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SOME METHOD OF DETERMINING THE CHARACTERISTIC FREQUENCIES OF SHIP'S YAWING AND ERRORS OF SHIP'S COMPASSES DURING THE SEA-TRIALS

ABSTRACT The paper presents some method of determining the characteristic frequencies of ship's yawing and own oscillations of ship's compasses. Such information offers the possibilities of studying marine compass errors in dynamic conditions with Fourier transforms.

INTRODUCTION

Readings of gyrocompasses commonly used in navigation as well as magnetic one, include errors that result from both design solutions of a specific compass and the effect of ship's motion. In the case of shipboard compasses, instability of ship's motion is a significant source of error, especially yawing. The ship's compasses are additionally affected by forces connected with the occurrence of linear accelerations and inertia of mechanical elements of compasses. This phenomenon is especially significant during rapid manoeuvres in speed or heading and after their completion. This means that gyrocompasses are instruments that maintain dynamic balance of measuring element. Therefore a change in outer conditions causes transient processes in the measurement system, i.e. varying in time errors in readings.

To determine fully and explicitly error values as well as the degree of their dependence on vessel's motion it would be necessary to know the real ships' headings, which should be removed from measurements made on moved ships. Discussion concerning variation of these errors is a separate issue. It is known from literature that they can not be described with deterministic dependencies. This information would be the most desirable for a navigator aboard a ship, but because of the known trouble in describing the process in the time domain an attempt has been made to describe them in the frequency domain.

REFERENCE SYSTEM

One of the basic problems related to the conduct of investigations of dynamic compass errors is the selection of the reference system, which could be used to compare with the heading (course) defined by means of the compasses under investigation. Such system should provide both high accuracy and high resistance to environmental conditions, especially ship's manoeuvres.

To check the accuracy of a shipboard compass commonly used are methods consisting in comparing the direction defined with it, with the direction of a leading mark, or with the azimuth of a specific celestial body. Such methods can only be used to determine constant corrections, but not to investigate their accuracy in dynamic conditions.

In recent years some special GPS receiver for such applications are available, e.g. products by such firms as Trimble, Novatel or Seagate. But authors used the set of 4 RTK-GPS receivers for the measurements reported in this paper. Three of receivers were situated on the ship and the next one on the shore. Three point of the ship defined by the antennas of the GPS receivers were used for calculates the orientation (heading) of the ship. Using such measurement technology the accuracy of measurement can be many times higher than the accuracy offered by compasses. In addition this technology is free of dynamic errors characteristic for compasses based on mechanical measurement elements.

Further in the paper some examples of recording of heading, measured with two different compasses as well as with a platform composed of three RTK-GPS receivers, will be shown.

FREQUENCY-RELATED COMPASS ERRORS INVESTIGASTION

In the experiment, along with recording the readings of all GPS receivers, which can be referred to as radio platform, the readings of ship's headings determined with a gyrocompass and a magnetic compass were computer-recorded. In the experiment GKU-1 gyrocompass and AZIMUTH-1000 fluxgate magnetic compass were used. The readings were compared with the reference heading calculated on the basis of the readings from the radio platform. Differences between the compass heading (*GH* – the gyrocompass heading, *MH* - the magnetic compass heading) and the reference (true) heading (*TH*) were recorded. The diagram of the measurement system used to carry out this stage of the experiment is shown in fig.1.

Fig. 2 shows some characteristic example of the results of the experiment as the difference between compass heading (*GH* and *MH*) and the reference heading (*TH*):

$$\begin{aligned} GE &= GH - TH \\ ME &= MH - TH \end{aligned} \tag{1}$$

for different characteristics of ship's manoeuvring.

