Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2016, 45 (117), 174–180
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/102

Received: 31.08.2015
Accepted: 08.12.2015
Published: 25.03.2016

An analysis of practices of monitoring the accuracy and reliability of compasses on modern merchant ships

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Key words: magnetic compass, gyrocompass monitoring, compass indication monitoring, international regulations, accuracy, reliability

Abstract
This article examines the current state of practices concerning the monitoring of the accuracy and reliability of compasses on modern ships in the global fleet. The author analyzes personally detected, bizarre, but commonly used practices that may indirectly lead to hazards to human life, and impose a serious risk of marine environmental pollution. The author indicates probable reasons for the present state, and proposes directions, resources and methods for rectifying the situation. The problems presented, which represent the results of a broad study, call for decisive solutions in such areas as technology, education, law, and morality.

Introduction

The history of navigation across the world includes many accidents related to inadequate or nonexistent monitoring of compasses. Today, gyrocompasses are the most accurate and commonly used compasses for normal ship operations (Lushnikov, 1999; 2007). However, international regulations require that, "All ships, irrespective of size, shall have a properly adjusted, standard magnetic compass, or other means, independent of any power supply, to determine the ship's heading and display the reading at the main steering position (IMO, 2004, p. V, Reg. 19.2.1.1)".

The *International Convention on Standards of Training, Certification and Watch Keeping for Seafarers* clearly specifies the mandatory minimum requirements for certification of officers in charge of a navigational watch on ships of 500 gross tons or more. They must know how to estimate magnetic compass and gyrocompass errors, and have the ability to compensate for them.

A whole range of regulations has been developed based on the conventions described above. Practical requirements are contained in the publications *Bridge Procedures Guide* and *Bridge Team Management*. The guidelines should be implemented on a daily basis by all navigation officers. For the purposes of this study, the most important message from these documents is that magnetic compass and gyrocompass errors should be checked and recorded during every watch, using either azimuth or transit bearings whenever possible (Swift & Bailey, 2004, p. 98).

The author's experience and research on deck department management, chief officers, and captains, shows unequivocally that each of the 212 participants, with an average of 16 years of sea service, has experienced a gyrocompass failure at least once. During such incidents, these officers were forced to use a magnetic compass, a less accurate but fully autonomous course indicator. A bridge equipped with a gyrocompass and a magnetic compass fully satisfies all regulatory, economic and navigational safety requirements.

The author's research has shown that the comparison of gyrocompass and magnetic compass headings is the main, and often the only, method used to monitor the accuracy and reliability of compasses.

Figure 1. The oil spill zone produced by the disastrous grounding of the "Torrey Canyon" in the English Channel (Tankers, Big Oil and Pollution, 2013)

This constitutes a blatant violation of the provisions of good navigational practices at sea (Bridge Procedures Guide, 2007, p. 57). One should bear in mind that a comparison of two sources of information results in a monitoring procedure operating at the level of the less accurate component. In the present context, the less accurate component is usually a magnetic compass.

A late or missed detection of a gyrocompass malfunction has often led to accidents at sea, as shown in Figure 1. To support contention one need only recall the twentieth-century disaster involving the "Torrey Canyon", a supertanker which ran aground on rocks in the English Channel, spilling 118,000 tons of oil into the sea. The crew was unaware of a gyrocompass defect, and visibility was reduced due to dense fog (Moscow, 1989).

The history of modern shipping includes many similar accidents, although most had less dramatic consequences. In 2012 alone, global statistics of accidents at sea show that inspectors detected 6,814 deficiencies related to the navigation safety in areas covered by the Paris Memorandum of Understanding (The Paris Memorandum of Understanding, 2013).

A dangerous gyrocompass failure experienced by the authors provides an example of the relationship between gyrocompass and magnetic compass information. In the narrow passage of the Fehmarn Belt, a ship was moving parallel to the shore in dense fog when a silent failure of the gyrocompass occurred. The gyro-pilot received a new, false course reading, and the ship began a course alteration to starboard. The distance to the shallow water close to the Danish shore rapidly decreased. Only immediate reference to the magnetic compass allowed further safe navigation.

Another incident occurred in the traffic separation zone near Finisterre. In very good weather and heavy traffic, a gyro-pilot received a new, false course reading as a result of a gyro failure, which sent the ship into uncontrolled circulation. There was a risk of collision with other ships. Although no alarm systems were triggered, the navigator was alerted to the perilous situation of the vessel only because he noticed the rapid movement of the moon between windows.

