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Structural Correction of Inertial System Circuit

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***Abstract* – Inertial system errors in case of using the new structural correction method have been determined. Inertial system errors, which determine the kinematic parameters of aircraft movement, are finally generated in the computing circuit. This is the part of inertial system structure which is presented as a closed loop with a feedback. The forward circuit of the main loop consists of several velocity and distance integrators connected in series. Accelerometer signal corrections are calculated in the feedback loop. New corrective circuits have been introduced to the inertial system structure. And the errors of the changed system have been determined. The structural corrective circuits got signals from exterior onboard navigation systems. The conducted research has shown that the use of structural corrective circuits in some cases leads to a considerable decrease of inertial system errors. It means that the new structural method of inertial system correction provides positive results. Further research of inertial system errors should be conducted for the case of its full structure.**

***Keywords* – Corrective circuit, distance integrator, error, inertial system, main loop, transmission factor, velocity integrator.**

I. Introduction

An inertial navigation system is a key element of flight-navigation complex on modern airplanes. The inertial system provides a huge amount of information about the navigation parameters of the flight [1]–[4]. However, inertial system errors increase in time and are stored within the system [5]. The reason for such an increase relates to the structure. The decisive element of the inertial system calculating flight speed and distance contains two integrators connected in series to each other [6]. The implementation of self-correction in the inertial system results in a number of positive feedbacks in its structure [7]–[9].

At present a relatively effective device [5], [10], [11] – Kalman filter – is applied for the calculation of navigation parameters in accordance with the results of inertial system operation and the global satellite system. Errors in determining navigation parameters are lower than inertial system errors [12]. However, errors of Kalman filter output increase with time [13].

The scientists of the Institute of Aviation of Riga Technical University [14] have developed a structural method of inertial system correction. This method is characterized by the introduction of some particular changes in the structure of a system under consideration.

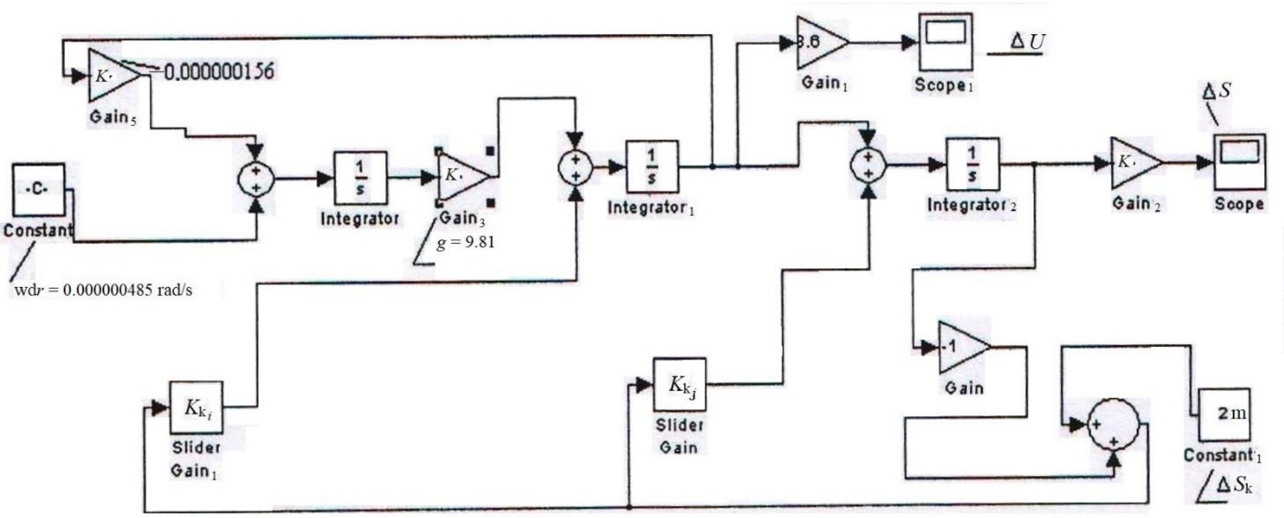

Fig. 1. Structure of the inertial system decisive circuit.

