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ANALYSIS OF MEASURING CONVERTER ERRORS WHICH RESULT DUE TO A CONTINUOUS CHANGE IN TIME OF ITS BLOCKS ADDITIVE ERRORS

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Abstract—*Analysis of conversion equations and equations of errors of the generalized block diagram of the iteratively integrating measuring converter which uses iterative integrating conversion method was performed. An analysis for the simplest case of combinations of input and output values, namely when all input values X, Z1 and Z2, as well as the output value Y are constant values was carry out. The results of the analysis can easily be extended to all the other cases. Here considers situation when the additive errors of all blocks change continuously in time. For ease of analysis the curve of change of the considered error by straight line segments within each conversion cycle was approximated. We can formulate the requirements for the errors of blocks of the measuring converter. The results of the analysis of the generalized block diagram of the measuring transducer can be used to create specific outlines of iteratively integrating converters, in particular, the requirements on the errors of their blocks can be formulated.*

Index Terms—Measuring converter; generalized block diagram; conversion equation; iterative integrating conversion method; iteratively correction of errors; imperfection of blocks.

I. INTRODUCTION

In author's publications [1], [2] the iteratively integrating measuring converter was analyzed. The possibility of achieving high metrological characteristics of this measuring converter [3]–[5] makes it possible to successfully use it when creating various information systems that are subject to increased requirements in terms of metrological parameters. Previously, the author carried out an analysis of the generalized circuit of the measuring converter proposed by the author [1]–[4], [6]–[12].

It is probably advisable to recall the simplified block diagram of the measuring transducer under consideration, which was proposed by the author in work [1].

II. PROBLEM STATEMENT

The simplified block diagram is shown in Fig. 1.

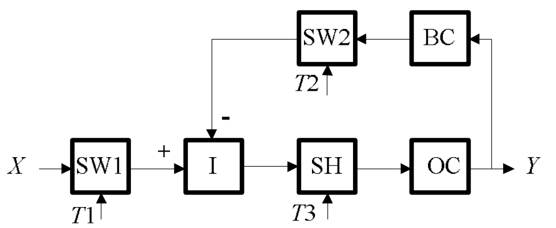

Fig. 1. Simplified generalized scheme of iteratively integrating converter

Here in the simplest case X is the input value; Y is the output value; OC is output converter, BC is back converter; K_{BC} is transfer coefficient of BC; SW1 and SW2 are switches, SH is sample-and-hold device; $T1$ is time interval of integration of the input variable X; $T2$ is time interval of integration of the value βY. The values of $T1$ and $T2$, along with X are input values.

The work comes in cycles. Each cycle is a step of iteration, the essence of which consists in the iterative approximation of the output value of the measuring converter to its steady-state value. This is done by iteratively correcting the error of the measuring converter. It consist of the integration time $T1$ by integrator I of variable X through a non-inverting input, integration time $T2$ by integrator I of variable $K_{BC}Y$ through an inverting input and memorizing by the sample-and-hold device SH of the integrator output value upon receipt at the end of the cycle of strobe $T3$. This value enters through the output converter OC to output of converter during the subsequent conversion cycle.

The operation of the measuring converter is carried out cyclically. Each transformation cycle can be considered as an iterative transformation step. In other words, each transformation cycle can be called a step of iterative error correction of a measuring converter. Each transformation cycle contains two time intervals, the first of which is the integration time $T1$ by integrator I of variable X through a non-inverting input, and the second is integration time $T2$ by integrator I of variable $K_{BC}Y$ through an inverting input.

The time intervals $T1$ and $T2$ within one conversion cycle can be alternately followed, and can partially or completely overlap each other.

