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Dry tuned gyroscope error identification

Vladimir Vukmirica, MSc (Eng)[1)]

The main sensors in the inertial navigation systems are gyroscopes and linear accelerometers i.e. specific force sensors. Error coefficients of dry tuned gyro, defined by IEEE dry tuned gyro model equation, are obtained by eight position test method. These coefficients have a significant dispersion, especially scale factor and bias. The method of linear gyro characteristics approximation, gives good estimation of gyro scale factor and bias, so it is used in this work in the comparison of "eight position test method".

Key words: **navigation system, inertial system, inertial navigation, dinamically tuned gyroscope, dry tuned gyroscope, sensor error, testing, scale factor, bias.**

Introduction

DRY tuned gyroscope (DTG) has been used for many years in the inertial navigation systems. A method for static coefficients determining and results obtained by testing of angular rate sensor with range of 60 °/s (Appendix A) have been presented here. Also, results from static tests are compared the results of dynamic tests. The influence of scale factors accuracy on the obtained results accuracy is estimated. Furthermore, spectral characteristic of gyro in low frequency domain, which is of order of the object natural frequency, is determined.

Most of the tests are based on standard definition methods [1], [2]. Tests were performed on the two-axis test table CARCO T-922 whose characteristics are presented in the Appendix B.

Test methods explained through mathematical model

IEEE gyro model

A simplified static error dry tuned gyro model equation (IEEE) for the *x*- and *y*-axes based on [2] in terms of scale factors K_x, K_y and output signals S_x, S_y has been presented in [1].

$\frac{S_x}{K_x} = \Omega_x$	– Inertial rate about *x*-axis
$+B_x$	– Bias, non-g-sensitive
$+D_{xx} a_x$	– Normal mass unbalance
$+D_{xx} a_y$	– Quadrature mass unbalance
$+D_{xz} a_z$	– "Dump" g-sensitivity
$+D_{xox} \Phi_x$	– Offset sensitivity, *x*
$+D_{xoy} \Phi_y$	– Offset sensitivity, *y*

Synchronous vibration sensitivity:

$D_{xv1} a_1$	– 1N axial
$D_{xv2} a_{2N_{xy}}$	– 2N radial
$D_{xv3} \left(d\Phi / dt \right)_{2Nxy}$	– 2N angular
$D_{xxz} a_z a_x$	– Anisoelasticity
$D_{xi} \left(d\Phi / dt \right)_x \left(d\Phi / dt \right)_z \omega$	– Frequency-sensitive anisoinertia
$\frac{S_y}{K_y} = \Omega_y$	– Inertial rate about *y*-axis
$+B_y$	– Bias, non-*g*-sensitive
$+D_{yy} a_y$	– Normal mass unbalance
$+D_{yx} a_x$	– Quadrature mass unbalance
$+D_{yz} a_z$	– "Dump" g-sensitivity
$+D_{yox} \Phi_x$	– Offset sensitivity, *x*
$+D_{yoy} \Phi_y$	– Offset sensitivity, *y*

Synchronous vibration sensitivity:

$D_{yv1} a_{1Nz}$	– 1N axial
$D_{yv2} a_{2N_{xy}}$	– 2N radial
$D_{yv3} \left(d\Phi / dt \right)_{2Nxy}$	– 2N angular
$D_{yyz} a_z a_y$	– Anisoelasticity
$D_{yi} \left(d\Phi / dt \right)_y \left(d\Phi / dt \right)_z (\omega)$	– Frequency-sensitive anisoinertia

A g notation is used for Earth gravitation which is: g = 9.805398 m/s^2 on the testing location.

The D_{ab} coefficient is defined as the drift on the a axis caused by unit acceleration along the axis b. Accelerations a_x, a_y include gravity.

Scale factors K_x, K_y and coefficients B_x, B_y, D_{yy}, D_{xx}, D_{yx}, D_{xy} defined above could be measured. Coefficients D_{yz} and D_{xz} are determined if zero offsets are not equal in the vertical and horizontal rotor position.

1) Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade

Mode of gyro characteristics with these coefficients is:

$$\frac{S_x}{K_x} = \Omega_x + B_x + D_{xx}a_x + D_{xy}a_y + D_{xz}a_z \quad (1)$$

Scale factor K_x will be determining in (rad/s)/V and gyro signal S_x in (V). In accordance with that, equations for inertial rate modeling in rad/s are:

$$\Omega_x = S_x K_x - B_x - D_{xx}a_x - D_{xy}a_y - D_{xz}a_z \quad (2)$$

It is similar for the y- axis:

$$\frac{S_y}{K_y} = \Omega_y + B_y + D_{yy}a_y + D_{yx}a_x + D_{yz}a_z \quad (3)$$

i.e.

$$\Omega_y = S_y K_y - B_y - D_{yy}a_y - D_{yx}a_x - D_{yz}a_z \quad (4)$$

In order to determine the coefficients, eight position tests are used. Long term stability of these coefficients is observed by periodically repeting the measurement. Temperature dependence on the corresponding coefficients can be obtained by testing in the temperature chambers.

Eight position gyro test

This is a static test in which the gyro is moved through eight positions. In the first group of four positions, the rotor spin axis (SA) is in the vertical position, and in the other four is in the horizontal, Fig.1.

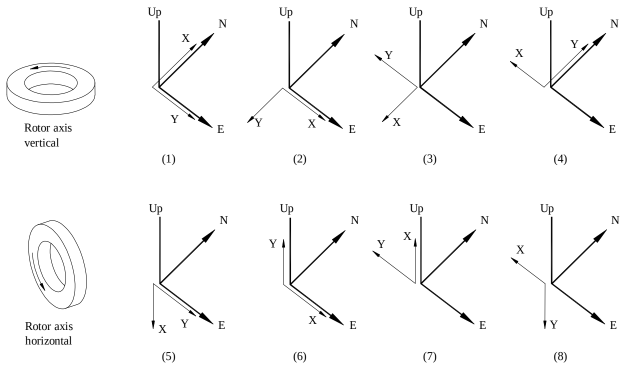

Figure 1. Eight position test sequence

First four positions are used for non-*g*-sensitive coefficients determination and other four for the *g*-sensitive coefficients determination.

Typically, a couple of minutes at each position will give sufficient accuracy for tactical gyros.

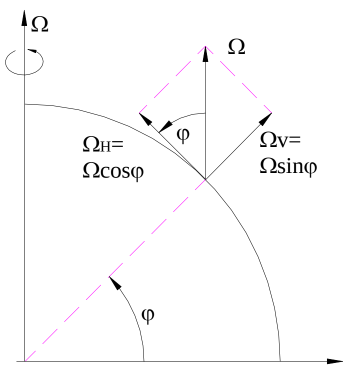

Figure 2. Earth rotation components

Earth rotation components are vertical Ω_V and horizontal Ω_H , Fig.2.

At the test position, the values of Ω_H and Ω_V are:

$$\varphi = 44.740873$$

$$\Omega_H = \Omega\cos 44.740873 = 7.292115\cdot 10^{-5}\cos 44.740873 = \\ = 5.179571\cdot 10^{-5}\ \mathrm{rad/s}\left(0.00296767\ {}^\circ/\mathrm{s}\right)$$

$$\Omega_V = \Omega\sin 44.740873 = 7.292115\cdot 10^{-5}\sin 44.740873 = \\ = 5.132931\cdot 10^{-5}\ \mathrm{rad/s}\left(0.00294095\ {}^\circ/\mathrm{s}\right)$$

In case when gyro axes are ideally perpendicular and lie exactly in the vertical, horizontal and 4 cardinal positions (N, S, E and W), from the 8 positions the following data can be derived:

Position 1: $K_x x_1 = B_x + \Omega_H$; $K_y y_1 = B_y$;

Position 2: $K_x x_2 = B_x$; $K_y y_2 = B_y - \Omega_H$;

Position 3: $K_x x_3 = B_x - \Omega_H$; $K_y y_3 = B_y$;

Position 4: $K_x x_4 = B_x$; $K_y y_4 = B_y + \Omega_H$;

Position 5: $K_x x_5 = B_x + D_{xx} - \Omega_V$; $K_y y_5 = B_y + D_{yx}$;

Position 6: $K_x x_6 = B_x - D_{xy}$; $K_y y_6 = B_y - D_{yy} + \Omega_V$;

Position 7: $K_x x_7 = B_x - D_{xx} + \Omega_V$; $K_y y_7 = B_y + D_{yx}$;

Position 8: $B_x + D_{xy}$; $K_y y_8 = B_y + D_{yy} - \Omega_V$;

