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HIGHLY EFFICIENT WELDING POWER SUPPLY

Final Report, May 1, 1978—September 30, 1980

By
James M. Thommes

September 1980

Work Performed Under Contract No. AC03-78CS40023

Cyclomatic Industries, Inc.
San Diego, California

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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FINAL REPORT
HIGHLY EFFICIENT WELDING POWER SUPPLY

Contract # EM-78-C-03-1837
MOD. # DE-AC03-78CS40023

From May 1, 1978 to September 30, 1980

James M. Thommes

September 1980

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ABSTRACT

This report discloses the results and findings of an energy efficient welding power source development project. The project was funded by the U.S. Department of Energy under DOE contract #EM-78-C-03-1837. The power source developed is to be used for electric arc welding processes in which 3.5 trillion BTU of energy (1978 example year) can be saved annually.

The power source development incorporates the use of switch mode power supply techniques in order to convert industrial supply mains (230/460 VAC 3 ϕ 60 Hz) to appropriate welding voltages and currents (up to 32 volts/up to 300 amps). A series capacitor switch mode power circuit was the circuit technique chosen in order to optimize energy efficiency, costs, reliability, size/weight, and welding performance.

Test results demonstrated an effective efficiency (taking into account "idle" power consumption) of 80% to 91% for the energy efficient power source while the conventional types of power sources tested ranged from 41% to 74% efficiency. Line power factor was also improved for the energy efficient power source. Field tests indicated additional refinements of weld process performance and power source audible noise emission reduction could be beneficial.

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INTRODUCTION

Energy plays a significant role in the metal joining processes. Sufficient heat must be generated in order to melt the metal to be welded (base metal) as well as any metal added to the weld area (filler metal) in such a way that all molten materials (weld metal) coalesce and form an intimate fusion bond. In electric arc welding, this heat is generated by an electric arc receiving power from a welding power source. Opportunities for energy conservation in electric arc welding have been identified by others [1]. One such opportunity is to reduce primary energy consumption for arc welding processes by improving welding power source efficiencies. This report discloses the efforts to develop a welding power source with improved efficiency.

ENERGY USAGE IN ARC WELDING

The total energy consumption used annually in the U.S. for electric arc welding has not been quantified by the welding industry. However, the magnitude of energy which may be conserved can be approximately determined using what is known as the consumable materials method [1]. This method determines the amount of energy consumed by arc welding processes based on the amount of filler metal used in the processes. It is based on the assumption that a specific amount of energy is required per pound of filler metal applied to the weld. Mathematically it is given in formula (1) [1, p10] :

$$E_p = \frac{W}{N_1 N_2} \times E' \quad (1)$$

- where
- W = Annual filler metal sales in pounds
 - E' = Specific energy required per pound of filler metal consumed in the weld process
 - N₁ = Effective welding power source efficiency
 - N₂ = .325 (see note)

NOTE: N₂ is the primary energy to electrical energy conversion efficiency (i.e. efficiency of converting barrels of oil to kilowatt hours). The Department of Energy uses a figure of .325.

Using 1978 as an example year, W is 1.108 billion pounds [2 p85], E' is approximately 1 KWH/lb. [1,3]), and N₁ is assumed .60 (values of .45 to .70 are used by others [1 p17]). Using these values, the total primary energy consumption in the U.S. for arc welding was approximately 5.7 billion KWH or 19 trillion BTU. If N₁ was 1.0 (representing a 100% efficient power source) the primary consumption for an equal volume of arc welding activity would be about 12 trillion BTU, resulting in a savings of about 7 trillion BTU. See Figure 1 for an illustration of the difference. Obviously a savings of 7 trillion BTU represents the ideal in terms of conservation by means of improving power source efficiency.

Figure 1. Ideal energy savings with 100% efficient welding power sources
Example year 1978

PROJECT OBJECTIVES

In order to realize a significant portion of the ideal energy savings, a commercially viable energy efficient power source was to be developed. If an energy efficient power source was developed, yet due to its high cost or poor welding performance it was not accepted by the average user, then no energy savings would be realized. The efficient welding power sources simply would not be put into use. Therefore, the development of a commercially viable energy efficient welding power source included consideration of the following general characteristics.

DESIGN CONCEPT

CONVENTIONAL AND SWITCH MODE TECHNOLOGIES

In order to achieve the project objectives described, the energy efficient welding power source was developed utilizing switch mode techniques. Presently available welding power sources utilize conventional techniques. The difference between these techniques is illustrated in Figure 2.

The purpose of a direct current welding power source is to receive 230V or 460V 60 Hz power from industrial electrical supply mains and deliver DC electrical power in the appropriate ranges of amperage and voltage required for arc welding process. The power source must have a means of controlling the amperage or voltage to a level consistent with the weld in process. Figure 2a illustrates the conventional technique which uses a 60 Hz transformer, T_p , connected to the supply mains and a series impedance, Z_c , used for controlling the output level. (It must be understood that Figure 2a is a simplification of the technique and is used for illustrative purposes. T_p and Z_c are not in all cases distinct and separate components; however, the principle illustrated here is valid and accurate.) T_p and Z_c are components which are generally lossy and dissipate waste heat internally. These components could be made efficient; however, it would generally require more material or more cost. Some welding authorities hold that improving efficiency of these components would also result in poor welding characteristics [5, p53]. CR_O and L are components which constitute the rectifier and output filter.

Figure 2b illustrates the switch mode technique. The supply mains are connected to a rectifier, CR_I , control switch, Sc , and transformer, T_H . CR_I takes the AC supply voltage and rectifies it to a DC potential. Sc switches on and off at a very fast rate from 1000 Hz to 5000 Hz. The time Sc is "on" compared to the time "off" determines the output level. T_H is a high frequency transformer which has less weight and total loss than its conventional counterpart, T_p , due to the higher frequency of operation. As illustrated, the switch mode technique can improve on two of the five characteristics previously identified, efficiency and weight savings. Efficiency is improved by using a transformer which dissipates less heat and by a control means, Sc , which ideally does not dissipate any heat. Furthermore, when the welding power source is idling (not delivering energy to an electric arc) all components except CR_I are disconnected from the supply; therefore, very little idle power is consumed. Weight is reduced by using a high frequency (1000 Hz to 5000 Hz) transformer with about one tenth the weight of its 60 Hz counterpart in the conventional technique.

