Experimental Study on Dynamic Properties of Power Sources for MIG/MAG Welding†

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Abstract

In the last several years a significant development of MIG/MAG power supply designs is observed. This has been partly due to the recent availability of high power thyristor and transistor systems for controlling the welding parameters directly and partly arises from the more specific requirements of fully automatic processes, controlled by computers or industrial robots. The performance of MIG/MAG power supplies is heavily dependent on their dynamic properties. The variety of power supply designs creates different conditions from the power source-arc system dynamic behaviour viewpoint. Therefore the up-to-date applied methodics of evaluation dynamic properties of MIG/MAG power supplies, based on the rate of rising of current dI/dt seems to be insufficient.

In order to confirm the mutual correlation between dynamic performance of MIG/MAG power supplies, which is determined by their principle of operation and welding process stability, some experimental study on the dynamic properties of conventional transformer-rectifier, thyristor controlled and switching transistor controlled welding rectifiers has been carried on. The output current and voltage waveforms under welding, open circuit and resistance load conditions were examined. The outcomes of the reported investigations allow conclusions to be drawn about dynamic performance of power supplies with different regulator systems as well as some new criterions for evaluation the dynamic properties of MIG/MAG power supplies have been proposed.

KEY WORDS: (MIG/MAG Welding) (GMA Welding) (CO_2 Welding) (Arc Welding) (Welding Power Sources) (Arc Characteristics) (Dynamic Characteristics)

1. Introduction

Welding with consumable electrode in shielding gas atmosphere (MIG/MAG) is recently one of the most frequently applied welding methods. Both stability of the process and quality of welded joints depend on many factors, among which the properties of welding equipment, particularly welding power sources play a significant role.

The properties of power supplies are defined by their static and dynamic characteristics. The static characteristics, which are the correlation between output voltage and current for variable loads determine power supply suitability to a specific welding process. The dynamic characteristics, which are welding voltage and current waveforms recordings, caused by metal transfer across the arc, welding parameters and electrical parameters of power source (resistance, capacity and inductance) determine the stability of welding process.

The dynamic properties of power supply are most significant for MIG/MAG welding, where the load is subject to rapid changes from an arc condition to a short-circuit condition and vice versa. For this method power sources with flat (constant potential) static characteristics are used. During a short-circuit by a drop of melted metal a rapid rise of current takes place to a value, which depends on short-circuit duration as well as rate of rising of current. This instantenous rise of current afects the pinch cut-off process of bridged molten cylinder between electrode wire tip and weld pool but on the other hand is a reason of metal spattering.

In last few years the tendency to widen the range of application of MIG/MAG method from semiautomatic to fully automatic process with industrial robots is observed. The application of this method to automatic welding sets creates some new requirements of welding power sup-

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plies, as for example the necessity of welding parameters stabilisation or remote control by electrical signals send from a basic unit of robot or computer. The necessity to fulfill above requirements as well as recent availability of high power thyristor (solid state) and transistor systems for controlling the current directly established conditions for new welding power source designs with semiconductor control devices compare with earlier designs so-called conventional DC transformer-rectifiers or DC generators.

Modern power supplies have been designed so as to fit to the welding process automatisation, but on the other hand sufficient precaution has not been done from the viewpoint of power source-arc system dynamic behaviour, like different output voltage waveforms with ripples etc. According to this, a new problem appeared – the evaluation of dynamic properties of power sources for MIG/MAG welding. It seems that the currently adopted method, based on the rate of rising of current dI/dt during a short-circuit electrode wire with weld pool by a drop of melted metal is insufficient. Therefore, the purpose of investigations reported here was to reveal the dynamic properties of the most frequently used power supplies for MIG/MAG welding, i.e. sliding brush auto-transformer with rectifier and two semiconductor transformer-rectifiers (first with thyristor, second with switching transistor control systems). All three power supplies had the same output power and the same range of application however their dynamic properties, resulting from the principle of operation were different.

For better understanding of the problems concerned the dynamic properties of power source-arc systems, brief description of MIG/MAG power source designs and performance will be given in section 2 of this report.

2. General Review of MIG/MAG Power Source Designs and Performance.

With regard to the electrical design and operating principle, the most widely used power supplies for MIG/MAG welding can be broadly categorised into following groups:

(1) conventional transformer-rectifiers with magnetic flux control,

(2) solid state AC phase controlled rectifiers,

(3) DC controlled power transistors.

The simplified block-diagrams of above power supplies are shown in **Fig. 1**.

The newest designs of power supplies – rectifiers with inverters as well as conventional DC generators due to their limited range of applications are not dealt with here.

For the first type of power supplies (Fig. 1a) the adjustment of the output is essentially mechanical as in tapped primary transformers, transformers with magnetic flux dissipation (moving iron core, moving coils etc.) or with continuously variable sliding brush auto-transformers. None of these systems lend themselves readily to remote control or output stabilisation, therefore they can not be employed in fully automatic welding sets or with industrial robots. These features (remote control, output stabilisation) are typical for power supplies, for which the adjustment of output parameters is done by means of semiconductor device systems, capable of direct control by low signals. In this case the output voltage of the power source is essentially capable of closed loop feedback control (Fig. 1b and c). Thus the electrical supply is regulated by thyristor (2a) or transistor (5) systems, the output of which is monitored by a detector (6). This proportional to the output voltage signal is compared with reference level R (7) and the difference is applied to the regulator via an amplifier with control system (8). Voltage feedback results in constant potential output, which combined with constant speed of electrode feeding gives stable welding parameters independent of both mains and arc length changes.

