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IMPLEMENTATION ERROR OF RELATIVE MEASUREMENTS

The RNE time scale parameters impact the NSC signal-tracking system operation and the forming of radio navigation signal parameter evaluations had been studied.

Keywords: error, measurement, frequency, reference generator, navigation spacecraft, phase.

Pseudorange measurement errors are affected by the instability of an automatic voltage control reference-frequency generator. The purpose of the analysis is to measure the impact parameters on the automatic voltage control provisional scale for low critical range of signal tracking system operation; and the formation of radio-navigation signal parameter evaluations.

An automatic voltage control provisional scale is formed on the base of reference generator frequency. The reference generators used, are not ideal and the reference generator frequency is unstable. These disadvantages affect the automatic voltage control provisional scale. There are two kinds of reference-frequency generator instabilities: the short-term instability and the long-term instability.

During fulfillment of the task, concerning relative coordinates' position measurement, the short-term instability of frequency can be of some interest. Short-term instability of frequency means that relatively quick changes of reference generator signal frequency that took place for example, during an interval of one second. Long-term instability of frequency does not impact tracking system operation; therefore it is possible to not consider it.

The frequency variation Δf_k that takes place during the time of a constant interval Δt_k is a random quantity within the Gaussian law and zero-centered. It is suggested that a value of frequency instability δ at a correct time interval, determined in the reference generator ratings (for example, $1{\cdot}10^{-11}$ per 1 second), is the limit (3σ) value of a frequency chance variation Δf_k for this time interval.

If a value of the reference generator instability during any time interval Δt is equal to δ, it means that by means of the completion moment in every following time interval Δt_k a current frequency value of the reference generator Δf_k can change, relatively to the frequency value $f(k-1)$, affecting the random value at the beginning of interval Δt_k. The limit value of a random quantity is calculated by using the following formula:

$$\Delta f_{\max} = \delta \cdot f_k. \quad (1)$$

Considering the fact that frequency deviation of a reference generator is much lower than the nominal value of the reference generator frequency, we can replace in formula (1) the frequency value $f(k-1)$ by the nominal frequency value of a reference generator f_{H}.

Then:

$$\Delta f_{\max} = \delta \cdot f_{\text{H}}. \quad (2)$$

It is recommended to study two variants of the frequency variation model during the time interval resulting from its instability (linear and steplike).

Under the linear frequency variation, a frequency variation of the reference generator takes place during the whole time interval Δt_k linearly, beginning from the value null; by the end of the interval it reaches the value Δf_k, which accidentally occurred in the given interval [1]. This variant is probably the closest to the actual processes of a reference generator. A frequency variation in the first model will occur if a frequency derivative change discontinuously at the beginning of interval Δf_k and remains unchanged during all of its extent. In this case a frequency derivative value can be the following:

$$f_k^{`} = \frac{\Delta f_k}{\Delta t}. \quad (3)$$

According to the linear model a phase variation of a reference generator signals $\Delta\varphi_k$ in interval Δt_k the value will be the following:

$$\Delta\varphi_k = 2\pi f_k^{`} \frac{\Delta t^2}{2} = 2\pi \frac{\Delta f_k \Delta t}{2}. \quad (4)$$

A phase variation limit value of a reference generator signal $\Delta\varphi \max$ is:

$$\Delta\varphi_{\max} = 2\pi \frac{\Delta f_{\max} \Delta t}{2} = 2\pi \frac{\delta \cdot f_H \Delta t}{2}. \quad (5)$$

In the case of a steplike frequency variation; a frequency variation Δf_k taking place discontinuously at the beginning of every interval Δt_k immediately on a whole magnitude of a frequency variation that occurred in the given interval and during the whole interval Δt_k remains unchanged. It seems to be an imperfect variant and it could be used for achieving the limit evaluations.

The change of the reference generator signal phase $\Delta\varphi_k$ is determined as:

$$\Delta\varphi_k = 2\pi\Delta f_k \Delta t \, . \quad (6)$$

In accordance to (6), a limit value of a RG phase variation $\Delta\varphi_{\max}$ will be:

$$\Delta\varphi_{\max} = 2\pi\delta f_H \Delta t. \quad (7)$$

Comparing formulas (6) and (7), it is easy to notice that a phase variation of a RG signal in a steplike frequency variation is twice as high as the changes in a linear model. A linear frequency variation would be enough to analyse the calculation results and a steplike frequency variation would be corrected.

