UDC 621.3.084.8(045)

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SIGNAL PROCESSING SYSTEM OF FREQUENCY AND CAPACITANCE INTELLIGENT SENSOR

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Abstract. *The scheme of signal processing system of frequency and capacitance intelligent sensor which does not require the inclusion of devices such as a microprocessor, microcontroller or programmable logic controller is described. When using the scheme of linearization in this sensor, the relative conversion error that is introduced by elements such as resistors, capacitors and op-amp can be as low as one hundredth of a percent.*

Keywords: frequency sensor; capacitance sensor; intelligent sensor; linear characteristic; nonlinearity; linearizing function; transfer characteristic.

I. INTRODUCTION

In every information-measuring system or automatic and telemechanics system the role of sensors (primary measuring transducers) is very important. The purpose of the sensor is transformation of measuring, controlled or regulating value into the value of another kind, convenient for further application. In the most cases the sensors transform non-electric value into electric. In some cases by means of the sensors the transformation of one electric value into another is performed [1].

The achievement of linearity of their functions transformation is very important for sensors application in such systems, and consequently for independence of static transformative characteristics from value of transformed quantity.

It is provided by application of product design and production methods, in particular, by using special materials, application of special technology of its production or special product design of transducer elements performance (usage of more qualitative elements, application of screens, thermostats, etc) [1]. But this not always allows achieving the needed linearity of transfer function with sufficient accuracy.

Structural methods of linearization of static characteristics of transducers (the sense of which is in application of additional correcting devices) are universal, relatively simple in realization during simultaneous providing of high degree of approximation of resultant transfer function to the needed [2]. Since the linearization of static characteristics is connected, as rule, with formation of signals in the correcting device, which are functionally connected with transferring quantity, then the simplest block diagram of linearized transducer will look like as series or parallel connection of main corrective and auxiliary correcting transducers.

Sensors as measuring devices, which contain not only primary transducers, but and elements of measuring diagrams, where these transducers are included (amplifiers, functional amplifiers, devices of conjunction with measuring and automation means), nowadays are realized on the base of different physical phenomena and different technologies. This makes possible to create them multifunctional (it provides by means of one sensor the transformation of many physical quantities) and intelligent (it allows discovering the influence of other quantities, which distort the result of transformation, during the transformation of measuring quantity). The value of these quantities, transformed in electric ones, can be applied for correction of result of measurement of measuring quantity. For example, during the measurement of pressure the sufficient influence is caused by changing the temperature of environment, where the pressure is measured. So, if you have the pressure sensor, which provides the transformation of temperature also under the defined conditions, the result of measurement which is applied for correction of the result of pressure measurement has not only the multi-functionality, but and new characteristics of sensor (self-adjustment or its intellectualization).

The measuring transducer, the output value of which the frequency is [3], has a wide application in information-measuring systems. Frequency representation of information has many advantages. Firstly, by means of frequency transducers it is possible to get higher accuracy with small informative signals, comparing with the transducers of signal amplitudes. Secondly, the frequency signal is more disturbances protective and less sensitive to measurement of parameters of connection lines. Thirdly, the processing of frequency signals and its precise integration in time can be executed very accurate.

The advantages of such transducers are wide functional possibilities, disturbances protection, and relative simplicity of realization and adjustment of schemes, manufacturability.

Capacity measuring transducers are capacitors, capacity of which change in the result of changing of parameters of transducer under the action of measuring quantity. They are widely used in devices for measurement of pressure and devices for measuring of levels.

There are a variety of capacitive transducers by design. Transmitters with variable distance between the electrodes in the devices used for measuring small displacement (typically 1 mm), and causing these movements, forces and pressures. With sensitive capacitive pressure transducers are the membrane and diaphragm, which convert the measured pressure in the movement. Thus they can simultaneously be used as the movable electrode. Converters with variable area of overlap plates by investigated medium used in the level meters.

The development of such industries as instrumentation, aerospace, aircraft, automotive, etc., require the creation of modern microelectronic sensors.

For example, the means of measuring space rocket carrier "Energy" to the orbital ship "Buran" (more than 3500 different sensors for telemetry and local control systems) to ensure that the full program run under the ground conditions during the prelaunch and flight mode [3].