Without dwelling on the details of the iterative process of setting the output value that were discussed in detail in [3]–[6], we note only that after

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several conversion process cycles , the output value of the measuring converter becomes equal according to the following equation

$$Y = \frac{T1}{T2\beta} X.$$

From this equation, which is an equation of the conversion of the iteratively integrating measuring converter, follows that the steady-state output value does not depend on the transformation coefficients of direct circuit blocks I, SH and OC (K_I, K_{SH} and K_{OC} respectively). Consider a generalized block diagram (Fig. 2). It has three inputs and one output, and, accordingly, in it X, $Z1$ and $Z2$ are input values, and Y is an output value. The generalized scheme contains the basic functions blocks: integrator I, sample-and-hold device SH, switches SW1 and SW2, and auxiliary converters CV_X, CV_{Z1}, CV_{Z2}, CI_1, CI_2, CO_1, CO_2,.., CO_m, BC, inverter INV, adder ADD, having transfer coefficients, respectively, K_X, K_{Z1}, K_{Z2}, K_{CI1}, K_{CI2}, K_{CO1}, K_{CO2},.., K_{COm}, β, K_{INV}, K_{ADD}.

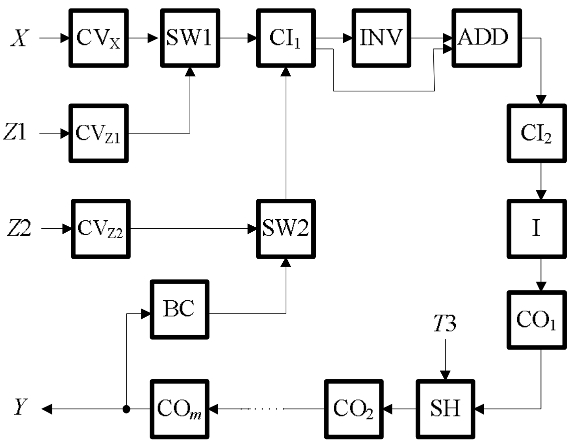

Fig. 2. A generalized structural scheme of iteratively integrating converter

In previous articles of the author, representing a series of articles devoted to iterative integrating measuring converter, various aspects were considered. So, in particular, in the works [7], [8] generalized scheme was analyzed, considering all the blocks as an ideal, that is, for the case where the transfer coefficients of all the blocks are constant. This makes it possible to analyze the operation of the converter depending on the input values. In the works [9], [10] generalized scheme was analyzed for the next three cases: first one – where the output value $Y = Y(t)$ is not a constant, while the input values X, $Z1$, $Z2$ are constant; second one – where the input value $X = X(t)$ and output value $Y = Y(t)$ are not constant, while the input values $Z1$, $Z2$ are constant, and third one – the input variable $X = X(t)$ is not a constant, while in the input values $Z1$, $Z2$ and output value Y are constant. In the works [11], [12] analysis taking into account the imperfection of all blocks of the measurement converter.

This publication considers situation when the additive errors of the transfer functions of all blocks change continuously in time.

III. Solution of the Problem

Let's perform an analysis for the simplest case of combinations of input and output values, namely when all input values X, $Z1$ and $Z2$, as well as the output value Y are constant values. It is obvious that the results of the analysis can easily be extended to all the other cases. We also assume that the SW1 and SW2 blocks and the INV inverter will be considered as ideal. The errors of these units can easily be taken into account by introducing them into the errors of other blocks.

A. Continuous Change of Additive Errors of Blocks SH, CO_2,.., CO_m

We approximate the curve of change of the considered error by straight line segments within each conversion cycle, as well as straight line segments in the closure time intervals of the SW2 key in each conversion cycle. Let us denote the relative increment of the output value in the jth conversion cycle, caused by the change in additive error under consideration, by δ_{aj}, and the relative change in output value during the time when the SW2 key in the jth conversion cycle is closed, at δ_{aj}^{**}. The resulting formulas are summarized in Table I.

The continuous change in the additive error of the SH, CO_2,.., CO_m blocks is "instantly" transmitted to the converter output, and the character of the correction of the measuring converter error caused by the change of errors of blocks considered is iterative in nature (i.e. the error accumulated in the previous conversion cycles becomes smaller and smaller). As a result, the total error of the measuring converter represents a composition of results of the "instantaneous" transmission of the errors of the blocks and the partially adjusted errors from the previous conversion cycles. Moreover, the fraction introduced by the error of each of the previous conversion cycles is, the smaller the further this cycle is from the considered conversion cycle. The nature and speed of correction of the constituent parts of the errors accumulated in the previous cycles depends on the value of Q.

