MARITIME UNIVERSITY IN SZCZECIN

ORGANIZATIONAL UNIT:

FACULTY OF NAVIGATION - DEPARTMENT OF NAVIGATION DEVICES

Instruction

1

PRINCIPLE OF OPERATION AND HANDLING OF THE GYROCOMPASS

Lab

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EXCERCISE NO 1

Subject: PRINCIPAL OF OPERATION AND HANDLING OF THE GYROCOMPASS

1. Purpose of exercise

The purpose of the exercise is to show the students the designation of the ship course by the Gyrocompass, the moment of the setting of the sensitive element during to start the operation of the Gyrocompass and analyse of the errors and corrects them.

2. Theoretical preparation

Before beginning classes, students should read theoretical exercises.

- Gyroscope,
- Effect of Earth rotation
- Precession
- Gyrocompass error,
  - Speed Error,
  - Inertia Error,
  - Quadrantal Error.

2.1. On the computer stations: I, II, III

Start the computer program showing the typical Gyrocompass device by example of Sperry MK 37 Gyrocompass type.

Description of the simulator panel.

Rys. 2 Simulator panel

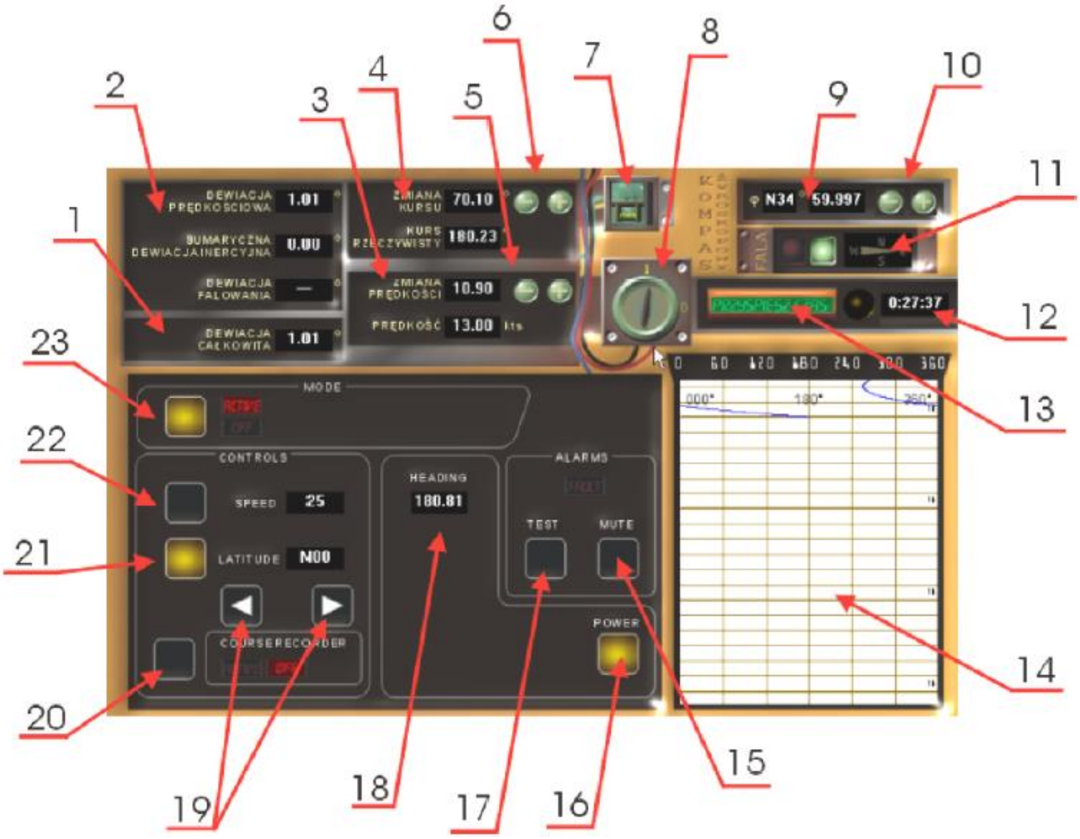

Fig.3 View of the program window of the simulator of the Gyro computer

Display of

1) Total deviation,
2) Speed Error, Inertia Error, Quadrantal Error,
3) Present speed and the set point of change of speed (in knots),
4) Present course and course alteration buttons,
5) Buttons to decrease / increase the speed of the ship,
6) Course alteration buttons from port to stbd,
7) Lever automatically stops motion simulation when you press the +/- button to change course or speed. After setting the required manoeuvre, switch the lever, this will light up the red light and resume the simulation.
8) 0/1 power switch gyrocompass,
9) Latitude at which the vessel sailing,
10) Buttons to decrease / increase value of latitude,
11) The start of the simulation wave from the west,
12) Program Time display,
13) Time Acceleration Button,
14) Course rekorder,
15) Button to reset the alarm,
16) Button to turn on the digital panel, note that when the panel is off the course recorder will not work,
17) Alarm Test button,
18) Gyro course repeater,
19) Course recorder start on button,