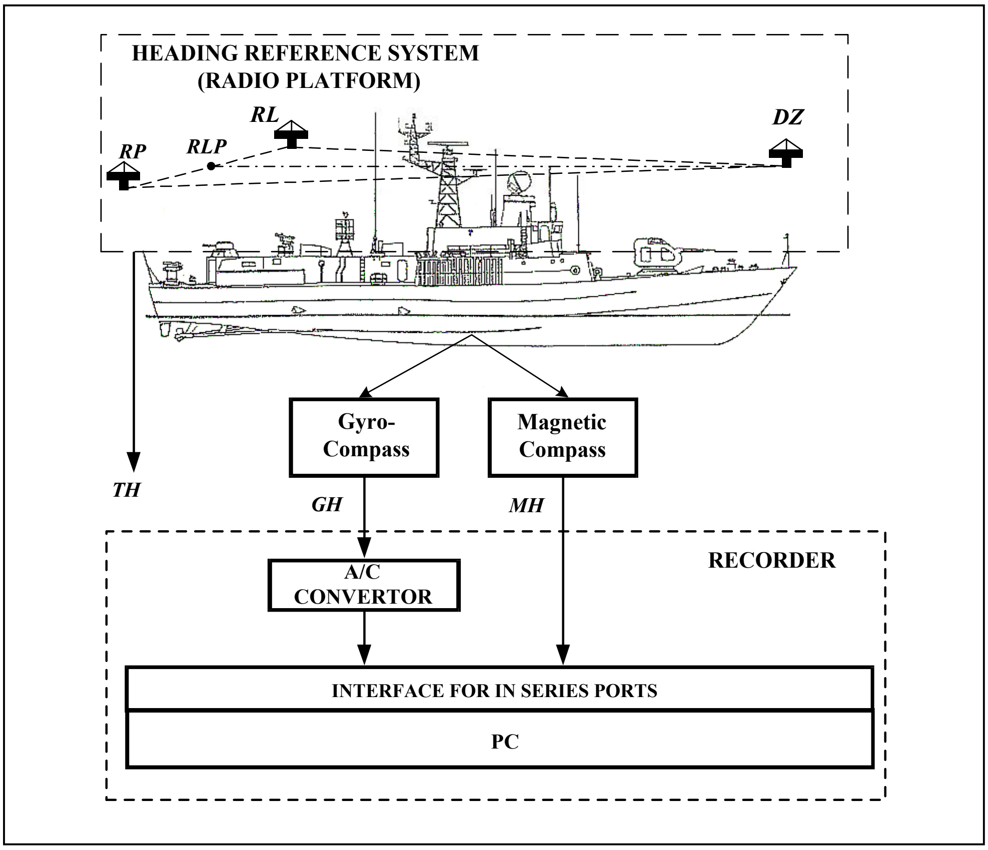

Fig. 1. Measurement system

It is an example of heading deviations determined with the fluxgate magnetic compass and the gyrocompass for steady speed (10 knots) and constant ship's motion – manoeuvring in the leading mark of 271.5^{o} after completing a turn by the ship.

Analysing the distributions in the diagrams above some periodical deviations from the real heading, both in the case of the magnetic compass and the gyrocompass, may be noticed. It can be supposed that mainly yawing causes them. The difference in amplitudes of these deviations shows the varying character of both distributions resulting from dumping of swinging in the gyro element. This is confirmed by literature data that shows that a gyrocompass is more resistant to short-period swinging than a magnetic compass.

Another kind of conclusions is drawn from studying the trend lines in both cases. Leaning of the trend line is smaller for the magnetic compass than for the gyrocompass. The only explanation is the effect of dynamic deviations on the readings of the gyrocompass. This kind of disturbances, of long period character, is typical of a gyrocompass due to the occurrence of inertial elements.

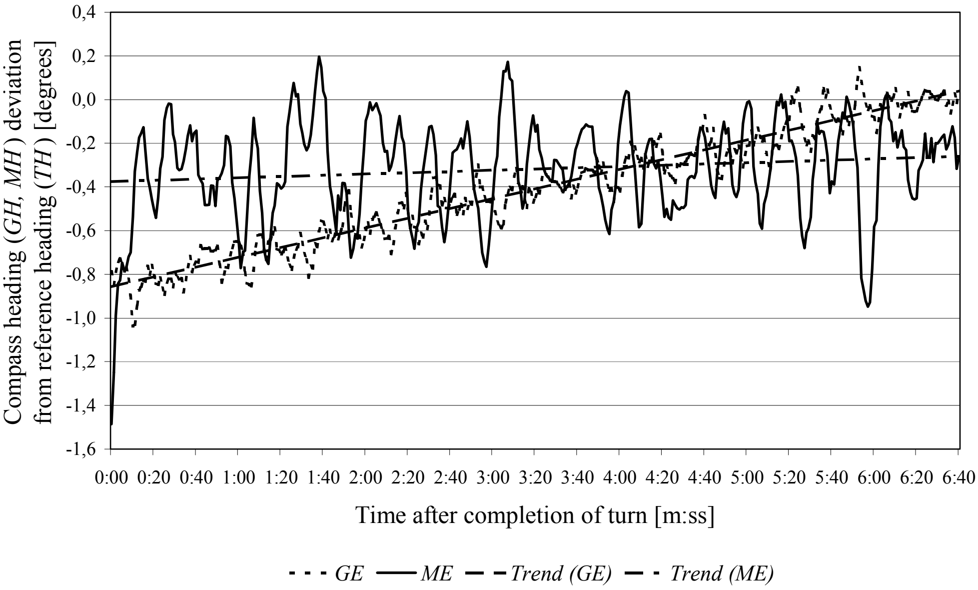

Fig. 2. Comparison of compass heading deviations from reference heading for the ship moving on constant heading (about 271.5°) at speed V=10 knots, after completion of turn.

