Hybrid Sensor for Determining the Angular Position

A A Tsatsin

1Joint Stock Company «Avionica», Moscow, Russia

E-mail: sand_e@mail.ru

Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Abstract
The basic provisions of the approach to the creation of hybrid angular position sensors, the principle of output signal correction are considered.

Keywords: analog angular position sensor, digital angular position sensor, hybrid angular position sensor, correction

1. Introduction
In the development of automatic control systems aircraft inevitably raises the question of the choice position sensors various objects: controls, steering surfaces, etc. Currently, there is a steady trend of transition from analog to digital sensors, while one of the main problems remains the need to ensure the specified accuracy of the sensor.

This article discusses the basic provisions of creating a prototype hybrid angular position sensor, which includes both analog and digital sensor, connected in a certain way both structurally and algorithmically in order to obtain a single output signal.

In aviation systems, analog sensors in their pure form are rarely used, more often they are used in conjunction with an analog-to-digital converter of the output signal. This integration makes it possible to significantly simplify the processing of the output signal in modern digital computing systems.

At the same time, the main disadvantage of analog sensors is a relatively high dependence of the output signal on external influences: temperature, humidity, pressure, etc.

Digital position sensors are significantly less affected by the external environment, but have their own disadvantages:
- incremental sensors have not yet found application in aviation, because in case of loss and subsequent restoration of power supply it is not possible to determine the current object angular position;
- absolute sensors with high accuracy have relatively large dimensions, which is why there are difficulties in the organization of redundancy channels to obtain information about the current position.

2. Basic information
To overcome the current situation with the shortcomings of existing angular position sensors, it is proposed to create a Hybrid Sensor (HS), the block diagram of which is presented in figure 1 [1].

The figure shows that the hybrid position sensor includes the following main elements:
- Digital Sensors (DS);
- Analog Sensor (AS);
- Analog-to-Digital Converter (ADC);
- Controller.

Figure 1. Block diagram of the Hybrid Sensor.
The basic idea of hybridization is to use different measurement principles. In this case, simultaneously with the analog angular position sensor, a digital direct conversion sensor "position-code" is used.

The sensors included in the hybrid have different approaches to measuring the angular position, so it is convenient to model and analyze the output characteristics of the sensors in a rectangular Cartesian coordinate system "specified angular position-output angular position". This allows you to get away from the consideration of physical phenomena occurring in the sensors and the parameters describing them.

At the initial stage of research in the mathematical modeling of the hybrid sensor, we assume the following assumptions:

- no noise of analog sensor and ADC;
- no "rattle" of the digital sensor.

For example, consider a hybrid angular position sensor, which includes a hypothetical digital and analog sensors with output characteristics, respectively, $\beta_d(\alpha)$ and $\beta_a(\alpha)$ (figure 2). The figure also shows the output characteristic of the angular position Ideal Sensor (IS).

![Figure 2. Output characteristics DS, AS and IS.](image)

As can be seen from figure 2, the output characteristic $\beta_a(\alpha)$ of a hypothetical Analog Sensor has bad features:

- different degree of curvature in different parts of the characteristic;
- there are offsets characteristics at $\alpha=0$ and $\alpha=\pi$;
- the characteristic offsets in $\alpha=0$ and $\alpha=\pi$ are not equal.

As a prototype, a mathematical model of a single-track binary Digital Sensor based on the $T$-sequence $T=\{0011\}$.

Digital Sensor — binary, has a bit width $n_d=2$ and therefore has the number of angular positions (quant) $N$ equal to

$$N = 2^n = 2^2 = 4.$$  

For any $i$-th quants of digital sensor, knowing the current values of the signals $\beta_d$, $\beta_a$, digital and analog sensors, respectively, it is possible to determine the value of the object current angle $\gamma$ [2].

$$\gamma = \frac{\beta_a - \beta_{ai}}{k_i} + \beta_{ai},$$  \hspace{1cm} (1)

where

$$k_i = \frac{\beta_{ai} - \beta_{ai-1}}{\alpha_{dl}},$$  \hspace{1cm} (2)

chord slope coefficient of the output characteristic AS in $i$-th quants, here $\beta_{ai}$ — the value of the analog sensor signal to the switching instants of the quants; $\alpha_{dl} = \beta_{di+1} - \beta_{di}$ — angular width of the $i$-th quants digital sensor.

![Figure 3. Calibration parameters of the $i$-th quants DS.](image)

Note that the values of the parameters $\beta_a$, $\beta_d$, and $\alpha_{dl}$ are determined during bench calibration. Performing rotation of the hybrid sensor shaft in the entire measurement range $\alpha \in [0, \pi]$, we obtain an array of the specified parameters for each $i$-th quants ($i = 1, N$). Also according to the formula (2) for each quants are calculated the values slope chord coefficient $k_i$ of the output characteristic for analog sensor. The resulting arrays of parameters values $\beta_a$, $\beta_d$, $\alpha_{dl}$ and $k_i$ are stored in the memory of the controller, and then they act as correction coefficients.

The calibration bench must have an external reference angle sensor. The reference sensor serves as a source of the angular position signal to determine the exact value of the angle at the moments of quants switching. This makes it possible to compensate for the instrumental error of the digital sensor, which can be caused by an error in the manufacture of the code disk or an error in the installation of the reading elements. Compensation is carried out by accurately measuring the parameters $\beta_d$, and $\alpha_{dl}$ during calibration, and taking these values into account in the calculation of the coefficients $k_i$ values according to the formula (2), and then
in the working process when calculating the of value of angular position to the formula (1).

3. Results of mathematical modeling

Figures 4 and 5 present the results of mathematical modeling of the Hybrid Angular Position Sensor without correction and with correction, respectively.

In the process of modeling, the absolute error relative to the characteristics of the ideal sensor was calculated (figure 2) for the output characteristic of the analog sensor without correction, as well as the absolute error for the output characteristic of the hybrid sensor, i.e. with correction.

The analysis of the simulation results shows that if the output characteristic of the analog sensor is monotonic and has no discontinuities, then regardless of the degree of its curvature, the output characteristic of the hybrid sensor has a much smaller absolute error.

Further full-scale tests of the experimental sample fully confirmed the performance of the hybrid angular position sensor [3].

The proposed principle of hybridization can serve as a basis for angular position sensors of different designs, as well as can be used in sensors for determining the linear position.

4. Summary

Thus, Hybrid Sensors can significantly reduce the error of angular position measurement even when using relatively coarse Digital and Analog Sensors in their composition. This makes it possible to use sensors of smaller dimensions as part of the hybrid, and also reduce the environmental impact on the output characteristic of the sensor.

References

[1] Zayets V F, Kulabukhov V S, Tsatsin A A and Tuktarev N A 2019 Gibridnyy datchik izmereniya uglovoogo polozheniya zayavitel' AO MNPK "Avionika" Zayavka no. 2019117876 ot 10.06.2019 Rossiyskaya Federatsiya, MPK H03M1 1/46

[2] Zayets V F, Kulabukhov V S, Tsatsin A A and Tuktarev N A 2019 Gibridnyy sposob izmereniya uglovoogo polozheniya AO MNPK "Avionika" Zayavka no. 2019117875 ot 10.06.2019 Rossiyskaya Federatsiya, MPK H03M1 1/46

[3] Tsatsin A A, Perepelitsin A V, Oklov A I, Firsov A M and Kalym N P 2018 Naturnoye modelirovanie gibridnogo datchika uglovoogo polozheniya Materialy V nauchno-prakticheskoy konferentsii pamyati O.V. Uspenskogo pp 39–45