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INTELLECTUALIZATION OF PROCESSES FOR CONTROL OF ARC WELDING PARAMETERS

A.E. KOROTYNSKY and **M.I. SKOPYUK**
E.O. Paton Electric Welding Institute, NASU
11 Kazimir Malevich Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua

Intellectualization is a tendency of current stage of technology development. In a greater degree it refers to welding equipment, where one of the important issues is intellectualization of control of main parameters in the arc processes. Present work considers the issues of design of multifunctional transducers, designs of which are unified according to IEEE 1451.4 standard. The systems of measurement equations are given. They allow controlling welding parameters with minimum systematic errors in real time mode. 12 Ref., 1 Table, 4 Figures.

Keywords: *smart transducers, multifunctional transducers, measurement equation, welding parameters, error*

General approach in design of smart transducers (ST) was proposed by Brignell J. and Dorey A. in 1983 [1]. A sensing element (SE) of such a transducer is connected to controlled circuit using a switch (S), which is controlled by imbedded microprocessor (MP). The latter in accordance with selected algorithms and developed programs controls all measurement procedures as well as sets the modes of internal self-control. It can be control of ambient temperature, tracking of voltage of zero drift in analogue systems etc. Different ST architectures are described in details in work [2].

General information system development, which is considered as one of the elements of public life intellectualization, has affected development of sensor devices. If before the results of measurement were processed almost manually, then current stage of development of microprocessor equipment allows carrying all processing (scaling, calibration, noise suppression etc.) using a microprocessor block, which is connected to the sensing element (SE) of sensor. Such devices are called smart sensors [3, 4]. At that a series of additional requirements is made to them. Modern sensor, in addition to SE, shall contain means for signal processing, switching means, independent power supply, user’s interface, facilities for protection from environment effect, aids which allow identifying sensor itself as well as point of its positioning(data take off place).

Current tendencies of design of the measurement systems are directed on development of smart sensors, which are integrated in a single crystal. Such sensors can contain whole smart multivariate (multi-channel) measuring systems (lab-on-chip) [5].

Engineer-researchers and designers, in order to develop necessary for customer sensor devices, work at reduction of their cost, size and levels of consumption; improvement of metrological parameters (sensitivity, accuracy, linearity etc.); standardization of communication process via interface buses or wireless systems; unification of manufacture and operation via standardization.

The first real step in a direction of global «intellectualization» of the transducers can be the International standard IEEE 1451.4, which sets the main requirements to primary measuring converters.

The Institute of Electrical and Electronics Engineers (IEEE) developed IEEE 1451.4 standard [6] as one of the elements of IEEE 1451 complex protocol. One of the aims of IEEE 1451.4 standard is simplification of sensor connection to measuring devices, facilities of signals processing and computer networks. The standard determines a set of interfaces and software structure as well as defines the main procedures of information exchange.

A block of IEEE 1451.4 standards regulates application of already existing analogue measuring converters of physical values as a part of computerized measuring analyzers. According to the standard each applied measuring converter shall have the Transducer Electronic Data Sheet (TEDS).

IEEE 1451.4 standard determines the procedures for table description of a sensor for electronic data sheet (TEDS), which in addition to baseline information (type of sensor, serial number, installation point etc.) can include the tables for calibration and linearization. A block diagram of TEDS application in smart sensors and sensor systems is shown in Figure 1.

Transducer interface contains a traditional analogue channel and not expensive serial digital channel, which provides access to TEDS structure. IEEE 1451.4 describes a mechanism of the analogue trans-

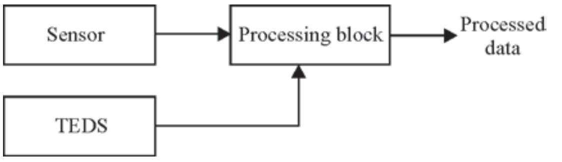

Figure 1. Scheme of TEDS application in smart sensors and sensor systems

ducers supporting an operation mode with self-description and communication protocol on serial channel. Presence of the analogue interface determines a necessity in providing compatibility of earlier manufactured and installed transducers with Plug&Play technology.

