AUTOMATIC CONTROL SYSTEMS

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PROVISION THE REQUIRED ACCURACY OF THE SENSORS OF ANGULAR VELOCITIES THAT WORK IN STRUCTURE OF AUTOMATIC CONTROL SYSTEMS

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Abstract—*Considered the method of providing the required accuracy of the angular velocities sensors, based on choosing their parameters, considering the frequency characteristics of the control object*

Index Terms—Speed sensor; frequency characteristic; damping coefficient; "single" gyroscope; amplitude error; the phase error; wave diagram; normalized characteristic; the relative.

I. INTRODUCTION

The presence of speed sensors (SS) in automatic control systems (ACS) provides the formation of the damping component in the stabilization moment. The efficiency of damping vibrations of control object is higher when the sensor's signal level is higher.

The frequency characteristics of the speed sensors are completely determined by the parameters of torsion gyroscope with two-degree-of-freedom, so as converters of angular deviations into proportional electric signals almost inertialess and are not affected on nature of the frequency dependencies. That's why as the SS output signal the angle β_o of relative frame turn is usually accepted.

The main frequency characteristics of speed sensor are:

– amplitude-phase frequency characteristic (APFC)

$$W(j\omega) = H/C_t \frac{\left[\left(1 - T_4^2\omega^2\right) - jT_3\omega\right]}{\left(1 - T_4^2\omega^2\right)^2 + T_3^2\omega^2};$$

– amplitude frequency characteristic (AFC)

$$A_m(\omega) = H/C_t \frac{1}{\sqrt{\left(1 - T_4^2\omega^2\right)^2 + T_3^2\omega^2}};$$

– phase frequency characteristic (PFC)

$$\varphi(\omega) = -\text{arctg}\frac{T_3\,\omega}{\left(1 - T_4^2\omega^2\right)}.$$

Characteristics, mentioned above, for the different values of damping coefficient $d_0 = \dfrac{T_3}{2T_4}$ are given in Figs 1 – 3. Characteristics are given for the case, when the input signal of sensor is the absolute speed of angular vibrations of its base $\Omega_0(t) = \Omega_{0m}\sin\omega t$.

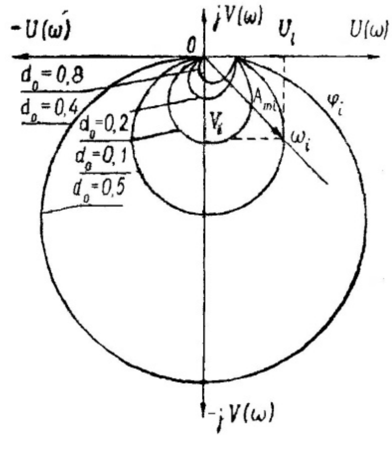

Fig. 1. Amplitude-phase frequency characteristic

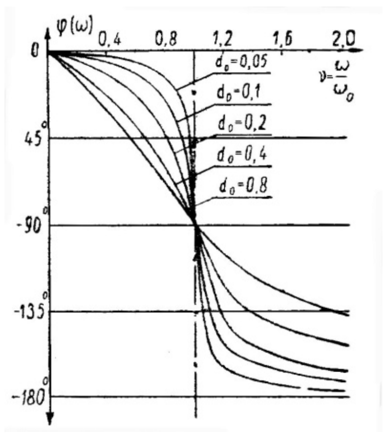

Fig. 2. Phase frequency characteristic

Frequency characteristics are received by substituting $s \to j\omega$ into the transfer function of speed sensor $W_{ss}(s)=\dfrac{\beta_0}{\Omega_0}=\dfrac{H/C_t}{T_4^2 s^2+T_3 s+1}$ and are constructed for "unit" gyro with transmission coefficient $\dfrac{H}{C_t}=1$ in the function of relative frequency $v=\dfrac{\omega}{\omega_0}=\omega T_1$ at $d_0=0{,}05;\ 0{,}1;\ 0{,}2;\ 0{,}4;\ 0{,}8$.