Production of sensors for a variety of measuring systems is the most dynamic sector of the world economy. Average sales growth of at least 6 % per year [3], while the production of smart sensors and sensors for automobiles is growing even faster – up to 20 %.

When creating a smart sensor the developers must first solve basic problems, mostly circuit engineering methods. Typically, this increase in accuracy, sensitivity, speed, resolution, data conversion devices (transmitters). However, along with this, there is also the problem of technological plan related to the need to overcome the limitations associated with the problems of miniaturization of devices, i.e. problems in microelectronics.

II. Problem Statement

While all these sensors have different principles of operation, developers face the problem, which is common for all sensors. It includes the necessity of acquisition of functional relationship between input and output values of sensor or device, which includes this sensor [4]–[9]. In the case, if the sensor has natural nonlinearity, it is necessary to implement its linearization. It means that auxiliary hard or software tools, entered into composition of intelligent sensor, are used to implement linear functional relationship between input and output values.

The sense of linearization is in the solution of inverse task of definition of transferring parameter according to the value of output signal of the sensor. Nowadays the methods of linearization, based on the usage of approximating functions [4]–[6], are widely applied. The main sense of linearization task of experimental data is the description of the dependence of variables by some known substantial function, and it is necessary to do it in such way that the accuracy of received description will be satisfactory to the requirements. Stepwise approximation and piecewise-linear approximation are the simplest ones from the point of view of hardware support.

III. Solution of the Problem

Assigned task can be easily solved, when the output value has been already converted into digital code. For this purpose there is need to be, for example, microprocessor, microcontroller, programmable logic controller or even computer in the structure of the device.

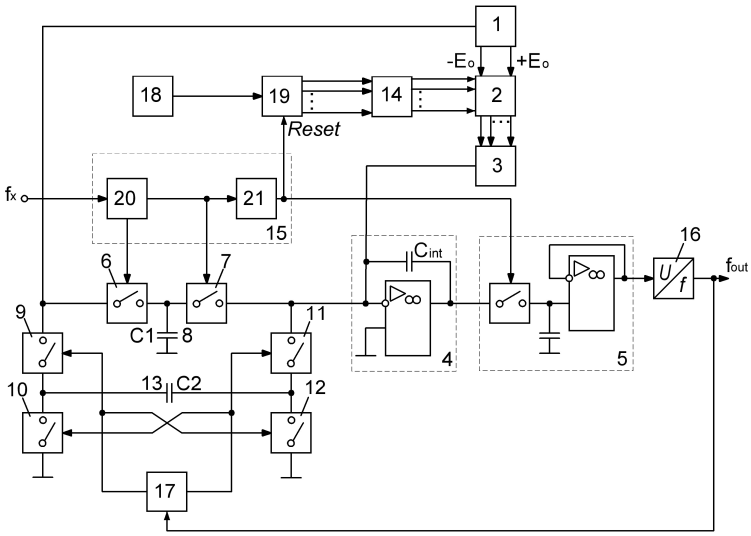
In the case of frequency sensor, if the further research of frequency is necessary (as convenient for transmission of unified signal), the application of microprocessors, microcontrollers, and programmable logic controllers for linearization is not reasonable. This will cause the considerable complication of device, and the application of additional transducer of code into the frequency will be needed.

Still in the case of intelligent sensor construction this is not desirable to include to its composition hardware components of above-listed devices. In this case designers of intelligent sensor face the necessity to find other solutions, by which assigned task can be achieved with using of hardware, which is more preferable to be included in intelligent sensor. Measuring converters, considered in researches [4]–[6], [10]–[12], and also intelligent frequency sensor developed by authors [7]–[9], [13], [14], exemplify such devices. The scheme of signal processing system of such intelligent frequency sensor (without sensors) represented on Figure.

IV. The Principle of the Device

The system of signal transformation of given intelligent frequency and capacity sensor is built on the base of iterative-integrative measuring transducer [7], [13], [14].