VARIOUS APPROACHES AND SWITCH DEVICES

Within the general category of switch mode techniques lie various approaches and switch devices. Before a detailed concept was formulated and a development project begun, decisions on which approach to use and which device to use had to be made.

Some authors have classified various switch mode circuit approaches [6, 7]. Such classifications involve four to six main classes with each class having a number of variations. This project identified nine basic circuit approaches. The best approach is one which maximizes the five general characteristics desired — efficiency, cost savings, reliability, weight savings, and welding performance. Appendix B lists the nine approaches and provides a detailed discussion and comparison of these approaches.

The control switch shown in Figure 2b is not a mechanical switch as one might initially assume. Due to the fast switching rate of 1000 Hz to 5000 Hz, an electronic switch device which synthe-

- 1) Energy Efficiency — the main thrust of the development is efficiency. Figure 1 illustrates an ideal energy savings of 7 trillion BTU annually of a 100% efficient source over a 60% efficient one. In order to recover half of the ideal savings or 3.5 trillion BTU, all of the power sources in use would have to have an average efficiency of 80%.
- 2) Cost — an energy efficient power source would have to be competitive in cost to presently available equipment. For example, assume a conventional power source set at 250 amps is used to weld with steel filler wire. The wire is deposited at a rate of approximately 6 lbs./hr. [4, p154, p164]. Further assuming that this weld is performed 2 hours each day, the yearly KWH requirement for the welding power source can be determined.

$$\frac{(2 \text{ hrs}) \times (260 \text{ work days/year}) \times (6 \text{ lb/hr}) \times (1 \text{ KWH/lb})}{.60 \text{ efficiency}} = 5200 \text{ KWH/year}$$

At \$.08/KWH, the welding power source requires \$416 worth of electricity yearly. An 80% efficient power source would require \$312 worth of electricity as determined by a similar calculation. Based on a one year payback criteria, the energy efficient power source could justify only a \$104 price premium over presently available equipment for this application. Therefore, even though national energy savings could be significant, power cost savings accruing to an individual 80% efficient power source is not a great amount. However, if the 80% efficient welding power sources were priced within these competitive limits, widespread use of such power sources would occur through new purchases replacing retired equipment as well as new purchases for expansion of capacity.

- 3) Reliability — various examples [4 p556] show that labor cost may vary from one third to one half the cost of a weld per foot. Therefore, power source reliability is an important consideration of the welding fabricator. If a power source is unreliable then the fabricator may experience an idle labor situation due to equipment down time. This situation can further increase an already large cost component of his process. If achieving improvement in power source efficiency requires the use of new technologies, then they must be thoroughly analyzed and tested for reliability.
- 4) Weight Savings — Reducing the weight of a welding power source will reduce shipping costs of a new unit and therefore improves the cost competitive position of such a power supply. However, this characteristic is separated from the cost characteristic because there are secondary energy saving effects of reduced weight. Transportation energy is saved in initial shipment as well as equipment movement within large facilities.
- 5) Welding Performance — in order to be acceptable to users, the 80% energy efficient power source must at least meet the welding performance characteristics of presently available power sources.

These five general characteristics were considered as part of the design criteria. Development of a detailed design concept explicitly took these characteristics into account. Proposed specification goals which elaborate on these general characteristics are provided in Appendix A. (Appendix A (p A2) also provides a specification of the power source developed in this project for comparative purposes.)

Figure 2. Conventional and Switch Mode Techniques

sizes a mechanical switch function must be used. Two such devices that are commercially available are the Bipolar Junction Transistor (BJT) and the Silicon Controlled Rectifier (SCR). Both of these devices are capable of switching on and off at rapid rates with minimum losses and thus closely approximating the ideal switch in Figure 2b. The choice between these devices depends on relative cost and performance as evaluated in the nine circuit approaches previously discussed. Appendix B provides a detailed comparison of these devices.

ARRIVAL AT A DETAILED CONCEPT

In order to arrive at a detailed concept on which further development was based, the circuit approach and switch device which maximize the five general characteristics desired was quantitatively identified. Weights applied to the characteristics are given in formula (2).

$$\begin{aligned} \text{Objective} = & .35 \text{ efficiency} + .30 \text{ cost savings} + .15 \text{ reliability} \\ & + .1 \text{ weight savings} + .1 \text{ welding performance} \end{aligned} \quad (2)$$

Quantified projections on efficiency and cost savings could be established on the nine approaches. Selection was based on these two characteristics which constitute .65 of the total weighting. A summary of such a quantitative evaluation is provided in Appendix B. The choice indicated by such an evaluation was that of a Series Resonant Current Source circuit approach implemented with SCR switches.

The choice of circuit approach was further refined by incorporating state of the art techniques described in U.S. patents No. 4152759, Frequency Converter; No. 4159409, Current Unit for Arc Welding; and No. 4117303 Arrangement in Electrical Welding Apparatus. Such patents are owned by a corporate affiliate of the contractor and are used as background patents in this project. Incorporating these patents allowed lower current stress on the circuit components thus enhancing reliability and component cost savings. In addition, the series resonant circuit is replaced by a series capacitor and is more accurately referred to as a Series Capacitor Switch Mode Circuit. These patents are detailed in Appendix C.

POWER SOURCE DESIGN AND DEVELOPMENT

ELECTRICAL DESIGN

Once the selection of a specific design concept (Series Capacitor Switch Mode Circuit implemented with SCR switch devices) was made, the details of the electrical design of the efficient welding power source could be defined. The electrical circuits logically divide into three categories: the Power Circuit, the SCR Controller/Driver, and the Process Control Circuit. The Power Circuit performs the function of converting the electrical supply (230V/460V 60 Hz) into controlled voltage and/or current levels consistent with the welding process requirements. The Power Circuit is the detailed implementation of the Series Capacitor Switch Mode Circuit. The SCR Controller/Driver is the control electronics for the Power Circuit. These control elements provide the proper signals to the switch devices, SCRs, in order for them to function and monitor the status of the power circuit. The Process Control Circuit monitors the volts and amps of the welding process and commands the SCR Controller/Driver as to the desired output level. Figure 3 illustrates the interrelation of these functions in block diagram form. Appendix D contains the detailed breadboard schematics.