International regulations versus common practices of recording compass headings on modern merchant ships

The logbook is a ship's most important document. It should contain all voyage details that might be used to reproduce the ship's course. The logbook, combined with charts, is the only document recognized by all maritime organizations. Logbook entries allow the reproduction of all events that occurred during a particular voyage.

The cadet on board should know from the very beginning that any falsification of information written down in the ship's logbook is against the law and, even worse, against good navigational practice. Thus, navigators should take extreme care when making entries in a ship's logbook. An unwritten rule says, "I write what I see; I don't write what I don't see".

The rules and regulations of a navigational watch and good sea practice require that courses, and gyrocompass and magnetic compass corrections, should be entered into the logbook at least once per watch and after every substantial alteration of course (Bridge Procedures Guide, 2007, p. 57).

To eliminate the daily routine of monitoring the accuracy of compass performance, navigators may use automated systems that automatically compare gyro and magnetic compass headings. If the difference is larger than a limit set by the operator, an alarm is activated. This, however, still represents a comparison of two sources of information.

If we record gyrocompass and magnetic compass headings simultaneously, differences between the values indicated by the two devices should appear. It is known *a priori* that if constant and random errors are not taken into account or compensated for, they have to produce a difference between true courses read from a gyrocompass and a magnetic compass. Human error adds to that difference, because ideal observers, equipment or observation conditions do not exist in the real world.

The total error of gyrocompass readings primarily depends on the following factors:

- accuracy of speed estimates, which depends on the accuracy of information about the speed of the ship, drift, and leeway;
- maneuvering, or inertial errors;
- errors due to ship motion;
- technical errors in settings, and the translation of the course to repeaters.

By contrast, errors affecting magnetic compass readings are determined by:

- calculation of the variation error;
- deviation error;
- deviation instability error, separate for coefficients B and C;
- insensitivity zone error (dry friction);
- error due to motion;
- technical errors in course translation.

Systematic errors can be compensated for, but not completely excluded. By definition, however, it is not possible to compensate for random errors (Lushnikov, 2004). The mean error, m, of the difference in true course between a magnetic compass and gyrocompass can be calculated from the following formula:

$$m = \sqrt{m_M^2 + m_V^2 + m_D^2 + m_G^2 + m_{GE}^2} \qquad (1)$$

where:

m_M – mean error of the magnetic compass;
m_V – mean error of the variation;
m_D – mean error of the deviation;
m_G – mean error of the gyrocompass;
m_{GE} – mean error of the gyrocompass correction.

Inspection of the equation shows that logbooks must contain a difference between the true courses as given by the gyrocompass and the magnetic compass. For modern compasses, the mean value of the difference of true courses equals approximately ±2.4° (Lushnikov, 2012). It follows that the discrepancy of courses in every second observation should be a minimum of ±1.5°. In every third observation, that difference should not exceed ±2.5°, and for every fourth observation, ±3° or more, and so on.

These are values that a careful observer will not overlook.

Statistical analysis of compass monitoring on global fleets

Copies of the logbooks were delivered by captains of ships calling at Szczecin in the years 2010–2012. The captains of 37 ships consented to the processing and publication of the data contained in their logbooks for this period.

An analysis of the entries showed that six of the 37 ships (16.2%) had recorded no data at all relating to compass monitoring. This constitutes a blatant violation of international rules and good sea practices.

Excluding single entries in logbooks that were badly edited or badly kept, a total of 2,193 entries were examined (Pleskacz, 2014). A *single entry* was defined as a record referring to one specific time of observation (i.e., a one-line entry in the logbook).

Statistical processing of data from the logbooks led to surprising results (see Table 1). Specifically, it was found that 100% of the true courses obtained from a gyrocompass and a magnetic compass as recorded in the logbooks *were exactly the same*.

