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The Technique of without dismantling control of metrological performance of industrial measurement devices

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Abstract

Industrial devices of measurement are in the heavy conditions of the operation. These factors can influence essentially on their metrological performance. Available calibrators are not suitable for realization of the metrological control without disconnection of measuring circuit. It is suggested to implement without dismantling metrological control without the breach of measuring circuit for taking into consideration the maximal amount of factors affects on metrological performance. It is considered a number of the functional schemes of reference devices for performance of the metrological control by way of parallel measurement or reproduction of informative parameter of transducers, including passive parameters, for example - resistance.

Streszczenie

Przemysłowe układy pomiarowe zazwyczaj pracują w skomplikowanych warunkach: szeroki zakres temperatur, niedokładne zasilanie, duży poziom zakłóceń. Wymienione czynniki mogą spowodować istotne zmiany charakterystyk metrologicznych. Również negatywny wpływ na dokładność może mieć podłączanie do innych układów systemu. Ponieważ wykorzystywane dla kontroli metrologicznej kalibratory wymagają demontażu obwodu pomiarowego, proponuje się wykonywanie takiej kontroli bez demontażu systemu pomiarowego w celu uwzględnienia maksymalnej ilości czynników wpływających. Rozpatrzono szereg schematów funkcyjnych układów wzorcowych dla prowadzania kontroli metrologicznej przez równoległe pomiary lub odtwarzanie parametrów informacyjnych przetworników, w tym przetworników biernych, na przykład rezystancji.

Słowa kluczowe: bezdemontażowy, kontrola metrologiczna, pomiary, wzorcowy, obwód pomiarowy
Keywords: without dismantling, metrological control, measurement, reference, measuring circuit

1. Introduction

For industrial measuring devices typically interaction both with object of measurement and with other devices for process control. Besides, they are in heavy conditions of the operation, caused by the increased or lowered ambient temperature, a high level of the noise, insufficient quality of the power-supply system. These factors presence frequently results in deterioration of metrological characteristics. Therefore it is important to investigate metrological characteristics of industrial measuring devices under operating conditions, including conditions of interaction of devices of measurement as with object of measurement so with other devices of system. All factors influencing accuracy of measurement, it is possible to take into account only carrying out procedures of check or calibration in a place of application of measuring device - that is without dismounting the device. Performance of check or calibration of the measuring device without dismounting is interfered by absence of the reference devices, allowing carrying out these procedures without break of a measuring circuit. To performance of check or calibration of the measuring device without dismounting complicates absence of the equipment of a class of the reference, which allows carrying out these procedures without break of a measuring circuit

There is a plenty of types of devices of the measurement intended for measurement of various physical magnitudes. Various metrological characteristics, design, functionalities, communication systems and functions are inherent in them. Obviously, it imposes the certain conditions and restrictions on procedures of check or calibration. However, despite of a variety of industrial measurement devices at them is much in common [7, 8, 18, 19, 22, 23, 24], namely:

- the most of devices like informative parameter measure voltage, current or resistance;
- error of measurements within from 0.1% to 0.5%;
- as a rule measuring circuit operate with the signals of low level;
- measuring circuit is highly tailored for measure in the narrow range of variation of informative parameter.

For today, there are a number of reference-class instruments, which intended for the control of metrological performance of measurement devices on a place of their installation. For example, the specialized calibrators for reproduction of informative parameters of temperature gauges [1, 2, 6] and calibrators for the metrological control of wide scale of devices of measurement [6, 11, 12, 13, 14].

However, the problem of creation of reference-class instruments for the control of metrological performance of industrial devices of measurement without dismounting stands sharply as existing tools or are too narrowly specialized, or their metrological characteristics insufficient, or the structure of their functionalities narrows a circle of the devices which are giving in to the metrological control.

Not deferring to this, the problem of creation reference-class instruments for without dismantling metrological control of industrial measuring devices stay sharply, as long as existing instruments or too highly tailored, or have got inadequate metrological performance, or the kit of their functions constrict the circle of devices accessible for metrological control. Primary - not all these calibrators are adapted to realization of the metrological control without break of a measuring circuit.

2. The control of metrological performance in one point of a measurement range without disconnecting of measuring circuit

Frequently in practice of industrial measurements, the controllable parameter is within the limits of some narrow range of values, or long enough does not change. Therefore to the user metrological properties of measuring device in narrow enough measurement range are important. It is usually undesirable to stop process of measurement for diagnostics of a measuring circuit or for control of metrological performance of the device. In such cases, at the distrust nascence about errors in the measurement, there is no need to accomplish the control of metrological performance of measuring device in entire volume (for example, to verify him in whole measurement range), enough is to determine the error of measurement of the meaning of controlled parameter. The comparison of measuring results obtained by testable and reference measuring devices, which concurrently and at the same time measure controlled parameter, yet conveniently for this to accomplish.