Where x_1 to x_8 and y_1 to y_8 denote gyro outputs in the corresponding positions, based on this the following applies:

$$K_x = 2\Omega_H / \left(x_1 - x_3\right) \quad (5)$$

$$K_y = 1/2\,\Omega_H / \left(y_4 - y_2\right) \quad (6)$$

$$B_x = 1/2\,K_x\left(x_1 + x_3\right) = 1/2\,K_x\left(x_2 + x_4\right) = \\ = 1/2\,K_x\left(x_5 + x_7\right) = 1/2\,K_x\left(x_6 + x_8\right)$$

$$B_y = 1/2\,K_y\left(y_1 + y_3\right) = 1/2\,K_y\left(y_2 + y_4\right) = \\ = 1/2\,K_y\left(y_5 + y_7\right) = 1/2\,K_y\left(y_6 + y_8\right)$$

$$D_{xx} = \Omega_v - 1/2 K_x\left(x_5 - x_7\right)$$

$$D_{yy} = \Omega_v - 1/2 K_y\left(y_6 - y_8\right)$$

$$D_{xy} = 1/2 K_x\left(x_8 - x_6\right)$$

$$D_{yx} = \Omega_v - 1/2 K_y\left(y_5 - y_7\right)$$

Linear regression method

Using precise input angular rates and measured signals from the gyro output it is possible to calculate gyro scale factor and bias. For this method, experimental results must be obtained with sufficient number of experiments for statistical calculations.

Linear approximation equations [5] are:

$$\tilde{\Omega}_x = \tilde{K}_x\Omega + \tilde{B}_x \quad (7)$$

$$\tilde{K}_x = \frac{E(\Omega\Omega_x) - E(\Omega)E(\Omega_x)}{E(\Omega^2) - [E(\Omega)]^2} \quad (8)$$

$$\tilde{B}_x = E(\Omega_x) - K_x E(\Omega) \quad (9)$$

where:

- Ω - input angular rate
- $\tilde{\Omega}$ - linear approximation of gyro characteristic
- $\tilde{K}_x$ - approximation of scale factor
- $\tilde{B}_x$ - approximation of gyro bias
- E - expectation

$$E(\Omega) = \bar{\Omega} = \frac{1}{n}\sum_{k=1}^{n}\Omega_k \quad (10)$$

$$E(\Omega) = \bar{\Omega} = \frac{1}{n}\sum_{k=1}^{n}\Omega_k \quad (11)$$

$$E(\Omega\Omega_x) = \overline{\Omega\Omega_x} = \frac{1}{n}\sum_{k=1}^{n}\Omega_k\Omega_{xk} \quad (12)$$

$$E(\Omega^2) = \overline{\Omega^2} = \frac{1}{n}\sum_{k=1}^{n}\Omega_k^2 \quad (13)$$

The similar set of equation (7) to (13) corresponds to y-axis.

Results of analysis

For the purpose of examining the accuracy of coefficients obtained by these methods, experimental measurements were done.

The measurements were done in all eight positions over the period of 3 minutes per set (simultaneous measurements of signals x and y of gyroscope). Sampling time period was 8 ms. Analysis was done based on average values in the 3 minute periods, Table 1.

Table1. Eight positions test results

Nr.	x-axis [V]	y-axis [V]
1	-0.005133297	0.00666228
2	-0.008178719	0.00362949
3	-0.01130791	0.00712712
4	-0.007525878	0.0110764
5	-0.007553021	0.00311511
6	-0.01199804	0.00807239
7	-0.007336572	0.0121424
8	-0.003654463	0.00606405

The calculated coefficients based on the test results are given in Table 2:

Table2. Calculated coefficients

Coefficient	Value	Dimension
K_x	$1.677699\cdot10^{-2}$	(rad/s)/V
K_y	$1.3910658\cdot10^{-2}$	(rad/s)/V
$B_x(1)$	$-1.37917\cdot10^{-4}$	rad/s
$B_x(2)$	$-1.31738\cdot10^{-4}$	rad/s
$B_x(3)$	$-1.24901\cdot10^{-4}$	rad/s
$B_x(4)$	$-1.31301\cdot10^{-4}$	rad/s
$B_y(1)$	$9.591\cdot10^{-5}$	rad/s
$B_y(2)$	$1.0228\cdot10^{-4}$	rad/s
$B_y(3)$	$1.0612\cdot10^{-4}$	rad/s
$B_y(4)$	$9.8324\cdot10^{-5}$	rad/s
D_{xx}	$4.95136\cdot10^{-5}$	rad/s/g
D_{yy}	$3.73606\cdot10^{-5}$	rad/s/g
D_{xy}	$-6.99901\cdot10^{-5}$	rad/s/g
D_{yx}	$-6.27878\cdot10^{-5}$	rad/s/g
D_{xz}	$-6.72635\cdot10^{-6}$	rad/s/g
D_{yz}	$-3.12524\cdot10^{-5}$	rad/s/g