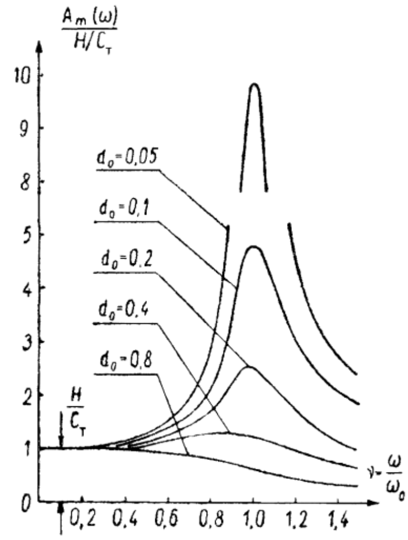

Fig. 3. Amplitude frequency characteristic

These frequency characteristics show that due to the inertia of the gyro frame and friction in its supports the forced precession vibrations of the frame fall behind in phase from the measured absolute angular velocity of the base (control object) and phase angle $\varphi(\omega)$ at frequency change from 0 to $+\infty$ changes from 0 to $-\pi$ (see Fig. 2). The greater the damping coefficient d_0, the more phase delay vibration gyroscope frame.

Relative amplitude of vibrations $A_m(\omega)=\dfrac{\beta_{0m}(\omega)}{\Omega_{0m}}$ at $d_0<1$ is growing while increasing the frequency, reaching its maximum value at $v=\sqrt{1-2d_0^2}$, and then decreases, asymptotically approaching to zero (see Fig. 3). The lower the damping coefficient, the more pronounced the resonance peak. At $d_0>1$ resonance phenomena are absent, and amplitude, with the increasing of frequency, monotonously decreases more faster with the increasing of damping coefficient.

Thus, the measurement of absolute angular velocity is performed by the gyro sensor with the defined amplitude-phase errors, the values of which depends on both own gyro parameters and base frequency oscillations.

II. Problem Statement

The influence of frequency vibrations of control object, the absolute angular speed of which is measuring, on the output signal of SS, determines the alternating character of sensors' errors. That's why the strict agreement of speed sensors parameters with the frequency characteristics of the control object is the necessary condition, that affects the quality of work of automated control systems.

III. Solution to the Problem

In accordance with amplitude-phase frequency characteristic (see Fig. 1) forced precession vibrations of gyroscope frame

$$\beta_0(t)=\beta_{0m}(\omega)\sin\left[\omega t+\varphi(\omega)\right]$$

can be represented by two components

$$\beta_0(t)=\beta_{0m}(\omega)\cos\varphi(\omega)\sin\omega t + \beta_{0m}(\omega)\sin\varphi(\omega)\cos\omega t.$$

Taking into account, that amplitude of precession frame vibrations $\beta_{0m}(\omega)=A_m(\omega)\Omega_{0m}$, and change in time of base angular turn $\alpha(t)=-\dfrac{\Omega_{0m}}{\omega}\cos\omega t$, we will obtain

$$\begin{aligned}\beta_0(t)&=A_m(\omega)\cos\varphi(\omega)\Omega_0(t)\\&\quad-\omega A_m(\omega)\sin\varphi(\omega)\alpha(t)\\&=U(\omega)\Omega_0(t)-\omega V(\omega)\alpha(t)=\beta_{0s}(t)+\beta_{0a}(t),\end{aligned} \tag{1}$$

where $U(\omega)=A_m(\omega)\cos\varphi(\omega)$ is the real frequency characteristic, and $V(\omega)=A_m(\omega)\sin\varphi(\omega)$ is the imaginary frequency characteristic of gyro (Figs 4 and 5).

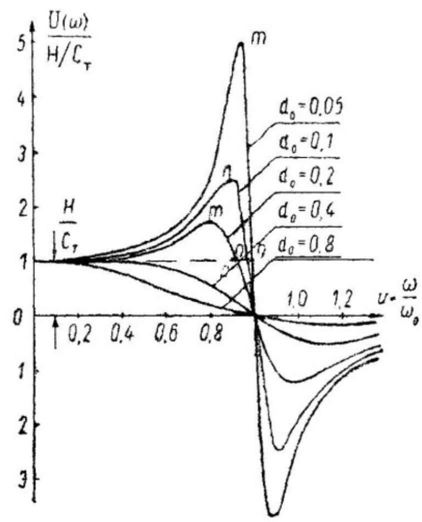

Fig. 4 Real frequency characteristic

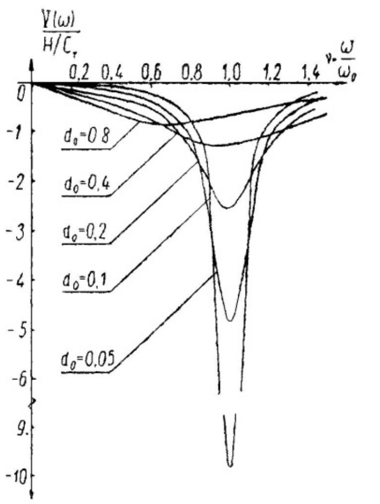

Fig. 5. Imaginary frequency characteristic

Component $\beta_{0s}(t)=U(\omega)\Omega_{o}(t)$ coincides by phase with absolute velocity of base and is useful output signal of sensor, and component $\beta_{0a}(t)=\omega V(\omega)\alpha(t)$ are coincides by phase with the change of base turn angle, thus is a phase error of sensor. The corresponding wave diagrams are given in Fig. 6.