At all convenience and, on the first opinion, simplicity of method of comparison with reference device, him realization without disconnecting of measuring circuit, by way of implementation parallel measurement, imposes peculiar demands to the reference device, namely:

- reference and tested devices must have got identical dynamical characteristics, otherwise variation of measuring parameter may bring to the essential difference of the measuring results;
- reference device must of mat highest noiseproof and protection from a noise than verifiable instrument (at the verification of the industrial measurement devices possible to assume the noiseproof on level 90-100 dB);
- reference device must not affect the measuring result of verifiable instrument (scilicet reference device must of mat enough large input resistance and in it must be take action for the penetration elimination of jitters into measuring circuit that are caused by the functioning of thereof active elements and the power system).
- reference devise must be protected from effect on him measuring result of the interaction of input circuit of verifiable device with primary transducer (among the most influential factors of interaction possible to exude the switching noise: what penetrate into measuring circuit during him reconfiguration; from switching, what associated with the algorithm of measuring and error correction; from the modulation or the instability of parametric sensor excitation).

2.1. The parallel measurement of active transducers signals

Active measuring transducer form output signal in the kind of voltage, or current. Yet simply to organize parallel measurement with verifiable device, into which like informative parameter is voltage. In many cases, measurable value is associated with the informative parameter of primary transducer by sophisticated dependency. For the measuring result calculation in the units (dimension) of measurable value, measuring device accomplishes functional conversion the measuring result of the informative parameter of primary transducer. In these cases, reference devise must reiterate functional scheme of verifiable measuring device, and accomplish such conversions. For example, reference measuring device for the parallel temperature measurement by means of thermocouple must be found to have two measuring channels [17] - one for measurement thermo-electromotive force of thermocouple (A1,UC3) and another - for the cold junction temperature measurement (UC1, UC2) by means of own temperature sensor (Fig. 1). In adder unit (SM1) is realized correction for the cold junction temperature into the measuring result of.

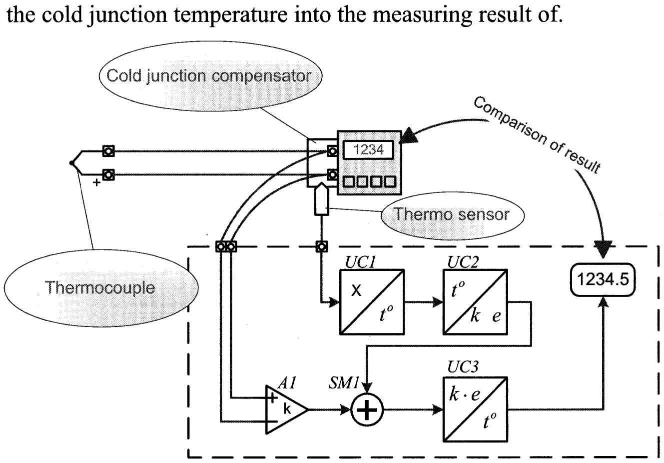

Fig. 1. Functional scheme of the reference device for the parallel temperature measurement by means of thermocouple

Parallel current measurement without the breach of measuring circuit is significantly difficult. In common case, parallel current measurement possible by way of the measurement voltage onto the shunt that is set on the input of verifiable instrument, or onto an external shunts that was preliminarily in-built into connection line. However, for holding such measurements it is necessary to know real value of these shunt resistance. Practically, we do not know real value of shunt resistance in-built into instrument. In addition, to install precision external shunt inexpediently. Measuring resistance of shunt before the beginning of parallel measurement on the background of measurable current is possible by way of the solution of this problem.

So long as through shunt leaks inalterable current per a time of measuring, then numerical meaning of shunt resistance possible to determine by results of two measurement that are performed at two well-known value of the excitation current (e.g., at nominal the and zero values of this current), as

$$N_{Rs} = \frac{N1 - N2}{N_{In}} = \frac{M \cdot (Ix + In) \cdot Rs - M \cdot Ix \cdot Rs}{N_{In}} = \frac{M \cdot In \cdot Rs}{N_{In}} \qquad (1)$$

where $N1, N2$ - the numerical quantity of two measuring results at nominal and zero values of excitation current; N_{In} - the numerical value of excitation current, which amounts to nominal value of product $M{\cdot}In$; M - the coefficient of the transformation of measurement value into numerical quantity; Ix - the measurable current; In - the excitation current; Rs - the shunt resistance.

