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MICROPROCESSOR-CONTROLLED DEVICE FOR FASTENING STEEL PEGS BY ELECTRIC ARC METHOD

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Abstract: A prototype device for connecting minute elements (such as pegs, bolts etc.) to sizeable metal surfaces is described in the paper. Engineering of this process and device design have been presented as well as basic measurements conducted during the weld-on process. The paper contains a schematic diagram of the power circuit based upon a thyristor rectifier bridge and block diagram of the control circuit. The device characteristics and operational parameters are also given.

Key words: electric arc, electrotechnology, power electronics.

1. Introduction

In industry, it is often necessary to join metal elements greatly differing in size. This happens in steel plant industry, when pegs holding fireproof brickwork must be fastened to the steel casing of the furnace or in automobile industry where small constructional elements such as hinges must be fastened to large metal plates. Fastening methods consisting of drilling and tapping holes helping to assembly the element are work-consuming and not highly effective. Joining by traditional welding causes overheating of elements and, subsequently, a decrease in their mechanical strength; if, on the other hand, welding is carried out at temperatures appropriate to small elements, the fusion weld is weakened and the connection's mechanical strength is decreased. In such cases best results are obtained when electric arc is applied for joining (arc operation causes partial melting of elements right at the connection spot and direct flow of electric current through joined elements). This effect may be achieved using capacitor-type devices which employ energy stored in the capacitor or power electronics devices which generate electric arc in the contact space between both elements [1, 2]. The capacitative devices are characterized by high working currents and short arc burn times (a few milliseconds). The main weakness of these devices lies in limited application range which is due to short duty periods (impulse operation) and complex systems for storing energy in capacitors. Power electronics devices do not exhibit those faults; they are able to operate with controlled working current and time of single duty cycle.

Difference in the use of capacitative and thyristor systems relates mostly to engineering of the process, in this case, to the technique of guiding the element fastened to the base. In the capacitative systems, the movement of element in question is directed towards the base only. In the thyristor systems, during the first stage of the process, the elements to be joined touch each other, then a smaller element (which is secured in the head) is rapidly lifted and after a set time it is again pressured to the base [3].

The current paper presents a microprocessor-controlled power electronics device, which makes possible fixing of metal pegs, bolts and other small elements to flat metal surfaces.

2. Device design

The device has been built as a test stand, what facilitates testing, and observing operation of different sub-assemblies (measurements and recording of selected electrical waveforms, checking of operation times of different blocks in the control circuit) as well as observation of elements during the joining process. The device is characterized by up-to-date structure of the control systems, which makes possible smooth electric arc current and time setting in accordance with the process engineering requirements. A schematic diagram of the device is shown in Fig.1.

Two basic blocks may be distinguished in the schematic diagram: a power circuit and a control circuit. The power circuit consists of two supply paths connected in parallel: the main arc and pilot arc circuits which are connected to the mains with the help of a circuit breaker WG. The main arc circuit consists of a load switch Rz, a three-phase transformer T1 rated at 4 kVA with short-circuit voltage (relative) equal to 52%, a controlled thyristor bridge 6-T made up of three thyristor blocks M2C7P-450-04-22 and current terminals used for connecting the working head G. The pilot arc circuit consists of a one-phase transformer T2 rated at 200 W, **a** diode bridge M2 and **a** reactor (choke) Ld, type ST-400, inductance 140 mH. The reactor is used to limit the current. The output of pilot arc supply is connected to the current terminals of the main arc. A cooling fan is also connected to the pilot arc supply.