The main peculiarity of the proposed approach is application of TEDS technology for practical fulfillment of functioning algorithms in different type transducers, designed for welding process control. Further ST development taking into account the requirements of described standard has followed the way of development of multifunctional reconfigurable structures [7]. Besides, it was directed on synthesis of the algorithms of their functioning, which could consider specifics of their operation in specific environment, for example in welding arc zone, which generates large number of destabilizing factors. This work in particular is dedicated to the analysis of measurement algorithms using smart multifunctional transducers.

It is well known fact that earlier a transducer was usually considered as a measuring device, which can perform selective processing of some parameter $x_1(t)$, acting at so-called negentropy input [8]. All other inputs (they are usually called entropy) $x_2(t)$, $x_3(t)$, ... $x_n(t)$ are determined by destabilizing factors acting in a control zone. Electromagnetic noises, developed by welding and technological equipment, own electric and magnetic noises, thermal fields, ionizing emissions etc. can be referred to them. Development and improvement of sensor equipment moved in a direction of development of such solutions, which eliminate or significantly reduce effect of indicated factors on final results of the measurement.

The results of first researches, related with development of multifunctional transducers (MFT) [9, 10] appeared at the end of the 1980th. In them part of the entropy inputs was transformed in negentropy ones. This significantly increased volume and reliability of received information in regards with several parameters of the investigated process.

Analytical problem of analysis and synthesis of MFT is formed in the following way. It is assumed that controlled functions $x_2(t)$, ... $x_k(t)$ are known in the main equation, which functionally describes some parameter $x_1(t)$ being measured. Earlier they were not taken into account that resulted in additional measurement error. Respectively, we come to a system of *k*-equations, solution of which gives the desired result on each *j*-parameter.

Metrological capabilities of MFT, related with extraction of information on some input parameters acting in some concentrated space, make it greatly perspective tool for scientific and technological researches. Development of computer measurement methods [11] in combination with MFT allow substantially raising their metrological and dynamic characteristics by realizing the algorithms of mutual correction of the parameters being processed.

Figure 2, *a* shows schematic image of MFT. Its SE is capable to receive some set of input parameters $\{x_1, x_2, ... x_n\} = X_j$. Moreover, they can have different physical nature, for example, the input actions for resistance strain gage can be deformations, temperatures and vibrations. Set of inputs X_j is assigned with set of output parameters $\{y_1, y_2, ... y_n\} = Y_j$. Functional relationship between them is described by set of transition factors $k_1, k_2, ... k_n\} = K_j$. Figure 2, *b* shows «classical» transducer being sensitive to variation of one parameter x_1, other inputs $x_2 - x_n$ (marked by broken line) are entropic for it and being characterized by disturbance effect. Adder (∑), used in the transducer, at the inputs of which act all output SE signals, realizes an algorithm of selection of controlled parameter x_1.

It is well known [8] that quasilinear transformation operator for such one-parameter transducer is described by an expression:

$$Z(t) = k_1 x_1 f_1(x_1, x_2, ... x_n) + \\ + b_1\varphi_1(x_2, x_3, ... x_n) + \psi_1(x_1, x_2, ... x_n), \quad (1)$$

