Interference elimination in digital controllers of automation systems of oil and gas complex

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Abstract. The given article considers the problems arising in the process of digital governors development for the systems of automatic control. In the case of interference, and also in case of high frequency of digitization, digital differentiation gives a big error. The problem is that the derivative is calculated as the difference of two close variables. The method of differentiation is offered to reduce this error, when there is a case of averaging the difference quotient of the series of meanings. The structure chart for the implementation of this differentiation method is offered in the case of governors construction.

1. Introduction
Currently, electronics and computer engineering are developing quite rapidly. There is emergence of high-speed analog-digital converters (ADC), high-speed microcontrollers. At the same time, there are problems which never existed before [1]. One of such problems is connected with a small digitization period in digital systems of automatic control. It is considered that the shorter digitization period is better, in other words, accuracy and regulation quality are higher. However, in case of a small digitization period, there can be a problem of numerical differentiation [2, 3].

The problem of numerical differentiation has at least two components [4, 5]. Firstly, in case of high-frequency interference in the signal, the result of differentiation will contain the reinforced interference. Secondly, in the case of small digitization period, the difference of signal meanings in previous in subsequent moments of digitization varies insignificantly. In case of subtraction of two close numbers, there is a computation error connected with a limited number of significant discharges of variables in which numbers are stored [6, 7].
2. Methods

2.1. The traditional method of digital PID-governor creation

Among governors, which are used in systems of automatic regulation, PID-regulators were widely spread [8]. The signal on the PID-regulator output is formed as the sum of proportional, integral and differential components.

The differential equation of the PID-regulator has form:

$$u(t) = k_p \cdot \left( x(t) + \frac{1}{T_i} \int_0^t x(t) \, dt + T_d \cdot \frac{dx(t)}{dt} \right).$$

Let us differentiate left and right sides:

$$\frac{du(t)}{dt} = k_p \cdot \left( \frac{dx(t)}{dt} + \frac{1}{T_i} \cdot x(t) + T_d \cdot \frac{d^2 x(t)}{dt^2} \right).$$

Let us enter the value of $T_{dis}$ - a digitization period. Let us turn to the equation in finite differences:

$$\Delta u_{dis} = k_p \cdot \left( \frac{\Delta x[n]}{\Delta t_{dis}} + \frac{1}{T_i} \cdot x[n] + T_d \cdot \frac{\Delta x[n]}{\Delta t_{dis}} \cdot \frac{\Delta x[n-1]}{\Delta t_{dis}} \right).$$

After conversion, one gets:

$$u[n] = u[n-1] + \left( \frac{k_p}{\Delta t_{dis}} + \frac{k_p}{\Delta t_{dis}} + \frac{k_p}{\Delta t_{dis}} \cdot T_d \right) \cdot x[n] - \left( \frac{k_p}{\Delta t_{dis}} + \frac{2 \cdot k_p}{\Delta t_{dis}} \cdot T_d \right) \cdot x[n-1] + \frac{k_p}{\Delta t_{dis}} \cdot x[n-2].$$

Let us give the definition:

$$d_0 = \frac{k_p}{\Delta t_{dis}} + \frac{k_p}{\Delta t_{dis}} + \frac{k_p}{\Delta t_{dis}} \cdot T_d;$$

$$d_1 = -\frac{k_p}{\Delta t_{dis}} + \frac{2 \cdot k_p}{\Delta t_{dis}} \cdot T_d;$$

$$d_2 = \frac{k_p}{\Delta t_{dis}} \cdot T_d. \quad (1)$$

One gets the result:

$$u[n] = u[n-1] + d_0 \cdot x[n] + d_1 \cdot x[n-1] + d_2 \cdot x[n-2].$$

The traditional skeleton diagram of the PID-governor is given in figure 1.
Figure 1. A skeleton diagram PID-of the regulator.

As it is seen from, the analysis of expression (1), in case of very small T_dis, this component of total sum will be incommensurably less than the other components. It will lead to a big error of calculation.

2.2. Anti-interference method of differentiation

The task is to calculate a derivative average component functioning on the segment, using results of a limited number of measurements, taking into account that the studied function contains a disturbing (interference) component. [3] The case should be considered when interference has predominant sinusoidal component \( A \cdot \sin(\omega \cdot t + \alpha) \):

\[
f_{\text{real}}(t) = f_{\text{id}}(t) + A \cdot \sin(\omega \cdot t + \alpha).
\]

It is supposed that function derivative \( f_{\text{id}}(t) \) on the considered segment is almost unchanged.

