The Management of Short Circuits' Mechanism of CO₂ Shielded Welding

Anatoliy F Knyaz'kov, Sergey A Knyaz'kov, Artur M Tabanov

National Research Tomsk Polytechnic University, 30, Lenin Street, Tomsk, 634050

E-mail: kaf@tpu.ru

Abstract: It is observed the mechanism of short circuits' management in the process of which drops of electrode material move to welding pool and all the phases of drops’ formation process are under control. It is shown the role of drop of electrode material and welding pool in the decreasing arc space, providing forced short circuit of arc space at the time of sharp decrease of welding current. Obtained results evidence that it is necessary to consider the movement of welding pool at the time of creation of model of electrode materials movement and creation of process management's algorithms, especially considering changeable position of welding pool, as the role of drop and welding pool in the decreasing arc space is almost the same.

Introduction

The process of CO₂ shielded consumable electrode welding [1] got a wide use in the industry due to its advantages. But existing disadvantages in some cases limit the extension of its application area.

The analysis of the process of CO₂ welding shows that large exposure of short circuits’ mechanism to external disturbances is the main reason of these disadvantages. The process of metal transfer during short-arc welding exists during short circuits (further named SC). The study of SC’s mechanism and the possibility of its management is an actual aim because the process of CO₂ welding with SC is one of the mass welding processes.

According to modern concepts, SC's mechanism can be imagined in the following way. The main reason of SC is that welding is led along the length of arc just the same as the size of drop. Decreasing length of arc, leading to short-circuiting of arc space, is determined by the following reasons:
- Increase of drop’s size;
- Drop's intention to take coaxial position with an electrode;
- Electrode feed;
- Counter movement of welding pool before short circuit in the process of its oscillation under forces' impact, appearing during SC and rupture of short-circuiting jumper.

The study of current's oscillograms and voltage of arc space shows that SC's duration and current at the moment of its termination are different during every certain SC, so extension of arc space during short-circuiting jumper's rupture is unstable for different periods of drops' formation that it generates non-periodicity of drops’ formation and leads to different primary conditions of drops' formation process. It leads to impairment of welded seam's formation especially in the positions different from low one and increase splashing. It should be mentioned the significant role of welding pool's oscillations in the short circuits’ mechanism. Welding pool has ultimate amplitude and frequency of its oscillations,
which cannot be exceeded as it can lead to interruption of process. It is especially dangerous in the positions of welding pool different from low one.

It is difficult to describe the process mathematically and to calculate the moment of short circuit's start, so while studying CO\textsubscript{2} welding process with SC people use the methods of mathematical statistics. The primary conditions, appropriate to the moment of SC's start, are unstable (the sizes of drops, their coaxiality with an electrode, the phases of welding pool's oscillations, current level, arc space's length, etc.). It leads in its turn to instability of regime's parameters at the time of SC as well as at the time of drop melting, producing in its turn instability of the primary conditions. Due to this welding process is characterized by:

- large exposure to external disturbances and connected with this one instability of process (period of drops' formation);
- low regulating abilities, as process proceed normally in the narrow range of arc space's voltages;
- increased splashing;
- non-optimal form of seam.

**Materials and methods of research**

Many works are known in the literature that directed to removal of these disadvantages. They can be divided in some groups according to principle of impact on welding process:

- stabilization of average parameters of regime ($U_{d}$,$I_{d}$);
- impact on regime's parameters during particular phases of period of drops' formation [6,7,9,11];
- stabilization of period of drops' formation at whole and at the same time of particular stages based on impulse supply.

In our opinion the last variant is more perspective. The meaning of process is forced providing of short circuits by impulse management of energetic parameters of welding arc.

Nowadays priority directions of removal of the mentioned disadvantages and of improvement of CO\textsubscript{2} shielded metal welding process are creation of methods and means, providing management of melt kinetics and electrode metal's transfer during period of drops' formation by instantaneous values of regime's parameters [10,11].

So in the work [2] it was proposed to enter periodically current decrease for forced formation of SC with the aim of drop's transfer to welding pool and to providing their almost periodic transfer. Further the amount of algorithms of drops' transfer management increased notably. It was developed so many methods of management of short circuits' mechanism by particular phases of drops' formation as well as by period of drops' formation at whole in all the phases.

