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Overview of the process control variants available in GMAW

Dr.-Ing. Birger Jaeschke, Lorch Schweißtechnik GmbH, Auenwald, Germany, 10/01/16

In the field of gas-shielded metal-arc welding (GMAW), users and decision-makers have come to enjoy a wide selection of process options that is guaranteed to afford them the solution that is most economical. Suppliers of welding power sources discriminate between their various process variants by choosing specific terms which, however, are not the result of a coordinated systematic approach but rather reflect aspects of their competitive environment. The resulting complexity and confusion is a central concern of the new Technical Bulletin DVS 0973 [1]. Grouping electronically controlled process variants in a group named "process control variants", the document proposes to establish a systematic classification that is based on technical criteria rather than criteria dictated by the competitive environment. Teaming up with manufacturers and institutions, the authors created an initial overview of terms and designations. Initially published under [6], this amended and updated document focuses on the key aspects of the bulletin in an effort to make it easier to understand and apply.

1 Introduction

Over the past few years, manufacturers of welding power sources have coined a plethora of new terms and names for the variants found in the field of MSG welding. The succinct designations generate certain expectations in the user as to the welding characteristics the equipment delivers.

The bulletin is the result of the close cooperation in which experts of the V2.4 working group "Inert gas welding with a melting electrode" engaged. This panel was set up by the Technical Committee (AfT) of the DVS. The document is intended to serve the user as a concise guide, providing an overview of the process variants that have entered the market for metal inert gas welding applications in recent years. Short and to the point, the descriptions the document contains presume that the reader has a basic understanding of welding technology.

A more comprehensive, in-depth and detailed description of the ample range of possible welding process applications would have gone beyond the scope of the bulletin. At this point of the description, the author would like to point out that the creation of the bulletin did not progress without, at times, profoundly controversial debates over the contents and wording of the document as well as the selection of terms to be used. The fact that the experts sitting on the committee managed to find their "lowest common denominator" despite the need for everyone to compromise substantially should give reason to hope that the bulletin at hand will be accepted as a regularly revised instrument which provides clear-cut descriptions and an adequate terminology.

This description will not reproduce the content of the bulletin. It is, therefore, recommended that you study the bulletin to obtain a fuller understanding of the explanations below.

The overview given herein of the process control variants used in MSG welding cannot be complete on account of the continuous further development taking place in this field. Consequently, the authors of the bulletin decided to focus on a selection of topics and describe them in combination. The authors, furthermore, attached particular importance to reducing the overabundance of terms that have sprouted over the years to a manageable number of terms that are correct from a technical standpoint as well as less redundant, thereby streamlining the terminology.

The bulletin examines process control variants that are closely linked to the electronic control of the GMAW power sources used. The overview disregards the classic non-controlled electronic process variants as they have been a long-standing and integral part of the state of the art and of the basics taught to learners of welding technology.

While they might be applicable to process control variants not listed in the bulletin, the statements the bulletin makes cannot automatically be applied to these variants. The descriptions of the characteristics the document accredits to the process control variants it identifies are given in cooperation and coordination with the commissioned manufacturers of welding power sources. The characteristics are grouped based on clearly measurable physical quantities. The bulletin is not supposed to and, in fact, must not make any qualitative evaluations of the process control variants offered by the various competitors.

2 Criteria of distinction

The bulletin's sharp focus on providing an overview of the process control variants available in MSG welding necessitates a marked distinction from the remaining applications found in the vast field of welding technologies.

A first limitation is the sole examination of the electronically controlled welding power source including the physical quantities of current, power and wire feed speed. This approach consequently excludes museum pieces, materials, process gases, auxiliary materials and accessories.

The second limitation is the concentration on one single arc as the source of the process energy. Further excluded are process variants involving several wires, multiple energy sources or hybrids.

The third limitation, which requires the greatest amount of explanation and is slightly nebulous, arises form the focus on "special" process control variants. Included in the examination are physical effects and characteristics that may lead to different process properties.

"Classic" GMAW technology is supposed to serve as a reference. The definition of what constitutes "classic" technology poses a first significant obstacle.
Alternative terms for "classic" are: Standard, normal, manual, conventional, non-controlled, historic and many more. While the globally applicable IEC/EN 60974-1 [2] standard, which pertains to professional welding power sources, specifies a standardised load characteristic $U = 14V + 0{,}05\Omega \cdot I$ for comparable type tests of GMAW power sources, such a load characteristic is not stipulated for GMAW processes in the real world and is also not suitable for all combinations of materials, wires and inert gases. What is more, electronically controlled (including digital) welding power sources can and, if combined with certain process control variants, actually do reproduce this "classic" behaviour of welding power sources with near or complete perfection.
What this means is that the design of the electronically controlled welding power source is not the exclusive factor that determines whether this specific welding power source features a special process control variant within the scope of this bulletin.