To solve the task of determination of the derivative average component function on the segment, the following method is offered, it is based on averaging calculation results of the difference quotient of the first order.

The following definitions should be used:

- \( n \) – quantity of the partial segments, segment \( l \) is divided into them;
- \( i=1,2..n \) – number of the partial segment;
- \( g_i \) – difference quotient of the couple \((t_i, t_{i+\frac{n}{2}})\);
- Every point of time \( t_i \) is in the middle of appropriate partial segment \([t_{i-\frac{1}{2}}, t_{i+\frac{1}{2}}]\).

On \( l \) segment function meanings, measurements are carried out in identical periods of time \( h \), equal to a half of the frequency period of sinusoidal interference:

\[
h = \frac{T}{2}.
\]

The first measurement is made later after the beginnings of \( l \) segment. According to the offered method, the quantity of \( n \) points should be multiple of 4:

\[
n = 4 \cdot k.
\]

The core idea of the determination method of the derivative average component function is the following. The given points are divided into couples \((t_i, t_{i+\frac{n}{2}})\), totally \( n/2 \) couples. These couples should be composed in the following way:

- \( t_i \) \( f(t_i) \) \( \text{first point} \)
- \( t_{i+\frac{n}{2}} \) \( f(t_{i+\frac{n}{2}}) \) \( \text{second point} \)

where \( i=1,2..n/2 \).

Every couple has its first point to the left of \( t_i \) (\( l \) segment midpoint), and the second point – to the right, (figures 2 and 3).
Phase shift between sinusoidal interference and moments of $t_1, t_2, t_3,... t_n$ depends on $\alpha$ and, as a rule it is of arbitrary character.

For every couple difference quotient $g_i$, mentioned above, is defined. Then, received difference quotients are averaged. It is essential that if couples are taken in a row that $(t_i, t_3), (t_3, t_5)$ and so on, then it will be equivalent as if one couple is taken from the first and the last point. Thus, after averaging, all midpoints can not influence the result. In the given method, due to a certain choice of couples, influence of each point on result of averaging of difference quotient is achieved.

Difference quotient $g_i$ is calculated in the following way:

$$g_i = \frac{f(t_{i+n/2}) - f(t_i)}{t_{i+n/2} - t_i} = \frac{f(t_{i+n/2}) - f(t_i)}{h \cdot (n/2)} , \quad i=1,2,...,n/2 .$$

The derivative of the average component function on the segment is calculated in the following way:
The given method is suitable for both cases: in the presence of sinusoidal interference, and in the presence of accidental interference. In the case of accidental interference, digitization rate is selected from conditions of normal operation of the governor.

2.3. Governor’s implementation using the given differentiation method

For governor’s implementation using the given differentiation method, it is expedient to make it of two parts. The first part is PI-governor executed by the traditional method. The second part is the developed unit of differentiation.

The differential equation of the PI-governor:

\[ u(t) = k_p \times \left( x(t) + \frac{1}{T_i} \int_0^t x(t) \, dt \right). \]

Let us differentiate left and right parts, and turn to the equation in finite differences:

\[ \frac{\Delta u}{T_{\text{dis}}} = k_p \cdot \left( \frac{\Delta x[n]}{T_{\text{dis}}} + \frac{1}{T_i} \cdot x[n] \right). \]

After transformation and introduction of \( d_0 \) and \( d_1 \), let us receive:

\[ u[n] = u[n-1] + d_0 \cdot x[n] + d_1 \cdot x[n-1]. \]

To implement the differentiation unit, the structure chart given in figure 4 should be made.

**Figure 4.** A structure chart of the differentiation unit.

As a result, let us receive the governor’s structure chart given in figure 5.
3. Conclusions
The given method of differentiation allows one to reject interference and interference present in the signal [6].

The offered method can be useful in the process of governors development, it is necessary to solve the number of complicated tasks [7], especially in the cases when digitization frequency is quite high. Also it can be useful if the frequency of the prevailing interference is known, in this case it is necessary to select a digitization rate twice higher than interference frequency.

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