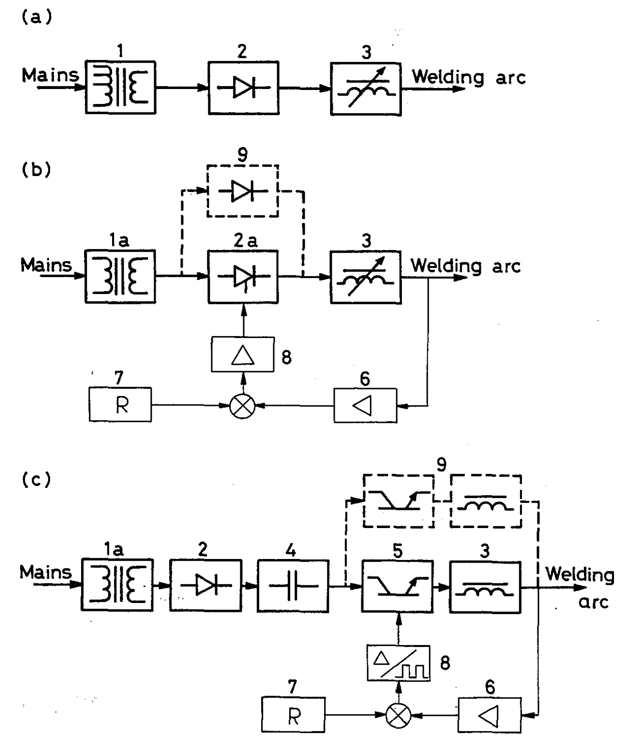


Fig. 1 Block-diagrams of power supplies for MIG/MAG welding: (a) conventional transformer-rectifier, (b) rectifier with thyristor control, (c) rectifier with transistor control. 1 transformer with taps or magnetic flux regulation, la transformer, 2 diode bridge rectifier, 2a thyristor or diode-thyristor bridge rectifier, 3 inductor, 4 filter, 5 transistor regulator, 6 output voltage detector, 7 reference system 8 amplifier with control system, 9 (broken line) additional background current systems.

Solid state AC phase controlled rectifiers are characterised by thyristor or thyristor-diode bridge systems operating on the alternating current side of the transformer-rectifier (Fig. 1b). The output is controlled by governing the phase angle of the AC voltage on which the thyristor system is turned on. The output waveform typically has ripples, which amplitude depends on thyristor firing angle. Large firing angle of thyristors (for low output voltage mean) may result in discontinuity of welding current. Low value of inductance added in series, required by welding process is not sufficient to reduce the ripple amplitude. In order to allow welding current supply continuity, often some additional systems are provided, as for example additional source, which produces constant background current with level 15 to 50 amps (shown by broken lines in Fig. 1).

There are two versions of DC controlled power transistor supplies. First, with the linear or analog transistor arrangements, second, with rapid switching transistors. Analog transistor power sources have very wide possibilities of regulation with excellent, electronicaly controlled dynamic properties, but their high cost limits the range of applications to research or special purposes. More wider industrial applications found cheaper switching transistor power sources (Fig. 1c). The mean output of these power supplies depends on switching frequency, which is usually done at high frequencies more than 1 kHz. Their output waveforms also have ripples, which frequency is more than three times higher compare with thyristor controlled power supplies, however the problem concerning welding current continuity is very similar for both types.

All power supplies for MIG/MAG welding should have flat (constant potential) static characteristics. The necessary condition of static equilibrium for the power supply-arc system is expressed by its positive resultant dynamic resistance as follow:

$$\left(\frac{\partial V_a}{\partial I} - \frac{\partial V}{\partial I}\right)_{I=I_a} > 0$$

where:

$\left(\frac{\partial V_a}{\partial I}\right)_{I=I_a}$ – dynamic resistance of the arc and

$\left(\frac{\partial V}{\partial I}\right)_{I=I_a}$ – dynamic resistance of the power supply

both in working (equilibrium) point, where current I is equal to the arc current I_a.

For MIG/MAG welding, where high current density is applied, the static arc characteristic has a rising shape and the expression $\left(\frac{\partial V_a}{\partial I}\right)_{I_a}$ is positive. In order to fulfill above condition the static characteristic of the power supply must be flat $\left(\frac{\partial V}{\partial I}\right)_{I_a} = 0$, droping $\left(\frac{\partial V}{\partial I}\right)_{I_a} < 0$ or rising, but its slope must be smaller than an arc characteristic slope, i.e. $\left(\frac{\partial V}{\partial I}\right)_{I_a} < \left(\frac{\partial V_a}{\partial I}\right)_{I_a}$. It should be noted, that the static equilibrium of the power supply-arc system is more stable for higher values of the resultant dynamic resistance. According to both static requirements and physics of MIG/MAG welding process the static characteristics of power supply are usually flat or slightly droping (rare slightly rising). In most cases its shape results from natural output characteristics of power supply current circuit structure.

The dynamic properties of power supplies are usually featured by the rate of rising of current during a short-circuit by metal drop dI/dt. The mean value of dI/dt, which depends first of all on welding circuit inductance, determines the manner of metal transfer. Many authors[2),3),6)] pointed out, that the optimum welding conditions took place for such a value of inductance, which enable to obtain the rising of current rate within the range 10~200 kA/s.

3. Experiments

3.1 Experiment procedures.

Three types of power supplies have been selected for investigations on dynamic properties of power source-arc system:

A – continuously variable sliding brush auto-transformer with rectifier,

B – thyristor controlled welding rectifier,

C – switching transistor controlled welding rectifier.

All three power sources had the same range of applications (MIG/MAG welding with current adjustment up to 500 amps), similar shape of static characteristics with 2~3V/100A slope-down within working range, however their dynamic performance, depended on principle of design and operation were different.

Experiments were based on voltage and current recordings during bead-on-plate welding. For all three power supplies common welding conditions were used, i.e. the same parameters settings corresponded to short-circuiting mode of transfer, constant wire extention (18 mm), CO_2 shielding gas flow rate (15 l/min) and welding speed (21 cm/min). Both base metal and electrode wire (dia. 0.8; 1.2; 1.6 mm) were mild steel type. The selection of CO_2 as a shielding gas results from a most difficult conditions this kind of atmosphere creates for the power supply load, i.e. short-circuiting transfer within wide range of welding parameters. The application of argon or argon-CO_2 mixture brings "milder" load conditions with tendency to free-flight transfer.

As an additional test experiments the following recordings have been done:

- current waveforms during a short-circuit of power source under both open circuit and resistance load conditions,
- no-load voltage waveform,
- voltage and current waveforms under resistance load (mean value of resistance equivalent to the arc resistance).

3.2 Welding dynamic characteristics of power supply-arc system

For dynamic characteristics of welding current and voltage waveforms recording the digital memoryscope conected with X-Y pen recorder was used. For each welding parameters setting a few seconds recordings have been done and next, for future analysis one of them, the most typical has been selected. As a variable parameters welding voltage and current were adjusted within the range, where short-circuiting transfer took place for each electrode wire diameter and each power supply.

Based on the results of described experiments it may be stated that the mode of transfer is similar for all tested power supplies in the wide range of parameters. It results from similar shape of voltage and current waveforms observed in oscillograms, counted frequency of short-circuiting transfers as well as beads appearance. The example of correlation among short-circuiting frequency, welding voltage and current are shown in **Fig. 2**. Some differences of arc stability and bead formation within both low range of voltage and high range of current (shown by broken lines in Fig. 2) have been observed. This will be described later in this report.