Fig. 1 demonstrates the diagram representing the structure of decisive circuit in the inertial system. The integrators of speed and distance connected in series have feedbacks. The decisive circuit is provided with a constant error corresponding to the drift of the platform of the accelerometers with an angular velocity 0.1 deg/h. The circuit of the decisive circuit contains a constant error corresponding to accelerometer platform drift with an angular velocity of 0.5 deg/s. Some additional elements are introduced into the structural scheme. The circuit contains two correcting negative feedbacks for the error of the distance signal. The output signal of one correcting circuit is supplied to the input of the distance integrator (K_{Kj}). This is the structure of the minor correcting loop. The second (major) correcting loop supplies its output signal to the input of the speed integrator (K_{Ki}).

The research estimates the opportunities to reduce inertial system errors [15] with the help of the developed structural method of correction. The dependencies of the errors of the decisive circuit according to the speed ΔU and distance ΔS on the structure and transfer factor K_K of the correcting loop were under the investigation.

Fig. 2 shows changes in the time of input signals coming from the speed integrator ΔU and distance integrator ΔS for the case when the inertial system operates without any correcting loops and for the case when its circuit contains a constant error.

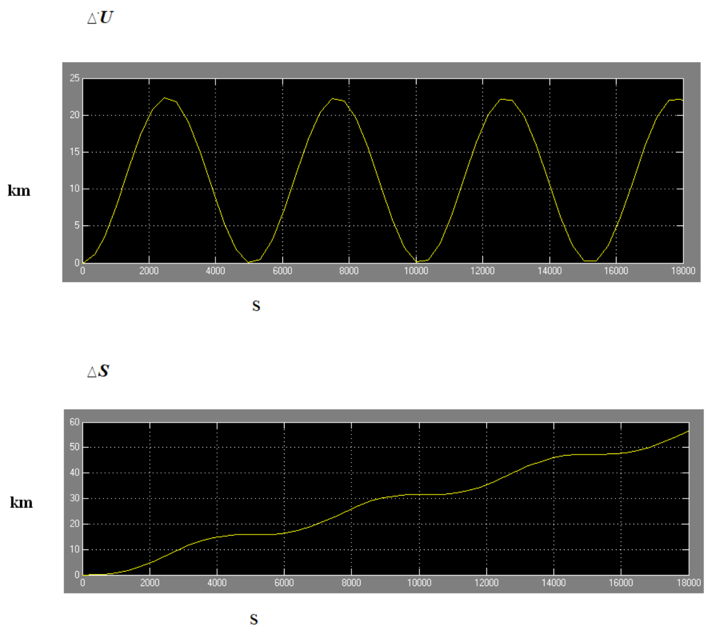

Fig. 2. Diagrams of input signals coming from the speed and distance integrators.

The error of flight speed ΔU changes in time in accordance with the periodic law. The amplitude of the error ΔU and its sign remain constant. The error of distance ΔS increases in time.

After introducing the corrective circuit [16] into the structure of the inertial system, the behavior of its errors changes significantly. Fig. 3 shows changes in the time of ΔU and ΔS errors in time for the case of the minor corrective circuit (Fig. 1, $K_{\mathrm{K}j}$ = var, $K_{\mathrm{K}i}$ = 0) operating according to the information about the distance.