Terms "iterative-integrative transformation" and "iterative-integrative measuring transducer" were introduced to measurement technology by the author [14]. An iterative-integrative measuring transducer works cyclically. In each cycle, the conversion is performed using an integrator integrating an input measured value (or a composition of several measured values of the input) and the output value of the measuring transducer. The result of integration in each cycle of conversion fixed by sample-and-hold device with subsequent conversion (if it is necessary) and delivery of results to the output of the measuring transducer. Thus, during the execution of a series of conversion cycles, formation is effected output value of the measuring transducer, i.e. performed iterative-integrative transformation. The process of this transformation which is described below is a geometric progression. Thanks iterative-integrative transformation conversion errors of mostly members of the transducer assemblies and components are excluded, which can significantly reduce the overall conversion error.



The scheme of signal processing system: 1 is Source of the reference voltage; 2 is Switchboard; 3 is Code managed resistive matrix; 4 is Integrator; 5 is Sample-and-hold device SH; 6, 7, 9,… 12 are Keys; 8, 13 are Capacitors; 14 is Decoder; 15 is Synchronization block ; 16 is Voltage-to-Frequency converter; 17, 20 are Pulse formers; 18 is Clock generator; 19 is Counter; 21 is Frequency divider

Considered intelligent sensor is multifunctional. From one side, this is frequency sensor, because one of its input quantities f_x and output quantities f_{out} is frequency. From another side this is capacitive sensor, because it contains two capacitors C_1 and C_2. The role of these capacitors can be done by capacitors with constant capacitance or capacitors of sensitive elements, i.e. capacitive sensors.

It includes such units as a Source of the reference voltage 1, Integrator 4, Sample-and-hold device SH5, Voltage-to-Frequency converter 16, Capacitors 8 and 13, Keys 6, 7, 9,… 12 and Synchronization block 15.

Required nonlinearity of response of intelligent sensor is created with the help of Switchboard 2, Code managed resistive matrix 3, Clock generator 18, Counter 19 and Decoder 14.

Such iterative-integration transducer works cyclically. During every cycle charging of Capacitors 8 and 13 C_1 and C_2 from Source of the reference voltage 1 is carried out, including subsequent discharging of it at the Integrator 4 input. Also sampling of integrator output voltage is implemented by Sample-and-hold device SH5. Then it follows its storage during time of cycle of continuous integration of Sample-and-hold device SH5 output voltage by Integrator 4, and its transformation by Voltage-to-Frequency converter 16 into the output frequency f_{out}.

Let's suppose that before the beginning of first from the considered cycles the frequency on the output of device is equal $f_{\text{out}\,0}$, and input frequency becomes equal to f_x.

Then after the ending of the first cycle the frequency at the output of device will be equal to:

$$f_{\text{out}\,1} = \left\{ \frac{NE_0C_1}{C_{\text{int}}} + \frac{1}{C_{\text{int}}} \sum\nolimits_{i=1}^{k} \frac{E_{0i}}{R_i} \left\{ \begin{array}{l} \left[\dfrac{N}{f_x} - (i-1)t_0 \right] \dfrac{\operatorname{sign}\left(it_0 - \dfrac{N}{f_x} \right) + 1}{2} \\ + t_0 \dfrac{\operatorname{sign}\left(\dfrac{N}{f_x} - it_0 \right) + 1}{2} + t_0 \dfrac{\operatorname{sign}\left(\dfrac{N}{f_x} - it_0 \right) + 1}{2} \end{array} \right\} \right\} K_{uf} + f_{\text{out}0} Q,$$

where C_{int} is capacitance of integrator of capacitor 4; R_1, R_2, …, R_i, R_k are resistance of resistors of the matrix 3; E_{0i} is voltage of the source 1, it is connected to resistor R_i through Switchboard 2 (E_{0i} is equal to E_0 or $-E_0$ dependently from i); t_0 is time, during which every resistor of matrix 3 is connected to the source 1; $i = 1, \ldots k$ is ordinal number of resistor of matrix 3; N is coefficient of recalculation of divisor 21;

$$Q = 1 - \frac{NK_{uf}C_2}{f_x C_{\text{int}}}; \quad \text{sing}(X) = \begin{cases} -1, X > 0, \\ +1, X \le 0. \end{cases}$$

