WAYS OF INCREASING THE TECHNOLOGICAL EFFICIENCY OF RECTIFIERS FOR MECHANIZED WELDING AND SURFACING (Review)

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Presented is the information on modern methods used to control the short-circuit current in transient processes caused by electrode metal transfer in mechanised CO_2 welding.

Keywords: *mechanised arc welding, consumable electrode, welding current, direct current, welding throttle*

In mechanised dip-transfer CO_2 welding, short-circuit current $I_{sh.-c}$ can be limited with a throttle or resistor in the DC circuit at a flat or gently sloping volt-ampere characteristic of the welding power source, or by using a power transformer with developed scattering in the welding rectifier [1, 2]. In this case the shape of the curve of $I_{sh.-c}$ depends on its limitation method (Figure 1).

Earlier, the simple multiple-operator power system was developed on the basis of inertialess limitation of $I_{sh.-c}$ with a resistor [3]. Compared to the inertia limitation of $I_{sh.-c}$, e.g. with a throttle, the inertialess method facilitates the initial excitation of the arc, this being particularly important for welding using the electrode wire with a diameter of 2 mm or more.

Methods used for limitation of $I_{sh.-c}$ in flat CO_2 welding are described in study [4]. In CO_2 welding of vertical and overhead welds the difference in the $I_{sh.-c}$ limitation methods is especially pronounced. It was established that the lower the amplitude value of $I_{sh.-c}$, the lower is the metal spattering. In flat welding, the minimal amplitude of $I_{sh.-c}$ is limited only by the process stabilisation condition [5].

In vertical and overhead welding, the $I_{sh.-c}$ value is chosen primarily on the basis of the metal transfer mode and weld formation. The higher the amplitude value of $I_{sh.-c}$ (up to a certain limit), the higher is the pulse towards a workpiece received by the electrode metal drop and pool, this being favourable for holding them on the vertical and overhead surfaces. So, there is an obvious contradiction between the requirements to decrease of spattering (minimal $I_{sh.-c}$) and ensuring of formation of the vertical and overhead welds (maximal $I_{sh.-c}$).

Welders often neglect spattering and operate at high amplitude values of $I_{sh.-c}$. As proved by practice, the best results are achieved with the inertia method of limitation of $I_{sh.-c}$. In case of the inertialess limitation of the current with a ballast rheostat the drops grow in size, this hampering their transfer into the pool and deteriorating the weld formation.

As a rule, the drops shift towards the lateral surface of an electrode, as at their initial contact, when the contact area is smaller than the section area of the neck between the electrode and a drop, the electrodynamic force is directed from the pool to the electrode, thus preventing transfer of the drops. The bulk of the drops are repelled from the pool. However, they do not loose link with the electrode and, being replenished with new portions of the liquid metal, grow in size. Subsequent contacts are accompanied by the same phenomena until a drop set in an intensive oscillatory motion by pushes of the electrodynamic force

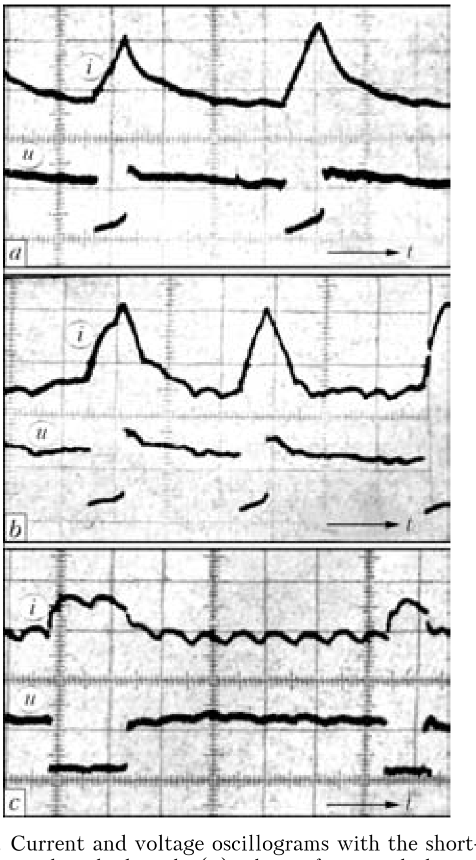

Figure 1. Current and voltage oscillograms with the short-circuit current limited with throttle (*a*), slope of external characteristic of welding rectifier the transformer of which has a developed scattering (*b*), and with resistor (*c*) [2]

