world shows that the spread of deviation in the table today is characterized by a $m_\delta = 4{,}8^0$. This clearly shows how the system had degraded.

Navigators have technical skills and theoretical knowledge to compensate the deviation by themselves, but in most cases and most fleets they have not been accustomed to do that and prefer to pay, out of ship owner's pocket. The navigator's passive attitude towards the control and compensation of deviation will persist until a simple method is developed that does not require substantial time, special knowledge, skills and qualifications.

6 ANALYSIS OF THE CURRENT STATE OF THE DEVIATION PROBLEM

It has long been known that the vast majority of vessels (symmetrical vessels) have the coefficients of deviation A and E that practically do not exceed $0{,}6^0$ and are very stable [1, 2, 4].

Uncompensated coefficient D in newly-built vessels is always positive and within $3^0 \div 5^0$. It also has a very high stability. After the first correction of factor (D) by means of soft magnetic iron balls or plates it is commensurate with the coefficients A and E (less than 0.6^0).

As a rule, at annual compensation of deviation only the least stable factors of deviation B and C are compensated. After their compensation, there are measurements of deviation on eight courses and recalculation of the entire table of deviation.

Modern methods of deviation compensation are performed in accordance to complex algorithms that do not permit any variations or allow for specific circumstances.

In fact, vessels with more or less the same coefficients *A, D* and *E* are operated without any compensation year after year.

It turns out that the annual coefficients *A, E* and *D* have low value and high stability.

If the coefficients *B* and *C* do not compensate up to zero, and restore their values from the existing tables, you create a situation in which there is no need to calculate a new table of deviation. with restored coefficients *B* and *C* and constant coefficients *A, E* and *D* we "return to the previous table of deviation. It can be signed again and provided with a new date to be used again.

Therefore, when you restore the old table of deviation, all work can be summarized on two main compass courses (e.g. N and E) instead of twelve courses of typical adjustment. The number of required courses is reduced six times. This gain is very important, especially when you keep in mind it can be executed by a gyrocompass without deviations polygon. In this situation, there is no need to process measurement data and calculate a new table of deviation.

The old table of deviation therefore can be extended for the next period. Instead of one and a half hours and costs of proceeding to the test sea area and back, it is better spend $10 \div 15$ minutes of time with no need for calculations.

7 RESTORATION OF THE DEVIATION TABLE

If the gyrocompass correction does not exceed half degree, as it often happens on modern vessels, it can be rounded off and regarded as zero. In this case, the gyrocompass course (GC) can be set to the true course TC or otherwise:

$$GC = CC + d + \delta = CC + CE \quad (1)$$

where:
CC - compass course from magnetic compass;
d - variation;
δ - the table value of deviation of magnetic compass;
CE - the compass error.

The coefficient *C of* magnetic compass deviation is compensated at the compass course $CC=0^0$. At the same compass course the gyrocompass course of the vessel is equal to the correction of magnetic compass:

$$GC= CE \quad (2)$$

If on the compass course $CC=0^0$ the conditions (2) are satisfied, the deviation δ corresponds exactly to the tabular value and any correction of the compass is not required. Otherwise, going on the same compass course $CC=0^0$, a regulator *C* (diametrical magnet-compensator) is setting the new value of deviation δ according to condition (2). Under this condition, the gyrocompass course GC is equal to *CE.* The coefficient *C* is restored.

Similarly, at the compass course $CC=90^0$ the factor *B* can be compensated. At this compass course the gyrocompass course is equal to:

$$GC = 90^0 + CE \quad (3)$$

If for the compass course $CC = 90^0$ the conditions (3) are fulfilled, adjustment is not required. Otherwise, going on the same compass course $CC=90^0$, regulator *B* (longitudinal magnet-compensator) is setting the new value of deviation δ so that (3) is satisfied. The coefficient *B* is restored.

To perform these operations, you should close the binnacle, provide the old table of deviation with the new date and signature.

Absolutely the same procedure for updating the table of deviation may be performed on any one of combinations of compass courses: (N-E), (N-W), (S-E), (S-W).

Panels of modern magnetic compasses MK-115, MK-145 include regulators (Fig.1) of semi-circle deviation coefficients *B* and *C*.

The mean error m_δ recovery of deviation to the table value is determined by the formula:

$$m_\delta = \sqrt{m_{GC}^2 + m_{CC}^2 + m_d^2} \quad (4)$$

where
m_{GC} - mean error of gyrocompass;
m_{CC} - mean error of observation of compass course;
m_d - mean error of declination.

When using this method, you should avoid areas of magnetic anomalies.

This simplified procedure for restoring the coefficients of deviation *B* and *C* resembles the computer option "*System Restore*".

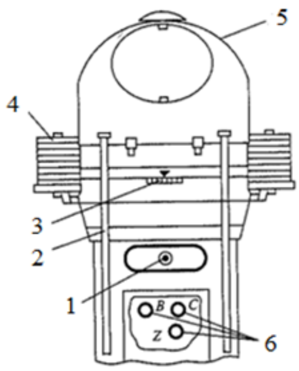

Figure 1. The top of magnetic compass KM-145. 1. potentiometer, 2. vertical soft iron, 3. scale of revolving round vertical axis, 4. compensators of coefficient D, 5. cap of compass, 6. regulator of coefficients B, C and vertical force Z.