Simulation is paused when the speed or course changes

Fig.6 Automatic simulation switch

Fig.7 Panel of the rolling parameters

Fig.8 Error indicator

3. Exercise course

The report should be a relation of the course activities with the purpose of the exercise. The report should include:

Purpose of the exercise

Describe Gyrocompass errors

- Set parameters: ϕ 30 ° N
- Start the simulation (accelerate time) and bring it to a state of equilibrium, redraw the curve, fixing the time after which it stabilizes,
- Draw a carve
- Conclusion!
- Set parameters: V = 13w, ϕ30 ° N, KR = 180 °,
- Note KŻ ... .., KR .... and compare with the indications of total deviation δc = ...

*Note the value of δv in the first table for V = 0

SPEED ERROR EXAMINATION

Change of the speed

- V=13w, φ 30° N, KR=180°,

V	0w	13w	26w
δv			

- Draw a carve
- Conclusion!

Change of the course

- V=13w, φ 30° N, KR=180 zmieniając kurs w prawo

TC	180°	225°	270°	315°	0°	45°	90°	135°
δv								

- Draw a carve
- Conclusion!

Change of the Latitude

V=13w KR=180°

φ	30° N	0°	30° S
δv			

- Draw a carve
- Conclusion!

INERCIA ERROR

Change of the course

- V=13w KR=135°, φ 30° S

KR	135°	255°	015°
δi			

- Draw a carve
- Conclusion!

Change of the speed

- V=13w KR=015°, φ 30° S

V	13w	26w	0w
δi			

- Draw a carve
- Conclusion!

QUADRANTAL ERROR

- Set your course: KR= 045, V=13w, ϕ 30° S
- Turn on the wave simulation
- Complete the table for ϕ

KR=045	φ 30° S	φ 60° S	φ 70° S
δf			

- Draw a carve
- Conclusion!
- Set ϕ 70° S, course 045°
- Alter your course to starboard until you reach 180°

KR	045°	090°	135°	180°
δf				

- Draw a carve
- Conclusion!

4 Literatura

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7. Instrukcja obsługi żyrokompasu CMZ 300X, wydanie polskie skrócone
8. Podręcznik techniczny Plath żyrokompas Navigat, Hamburg
9. Strona internetowa: http://www.sperry.com
10. Strona internetowa: http://www.plath.com

8. Theory

8.1 The gyroscope

The gyroscope is heavy, metal disc with a symmetrical shape that rotates around the axis of rotation with the high speed. The gyroscope has three degrees of freedom and the ability to rotate according to the three axes of the spatial coordinate system: x y z. In practical terms, the free gyroscope is a circle in which its mass is distributed over a large radius so as to obtain its maximum moment of inertia relative to the axis of rotation x. The most important property of the gyroscope is its ability to maintain a steady direction relative to the stationary reference system.

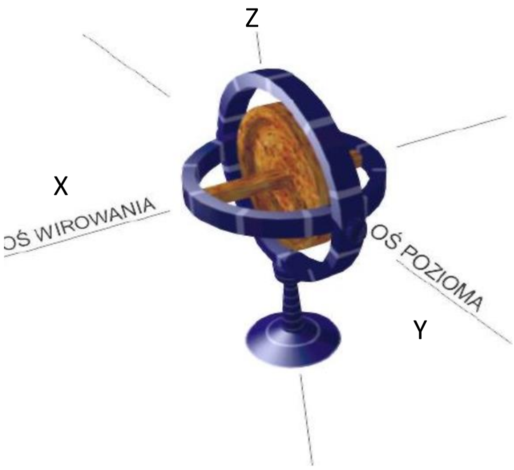


Fig.1. Gyroscope

The gyroscope (fig.1), can rotate with respect to the three axes of rotation, thanks to placement in the cardan suspension. Gyroscope can be as a direction indicator only if a tany initial setting, its main axis in any latitude, this axis will automatically set in the plane (on the surface) of the meridian and on the fixed horizontal plane.