For all three power sources the maximum short-circuiting rate takes place for 18 V and around 200 A. The increase of welding current density afects the decrease of short-circuiting rate and its maximum value is shifted into voltage range 20~22 V. However the general relation between welding parameters and mode of transfer is similar for all power sources (Fig. 2) and typical for CO_2 welding, some differences of power process stability, bead formation and rate of spatter have been observed. It may be supposed, that these differences result from different dynamic properties of power supplies.

As it was earlier described, usually the dynamic properties of power supply are characterised by rate of rising of current dI/dt, which mean value could be calculated in two ways. First, the average values of both short-circuit current and short-circuit duration are measured from an oscillogram recorded for given welding conditions and next by dividing these two values, the mean of dI/dt can be obtained. Second, the mean of dI/dt is calculated for each short-circuit in an oscillogram and next their average value. In both cases the simplification is done, that the rise of short-circuit current is linear, however in real conditions it is similar to expotential function curve. This

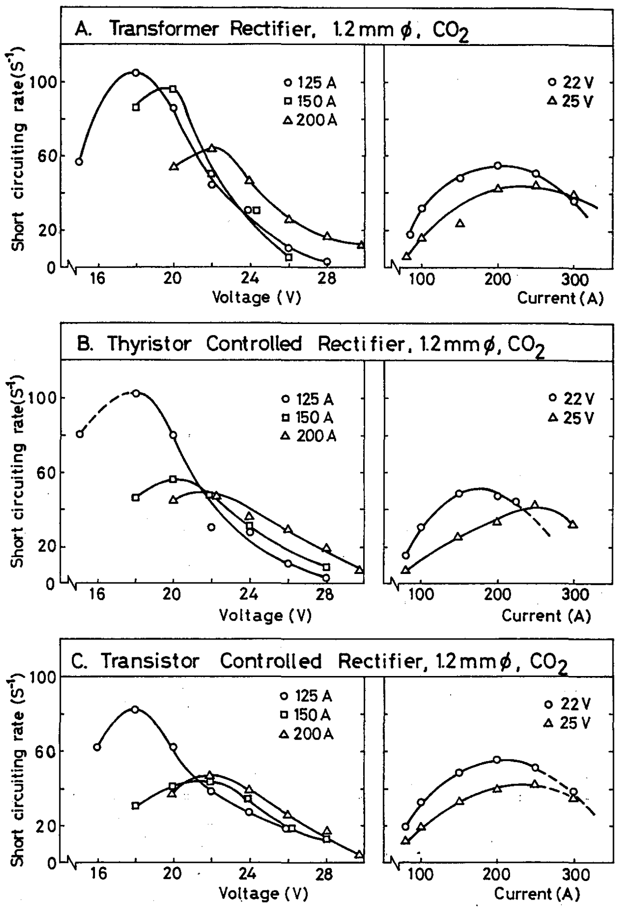


Fig. 2 Short-circuiting rate as a function of welding voltage and current.

simplification may caused significant differences in dI/dt mean calculations. It can be explained by the following example. **Figure 3** shows a fragment of an oscillogram recorded for thyristor controlled power supply (wire dia. 1.6 mm, current 200 A, voltage 18 V). The calculated values of dI/dt for each short-circuit indicated from 1 to 4 in Fig. 3 are as follow:

$$1)\ dI/dt = \frac{540\text{A} - 110\text{A}}{15\text{ ms}} = 28.7\text{ kA/s}$$

$$2)\ dI/dt = \frac{310\text{A} - 100\text{A}}{3{,}75\text{ ms}} = 56.0\text{ kA/s}$$

$$3)\ dI/dt = \frac{570\text{A} - 130\text{A}}{22{,}5\text{ ms}} = 19.5\text{ kA/s}$$

$$4)\ dI/dt = \frac{430\text{A} - 80\text{A}}{9\text{ ms}} = 38.8\text{ kA/s}$$

The average mean of dI/dt for all given above short-circuits is 35.8 kA/s, whereas the same value calculated from 1-second long oscillogram is 30.8 kA/s.

From the above example it may be seen that the mean value of dI/dt rate varies with short-circuit duration changes, even almost three times in case of shortest and longest short-circuit duration. Than, which of given above values of dI/dt rate should be taken into consideration as a criterion of dynamic properties evaluation? Particularly these kind of doubts occured in all cases, where large differences in short-circuit duration are observed in oscillograms. The relation between dI/dt values and short-circuit durations, which is similar for all tested power supplies in shown in **Fig. 4** and some examples of short-circuit duration distributions, done for the welding voltage range 18~24 V (typical range of short-circuit transfer) in **Fig. 5**.

As it may be seen in Fig. 5 the short-circuit duration are usually set within the range 1~10 ms, for which the largest differences of the rate dI/dt value occur (Fig. 4).

The conclusion may be drawn that the criterion based on the rate dI/dt value does not well explain the actual dynamic phenomena and therefore it should not be applied as an only measure of dynamic characteristics of power source.

3.3 Short-circuit characteristics of power supplies

As it was earlier described, the mean value of dI/dt rate varies with short-circuit duration changes. This result from the shape of short-circuit current waveform. It may be supposed that however short-circuit duration, its frequency and arcing time between short-circuits are afected

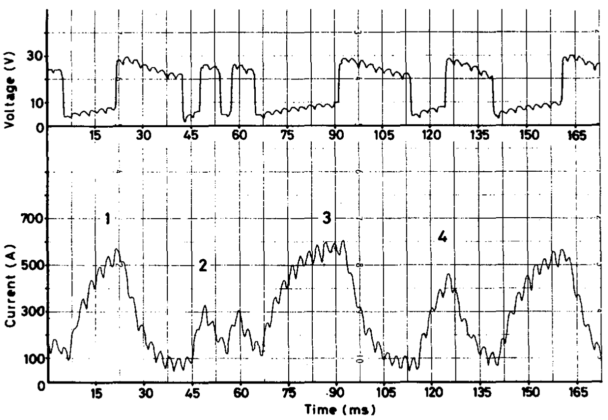


Fig. 3 Welding voltage and current waveforms for different short-circuit duration.