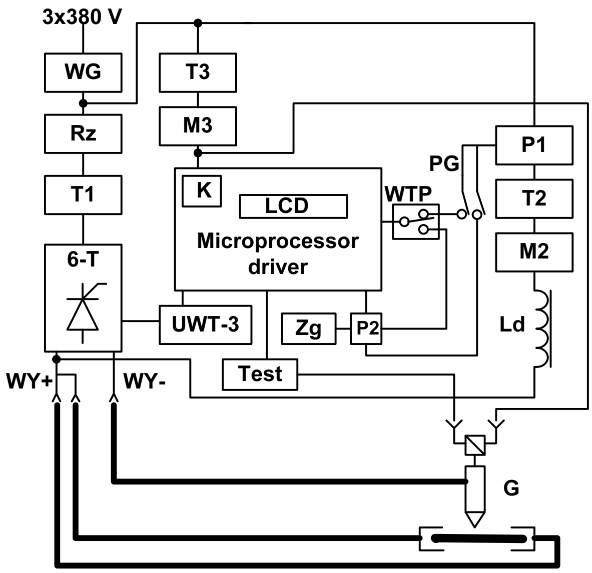

Fig. 1. Schematic diagram of peg fastening device.

The microprocessor control circuit has been built on the basis of the microcontroller unit MC68HC908JL3. It is equipped with FLASH memory, 4 kB size; RAM memory of 128 bytes; two independent 16-bit counters with possibility of generating impulses and measuring their duration; a 12-channel, 8-bit A/D converter; general purpose input/output ports. Operation with an internal RC oscillator or external crystal-oscillator (1-32 MHz) is possible. The microprocessor driver is coupled with a thyristor tripping circuit UWT-3 and fulfils the following functions:

- control of pilot arc circuit,
- control of main circuit,
- control of working head,
- control of gas valve and operation of "Test" function
- protection

Setting of operational parameters is achieved with the help of a numeric keyboard and a LCD display. If the fusion weld is to possess appropriate mechanical strength, it is necessary to set work time and work current values. The work time is set by choosing "time" option and entering the time in seconds. The work current value is set by choosing "current" option and entering value in amperes or else, by choosing "angle" option and entering thyristor tripping angle in degrees. Another possibility is to choose a pre-selected parameter set from microprocessor unit memory (in this case, a number is entered and work time and current are set automatically). The LCD display cooperating with the driver helps to set precisely the required current values.

The "Test" function is used to set a correct distance between joined elements. In "Test" mode the main and pilot arc supplies are blocked. The WTP switch is used to choose an operational mode, with or without gas blanketing. The microprocessor circuit also executes protection of the main circuits (from faults such as overloads and short-circuiting) and protects the working head against accidental activation. Control of the working head consists of switching the electromagnet winding on, which results in lifting the peg and start-up of main rectifier. After a set time interval the winding voltage is turned off and the peg is pressed down into the base by the force of the spring.

The working head (actuator) is secured in a plastic holder in the shape of a gun. The working head consists of the following parts:

- a holder,
- a control button,
- an electromagnet connected to a spring,
- a current terminal,
- a pilot sleeve,
- a working shaft,
- replaceable end-elements in working shaft,
- a housing and a ceramic attachment screwed together.

The working head driven by the power electronics circuit executes kinematic part of the process. This consists of: determining distance of the peg from the base and peg pressure force. The control buttons in the holder make it possible to initiate the process at a certain distance from the stand (this distance is limited by the length of power and control wires). The design of the actuator part of the working head is shown in Fig.2.

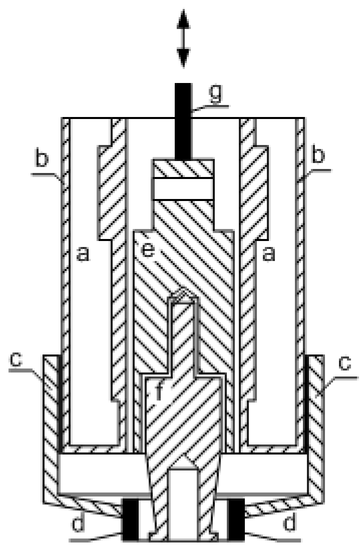

Fig. 2. Working head design.