3 Performance measurement as a criterion

A possible criterion of distinction that is currently being discussed is the type of required performance calculation.
There are electro-technical reasons that corroborate the notion that the formula traditionally applied to calculate the electric power by multiplying the medians of current and voltage actually delivers adequate accuracy across all power ranges when used in real-world conditions and for "classic" GMAW applications only.
We can, furthermore, mathematically derive that the multiplication of current and voltage medians does definitely not produce the correct results when it comes to calculating the performance of more complex process control variants [3], [4], [5].

<u>"Classic" nearly horizontal output voltage characteristic curve:</u>

Welding power sources used for "classic" GMAW applications primarily possess a linear, slightly descending, nearly horizontal output voltage characteristic curve, which is also referred to, not quite correctly, as a Constant Voltage (CV) characteristic. Affording the operator the ability to influence the dynamic of the welding current, these "classic" GMAW power sources are equipped with a real inductor (including iron core), which is symmetrical from an energetic standpoint, i.e. the energy absorbed by the magnetic field of the inductor during a short-circuit phase is released back into the welding circuit at the beginning of the next arc phase; see, in particular, the detailed explanations in [3].

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The average output voltage $\bar{U}$ of the welding power source will then correspond to the following function:

$\bar{U} = U_K - R_i \cdot \bar{I}$ (Eqn.1).

In this context, U_K represents the (off-load) constant voltage of the welding power source, while R_i determines the current-dependent linear slope of the U-I characteristic as an exemplary resistivity measurement. U_K in "classic" GMAW power sources like these approximately equals the open circuit voltage of the selected transformer stage.

$\bar{U}$ and $\bar{I}$ are the arithmetic medians of welding voltage and welding current. Welding power sources of this type interact with the GMAW process in line with the known "classic" internal control and allow for a correct calculation of the $\bar{P}$ arc power based on the following relation:

$\bar{P} = \bar{U} \cdot \bar{I} - R_i \cdot \left(\tilde{I}^2 - \bar{I}^2\right)$ (Eqn.2).

$\tilde{I}$ is the effective (root mean square) value of the welding current. During practical use, the term $R_i \cdot \left(\tilde{I}^2 - \bar{I}^2\right)$ will be rather small and usually disregarded.

As a result, the known formula commonly used to calculate power can be applied to "classic" MSG welding processes:

$\bar{P} \approx \bar{U} \cdot \bar{I}$ with a "classic" welding power source.

Conversely, we can deduce the following, paying particular attention to the inequality sign:

$\bar{P} \neq \bar{U} \cdot \bar{I} \rightarrow$ special process control variant.

<u>Primarily non-short-circuiting dynamic process control variants:</u>

There is a different option to calculate power in a simplified way during pulse welding, which is predominantly non-short-circuiting and particularly prone to produce the most inaccurate results when subjected to the classic approach of power calculation.

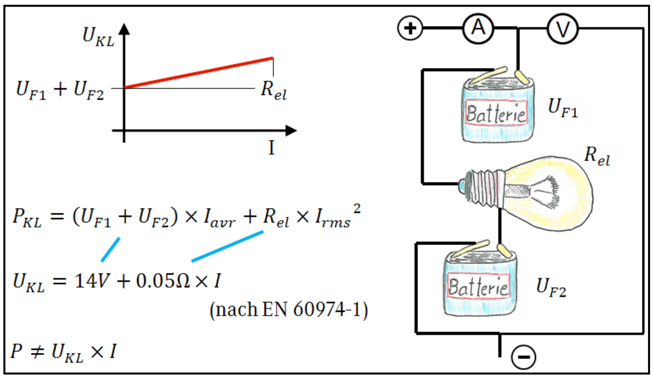

Fig. 1: Electrical equivocal circuit diagram for a simplified arc welding process model

Assuming the presence of a linear arc welding process model (Fig. 1), the

$$U_{mod} = U_{mp} + R_{mp} \cdot I$$

following equation (Eqn.3) according to [4] can be derived for mainly non-short-circuiting processes:

$$\bar{P}_{mod} = U_{avr} \cdot I_{avr} + \sqrt{\left(U_{rms}^{\;2} - U_{avr}^{\;2}\right) \cdot \left(I_{rms}^{\;2} - I_{avr}^{\;2}\right)}$$

The resulting value $\bar{P}_{mod}$ is the median of the power measured for the linear arc welding process model.

While the real welding process will certainly deviate from the linear arc welding process model, (Eqn.3) makes it possible to reduce the error occurring during the calculation of the electrical power. However, one aspect that needs to be kept in mind is that (Eqn.3) only applies to arc welding processes that are primarily non-short-circuiting.

