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The course correction implementation of the inertial navigation system based on the information from the aircraft satellite navigation system before take-off

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Abstract. The use of the correction course option before aircraft take-off after inertial navigation system (INS) inaccurate alignment based on the platform attitude-and-heading reference system in azimuth is considered in the paper. A course correction is performed based on the track angle defined by the information received from the satellite navigation system (SNS). The course correction incudes a calculated track error definition during ground taxiing along straight sections before take-off with its input in the onboard digital computational system like amendment for using in the current flight. The track error calculation is performed by the statistical evaluation of the track angle comparison defined by the SNS information with the current course measured by INS for a given number of measurements on the realizable time interval. The course correction testing results and recommendation application are given in the paper. The course correction based on the information from SNS can be used for improving accuracy characteristics for determining an aircraft path after making accelerated INS preparation concerning inaccurate initial azimuth alignment.

1. Introduction

In the first place, the aircraft path determining accuracy is specified by the initial exposure accuracy of the inertial navigation system in azimuth. The most widely used azimuth alignment in the INS option is gyrocompass azimuth alignment providing necessary and sufficient ramp heading determination accuracy characteristics. But this option has one essential shortcoming for the INS. It is the process of 10…20 min duration.

If it is necessary to reduce the preparation time for departure, one determines the magnetic heading by means of an inductive sensor and then translates it into the true heading with regard to a given magnetic declination and uses the last path value saved by the on-board navigation system after setting the aircraft into the parking space. In addition, this method does not need additional devices or a fine binding of the aircraft to the parking space.

Whereas there is a clear advantage in preparation time, the data error is about 1°, which is insufficiently satisfactory for execution of some proposed tasks. The course error compensation is usually performed by using an additional course correction on the runway, with moving and running start on centerline of a taxiway strip.

The correction course option based on the information from SNS before take-off is aimed at as an alternative method to specify the course value after reduction of the preparation time for departure. The full capacity deployment of satellite orbital constellation GLONASS allows receiving measured parameters with the required accuracy and enables the use of the course correction based on the information from SNS.

2. Course correction based on the information from SNS before take-off

The course correction based on the information from SNS is founded on the assumption of equality of the track angle and the true angle located on straight sections of aircraft taxiing. It should be kept in mind that this assumption can be observed with some error caused by design features of the aircraft.

The current track angle definition based on the information from SNS and its comparison with the current course measured by INS is provided during the course correction of the taxiing sections.

It is assumed that track speeds and accordingly track angles measurement errors based on the information of SNS during straight aircraft movement along the ground are subjected to the normal distribution law with almost zero expectation (which is acceptable for SNS operating in GLONASS in a GPS mode (with turned-off selective availability).

It is also assumed that course wavering measured by SNS relatively the actual track angle during aircraft movement is subjected to the normal distribution law without noticeable INS azimuth drift.

Thus, the course measured by INS and the track angle defined basing on the information from the SNS mismatch expectation may be taken as the INS course error.

The following conditions are used as a criterion, which allows accepting the course measured by INS and the track angle defined basing on the information from the SNS mismatch expectation as a course error:

- the accordance of mismatch to the normal distribution law;
- the accordance of mismatch dispersion to the sum dispersions measured basing on the information from the SNS track angle and measured by the INS course relatively the actual track angle during aircraft movement;
- the required accuracy is provided by the mismatch measurements number.

3. Implementation and testing course correction based on the information from the SNS mode

The present mode was integrated in the onboard complex software of the aircraft of L-39 type for testing the course correction based on the information from SNS. The mode calculations were implemented by the onboard digital computational system with results registered on the onboard drive and their subsequent processing by the ground workstation.

The course correction based on the information from the SNS mode functioning scheme is represented in Figure 1. It consists of SNS at the evaluation stage of the parking space parameters, the course error according to the taxiing sections calculation and manually through the multifunctional display of the course correction stage.

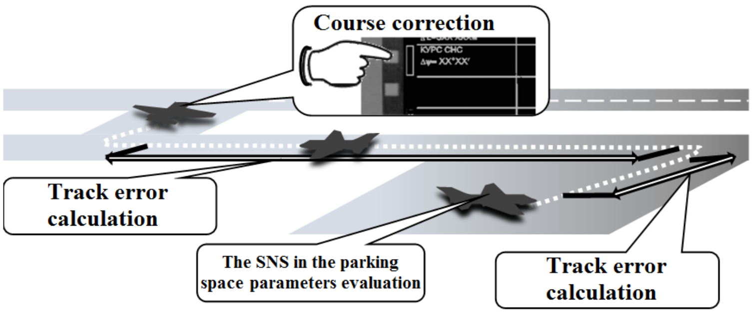

Figure 1. Scheme of the course correction mode.