Then current that leaks through shunt possible to determine as

$$N_{Ix} = \frac{N2}{N_{Rs}} = \frac{M \cdot Ix \cdot Rs}{M \cdot In \cdot Rs} \cdot N_{In} = \frac{Ix}{In} \cdot N_{In} \qquad (2)$$

Functional scheme of reference device that will realize such measuring algorithm represented on the fig. 2. Measuring current executed in two stages. On the first stage measured shunt resistance, and on the second - just measured current value. The switch (SW1) modulates excitation current (In) and transfers a voltage on the shunt, formed at two values of the excitation current, to the subtracting device (SB1) for determination of the shunt resistance. Thus, on an output of the divider (DV1) we receive value proportional to resistance of the shunt. Hereby, the listed elements of the circuit form an ohmmeter with correction of an additive making error [16].

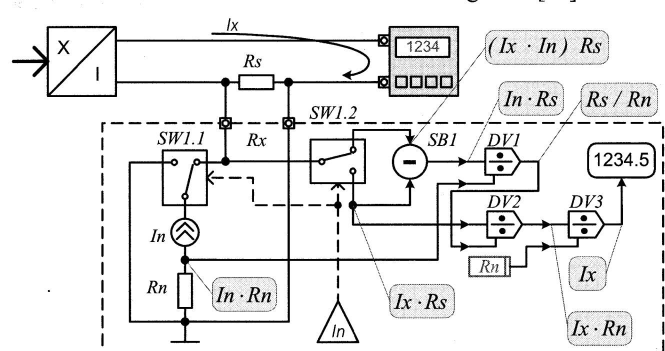

Fig. 2. The functional scheme of reference device for parallel measurement of current

On second stage the switch (SW1) fixed in reverse condition and voltage on shunt transferred on divider (DV2). The divider DV2 and DV3 calculate the value of measurable current using the value of voltage on the shunt, the stored value on the output of divider DV1, and the numerical quantity of resistance of reference resistor Rn. The value of measurable current may be functionally converted, analogically to conversions into verifiable measuring device, if necessary (on scheme these elements are not described). This would enable easily to compare the measuring results of verifiable and reference measuring devices.

Modulation of the excitation current brings to the voltage variation on the shunt of verifiable measuring devices. In one's turn, this brings to variation the measuring result of the verifiable measuring devices for the duration measuring of shunt resistance. To minimize impact of modulation of the excitation current possible by reducing the duration time of excitation current passing and by reducing the itself value of this current.

2.2. The parallel Measurement of parametrical transducers signals

The peculiarity of measuring informative parameters of parametric transducers is the necessity of the formation of some excitation for reception the reaction of transducer in the kind of voltage or current. Thereat reaction of transducer may contain as reaction of informative so the reaction of not-informative parameters. For influence elimination of not informative parameters onto results of measurement in measuring circuit are exists tight interaction between excitation circuit and by functional units that convert signal the reaction of transducer. The character of this interaction is defined by the method of the measuring informative parameter of transducer. So reference measuring device, for accomplish parallel measurements of informative parameters of parametric transducers, must have two measuring channels - one for the measuring parameters of excitation and another - for the measuring reaction of parametric transducer, and functional knots[nodes] which reproduce measurement method of verifiable device. Therefore structure of the reference device directly depends on the type of parametric transducer, the method of measuring thereof informative parameter and the mode of excitation.

At first glance, the problem of design of reference device of measurement for parallel measurement of informative parameters of parametrical transducers looks difficult for solution. Cause of these is bulk variety of parametrical transducers and methods of measuring their informative parameters. However, long term practice of application such transducers brought to optimization and decrease the amount of their kinds and the methods of measuring their informative parameters. This enabled to create the series of microelectronic device for measuring informative parameters of parametrical transducers [3, 4, 5, 9, 10, 15]. At present among parametrical transducers are prevalent the transducer, which informative parameter is resistance that changes under the action of temperature or another magnitude [17, 19, 22, 23]. Majority resistive transducers connected up to measuring device by three - or four connecting line. More seldom is met connection by two lines with compensational resistor, which resistance amounts to total resistance of lines. Basically excitation of transducer perform by fixed current, more seldom - by current generated by excitation voltage into series connected reference and measurable (transducers) resistance [4, 9, 20, 21]. For allowing invariance results of resistance measurement to instability of excitation current the reference voltage for analog-to-digital converter formed by the reference resistor Rn (Fig. 3). At three-line resistive transducer connecting for not-informative line resistance compensation, use the quasi-bridge structure of measurement circuit (Fig. 3c), or mirror current source (Fig. 3d). The latest variant of the building of measuring circuit found the most occurrences in industrial measuring device [4, 19].