Table 1. Comparison of true courses obtained from observations of a magnetic compass (TC_M) and gyrocompass (TC_G)

No.	Ship's name	Number of observations	$\Delta C = \lvert TC_M - TC_G \rvert$ (°)
1	Fast Sam	60	0
2	Celine	44	0
3	Kapitan Zhikharev	56	0
4	OW Scandinavia	59	0
5	Transwing	57	0
6	Zillertal	51	0
7	Steinau	50	0
8	Lady Elena	58	0
9	Gas Evoluzione	120	0
10	Walka Młodych	56	0
11	Flottbek	51	0
12	Transmar	60	0
13	Hans Lehmann	96	0
14	Karina G	55	0
15	Clare Christine	53	0
16	Pitztal	72	0
17	Crystal Topaz	104	0
18	Taganrogskiy Zaliv	120	0
19	Ametyst	75	0
20	Finland	60	0
21	Fjordstraum	111	0
22	Flinterhaven	60	0
23	SV.Knyaz Vladimir	92	0
24	Fast Sam	49	0
25	Ostanhav	60	0
26	Gas Arctic	54	0
27	Frisian Ocean	51	0
28	Leonid Leonov	113	0
29	RMS Ratingen	59	0
30	Yigt Bay 1	102	0
31	Elizabeth	85	0

It has been scientifically proven that such a similarity of results is impossible. An absurd situation arises when scientific fact contradicts practice. Philosophy tells us that practice should be a criterion defined by the state of our scientific knowledge.

The signs are that the navigators of today routinely ignored both good sea practice and the knowledge acquired through training.

The question then arises: What is the meaning of such divergence of practice from scientific knowledge?

To determine the actual values of magnetic compasses and gyrocompasses, corrections were made to measurements on various ships entering and leaving Szczecin. In order to do this, actual courses were specified based on magnetic compasses and gyrocompasses.

All measurements were made with the consent of the ships' captains. Directions were read out from the gyrocompass and magnetic compass each time a ship proceeded on the leading line, and the helmsman was steering on that line such that the ship's centerline was aligned with the leading line (Bowditch, 2002).

Measurements, as shown in Figure 2, were made between March 2, 2012 and June 28, 2012 by the pilot Piotr Szelepajło, a master mariner. Mr. Szelepajło had previously been briefed on the principles of such measurements and the details he should attend to. A short period of observation guaranteed minimal changes of magnetic variation which, in the area and time of observation, was – var. = +3˚. To eliminate the influence of drift and leeway, the only days chosen for measurements were days of good hydrometeorological conditions.

The readouts were made when ships were on one of the following leading lines:

- Byki – true direction 173.9°;
- Mańków – 141.3°;
- Łąki – 354.0°;
- Raduń – 168.0°;
- Karsibór – 321.2°.

The data obtained from these observations were processed to estimate gyro error (GE) and deviation (D), using equations (2) and (3), respectively.