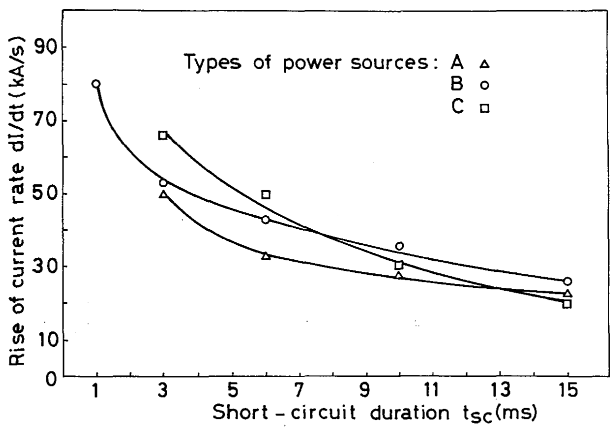


Fig. 4 The rise of current rate as a function of short-circuit duration.

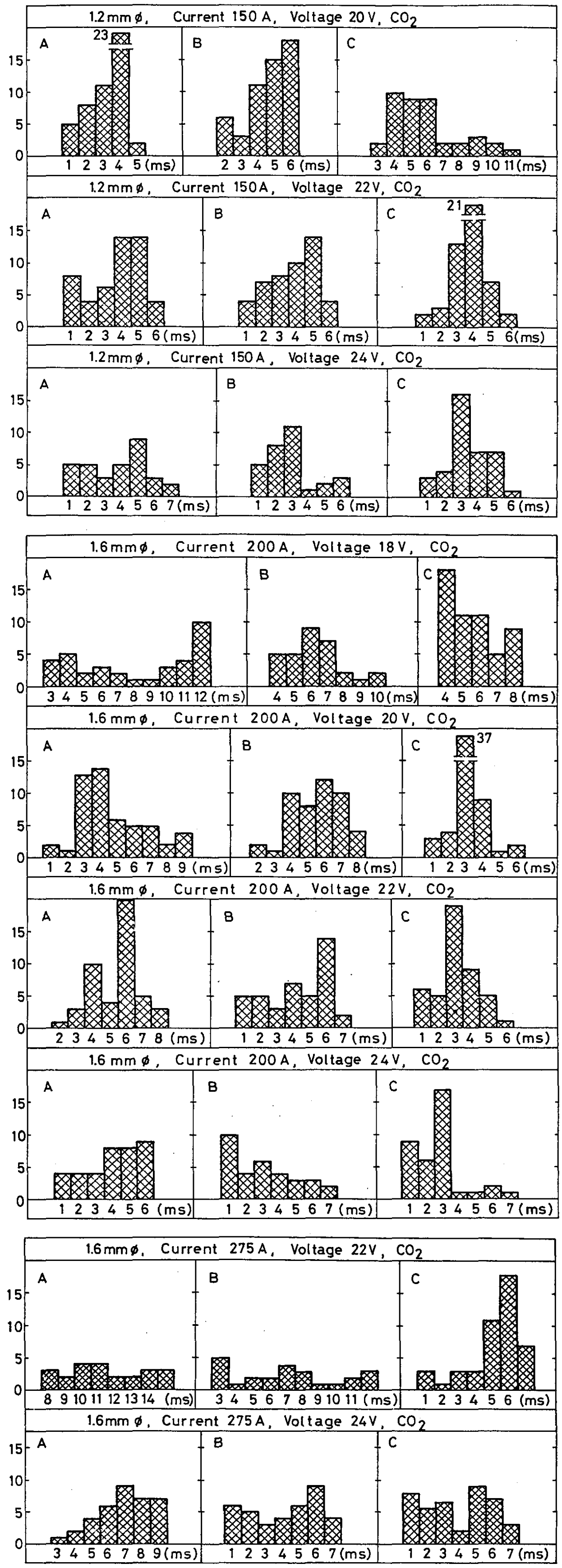


Fig. 5 Distribution of short-circuit duration (A, B, C types of power sources).

by welding parameters, kind of electrode and base metal as well as kind of shielding atmosphere, but the waveform of short-circuit current itself is a result of dynamic properties of welding electrical circuit, which are first of all afected by power source properties.

Acquiescing this conclusion, it may be stated that it is possible to establish an objective criterion for MIG/MAG power supplies dynamic properties evaluation based on analysis of dynamic characteristics of short-circuit current of power source itself.

For this purpose some short-circuit current waveforms for tested power sources have been recorded. The short-circuit tests were done under both open circuit and resistance load conditions, where the resistance value was equivalent to the arc resistance. Typical examples of recorded waveforms are shown in **Figs. 6** and 7. The short-circuit current waveforms for each power supply are similar and independent of no-load voltage setting, only the level of equilibrium short-circuit current is changed. The mean values of equilibrium short-circuit current I_{sc} for tested power sources are given in **Table 1**.

From values listed in Table 1 may be seen that I_{sc} value for type A (auto-transformer with rectifier) power source is almost two times higher than for type C (transistor controlled rectifier). In most transistor or thyristor controlled power supply designs the limited level of maximum output current is applied in order to protect solid state elements against overloading and demage. From the welding process viewpoint the maximum level of equilibrium short-circuit current plays a significant role in case of high current welding (higher than 300 A). Low level of short-circuit current makes difficult drops cut-off from an electrode wire tip. The comparison of dynamic characteristics recorded for 350 A welding current are shown in **Fig. 8**. The maximum output current limit in type C power source causes long short-circuit duration and instability of welding process (Fig. 8c). For this power source type a stable welding process was obtained for the current up to 250 A (the range above this value indicated by broken line in Fig. 2).

From analysis of oscillograms recorded for high welding current range results that the stable welding process can be obtain when the maximum short-circuit current is not less than 2.5 times of the welding current.

The short-circuit current waveform may be characterised by the time constant T_c, which is equal to the tangent of slope angle α at point $t = 0$. The simplified way of T_c calculation is shown in **Fig. 9**. **Table 2** lists the calculated values of time constant T_c for tested power sources.

As may be seen from Table 2, the time constant T_c slightly varies for type A and is constant for type B power sources. For type C power source as the result of built-in so-called electronic reactance current waveform is not typical (Fig. 6) and makes impossible to calculate T_c. This value can be calculated for the current waveform recorded during short-circuit from resistance load state (Fig. 7). The changes of output current for instantenous changes of the output load are fastest for type C and slowest for type A of power sources. One more tendency should be considered. For type A power source the value of T_c decreases with rise of voltage setting. The reason is clear, because for higher voltage setting the maximum short-circuit current is proportionaly higher and the build-up of current within the range 0–0.63 I_{sc} is more rapid. The oposite tendency for type C power source results from output current limit.