8.2 Effect of Earth rotation:

The gyroscope has three degrees of freedom and the friction force around the three axes is close to zero. When you operate the gyroscope, the main axis of the gyroscope keeps not the same direction as the surface of the earth, but keeps the same direction in the relation to the universe. At the moment the gyro is operate, and we will direct its main gyro axis to a fixed star, the gyro will continue to point to this star, imitating this star motion. However, in relation to the earth, this axis will change its position, because the earth rotates around its axis.

Apparent motion of the main axis of the gyroscope at the difference position on the earth:

1. The gyroscope is set on the North, where the X axis is parallel to the horizon (fig 2). The X-axis moves smoothly in the horizontal plane according to a clockwise direction. The angular velocity of the X-axis equals the angular velocity of the earth around its axis.

2. A gyroscope positioned at the South, where the X-axis is parallel to the horizon. The X-axis moves smoothly in the plane of the horizon anticlockwise direction
3. A gyroscope positioned at the N or S pole, where the X-axis occupies a vertical position, it is the extension of the earth axis; the X-axis is not displaced to the earth because the Earth axis receives a constant direction relative to the universe.
4. We set the gyroscope on the equator, and on the beginning, X is parallel to the horizon and is directed at E, we notice that after 3 hours it will rise to the horizon by 45 °. After 6 axis of the gyroscope X, it will be perpendicular to the horizon. After 12 hours, the X-axis will occupy a horizontal position, with its black end pointing to W until it is fully operational within 24 hours and returning to its initial position. Within 24 hours the gyro will perform a full rotation around the Y-axis.
5. If the gyroscope is set at mid-latitude so that it is neither parallel nor perpendicular to the axis of the earth, to keep the constant direction in the universe unchanged, it will circle the cone with ellipses.
6. The gyroscope is set on the equator and the X-axis is pointing at N. With a parallel position to the axis of the earth - no X-axis motion is observed against the earth. The X-axis will be doing harmonic fluctuation relative to the meridian and in this situation it cannot be a good device to designate the course of the ship.

Fig. 2 Effect of Earth rotation

8.3 Precession motion

Fast-spinning gyroscope wheel and frictional forces among other factors utilising the basic physical laws, influences of gravity and the Earth's rotation to find the true north.

The first step to turn a gyros into a Gyro Compass is to lower the centre of gravity of the gyroscope. This solution is used two mechanically connected gyros. The second way is to add a pair of connected pairs to the gyros vessel with mercury. The mercury spills in these two vessels (N and S) are carried out without dull. In a mercury-vessel gyrocompass (Figure 2), the rotor and the chamber are balanced in such a way that their common center of gravity coincides with the point of suspension. A system of interconnected vessels that are partially filled with mercury is attached to the chamber. A so-called foot connecting the vessels with the chamber is attached to the right-hand vessel. Upon deviation of the gyroscope’s axis from the plane of the horizon, an excess of mercury in one of the vessels causes the application to the gyrocompass of a gravity force moment analogous to the moment in the pendulum gyrocompass. The mercury-vessel gyrocompass is the more frequently used type of one-rotor gyrocompass. Use of each of these techniques, creates torque if the gyro axis is deviated from the plane of the horizon. Under the action of this moment of strength (torque), the gyroscope will perform a precession motion - rotation with respect to the Z-axis.

The movement of the gyroscope caused by the action of external moment of torque is called precession motion. The precession stops when the cause is removed. If the force is applied to the gyroscope, its physical properties will not rotate with respect to the horizontal axis y, but it will precipitate with respect to the vertical axis Z.

The precession is associated only with spinning bodies and is the resultant motion due to a couple or torque being supplied to such a body. The effect of external force applied to the gimbals rings of the gyroscope is experienced 90 ahead in the direction of rotation of gyroscope

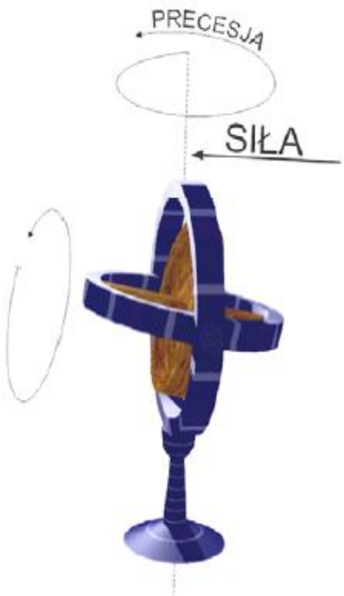


Fig.3 The behaviour of the gyro under the action of an external force.

As for the Earth's circular motion and steering direction, we will find that the axis of the gyroscope will circle the cone with ellipses. The vertical axis of the cone will coincide with the meridian of Earth. The axis of the gyro will swing the harmonious meridian in the vertical and horizontal plane.