Figure 3. Block Diagram of Electrical Circuits

The electrical components were connected together in an open, laboratory environment for initial testing of the circuits. This is a design technique called "breadboarding." From this effort, electrical and thermal information was gathered to finalize electrical component values and determine cooling requirements of the final package form. Finalized schematics of the welding power source system are provided in Appendix E.

PACKAGE DESIGN

Once the electrical design was finalized, the design of the total welding power source package was begun. The package design was developed with the following design requirements:

- 1) The package design must provide for the mounting and housing of electrical components in such a way as to protect them from environment conditions (such as dirt or moisture) found in an average weld fabrication shop.
- 2) The package design must provide for adequate cooling of those parts which generate waste heat.
- 3) The package design must provide protection of the user from electrical shock by preventing user contact of high voltage electrical components.
- 4) The package design must provide for easy assembly and service. Electrical components must be disconnectable and accessible for installation and replacement.
- 5) The package design must provide access and visibility of controls, meters, and indicators used for setting power source characteristics for the weld process to be performed.

Figure 4a through 4j provides a photographic series of the power supply unit identified as a Model PS-25. This series illustrates the package design requirements as incorporated into the Model PS-25.

Figure 4a. Front of the Model PS-25 power source showing meters, controls, and output terminals.

Figure 4b. Rear of the Model PS-25 power source showing input power cable, circuit breaker and fan outlet.

Figure 4c. PS-25 with top cover removed exposing the electronics used to control the power converter.

Figure 4d. PS-25 with top cover removed exposing the main output circuit rectifiers.

Figure 4e. Chassis Plate Assembly of the PS-25. Primary voltage changeover terminals (230VAC or 460VAC) are visible.

Figure 4f. Base Assembly of the PS-25 showing wiring of transformers and inductors. Circuit boards mount large power capacitors.

Figure 4g. Heat Sink Assembly of the PS-25 showing the method used to cool high power semiconductor devices which control the power source output level.

Figure 4h. Heat Sink fins dissipate heat into a forced air flow in order to cool power semiconductor devices.

Figure 4i. Central Printed Circuit Board Assembly of the PS-25. These circuits control the switching of the power semiconductor devices which in turn control the power source output level.

Figure 4j. Process Control Printed Circuit Board Assembly of the PS-25. These circuits control the characteristics of the power source output as required for various arc welding process applications.

COST ANALYSIS

A formal cost analysis of all electrical parts was performed in the development effort. The scope of the cost analysis effort was limited to that of electrical parts. While electrical parts cost can be projected into production quantities, labor and certain packaging parts cannot be readily projected [9, p6-2]. According to the estimate in the project's Topical Report [9], electrical parts constitute approximately 3/4 of the total material costs for a switch mode type welding power source. Also, the report estimates that labor costs for producing such a power source are significantly less than material costs. Therefore, a cost analysis of only electrical parts cost still provides useful information.

The cost analysis consisted of a detailed cost estimate of electrical parts. A production quantity of 1500 was assumed; costs are given in 1978 dollars. This cost estimate was compared against the cost goals established by the Topical Report [9 pE-1,2]. Appendix G contains the cost estimate of electrical parts of schematics of Appendix D. The results of the cost analysis are summarized in Table I. The results show that the electrical design conformed to the cost goals established in the Topical Report. These cost goals were established with a selling price of \$1600 list - 1978 dollars (see Appendix A, specification goals). As can be seen from Table I, the cost estimate was less than the cost goal. This result indicates that switch mode technology can be cost effective as well as energy efficient in welding power sources.

Description	Cost Goal (1978 \$)	Cost Estimate (1978 \$)
Power Circuit SK942	276.00	281.85
SCR Controller/Driver SK950	37.06	16.21
Process Control SK988	81.07	71.64
Total	394.13	369.70

Table I. Electrical parts cost compared to Cost Goals.

POWER SOURCE TEST RESULTS

Three forms of testing were performed on the model PS-25 welding power source: in-plant testing, field testing, and comparative testing. In-plant testing was performed in the Contractor's facility on the first PS-25 produced for the purpose of verifying efficiency and power factor goal achievement. Field testing was performed on two PS-25 units in San Diego area facilities of Rohr Industries and National Steel and Shipyard Company. The purpose of field tests was to obtain user reactions of the PS-25 power source in actual welding applications. Comparative testing was performed on one PS-25 to compare its efficiency and welding performance characteristics to two conventional power sources of equivalent capacity manufactured by a leading welding power source manufacturer. A total of four PS-25 power sources were constructed for testing purposes.

IN PLANT TESTING

The first PS-25 (SN 001) was constructed approximately 6 weeks in advance of three subsequent units. This unit was to serve as a prototype unit to be subjected to certain testing. In addition to preliminary testing of unit efficiency and power factor, form fit and function checks were performed prior to assembling the remaining three units. In-plant efficiency and power factor data were gathered under laboratory conditions using a simulated resistance load rather than an electric welding arc for a load. The simulated resistance load simplified the test set up for ease of operation and data acquisition. Efficiency tests under arc welding conditions were performed in the comparative testing sequence.

Appendix G contains the tabulated test data for in-plant testing. Selected efficiency data points are plotted in Figure 5 showing the relationship of efficiency as a function of output power level for various load resistances from .136 ohms to .300 ohms. The PS-25 exceeded its full load efficiency goal of 85% (see Appendix A) under these conditions. At a 9KW output level, the PS-25 was approximately 93% efficient (see Figure 5). The efficiency remained in the high eighty percent level or higher over two thirds of its operating range (from 3KW to 9KW). For comparative purposes, similar data was taken on a conventional power source; this data is also plotted in Figure 5. Over the full range of operation (0-9KW) the PS-25's efficiency exceeds that of the conventional unit by 5-15 percentage points.

Power factor data for this first PS-25 unit was also taken during in-plant testing. Appendix G contains the tabulated test data for power factor measurements. Data points are plotted in Figure 6 showing the relationship of power factor as a function of output voltage for two output settings on the PS-25. The PS-25 met its power factor goal of .98 (see Appendix A) for all the conditions measured. For comparative purposes, similar data was taken on a conventional power source; this data is also plotted in Figure 6. Over the range tested, the PS-25's power factor exceeded that of the conventional unit by a margin of approximately .2 to .4 on a scale of 1.0.

