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COMPASS DEVIATION REVISITED

ABSTRACT

The system for calculating and updating deviation data for magnetic compass is developed. The method and algorithm for on-line data acquisition and calculation of new deviation corrections is presented. The system is tested by simulations and by experimental data. The system is developed for mobile platforms with compact electrical systems installed on-board with strong variation of vehicle electromagnetic field.

Keywords:

magnetic compass, deviation, correction.

NOMENCLATURE

- KK_C' — compass course from the sensor
 KK_C — filtered compass course
 KM_C — magnetic course from magnetic sensor
 KM_Z — magnetic course from external source
 ΔKM — magnetic course error
 δ — deviation angle from actual database
 δ_z — actual deviation angle measured by external sensor)

INTRODUCTION

The magnetic compass was a fundamental source of direction finding in navigation for a long time [3]. In integrated navigation systems of many mobile platforms compass is still a valuable sensor of direction, due to its simplicity and reliability of operation [1, 2].

Modern solid state magnetometers give very high accuracy of measurements but are susceptible to external electromagnetic perturbations. The short term disturbances

may be filtered, so the main source of compass errors is deterioration of Earth magnetic field by disturbances external to the sensor. These disturbances are substantial on-board of small mobile platforms with electrical drive system and equipment. Electromagnetic field disturbing compass indications may vary depending of the status of on-board systems.

The research was undertaken for developing the system which would compensate changes of electromagnetic environment by on-line gathering the data and making decision of calculation new deviation corrections.

The deviation of a magnetic compass is a difference between a compass indication and a real magnetic course caused by disturbances of Earth magnetic field. A compass deviation may change during a mobile platform operation due to changes in local, close to sensor magnetic field, resulting from various reasons, such as for instance status of vehicle electric equipment, external electric lines, etc. In such cases the initially determined deviation data may become incorrect during vehicle operation and the magnetic compass indications may become useless for navigation purposes.

The deviation may be compensated by using hardware devices, such as irons/magnets placed close to compass or by measuring the deviation values for various platform courses and using them as corrections for compass indications. The second method is investigated in this study.

The compass deviation data is needed for the whole range of platform course angle i.e. 0–360 deg and it is usually calculated as function of the platform heading.

To determine the deviation, the measurements of compass indications are done for the selected set of platform headings. Assuming that the values of true and compass courses are available for arbitrary set of heading data, the more sophisticated methods (filtering, interpolation or approximation) may be used to determine the compass deviation.

In this study a method is developed for identification of such cases with proper remedy for preserving compass data reliability and accuracy. The method uses the reference source of platform true magnetic headings, both for calculating the preliminary deviation data (before platform operation) and during operation in the field. The true magnetic headings may be obtained by subtracting actual magnetic declination for the place of platform operation from GPS or IMU data.

CORRECTION OF MAGNETIC COMPASS DEVIATION

The structure of compensation system is shown in figure 1. The magnetic sensor provides the signal of compass course KK_C ' which is filtered to eliminate the hardware measurement errors including noise and as a result the actual compass heading

KK_C is obtained. Various methods for signal filtering may be used here depending of the knowledge about the sensor errors.

For KK_C course the deviation angle δ is calculated using actual deviation database and the magnetic compass course KM_C is calculated.

The real deviation δ_z for the actual instant of time and a vehicle heading is calculated using external magnetic course KM_z data. The real deviation values are stored in the database for prospective deviation data updating.

The value of real deviation is monitored. If the real deviation δ_z values differ substantially from the values stored in the actual database, the process of deviation database updating is performed during which the new deviation database is calculated, and next the actual deviation database is replaced by the new one. The algorithm of updating process depends on the form of deviation database.