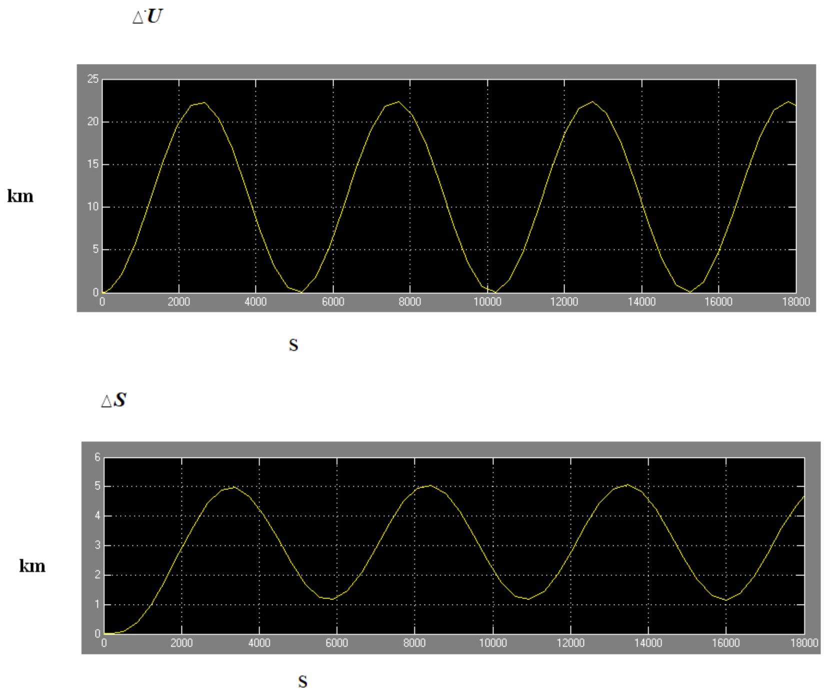

Fig. 3. Diagrams of ΔU and ΔS errors.

The transfer factor of the correcting circuit is $K_{\mathrm{K}j} = 0.001$. The error of the on-board correcting system is 2 m (the satellite navigation system). The error of speed ΔU does not change in comparison with the uncorrected variant of inertial system. The error of distance ΔS does not increase with time any more. The indicator ΔS is oscillating around the average value (3 km). The corrective circuit decreases the error of only those elements the structure of which it covers. Then the structure of the correcting loop changes. A large correcting loop is introduced into the operation (Fig. 1, $K_{\mathrm{K}i}$ = var, $K_{\mathrm{K}j}$ = 0), and the values of maximum error ΔU and ΔS during the modelling period of 5 hours are determined. The results were fixed by means of graphs.

II. Inertial System Correction by Means of Distance Covered Information

The errors of the inertial system [17] were investigated for the case when the structure and transfer factors of corrective circuit changed. Fig. 4 shows the dependence of the values of errors ΔU (curve 1.ΔU and 2.ΔU) and ΔS (curves 1.ΔS and 2.ΔS) on the level of the correcting loop transfer factor K_{K}. These curves were taken for correction according to the parameters of distance for the minor (curves 1.ΔU and 1.ΔS) and major (curves 2.ΔU and 2.ΔS) corrective circuits.

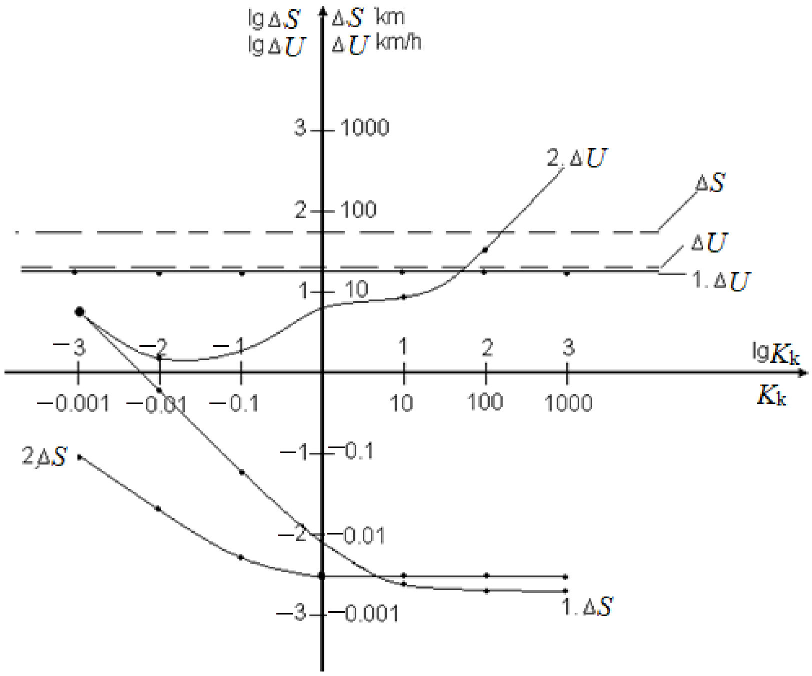

Fig. 4. Dependence of the values of Δ*U* and Δ*S* errors on the corrective circuit transfer factor.