The plastic housing end "a" is permanently connected to brazen sleeve "b" (Fig. 2). This sleeve is equipped with an external thread, and housing ("c") with **a** ceramic guard ring ("d") is screwed onto this thread. The depth of screwing housing "c" determines the distance/height of lifting the element during the joining process. Elements "a", "b", "c" and "d" do not move in relation to each other during the engineering process. The movable parts of the head are: a working shaft "e" which is connected to a replaceable end-element "f" and flexible connector "g". These elements are connected to an electromagnet armature and move inside the sleeve "b" during the process. The replaceable end-element "f" makes it possible to work with parts of different shapes and sizes.

3. Principle of operation and operating practice

The principle of operation is shown in Fig.3. In the initial stage, the peg is placed on the base. When the working head is activated with button PG, the pilot arc supply is started and the peg is lifted up by the force of electromagnet. After a short delay, the main arc supply starts, and a work current starts to flow (value of the current has been previously set). When the set time is passed, the peg is pressed down into the base by the force of the spring, and the main circuit is switched off.

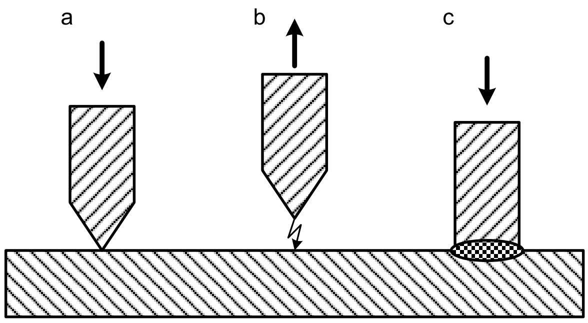

Fig. 3. Principle of operation.

When this work cycle is finished, the peg is permanently joined to the base. In order to execute the process, the device must be appropriately set up. A replaceable end-element corresponding in size to peg's diameter must be fastened to the working head, then the peg must also be placed in position, and the main circuit breaker WG must be switched on. In order to determine the peg lifting distance (away from the base), the "Test" switch must be turned on (and the electromagnet winding activated), but simultaneously all other functions of the system must be blocked. The movable housing "c" is then used to adjust the distance. Next, work time and arc current values must be set. The last activity is selecting a mode of operation (with or without blanketing gas). Switching "Test" switch off causes unblocking of all circuits, and the system is ready for action. The joining process itself starts with manual pressing of primed working head and pushing button PG. This having been done, the arc is automatically initiated, the peg is lifted, and when the set time has passed, the peg is again pressed into the base, while at the same time the electric circuits are deactivated. In order to obtain a permanent joint, the process time and arc current must be adjusted so that conical part of the element is completely melted, and a lake of fluid metal is melted in the base, with the diameter somewhat greater than the peg diameter and depth ranging from 0.1 to 0.3 mm (depending on base thickness).

4. Selected measurements and their interpretations

The built prototype has been tried and subjected to tests and measurements. The tests have showed that the maximum short-circuit current (when thyristors fully conduct) is equal to 600 A, and no-load voltage is equal to 70 V. The process engineering tests have been aimed at observing the impact of settable electrical parameters on the quality of fusion weld and, at the same time, they make it possible to determine optimum settings necessary to obtain the weld with required parameters. Figs. 4, 5 and 6 present arc currents and voltages obtained during fixing a steel screw of 8 mm diameter, to the steel base with 30 mm diameter. Different values of work current have been applied. Fig.4 shows voltage and current waveforms with current value much less than optimum value.

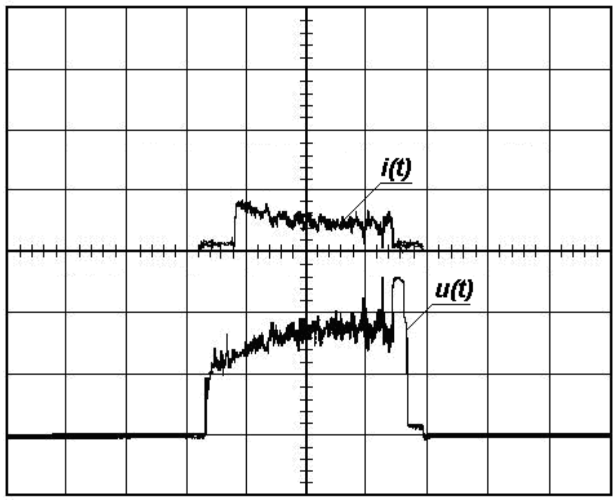

Fig. 4. Electric arc current and voltage waveforms during assembly of steel bolt to steel base, oscilloscope scaling factors i(t) 100A/div, u(t) 20V/div.