$$GE = TB - GB \tag{2}$$

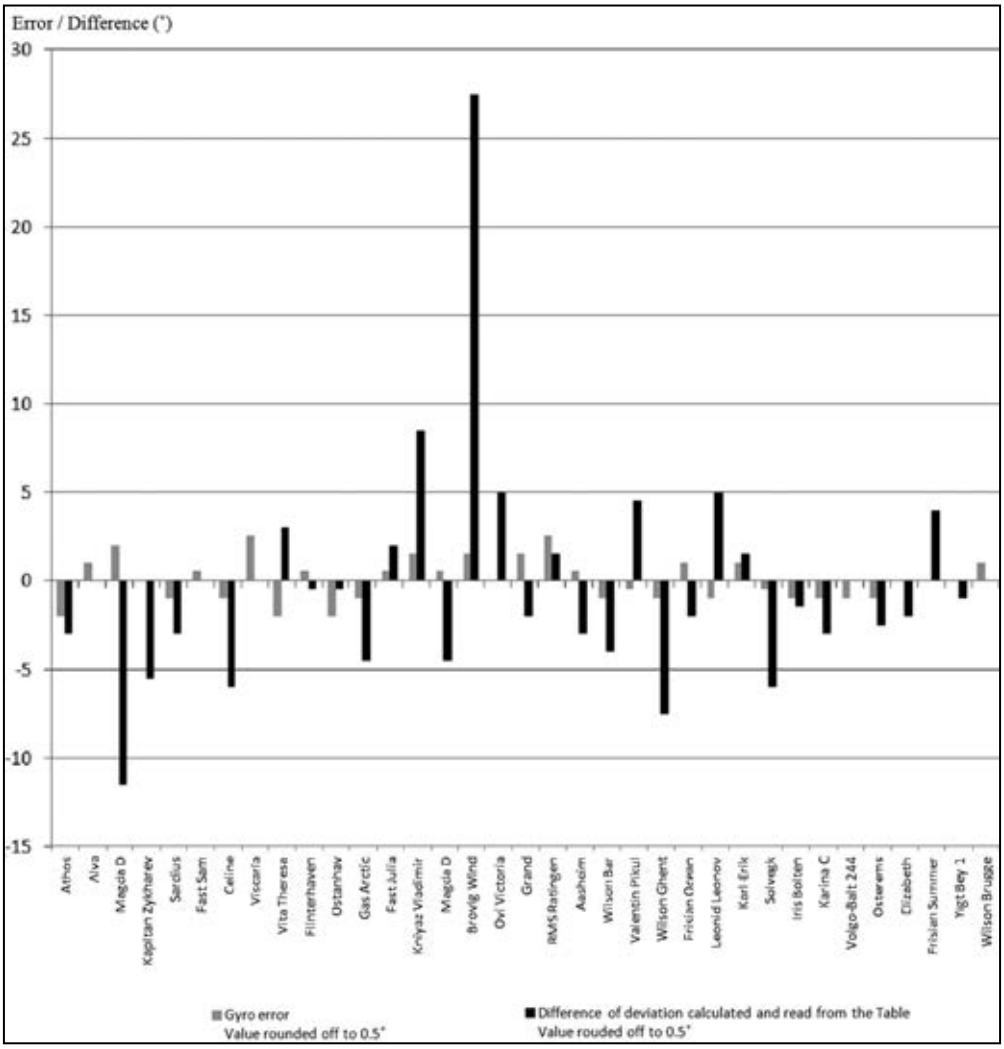

Figure 2. Results of gyrocompass and magnetic compass indication control

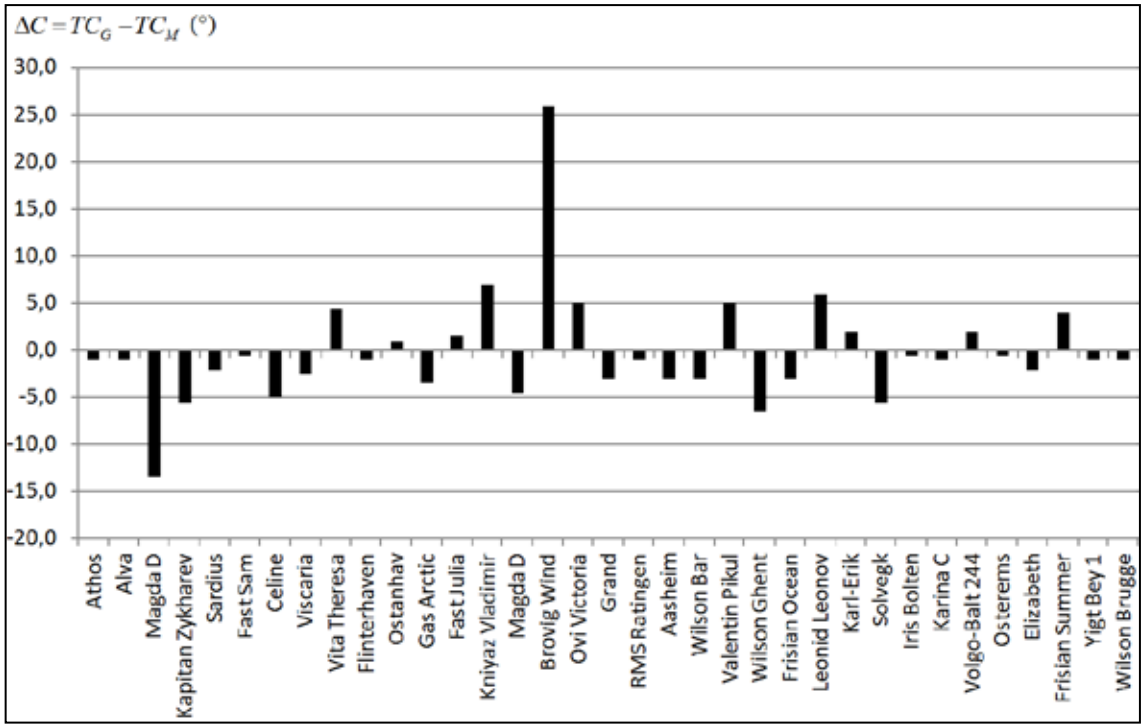

Figure 3. Comparison of true courses obtained from various course indicators

where:
GE – gyro error;
TB – true direction read from a chart;
GB – gyrocompass bearing.

$$D = TB - CB - \text{var.} \quad (3)$$

where:
D – deviation;
CB – compass bearing;
var. – magnetic variation.