After the ending of n-cycle:

$$f_{\text{out}\,n} = \left\{ \frac{NE_0C_1}{C_{\text{int}}} + \frac{1}{C_{\text{int}}}\sum_{i=1}^{k}\frac{E_{0i}}{R_i}\left\{ \begin{matrix} \left[\frac{N}{f_x} - (i-1)t_0\right] \times \frac{\text{sign}\left(it_0 - \frac{N}{f_x}\right)+1}{2} \\ +t_0\frac{\text{sign}\left(\frac{N}{f_x} - it_0\right)+1}{2} + t_0\frac{\text{sign}\left(\frac{N}{f_x} - it_0\right)+1}{2} \end{matrix} \right\} \right\} K_{uf}\sum_{j=1}^{n} Q^{j-1} + f_{\text{out}\,0}Q^n,$$

where $j = 1,\ldots n$ is ordinal number of cycle.

The last expression consists of two components, the first is a geometrical progression with denominator of progression Q. Using formula for calculation of sum of members of geometrical progression, write to what will the frequency be equal at the output of device after the ending of transient process (at $n \to \infty$):

$$f_{\text{out}\infty} = \frac{E_0C_1}{C_2}f_x + \frac{f_x}{C_2}\sum_{i=1}^{k}\frac{E_{0i}}{R_i}\left\{ \left[\frac{N}{f_x} - (i-1)t_0\right]\frac{\text{sign}\left(it_0 - \frac{N}{f_x}\right)+1}{2} + t_0\frac{\text{sign}\left(\frac{N}{f_x} - it_0\right)+1}{2} \right\}.$$

Given expression introduces the equation of transformation of considered device. From analysis we can say, that it has two components – linear and non-linear. Linear component provides transformation of multiplication of input frequency f_x and ratio of capacities of two capacitors C_1 and C_2 into linear component of output frequency f_{out}. Non-linear component transforms input frequency f_x into non-linear component of output frequency f_{out}, which depends on frequency f_x and resistances of resistors R_1, ..., R_k of matrix 3, and also on signs of voltages E_{0i}.

V. Conclusion

Multifunctional intelligent frequency and capacity sensor with non-linear transfer function is considered.

Signal processing system of such intelligent frequency sensor can be constructed according to the considered scheme; it does not require the inclusion of devices such as a microprocessor, microcontroller or programmable logic controller, and Code-to-Frequency converter.

In this case, taking into account the errors introduced by such elements as resistors, capacitors and an operational amplifier, an intelligent frequency sensor can be created according to this circuit, which has relative errors of the conversion at the level of hundredths of a percent.

In this case the formation of a wide range of linearizing functions to obtain the desired conversion function may be possibly.

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Received 16 November 2013

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І. Ю. Сергеєв, І. В. Седень, О. В. Баркулов. Система оброблення сигнала частотного та ємнісного сенсора

Розглянуто систему оброблення сигналу частотного і ємнісного інтелектуального сенсора, який не вимагає у своєму складі таких пристроїв, як мікропроцесор, мікроконтролер або логічний програмований контролер. У разі використання схеми лінеаризації у цьому сенсорі відносна похибка перетворення, яку зазвичай зумовлено неідеальністю таких елементів як резистори, конденсатори та операційні підсилювачі, може знаходитися на рівні сотих часток відсотка.

Ключові слова: датчик частоти; ємнісний датчик; інтелектуальний датчик; лінійна характеристика; нелінійність; функція лінеаризації; передатна характеристика.

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И. Ю. Сергеєв, И. В. Седень, О. В. Баркулов. Система обработки сигнала частотного и емкостного сенсора

Рассмотрена система обработки сигнала частотного и емкостного интеллектуального сенсора, который не требует в своем составе таких устройств, как микропроцессор, микроконтроллер или логический программируемый контроллер. При использовании схемы линеаризации в этом сенсоре относительная погрешность преобразования, которая обычно обусловлена неидеальностью таких элементов как резисторы, конденсаторы и операционные усилители, может находиться на уровне сотых долей процента.

Ключевые слова: датчик частоты; емкостный датчик; интеллектуальный датчик; линейная характеристика; нелинейность; функция линеаризации; передаточная характеристика.

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