TABLE I. THE CONTINUOUS CHANGE IN THE ADDITIVE ERRORS OF THE BLOCKS SH, CO_2, .., CO_M

$$Y_0^{(a1d)} = Y_\infty$$
$$Y_1^{(a1d)} = Y_\infty(1+\delta_{ap1})$$
$$Y_2^{(a1d)} = Y_\infty(1+\delta_{ap1}Q+\delta_{ap2})$$
....
$$Y_n^{(a1d)} = Y_\infty(1+\sum_{j=1}^{n}\delta_{apj}Q^{n-1})$$
$$\gamma_n^{a1d} = \frac{Y_n^{(a1d)}-Y_\infty}{Y_\infty} = \sum_{j=1}^{n}\delta_{apj}Q^{n-\lambda}$$
where
$$\delta_{apj} = \delta_{aj} - \frac{\delta_{aj}^{**}}{2}(1+\sum_{\lambda=1}^{j-1}\delta_{ap\lambda}Q^{n-\lambda})\beta Z2K_{Z2}\prod_{i=1}^{l}K_i$$
for $|Q| \ll 1$:
$$Y_n^{(a1d)} \cong Y_\infty\left[1+\delta_{ap(n-1)}Q+\delta_{apn}\right] \cong Y_\infty\left[\left[1+\left[\delta_{a(n-1)}-\frac{\delta_{a(n-1)}^{**}}{2}\right]Q+\delta_{an}-\frac{\delta_{an}^{**}}{2}\right]\right]$$
$$\gamma_n^{a1d} \cong \delta_{ap(n-1)}Q+\delta_{apn} \cong \left[\delta_{a(n-1)}-\frac{\delta_{a(n-1)}^{**}}{2}\right]Q+\delta_{an}-\frac{\delta_{an}^{**}}{2}$$

B. Continuous change of additive error of block CO_1

As in the previous paragraph let's approximate the curve of change of the considered error by straight line segments within each conversion cycle and let us denote the relative increment of the output value of the measuring transducer in the *j*th conversion cycle, caused by the change of the considered error, by δ_{aj}. All the corresponding formulas obtained for this case are summarized in Table II. From the analysis of the above expressions, it follows that this case in terms of the nature of the correction of the error of the measuring transducer is in general terms similar to that considered earlier.

TABLE II. THE CONTINUOUS CHANGE IN THE ADDITIVE ERRORS OF THE BLOCKS CO_1

$$Y_0^{(a2d)} = Y_\infty$$
$$Y_1^{(a2d)} = Y_\infty(1+\delta_{a1})$$
$$Y_2^{(a2d)} = Y_\infty(1+\delta_{a1}Q+\delta_{a2})$$
....
$$Y_n^{(a2d)} = Y_\infty(1+\sum_{j=1}^{n}\delta_{aj}Q^{n-j})$$
$$\gamma_n^{a2d} = \frac{Y_n^{(a2d)}-Y_\infty}{Y_\infty} = \sum_{j=1}^{n}\delta_{aj}Q^{n-j}$$
where
$$Q = 1-\beta Z2K_{Z2}\prod_{i=1}^{l}K_i$$
for $|Q| \ll 1$:
$$Y_n^{(a2d)} \cong Y_\infty\left[1+\delta_{a(n-1)}Q+\delta_{an}\right]$$
$$\gamma_n^{a2d} \cong \left[1+\delta_{a(n-1)}Q+\delta_{an}\right]$$

The only difference is that the change in the additive error of the CO_1 block is not transmitted "instantly" to the output of the measuring transducer, as in the previous case, but only after the end of the considered conversion cycle. As a result, the error of the measuring transducer accumulated in this conversion cycle begins to be corrected only in the next conversion cycle. And therefore, in this case, with equal relative to the measuring transducer output to the relative changes in the output value of the measuring transducer, due to the errors of the corresponding blocks being considered changes, the error of the measuring transducer is less than in the previous case.