FIELD TESTING

Two PS-25 units (SN 003, SN 004) were placed in San Diego area facilities of Rohr Industries and National Steel and Shipbuilding Company. The purpose of these tests was to obtain field experience on the use and application of the PS-25 power source. Data resulting from these tests is not generally quantitative data, but instead, it is qualitative data in the form of user opinions of welding performance and usability. These field tests were conducted over a five month period from February 1980 through June 1980. A brief chronology of each installation's field test period is provided on page 20.

Figure 5. Operating Efficiency

Figure 6. Power Factor

Rohr Industries

January 22	Model PS-25 (SN 003) delivered to Rohr.
February 15	Model PS-25 modified to be compatible with existing Rohr Equipment.
March 6	Received report from Rohr that the power source was in daily use; Operators complained of audible noise emissions.
March 17	Received report from Rohr that the power source was malfunctioning.
March 24	Reported to Rohr our desire to upgrade the power source with changes indicated by comparative testing.
April 16	Serviced and upgraded power source, operator reported satisfied with repair and upgrade.
April 28	Received report from Rohr that the power source was again malfunctioning.
May 6	Attempted to service the power source, however, no malfunction could be identified. Operation continued.
June 16	Unit returned.
June 20	Letter report received from Rohr [10].

National Steel and Shipbuilding Company (NASSCO)

January 22	Model PS-25 (SN 004) delivered to NASSCO.
February 25	Received report from NASSCO that audible noise emitted from the power source was unacceptable. A 97 db noise level was reported. Test to be discontinued.
February 28	Follow-up call to observe NASSCO installation and audible noise problem. Agreed to discontinue tests until the noise problem could be addressed.
April 22-23	Upgraded power source with changes indicated by comparative testing. Replaced an audibly noisy component with an alternate component modified in an attempt to reduce audible noise. Replacement part was marginally better (noise levels subsequently reported from 85-95 db).
July 12	Letter report received from NASSCO [11].

Field testing identified three items concerning the PS-25 which required improvement in order to achieve operator acceptance. These items, which are indicated or implied in the preceding chronologies, are: an unacceptable audible noise level, sub par welding performance in certain processes, and malfunctions.

First, audible noise emission is probably the more serious of the three items. NASSCO states in their report that the PS-25 in its present condition is not usable mainly because of the noise emissions [11]. Both Rohr and NASSCO identified this problem through operator complaint. NASSCO undertook some noise measurements as indicated in the chronology. These noise measurements exceeded an industry recognized upper limit on audible noise of 85 db.

The Contractor was not unaware of the noise emission, however, the Contractor did not anticipate the operator reaction. Arc welding can be a noisy process which takes place in a noisy environment. However, the noise emission of the power supply is high pitched and somewhat foreign to the typical operator, therefore, it is easily noticed and questioned. Testing has identified the source of the noise emission as a single component in the power circuit. The noise, although it cannot be eliminated, can be reduced to industry accepted levels with some additional expense in component cost.

Second, sub par welding performance in certain processes was also identified by field testing. NASSCO reported that the PS-25 performed at acceptable standards for the SMAW process but not for GTAW or GMAW processes [11]. Rohr also reported sub-standard performance for GMAW processes [10]. (They did not test SMAW processes.) Comparative tests (see next subsection) also indicated that GMAW processes performed sub-standard while SMAW and FCAW processes were acceptable. In mid-April, 1980, PS-25 units were upgraded in the GMAW and GTAW process as indicated in the chronologies. Improvement was reported, however, performance levels were still sub par. The upgraded changes which consisted of process control reprogramming did demonstrate the ease with which welding characteristics can be changed on the PS-25. The Contractor estimates that given a sufficient research and development effort, all intended processes (SMAW, FCAW, GMAW, GTAW) can be made to perform to acceptable standards with such process control programming changes.

Third, malfunctions were reported by one of the field sites (Rohr) during field testing. Information in the area of malfunctions is conflicting. On one occasion Contractor personnel responded to a service need at Rohr and could not find a malfunction (May 6). It was later discovered that under certain conditions the power source programming locked into a "no output" condition thus the operator could not strike an arc whatsoever. Simply turning power to the unit off and then on again reset the program and corrected the condition. This problem could have caused the event of May 6 at Rohr. (This problem, once identified, was again easily corrected by process control reprogramming). Furthermore, no "hard" failures such as burned out components or switches or broken parts occurred at any time during field testing indicating soundness of hardware design and component selection.

COMPARATIVE TESTING

One PS-25 unit (SN 005) was subjected to comparison testing. Comparisons of energy efficiency and welding performance of the PS-25 to that of two conventional power sources under welding conditions were made. Two different types of conventional power sources were used for the comparison - a constant potential type, and a constant current type. These two types of conventional power sources were required to cover the range of intended applications for the PS-25; one single conventional type could not cover the full application range of the PS-25.

Energy efficiency data was taken for various output power levels for SMAW, GMAW, and FCAW processes. This data is tabulated in Appendix G. Table 2 provides a comparison of test results for the PS-25 and conventional power sources for power factor and efficiency data. Table 2 contains

Welding Application	Power Factor		Operating Efficiency %		Effective Efficiency %	
	PS-25	Conventional	PS-25	Conventional	PS-25	Conventional
SMAW E6011 1/8 DIA	1.0	.51*	93.3	69.9*	87.4	41.4*
SMAW E6011 3/16 DIA	.999	.58*	94.7	72.9*	90.2	52.6*
SMAW E7018 1/8 DIA	.997	.50*	90.7	72.5*	85.0	45.8*
SMAW E1018 5/32 DIA	.999	.54*	91.0	73.8*	87.0	51.9*
SMAW E6013 3/16 DIA	.999	.56*	93.9	73.9*	90.4	55.3*
SMAW E7028 e/16 DIA	.999	.62*	93.7	77.5*	91.3	61.3*
GMAW E705-6 .035 DIA	.998	.83**	90.2	80.2**	82.9	60.3**
GMAW E705-6 .035 DIA	.999	.82**	88.6	78.7**	83.1	63.2**
GMAW E705-6 .045 DIA	.999	.82**	93.5	85.8**	88.0	69.5**
GMAW E705-6 .045 DIA	.999	.82**	87.6	82.7**	83.7	70.1**
FCAW E70T-1 .052 DIA	.999	.82**	84.0	80.9**	80.7	68.1**
FCAW E70T-1 .052 DIA	.999	.82**	87.3	83.8**	84.7	74.2**