The SNS information in the GLONASS+GPS mode with the measurement parameters frequency of 10 Hz and geometric factor of less than 2 provided with continuity monitoring and continuity measurement by the SNS data is used as the background information for mode evaluation.

The SNS parameters evaluation of the parking space was implemented in the continuous measurement interval of 10-30 sec with the SNS ground speed values not exceeding 0.2 m/s. Speed components provided by the SNS information, which define a given track angle, are the estimated parameters.

Measurement errors of the northern (WN) and eastern (WE) speed components by the SNS information (σ), which are defined in the measurement interval of 10…30 s with the frequency of 10 Hz, and distribution curves of total speed value expectation (M) in the measurement interval of 10 s and 30 s are represented in Figure 2. The results are obtained from more than 500 implementations, which are spaced in time and place.

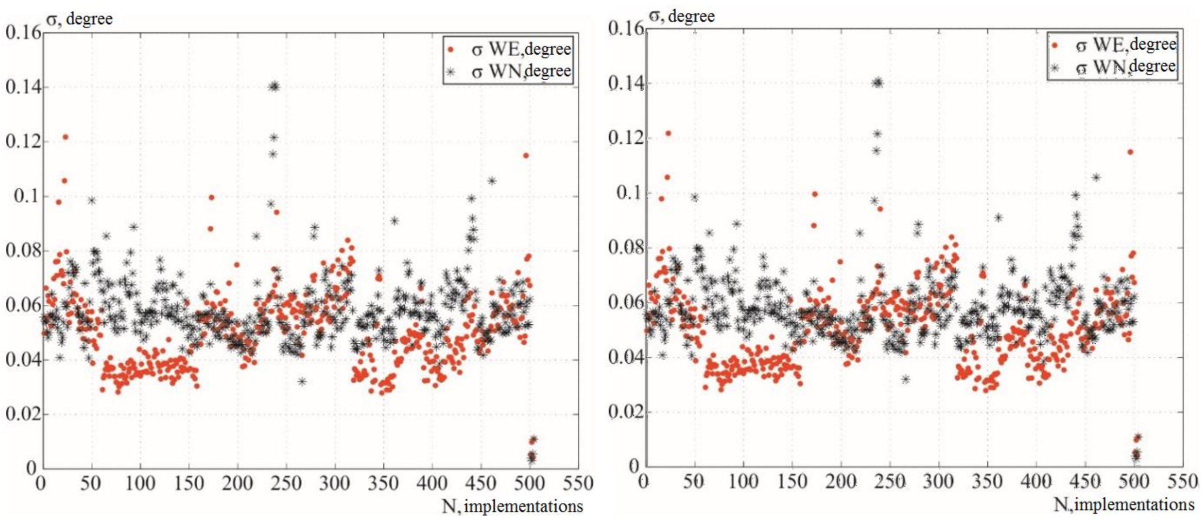

Figure 2. Measurement error of speed components based on the information from SNS and the distribution curves of total SNS speed value expectation.

Speed components measurement errors, which are obtained from the SNS information, are matched to declared characteristics, when SNS operates in the GLONASS mode with the standard accuracy and in the GPS mode with the absence of selective access. Speed measurement errors are up to 0.2 m/s (2σ).

The track error calculation was implemented along the straight section of the airplane movement, which is characterized by the absence of a turn sign and by the track speed obtained from SNS, which exceeded the given threshold value, allowing the obtainment of the sufficient accuracy of the track angle calculation. The INS course changing speed by more than 1 °/sec was accepted as a turn sing. The INS course changing speed value equal to 6 m/s was accepted as a threshold value of speed.
A discrete course error was defined as a difference between the course measured by INS and the track angles calculated by track SNS speed components according to the following formula:

$$\Delta\varphi = \varphi_{\mathrm{i}}^{\mathrm{INS}} - \mathrm{arctg}\left(\frac{WE_{\mathrm{i}}}{WN_{\mathrm{i}}}\right)$$

where $\Delta\varphi_i$ – discrete course error of the *i*-th calculation cycle; φ_i^{INS} – true course, measured by INS; WN_{i}, WE_{i} – northern and eastern track of SNS speed components.