The dotted lines indicate the level of Δ*S* and Δ*U* errors in the inertial system without any correcting loops. It can be concluded from Fig. 4 that along with the increase of the transfer factor K_K the errors of distance calculation (curve 1.ΔS) are decreasing at the distance correction and for the case of the minor correcting loop. With a higher K_K factor the value of error Δ*S* is stabilized at the level of correcting system error (2 m). However, the high values of K_K factor initiate oscillations in the inertial system loop in relation to high frequency. When performing the correction of distance in the case of the minor correction loop (curves 1.Δ*U*), Δ*U* errors will be the same as those for the inertial system without correction. This happens because the correcting loop does not cover the integrator of speed in the inertial system loop.

When performing the correction of distance in the case of the major correcting loop, the integrator of speed will be covered by the correcting loop. Then the errors of speed Δ*U* (curve 2.Δ*U*) decrease along with the decrease of the transfer factor K_K. In the case of the major correcting loop and with the correction of distance, Δ*S* error (curves 2.Δ*S*) decreases along with the increase of the transfer factor K_K. Fig. 4 illustrates that the optimum values of transfer factor for the correcting loop K_K are within the range of low values when the errors Δ*U* and Δ*S* are minimal (from 0.1 to 1.0).

III. Inertial System Correction by Means of Flight Speed Information

Inertial system errors were researched with the correcting loop operating in accordance with flight speed information. Fig. 5 illustrates the structural scheme of the loops in the decisive circuit of the inertial system.

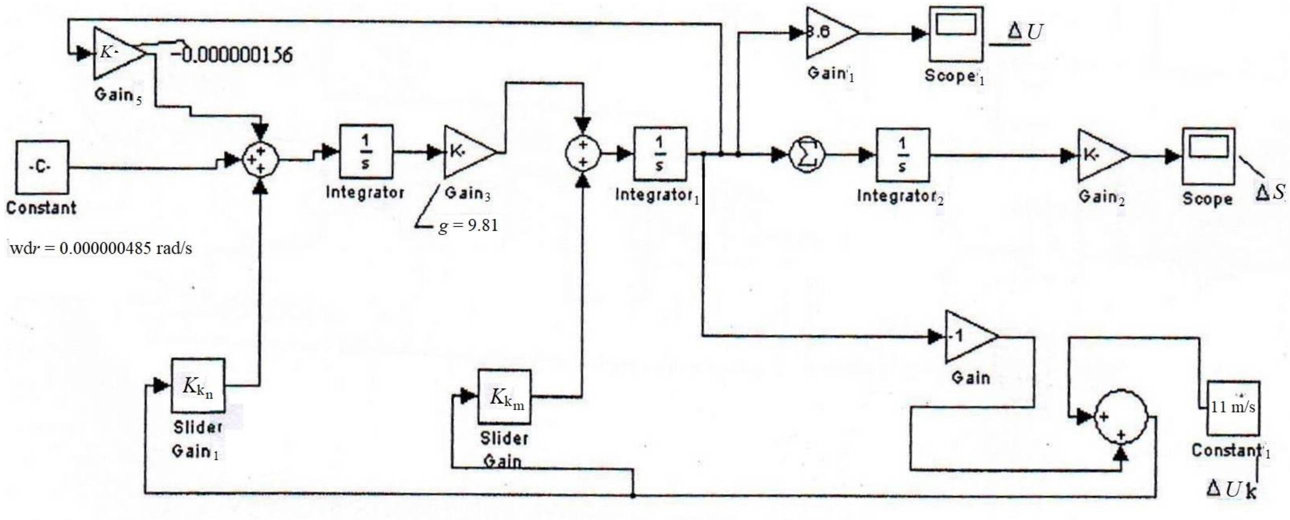

Fig. 5. Structural scheme of the inertial system decisive circuit.

The correcting loops are connected in parallel with the decisive circuit of the inertial system. The integrator of distance is not covered with the circuit. The error of the correcting system was assumed to be equal to 11 m/s. This additional error is introduced directly into the main loop of the inertial system decisive circuit in the case of the second variant of correction (Fig. 5).