An analysis of the data obtained from the tested ships showed that the value of the mean error of the gyrocompass, m_G, was ±1.2°, and that the standard deviation of the magnetic compass deviation, m_d, was ±4.8°.

The larger error of deviation for the magnetic compass may be due to the lower perceived status of the magnetic compass and to its being treated as a control or standby device. Combining the results in Figure 2, we can easily compare corresponding true courses obtained from gyrocompasses and magnetic compasses.

Equation (4) shows the difference in headings, Δ*C*, resulting from simultaneous observations of a gyrocompass and a magnetic compass:

$$\Delta C = TC_G - TC_M \quad (4)$$

where:
TC_G – true course from a gyrocompass;
TC_M – true course from magnetic compass.

It clearly follows from the results that ΔC value differences of 0°, as commonly recorded on ships around the world, *do not occur*. In 17 cases, the difference exceeded 5°; on nine ships it ranged from 3° to 5°; and on another nine ships the difference was less than 3°.

The mean error ($m_{\Delta C}$) of Δ*C* determined for the statistical ship was ±2°.

The results of an expert study also indicated that only 56% of experts declared that they regularly monitored the magnetic compass, while no more than 76% of these respondents declared that they regularly monitored the gyrocompass, either (Lushnikov & Pleskacz, 2012). Interestingly, 14% of crew members had never witnessed the adjustment of a magnetic compass, and 7% of personnel with 16 years of sea service had never seen a compass adjuster working on a ship. Improper practices were confirmed by 9% of respondents, who declared that the deviation table of the magnetic compass used on their previous ships had not been drawn up by either an adjuster or a crew member. This is against the regulations and good sea practice. The regulations explicitly provide the procedures to be followed to monitor course indicators. The only way to acquire a table of magnetic compass deviation is its preparation by a crew member or a qualified adjuster.

Thus, the research data gathered here supports the contention that the whole seafaring world acts improperly in reference to compass monitoring.

Conceptual analysis of causes and consequences related to breaking the rules and regulations of compass monitoring

The statistical data collected here indicate that deck officers *expect* identical values when true course headings as determined by gyrocompasses are compared with true course headings as determined by and magnetic compasses. An analysis of the difference in true courses obtained for one ship steering a specific course is considered by navigators to be an artificial problem, and they know how to avoid it. All they do is to "slightly adjust" the readout from the less accurate magnetic compass to align with the more accurate true course produced by the gyrocompass. Thus, mandatory routine calculations of magnetic compass corrections are neglected. Naturally, such "adjustments" of a magnetic compass correction has little to do with reality. Magnetic compass correction cannot be carried out accurately using a randomly estimated value; it is a scientific concept, a sum of declinations and deviations. If a ship's compass corrections were determined in accordance with procedures taught at training institutions, then true courses obtained from a gyrocompass and a magnetic compass would not be equal, and the value of the calculated difference between the true courses would allow an estimate of the reliability of the indicators (Bowditch, 2002)

Values of "doctored" true courses give no information on the quality of compass indications. One may then ask: What is the magnetic deviation table for? What are magnetic variation data for? Why should we take all these things into account on a daily basis (A.382(X)) (IMO, 1977)?

Does the situation mean that today's navigators deliberately falsify data essential for navigational safety? An affirmative answer would require taking on great responsibility. In reality, we can assume that navigators' behaviors and attitudes cover a wide spectrum. Some probably do not understand or appreciate the problem, while others consciously eliminate certain things to gain temporary benefits. This author believes that navigators in all parts of the world take an easy way out that has long been seen as a method of simplifying the daily routine, even at the cost of forgery. In an age in which GPS position is continuously displayed, navigators seem to lack the motivation to strive for the extra measure of accuracy conferred by magnetic compasses.