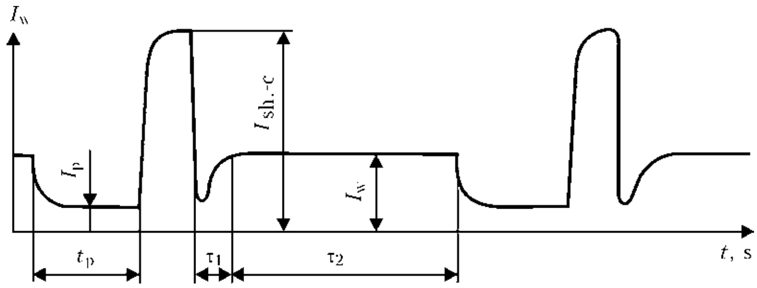

Figure 2. Oscillogram of current in dip-transfer welding using a thyristor key: τ_1 — duration of pause in flow of the welding current by the moment of bridge disruption; τ_2 — electrode melting duration; t_p — duration of the pause before short-circuiting

detaches from the electrode and flies away or collides with the pool with a major part of its surface and is absorbed by the latter, which happens more rarely in welding in the vertical position.

In flat welding, formation of a big drop does not affect formation of the weld, as the gravity force favours its movement to the electrode tip and, in the majority of cases, to the pool. To decrease the electrodynamic force that repels the drop from the pool at the first moment of their contact it is necessary to decrease $I_{sh.-c}$. However, the value of $I_{sh.-c}$ should be sufficient to generate a corresponding pulse for subsequent pressing of the drop to the pool. These requirements are not met when $I_{sh.-c}$ is limited with a ballast rheostat.

In search for optimal solutions, in 1985 associates of the E.O. Paton Electric Welding Institute and Tomsk Polytechnic Institute conducted experiments by using a thyristor key [6] and suggested a dip-transfer arc welding method, the point of which consists in controlling the current in transient processes caused by metal transfer (Figure 2).

In welding with the DC power source comprising a throttle in its welding circuit, the current is decreased momentarily for a period of t_p before short-circuiting of the arc gap. At the moment of beginning of a short-circuit the throttle is shunted by the resistor, this leading to a sudden growth of the current from the minimal to peak value. The dramatic increase of the short-circuit current causes growth of the electrodynamic force directed from the electrode to the weld pool and tending to accelerate transfer of the electrode metal to the weld pool due to the pinch-effect along the electrode melting line. This causes reduction of the short-circuit duration from $(4-5)\cdot 10^{-3}$ s (the average short-circuit duration with the throttle present in the welding circuit) to $(1.5-2.0)\cdot 10^{-3}$ s.

When a bridge between the weld pool and non-melted part of the electrode reaches its critical size (U_a = 6–8 V), the welding current is abruptly decreased to 20–40 A for $(0.2-0.4)\cdot 10^{-3}$ s (τ_1 in Figure 2). At the expiration of pause duration τ_1 the welding current is again increased. As this takes place, the throttle, the presence of which increases elasticity of the arc and improves its burning stability in a period of electrode melting, τ_2, and decrease of the current before a short-circuit, t_p, is again connected to the current circuit (see Figure 2).

Such conditions lead to a substantial decrease in the arc gap and size of a drop of the metal transferred to the pool. Reduction of the short-circuit duration makes it possible to increase the electrode wire feed speed and, accordingly, the productivity of the welding process, its stability being maintained at a high level and the value of open-circuit voltage $U_{o.-c}$ being kept insignificant.

In the middle of the 1990s the above arc welding method was further developed in the «Lincoln Electric» STT (Surface Tension Transfer) process for welding of the root welds [6].

The STT process is a successor of the conventional process of mechanised gas-shielded welding, where metal is transferred through short-circuits of the arc gap. However, STT is radically different from it in the possibility of directly controlling conditions of transfer of the electrode metal into the weld pool, which is provided due to a high-speed inverter circuit of the power source, special electron microprocessor module that forces the required level of the welding current, and feedback loop that dynamically traces variations in the arc voltage. During the entire cycle of transfer of the drop into the weld pool the value of the welding current strongly depends on the phase of formation of the drop and its subsequent transfer to the pool. The transfer phase is identified by processing the values of the voltage continuously taken from the arc gap.

Particularly for this process «Lincoln Electric» developed the 225 A inverter power source Invertec STT II [7], which realises the welding current waveform control technology. Invertec STT II differs from the conventional welding power sources, as it is a source with neither flat nor steeply drooping characteristic. The device is fitted with the feedback that traces the main phases of the drop transfer and immediately responses to the processes occurring between the electrode and weld pool by changing the value and waveform of the welding current.

It should be noted that the STT process equipment is rather expensive and requires appropriate service conditions. The same refers to the process with a minimal heat transfer, i.e. CMT (Cold Metal Transfer) developed by «Fronius» [8]. The metal transfer process occurs due to reversion of the electrode wire feed at the moment of the short-circuit formation, which favours the drop detachment. In this case the short-circuit current is insignificant, thus providing metal transfer with a minimal spattering.