For creation of models of short circuits' mechanism, of algorithms of their management and systems of welding arc's supply it is necessary to know the role of drop and welding pool in the decreasing arc space during sharp current decrease, providing forced SC and drop's transfer to welding pool. But in scientific and technical literature except [3], there is not detailed analysis of drop's movement and welding pool and their shared parts in arc space's decrease and SCs creation during sharp current decrease. In some works it is shown the results of welding pool's movements during ordinary CO\textsubscript{2} welding process with SC, but there are not such data during controlled SC's mechanism [12]. While reliable information about this process is very important for studying kinetics of melting and transfer of electrode metal, especially in the positions different from low one.

The aim of this work is determination of the role of drop and welding pool in the creation of SC of arc space during CO\textsubscript{2} welding.

For this purpose we should observe the process [4], for which in the picture 1 synchronous kinograms with the oscillograms of current and voltage are represented. At the present time this process abbreviated as STT is widely used in the welding practice.

In this process for drop's transfer in the welding pool forced SC are created by current decrease until the meaning of a few dozens of ampere. At the same time the forces that influence on the drop and welding pool acutely fall. Metal of welding pool along the surface of crystallization's front, partly crystallized, under its own weight start to return under an electrode. The drop, pressed by forces' action,
aims to take coaxial position with an electrode. In the results of counter movements of drop and welding pool, their contact appears in the first touching, as welding current is minor. The creation of stable jumper appears between continuous electrode and welding pool.

![Fig.1 Oscillograms of current and voltage of welding cycle with controlled SC's mechanism synchronously with kinograms (U_i=37 V, U_a=26-26.5 V, I_w=155-165 A, V_w=15 m/h, L_e=11 mm.)](image)

The drop of electrode metal transfers into welding pool under influence of the complex of forces. The jumper appears at the time of rupture of which current decrease until 15-30 ampere.

From the moment of jumper's rupture and arc starting at the moment of time t_7 the energy is dosed, that is used for drop's melting (the variant of dosing by melting's time). After melting drop of certain size at the moment of time t_17 welding current decrease until the meaning of a few dozens of ampere, providing forced short circuit. On the interval from t_7 to t_17 it is decreasing the length of arc space till its shorting by supply of wire, counter movement of welding pool and movement melting drop to the coaxial position with an electrode.

As on this interval arc pressure is minor due to small amount of current, so the role of welding pool's movement (as well as drop) greatly increases compared ordinary process.

At the moment of time t_24 (as well as at the moment of time t_1) next SC happens, and as to this moment primary conditions almost similar for every process of drops' formation, so far as on the interval from t_7 to t_17 energetic parameters are unchangeable, so current curve of SC will be almost the same for every SC, as well as SC's duration.
So kinetics of processes of drops' formation is drawn into synchronism with the change of energetic parameters. The complex of actions, describing above, provides similar primary conditions at the moment of SC's start and during the whole periodic process.

**The results of the study and their discussion**

This process as well as ordinary one is characterized by average current and arc space's voltage and is controlled by indicated instruments. It is necessary to install the following parameters:

- \( U_i \) - voltage of idling (V);
- \( V_f \) - speed of electrode feed (m/h);
- \( V_w \) - speed of welding (m/h);
- \( L_e \) - electrode extension (mm);
- \( t_a \) - time of arcing for drop's melting (msec);
- \( I_{p,a} \) - pilot arc's current (A);
- \( \alpha \) - angle of electrode's inclination (°).

The following parameters will be derivative:

- \( I_a \) - average current;
- \( U_{a,a} \) - average voltage of arc;
- \( I_{max} \) - maximal current of short circuit;
- \( I_{min} \) - minimal arcing;
- \( U_{a,max} \) - maximal voltage of arcing;
- \( U_{a,min} \) - minimal voltage of arcing;
- \( I_{a,a} \) - average current during welding cycle (period of drop's transfer);
- \( U_{a,a} \) - average voltage of arcing during welding cycle (period of drop's transfer);
- \( t_{sc} \) - duration of short circuit;
- \( t_p \) - duration of pause before SC;
- \( b \) - seam's width;
- \( h \) - height of seam's strengthening;
- \( g \) - depth of penetration.

Regime's installation on equal conditions should be made by two parameters of regime \( U_i \) and \( t_a \). The peculiarity of welding process with management of short circuits' mechanism is overvoltage of idling compared with ordinary process, that allows to regulate the seam's width in a wide range. The pause of current before SC determines current increase on the interval of arcing, that increases intensity of self-regularity and impact on the main metal, strengthens welding pool's oscillations and contributes some setting of welding pool from an electrode. Due to current is lower at the moment of SC's start than in the ordinary process, it can be admitted high speeds of current increase of SC.