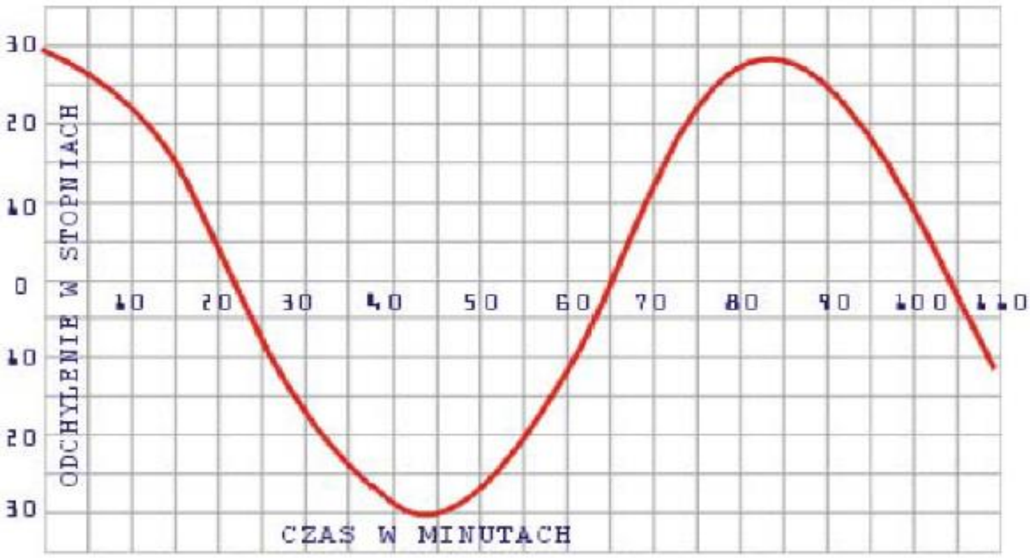


Fig.4 Process of the absence of damping axis gyroscope (84.4 min)

The sensing element of the two-rotor gyrocompass (Figure 5)—the gyrosphere, or float—is a hollow sphere. The float contains two gyroscopes and a hydraulic stabilizer to damp the natural oscillations. The axes of the proper rotation of the gyroscopes are horizontal, whereas the axes of precession are vertical and are connected with the swivel mechanism by a coupler, which is connected to the float body by springs. In the initial state (when the rotors are stationary), the gyroscope's axes form the angles ϵ = 45° with the NS direction of the float. The center of gravity of the float is situated on its vertical axis below its geometric center, which generates the required pendulum moment, as in the one-rotor gyrocompass. The float is submerged in a liquid; therefore, only viscous friction occurs in the suspension. To provide stability of the gyrocompass during acceleration of the object, the parameters of the system are selected in such a way that the period of the float's precession oscillations in the absence of damping is 84.4 min. The presence of two gyroscopes in the gyrocompass substantially reduces the errors of the instrument during the rolling of a ship. The error of a gyrocompass does not exceed several tenths of a degree of an arc when the ship is on a straight course with a constant speed.

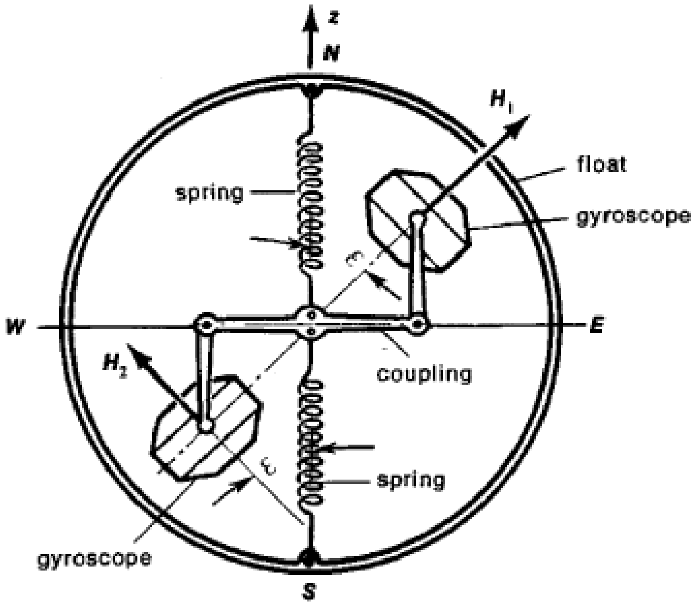


Fig. 5 Schematic diagram of the sensing element of a two-rotor gyrocompass: *NS* and *WE* are the north-south and west-east directions, respectively; H_1, and H_2 are the kinetic moments of the gyroscopes. http://encyclopedia2.thefreedictionary.com/Gyro+compass

The top of the gyrosphere contains an annular damping trough, half filled with a viscous fluid. The fluid damps azimuthal oscillations of the gyroscope system. The oscillation period is tuned to the Schuler period of 84.4 minutes, so that heading errors during horizontal acceleration due to changes in speed and/or direction are prevented.