Nevertheless for all tested power supplies the time constant T_c, which characterised the short-circuit current waveform varies slightly according to the voltage setting or short-circuit manner (under open circuit or resistance load conditions). The conclusion may be drawn, that on a base of time constant of short-circuit current waveform a criterion of MIG/MAG power supplies dynamic properties evaluation may be established.

As a result of described above relations, analysis of welding dynamic characteristics, welded beads quality and observations of welding process such a criterion may be formulated as follow. The dynamic performance of MIG/MAG power supplies is good, when their short-circuit current waveform time constant T_c is set within the range 5 ms $\leqslant T_c \leqslant$ 15 ms. The lower value determines the maximum rate of rising of current and has a direct influence on amount of spatter whereas the upper value determines the maximum rate of rise, which enable the stable metal transfer process.

3.4 Output voltage and current waveforms of power sources

Apart from earlier described aspects of power supplies dynamic performance, the output voltage and current waveforms under steady state conditions have also the significant influence on welding process stability. Particularly disadvantageous output waveforms, which are characterised by large ripple are remarkable in thyristor or switching transistor controlled rectifiers. Conventional transformer-rectifiers have much more smooth output waveforms, in which a small ripple results from the rectifier arrangements. The most advantageous output waveforms are formed by analog transistor power supplies, but not dealt with here due to the reason described earlier.

Some typical output voltage waveforms under open circuit conditions are shown in **Fig. 10** and waveforms under the resistance load in **Fig. 11**. Characteristic values of both waveforms are listed in **Table 3**.

The no-load voltage waveforms of type C power source are not shown, because under open circuit conditions it produces constant value of voltage equal to 78 V, which is resulted from its control system and is independent of regulating device position.

As it may be seen in Figs. 10 and 11 as well as given in Table 3 values the output waveforms of both type B and type C power sources have large ripple compared with

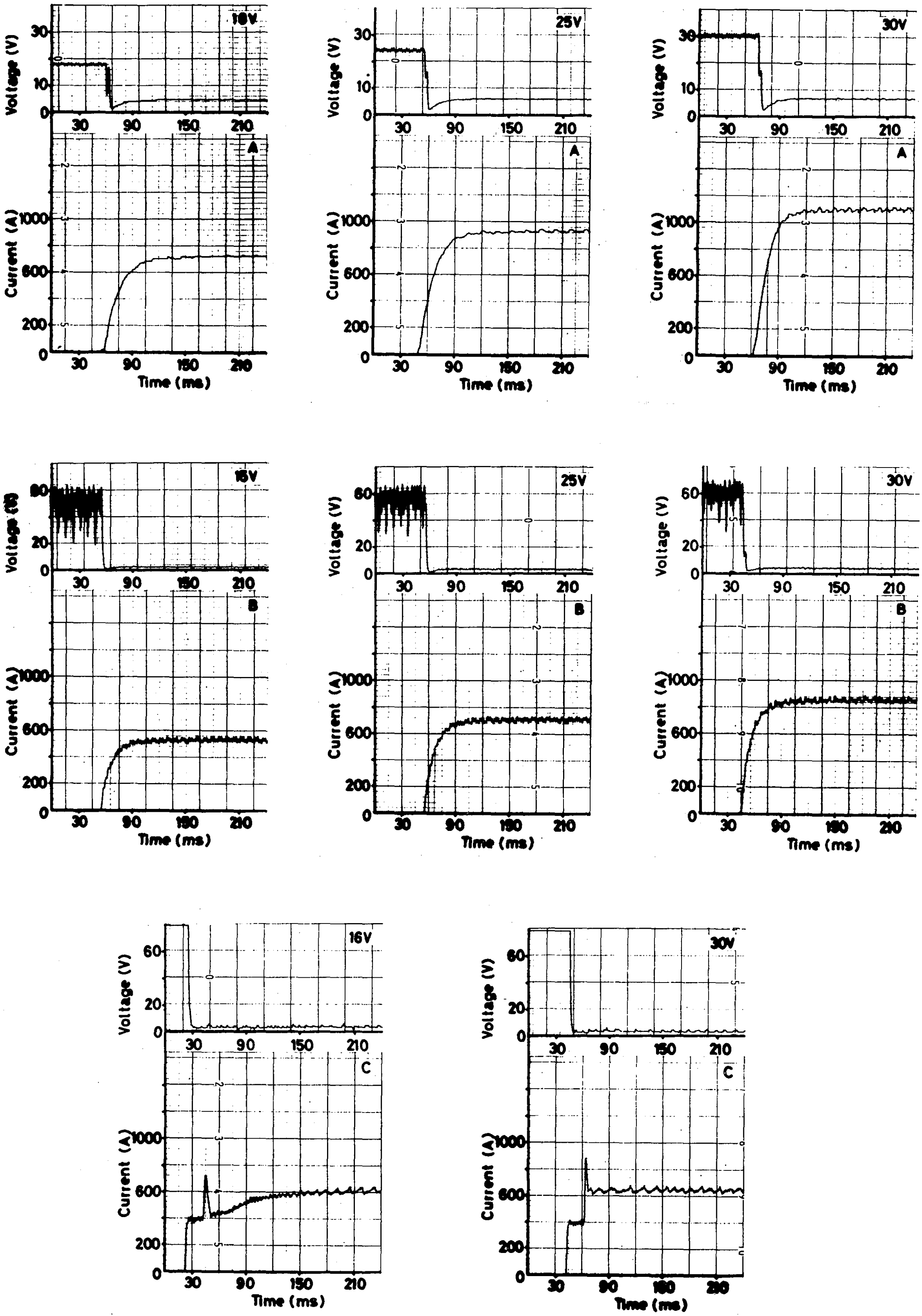


Fig. 6 Short-circuit current and voltage waveforms (short-circuit from open circuit) for A, B and C types of power sources.

almost smooth output waveforms of type A power source. From the welding process stability viewpoint ripples themselves in no-load or welding voltage waveforms are not so significant as the minimum value, which these waveforms reach periodically (V_{omin} or V_{rmin}). Insufficient welding process stability was observed for parameters settings, which caused output voltage waveforms periodically drop under the level of 12 V. An example of