To accomplish parallel resistance measurement is possible by two ways. First way - so like this got at measuring resistance of shunt (Fig. 2). However, in this case inevitable distortion the measuring results of verifiable measurement device. Second way - by measuring excitation current in the resistive transducer, voltage in this transducer and calculate resistance value like ratio this voltage to current. The excitation current of resistive transducer we can measure do it like parallel current measuring, using for this as shunt additional resistor in one of current line or proper resistance of line or resistive transducer like a shunt (Fig. 4). If measuring circuit build like a quasi-bridge structure (Fig. 3c) then in reference devise is necessary to repeat functionally this structure. This signifies that reference devise must have an additional voltage-sense input like is shown in Fig. 4b.

Measuring resistance consists out of two stages. On the first stage is fixed the excitation current (In). On the second stage is determined value of transducer resistance as dividing the voltage on transducer by excitation current.

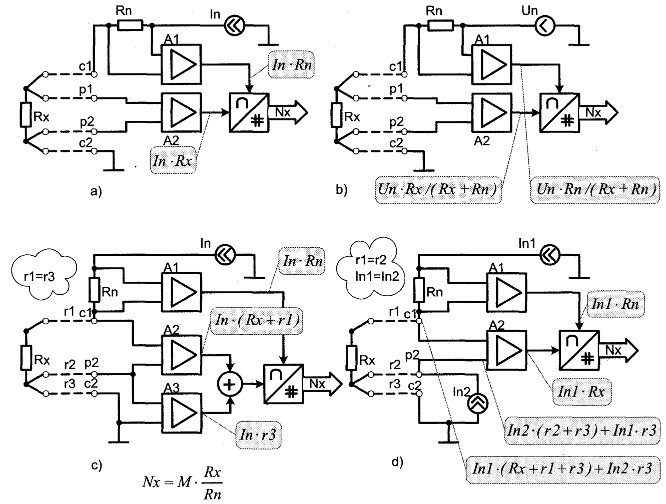

Fig. 3. Variants of circuit for resistance measurement

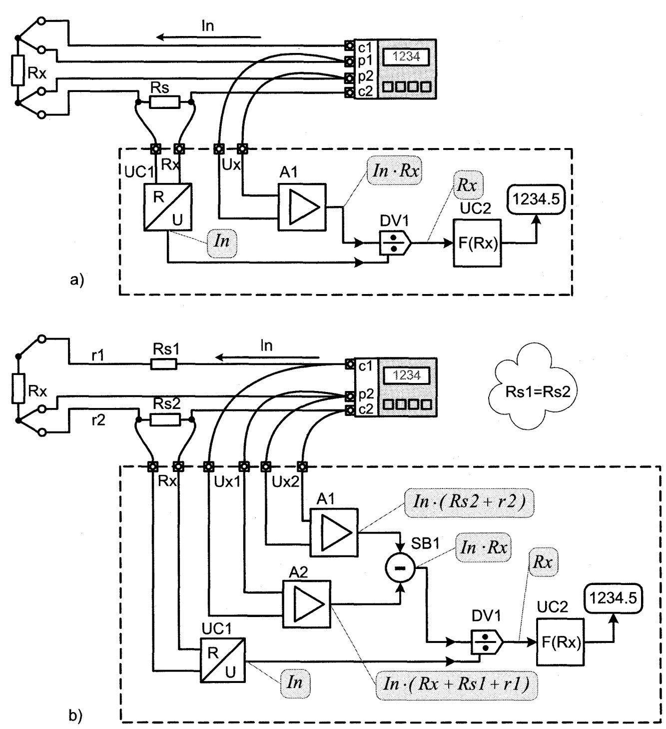

Fig. 4. The functional schemes of reference device for the parallel measuring resistance of transducer

3. The metrological performance control in several points of the measurement range without disconnecting of measuring circuit

3.1. The active transducers signal reproduction

To reproduce the signal of active converter possible simply putting together concurrently transducer and reference source. However, at the parallel connection reference source to transducer, which informative parameter is a voltage, at the significant difference their output voltage and the small output resistance of transducer into the measuring circle can leak such current that will to damage transducer or reference source. This, in many cases, makes impossible implementation the metrological performance control of measuring device without disconnecting measuring circuit. To evade this problem possible having plugged resistor in into breach one of line, which will limit current that arises in measuring circuit in the result of mutual connecting two voltage sources. In reference source must be divided current and sense lines for the reproduction of reference voltage on the input of measuring devise. The functional scheme of such reference source showed in Fig. 5, where units A1, A2, SB1, and UC1 form tracing system, which reproduces voltage value in the input of verifiable device given by input unit DI1. As variant, possible connect current line to plugged resistor, if current out of reference source through transducer inadmissible.