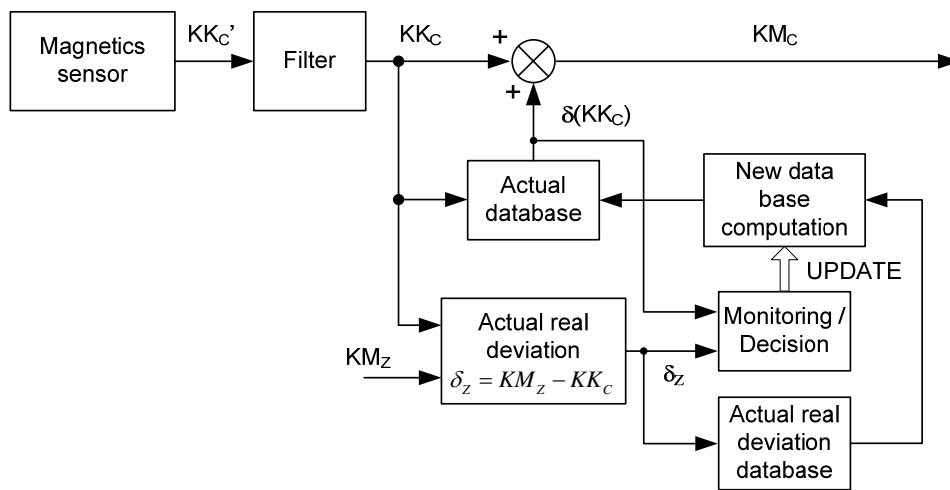


Fig. 1. System structure

SYSTEM ELEMENTS AND THEIR FUNCTIONS

Sensor data filtering

The various methods for compass data filtering may be applied, such as low-pass or Kalman. The noise free compass course KK_C is the output of this block used for obtaining actual deviation values from the data base.

Magnetic course from compass

For the noise free compass course KK_C the deviation values δ are obtained from the actual data base and are used to calculate magnetic compass course of the platform

$$KM_C = KK_C + \delta(KK_C). \quad (1)$$

Database of deviation values

The deviation database provides the possibility of unique calculation of deviation corrections for a given compass course. The deviation database is assumed as a function which parameters are calculated by some calibration process, placed in figure 1 in the block of 'new deviation data calculations'

$$\delta = f_{\delta}(a_1, a_2, \dots, a_i, \dots, a_n, KK_C). \quad (2)$$

The form of a function and the method of estimation its parameters a_i determines the volume and the structure of actual deviation database. The estimation method may use single/multiply data for each platform course.

Two forms of harmonic functions were considered in this study: second harmonic function (Archibald Smith formulae) and general N-th harmonic function. The Archibald Smith formulae for compass deviation has form:

$$\delta = A + B \sin \psi + C \cos \psi + D \sin 2\psi + E \cos 2\psi. \quad (3)$$

Only eight values of magnetic headings, i.e. 0, 45, 90, 135, 180, 225, 270 and 315 degrees are needed to obtain the expressions for its coefficients in an analytical form:

$$A = \frac{\delta_0 + \delta_{45} + \delta_{90} + \delta_{135} + \delta_{180} + \delta_{225} + \delta_{270} + \delta_{315}}{8}; \quad B = \frac{\delta_{90} - \delta_{270}}{2}; \quad C = \frac{\delta_0 - \delta_{180}}{2};$$

$$D = \frac{(\delta_{45} + \delta_{225}) - (\delta_{135} + \delta_{315})}{4}; \quad E = \frac{(\delta_0 + \delta_{180}) - (\delta_{90} + \delta_{270})}{4}. \quad (4)$$

The N-th harmonic function is more general and covers the previous formulae. The deviation function is similar for m harmonic has the form:

$$\delta = A_1 + A_2 \sin \psi + A_3 \cos \psi + \dots + A_{2k} \sin k\psi +$$

$$+ A_{2k+1} \cos k\psi + \dots + A_{2m} \sin m\psi + A_{2m+1} \cos m\psi. \quad (5)$$

According to Shannon theorem the $m+1$ data samples and equations are required to obtain the parameters A_k . The uniformly distributed data in total range of vehicle headings makes calculation of coefficients more efficient.

Actual deviation database

Using measurements done at the special place/test stand the parameters of initial deviation function are estimated and stored in the actual database before the platform is deployed into the operating area. The actual real deviation values are computed using magnetic heading KM_z from the external sources as:

$$\delta_z = KM_z - KK_c. \tag{6}$$

The actual real deviation data is stored in the database (actual real deviation database block in fig. 1) in the form suitable for calculating the deviation function parameters. The real deviation values δ_z are measured and stored continuously during the system operation.