The situation may be described as "throwing the baby out with the bath water". After all, the main aim of simultaneous monitoring of the two compasses is to know whether we should give up relying on one of them when the difference between them becomes unacceptably large. In an attempt to expedite their daily work, navigators have lost sight of the original objective of comparative monitoring of the two compasses.

The issue of gyrocompass and magnetic compass accuracy assessment under real onboard conditions is considered by navigators to be purely academic. That is why they abstain from a real assessment of the differences, preferring instead to fiddle with observations.

One of the reasons for logbook entries falsely representing reality is the navigators' general outlook on the accuracy of measuring instruments. The more accurate the instrument, the less essential it seems to monitor its accuracy along with a multitude of other routine activities. Such acts of negligence committed to lessen work load qualify as a violation of the regulations and good nautical practice. This kind of negligence can be regarded as unlawful and harmful because, in the case of a ship running aground, it does not matter if the human error was conscious or not. Everyone, often unaware that they are doing so, subjectively distorts information to a certain degree. However, in vital matters, a qualified worker follows the principles acquired during specialized training. In the case considered here, the question is raised as to whether navigators' training draws sufficient attention to the right details.

Attempts to make navigation simpler by eliminating precautions that detect very infrequent but critical problems are illegal and against good sea practice. As the problem touches the whole seafaring world, the shortsightedness of the navigators who take these shortcuts with safety should be tackled with all available resources and methods.

If hundreds of navigators make the same mistakes on a daily basis, we should know exactly why they do so. What are the reasons for such wrongdoing? Where are the roots of evil? How can it be counteracted? To answer these questions, we should first verify the wording of basic terms and principles adopted in relevant legal acts and in navigators' training programs at all levels of education.

The problem is that authors and executors of maritime education systems all over the world have not foreseen that the fundamental principle of logbook keeping, the principle of writing down only true information, would be commonly broken.

Customary fiddling with data instead of conducting a professional analysis is definitely not what course indicator monitoring is intended to be.

If a substantial discrepancy between compass indications exists, the navigator used to routine "adjusting" of the data without proper analysis will remain unaware of the potential danger for a long time. Thus he will not be ready to respond to a real hazard when it occurs.

To change the mentality of navigators throughout the world is a difficult task. The appropriate actions must address the following issues:

- navigational safety – the problem of personnel that has always been and will always be a priority;
- technical and economical – regular monitoring will eliminate the risk of major accidents, and consequently may reduce overall operating costs;
- legal – following the regulations and best sea practices;
- scientific – related to research, and the development and design of new devices;
- educational – imparting the latest theoretical and practical knowledge to those responsible for safe navigation.

Only a real monitoring of the difference between true courses obtained from a gyrocompass and a magnetic compass creates the basis for the proper assessment of how reliable a ship's course-control system is.

Conclusions

The actual practice on global fleet ships of making entries into logbooks related to compass monitoring does not satisfy common navigational safety requirements.

The main source of errors related to compasses control is human error. Statistical data indicates that human error is the cause of 85% of accidents at sea. In the case of compasses, this reaches a significantly higher value. Several categories should be considered: human information processes, habits (especially bad habits), inadequate training, lack of discipline, and lack of responsibility.

Changing the true course indicated by a magnetic compass to match that of a gyrocompass, proven to occur on ships of various flagged states, is a regulatory offence that eliminates the main goal of comparing the courses of the two indicators. Improper and routine performance of compass monitoring by seafarers on ships of all flags should be reviled and eliminated. The responsibility for this task rests mainly on maritime universities and other maritime education and training institutions, including secondary schools.

The problem of compass monitoring can be solved by developing and implementing automated processes that record gyrocompass and magnetic compass courses and their corrections. The operator should be able to set an alarm function that is triggered when a preset limiting value of deviation is exceeded. Automatically calculated values of magnetic compass deviation and gyrocompass correction must be saved in an electronic logbook, meeting the regulations of documenting course indicator monitoring. Implementation of this procedure will allow navigating officers to more easily focus on the safe navigation of the ship. Automatic display of the compass error value will make using compass bearing finders easier, and will eliminate errors of magnetic variation updating. Moreover, a graphical program can be applied to generate a table or diagram of magnetic deviation. Such a table would present the dependence of deviation on the magnetic compass course. As the monitoring may be carried out at any bearing measurement, the table or diagram of magnetic compass deviation will reflect the present and actual situation.

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