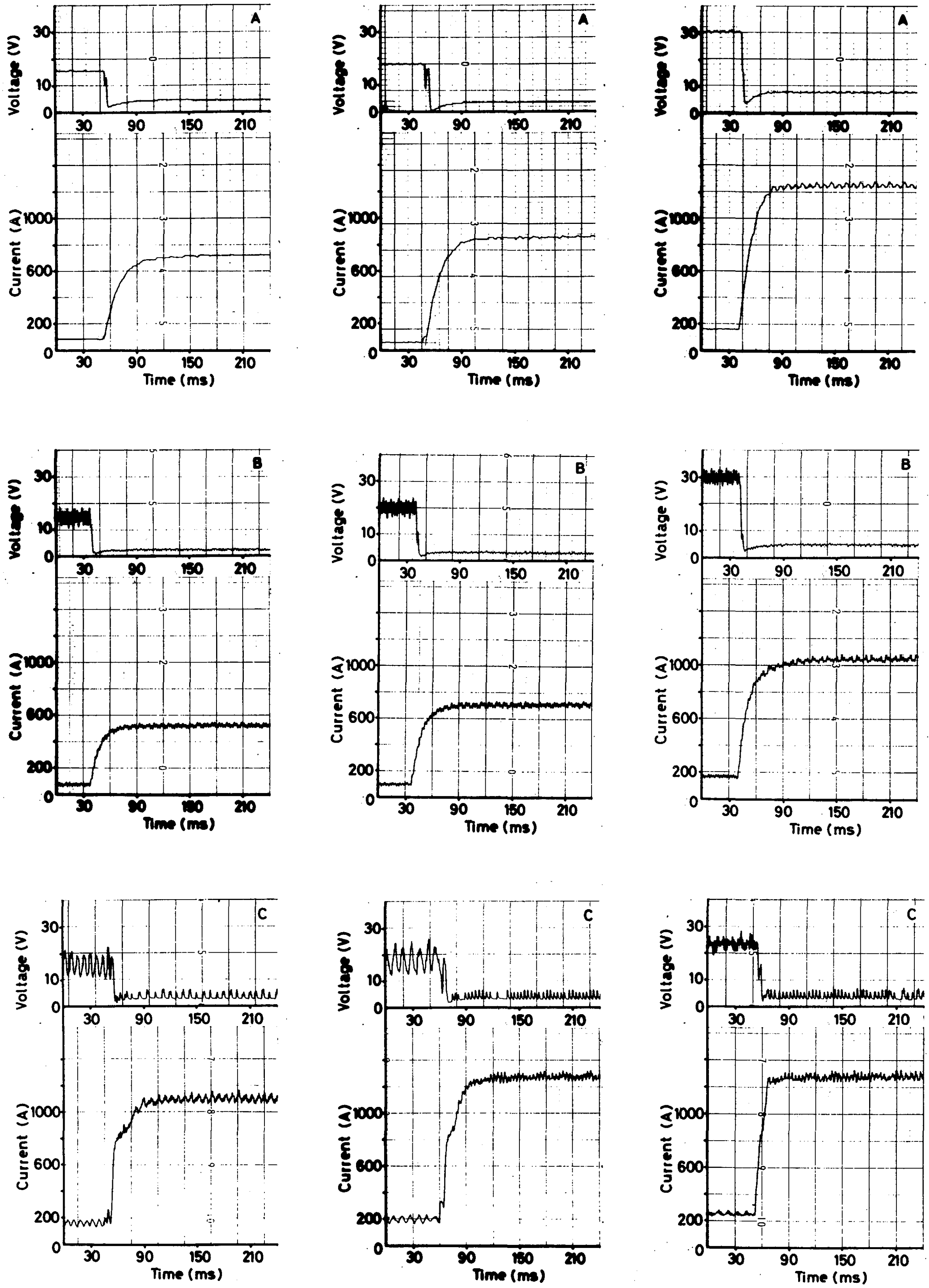


Fig. 7 Short-circuit current and voltage waveforms (short-circuit from resistance load) for A, B and C power sources.

Table 1 Short-circuit current mean values I_{sc}.

Type of power source	A				B				C			
Voltage setting* V(volts)	16	20	25	30	15	20	25	30	15	20	25	30
I_{sc}(amps)	720	900	1060	1240	520	700	850	1050	600	640	640	650

* Voltage setting of power source corresponds to the working (welding) voltage given in the table.

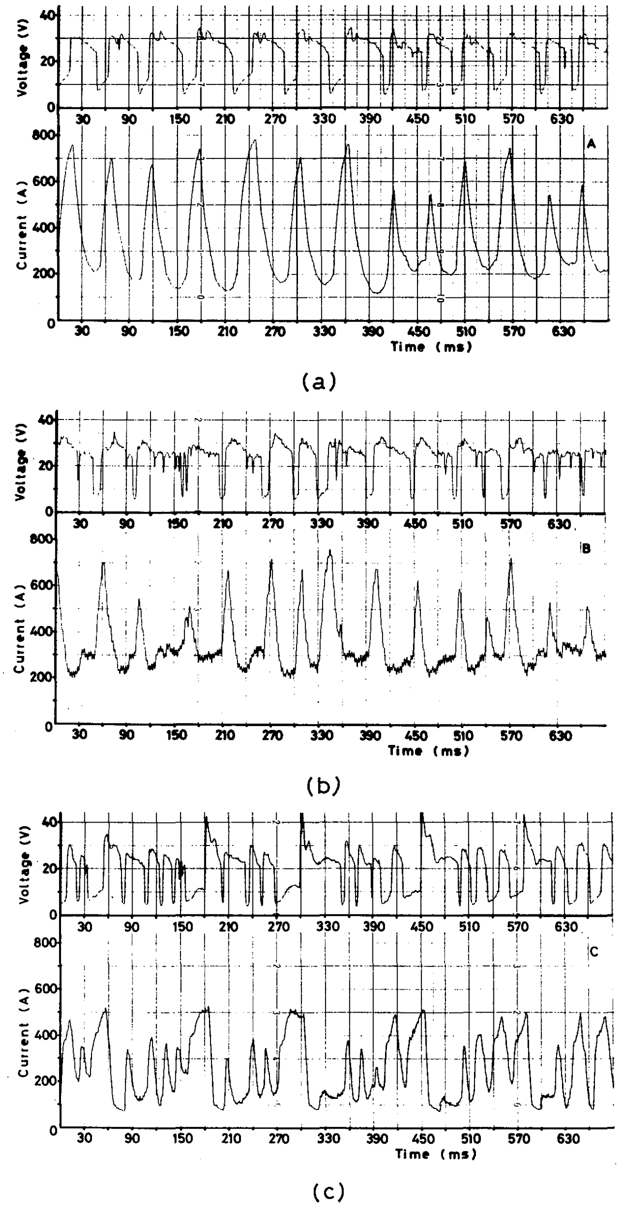


Fig. 8 Typical current and voltage waveforms of 350 A welding current for A, B and C power sources.