*Constant Current Type Conventional Power Source

**Constant Potential Type Conventional Power Source

Table 2
Comparison of Efficiency & Power Factor Data
for the PS-25 and Conventional Power Sources

two efficiency columns; one is operating efficiency, the other is effective efficiency. Operating efficiency is the efficiency of the power source as measured during the arc welding process. Effective efficiency is the efficiency of the power source for a given period of time of normal operation such as an eight hour work shift. During a normal eight hour shift, the welding power source is turned on for the full eight hours but typically is welding only 20% of that time. During the "idle" on time the power source dissipates energy in the form of idle power consumption. Effective efficiency therefore considers the ratio of total energy consumed by a power source, including idle power, to the energy delivered by the power source to be consumed by the welding arc. Idle power measurements are compared in Table 3. Effective efficiency shown in Table 2 includes the effect of idle power consumptions shown in Table 3 assuming a 20% weld time factor. As shown in Table 2 the PS-25 compares significantly better than the conventional power sources in power factor, operating efficiency, and effective efficiency for the weld applications measured. Effective efficiency ranges from about a 10 to 46 percentage point improvement in effective efficiency.

Power Source	Idle Power Consumption
PS-25	60 Watts
Conventional Constant Current	685 Watts
Conventional Constant Voltage	255 Watts

Table 3

Idle Power Consumptions

Weld performance comparisons cannot be made on a quantitative basis. However, comparisons were made and operator opinions were solicited for GMAW, SMAW, and FCAW processes. Victor California, a welding equipment distributor with expertise in welding processes and power sources, participated in comparative welding performance testing which took place in their facility in Berkeley, California. Their conclusions essentially substantiate those arrived at as a result of field tests. GMAW process performance was found to be sub par. FCAW and SMAW process performance was acceptable compared to conventional power sources and certain features of the PS-25 SMAW process performance were found highly desirable. Appendix G includes a copy of Victor California's letter report on comparative performance testing.

To further aid comparison between the PS-25 and conventional power sources, Table 4 lists other data for comparison purposes. The PS-25 is smaller and lighter for essentially the same rating. The PS-25 is applicable to the same range of process application as that of both conventional units combined; yet the PS-25 is comparable in price to each individual type of conventional power source.

		Conventional Constant Current	Conventional Constant Potential	PS-25
Rating	Output ..	300 amps @ 60% DC	250 amps @ 100% DC	250 amps @ 100% P.C.
	Input ...	230/460 VAC 3 ϕ @ 60/30 amps	208/230/460 VAC 3 ϕ @ 33/30/15 amps	230/460 VAC 3 ϕ @ 23/11.5 amps
Processes:	SMAW ..	Yes	No	Yes
	GMAW ..	No	Yes	Yes
	FCAW ..	No	Yes	Yes
	GTAW ..	Limited*	No	Limited*
Weight		639 lb.	415 lb.	140 lb.
Dimensions		30" x 22" x 36"	31" x 22" x 36"	17" x 17" x 24"
Instrumentation/ Controls		Amperage control	Meters, Open Circuit Voltage control	Meters, Weld level control Penetration control
Price		\$1031 list (San Diego)	\$1020 list (San Diego)	Not available but estimated \$1100-1400

* Scratch start only

Table 4
Comparison of Other Data

CONCLUSIONS

Opportunities for energy conservation in electric arc welding processes exist. In 1978 it is estimated that 15.2 trillion BTU is lost in primary energy conversion and welding power source electrical power conversion. By increasing average welding power source conversion efficiency from 60% to 80%, 3.5 trillion BTU could be saved.

This project designed and developed a welding power source (Model PS-25) according to a set of goals which included not only energy efficiency goals but also cost, weight, and performance goals. These goals are considered important in order to achieve widespread use of such an energy efficient power source and thereby take advantage of the conservation opportunities.

Several prototype power sources were constructed and subjected to in-plant, field, and comparative tests. Tests indicated that the conventional power source tested achieved effective efficiencies under actual welding conditions ranging from 41% to 74% depending on the process. The PS-25 power source under the same conditions achieved effective efficiencies ranging from 80% to 91%. The PS-25 power source achieved these high effective efficiencies due to its low idle power consumption of 60 watts compared to the conventional power sources tested with idle power consumptions of 685 watts and 225 watts. The 3.5 trillion BTU potential savings of 1978 based on average efficiency improvement from 60% to 80% appears to be a conservative estimate based on test results. While this conservation potential exists, it should be noted that it may require several decades to achieve since conventional power sources would be gradually replaced by energy efficient ones as conventional power sources wear out.

Test results also demonstrated that the PS-25 power source achieved a power factor of .987 to .988 while the conventional power sources tested achieved power factors ranging from .59 to .81. In this measure also, the PS-25 was significantly superior to the conventional power sources tested. Cost analyses, weight reductions over conventional units, and a measure of success in welding performance also indicated the commercial viability of the PS-25 energy efficient welding power source.

Test results also showed that energy efficient power sources using the same technology as that of the PS-25 power source would benefit from additional research and development. Such efforts should be directed toward the reduction of audible noise emissions identified by field testing and toward weld process performance improvements in those processes where power source performance was lacking (GTAW, GMAW).

Overall results of this development project demonstrated not only energy saving potential in electric arc welding but also a new welding power source technology that is more efficient than existing technology and is commercially viable. Efficiency and commercial viability were demonstrated by the design, construction, and testing of several prototype power sources.

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APPENDIX A

PROPOSAL SPECIFICATION GOALS

Output

Amperage	300 amps
Duty Cycle	60%
Open Circuit Voltage	65 Volts

Input

Either or	460V 3 ϕ 60Hz
Both of	230V 3 ϕ 60Hz

Power Factor

(At full rating)	.98
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Real Power Efficiency

85%

Size

15 ft.³

Weight

Less than 200 lbs.