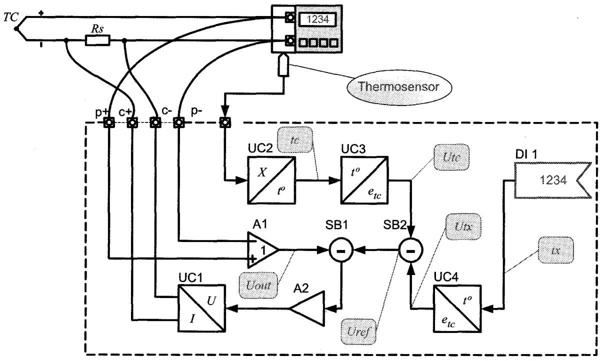

Fig. 5. The functional scheme of reference devise for the parallel reproduction of voltage

The functional scheme of reference devise for parallel reproduction electromotive force of thermocouple showed in Fig. 6. Into it are introduced elements that enter correction into the output voltage in relation from cold junction temperature (UC2, UC3 SB2).

Necessary to annotate that circuit A1, SB1, A2 and UC1, at sufficient dynamic characteristics her component, makes input voltage of verifiable device entirely invariance to the parameters of transducer and communication lines. In this way, from procedure of metrological control is excluding such important factor of influence as normal-mode interference. This "lack" may become very useful in case of need search of the reasons of metrological discrepancy by exception of influencing factors.

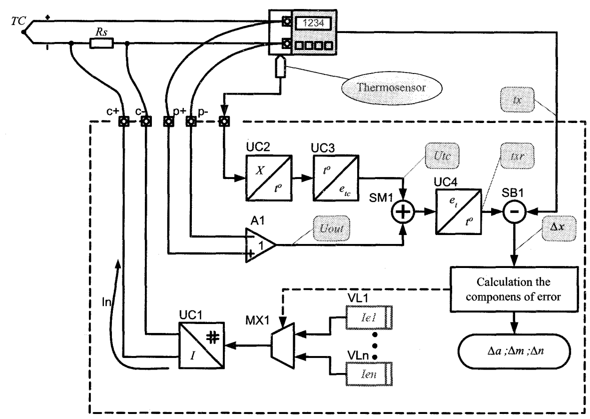

Fig. 6. The functional scheme of reference devise for the parallel reproduction of electromotive force of thermocouple

To capture the metrological control all influencing factors it is possible by formation of some set of additive test influences on an input of the verifiable device. In our case - by forming in a measuring circuit some of increments of an input voltage of the verifiable device.

Let us consider algorithm of definition of additive and multiplicative component of error of the verifiable device by a method of formation increments of informative parameter.

Let we have next conditions:

- verifiable device measures informative parameter X in range from $Xmin$ to $Xmax$;
- the result of measurement is represented by a number N which nominally is associated with informative parameter by linear function $A+B\bullet X$;
- there is an opportunity to form some additive increment Xni of informative parameter;
- during the time of formation increments informative parameter matters Xx to which there corresponds result of measurement Nx.

For the definitions component of error, including component of nonlinearity error, calculate $k>5$ values Xn in order to $Xx+Xni$ were allocated uniformly within from $Xmin$ to $Xmax$. After perform this increments we shall derive the range of measuring result which possible to inscribe as

$$N_i = \alpha + \beta \cdot (Xx + Xn_i) + \chi(Xx + Xn_i) \quad (3)$$

where $\chi()$ - function that delineates nonlinearity error; α and β - real value of coefficients of the conversion function.

The value of coefficients α and β possible to find from the range of measuring result Ni by the least-squares method believing that these coefficients of linear interpolation function. However, for this necessary to know value Xx, otherwise we can to find only coefficient β. This value (Xx) possible obtains performing the parallel measurement. Obtained in this way coefficients α and β possible apply for determination error components of verifiable device.

$$\Delta a = \frac{\alpha - A}{B}; \quad \delta m = \frac{\beta - B}{B}; \quad \delta n = \frac{max\{Ni - [\alpha + \beta \cdot (Xx_i + Xn_i)]\}}{B \cdot (X\,max - X\,min)}. \quad (4)$$

where $\Delta\alpha$, δm and δn - adjusted to device input value of additive, multiplicative and nonlinearity components of error accordingly; Xx_i - the value of informative parameter at the moment of the formation of reference increment Xn_i.