The difference of the biases $B_x(1)$ and $B_x(2)$ in vertical position and $B_x(3)$ and $B_x(4)$ in horizontal position is:

$$\frac{B_x(1)+B_x(2)}{2} - \frac{B_x(3)+B_x(4)}{2} = -6.72635\cdot10^{-6}\,\text{rad/s}$$

The difference of the biases $B_y(1)$ and $B_y(2)$ in vertical position and $B_y(3)$ and $B_y(4)$ in horizontal position is:

$$\frac{B_y(1)+B_y(2)}{2} - \frac{B_y(3)+B_y(4)}{2} = -3.12524\cdot10^{-6}\,\text{rad/s}$$

These differences are coefficients D_{xz} and D_{yz} (the "dump" g-sensitivity). These coefficients may result from the vibration generated in the bearings with bearing load, which changes when the gyro is turned from SA-up to SA-down.

Influence of scale factor coefficients accuracy on other coefficients

The coefficients B_x, B_y, D_{yy}, D_{xx}, D_{yx}, D_{xy}, D_{xz}, D_{yz} are dependent on the scale factors K_x and K_y. Scale factors are calculated from (5) and (6). The second set of measurements was done to see if there is a difference in the test results. These results are given in Table 3.

Table3. Eight position test results, second set of measurements

Nr.	x-axis [V]	y-axis [V]
1	-0.005095223	0.00718394
2	-0.007967139	0.00409419
3	-0.01147.011	0.00695063
4	-0.008158664	0.0100481
5	-0.008924021	0.00211774
6	-0.0128709	0.00734245
7	-0.007222596	0.0124117
8	-0.003433681	0.00650193

The calculated coefficients based on the test results are given in Table 4:

Table 4. Calculated coefficients

Coefficient	Value	Dimension
K_x	$1.677699\cdot10^{-2}$	(rad/s)/V
K_y	$1.3910658\cdot10^{-2}$	(rad/s)/V
$B_x(1)$	$-1.37917\cdot10^{-4}$	rad/s
$B_x(2)$	$-1.31738\cdot10^{-4}$	rad/s
$B_x(3)$	$-1.24901\cdot10^{-4}$	rad/s
$B_x(4)$	$-1.31301\cdot10^{-4}$	rad/s
$B_y(1)$	$9.591\cdot10^{-5}$	rad/s
$B_y(2)$	$1.0228\cdot10^{-4}$	rad/s
$B_y(3)$	$1.0612\cdot10^{-4}$	rad/s
$B_y(4)$	$9.8324\cdot10^{-5}$	rad/s
D_{xx}	$4.95136\cdot10^{-5}$	rad/s/g
D_{yy}	$3.73606\cdot10^{-5}$	rad/s/g
D_{xy}	$-6.99901\cdot10^{-5}$	rad/s/g
D_{yx}	$-6.27878\cdot10^{-5}$	rad/s/g
D_{xz}	$-6.72635\cdot10^{-6}$	rad/s/g
D_{yz}	$-3.12524\cdot10^{-6}$	rad/s/g

The difference of the biases $B_x(1)$ and $B_x(2)$ in vertical position and $B_x(3)$ and $B_x(4)$ in horizontal position is:

$$\frac{B_x(1)+B_x(2)}{2} - \frac{B_x(3)+B_x(4)}{2} = -9.74743\cdot10^{-7}\,\text{rad/s}$$

The difference of the biases $B_y(1)$ and $B_y(2)$ in vertical position and $B_y(3)$ and $B_y(4)$ in horizontal position is:

$$\frac{B_y(1)+B_y(2)}{2}-\frac{B_y(3)+B_y(4)}{2}=-4.21749\cdot 10^{-7}\text{ rad/s}$$

The coefficients calculated from the first and second measurements are given in Table 5.