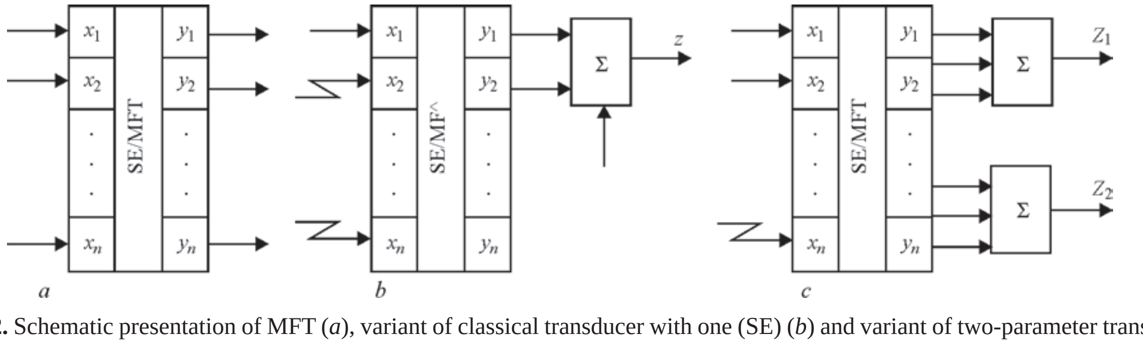

Figure 2. Schematic presentation of MFT (*a*), variant of classical transducer with one (SE) (*b*) and variant of two-parameter transducer (*c*)

where $Z(t)$ is the response function (output measuring signal); k_1 is the transition factor on controlled parameter; f_1 is the influence function taking into account effect of x_1 parameter and disturbances; φ_1 is the function taking into account effect of disturbances at the initial signal level; b_1 is the additive constituent of output signal; ψ_1 is the function of destabilizing factors considering non-linearity of transducer output characteristic.

Respectively, for two-parameter MFT, scheme of which is given in Figure 2, *c*, a system of quasilinear operators can be written in form of equations:

$$\begin{aligned} Z_1(t) &= k_1x_1f_1(x_1, x_2, \ldots x_n) + \\ &+ b_1\varphi_1\{x_2, x_3, \ldots x_n) + \psi_1(x_1, x_2, \ldots x_n), \\ Z_2(t) &= k_2x_2f_2(x_1, x_2, \ldots x_n) + \\ &+ b_2\varphi_2\{x_2, x_3, \ldots x_n) + \psi_2(x_1, x_2, \ldots x_n). \end{aligned} \tag{2}$$

Simultaneous solution of these equations allows finding the values of required parameters x_1 and x_2, information about which is set by one SE. And, respectively, three-parameter MFT is determined by a system of equations:

$$\begin{aligned} Z_1(t) &= k_1x_1f_1(x_1, x_2, \ldots x_n) + \\ &+ b_1\varphi_1\{x_2, x_3, \ldots x_n) + \psi_1(x_1, x_2, \ldots x_n), \\ Z_2(t) &= k_2x_2f_2(x_1, x_2, \ldots x_n) + \\ &+ b_2\varphi_2\{x_2, x_3, \ldots x_n) + \psi_2(x_1, x_2, \ldots x_n), \\ Z_3(t) &= k_3x_3f_3(x_1, x_2, \ldots x_n) + \\ &+ b_3\varphi_3\{x_2, x_3, \ldots x_n) + \psi_3(x_1, x_2, \ldots x_n). \end{aligned} \tag{3}$$

Thus, it follows from mentioned above that the expression for general member of system of n-equations, describing *n*-parametric MFT, should have form:

$$\begin{aligned} Z_n(t) &= k_nx_nf_n(x_1, x_2, \ldots x_n) + \\ &+ b_n\varphi_n\{x_2, x_3, \ldots x_n) + \psi_n(x_1, x_2, \ldots x_n). \end{aligned} \tag{4}$$

It is easy to see that expression (4) is an analytical presentation of principle of MFT multidimensional selectivity. As it follows from given equations (1)–(4), mutual consideration of joint effect of all acting factors requires information on such large number of initial data, that solution of MFT design problem in general form looses practical relevance. Therefore, further presentation will only deal with specific types of transducers, peculiarities of tracing selection of parameters being measured.

TEDS technology provides formation of transducer electronic data sheet (TEDS) which is inserted directly in a device chip. Using it the transducer communicates its parameters to connected data collection system.