Necessary to annotate that in practice to achieve the stability of Xx during long time is impossible. Therefore, all operations of formation reference increments necessarily to pass maximally quickly - scilicet to pass the control of metrological performance in automatic regime. Except these, on informative signal can be imposed noise and (or) into the measuring result of can be present random component of error. For the deduction of these factors necessary a few times to repeat increments performing and apply mathematical statistics methods for elimination their effect on verification.

We shall consider the functional scheme of reference device for the determination components of error by a method of formation increments of informative parameter (Fig. 7). In our case, verifiable device measures temperature in kit with thermocouple transducer TC. The reference device consists of two parts. One part is for parallels measurement electromotive force of thermocouple (elements A1, UC2, UC3, UC4, SM1), like device in Fig. 1. Second part is for performing increments in the input of verifiable device (elements UC1, MX1, VLi). Increments performed by stepping current (In) sourced to the additional resistor (R). Stepping of current proceed by multiplexing set point current (VLi) to number-to-current converter (UC1). The multiplexing set point of current controlled by the element of calculation of error components. This element processes errors value are received on each step of increment as difference the measuring result of reference and verifiable devices.

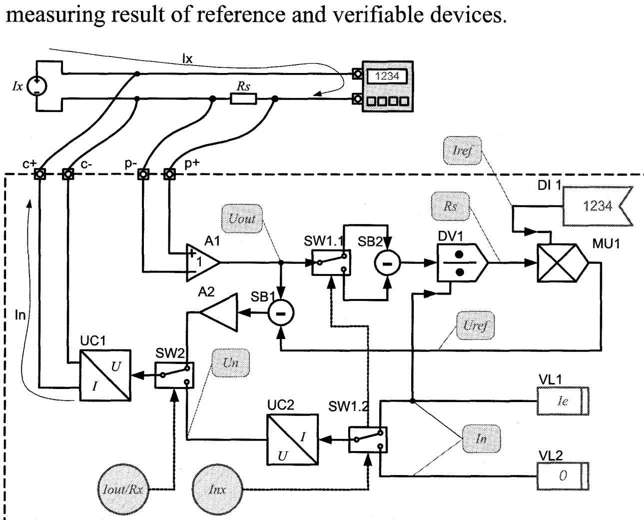

Fig. 7. The functional scheme of reference device for the determination components of error by a method of formation increments of informative parameter

A problem of mutual shunting reference and controlled appliances does not arise during parallel reproduction of current. This betokens that technically easily to perform increasing of measurable current. For the formation of reference current on the input of verifiable device or the determination of measurable current value, it is necessary to have shunt with well-known value. As shunt the internal shunt of verifiable devices or the resistor included in break of the communication line, as in a case of parallel measurements of a current may be used

The functional scheme of reference devise for parallel reproduction current is showed in Fig. 8. This reference device has a circuit for measurement of resistance of the shunt Rs (components A1, SW1, DV1), a circuit of formation of two values of excitation current In (components UC1, UC2, SW1.2, VL1, VL2) and tracing system (components A1, A2, UC1), providing reproduction of a required current. Switch (SW2) provides switching the voltage-current converter (UC1) from a mode of operation in tracing system in a mode of excitation current generation. The multiplier (MU1) forms a set point to tracing system by multiplication of value of the shunt resistance to a preset value of a current. The reference device measures value of the shunt resistance before the beginning of a current reproduction. For this purpose switch (SW2) placed in the bottom position.

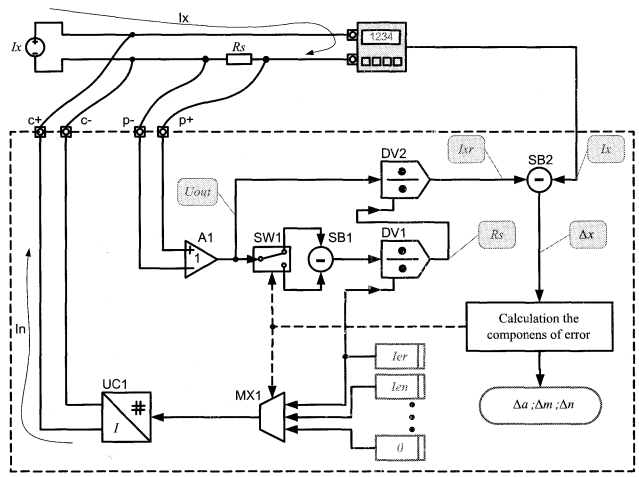

Fig. 8. The functional scheme of reference devise for parallel reproduction of reference current