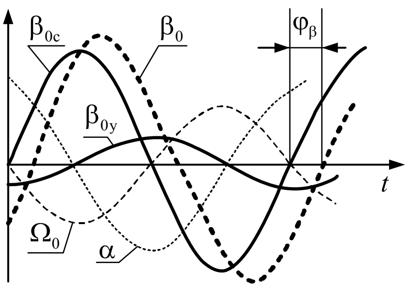

Fig. 6. Wave diagrams of the control object and speed sensor frame vibrations at $\omega = \mathrm{const}$

Knowing the amplitude of the useful sensor output

$$\beta_{0csm}=U(\omega)\Omega_{0m}=\frac{H}{C_{t}}\frac{1-T_4^2\omega^2}{\left(1-T_4^2\omega^2\right)^2+T_3^2\omega^2}\Omega_{0m},$$

we determine the dependence of the amplitude error measurements of absolute rate from the frequency

$$\Delta\beta_{0sm}(\omega)=\beta_{0sm}(\omega)-\frac{H}{C_{t}}\Omega_{0m}=\left[U(\omega)-\frac{H}{C_{t}}\right]\Omega_{0m}.$$

Thus, amplitude error is defined by the real frequency characteristic of gyro speed sensor (Fig.4). In other words - is a scaled real frequency characteristic of gyro speed sensor. Just like the real frequency characteristic, the amplitude error is a nonlinear function of frequency, and the nature of the nonlinearity depends on the damping coefficient d_0.

Characteristic analyses shows, that only at $\nu \le 0,2...0,25$ in the first approach it is possible to consider $\Delta\beta_{0sm}(\omega)\approx 0$. If $d_0 < 0,707$, the amplitude error rises at first, approaching at $\nu=\sqrt{1-2d_0}$ its maximum value (points m at Fig. 4), and then decreases and at $\nu=\sqrt{1-4d_0}$ changes its sign.

Thus, with the real frequency characteristic of the gyro sensor, knowing its damping coefficient, one can determine the amplitude error for any of the operating frequencies.

Similarly determined the amplitude of the phase error by the imaginary frequency characteristic of the sensor's gyroscope (see Fig. 5).

Knowing the amplitude of the component

$$\beta_{0am}=\omega V(\omega)\alpha_{m}=\frac{H}{C_{t}}\frac{T_3\omega^2}{\left(1-T_4^2\omega^2\right)^2+T_3^2\omega^2}\alpha_{m},$$

we determine the dependence of the phase error measurement of the absolute speed from the frequency

$$\Delta\beta_{0am}(\omega)=\beta_{0am}-\frac{H}{C_{t}}\Omega_{0m}=\left[V(\omega)-\frac{H}{C_{t}}\right]\omega\ \alpha_{m}.$$

Consequently, the amplitude of the phase error is completely determined by the imaginary frequency characteristic (see Fig. 5) of the speed sensor's gyro.

The imaginary frequency characteristic throughout the frequency range is negative. Its module with increasing frequency nonlinearly increases, reaching a maximum at $\nu = 1$. In the initial section ($\nu \le 0,3$) we can assume that $V(\omega)$ is proportional to the frequency.

During structural analyses of automatic control systems, the input signal of speed sensor is usually considered not the angular velocity of control object, but a corresponding to it the angle of rotation. It is expedient to do as, firstly, angle is the regulated coordinate of system, secondly, the simplest is to measure frequency characteristics, changing the frequency of angular vibrations at constant amplitude, and thirdly, it is easier to perform the analyses and calculation of frequency characteristics relatively to the angle, than to the velocity.