Track error distribution curves for 11 implementations with more than 400 measurement error cycles in every implementation with total taxi time from 20 s to 120 s are represented in Figure 3. These curves are matched to the normal distribution law with the insignificant deviation, which are determined due to the airplane performance during movement and environmental characteristics. The oscillation amplitude of the course relative track angle measured by INS during airplane movement was less than 1°.

The unknown quantity of the INS error, which is defined according to the information from SNS, is an expectation and is defined along the straight section of the airplane movement according to the following formula:

$$\Delta\Psi_{av_i}=\Delta\Psi_{av_{i-1}}+\frac{1}{i}\left(\Delta\Psi_i-\Delta\Psi_{av_{i-1}}\right);$$

where $\Delta\psi av_i$ – track error after the *i*-th calculation cycle; $\Delta\psi av_{i-1}$ – track error after the $(i-1)$-th calculation cycle.

The number sufficiency of measurements is defined using the track error measurement accuracy calculation (ε):

$$\varepsilon^2=1.96^2\cdot\frac{\sigma_i^2}{(i-1)}$$

where variance (σ_i^2) is defined according to the following formula:

$$\sigma_i^2=\sigma_{i-1}^2\cdot\frac{(i-2)}{(i-1)}+\frac{(\Delta\Psi_i-\Delta\Psi_{av_{i-1}})^2}{i}$$

A sufficient track error measurement accuracy is considered to be 0.05º, which matched more than 400 course measurement error calculation cycles on the average.

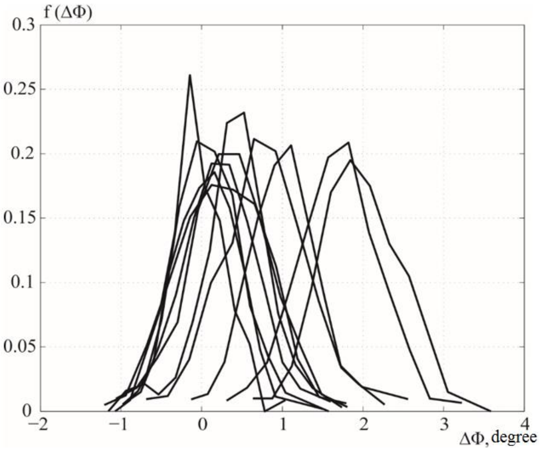

Figure 3. Track error distribution curves.

The mean square deviation of the track error in the measurement of the interval aimed at as substituting criteria of the calculated track error of the normal distribution law and of the absence of bias in its assessment. The criteria value should not exceed 0.3°.

The given mean square deviation is defined according to the following formula:

$$\sigma[\Delta\varphi_{av}]_i^2=\sigma[\Delta\varphi_{av}]_{i-1}^2\cdot\frac{(i-2)}{(i-1)}+(\Delta\varphi_{avp_i}-M\left[\Delta\varphi_{av}\right]_{i-1})^2/i$$

where

$$M[\Delta\Psi_{av}]_i=M[\Delta\Psi_{av}]_{i-1}+\frac{1}{i}\left(\Delta\Psi_{av_i}-M[\Delta\Psi_{av}]_{i-1}\right);$$

$\sigma[\Delta\psi av]_i$ – track error mean square deviation in the measurement interval of the *i*-th calculation cycle.

The course correction mode evaluation using the information from SNS was implemented by a comparison of the corrected course obtained from the SNS information, leading to the parking space, with a reference value.

The ramp heading value, which is defined through a theodolite, is aimed at as the reference value.

The error value, which was obtained during correction of the information obtained from SNS by all implementations, did not exceed 20′. This fact makes implementation of this correction of the INS inaccurate alignment by azimuth worthwhile.

According to the ground tests result, the course correction mode based on the information obtained from SNS was recommended to use for clarification of the airplane course after the INS accelerated preparing with the initial azimuth defined by the magnetic corrector.

4. Conclusion

The course correction based on the information obtained from SNS before take-off can be used for improving the accuracy characteristics of the definition of the airplane course, if the airplane has an inertial navigation system based on the platform of the attitude-and-heading reference system, after the INS accelerated preparing with the specified initial azimuth determined by a magnetic corrector.

The course error value for correction is defined during airplane taxiing for 20 s with operating SNS in the GLONASS or GPS mode (with turned-off selective availability) and is available using data of integrity monitoring, and with the operating additional parametric control of measured and calculated parameters. The calculation error will not exceed 20′.

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