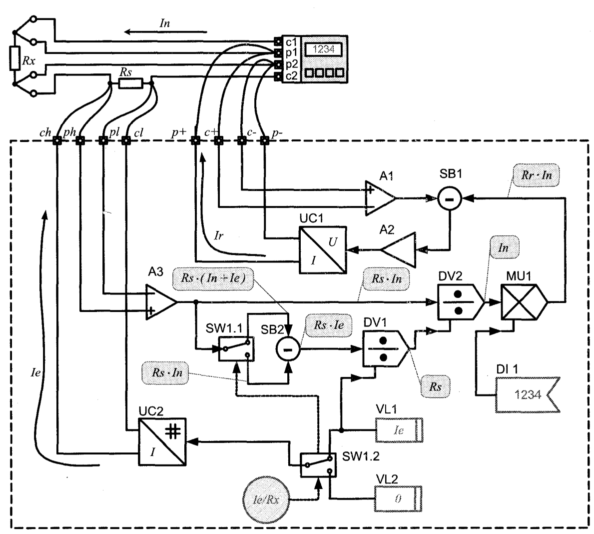

Fig. 9. The functional scheme of reference device for parallel reproduction of current and the determination components of error by a method of formation increments of informative parameter

For definition components of error of the verifiable device by method a of increments informative parameters in the circuit, represented on Fig. 8, it is necessary to enter the elements providing parallel measurement of a current (DV2) and to organize an opportunity to form increments of a excitation current (Iei, MX1). In this case, one known value of an increment of a current for formation of a current of excitation used at measurement of resistance of the shunt (Fig. 9).

3.2. Reproduction of informative parameters of parametrical transducers without break of a measuring circuit

Any means of measurement for definition of informative parameter of the parametrical transducer forms some excitation by a current or voltage [18, 22, 24]. That is, reaction of the transducer functionally joined to excitation. Measuring circuit of the measuring device build so that to provide reaction to excitation proportional to informative parameter. If definitely to deform reaction of the transducer, the measuring device will apprehend it as change of informative parameter. If these distortions will be proportional to excitation, we are feasible imitation of informative parameter of the transducer. For example, let the device measures resistance in a mode of the fixed current. The voltage actually measured and recalculated in value of resistance as *Ur/Ie*. If in parallel to the resistor to connect, a source of voltage indications of the measuring device will change. If we do not know value of a current of excitation, reaction of the measuring device to distortions of a voltage in the resistor will be unpredictable. However, if to connect a voltage of a source with a current of excitation in some factor r the voltage on the resistor will be equal *r•Ie* and the measuring device will determine that measuring resistance matters *r*. Thus, we have made imitation of resistance *r* not breaking off a measuring circuit.

The example of a function chart of the device, realizing this method of imitation of informative parameter, is shown on Fig. 10. This reference device contains tracing system (elements A1, SB1, A2, UC1) for formation of the deformed value of a voltage on the resistor, a circuit of definition of value of the shunt resistance (elements A3, SW1, SB2, DV1), a circuit of definition of value of a excitation current (A3, DV2) and a circuit of formation of an increment of a current for definition of the shunt resistance (VL1, VL2, SW1.2, UC2).

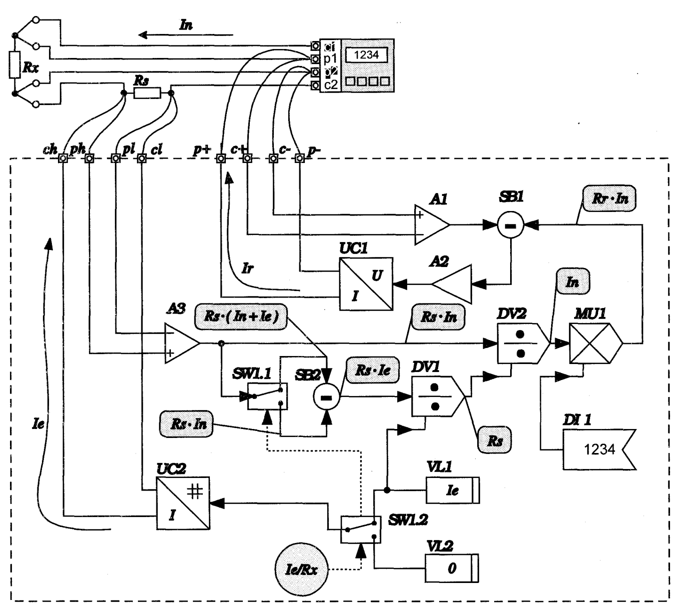

Fig. 10. The reference device, realizing method of resistance imitation

4. Conclusions

There is an opportunity of realization of the metrological control of measuring device without dismantle and reconnecting of a measuring circuit.