The research material collected during such experiment can be used to analyse the effect of ship's motion on the accuracy of compass readings. It was assumed that the main disturbance having the essential significance with regard to the accuracy of compass readings would be ship's motion. It should be remembered that also the real ship's heading deviations would result from movement of the ship. In other words the motion mentioned will determine both the real ship's heading deviation and the errors in measuring it.

It might seem that the comparison itself of the compass heading with the reference heading determined by means of the radio platform will enable a full analysis of changes caused by ship's motion. Unfortunately it appears that this kind of comparison will only provide information on absolute values of heading deviations for specific moments of observation, giving no information on their character. It follows from the synthesis of errors in classic gyrocompasses that ship's manoeuvring causes long period deviations in heading readings resulting from dynamic deviation. On the other hand ship's yawing leads to dumping of heading variations that it directly causes. These kinds of errors have no deterministic character. The analysis conducted led to the conclusion that it is necessary to analyze the distributions not only in the time domain but also in the frequency domain.

One of the basic tools used in the theory of signal processing - Fourier transformation - was used for this purpose. As the investigated distributions of ship’s headings have the character of a determined discrete signal of periodical character x_i the period of sampling for such a signal can be described as:

$$x_i = A_0 + \sum_{r=1}^{\frac{N-1}{2}} A_r \cos\left(\omega' r i \Delta t + \varphi_r\right) \tag{2}$$

where: A_0 - initial amplitude of signal;

A_r - amplitudes of components of harmonic signals;

$\omega' = \frac{2\pi}{N\Delta t}$ - pulsation of the main components of harmonic signal (for r=1);

φ_r - phases of components of harmonic signals.

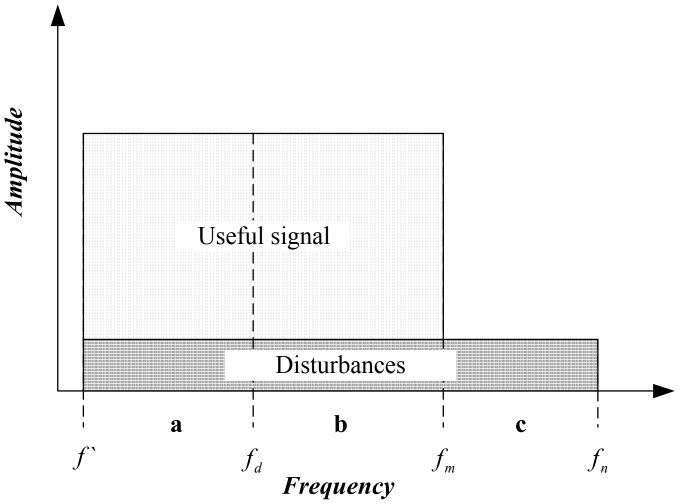

Fig. 3. The general model oscillation in compass readings in dynamic conditions.

To sum up, the Fourier analysis of the determined signal (1) while enabling studying of its distribution in the frequency domain it enables determining the effect of particular distributions of components of various character on the whole signal.

Analysis of publications on error character in the compasses used as well as the experiments conducted permit concluding that the whole spectrum of the oscillations recorded can be divided into three characteristic parts (fig.3):

- the long term errors (**a**);
- the medium term errors (**b**);
- the short term errors (**c**).

It can be predicted that intervals “**a**” and “**b**” related to ship’s dynamics and course oscillations recorded will result from ship’s yawning and compass dynamic deviation. The interval “**c**”, above the frequencies related to ship’s yawning should not be dependent on ship’s motions. It may also be expected that the interval “**a**” should be characteristic only for the gyrocompass.

Further in the paper presented is a proposal for determining boundaries of spectrum interval defined in this way. The range of signal amplitude A_r is constrained in its lower range by the frequency *f'* determined by the whole period of observation *T*, in its upper range by the so-called Nyquist frequency $f_n = f_r /2$ (f_r – sampling frequency).

Obviously the amplitude of error in compass readings in frequency function will be varying. It means the amplitude value in fig. 3 is to symbolise only the fact that in some intervals we encounter compass errors adding to ship's yawning while in other frequency range the compass may record exclusively course errors, since yawning does not exist in this interval.