Table 5. First and second measurement coefficients

Coefficient	1st test	2nd test
K_x (rad/s)/V	$1.677699\cdot10^{-2}$	$1.6249923\cdot10^{-2}$
K_y (rad/s)/V	$1.3910658\cdot10^{-2}$	$1.7398889\cdot10^{-2}$
$B_x(1)$ (rad/s)	$-1.37917\cdot10^{-4}$	$-1.34593\cdot10^{-4}$
$B_x(2)$ (rad/s)	$-1.31738\cdot10^{-4}$	$-1.31022\cdot10^{-4}$
$B_x(3)$ (rad/s)	$-1.24901\cdot10^{-4}$	$-1.31191\cdot10^{-4}$
$B_x(4)$ (rad/s)	$-1.31301\cdot10^{-4}$	$-1.32474\cdot10^{-4}$
$B_y(1)$ (rad/s)	$9.591\cdot10^{-5}$	$1.22963\cdot10^{-4}$
$B_y(2)$ (rad/s)	$1.0228\cdot10^{-4}$	$1.2303\cdot10^{-4}$
$B_y(3)$ (rad/s)	$1.0612\cdot10^{-4}$	$1.26398\cdot10^{-4}$
$B_y(4)$ (rad/s)	$9.8324\cdot10^{-5}$	$1.20438\cdot10^{-4}$
D_{xx} (rad/s/g)	$4.95136\cdot10^{-5}$	$3.75053\cdot10^{-5}$
D_{yy} (rad/s/g)	$3.73606\cdot10^{-5}$	$4.40173\cdot10^{-5}$
D_{xy} (rad/s/g)	$-6.99901\cdot10^{-5}$	$-7.6677\cdot10^{-5}$
D_{yx} (rad/s/g)	$-6.27878\cdot10^{-5}$	$-8.95517\cdot10^{-5}$
D_{xz} (rad/s/g)	$-6.72635\cdot10^{-6}$	$-9.74743\cdot10^{-7}$
D_{yz} (rad/s/g)	$-3.12524\cdot10^{-6}$	$-4.21749\cdot10^{-7}$

There is a significant difference of coefficients from the first and second measurements. This indicates that coefficients must be calculated using the average value of a greater number of measurements.

There is also a significant difference of the scale factors from these two measurements. This results in the difference between coefficients B_x and B_y. In the case of the same scale factors, these differences will be smaller.

The scale factors should be derived in another way. Let the received results be compare with coefficients calculated using linear approximation.

The precise angular rate test table is used to measure these coefficients. Input angular rates range from the maximum negative to maximum positive, Table 6. Scale factors are calculated by the method of linear approximation of mean squares.

Table 6. Angular rate test table results

Input test table angular rate Ω_T [°/s]	Measured angular rate Ω (x-axis) [V]	Measured angular rate Ω (y-axis) [V]
-4.0	-4.396752412	-4.438191904
-2.0	-2.201271749	-2.215080649
-1.0	-1.105343622	-1.10328128
-0.5	-0.556644249	-0.548213652
-0.1	-0.117097659	-0.103668301
-0.01	-0.008981766	-0.004103784
-0.001	-0.008956163	0.006080217
0.001	-0.007372	0.008645655
0.01	0.00281	0.019198805
0.1	0.10119	0.118809424
0.5	0.54019	0.562453997
1.0	1.08917	1.11810351
2.0	2.18961	2.229918858
4.0	4.38111	4.451156313

The scale factors are calculated based on results from Table 6 and equations (7) to (13).

$$\tilde{K}_x = 0.015905441\,\frac{\text{rad/s}}{\text{V}} \tag{14}$$

$$\tilde{B}_x = -0.000111724\text{ rad/s} \tag{15}$$

$$\tilde{K}_y = 0.015707323\,\frac{\text{rad/s}}{\text{V}} \tag{16}$$

$$\tilde{B}_y = 0.000114245\text{ rad/s} \tag{17}$$

The linear characteristic can be non-symmetric, i.e. positive and negative parts should be different. To estimate non-symmetric characteristics, positive and negative biases and scale factors are calculated. The results are:

$$\tilde{K}_{x+} = 0.015901223\,\frac{\text{rad/s}}{\text{V}} \tag{18}$$

$$\tilde{K}_{x-} = 0.015895603\,\frac{\text{rad/s}}{\text{V}} \tag{19}$$

$$\tilde{B}_{x+} = -0.000130\text{ rad/s} \tag{20}$$

$$\tilde{B}_{x-} = -0.0000867618\text{ rad/s} \tag{21}$$

$$\tilde{K}_{y+} = 0.015710778\,\frac{\text{rad/s}}{\text{V}} \tag{22}$$

$$\tilde{K}_{y-} = 0.015704726\,\frac{\text{rad/s}}{\text{V}} \tag{23}$$

$$\tilde{B}_{y+} = 0.000119256\text{ rad/s} \tag{24}$$

$$\tilde{B}_{y-} = 0.000116553\text{ rad/s} \tag{25}$$

All the coefficients are symmetrical; the positive and negative values are very similar except B_x. This characteristic is represented in Fig.3, based on the results given in Table 7.

Table 7. Angular rate test table results - fine range

Test table rate ΩT [deg/s]	Input rate (ΩT - ΩV)[deg/s]	x-axis gyro output [V]
-0.1	-0.10294095	-0.117097659
-0.01	-0.01294095	-0.008981766
-0.001	-0.00394095	-0.008956163
0.001	-0.00194095	-0.007372
0.01	0.00705905	0.00281
0.1	0.09705905	0.10119

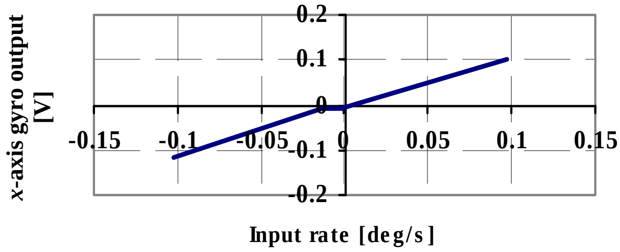

Figure 3. x-axis characteristic

The biases were measured eight times for each axis, which is sufficient for statistic. The mean values are:

$$\bar{B}_x = \frac{1}{8}\sum_{i=1}^{i=8} B_{xi} = -0.000131892 \tag{26}$$

$$\bar{B}_y = \frac{1}{8}\sum_{i=1}^{i=8} B_{yi} = 0.000111934 \qquad (27)$$

There is a good agreement of coefficient B_y in all three cases (17), (24) and (25). The coefficient B_x from (26) corresponds to B_x for positive angular rates (20).

Spectral characteristic of the gyroscope

Along with the gyro coefficients determination, it is necessary to make a spectral analysis of gyro output signal to determine whether there is a frequency with significant amplitude of spectral density within the gyro measuring range.

Spectral characteristic was determined by one of 8 position tests in which the input gyro axis is in the east-west direction. In this position there is no influence of the Earth rotation. PSD represents the spectral characteristic of the operated gyro without the input angular rate.

The spectral analysis results are presents in the Figures 4 - 5. There is clearly a frequency of approximately 5.5 Hz on both gyro axes. All the conditions for proper operation of the gyroscope must be realized during assembling and tuning. Because these conditions can not be ideally matched, there is an undesired frequency.

