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COMPUTER SYSTEM FOR MEASUREMENT OF WELDING PROCESS PARAMETERS

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Abstract: This paper presents both hardware and software of system for measurement of welding process electric parameters.

The distinctive feature of the system is its application for control of the process of high-quality contact micro-welding of critical destination products which is characterized by the pulse current in the range from 100 A to 20kA and by the pulse duration from a few to hundreds of milliseconds. The system is portable and consists of the measuring coaxial shunt, oscillograph and computer with a software. Structure and main principles of constructing the system components are described. Its technical and metrological parameters are given.

Keywords: measuring shunt, pulse current, welding.

1. INRODUCTION

In order to join small-thickness precise mechanical details with high-quality the contact welding by means of amplitude-modulated unipolar current is used. The shape of welding current pulse is set according to welded object. At the same time current amplitude can vary from 100 A to 20 kA and the pulse duration value – from 1 ms to 100 ms. The existing industrial measurement instrumentation does not allow to confirm metrological characteristics of such welding equipment and to control the technological welding process because of the too large current dynamic range and short pulse duration [1]. Utilization of such the welding equipment in production technological processes requires its certification. The latter, in turn, needs to have measuring system to be included into State Register of Measuring Instruments.

To measure current in industrial environment there can be usually used one of three main methods:

- resistive shunt,
- current transformers (current clamps [2] and so called Rogowski coils [3]), and
- Hall effect-based sensors.

Each technology has its own tradeoffs conformably to measuring current pulses of big amplitude. The current transformer and Hall effect sensors are based on Ampere's law. Current transformers are rather inexpensive and provide isolation, but work only for AC circuit. Rogowski coils are applicable to measuring large current pulses but with small duration – right up to several nanoseconds [4]. Hall sensors, both open- and closed-loop, provide isolation and DC to high-frequency (200 kHz) AC operation, but have limitations in cost, size, linearity, and temperature performance.

Recently, new perspective technologies appear such as magnetoresistive sensing and Faraday effect-based optical transducers but they do not allow to measure current pulses up to 20 kA so far.

To solve the problem we have chosen the shunt [5] that works on the principle of Ohm's law. In spite of it does not provide isolation and inserts a voltage drop, this decision proves to be most preferable. The shunt offers low-cost DC and AC sensing, law waveform distortion, conversion coefficient invariability in broad band up to several megahertzes. Being used for AC operation they provide a possibility to be calibrated for DC operation.

In Section 2, it will be described a structure and operation of the measurement system SIBT that has been designed at the Department of Computer-aided Measurement System and Metrology of the Tomsk Polytechnic University. In Section 3 modeling results of two type of shunts, plain and coaxial, are presented. And in Section 4 will be discussed design calculation of the selected shunt type for the developed system that is coaxial one.

2. THE SYSTEM STRUCTURE AND OPERATION

The developed system is based on the current-to-voltage primary conversion and on further voltage conversion by tools available in the market. The connection layout of the system is shown in Fig. 1.

The system allows to measure instantaneous amplitudes input electric current pulses in the range from 100 A to 20 kA with main reduced error limit ± 5 %.

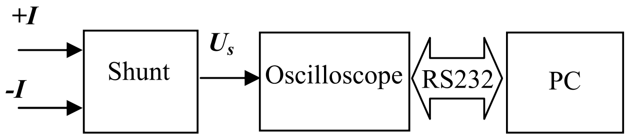

Fig. 1. The system structure

Appearance of the system SIBT is shown in the Fig. 2.

Power supply's current for contact welding is measured with the help of current-to-voltage converter CVC and digital oscilloscope Agilent 54621A (Fig. 2). Then measuring data for indication, storing and recordation are transmitted through the serial asynchronous interface bus RS232 into the notebook. The current-to-voltage converter CVC is implemented on the base of coaxial shunt with an axial outlet of a voltage circuit [2].

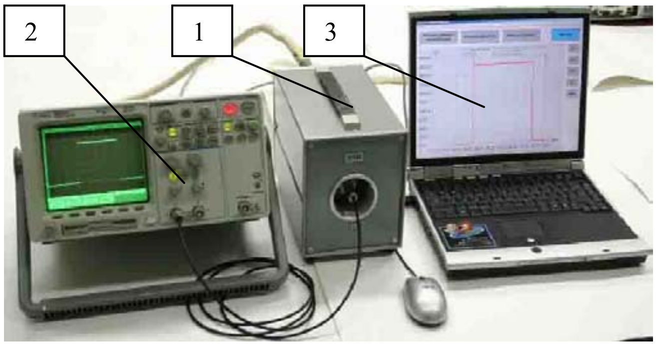

Fig. 2. Appearance of the system SIBT: 1 – current-to-voltage converter (CVC); 2 – oscilloscope; 3 – notebook.