Application of such procedure of the metrological control allows taking into account the factors influencing an error of measurement, in full

The submitted function charts of exemplary devices show presence in them of a plenty of the common elements that creates good preconditions for creation of the universal device for realization the without dismantling metrological control.

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Tytuł: Bezdemontażowa kontrola metrologiczna przemysłowych układów pomiarowych

Artykuł recenzowany

RECENZJE

Boyes Walt (red.) i 51 współautorów

Instrumentation Reference Book (Poradnik Techniki Pomiarowej)

Butterworth Heinemann, Elsevier Science, Boston 2003

wydanie 3, ISBN 0-7506-7123-8 - książka w języku angielskim

Na ostatnich Międzynarodowych Targach Książki w maju br. w Warszawie firma A.B.E. Marketing z Warszawy zaprezentowała po raz pierwszy w Polsce wydaną w tym roku najnowszą wersję tego znakomitego brytyjskiego opracowania z dziedziny techniki pomiarowej, które będzie nazywane dalej Poradnikiem. Angielski termin „Instrumentation" użyto tu w tytule w szerszym sensie - jako „Instrumentation Technology". Nie należy więc go dosłowne tłumaczyć - jako „aparatura pomiarowa" lub „oprzyrządowanie". Jako zbliżony doń pojęciowo polskim odpowiednik proponuje się „Technikę pomiarową".

Powyższa pozycja wydawnicza powinna w dużym stopniu zainteresować nie tylko polskich pomiarowców i automatyków, ale i wielu innych specjalistów z przemysłu, laboratoriów, placówek badawczych i naukowych, oraz nauczycieli akademickich i studentów. Nie istnieje obecnie w języku polskim zbliżone doń, aktualne opracowanie. Ostatnia, tak szeroko zakrojona tematycznie książka z tej dziedziny to Podręcznik Metrologii pod redakcją P.H. Sydenhama, część 1 i 2, wydany przez WKiŁ Warszawa w 1988 i 1990 roku. Jest to tłumaczenie z oryginałów angielskich jeszcze z lat 1982, 1983. Ma też ono odmienny i węższy zakres tematyczny. Nie wydaje się też możliwe, aby podobne do omawianego tu Poradnika, tak ogromne dzieło, mogło w najbliższym czasie powstać w Polsce na zasadach nie tylko czysto komercyjnych, ale nawet i przy pozyskaniu odpowiednich sponsorów. Trudno by było znaleźć wystarczająco liczne grono polskich autorów o podobnym specjalistycznym doświadczeniu w poszczególnych technikach pomiarowych. Warto więc szczegółowo omówić treść tego Poradnika.

Poradnik składa się z 43 rozdziałów zgrupowanych w 5 części, z 4 dodatków i indeksu terminów. Łącznie liczy aż 1062 stron bogato ilustrowanych 1107 rysunkami i fotografiami oraz 125 tabelami.

Część 1 - **Pomiary mechaniczne** obejmuje rozdziały 1-13. Omówiono tu pomiary: przepływu, długości, naprężenia, poziomu i objętości, wibracji, siły, gęstości, ciśnienia, próżni i rozmiarów cząstek pyłu. Opisano też zastosowania światłowodów w aparaturze kontrolno-pomiarowej i inteligentne przetworniki pomiarowe wykorzystujące mikroprocesory.

Część 2 - **Pomiary temperatury i składu chemicznego** (rozdziały 14-19), obok opisu pomiarów temperatury zawiera wstęp do analizy chemicznej, oraz omówienie metod spektroskopowych, elektrochemicznych, analizy gazów i pomiarów wilgotności.

Część 3 - **Pomiary elektryczne i promieniowania** (rozdziały 20-25) prezentuje obszernie pomiary wielkości elektrycznych, pomiary optyczne, pomiary promieniowania jądrowego i zastosowania techniki jądrowej oraz badania nieniszczące i pomiary szumów.

cd. Recenzji na stronie 56