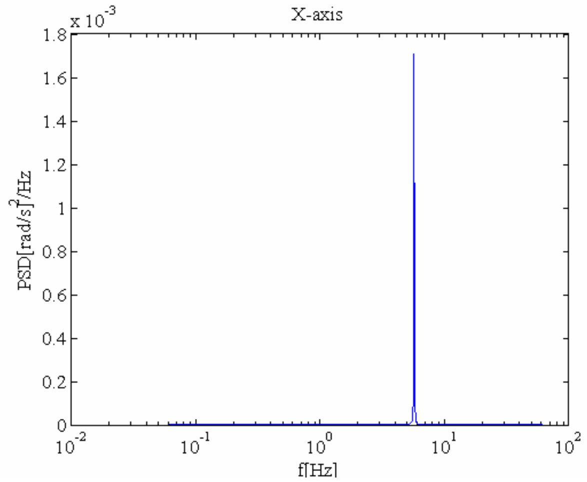

Figure 4. *x*-axis spectral characteristic

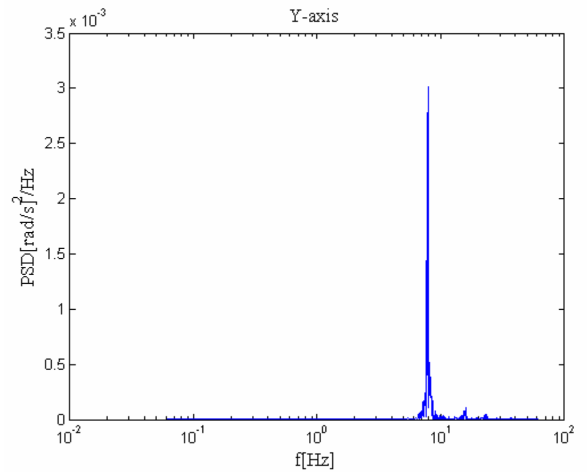

Figure 5. *y*-axis spectral characteristic

Model of gyroscope based on the derived test coefficients

If the following coefficients are neglected:

$D_{y0x}\Phi_x$	Offset sensitivity, *x*
$D_{y0y}\Phi_y$	Offset sensitivity, *y*

Synchronous vibration sensitivity:

$D_{yv1}a_{1Nz}$	1N axial
$D_{yv2}a_{2Nxy}$	2N radial
$D_{yv3}\left(d\Phi/dt\right)_{2Nxy}$	2N angular
$D_{yyz}a_z a_y$	Anisoelasticity
$D_{yi}\left(d\Phi/dt\right)_y\left(d\Phi/dt\right)_z(\omega)$	Frequency-sensitive anisoinertia

and the corresponding coefficients for *y*-axis, then the equations for the gyroscope should be in the form:
for the *x*-axis

$$\Omega_x = S_x K_x - B_x - D_{xx}a_x - D_{xy}a_y - D_{xz}a_z \qquad (28)$$

for the *y*-axis

$$\Omega_y = S_y K_y - B_y - D_{yy}a_y - D_{yx}a_x - D_{yz}a_z \qquad (29)$$

Conclusion

Dry tuned gyroscope model with neglected offset sensitivity coefficients and synchronous vibration sensitivity can be represened by equations (28) and (29). The represented model also disregards the axis cross-coupling.

Static eight position test are used for deriving the scale factors K_x, K_y and coefficients B_x, B_y, D_{yy}, D_{xx}, D_{yx}, D_{xy}, D_{yz} and D_{xz} of dry tuned gyroscope. The 8 positions are defined by [1] and [2]. Because there is a significant dispersion of data during this test, necessary to repeat it a number of times in order to obtain coefficients as the average value of the measurements. This test does not provide the right information about the scale factors and biases for positive and negative input angular rates. To receive a better estimation of those coefficients it is necessary to perform tests in the full angular rate measuring range. The combination of these two types of tests supplies more reliable results for the scale factors K_x, K_y and biases B_x, B_y (see Table 8). Eight position tests are good for estimating of the *g*-sensitive coefficients D_{yy}, D_{xx}, D_{yx}, D_{xy}, D_{yz} and D_{xz}.

Table 8. Values of two methods coefficients calculation

Coeffi-cient	Unit	8 position test		Linear approximation
		1st test	2nd test	
K_x	(rad/s)/V	$1.677699\cdot10^{-2}$	$1.6249923\cdot10^{-2}$	$\tilde{K}_{x+} = 1.5901223\cdot10^{-2}$
				$\tilde{K}_{x-} = 1.5895603\cdot10^{-2}$
K_y	(rad/s)/V	$1.3910658\cdot10^{-2}$	$1.7398889\cdot10^{-2}$	$\tilde{K}_{y+} = 1.5710778\cdot10^{-2}$
				$\tilde{K}_{y-} = 1.5704726\cdot10^{-2}$
B_x	rad/s	$-1.37917\cdot10^{-4}$	$-1.34593\cdot10^{-4}$	$\tilde{B}_{x+} = -1.30\cdot10^{-4}$
		$-1.31738\cdot10^{-4}$	$-1.31022\cdot10^{-4}$	
		$-1.24901\cdot10^{-4}$	$-1.31191\cdot10^{-4}$	$\tilde{B}_{x-} = -0.867618\cdot10^{-4}$
		$-1.31301\cdot10^{-4}$	$-1.32474\cdot10^{-4}$	
B_y	rad/s	$9.591\cdot10^{-5}$	$1.22963\cdot10^{-4}$	$\tilde{B}_{y+} = 1.19256\cdot10^{-4}$
		$1.0228\cdot10^{-4}$	$1.2303\cdot10^{-4}$	
		$1.0612\cdot10^{-4}$	$1.26398\cdot10^{-4}$	$\tilde{B}_{y-} = 1.16553\cdot10^{-4}$
		$9.8324\cdot10^{-5}$	$1.20438\cdot10^{-4}$	

Errors in manufacturing and tuning the gyroscope should be the sources of undesirable oscillations which are of the order of object movement. For determining these frequencies it is necessary to make a spectral analysis with zero angular rate input. In the gyroscope used for this analysis undesirable frequency is approximately 5.5 Hz. If an object with STDINS should make the maneuvers with this frequency, it is not possible to make a filtration of these frequencies.