The measuring information (pulse form, instantaneous values of time and current amplitude) is indicated in the computer monitor screen. The measurement software represents the 32-bit Windows-application. Importation of data from oscilloscope is performed trough COM-port and then their mathematical processing is carried out.
The measuring signal is registered on the personal computer monitor screen in the form of a pulse and in reconfigurable scale. The maximal frequency of measurements of instant current values can be up to 200 MHz.

3. COAXIAL SHUNT: MODELING

Usually, pulse current measurement by means of a shunt is an oscillographic recording of corresponding voltage pulses. To secure undistorted recording it is necessary the shunt resistance for pulse current to be the same as for DC operation. At the same time the oscilloscope sensitivity must be maximal in order to decrease its own noises influence on measurement results.

In Fig. 3 a simplified equivalent circuit of the AC shunt is shown [5]. It is evident from the diagram that high-ohmic shunt has a time constant that is defined mainly by capacitive component. In low-resistance shunt impact of inductive component is manifested stronger comparatively with the capacitive one.

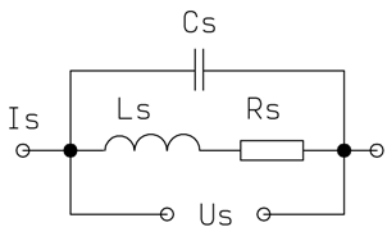

Fig. 3. Simplified equivalent circuit of the AC shunt

When measuring large currents, power consideration force to use low-resistence shunts. Hence, our aim is to minimize the inductive component.

It is especially important as contact welding sources are characterized by current rippling with frequency of about 30 kHz. In this case the inductive component will result in considerable presence of a noise in useful signal. This can be easily seen on MATHCAD model corresponding to the diagram in Fig. 3. Let the rippling amplitude be equal to 1A and the rate of its rise be 1.5 μs. Fig. 4 shows (with doted lines) the current I_{s1} through the plain shunt with typical parameters L_{s1} = 11 nH and R_{s1} = 25 μΩ and the current I_{s2} (with solid lines) through the shunt with diminished inductivity L_{s2} = 1.2 nH and R_{s2} = 160 μΩ.

One can see that the second shunt has the rippling amplitude 60 times less than the first one.

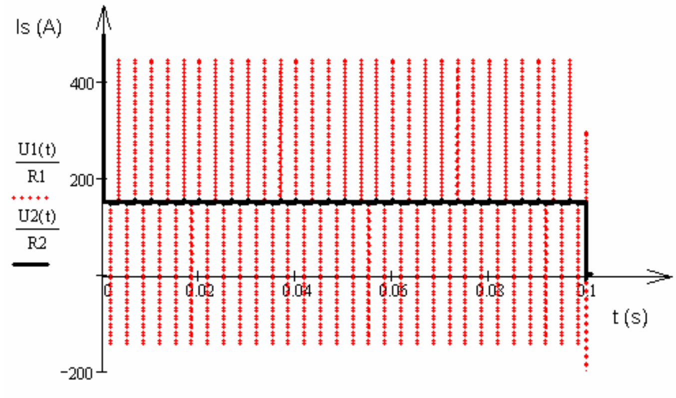

Fig. 4. Modeling results for plain (doted lines) and coaxial shunts (solid lines)

Thus, shunt voltage U_s in the presence of inductive component L_s depends not only on current I_s amplitude and also on a rate of the current change. The latter results in additional error when measuring different current shapes. To provide precise measurements it is necessary to use special embodiment of shunt's current circuit and also wiring and arrangement points of the shunt voltage circuit.

As conducted investigations show, most precise for current measuring in contact micro-welding power sources is a **coaxial shunt**. It has low inductance and additionally allows to reduce a harmful effect of external magnetic field.

4. COAXIAL SHUNT: DESIGN CALCULATION

Fig. 5 shows designation of main mechanical dimensions of the designed coaxial shunt. The shunt represents two nested cylinders where the external cylinder is conductive and made of copper; the inner cylinder is made of a resistive material. We use a 1.5 mm thick manganin (Cu, Mn, Ni) plate to make the inner cylinder.

Measured current pulse has the following parameters: maximal amplitude $I_{\max} = 2 \cdot 10^4$ A , duration $t \le 0.12$ s .

4.1. The shunt current circuit parameters

The minimal measured current $I_{\min}$ = 100 A, in order to record it 15 mV voltage must be at the oscilloscope input, hence the calculated shunt resistance value $R_s = 1.5 \cdot 10^{-4}\ \Omega$.