Cooling

Air cooled (fan)

Processes

G.M.A.W., S.M.A.W., G.T.A.W.
or effective combinations

Controls

Output voltage (G.M.A.W.)
Output current (G.T.A.W./S.M.A.W.)
Slope
Inductance
Process selection
Polarity

Price

\$1,600 in quantity production

MODEL PS-25 SPECIFICATIONS

Output Rating (NEMA Class I)	Lo Range	Hi Range
Welding Amps DC	150	250
Welding Volts DC	26	30
Duty Cycle	100%	100%
Welding Voltage and Current Range		
Stick/TIG* Mode Min/Max	15A/175A @ 27V	30A/312A @ 32V
MIG Short Arc Mode Max	—	32V @ 312A
MIG Pulsed Spray Mode Min/Max	—	15V/40V @ 250A
Input Rating		
Line Voltage	230V/460V 60Hz	
Phase	3	
Line Amps @ Rated Load	23A/11.5A	
Power Factor @ Rated Load	.955 minimum	
Eff. @ Rated Load	85% minimum	
Auxiliary Power Capacity	.36 KVA	
Fuse Size	30A/20A	
Power Input Wiring Gauge	#12/#14	
Weight		
Net	140 lbs.	
Shipping	200 lbs.	
Dimensions		
Height	16.5 in.	
Width	17.0 in.	
Depth	24.0 in.	
Required Floor Space	2.5 ft. x 2.0 ft.	

*Requires an external hi-frequency starter for GTAW unless "scratch start" technique is used.

APPENDIX B

APPROACHES TO SWITCH MODE TECHNIQUES

INTRODUCTION

Power circuit architecture and the type of switch devices are the most important areas of consideration to correct application of switch mode techniques. The approach in these areas will effect the total design down to the least detail. This Appendix lists the schematics of the various approaches which fall under one of three categories; pre-regulation, post regulation, and integral converter-regulator operation. Nine circuits are listed in Figure B2 b thru j. Each one shown is capable of 230/460 volt operation by a split primary. Figure B1 shows a rough matrix comparison of the circuits. This comparison matrix was developed through expert analysis and consultation.

SWITCH DEVICES, BJT OR SCR

Tied closely to the selection of the power circuit is the type of switching devices to be used. The type of device used will effect the power circuit as indicated in the first two columns of Figure B1 and in the switch configurations in Figure B2. The alternative switch devices are Bipolar Junction Transistors (BJT) or Silicon Controlled Rectifiers (SCR). BJTs are lower current devices with the bulk of the ratings in the 10 & 20 amp, 375 to 400 volt range. The amperage requirements for the full bridge circuit switch devices, Figure B2-b, would be around 32 amps. Voltage stress would be 356V maximum. In order to achieve these stress capabilities, 2 or 3 BJTs would have to be paralleled which can become complicated and potentially unreliable because of unequal current sharing; also, little surge capability is available. SCRs on the other hand are readily available in currents up to 1200 amps and voltages up to 1200 volts; therefore, a single device could be selected. BJTs are recently becoming available in the 50, 70, 120 amp range, however, they are quite expensive.

The main disadvantage of the SCR is that it is not easily turned off like the BJT. It must be commutated off and therefore auxillary circuits must be used to commutate the SCR device off. In almost all the circuits compared in Figure B1, the SCR approach takes twice as many devices as would BJTs of equal current carrying capability. This increased component count is offset by increased ruggedness since SCRs can handle much higher surges than BJTs. Also, in higher current ranges, SCRs are less costly than BJTs.

SWITCH DEVICE COST

Generally speaking, a device voltage capability increase from 400 to 800 volts is more expensive than a current increase from 32 amps to 64 amps. This is especially true in SCRs where current ratings are flexible depending on other parameters such as temperature and frequency of operation. Table B1 provides an example of one manufacturer's 1974 SCR price list.

MFGR.	PART	DESCRIPTION	10 PC. PRICE	NORMALIZED
I. R.	81RM40	SCR 80 AMP 400 V	\$39.96	1
I. R.	81RM80	SCR 80 AMP 800 V	\$76.63	1.92
I. R.	151RF40	SCR 150 AMP 400 V	\$57.23	1.43

TABLE B1 - Example of Voltage/Current Ratings on Price

		Number of Switch Devices SCR	Number of Switch Devices BJT	*Voltage Stress	*Current Stress	Switching/ Commutation Losses	Efficiency Potential	Ease of Obtaining Rated Current	Inherent Reliability	Potential Welding Performance	Ease of Control	Filter/Passive Component Cost
	Full Bridge (TRC Primary)	16	3	1.0	1.0	High	88%	Good	Good	Good	Medium	Medium
	Half Bridge (TRC Primary)	8	4	1.0	2.0	High	85%	Poor to Medium	Medium	Good	Good	Medium
	Centertap (TRC Primary)	8	4	2.0	1.0	High	88%	Poor to Medium	Medium to Good	Medium	Medium	Medium
	Full Bridge (PWM Secondary)	16	8	1.0	1.0	Medium	84%	Good	Good	Good	Poor	Medium
	Half Bridge (PWM Secondary)	8	4	1.0	2.0	Medium	82%	Medium	Medium to Good	Good	Good	Medium
	Centertap (PWM Secondary)	8	4	2.0	1.0	Medium	84%	Medium	Medium to Good	Medium	Medium	Medium
	Forward Converter (Push-Pull)	4	2	2.0	2.0	Medium	87%	Poor to Medium	Poor to Medium	Medium	Medium to Good	Low
	Centertap (TRC Pre Regulator)	8		2.0	1.0	Low	90%	Poor	Poor	Poor to Medium	Medium	High
	Series Resonant Current Source	4	4	1.0	3.14	Low	92%	Good	Good	Medium to Good	Medium	Medium to High

* Full bridge current & voltage stress normalized

As can be seen from the normalized price column of Table B1, for an SCR it costs roughly double to double voltage capability; however it costs roughly only half again to double current capability.

Table B2 provides a rough sampling of both BJT and SCR devices and their respective costs (in 100 pc. quantities, 1978 pricing). At the expected power levels and frequencies, BJTs might be more competitive only in the full bridge circuit configuration, but generally, BJTs are more costly. In addition, higher capacity power sources could easily be scaled up from the developed supply if it were an SCR type with only moderate increases in cost. The selection of SCRs as a device type then would not only be potentially more economical for the supply developed in this project but also enhance the marketability of the technology by enhancing expandability of the eventual product line with higher amperage capacity units.