welding dynamic characteristics (oscillograms) for type A power supply, which output voltage waveforms have only very small ripple and type B power supply, for which the

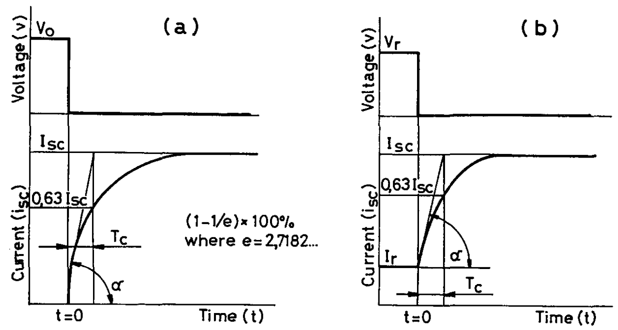


Fig. 9 Method of calculating the time constant T_c for short-circuit current waveforms (a) short-circuit from open circuit, (b) short-circuit from resistance load. V_o no-load voltage, V_r and I_r voltage and current for resistance load respectively.

Table 2 The time constant T_c(ms) of short-circuit current waveforms.

Type of power source	A		B		C	
Voltage setting* V(volts)	16	30	15	30	15	30
Short-circuit from open circuit T_c(ms)	17	15	11	11	-	-
Short-circuit from resistance load T_c(ms)	16	14	11	11	6	10

same waveforms have 16 V ripple with minimum value 8 V are shown in **Fig. 12**a and b respectively. In order to obtain stable welding process some additional systems must be provided, as for example additional power source, which producing low level constant background current (usually from 15 to 50 amps) allows welding arc continuity. Such a solution was applied in type C power supply, for which even under similar conditions as for type B power supply (voltage ripple amplitude 25 V with minimum value 10 V) the stable welding process was obtained (see Fig. 12c).

Summing up, the conclusion may be drawn that the stable welding process can be obtain, if the minimum value of ripple in output voltage waveforms is not less than 12 volts. For lower values some additional systems, which can assure the welding arc continuity are required.

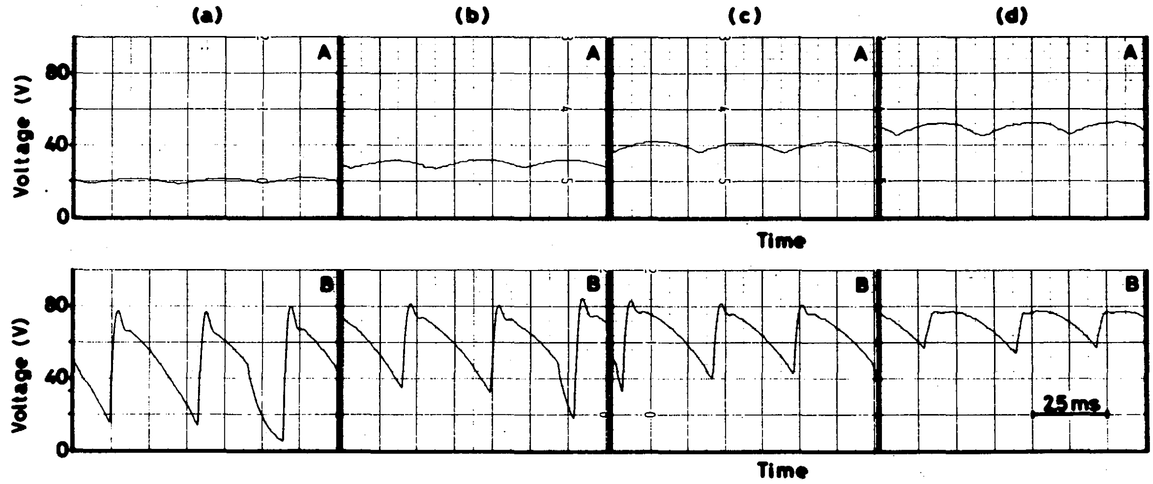


Fig. 10 No-load voltage waveforms for A and B power sources. Voltage settings: 16 V (a), 25 V (b), 30 V (c) and 35 V (d).

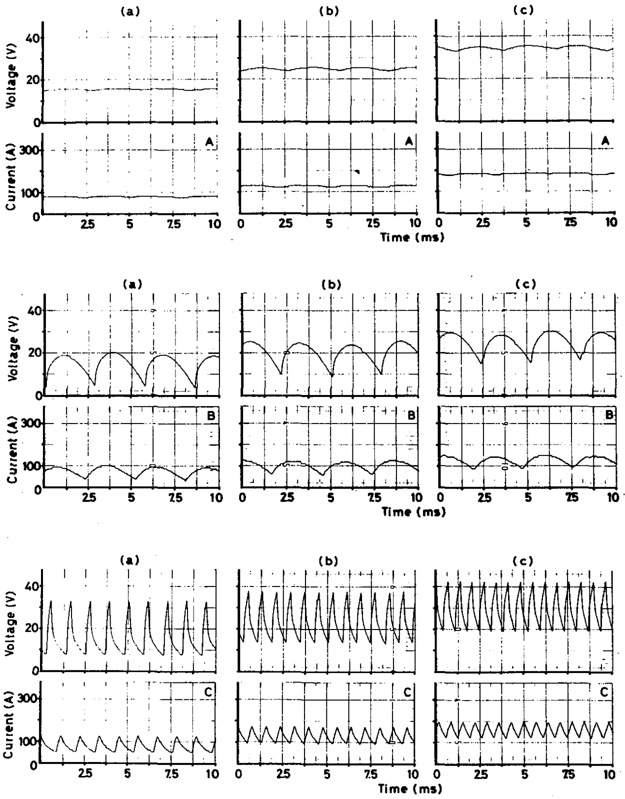
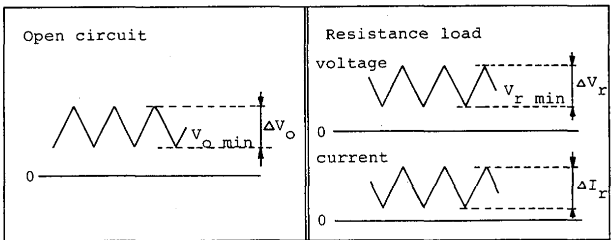


Fig. 11 Typical current and voltage waveforms undeer resistance load condition for A, B and C power sources. Voltage settings: 16 V (a), 20 V (b) and 30 V (c).

Table 3 Characteristic values of voltage and currnet waveforms under steady state conditions.