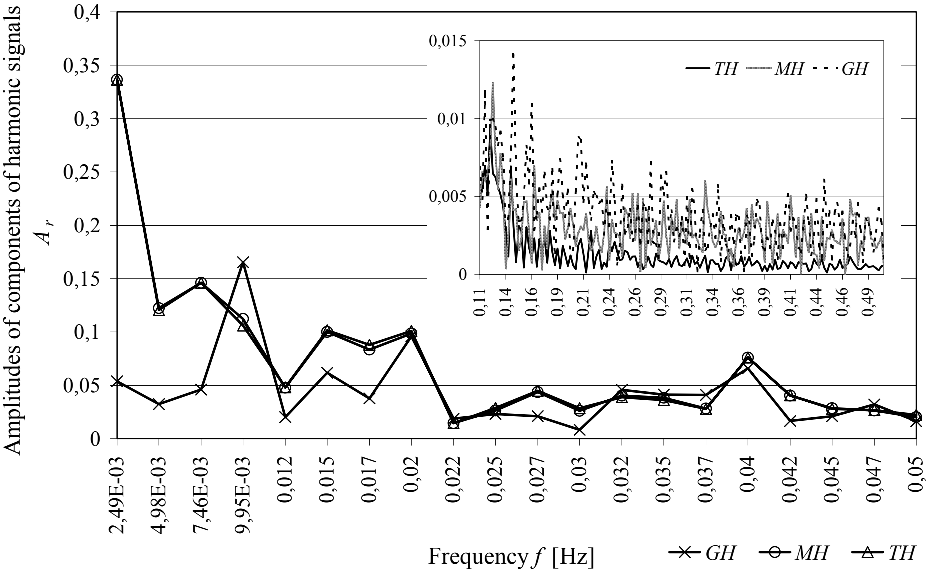

Fig. 4. Example of spectrum distribution in investigated system

This can relatively clearly be noticed in fig. 4, where in the initial part of the diagram distributions differ from each other in a significant degree, but in the middle part of the spectrum the distributions show a significant similarity.

The proposed method of determining spectrum intervals defined as in fig. 3 brings itself to determining correlation absolute value $|K(f)|$ among spectra of measurements obtained from the particular measuring devices.

For this purpose, using Fourier transformation method, determined were amplitude spectra of courses measured with the magnetic compass, the gyroscope compass and the radio platform in the particular tests, which lasted about 30 minutes. Then correlation of spectra describing the measurements, done with the compasses with the course spectrum, which had been measured by means of the platform, was determined.

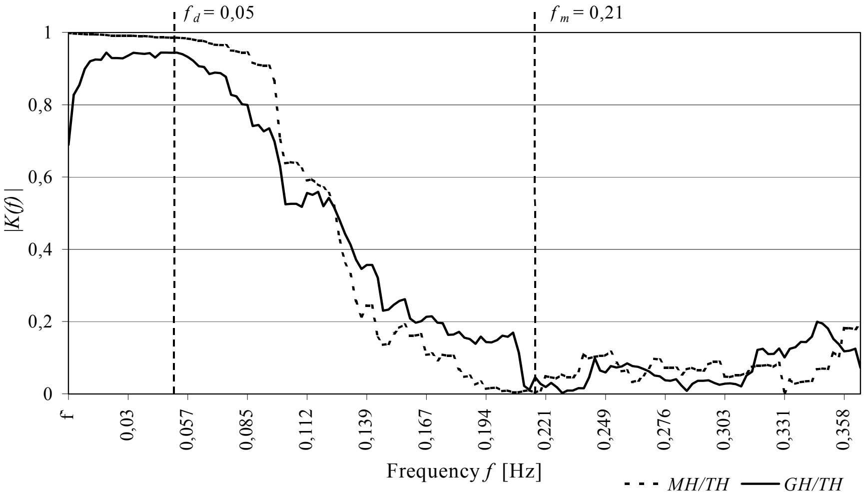

Fig. 5. Example of correlation of the course, measured with magnetic compass, with true course, and of the course, measured with gyrocompass, with true course.

Strong correlation of readings in the two compasses with the measurements done with the radio platform in the band from frequency f ` to about 0.05 Hz is clearly noticeable. Then noticed is clear fall in correlation, which reaches minimum value for frequency about 0.2-0.3Hz. From the other hand, the observe increase of the true heading amplitude *TH* (fig. 4) is appeared below the same range of frequencies.

Near the right part of the scale of fig.5 an increase in correlation values is noticed. However, these values can not be reliable, as the number of data used for calculation decreases with the increase in frequency in the diagram. The underlying principle of making this diagram consists in calculating correlation values for samples which include the frequency band being in succession broadened from the value f_n which constitutes the right boundary of the diagram.

CONCLUSIONS

The analysis of the ship's motion in the frequency domain, especially in the case where there exists a possibility of comparing data simultaneously recorded with a few, different instruments or methods, creates extremely broad, new research opportunities. Thus the frequency analysis of marine compass errors may constitute a useful tool used to investigate this kind of phenomena. This apparatus especially enables isolation of errors made by ship's yawing, which often have to appear in headings records regardless of the type of measuring instrument. This also creates a base for analysing the effect of outer factors on the measurement process. Additionally the frequency analysis enables estimating better the effect of errors by heading measuring instruments on the process of navigation.

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