If the arc current is too small, then the arc energy is also too small, and the peg tip and base in the contact zone do not reach proper plasticity. In such a case, even pressing the peg into the base does not effect short-circuit current characteristic of the last phase of the process (since contact resistance is too high). The result is that the weld is not strong enough, and the peg may be torn off with the application of slight force.

Bad quality of the weld occurs also when work current is too high (Fig.5). In this case too much energy is fed into the work space. This energy results in too rapid melting of the peg, and flowing drops of metal cause short-circuiting and extinction of the arc during the welding process. Due to short-circuits and arc extinction, the joined elements do not attain the correct degree of plasticity. As a result, the weld does not reach the required strength.

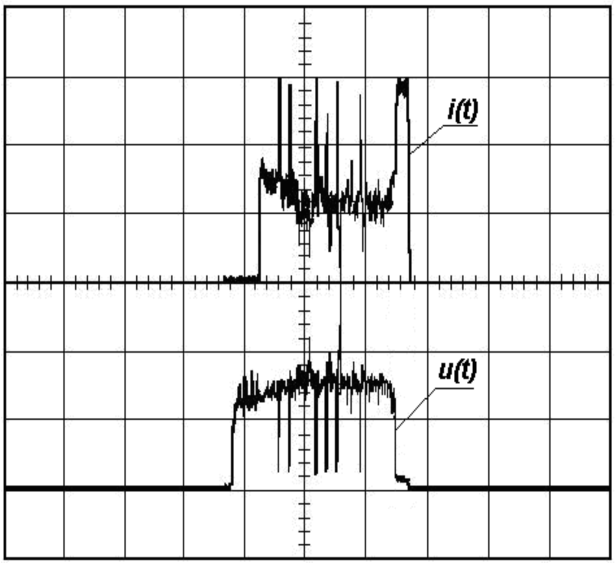

Fig. 5. Electric arc current and voltage waveforms during assembly of steel bolt to steel base, oscilloscope scaling factors i(t) 200A/div, u(t) 20V/div.

Fig.6 demonstrates arc current and voltage waveforms for correctly selected parameters of joining process.

In that case, we observe a typical increase of the current in the final stage of the process. This is caused by pressing the peg into the base. During the pressing, the electric arc is extinguished, partially melted parts are joined and a fusion weld is created with strength comparable to that of a welded joint. The rapid increase of current in this phase of the process is the result of small contact resistance; this indicates sufficient plasticity of the peg and base, i.e. good quality of the joint.

Fig.7 shows results of the experiment, when a bolt was joined to the base with thermal capacity much greater than that of the bolt itself. Two cases are illustrated: when a ceramic ring is used (for weld forming), and when the ring is absent (direct joining).

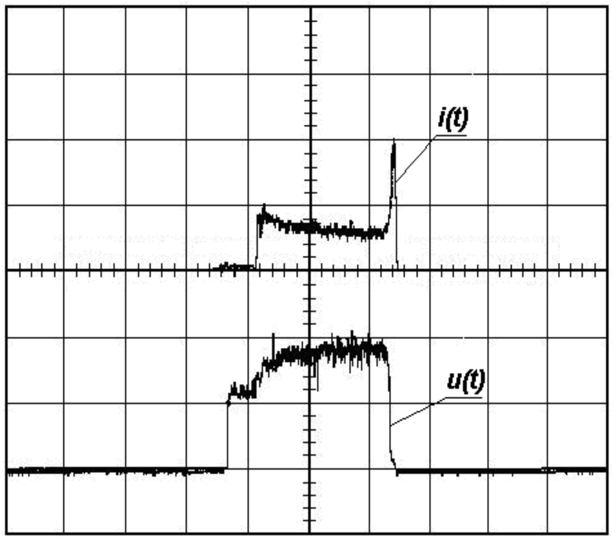

Fig. 6. Electric arc current and voltage waveforms during assembly of steel bolt to steel base, oscilloscope scaling factors i(t) 200A/div, u(t) 20V/div.