The shunt voltage drop under maximal current is

$$U_{\max} = R_s I_{\max} = 1{,}5 \cdot 10^{-4} \cdot 2 \cdot 10^4 = 3 \text{ V}.$$

Maximal power is $P_{\max} = 2 \cdot 10^4 \cdot 3 = 6 \cdot 10^4$ W.

Energy liberated in the shunt is

$E_s = P_{\max} t = 6 \cdot 10^4 \cdot 0.12 = 0.72 \cdot 10^4$ J .

Volume of the shunt current circuit is defined by formula

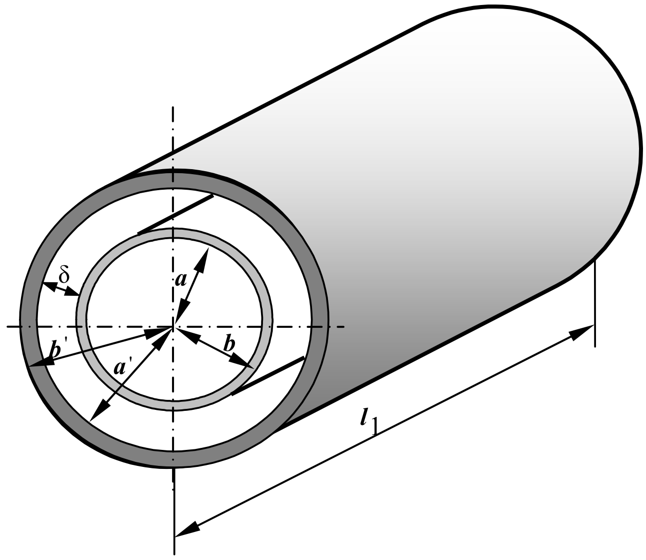

Fig. 5. Mechanical dimensions of the coaxial shunt

$$V = \frac{E_s}{C\gamma\theta},$$

where $C = 396\dfrac{\mathrm{J}}{\mathrm{kg \cdot K}}$ is manganin specific heat,

$\gamma = 8300\dfrac{\mathrm{kg}}{\mathrm{m}^3}$ is manganin density,

θ is overheating temperature in centigrades.

Then the volume is

$$V = \frac{0,72\cdot10^4}{396\cdot8300\cdot\theta} = \frac{2,19}{\theta}\cdot10^{-3}\ \mathrm{m}^3.$$

The particular value of V can be chosen depending on desirable overheating temperature (Table 1).

Length of the shunt current circuit is defined by formula [6]

$$l = \sqrt{\frac{VR_s}{\rho}},$$

where $\rho = 0.46\cdot10^{-6}\ \Omega\cdot\mathrm{m}$ is manganin specific resistance.

Sectional area the shunt current circuit can be calculated by formula

$$S = \sqrt{\frac{V\rho}{R_s}}.$$

Calculation results are reduced in Table 1.

TABLE 1. Volume, length and sectional area of the shunt current circuit and overheating temperature

θ°	V, m^3	l, m	S, m^2
40	$54.75\cdot10^{-6}$	$13.36\cdot10^{-2}$	$4.098\cdot10^{-4}$
50	$43.81\cdot10^{-6}$	$11.95\cdot10^{-2}$	$3.665\cdot10^{-4}$

4.2. The shunt timing data

Thickness of the cylindrical shunt wall is

$$\Delta \le \pi\sqrt{\frac{0.1t_1\rho}{\mu}},$$

where $\mu = 4\pi\cdot10^{-7}\ \mathrm{H\cdot m^{-1}}$ is manganin absolute permeability,

t_1 is the pulse acceleration time in s.

Since we have the 1.5 mm thick manganin plate, that is $\Delta = 1,5\cdot10^{-3}$ m, the pulse acceleration time can be calculated as

$$t_1 \ge 10\frac{\mu}{\rho}\cdot\left(\frac{\Delta}{\pi}\right)^2$$

from where $t_1 \ge 6.23\cdot10^{-6}$ s.

4.3. The shunt mechanical dimensions

Overall shunt length is defined as

$$l_1 = \frac{S}{\Delta},$$

Let us determine interior a and external b diameters of the manganin cylinder. As $l_1 = 2\pi a$, we have

$$a = \frac{l_1}{2\pi} \text{ and}$$

$$b = a + \Delta.$$

Calculation results are reduced in Table 2.

TABLE 2. The shunt mechanical dimensions

θ°	l_1, m	a, m	b, m
40	$27.3\cdot10^{-2}$	$4.35\cdot10^{-2}$	$4.5\cdot10^{-2}$
50	$24.43\cdot10^{-2}$	$3.89\cdot10^{-2}$	$4.04\cdot10^{-2}$

Spacing δ between cylinders we accept to be 2 mm.