Scheme of measurement, represented in the picture 2, is used for identification of drop and welding pool's participation in the creation short circuit. For measuring the point of crossing of electrode's axis and top edge of frame is considered as fixed point of countdown, as far as top edge of frame is fixed concerning image, as well as side edges of frame concerning electrode's axis.

But it is not convenient to measure this point, as charts, taken by traditional position of axis (when zero is point of crossing of axis), are inverted, and it is difficult to interpret experimental data. So imaginary low point of countdown, which is lower than sample, is on the crossing of imaginary line parallel to top edge of frame and electrode's axis. All the measurements according to the following scheme (fig.2) was made from this point of crossing [5].

![Fig 2. The scheme of measurements: L1 - space from base to crossing of welding pool's surface with electrode's axis; L2 - space from base to crossing of low surface of electrode metal's drop with electrode's axis; L3 - space from base to crossing of fusion's front with electrode's axis](image-url)

Because of this fact that space L3 isn't seen clearly in the picture, it was found in the following way: it was determined positions on the left and the right sides of electrode, where it started to deviate from...
diameter and to transfer into drop, and they were joined by direct line, which was considered the line of electrode and drop's fusion.

As large-scale coefficient we took diameter of welding wire, which was known initially. So increase of diameter of welding wire at ten times in the picture leads to increase the whole image at ten times.

The measurements were made by the following way. Photographed kinogram was regarded, and only such welding cycles were taken that contained no failures and approximate by amount of cadres. Despite amount of cadres in the cycle we made measurements over three or five cadres. The charts were built according to the results of measurements.

**The discussion of obtained results**

The analysis of obtained charts and comparison of them with the cadres and oscillograms, represented in the figure 1, shows precise correlation between the change of welding regimes during the cycle of drop's transfer and oscillation of welding pool's surface, and also electrode metal's drop on the face of wire electrode.

During welding and fusion in low position one of the main physics factors that influence on periodic oscillation of welding pool and electrode metal's drop is arc pressure $R_a=ci^2$, where $c$ - coefficient, depended on type of welding. For consumable electrode welding $c=(3.12 \div 5.62)10^{-5}$ g/а$^2$.

So, by changing, power of welding arc, according to chart represented in the picture 1, affects on the surface of welding pool's metal and volume of electrode metal's drop by pressure of arc.

The measurement was made from the moment of jumper's rupture between drop and electrode and to next jumper's rupture. In the charts of picture 3 the moment of jumper's rupture is clearly observed, when welding arc burns up like explosion, the pressure of welding arc increases instantly (gas-dynamic impact), welding pool is thrown away from electrode for maximal distance, maximal length of arc. Welding pool due to its inertness with little lateness starts to influence on increasing arc's length. Also in the charts it is noticed the influence of molten metal's wave, rising on the side surface of welding pool on the primary stage of arcing. During the process of arcing, arc pressure decreases, electrode metal's drop grows, welding pool flows under arc, moving on the surface of crystallization under impact of hydrostatic pressure, this all decreases arc length.

![Fig 3. Experimental charts of movement of front of drop's fusion, electrode and welding pool.](image)

After sharp decrease of welding current to ordinary one electrode metal's drop tries to take coaxial position with electrode, moves to welding pool, which in its turn starts to rise to electrode. In the charts of figure 3 it is clearly observed that this movement is more slow due to welding pool has large weight and partly so larger lag compared with metal's drop, and welding pool needs some time to flow from the surface of crystallization into crater and fill it, and then on the anterior front by taken potential energy it starts to rise to electrode. Short circuit appears.
According obtained data, during management of process of CO\textsubscript{2} welding by changing energetic parameters of arc welding pool takes direct part in the creation of short circuit on a level with electrode metal's drop.

**Conclusion**

1. The obtained results evidence that creating models of electrode metal's transfer during short circuits and creating algorithms of process management, especially changing space position of welding pool, it is necessary to take account the movement of welding pool, as role of drop and welding pool in decrease of arc space is almost the same.
2. Decrease of welding current to normal one leads to sharp acceleration of counter movement of welding pool and drop.
3. The role of drop and welding pool in short circuits' mechanism is almost the same.
4. By changing regime's parameters on the stage of electrode's fusion, it is possible to force or to weak welding pool movement.
5. Line of front of electrode fusion behaves conservatively in relation to changing thermal flow.