Thus, a quasilinear operator of any of used transducer, presented in form of polynomials (1)–(4), is fed into a reprogrammable memory (RM) for further application in all measuring procedures. Such approach, to significant extent, promotes rise of MFT metrological parameters.

As an example let's consider a problem of MFT development, which can simultaneously control two information parameters (deformation and intensity of acoustic emission) in pipeline assemblies testing. Currently, the procedure used for this is based on measurement of acoustic-emission radiation in the part subjected to deformation effect. However, the results of identification of these changes are not always single-value. Work [12] shows that the deformation approach gives more efficient estimations of vibration parameters.

Developed MFT, design scheme of which is given in Figure 3, joins indicated procedures of vibromeasurements. TsTS-21 piezoceramics is used in the transducer as SE. It interprets mechanical oscillations in the controlled part in a wide frequency range. Frequency selection of information parameters was used for division of deformation signals $\varepsilon(t)$ and signals of acoustic emission intensity N_{AE}. Two channels can be outlined in MFT structure, namely high-frequency used for N_{AE} registration and low-frequency for $\varepsilon(t)$ measurement. The functional blocks are identical, i.e. band filters (BF), linear amplitude detectors (LAD) and corresponding voltage converters (VC). The peculiarity is the working frequency range. In the first case it is Δf = 450–900 kHz, in the second case Δf = = 560–8500 Hz. $\varepsilon(t)$ channel is additionally equipped with converter of damping logarithmic decrement (CDLD), input of which is connected to LAD2. Such spread of working frequencies provides high accuracy of decoupling of channels for measurement of indicated parameters.

Since method of signal processing in N_{AE} path does not require special explanations (preliminary ampli-

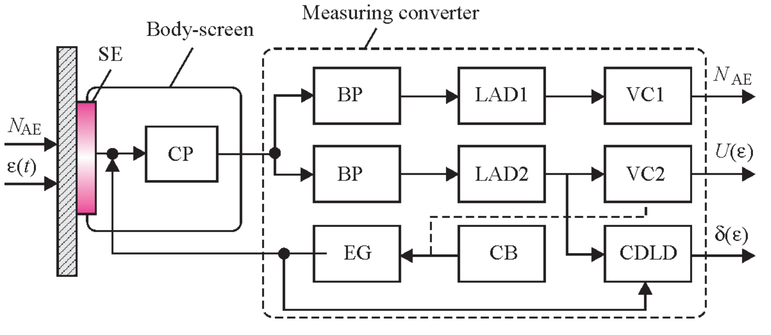

Figure 3. MFT design scheme

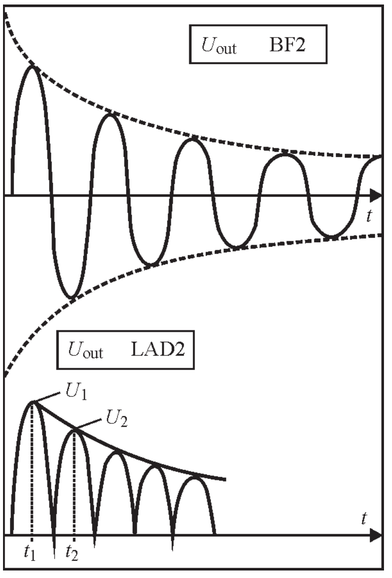

Figure 4. Diagram of work of DLD gage

fication in CP block, filtration, amplitude detection and registration in VC1), then let's elaborate on description of operation of deformation measurement path. It is based on a principle of measurement of static forces, caused by deformation of the part being controlled. At that, sine voltage, frequency of which corresponds to resonance frequency of piezoelement, is supplied to SE coating using excitation generator (EG) synchronized with control block (CB). Transformation function of CB output signal is significantly simplified:

$$U(t) = U_m \exp(-ht)\sin\omega t, \quad (5)$$

where h is the parameter determining a level of SE deformation; ω is the frequency of damped oscillations.