Like the correction according to the distance, the decisive circuit operation according to the speed was modelled in two stages. During the first stage only the loop with minor structure operated (Fig. 5. K_{Km} = var, K_{Kn} = 0). Then the loop with major structure was investigated (Fig. 5. K_{Kn} = var, K_{Km} = 0).

Fig. 6 represents the dependencies of ΔU (curves 1.ΔU and 2.ΔU) and ΔS (curves 1.ΔS and 2.ΔS) errors on the value of the correcting loop transfer factor K_K. The curves 2.ΔU and 1.ΔS relate to the case when the correcting loops have the minor structure. The curves 1.ΔU and 2.ΔS relate to the case when the correcting loops have the major structure.

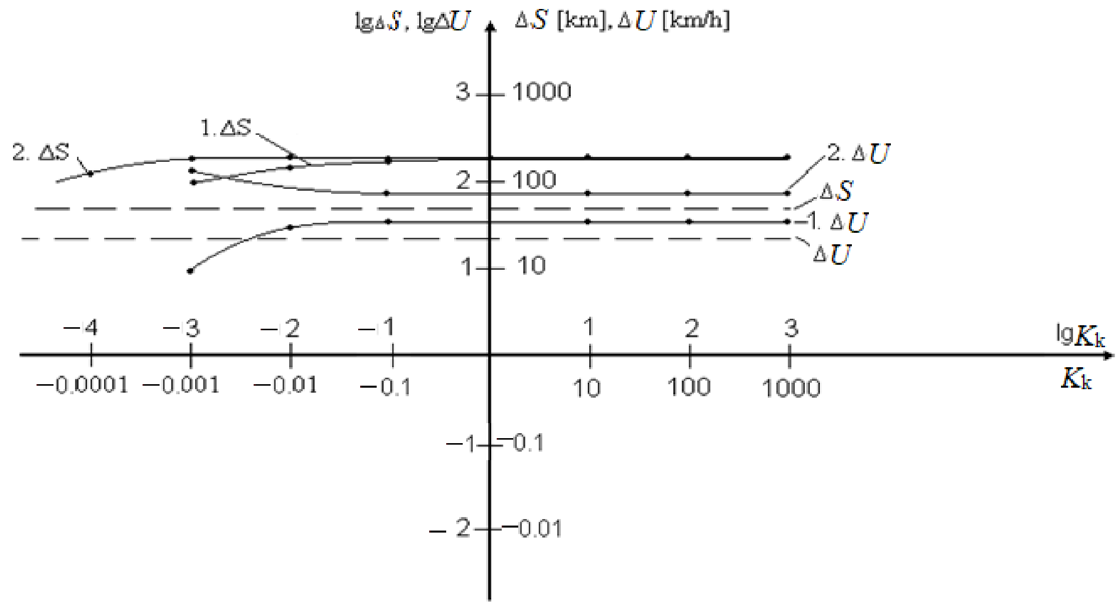

Fig. 6. Dependencies of ΔU and ΔS errors on the transfer factor.

The dotted lines indicate the level of ΔS and ΔU errors of the inertial system without any correcting loops. The analysis of graphs in Fig. 6 states that the positive effect, i.e. error reduction, will occur only in the case of very low transfer factors of correcting loops K_K. The positive effect takes place earlier (with relatively low K_K), with major structure correcting loops.

The basic conclusion of this work is that under particular conditions the structural correcting method gives a positive effect for the decreasing of the errors of inertial system.

IV. Conclusion

1. The introduction of correcting loops into the inertial system structure leads to significant changes in the behavior of system errors.
2. The corrective circuit decreases the error of only those elements the structure of which it covers.
3. In the case of correction according to distance the optimum values of the correcting loop transfer factor K_K lie within the range of low values (from 0.1 to 1.0).
4. In the case of correction according to speed the errors of the inertial system ΔU and ΔS will be larger, then for the case of distance correction. And with very low values of K_K they will decrease becoming closer to the values of ΔU and ΔS at the operation of the inertial system without correction.

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