<u>All other process control variants or a general solution:</u>

It is essential that the electric arc power for special process control variants be measured as a real power value according to (Eqn.4), as a comparison of the energetic effects of different settings and process control variants will otherwise not be possible:

$\bar{P} = \frac{1}{T} \int_T [u(t) \cdot \mathrm{i(t)}] dt$ (Eqn.4).

Reference is also made at this point to ISO/TR 18491: Guidelines for measurement of welding energies [7]. It specifies the affected process control variants as "waveform controlled welding processes" "if any doubt exists" and identifies the corresponding correct calculation according to (Eqn.4) as "instantaneous energy, instantaneous power". In the North American language area, the term "instantaneous" is often replaced by "true" or "real".

4 Content of the bulletin

The bulletin (as of the 2015 revision) discusses the following topics following the chapter structure given below:

1. Introduction
2. Equipment technology
3. Metal transfer (arc type)
   - 3.1. Modes
   - 3.2. Short-circuiting transfer
   - 3.3. Non-short-circuiting transfer
4. Technological effects
   - 4.1. Heat input
   - 4.2. Force effects
   - 4.3. Complex relationships
5. Process control variants
   - 5.1. Internal and external control
   - 5.2. Uncontrolled short arc
   - 5.3. Controlled / modified short arc
     - 5.3.1. Low-spatter short arc
     - 5.3.2. Energy-reduced short arc
     - 5.3.3. High-performance short arc
   - 5.4. Spray arc
   - 5.5. Modified spray arc
   - 5.6. Conventional pulsed arc
   - 5.7. Modified pulsed arc
   - 5.8. Alternating current processes
   - 5.9. Combined process variants
   - 5.10. Cyclic wire movement
6. Application
   - 6.1. Technological allocation
   - 6.2. Heat input, energy per unit length of weld
   - 6.3. Settting and operation
7. Manufacturer designations
8. References
   - 8.1. Regulations
   - 8.2. Bibliography

The bulletin is supplemented by a tabular overview of manufacturer-specific process control variants and their assignment to groups of characteristics that correspond to the chapter structure given above.

5 Energy-reduced process control variants

A catch-all term in today's media landscape, "energy reduction" is associated with various different aspects:

- energy-reduced (energy-efficient) in the sense of low energy consumption during welding for the purpose of resource conservation;
- energy-reduced in the sense of low heat input into the workpiece.

Both aspects are interconnected, but not necessarily mutually dependent. Any assessment of energy-reduced process control variants, therefore, needs to define specifically which aspects will be evaluated and to which factor the energy reduction is put into relation. For this reason, the bulletin does not contain any general classification of energy-reduced process control variants.

Energy reduction in the sense of low energy consumption during welding as a means to conserve resources can be attained in various different ways - even while preparing the application of the joining technology.

The bulletin expressly discusses the low-energy short arc as it achieves the greatest amount of energy reduction in terms of a low degree of heat input into the workpiece.

When analysing the power factor, we must consider $\overline{P} \neq \overline{U} \cdot \overline{I}$ (inequality) as a vital aspect in the context of these special process control variants.
This means that the medians (readouts) of current and voltage are insufficient when it comes to providing an accurate comparison among these special process control variants and in relation to other process control variants. An accurate comparison dictates a measurement of the actual (true) active electric power according to (Eqn.3) or a correct active electrical power readout of the welding power source.

6 Technological assignment

In principle, GMAW process control variants are subsumed in the categories of gas-shielded metal-arc welding (13) – intert-gas metal arc welding (MIG, 131) / active-gas metal arc welding (MAG, 135).
All process control variants must be applied and evaluated based on their properties in accordance with the recommendations given by the corresponding expert manufacturer.

The possible GMAW process window is expanded by the process control variants, cf. **Fig. 2**.

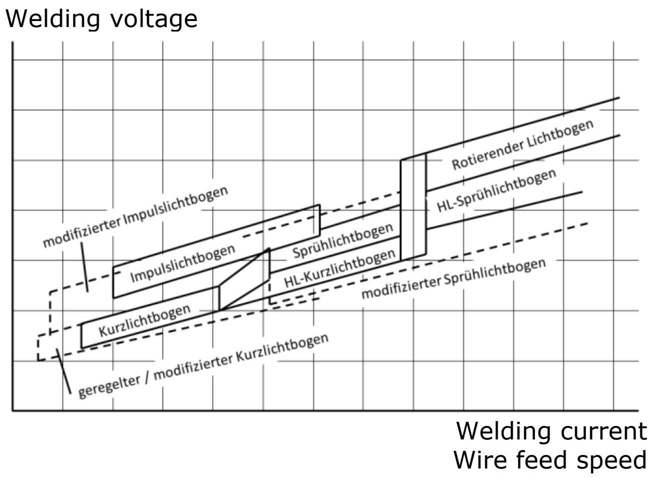

Fig. 2: General position of process windows and their expansions by modified process control variants

7 Interchangeability

Are process control variants supplied by different manufacturers or possessing different historic stages of development interchangeable? Is it possible to transfer welding procedure specifications that came about from work samples carried out with process control variant A to a process control variant B?