If to consider angular oscillations of control object as the input signal $\alpha(t)=\alpha_m \sin\omega t$, then frequency characteristics are determined by substitution $s \to j\omega$ into the transfer function

$$W_{ss}(s) = \frac{\beta_0}{\alpha_0} = \frac{\frac{H}{C_t} s}{T_4^2 p^2 + T_3\, p + 1}.$$

In this case amplitude-phase frequency characteristics are circles with the coordinate centers $\left(\frac{H}{2C_t T_3};\ j0\right)$ and diameter, equal to $\frac{H}{C_t T_3}$. Parametric equation of these circles is

$$\left(U_\alpha - \frac{H}{2C_t T_3}\right)^2 + V_\alpha^2 = \frac{H^2}{4C_t^2 T_3^2}.$$

Thus, amplitude-phase frequency characteristic $U_\alpha(\omega_i) \to jV_\alpha(\omega_i)$ may be constructed by one given or experimentally obtained point. It is also simple to determine for the chosen type of gyro damping coefficient.

Having real and imaginary characteristics, we can determine constituents $\beta_{0s}(t)$ and $\beta_{0a}(t)$ of the output signal of gyro speed sensor

$$\beta_0^\alpha(t) = V_\alpha(\omega)\Omega_0(t) + U_\alpha(\omega)\alpha(t). \qquad (2)$$

It is easy to make sure the equations (1) and (2) are equivalent.

Important advantage of received frequency characteristics is the possibility to represent them in a standardized form, which sufficiently simplifies all the calculations.

Really, taking per unit scale $A_{\max}^\alpha = \frac{H}{C_t T_3}$, we will receive instead of family of amplitude-phase frequency characteristics one circle of unit radius. If to choose a scale relatively to frequency $\nu = \frac{\omega}{\omega_0}$ so, that $\nu = 2$ corresponded to $\alpha_{m\beta}^\alpha = \frac{A_{m\beta}^\alpha}{A_{\max}^\alpha} = 1$, then all frequency characteristics may be united into one graph.

When choosing speed sensor parameters, are taking into account, first of all, the conditions of its work on the stabilized control object. Usually in the technical task for the design of the sensor are indicated:

– the range of possible angular velocities that must be measured by a sensor;

– the range of possible frequencies of angular vibrations of the control object;

– the permissible value of the errors measurement of the angular velocity.

If the parameters of the gyroscope and the transducer of the angular deviations on the basic parameters are selected and sufficiently are in good agreement, then are moving to the definition of the damping coefficient d_0. For given values of amplitude and phase errors allowable value of the damping coefficient is computed based on the normalized frequency characteristics of a class of gyros. If the average error values are given, it is taken into account the mean value of the measured angular velocity. If you have the maximum value of errors, the damping coefficient is determined by the maximum amplitude of the angular velocity.

IV. Conclusions

1) Matching of parameters of speed sensors with the frequency characteristics of the control object is a prerequisite while designing the sensors, on which depends the quality of the automatic control systems.

2) The presence of the normalized frequency characteristics of a class of gyroscopes allows:

– on the set of damping coefficients define the value of the amplitude and phase errors of the speed sensors and make a decision on according the sensor to the technical requirements for measurement accuracy;

– for given values of the amplitude and the phase errors of velocity sensor find the desired value of damping coefficient with the aim to optimize the sensor parameters.

3) Application of the normalized frequency characteristics when choosing a speed sensor parameters significantly reduces the amount of computation.

4) Construction of the families of such characteristics is facilitated by the use of software packages.

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О. К. Аблесімов, К. О. Адамчук, А. М. Рябоконєв. Забезпечення необхідної точності датчиків кутової швидкості, що працюють у складі систем автоматичного керування

Розглянуто методику забезпечення необхідної точності датчиків кутових швидкостей, яка заснована на виборі їх параметрів з урахуванням частотних характеристик об'єктів керування.

Ключові слова: датчик швидкості; частотна характеристика; коефіцієнт загасання; «одиничний» гіроскоп; амплітудна помилка; фазова помилка; хвильова діаграма; нормована характеристика; відносна частота.

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А. К. Аблесимов, Е. А. Адамчук, А. М. Рябоконев. Обеспечение требуемой точности датчиков угловых скоростей, работающих в составе систем автоматического управления

Рассмотрена методика обеспечения требуемой точности датчиков угловых скоростей, основанная на выборе их параметров с учетом частотных характеристик объектов управления

Ключевые слова: датчик скорости; частотная характеристика; коэффициент затухания; «единичный» гироскоп; амплитудная ошибка; фазовая ошибка; волновая диаграмма; нормированная характеристика; относительная частота.

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