In this study for the data storage the course range 0-360 deg was divided into n equal parts with ΔK steps, as it is shown in figure 2. The acquisition algorithm stores one value of all t_i, δ_{z_i} parameters within one of the part of the course range in the form of the matrix \mathbf{K}_p :

$$\mathbf{K}_p = \begin{bmatrix} 1 & t_1 & \delta_{z1} \\ \vdots & \vdots & \vdots \\ n & t_n & \delta_{zn} \end{bmatrix}. \tag{7}$$

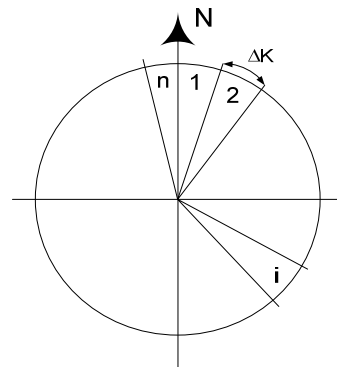


Fig. 2. Heading parts

The i -th row of the matrix \mathbf{K}_p is updated each time when measured parameter KK_C have the value within the range of i -th increment of the course range. The increment number is determined as integer part of the quotient of KK_C and ΔK values plus one:

$$i = \left\lfloor \frac{KK_C}{\Delta K} \right\rfloor + 1 \quad (8)$$

are estimated using elements of matrix \mathbf{K}_p .

Monitoring deviation value

The real and compass magnetic course error ΔKM is the difference:

$$\Delta KM = |KM_Z - KM_C| = |\delta_Z - \delta|. \quad (9)$$

If the actual real value of deviation δ_Z differs substantially from that δ stored in the actual database, i.e. when the difference is greater than acceptable value ε :

$$|\delta_Z - \delta| > \varepsilon \quad (10)$$

the subsequent actions may be undertaken by the monitoring function block:

- terminating the compass data usage in the platform navigation system;
- updating the deviation table;
- restoring usage of compass data with new actual deviation database.

Updating deviation database

If the updating process is requested the new set of parameters of variation function calculated and stored as vector:

$$\mathbf{A} = [a'_1 \quad a'_2 \quad \dots \quad a'_i \quad \dots \quad a'_n]. \quad (11)$$

The actual deviation database is updated by replacing the old function parameters a_i by the new ones:

$$a_i = a'_i. \quad (12)$$

SYSTEM VALIDATION TESTS

The concept of the system was validated using generic data first and then using the data from the real magnetic sensor.

Deviation databases

In the existing version of the software the N-th harmonic functions for compass deviation may be assumed. For simulations the two second harmonic deviation functions (dev1 and dev2) were assumed. The coefficients are given in table 1, plots in figure 3 and the values of deviations for eight compass courses in table 2. The deviation are shown in figure 3.

Table 1.

KK_C	A	B	C	D	E
δ_{dev1}	0.2	0.5	0.25	0.3	0.4
δ_{dev2}	-0.2	0.3	-0.2	-0.5	0.15

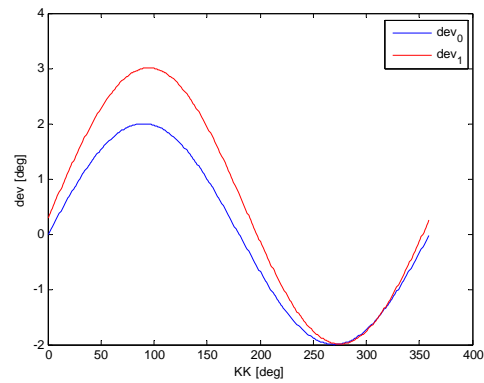
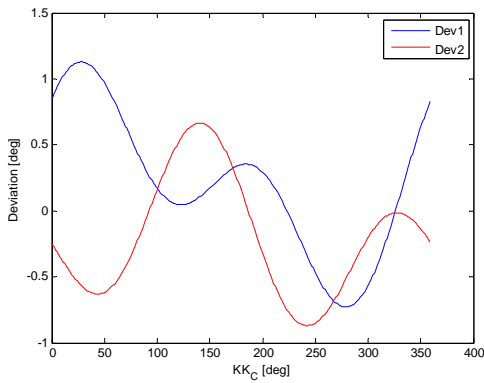


Fig. 3. Deviation used for reconfiguration testing Fig. 4. Deviation used for data-bases updating testing

Table 2.