Appendix A - Gyro characteristics

Characteristics of the gyroscope used in this analysis:

Random drift	0.2 °/h
G-independent drift	± 25 °/h
G-dependent drift	± 25 °/h/g
Torquer scale factor	400 (°/s)/A
Angular rate	60°/s continuously 300 °/s short time
Power supply	15(11)V, 360Hz±10%motor
2.5 V, 19.2 KHz	angular sensor
115 V, 400 Hz	heaters
Overall dimensions	ø42 x 46 mm
Mass	200 g

Appendix B – Two-axis test table characteristics

Type	CARCO T-922
Inner axis:	
Freedom:	±360 degree
Two mode of operation:	position and rate
Position accuracy:	±0.0001 degree
Rate range:	±0.0001 degree/s to 999 degree/s
Rate accuracy:	±0.0001 degree/s
Outer axis:	
Freedom:	±185 degree
One mode of operation:	position
Position accuracy:	0.0001 degree

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Identifikacija dinamički podešenog žiroskopa

Osnovni senzori u sistemima inercijalne navigacije su žiroskopi i linearni akcelerometri tj. senzori specifične sile. Koeficijenti greške dinamički podešenog žiroskopa, koji su definisani IEEE jednačinom modela dinamički podešenog žiroskopa su dobiveni testom u osam pozicija. Ovi koeficijenti imaju značajnu disperziju, specijalno koeficijent skaliranja i odstupanje nule. Metoda linearne aproksimacije koeficijenata daje dobru ocenu žiroskopskog koeficijenta skaliranja i odstupanja nule, pa je korišćena u ovom radu za poređenje sa "testom u osam pozicija".

Ključne reči: **navigacioni sistem, inercijalni sistem, inercijalna navigacija, dinamički podešen žiroskop, suvi podešen žiroskop, greška senzora, testiranje, koeficijent sklairanja, odstupanje nule.**

Идентификация динамически приспособленного гироскопа

Основными чувствительными элементами в системах инерциальной навигации являются гироскопы и линейные ускорители, т.е. чувствительные элементы удельной мощности. Коэффициенты ошибки динамически настраиваеного гироскопа, которые определены ИЕЕЕ уравнением модели динамически настраиваеного гироскопа, получены путём теста во восемь позициях. У этих коэффициентов есть особая (значительная) дисперсия, особенно коэффициент масштаба и нулевое смещение. Метод линейной аппроксимации коэффициента даёт хорошую оценку гироскопического коэффициента масштаба и нулевого смещения и из-за того он и пользован в этой работе для сравнения со "тестом во восемь позициях".

Ключевые слова: навигационная система, инерциальная система, инерциальная навигация, динамически настраивеный гироскоп, сухой настраивеный гироскоп, ошибка чувствительного элемента, испытание, коэффициент масштаба, нулевое смещение.

Idéntification du gyroscope dynamiquement réglé

Dans les systèmes de navigation inertiele les systèmes principaux sont les gyroscopes et les accéléromètres linéaires, c'est-à-dire les sensors de force spécifique. Les coefficients d'erreur chez le gyroscope à suspension accorée, définis par l'équation IEEE du modèle de gyroscope dynamiquement réglé, ont été obtenus par le test effectué dans 8 positions. Ces coefficients ont une dispersion importante, en particulier le coefficient de graduation et déviation du zéro. La méthode d'approximation linéaire des coefficients donne une bonne estimation du coefficient gyroscopique et de la déviation du zéro; c'est pourquoi cette méthode est employée dans ce travail pour la comparaison avec «le test dans huit positions».

Mots clés: **système de navigation, système inertiel, navigation inertiele, gyroscope, gyroscope à suspension accordée, erreur de sensor, test, coefficient de graduation, déviation du zéro.**