This option is very often helpful to users of personal computers, allowing them to regain the lost elements of the Windows system, by the periodic automatic records of system settings.

A simplified method to restore the relevance of an obsolete table of deviation may be used for a relatively long time (10 years or longer), if no significant structure-borne iron replacement, and the replacement of engines takes place in the meantime.

Such an approach will help reconcile the cost of maintaining the effectiveness of the magnetic compass and its impact, both in terms of economy and safety of navigation.

Ships' navigational service performs a control magnetic compass deviation, and if necessary, restores the table of deviation. If the alteration of deviation is substantial (due to major repairs, reconstruction of the ship), ship's technical service must order a compass adjuster on board of the ship.

It is clear that the introduction of such a system of deviation compensation must be legalized by the relevant legal instruments adopted at the national and international level.

It is interesting that modern "Rules on Convention Equipment of the Ships" [5] has a notation that "The Register does not oversee the timeliness and quality of the identification and destruction of deviation of magnetic compasses." It follows that the deviation of a magnetic compass is the problem of the ship.

The issue of accuracy standards for deviation compensation is also very important. Traditional requirements for the accuracy of deviation compensation were established in the 20th century. For the master magnetic compass [5] the maximum value of deviation after its compensation was set to be $\pm 3^0$. The value of deviation for steering compass shall not exceed $\pm 5^0$. These demands were understandable and reasonable for those times when there was no satellite navigation and the role of the magnetic compass was more vital.

Satellite navigation has increased very much the safety of navigation. The master always has high-precision coordinates, controls the movement of the vessel, and the accuracy requirements of the magnetic compass no longer play the former role. It has preserved remained its backup role (to be used just in case).

During satellite navigation, even if the magnetic compass is not very accurate, there is always a possibility of using two points from GPS and getting a reasonably accurate ground track angle. In emergency conditions (failure of gyrocompass) when the GPS is in operation, the requirement is rather for magnetic compass stability, reliability being less crucial.

Being aware of this fact allows not to meet the strict and expensive standard for compensation of deviation of the main compass (± 3^0). In the new circumstances, it is sufficient to maintain the same level as for the steering compass (± 5^0).

Experimental verification of the proposed method was carried out at the deviascope, in the premises of Szczecin Maritime University. The results are presented in Table 1.

Originally, the compensated deviation is presented on eight courses in the first column. The coefficients of deviation *A, B, C, D, E* are given at the bottom of this column.

Uncompensated deviation under the new position of deviation magnets and its coefficients are presented in the second column of the table.

The restored deviation and its coefficients are presented in the third column of the table.

Table 2. Return of the table of deviation on the compass courses N and S.

Compensated deviation			Uncompensated deviation			Restored deviation		
MK^0	KK^0	Δ^0	MK^0	KK^0	Δ^0	MK^0	KK^0	Δ^0
0	0.5	-0.5	0	2.5	-2.5	0	0.5	-0.5
45	43.5	1.5	45	48	-3.0	45	43.25	1.75
90	89.5	0.5	90	93	-3.0	90	89.5	0.5
135	134.5	0.5	135	136	-1.0	135	134	1.0
180	179.5	0.5	180	177.5	2.5	180	179.5	0.5
225	224	1.0	225	220.5	4.5	225	225	0.0
270	270	0.0	270	267	3.0	270	270.7	-0.75
315	315.5	-0.5	315	314.5	0.5	315	316.5	-1.25
A = + 0.4^0			A = + 0.1^0			A = + 0.2^0		
B = + 0.4^0			B = − 3.1^0			B = + 1.0^0		
C = − 0.3^0			C = − 1.8^0			C = − 0.2^0		
D = + 0.6^0			D = + 0.5^0			D = + 0.5^0		
E = − 0.1^0			E = ± 0.0^0			E = + 0.1^0		

Comparison of the coefficients *A, B, C, D, E* in the first and third columns indicates that the coefficient *B* is restored to within 0.6^0. The accuracy of reproduction of the remaining four coefficients is at the level ± 0.2^0. Such a result could be described as *excellent*.

In real conditions the error of restoring deviation will be substantially higher. The reasons for this, as can be seen from the formula (4) is the total error of gyrocompass m_{GC} and of magnetic declination m_d. Today it can be equal to not more than one degree $m_{ГК} = 1{,}0^0$ and $m_d = 1{,}0^0$. The mean error of **observation** compass course from a magnetic compass can be taken as $m_{CC} = 0{,}5^0$. The mean error of deviation recovery under this condition is $m_\delta = 1{,}5^0$. This result can be considered as good.

8 CONCLUSION

1 Regulations of classification societies concerning annual deviation compensation are obsolete. They do not pay off and unnecessarily burden ship owners and seafarers. In the era of satellite navigation the requirement of annual deviation compensation to the accuracy level of 3^0 must be reformulated.
2 The herein proposed method of updating a table of deviation using the gyrocompass allows to compensate the deviation quickly and simply in any situation.
3 The easy-to-use and affordable method guarantees the achievement of a positive result and provides saves labor in reference to deviation compensation work.

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