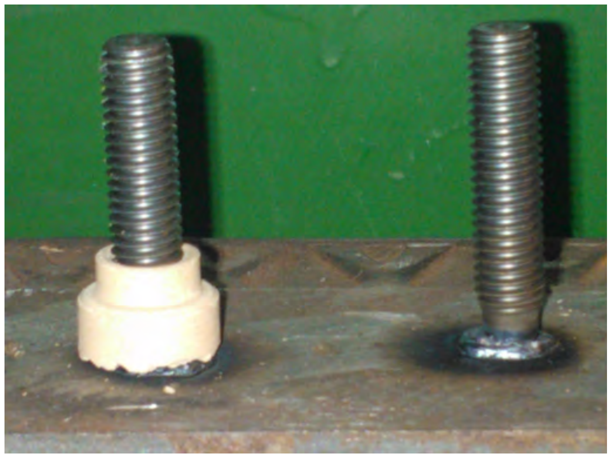

Fig. 7. Results of connecting a small element to sizeable surface with and without using ceramic ring for weld forming.

6. Conclusions

The experiments have shown that quality of the weld is affected by the following parameters: shape of a joined element tip, arc current rms-value and duration of the process. The shape of the element at the point of its securing to the head should be conical with angle of flare equal to 90º. This type of tip ensures uniform melting of the element and the base. If a peg tip angle of flare is greater than 90º, the base melts more quickly than the tip. If a peg tip angle of flare is less than the optimum angle, the end melts too rapidly and drops of melted metal cause short-circuiting and extinction of the arc in work space. If a work current value is too low, then the tip does not melt completely, and degree of plasticity of the base is too low; as a result, this fusion weld does not fulfil the requirements. Duration of the work cycle is highly dependent on joined elements diameters. If this time is wrongly selected, then elements in the work space are overheated, or their plasticity is too low; in either case the mechanical strength of the resultant joint is too low. The impact of force pressing the peg into the base is also significant together with the depth attained by the element tip. For steel pegs fixed to steel plates about 30 mm thick the correct parameters of joining process are set out in Table 1.

Table1

Electric arc current and cycle duration for selected steel pegs

Peg diameter	Depth of pit	Duty cycle duration	Arc current
mm	mm	s	A
6	1 – 1.5	0.5 – 0.7	100
8	1.5 – 2	0.7 – 1	200
10	1.5 – 2	1 – 1.4	300

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КОНТРОЛЬОВАНИЙ МІКРОПРОЦЕСОРОМ ПРИСТРІЙ ДЛЯ ПРИКРІПЛЕННЯ СТАЛЕВИХ ШТИФТІВ ЕЛЕКТРИЧНО-ДУГОВИМ МЕТОДОМ

Анджей Кандиба

У цій роботі описано прототип пристрою для з'єднання малогабаритних деталей (штифтів, прогоничів і т.п.) з металевими поверхнями значних розмірів. Подано технологію цього процесу та конструкцію пристрою, а також результати основних вимірювань, проведених під чам процесу зварювання. У роботі наведено блок-схему відповідного електричного кола на основі тиристорного випростувального моста і блок-схему кіл автоматики та контролю. Подано також характеристики пристрою та його робочі параметри.

Andrzej Kandyba – Ph.D., researcher and professor of the Department of Power Electronics, Electrical Drives and Robotics at Silesian University of Technology, Poland. His area of interest concern power electronic supply systems for electrical drives and electrothermal devices, especially plasma devices and power electronic converters that are parts of renewable energy systems using wind, water, and solar energy.