Synchronous integration of obtain signal with the help of VC2 allows forming output voltage as a deformation function: $U(\varepsilon) = f(h)$. Inverse dependence of $h = F[U(\varepsilon)]$ type can be used for transducer calibration.

Described scheme of MFT, as it follows from Figure 4, allows determining such an important characteristic of oscillating systems as damping logarithmic decrement (DLD):

$$d = \ln\left[U(t_1)/U(t_2)\right] = h(t_2 - t_1), \quad (6)$$

where $U(t_1)$, $U(t_2)$ are the instantaneous values of voltage registered by DLD converter in corresponding moments of time t_1, t_2.

It is necessary to note that this MFT has aperture time during which it does not perceive measurement information. This time is determined by EG oscillation period and makes ≤0.5 ms, and their $F_{EG} \geq 1$ Hz. In pauses the signals can be regenerated with necessary accuracy, corresponding to approximating function.

MFT is good to present by classification formula, taking into account their structural imaging. It looks like:

$$\text{MFT: } \{p_i/q_j/N(A_n/D_m)\},$$

where p_i is the number of controlled parameters; q_j is the number of used SE; N is the number of analogue (A_n) and discrete (D_m) output signals.

Respectively, two-parameter transducer with one SE and two output analogue signals, shown in Figure 1, *c*, can be set by the formula: $\{p_2/q_1/N(A_2)\}$.

E.O. Paton Electric Welding Institute of the NASU applicable to specific tasks of technological control has developed a series of MFT, characteristics of which are given in the Table. The Table also includes the following designations, namely SE–PC — piezoceramics type TsTS-21; STC — semi-con-

MFT characteristics

Designation	Function	Classification formula	Transducers' specification		
			SE type	Measuring transducer	Form of output signal
MFT of welding current and reactor temperature*	Fitting-out of welding equipment	$p_2/q_1/N(A_2)$	PC (TsTS-21)	IC/CVC	NAV/NAV
MFT of temperature and AE intensity*	Investigation of samples	$p_2/q_1/N(A_1D_1)$	PC (TsTS-21)	CVC/BF	NAV/NS
MFT of temperature and volumetric consumption of shielding gases	Fitting-out of welding equipment	$p_2/q_1/N(A_2)$	STC (Fonon-3)	CMC	NAV
MFT of bending value of AE intensity*	Technological tests	$p_2/q_1/N(A_1D_1)$	PC (TsTS-21)	PC/BF	NAV/NS
MFT of movement rate and welding torch position*	Fitting-out of welding equipment	$p_2/q_2/N(A_1D_1)$	FEC/R	TPC/SC	NS/NAV
MFT of welding deformations, temperature and AE intensity	Technological tests	$p_4/q_1/N(D_3)$	SGC	ACB/TNC/BF	NS/NAV
MFT of temperature, conductivity and dielectric constant of flux	Investigation of fluxes	$p_3/q_1/N(A_1D_2)$	CC	TNC/ACB	NAV/NS

*Results on MFT development were presented for the first time by the authors at the International Seminar of Poland Institute of Welding (Gliwice) in 1997.

ducting thermal electric converter Fonon-3; FEC — photoelectric converter; R — resistor transducer, SGC — strain-gauge converter.

The procedure of primary measurement conversion in given MFT is carried out using the following devices, namely IC — integrating converter; CVC — capacity-voltage converter; BF — band filter; CMC-calorimetric converter; PC — pressure converter; TPC — time-pulse converter; SC — scaling converter; ACB — alternating current bridge and thermal noise gage converter (TNC). The output signals of all indicated converters are rated in a way to correspond the requirements of input channels of computer hardware interfaces.

In the conclusion it should be noted that application of smart MFT in welding equipment allows significant expansion of volumes of received information relatively to technological processes, realized with their help. It is particularly important to note the possibility of mutual correction of received measuring signals at simultaneous control of several parameters of investigated process. As a result it allows significantly increasing measurement accuracy, and, respectively, quality of produced welded joints.

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