KK_C	0	45	90	135	180	225	270	315
δ_{dev1}	0.85	1.03	0.30	0.08	0.35	-0.03	-0.7	-0.28
δ_{dev2}	-0.25	-0.62	-0.05	0.65	0.15	-0.77	-0.65	-0.05

These functions were used for validating the system reconfiguration capabilities. The first set was assumed as initial actual database. The values of deviation angles δ_{dev2} from Table 2 were gathered during the simulated circle of the vehicle.

The updating the deviation function for second deviation dev2 values was executed when the absolute value of deviation was greater than 0.2. The updating of database led to calculating the coefficients of δ_{dev2} given in Table 1, which proved the proper updating the deviation database during the system operation.

Update compensation function test

The tasks of this test was to investigate the update function and influence of the accuracy of the updating data onto compensation efficiency.

The two simple deviation data was generated: preliminary (dev_0) and operating area (dev_1) deviation data is shown in figure 4. The system was preliminary compensated using dev_0 . The system was set to multiply curse changes in operating area in which the another deviation (dev_1) was present. The update function setting enabled to update the compensation function if the course error ΔKM was greater than 0.95 degrees.

The two cases of the compensation function update were tested. The first one was done under constrains that the database contained the stored deviation values for all cardinals courses 0, 45, 90, 135, 180, 225, 270 and 315. The second test was done for the deviation values which was measured for arbitrary the compass course values. The values which was closed to the cardinals courses was used to deviation function update.

The results in figure 5 and figure 6 show the course and course error changes. The compensation algorithm was updated in about 40 seconds of simulation. Using the database which contains actual deviation values for cardinals courses provided better compensation results than random one.

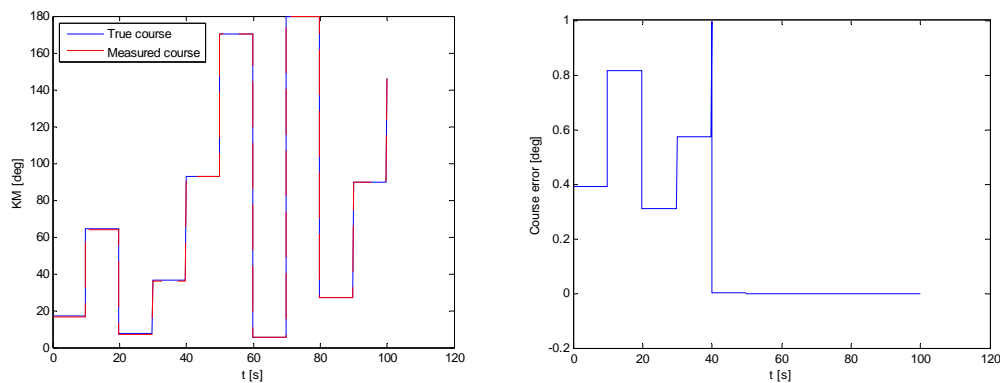


Fig. 5. Simulation of compensation function update with appropriate data

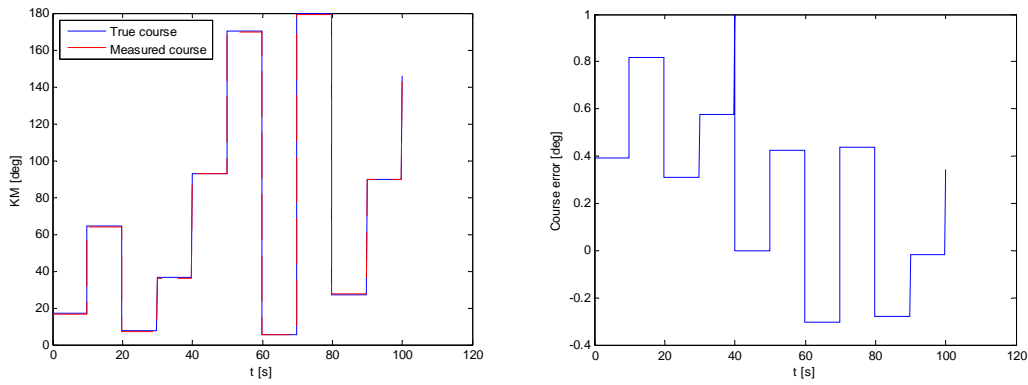


Fig. 6. Simulation of compensation function update with optional data

The HMR experimental data test

The magnetic course was measured using HMR3000 magnetometer. The measured range was divided into 36 parts which means the measured course step ΔK was 10 degrees. The compass was preliminary compensated for experimental stand environment. Then the magnetic field was disturbed twice by a piece of iron added to the stand. The only *Deviation function estimation* algorithms were tested in those tests.