**References**

[1] Novozhilov N.M., Suslov V.N. *Svarka plavyashimsya elektrodom v uglekislom gaze* [Consumable electrode CO\textsubscript{2} welding] Moscow, Mashgiz, 1958. 194 p.
[2] Sh'ekin V.A., D'ergerov N.G., Sagirov H.N., Nebilitsin L.E. *Prinuditel'niy perenos metalla pri svarke modulirovannim tokom v uglekislom gaze* [Forced metal's transfer during module current CO\textsubscript{2} welding]. Svarochnoe proizvodstvo, 1973, no.3, pp.23
[3] Chernishov G.G., Spitsin V.V. *Dinamichesko vozdeistvie svarochnoy dugi, goryash'ey v CO\textsubscript{2} na svarochnuyu vannu* [Dynamic impact of CO\textsubscript{2} welding arc on welding pool]. Svarochnoe proizvodstvo, 1971, no.4, pp. 8-9.
[4] No.1371821. Timoshenko A.K., Saraev U.N., Knyaz'kov A.F. Sposob elektrodugovoy svarki s korotkimi zamikaniyiymu dugovogo promezhutka i ustroistvo dlya ego osushestvleniya [The way of arc welding with short circuits of arc space and device for its providing]. Pub. 07.02.88, bul. no.5
[5] Knyaz'kov A.F., Petrikov A.V. *Metodika provedeniya issledovaniyi dvizheniya svarochnoi vanni* [The methodic of exploration of welding pool's movements] Trudy of XIV nauchnoy konferencyi, posvyashenny 300-letiyu inzhenernernogo obrazovaniya v Rossii. Urga, 2001. 207 p.
[6] Zaruba I.I., Andrev V.V. osobennosti primenyaemyx sposobov ogranicheniya toka korotkogo zamikaniyi pri svarke v uglekislom gaze [The peculiarities of used ways of current limitation of short circuit during CO\textsubscript{2} welding]. Avtomaticheskaya svarka, 1978, no.1, pp. 16-19.
[7] Zaruba I.I., Bargamen V.P., Andrev V.V., Sidorenko M.N. Vliyanie metodica ogranicheniya toka korotkogo zamikaniyi na formirovanie vertikal'nyih i potolochnyh shovov pri svarke v uglekislom gaze [The influence of current limitation of short circuit's method on formation of vertical and overheld welds during CO\textsubscript{2} welding]. Avtomaticheskaya svarka, 1973, no.4, pp. 64-67.
[8] Zaruba I.I., Andrev V.V., Stepahno V.I., Koritskiy V.A. Puti povysheniya tehnologicheskoy effektivnosti vypryamiteley dlya mekhanizirovannoy svarki i naplavki [The ways of improvement of technological efficiency of rectifiers for mechanized welding and fusion]. Avtomaticheskaya svarka, 2011, no.11, pp. 45-49.
[9] Zaruba I.I. Usloviye ustoichivosti protsesa svarki s korotkimi zamikaniyi [The condition of welding process stability with short circuits]. Avtomaticheskaya svarka, 1971, no.2, pp. 23-25
[10] 1-4 A.s. 1310140 SSsr, MPK V 23 K 9/00. Zaruba I.I., Saraev U.N., Knyaz'kov A.F., Timoshenko A.K. Sposob dugovoy svarki s korotkimi zamikaniyiymu dugovogo promezhutka i ustroistvo dlya cfo osushestvleniya [The way of arc welding with short circuits of arc space and device for its providing].Pub. 15/05/87; bul.no.18
[11] Ioffe U.E., Kvasov F.V. Novye vysokotehnologichnye sistemy poluavtomaticheskoy svarki kompanii "Linkol'n Elektrik" [The new high technologic sustems of semi-automatic welding by company "Lincoln Electric"]. Svarochnoe proizvodstvo, 1997, no.4, pp. 40-43.
[12] Getskin O.B., Poloskov S.I., Erofeev V.A., Vit'ko O.P. Phiziko-matematicheskaya model' sistemy "istochnik pitaniya-duga" dlya svarki plavyash'imsya elektrodom v zash'itnyh gazah [Physical and mathematical model of system "power source - arc" for consumable electrode shielded welding]. Tyazheloemashinostroenie, 2008, no.6, pp. 18-20.