At present this technology is applied in the cases where a decreased, flexibly adjusted heat input is required. In operation with thin and ultra thin sheets a very high productivity of the welding process allows filling up the wider gaps. Low dilution with the base metal opens up new possibilities and provides special advantages.

Main peculiarities of the process are as follows:

- adjustment of the short arc exclusively in the power source;
- new dynamic inverting circuit;
- very quick digital regulation of the process;
- considerable decrease of the power peak in re-ignition of the arc;
- substantial decrease of heat transfer at the melting stage.

Acceleration of transfer of the drop to the pool by way of forced switching off of the current in the circuit at the first and last short-circuit phases allows the productivity of the process to be increased. However, practical utilisation of the key elements in the mechanised welding units is difficult so far because of complexity of the devices and high cost of the main elements of the circuit. Therefore, the better candidates are comparatively inexpensive devices, such as throttles, which are used to fit up commercial rectifiers for mechanised welding and surfacing. As shown by our investigations, the similar results can be obtained using no sophisticated systems for incorporation of feedbacks.

We paid attention to the effect of the energy accumulated in the throttle and welding circuit at short-circuiting of the arc gap on the subsequent arc excitation and electrode melting intensity. It turned out that the forced control of this energy by means of the internal feedback makes it possible to obtain the positive results on the quality of the weld formation and metal losses. It is enough to control the energy of the throttle to minimise the arc length and, hence, the size of the electrode metal drops after short-circuiting.

In dip-transfer CO_2 welding the spattering of metal depends to some extent on the arc voltage, as size of the drop and energy of explosion of the bridge are proportional to the length of the arc gap [9]. Therefore, the trend to performing welding under conditions with a low arc voltage is not always technologically justified. As shown by observations, when the short-circuit current is limited with the throttle, the electromagnetic energy stored in it in a growing part of the transient process after disruption of the bridge causes a dramatic increase of the arc gap due to intensive melting of the electrode, which can be seen in typical oscillograms of the arc voltage. We investigated the possibility of controlling and stabilising the length of the arc gap by proportioning of the energy input into the arc after short-circuiting. For this we developed and tested a special throttle, the electric circuit of which is shown in Figure 3 [10].

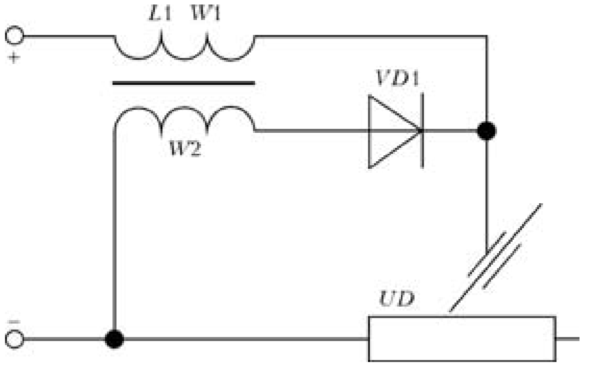

Figure 3. Electric circuit of the throttle with diode in the control winding circuit

Throttle $L1$ comprises power winding $W1$ connected in series to the welding circuit, auxiliary winding $W2$, magnetic core, and diode $WD1$ in the auxiliary winding circuit, the diode being connected through a cathode to the electrode when welding is performed at a reverse polarity current, and the end of winding $W2$ being connected to a workpiece. When welding is performed at a straight polarity current, connection of the diode is changed.

The device operates under transient conditions caused by closing of the arc gap by the molten metal drops. Increase of the power winding current is accompanied by increase of the auxiliary winding current, which is summed up with the main current. Dramatic decrease of the welding current after disruption of the liquid bridge between the electrode and the weld pool is caused by a change in the resultant magnetic flux of the throttle at a stage of growth of the welding current, as well as in the throttle inductance value.

This causes a more dramatic short-time increase of the current in a short-circuiting period, which leads to active constriction of the molten electrode metal bridge and its destruction. This is accompanied by a substantial reduction of duration of the short-circuits and increase in their frequency (Figure 4). The metal transfer becomes of a spray type. Dramatic decrease of the current after short-circuiting provides a minimal length of the arc gap.

At present, such throttles are used to fit up welding rectifiers VS-650SR manufactured by the Pilot Plant for Welding Equipment of the E.O. Paton Electric Welding Institute [11]. Unlike traditional welding rectifiers, owing to an original throttle with internal feedback this source provides stabilisation of the length of the arc gap and size of the drops of the transferred metal in dip-transfer gas-shielded welding, which considerably improves the weld formation and quality of welding in all spatial positions with a minimal spattering of the electrode metal (Figure 5).