The results of second harmonic function update are shown in figure 7 and figure 8 for first and second configuration respectively. The results present the magnetic course value KM and its error as a function of laboratory stand yaw angle ψ . The calculated mean and standard deviation of the error are presented in table 3.

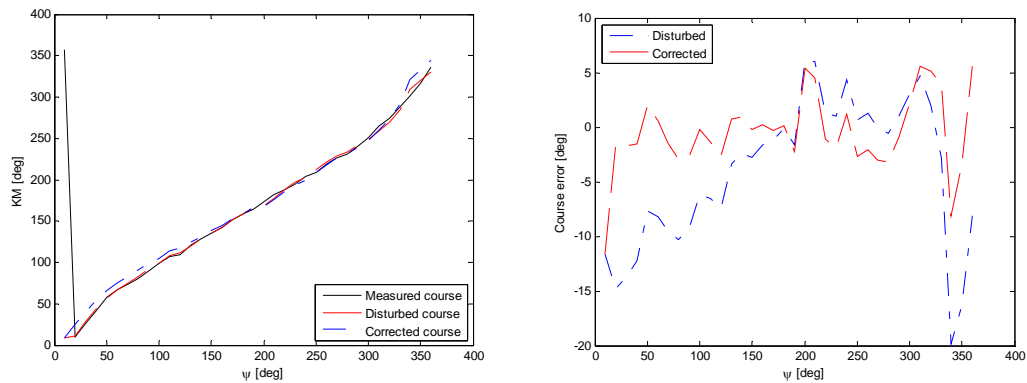


Fig. 7. Second harmonic function for 1st disturbance configuration

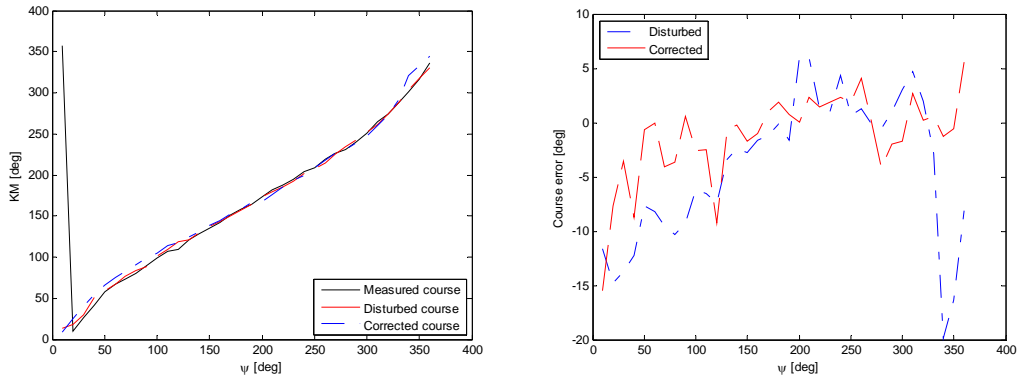


Fig. 8. Second harmonic function for 2nd disturbance configuration

Table 3.

Disturbance configuration	Case	Mean	Standard deviation
1st	Disturbed	-4.086	6.624
	Corrected	-0.523	3.559
2nd	Disturbed	-4.086	6.624
	Corrected	-1.218	4.053

Test of the data acquisition and the databases updating

In the actual real deviation database the arithmetic mean values for all measured real δ_z deviations at given magnetic course range are calculated and stored. The vehicle was rotated 4 times around the yaw axis and compass course K_c was measured with resolution ΔK_c of 1 degree. The random noise was added to the course measurement.