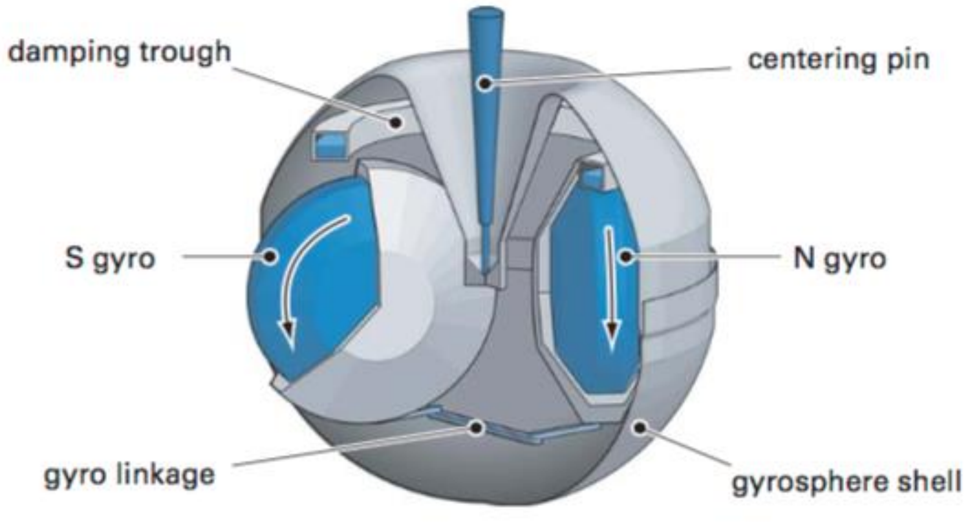


Fig. 4 The Gyrosphere

In the same way, the force moment (torque or twist) is directed along the long thumb of the right hand when the fingers of the hand curl in the direction of rotation that the force tries to generate. Here are the basic gyro laws: When the torque is applied to the gyro, it rotates (or cuts) to equalize its torque with torque. Precession is related to the space of inertia - a reference space that is not "fixed" to "fixed stars". Note that the Earth is not part of the space of inertia due to its daily rotation. The precession size is directly proportional to the torque and inversely proportional to the magnitude of the torque. When no torque is applied, the rotary axis remains stationary relative to the inertial space; If directed towards the star, it remains directed towards the stars, so one end of the axis seems to be the Earth observer during the day to rise in the east and set in the west. When applied torque tends to rotate the gyro around the vertical axis, the spinning rod will increase or submerge when it attempts to determine torque with torque. Likewise, the applied torque around the horizontal axis will cause the rotary axis to behave around the vertical axis.