Also, we developed variants of designs of the device with a thyristor in the control winding circuit [12]. The use of the thyristor control in the throttle allows a substantial decrease in the rate of growth of the

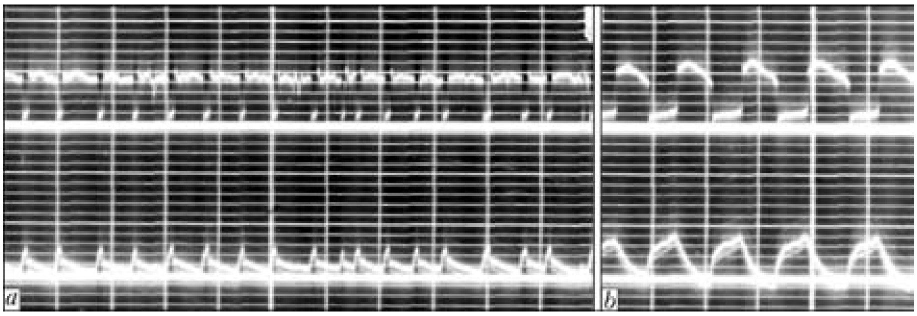

Figure 4. Oscillograms of arc voltage and welding current (U_a = 20 V, I_w = 100 A, $U_{o.-c}$ = 26 V, $D_{e.w}$ = 1.2 mm): *a* — throttle with internal feedback; *b* — throttle without internal feedback

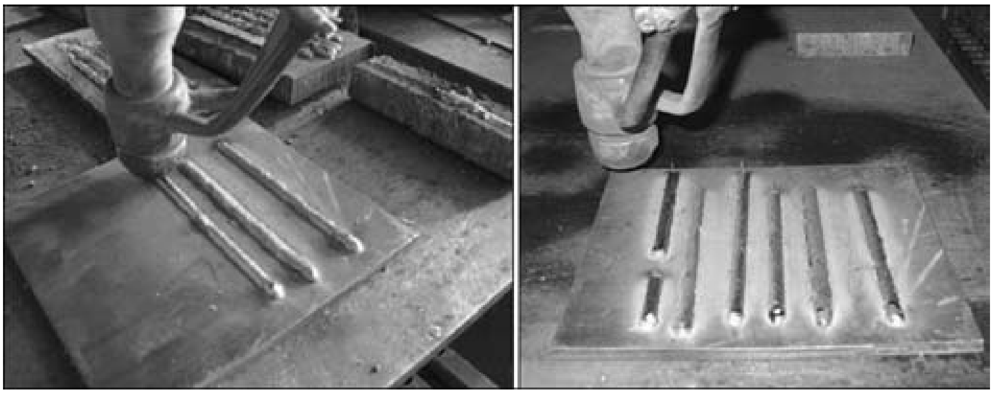

Figure 5. Appearance of deposited beads in CO_2 welding using rectifier with the throttle fitted with internal feedback

current at the beginning of a short-circuit, this ensuring reliable coalescence of the drop with the molten metal pool. Owing to the thyristor control, the maximal value of the short-circuit current can be optimised to a certain degree and selected so that it provides reliable disruption of the liquid bridge between the drop and electrode, as well as transfer of the drop to the pool.

At the same time, this regulation can decrease the maximal value of the short-circuit current, thus limiting the energy of explosion of the liquid bridge and reducing the probability of an outburst of the drop outside the weld pool. All this adds to reduction of the metal spattering factor. Accelerated decrease of the welding current after the end of a short-circuit reduces overheating of metal and burn-out of alloying elements, this being of a high technological importance in a number of cases. Connection of a low constant voltage source in series to the throttle control winding and thyristor offers a much wider possibility for controlling the energy of the welding throttle in transient processes due to regulation of the level and waveform of the short-circuit current.

Therefore, upgrading of the throttles of commercial welding rectifiers by fitting them with a special additional winding of the internal feedback provides a technological effect comparable with such in welding by using the expensive equipment.

The key advantages of the device include simplicity, targeted utilisation of the electromagnetic energy stored by the throttle and improvement of the quality of welding. Welding by using the internal feedback in the throttle provides a spray transfer of the electrode metal at its low losses for formation of fumes and spattering, reduction of burn-out of alloying elements and oxidation of the electrode metal because of the reduced time of dwelling of the molten metal drop in the arc zone, improvement of stability of the welding process and arc burning, self-regulation of the level of $I_{sh.-c}$, reduction of the time of $I_{sh.-c}$, increase in frequency of $I_{sh.-c}$, and quality welding in all spatial positions.

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