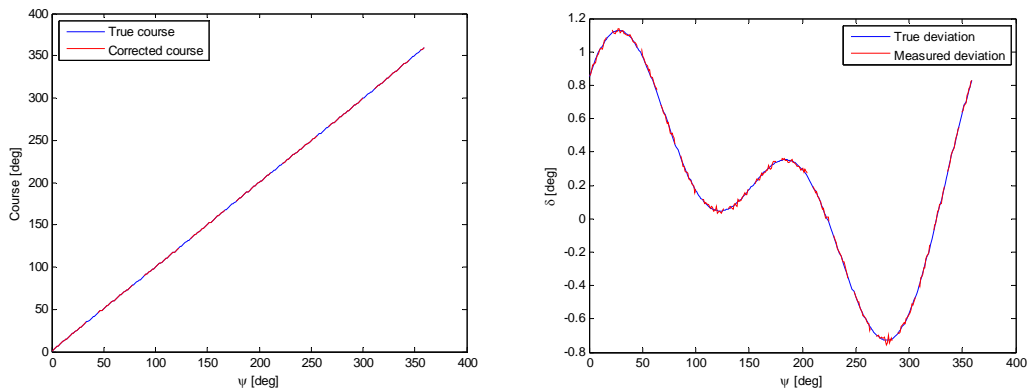


Fig. 9. Acquisition of initial deviation

The acquisition algorithm for initial compensation was tested at first. The value of courses and deviations for initial deviation function are shown in figure 9. Next, the acquisition of new deviation data was done for four rotations, as before. The real deviation data was changed, but the compensation function was not initiated. The differences in course compensation and stored value of deviation is shown in figure 10. The results of compensation function update after four vehicle rotation are shown in figure 11.

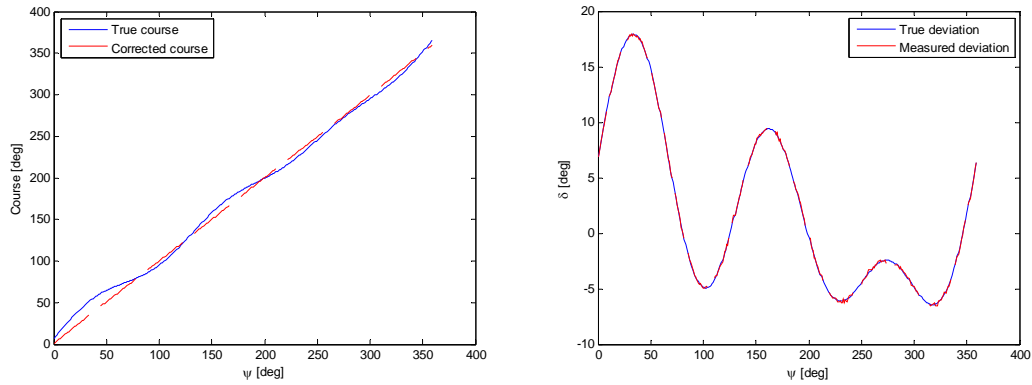


Fig. 10. Acquisition of new deviation

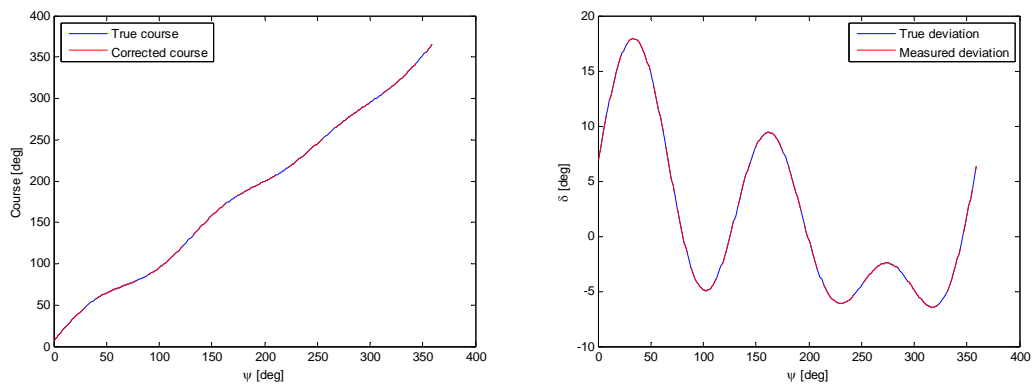


Fig. 11. Acquisition and update of new deviation

Test of the data acquisition and the databases updating using real HMR data

Two tests were performed for different external disturbances of Earth magnetic field. In each test the HMR magnetometer was rotated 3 times around the yaw axis and compass course K_c was measured with resolution ΔK_c of 1 degree.