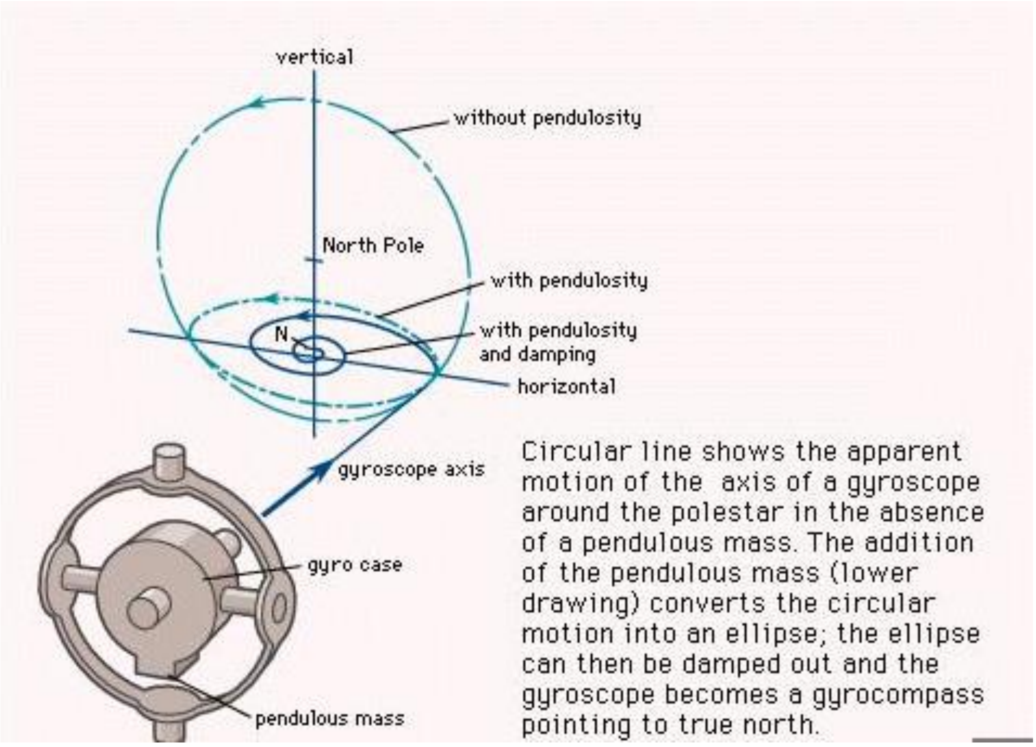
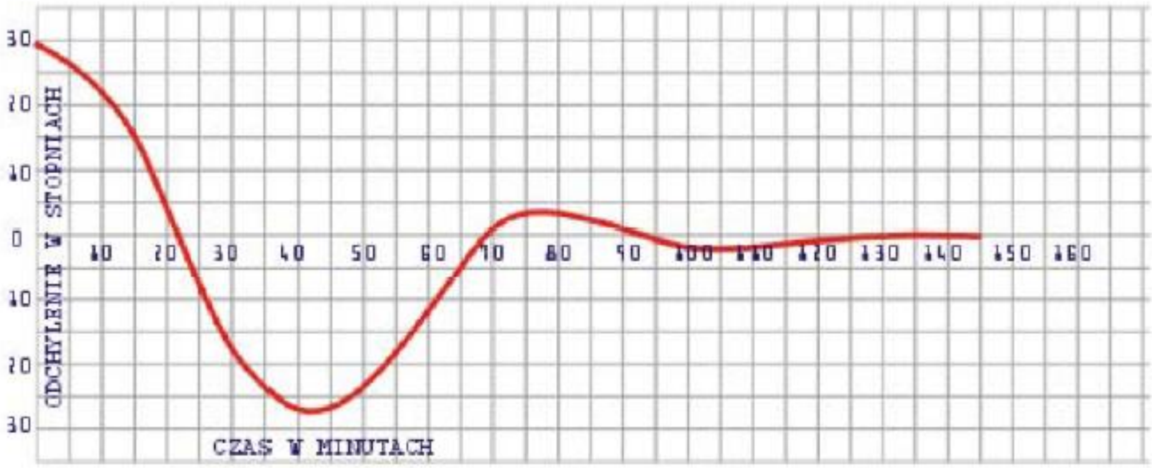


Fig.5 Gyrocompass operation. https://www.britannica.com/technology/gyrocompass

The gyroscope is a gyro with a mask imbalance that gives a right angle to the axis of rotation. Under normal circumstances, the axis of rotation will be almost horizontal and facing north, while the pendulum is down. Let's consider that gyrocompass started from the axis of rotation in the horizontal axis and pointed a few degrees to the east of the north. Earth's rotation causes the axis of rotation to rise above the horizon observed by the Earth observer (more precisely, the horizon is reduced below the axis of rotation which initially remains stationary in the inertia space). This action causes the noise level in the west due to the weight of the pendulum. The rotating axis, in line with the basic law of the gyroscope, runs vertically toward the meridian, continuing to grow as a result of rotation of the Earth to the meridian. At this moment the torque is maximum and the axis of rotation is continued through the meridian. When the axis of rotation is to the west of the meridian, the rotation of the Earth's axis causes the axis of rotation to rotate, reducing the torque. In the same west of midnight because the direction of departure was east of north, the axis of rotation is horizontal again, but due to rotation of the Earth is still set. This causes immersion below the horizon and causes eastward rotation from the rotational torque, causing the rotary axis to again meridian again and eventually pass through the meridian and return to the original direction in which the whole process is repeated. The spin axis tracks the ellipse around the meridian and horizontal. The period of ellipticity and oscillation depends on the strength of the pendulosa. For a gyrocompass to point north, it is necessary that the oscillation be damped out so that the unit can settle on the meridian and not keep passing through it. Damping an oscillator involves changing its energy state by opposing the velocity of the body. Two principle methods for damping have been used. The first, used in all gyrocompasses except the Sperry, was developed by Schuler. It consists of applying an antipendulous torque caused by the restricted flow of a viscous fluid responding to the tilt of the gyroscopic element. Viscosity and direction of flow through the constriction are combined so that the torque is applied in the proper phase for damping. The torque is horizontal and ideally is directed so as to process the gyro toward the meridian at all times: it points west when the spin axis is east of the meridian and east when the spin axis is west of the meridian. The combined action of pendulous and damping torques changes the previously mentioned elliptical motion of the undammed regime to a spiralling-in motion toward the meridian. Viscous friction absorbs the energy withdrawn to affect the damping.