Analyzing the impact of short-time instability of a RG on Servo Systems filter operation that measures a signal phase (and its derivations), there has been a consideration. When an interval of a filter discretization is 1 second, 100 milliseconds, and 10 milliseconds – the analysis should be performed.

The nominal value of a RG frequency is equal to 10 megahertz.

During the 1 second interval the value is $\delta = 1 \cdot 10^{-11}$. According to the formula (7), the maximum phase shift of the RG output signal for one second for the linear variant equals 0.018°. For the period of 100 msec the RG signal phase shift will be 0.00018°, for 10 msec – 0.00018°. The given changes of the RG phase are equal to the shift of the radio navigation equipment timeline, thus $5 \cdot 10^{-12}$ sec, $5 \cdot 10^{-13}$ sec и $5 \cdot 10^{-14}$ sec.

Resulting from the multiplication of the RG frequency and the Phase-Locked Loop, and forming conversion signals of radio navigation equipment (the overall multiplication coefficient ≈ 160) on NSV carrier frequency phase shift will be $\approx 3°$ for 1 sec, $\approx 3°$ for 100 msec, $\approx 0.03°$ for 10 msec.

The received values of signal phase variation caused by RG frequency instability are considered to be valid in terms of a phase estimation dynamic error for all analyzed interval values of a filter discretization. A limited value of this error $\approx 9°$ (when a discriminator curve aperture of phase discriminator is $\pm 90°$).

It is possible to compare the given values of additional fluctuations for an input signal phase determined by the RG instability, and the value of a random error component (noise error). Under the selected interval values of a filter discretization, the maximum values for a coherent integration interval in a phase filter discriminator (PD) comprises 1 sec, 100 msec and 10 msec. Noise values in these conditions are 1 Hz, 10 Hz and 100 Hz, consequently.

It is obvious that the values for a discretization interval and a coherent integration interval in PD could be different. For example, by using a discretization interval of 100 msec it is possible to apply an acquisition interval of 10 msec; however this case is limited.

With the bottom value of an energy potential in GLONASS/GPS radio navigation equipment (≈ 35dBHz), a noise error of a phase estimation ($\sigma\varphi$) has the following values (for 1 Hz $\sigma_\varphi \approx 1°$, for 10 Hz $\sigma_\varphi \approx 2.5°$, for 100 Hz $\sigma_\varphi \approx 8°$).

For the intervals of 10 msec and 100 msec additional phase fluctuations caused by RG instability are lower than a value of a noise error. At the same time for the accumulation interval of one second an error resulted from RG instability is dominant.

It can be concluded that for the long-duration coherent integration intervals (≥ 1 sec) in a PD it is recommended to use RG with improved characteristics of short-time instability).

A limit value of a short-time instability of the RG frequency is determined as a value that includes a chance variation of a phase difference between input signal and reference signal caused by the change of reference signals (including heterodyne signals) during the filter discretization interval providing a phase evaluation of an input signal.

The threshold value of phase fluctuation is possible to be equal to 9°; at various discretization critical change intervals, the reference signal phase will be caused by the different levels of the RG instability. The changing of the reference signal phase by 9° will take place in phase change of the RG of $\approx 0.06°$. It is necessary to determine that the allowable instability of the RG frequency for the discretization interval during one second equals $3.5 \cdot 10 \cdot 11^{-11}$ ($1.6 \cdot 10^{-11}$). For the intervals of 100 msec and 10 msec the possible values of instability will be $3.3 \cdot 10^{-10}$ ($1.6 \cdot 10^{-10}$), $3.3 \cdot 10^{-9}$ ($1.6 \cdot 10^{-9}$).

Using this way it is possible to estimate the instability value that would not just be admissible, but be "working". As a criterion it is advisable to take the value of the heterodyne oscillator phase noises 1°.

The heterodyne oscillator phase will become 1° in condition that the reference generator phase will be changed to $\approx 0.006°$. On this basis a required instability of the RG frequency for the discretization interval of 1 second equals $3.5 \cdot 10^{-12}$. For the intervals of 100 msec and 10 msec the desired values of instability will be $3.5 \cdot 10 \cdot 11^{-11}$ and $3.5 \cdot 10^{-10}$. The shift of the RNE time scale in the specified target values of instability will not exceed $1.6 \cdot 10^{-12}$ sec.

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