4.4. The shunt inductivity

Then the shunt inductivity is

$$L = 2\cdot10^{-7} l\,\mathbf{ln}\frac{2a'}{2b}\ \mathrm{H}.$$

If θ = 40° the inductivity $L = 2\cdot10^{-7}\cdot13.4\cdot10^{-2}\mathbf{ln}\dfrac{4.7}{4.5}$ H and finally we have $L = 1,2\cdot10^{-9}$ H.

4.5. The shunt implementation

Real construction of the coaxial shunt based on the above design calculation is presented in Fig. 6 and 7.

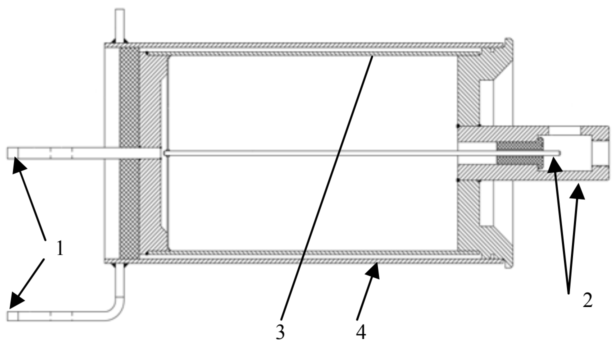

Fig. 6. Profile of the coaxial shunt designed: 1 – current circuit leads; 2 – voltage circuit leads; 3 – manganin cylinder (curremt circuit); 4 – copper cylinder (curremt circuit)

Fig. 7. Appearance of the shunt

Application of the shunt allows considerably to simplify a verification procedure of the developed measurement system.

Fig. 8 and 9 shows oscillograms of welding current measured using ordinary plain shunt and the designed coaxial shunt correspondingly. They are in complete correspondence with modeling results (see section 3).

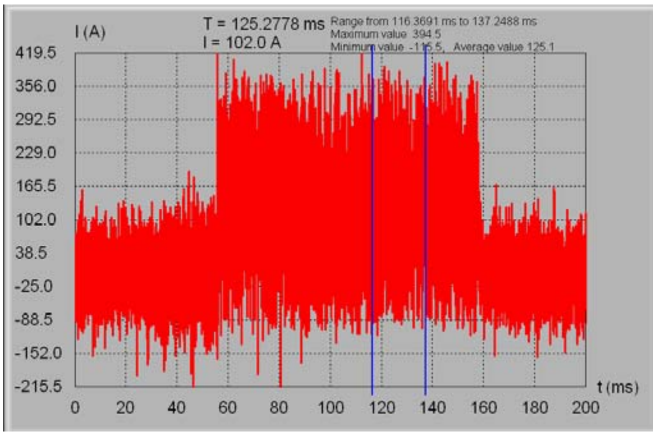

Fig. 8. Oscillogram of welding current for ordinary plain shunt

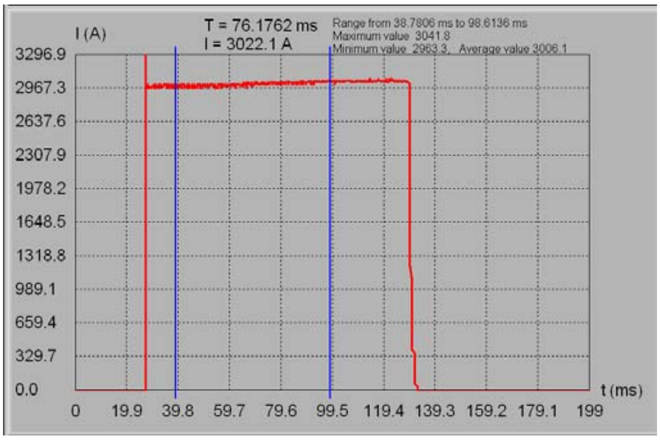

Fig. 9. Oscillogram of welding current for designed coaxial shunt

5. CONCLUSION

As a result of positive test outcomes the measurement system of large currents SIBT is registered in the State Register of Measuring Instruments (№ 28856-05) and released in Russian Federation. Now the system functions in the enterprise "Factory of Chemical Concentrates" Ltd. (Novosibirsk) and is used for balancing, commissioning, and adjusting welding stations at their production and metrological attestation.

At present, under certification of welding equipment only maximal value of the welding current is standardized [7]. It is necessary to note that welding quality depends also on the current waveform. Now there is appearing a new generation of welding equipment for which characteristics of the welding current waveform are standardized [8]. The system SIBT can be applied also and for metrological assurance of that kind of equipment. In this case, however, not only active resistance of the shunt must be under test and its reactance.

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