IV. Conclusion

From the analysis of the impact on the overall error of the measuring converter of the change continuously in time additive errors of its blocks, we can draw the following conclusions:

1) The continuous change in the additive error of the SH, CO_2,.., CO_m blocks is "instantly" transmitted to the converter output, and the character of the correction of the measuring converter error caused by the change of errors of blocks considered is iterative in nature (i.e. the error accumulated in the previous conversion cycles becomes smaller and smaller). As a result, the total error of the measuring converter represents a composition of results of the "instantaneous" transmission of the errors of the blocks and the partially adjusted errors from the previous conversion cycles. Moreover, the fraction introduced by the error of each of the previous conversion cycles is, the smaller the further this cycle is from the considered conversion cycle. The nature and speed of correction of the constituent parts of the errors accumulated in the previous cycles depends on the value of Q.

2) The continuous change in the additive error of the CO_1 block in terms of the nature of the correction of the error of the measuring transducer is in general terms similar to that considered earlier. The only difference is that the change in the additive error of the CO1 block is not transmitted "instantly" to the output of the measuring transducer, as in the previous case, but only after the end of the considered conversion cycle. As a result, the error of the measuring transducer accumulated in this conversion cycle begins to be corrected only in the next conversion cycle. And therefore, in this case, with equal relative to the measuring transducer output to the relative changes in the output value of the measuring transducer, due to the errors of the corresponding blocks being considered changes, the error of the measuring transducer is less than in the previous case.

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І. Ю. Сергєєв. Аналіз похибок вимірювального перетворювача, обумовлених безперервною у часі зміною адитивних похибок його блоків

Проведено аналіз рівнянь перетворення і рівнянь похибок узагальненої структурної схеми ітеративно-інтегруючого вимірювального перетворювача, що використовує метод ітеративно-інтегруючого перетворення. Проведений аналіз для найпростішого випадку комбінацій вхідних і вихідних величин, а саме, коли всі вхідні величини X, Z1 і Z2, а також вихідна величина Y постійні в часі. Результати аналізу можуть бути легко поширені на всі інші випадки. Розглянуто ситуацію, коли адитивні похибки всіх блоків безперервно змінюються в часі. Для простоти аналізу крива зміни даної похибки апроксимована відрізками прямої в кожному циклі перетворення. Сформульовано вимоги до похибок блоків вимірювального перетворювача. Результати аналізу узагальненої структурної схеми вимірювального перетворювача можуть бути використані для створення конкретних втілень ітеративно-інтегруючих перетворювачів, для яких можуть бути сформульовані вимоги до похибок їх блоків.

Ключові слова: вимірювальний перетворювач; узагальнена структурна схема; рівняння перетворення; метод итеративно-інтегруючого перетворення; ітеративна корекція похибок; недосконалість блоків.

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И. Ю. Сергеев. Анализ погрешностей измерительного преобразователя, обусловленных непрерывным во времени изменением аддитивных погрешностей его блоков

Проведен анализ уравнений преобразования и уравнений погрешностей обобщенной структурной схемы итеративно-интегрирующего измерительного преобразователя, использующего метод итеративно интегрирующего преобразования. Проведен анализ для простейшего случая комбинаций входных и выходных величин, а именно, когда все входные величины X, Z1 и Z2, а также выходная величина Y постоянны во времени. Результаты анализа могут быть легко распространены на все остальные случаи. Рассмотрена ситуация, когда аддитивные погрешности всех блоков непрерывно изменяются во времени. Для простоты анализа кривая изменения рассматриваемой погрешности была аппроксимирована отрезками прямой в каждом цикле преобразования. Сформулированы требования к погрешностям блоков измерительного преобразователя. Результаты анализа обобщенной структурной схемы измерительного преобразователя могут быть использованы для создания конкретных воплощений итеративно-интегрирующих преобразователей, для которых могут быть сформулированы требования к погрешностям их блоков.

Ключевые слова: измерительный преобразователь; обобщенная структурная схема; уравнения преобразования; метод итеративно-интегрирующего преобразования; итеративная коррекция ошибок; несовершенство блоков.

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