Rys.6 Settling Curve

8.4 Gyro Errors

8.4.1 Speed Error

The magnitude of the speed error is dependent upon the speed, course, and latitude of the ship in which the compass is installed. A ship at the equator is being carried around by the earth's rotation at a velocity of 900 knots. At any latitude other than the equator, this velocity becomes 900 times the cosine of the latitude. If a ship is steaming due west, its speed opposes that of the earth; if steaming due east its speed is added to the movement of the earth. Neither course causes a speed error, but both have a slight effect on the directive force of the wheel. If, however, a ship starts at the equator and sails due north, its speed is at a right angle to the speed with which the rotation of the earth is carrying the gyrocompass around in space. Assume that the vessel in Figure 17-18 starts at A and is making a speed of 2,026 feet per minute or 20 knots, along the course line A-A'; the speed of rotation of the earth is 92,400 feet per minute along A-B. The actual speed and direction in which the compass is being carried around in space is A-C, and the actual axis about which it is carried around is not the earth's polar axis N-S, but an axis at a right angle to A-C. The gyro axle will, therefore, settle on a line N'-S' and not on the true meridian. The true north will be toward the east of the indicated north by an angle N'-A-N which will be 1.25 degrees for a speed of 20 knots. If the ship starts from the equator and sails due south, the deviation will be toward the opposite side, that is, the true north will be west of the indicated north. If the course is neither due north nor due south, the deviation will have a value between zero and 1.25 degrees. If the ship is at 60 degrees north latitude, steaming at 2,026 feet per minute, or 20 knots, due north as at E-E', and the earth's rotation at this latitude E-F is 46,200 feet per minute, the compass is being carried around with a velocity E-G and is being rotated about an axis N"-S" at a right angle to the resultant E-G. The axle will align itself with N"-S". Thus, in this latitude and at the given speed, the true north will be 2.5 degrees eastward of that indicated by the compass. On northeasterly-or northwesterly courses, the deviation will be between zero and 2.5 degrees (Fig. 7)

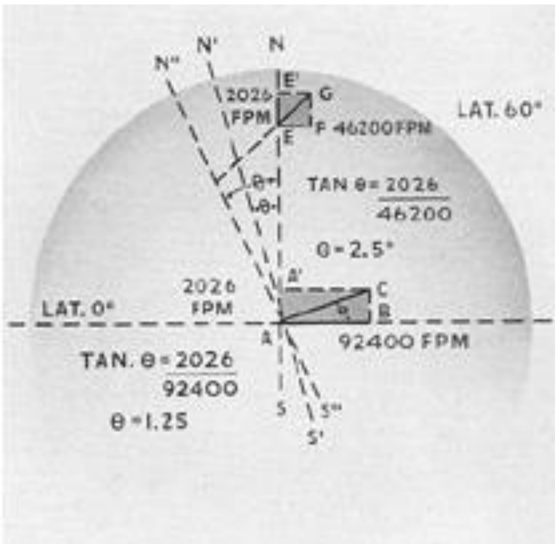


Fig. 7 Speed course latitude error

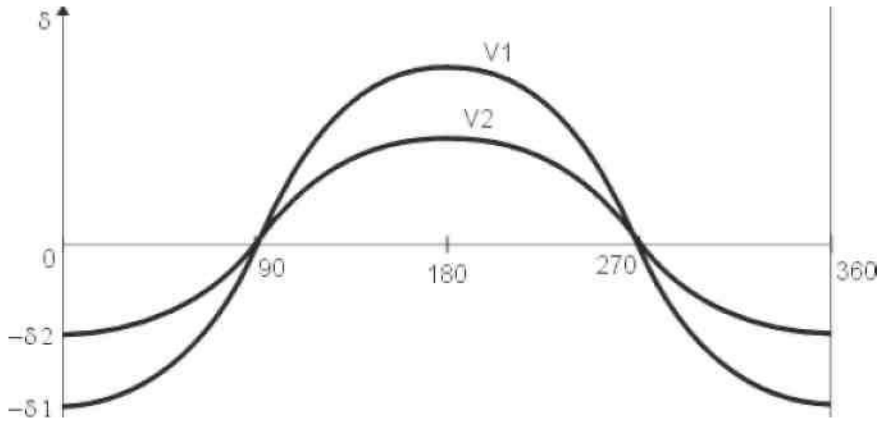
The value of speed error can be determined from two formulas, using true course and compass course.