MFR.	PART	DESCRIPTION	PRICE (1978 DOLLARS)	
			1 pc.	100 pcs.
G. E.	C149D20	SCR 63 AMP 400V	31.00	18.75
WEST.	T507044064AA	SCR 63 AMP 400V	41.25	20.50
FMC	07904HRA	SCR 80 AMP 400V	48.85	22.00
FMC	03904HRA	SCR 63 AMP 400V	33.70	15.10
G. E.	C49D20	SCR 110 AMP 400V	47.20	21.20
WEST.	T507047064AA	SCR 110 AMP 400V	43.50	21.50
I. R.	81RM40	SCR 125 AMP 400V	49.23	25.08
I. R.	IR6062	BJT 20 AMP 450V	8.00	6.20
G. E.	GE6062	BJT 20 AMP 450V	8.00	6.20
SOLITRON	SDT55464	BJT 30 AMP 400V	98.00	88.00
POWER TECH	PT3526	BJT 40 AMP 600V	260.75	149.00
POWER TECH	PT3513	BJT 70 AMP 400V	216.10	112.50
POWER TECH	PT3523	BJT 90 AMP 400V	227.75	129.00
POWER TECH	PT4503	BJT 110 AMP 400V	267.00	154.00
WEST.	D60T406010	BJT 100 AMP 450V	285.00	---

Table B2. Selected SCR/BJT Pricing (1978)

POWER CIRCUIT ARCHITECTURE

After understanding the pricing behavior in switch devices, the matrix comparison of the nine circuits, Figure B1, takes on more meaning especially the first four columns. Using the IR6062 price (1978) as a base price for BJT switches and the C149D20 price (1978) as a base price for SCR switches, the prices for the switch devices of various capacity can be compared. The results are tabulated in Table B3. It should be cautioned that these prices are projections based on device capacity. As an example, an SCR with a normalized voltage and current stress of 1 is listed as \$13.12. A specific part may not be available at that exact price, however, the approximate price is useful to compare costs of the semiconductors of the various power circuits.

Table B4 summarizes switch device costs for each circuit architecture. It also lists additional passive component costs required by the circuit architecture above that of the first circuit listed,

	Cur. Stress	Volt Stress	Calculation	Price Per Device (1978 Dollar)
BJTs	1.0	1.0	3 x Base (IR6062)	= 25.05
	2.0	1.0	2 x 25.05	= 50.10
	1.0	2.0	1.92 x 25.05	= 48.10
	2.0	2.0	1.92 x 50.10	= 96.20
	3.14	1.0	3.14 x 25.05	= 78.66
SCRs	1.0	1.0	18.75 ÷ 1.43	= 13.12
	2.0	1.0	Base (C149020)	= 18.75
	1.0	2.0	13.12 x 1.92	= 25.20
	2.0	2.0	18.75 x 1.92	= 36.00
	3.14	1.0	13.12 x 1.80*	= 23.67

*1.80 factor is calculated based on 3.14 current stress

Table D3. Switch Device Price Estimates

the full bridge (TRC Primary). The costs in Table B4 can now be compared to other circuit attributes listed in the matrix, Figure B1.

The full bridge, both primary and secondary controlled, offers good performance in other areas, and 88% and 84% potential efficiency, however; it is also the most expensive due to the numbers of components. The half bridge has half the components as the full bridge and, therefore, when implemented with SCRs is less costly (because doubling current stress does not double cost). The secondary controlled version of the half bridge has better performance, but at the sake of higher cost (with additional required parts) and lower efficiency. The center tap schemes (both TRC primary and PWM secondary controlled) are generally more expensive and not good performers. The Forward Converter offers minimum parts count and is fairly economical with good efficiency; however, other performance areas are only poor to medium. The pre-regulated center-tap circuit offers a very good efficiency, however, it is high in cost and draws poor ratings mainly due to its short circuit susceptibility.

The series resonant current source, however, is a newcomer to switch mode technology with practical circuits reported on in 1975 and 1976 [8]. Cost is minimal with good performance ratings and 92% efficiency potential. Efficiency is achieved by minimizing switching losses through resonant zero crossover switching. Attainment of rated current and reliability is enhanced by the fact that the SCRs are self commutated in *series* with the load. Auxilliary circuits are not needed to commute switch devices in this architecture, thus parts count is kept down. Plus all commutation current flows *through* the load instead of *in addition* to load current as in the other SCR schemes.

OPTIMAL CIRCUIT AND DEVICE SELECTION

In terms of the general characteristics weighted according to equation (2) in the text of the report, the rankings shown in Table B5 can be made for the various circuits. These rankings consider only efficiency and cost. Cost (Table B4) was normalized to \$200; efficiency (Figure B1) was normalized to 1.0. The three best circuits are the Series Resonant Current Source, the Forward Converter (push-pull) and the Half Bridge (TRC Primary) respectively. Since the Series Resonant Current Source has good ratings in other areas it stands out as the best circuit when implemented with SCR switches.

Circuit Architecture	SCR Cost (1978 Dollars)	BJT Cost (1978 Dollars)	Additional (1978 Dollars)
Full Bridge (TRC Primary)	209.92	200.40	Primary CAP 20.00
Half Bridge (TRC Primary)	150.00	200.40	
Center Tap (TRC Primary)	201.60	192.40	
Full Bridge (PWM Secondary)	209.92	200.40	Secondary SCR 27.50
Half Bridge (PWM Secondary)	150.00	200.40	SCR 27.60 CAP 20.00
Center Tap (PWM Secondary)	201.60	192.40	Secondary SCR 27.50
Forward Converter (Push-pull)	144.00	192.40	Secondary CAP 50.00
Center Tap	201.60	--	
(TRC-PRE REGULATOR)			
Series Resonant	94.68	314.64	Secondary CAP 50.00
Current Source			

Table B4

Estimated Costs for Each Circuit Architecture

Circuit Architecture	Rating*	Rank
Series Resonant Current Source	.7367	1
Forward Converter (push-pull)	.7211	2
Half Bridge (TRC Primary)	.6504	3
Center Tap (TRC Primary)	.6056	4
Full Bridge (TRC Primary)	.5938	5
Half Bridge (PWM Secondary)	.5908	6
Center Tap (PWM Secondary)	.5559	7
Center Tap (TRC - Pre-regulator)	.5535	8
Full Bridge (PWM Secondary)	.5467	9

$$* \text{Rating} = .35 (\text{Efficiency}) + .30 \left(\frac{200}{\text{Cost}} \right)$$

Table B5. Circuit Rankings Based on Design Criteria

D.C. PRE-REGULATOR / CHOPPER

D. C. POST-REGULATOR / CHOPPER

TIME RATIO CONTROL / MODULATED CONVERTER:

Figure B2a

Figure B2b

Figure B2c

Figure B2d

Figure B2e

Figure B2f

Figure B2g.