The answer: Not just like that. Theoretical conclusions are inadequate when it comes to producing reliable assumptions.
The reason behind this sobering judgement is that even process control variants that feature the exact same characteristics in terms of particular details or individual parameter values may differ from an energetic standpoint. As a consequence, the user will always have to carry out trials and comparative measurements to arrive at conclusive results.
The Technical Bulletin DVS 0973 is a helpful instrument all the same. Identical feature characteristics of process control variants may narrow the trial field. A large number of different characteristics, on the other hand, points to a weak relationship.

The effect of the equipment on applicability during standard procedure qualification tests (WPS) may be a point at issue. [8] clearly points out that procedure qualification tests need to be machine-specific to circumvent the need to prove electrical comparability when using other machines.

8 Overview of GMAW process control variants

The process control variants listed in the table are sorted alphabetically by name.

The crosses given in the respective columns indicate that the corresponding process control variant does possess that particular characteristic. This approach produces a feature characteristic for each and every process control variant. Process control variants with an identical feature characteristic are interrelated from a functional standpoint. However, they are not identical as their parameters may have been set differently.

Process control variants registered by Lorch in DVS bulletin 0973, supplement 1 (2015)

Designation	Manufacturer	Classes of characteristics									
		A	B	C	D	E	F	G	H	I	J
SpeedArc	**Lorch**	X			X	X					
SpeedCold	**Lorch**	X		X							
SpeedPulse	**Lorch**						X	X			
SpeedRoot	**Lorch**	X	X								
SpeedUp	**Lorch**	X					X	X		X	X

Classes of characteristics:			
(A)	Controlled short arc, chapter 5.3	(F)	Pulsed arc, chapter 5.6
(B)	Low-spatter short arc, chapter 5.3.1	(G)	Modified pulsed arc, chapter 5.7
(C)	energy reduced short arc, chapter 5.3.2	(H)	Alternating current process, chapter 5.8
(D)	High performance short arc, chapter 5.3.3	(I)	Combined process variants, chapter 5.9
(E)	Modified spray arc, chapter 5.5	(J)	Cyclic wire movement, chapter 5.10

9 List of references

[1] Technical Bulletin DVS 0973 "Overview of process control variants for gas-shielded metal-arc welding", DVS Media; also published in Schweißen und Schneiden 66 (2014), issue 9, p. 538 et sqq., DVS Media GmbH, Düsseldorf

[2] IEC 60974-1 ed.4, Chapter 11.2 (Type test values of the conventional load voltage), INTERNATIONAL ELECTROTECHNICAL COMMISSION, ARC WELDING EQUIPMENT, Part 1: Welding power sources, Beuth Verlag GmbH, Berlin

[3] B. Jaeschke, J. Kruscha: Leistungs- und Modellparameter kurzschlussbehafteter Lichtbogenprozesse, Schweißen und Schneiden 67 (2015), issue 11, p. 674 et sqq. DVS Publishing House, Düsseldorf 2015.

[4] B. Jaeschke, J. Kruscha: Leistungs- und Modellparameter kurzschlussfreier Lichtbogenprozesse. Trade journal "Schweißen und Schneiden" 65 (2013), issue 9, p. 616 et sqq. DVS Publishing House, Düsseldorf 2013.

[5] B. Jaeschke, W. Ernst, M. Luritzhofer: Verringerung von Fehlern bei der werkstoffspezifischen Bestimmung von Streckenenergie und Wärmeeinbringung moderner Lichtbogenschweißprozesse. DVS reports Volume 296, DVS Congress 2013, p. 302 et sqq. DVS Media, Düsseldorf 2013.

[6] B. Jaeschke: Durchblick verloren? - Übersicht der Prozessregelvarianten zum MSG-Schweißen, DVS reports Volume 315, DVS Congress 2015, p. 76 et sqq., DVS Media, Düsseldorf 2015.

[7] ISO/TR 18491:2013, Guidelines for measurement of welding energies

[8] DVS society, German Electrical and Electronic Manufacturers' Association (ZVEI): Bulletin "Übertragbarkeit von Standardschweißverfahrensprüfungen (WPS)", July 2015