$$tg\delta = -\frac{V*cosKR}{900*cos\varphi + VsinKR} \qquad\qquad sin\delta = -\frac{V*cosKK}{900*cos\varphi}$$

gdzie:

KR- True Course
KK- Gyro Course
V- Vessel speed

The value of the speed error it is directly proportional to the vessel speed. The speed error depends to the course of the ship. On the course of 090° and 270° the speed error reach the value equal zero. On the course of 180° and 000° can reach the maximum values (fig.8). The contemporary Gyrocompass has automatic speed error correction.



Rys.8 The course of the ship influence on the speed error

8.4.2.

Ballistic deflection error. In Figure 9, the gyro axis is assumed to be pointing along OA. ON is the true north. The angle NOA is the speed error for an assumed course of north and an assumed speed of 20 knots. For a true east course for any speed or latitude, the speed error is zero. Therefore, the axis of the gyro points along ON if the course is east. Let us suppose that the ship, which is on a northerly course and is traveling at a speed of 20 knots, should change to an easterly course. This change of course is made in about 2 minutes. During this time, the north end of the gyro must process to the east so that by the time the ship is headed east, the axis of the gyro will point along the line ON. If the gyro, by the time the ship is on an easterly course, is not pointing along the meridian ON, it will produce an erroneous reading on the compass and its repeaters. If the compass is to have the proper ballistic deflection during the time that the vessel is actually changing course, it must have a definite amount of pendulousness for the latitude which will make it process exactly to the settling point required for the new course in a deadbeat manner. The ballistic deflection error is prevented in the Arma compass by varying the speed of the gyro rotors in accordance with the cosine of the latitude of the vessel's position. This variation in speed is effected by changing the speed of the motor generator through a field rheostat on the control panel.

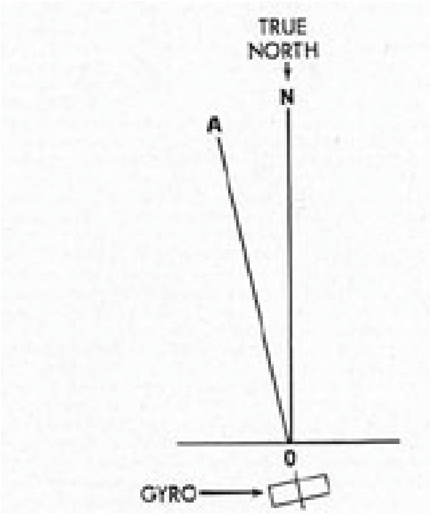


Fig.9 Ballistic deflection error, ship on northerly course.

Ballistic damping error. The oil damping arrangement of the Arma compass allows a small quantity of oil to flow from one tank to the other when the compass is subjected to the inertia forces caused by acceleration or deceleration of the ship during a change of course or speed so that an unbalanced condition is set up. This unbalanced condition results in a precession about the vertical axis and causes an oscillation which must be damped out in the regular manner. In all the later Arma compasses, damping is eliminated for changes of course of 15 degrees or over, thereby eliminating this error. This is accomplished by a solenoid-operated valve controlled by contacts in the follow-up system.

8.4.3 Quadrant error (Rolling error)

This error is due to rolling of the ship. During the rolling of the ship, acceleration occurs. Acceleration acts on the lower center of gravity in the sensitivity element. Influence of rolling on the accuracy in the two rotors gyroscope in the sensitive element is lower then in the gyroscope with the single rotor. Use of the two rotors stabilizes the sensitive element according N-S direction. During the big rolling the quadrant error in the high rolling reach +/- 1,5^{O}, in the medium latitude reach only +/- 0,5^{O}.

The quadrant error for the gyroscope with two rotors can be determined by:

$$\delta = \frac{LAB}{4Hr * (\omega * cos\varphi + {}^{V_E}/_{R})} * \sin(2 * KK)$$

The quadrant error for the gyroscope with single rotor can be determined by:

$$\delta = \frac{AB}{4H\omega * cos\varphi} * \sin(2 * KK)$$

Where:
A - amplitude coefficient of the rolling acceleration,
L - the coefficient determining the centre of gravity of the compass from the ship's centre of rolling,
H - the kinetic moment of the sensitive element,
B - dual-band compass torque module,
KK - direction of rolling of the ship.

The maximum value of this error reach on the quarter course: 45^{O}, 135^{O} etc. In practice, no correction is made to this error, but it should be taken into account the deterioration of course during the rolling of the ship.