Type of power source	A		B		C	
Voltage setting* V(volts)	16	30	15	30	15	30
$V_{o\ min}$(volts)	18	36	5	24	78	78
ΔV_o(volts)	4	6	70	42	0	0
$V_{r\ min}$(volts)	15	29	5	24	8	19
ΔV_r(volts)	1	3	16	14	25	23
ΔI_r(amps)	8	10	62	60	70	80

* Voltage setting of power source corresponds to the working (welding) voltage given in the table.

4. Summary and Conclusions

Based on the results of investigations reported here, it was confirmed that MIG/MAG power supply designs determine not only the range of their applications (semiautomatic or fully automatic welding) but dynamic properties too, which affected the welding process stability. In conventional transformer-rectifier power supplies the control of the output is essentially mechanical, which makes some difficulties in both remote control by electrical signals and output stabilisation. From these reasons they are not suitable for application in fully automatic welding sets controlled by computers or industrial robots. On the other hand these kind of power supplies output current and voltage waveforms are characterised by low ripple what determine their good performance in wide range of welding parameters.

MIG/MAG power supplies with semiconductor control systems (thyristor or transistor) have necessary abilities from the viewpoint of their application in automatic welding sets (output stabilisation remote control) but their properties allow to obtain good performance only within narrow range of welding parameters. Their output waveforms with large amplitude ripple make impossible to obtain stable welding process for low range of voltage (less than 20 V) without any additional systems, which allow to obtain current continuity with respect to the welding

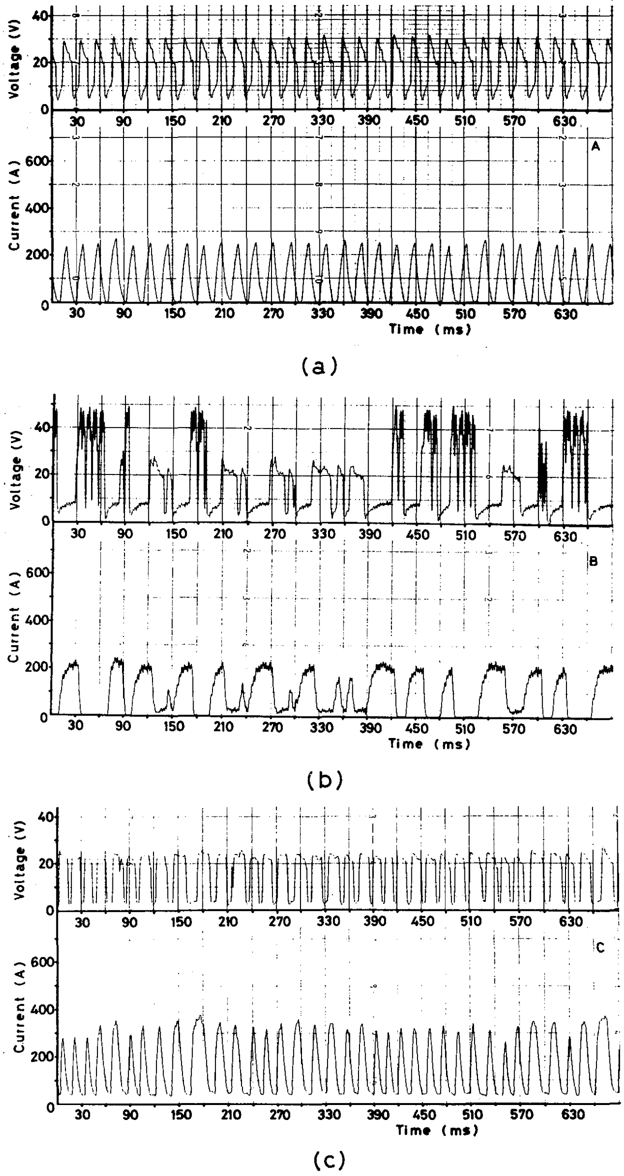


Fig. 12 Typical current and voltage waveforms of 18 V welding voltage for A, B and C power sources.

arc. The maximum output current limit applied in order to protect semiconductor regulator systems caused poor welding process stability in large current range i.e. usually over 300 amps.

It should be concidered, that for switching transistor controlled power sources due to the higher ripple frequency compare with thyristor controlled rectifiers the welding process stability is better. Also their dynamic response time, controlled by electronic regulation system, to a step change in output load may be relatively short. This enable the application of transistor controlled power supplies to pulsed welding with high frequencies for control of metal transfer, whereas thyristor controlled power supplies can be only apply to pulsed welding at relatively low frequencies for weld pool control. Magnetic flux controlled power supplies (conventional transformer-rectifiers) due to their slow response are not suitable for output waveforms modification.

For MIG/MAG welding the dynamic properties of power supplies play a significant role, therefore the proper methodics of their evaluation is necessary. Particularly it is very important for new power source designs or for optimal power supply selection for fixed welding conditions.

As a result of experimental study reported here, the following criterions for evaluation the dynamic properties of power supplies for MIG/MAG welding may be proposed:

(1) The time constant T_c of power supply short-circuit current waveform (short-circuit from open circuit or resistance load) should be set within the range: 5 ms $\leqslant T_c \leqslant$ 15 ms for the whole range of welding parameters adjustment.

(2) The minimum mean value of amplitude ripple in output voltage waveforms should be not less than 12 volts.

(3) The equilibrium value of power supply short-circuit current should be not less than 2.5 times of welding current.

MIG/MAG power supplies, which fulfill simultaneously all three described above criterions have good performance from the power supply-arc system dynamic phenomena viewpoint.

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References

1) J.F. Lancaster "The Physics of Welding" Pergamon International Library, Oxford, New York 1984.

2) A.A. Smith "Characteristics of the Short-Circuiting CO_2-Shielded Arc" Symposium "Physics of the Welding Arc"-1962, Institute of Welding, London 1966.

3) "Review of New Designs of Power Sources for Arc Welding Process"-IIW Doc. XII-F-217-80.

4) H.E. Weinschenk, M. Schellhase "Statistical Analysis of Arcing Voltage in the CO_2-shielded Welding Process" Symposium "Arc Physics and Weld Pool Behaviour" The Welding Institute, London 1979.

5) K. Nishiguchi "Evaluation of DC Power Sources Used for Gas Shield Arc Welding, Especially MIG/MAG Process" IIW Doc. XII-F-185-77.

6) W. Dymek "Elektryczne Urzadzenia Spawalnicze" Politechnika Warszawska, Warszawa 1975 (in Polish).