In each test the three rotations were treated as collecting data for updating deviation database. The data was stored during the test and the compensation function was updated after the each rotation using the data from the one, two or three rotations. The calculated coefficient of deviation functions are given in table 4. The results of course measurement and deviation function diagram for three magnetometer rotation are shown in figure 12 and figure 13 for first and second disturbance respectively. The deviation function coefficients for each rotation are shown in table 4.

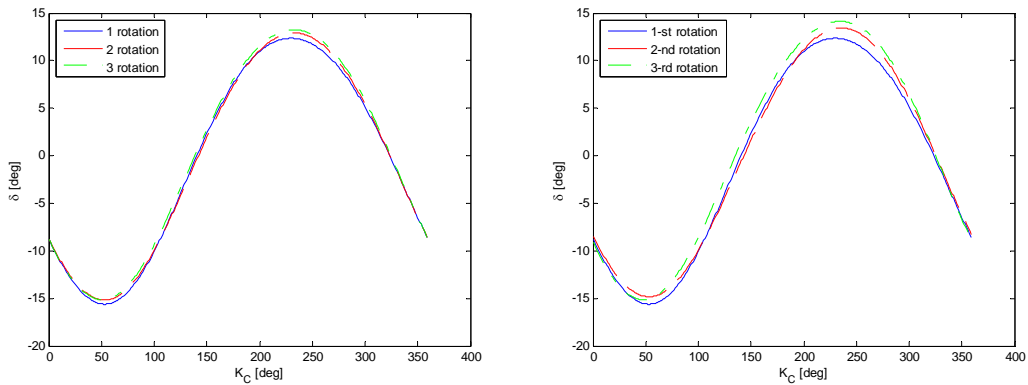


Fig. 12. Acquisition and update of new deviation for HMR data – 1st disturbance

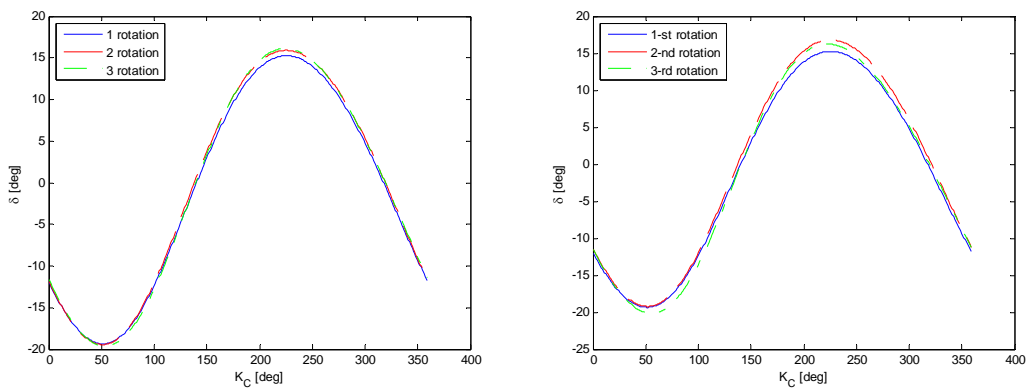


Fig. 13. Acquisition and update of new deviation for HMR data — 2nd disturbance

Table 4.

Rotation number	Deviation function coefficients				
	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
Disturbance case I					
1	-0.635	-10.994	-8.62	-0.919	0.434
2	-0.469	-11.181	-8.48	-0.633	0.179
3	-0.107	-11.125	-8.81	-0.836	0.114
Disturbance case II					
1	-1.222	-13.037	-11.34	-0.759	0.546
2	-0.795	-13.251	-11.655	-0.906	0.557
3	-0.901	-11.55	-11.552	-0.736	0.821

CONCLUSIONS

The algorithm developed for on-line deviation compensation was tested and proved its efficiency in simulations. All parts of algorithm work effectively and reconfiguration of the deviation database is performed in a very short time. The system will be implemented on the ground vehicle and other mobile platforms.

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