Figure B2h

Figure B2i

Figure B2j

APPENDIX C

Background Patents

[54] FREQUENCY CONVERTER

[75] Inventor: John B. G. Hedberg, Göteborg,
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[73] Assignee: AB SVETSIA, Askim, Sweden

[21] Appl. No.: 795,502

[22] Filed: May 10, 1977

[30] Foreign Application Priority Data

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[51] Int. Cl.² H02M 5/45

[52] U.S. Cl. 363/160; 363/27;
363/58; 363/136

[58] Field of Search 363/27, 28, 55-58,
363/96, 135, 136, 159, 160, 169; 219/130.1

[56]

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Primary Examiner—William M. Shoop
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[57]

ABSTRACT

A frequency converter of the series-capacitor type is made substantially insensitive to changes in output load by providing the same with means for limiting the voltage across the transformer and load capacitor or capacitors thereof to a pre-determined value.

13 Claims, 11 Drawing Figures

Fig. 3

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

FREQUENCY CONVERTER

The present invention relates to a frequency converter of the series-capacitor type with small internal damping and with thyristors as switching elements.

One advantage afforded by such frequency converters is that they are of extremely simple construction, are relatively light in weight, are cheap to manufacture and are capable of dealing with high powers. One disadvantage, however, is that such frequency converters are sensitive to changes in load; in particular problems arise when the output current is low and/or the output voltage is high. This renders such a frequency converter unsuitable as a source of welding current, for example, since variations in load are often experienced in electric welding operations. Because of this it has been necessary, when using a frequency converter as a source of welding current, to design the converter so that it has high internal losses which in itself dampens the excess voltages which could otherwise occur with the small internal damping in the frequency converter when the load thereon is low. The efficiency of a frequency converter thus designed, however, is very poor. Alternatively, the transformer of the frequency converter can be designed to deal with low loads without becoming saturated, which increases manufacture costs and the weight of the transformer, however.

An object of the present invention is to provide an improved frequency converter of the type mentioned in the introduction having but small weight and high efficiency and being substantially insensitive to changes in load.

Accordingly, this invention consists in a frequency converter of the series-capacitor type having small internal damping and comprising switching elements in the form of thyristors, said converter further comprising a transformer having a primary winding and at least one secondary winding, said primary winding being connected in series to at least one load capacitor, and voltage limiting means effective to limit the voltage across the transformer and said at least one load capacitor to a predetermined voltage value.

Preferably in a frequency converter according to the invention the voltage limiting means comprises circuits connected between the common point of the capacitor circuit and the primary winding of the transformer or between a point on the primary winding of the transformer and a respective one of the input lines of the supply voltage, which circuits become conductive at a voltage which is equal to the difference between said predetermined voltage value and the supply voltage. Further the said circuits preferably comprise at least one zener diode or varistor. Alternatively the voltage limiting means comprises a circuit connected in parallel with the primary winding of the transformer which circuit becomes conductive at said predetermined voltage value. In this case said circuit preferably comprises two zener diodes connected in series opposition or a varistor.

Conveniently, the voltage limiting means comprises a circuit connected in parallel with at least part of the primary winding of the transformer, and means for making said circuit conductive at said predetermined voltage value. Preferably said means for making the circuit conductive comprises two zener diodes connected in series opposition or a varistor in said circuit.

In accordance with a further embodiment the voltage means comprises an additional secondary winding having a number of turns which is equal to or less than the number of turns of the primary winding, and wherein the end terminals of the additional secondary winding are connected via a rectifying bridge to a respective one of the input lines of the supply voltage.

So that the invention will be more readily understood and optional features thereof made apparent, a number of exemplary embodiments thereof will be described with reference to the accompanying schematic drawings, in which:

FIG. 1 is a circuit diagram of a frequency converter including voltage-limiting means according to the invention;

FIG. 2 is a circuit diagram of a control circuit intended for use in conjunction with the frequency converter of FIG. 1;

FIGS. 3 and 4 show voltage and current curves which would occur in the frequency converter during normal operation and operation at low loads if no voltage limiting means were provided;

FIG. 5 shows corresponding voltage and current curves occurring with a frequency converter according to FIGS. 1 and 2 operating at low load and being provided with a voltage limiting means according to FIG. 1 or FIG. 7;

FIG. 6 shows corresponding voltage and current curves occurring with a frequency converter according to FIGS. 1 and 2 subjected to a low load and provided with a voltage limiting means according to FIGS. 8 and 9;

FIGS. 7-10 show modifications of the voltage limiting means according to FIG. 1; and

FIG. 11 shows corresponding voltage and current curves occurring with a frequency converter according to FIGS. 1 and 2 subjected to a low load and provided with a voltage limiting means according to FIG. 10.

The frequency converter shown in FIG. 1 is connected at 10 to a three-phase alternating current mains supply. The input current is rectified in a six-element full-wave rectifier 11, the rectified output voltage on the lines 12, 13 being smoothed by a buffer capacitor 14, the converter having a low input impedance as a consequence of the shown arrangement of elements 11 to 14.

The switching elements of the frequency converter are thyristors 15, 16, which are controlled so as to be conductive alternately. The transformer of the frequency converter is generally shown at 17. The transformer has a primary winding 18 connected in series with load capacitors 19, 20, and a secondary winding 21 connected to terminals 24, 25 via a rectifier bridge 22 and a choke 23. The two terminals of a load, such as a welding electrode holder and a workpiece to be welded can be connected between the terminals 24, 25. In the embodiment of FIG. 1, there is connected between the terminals 24, 25 a capacitor 26 which, when the frequency converter is used as a source of welding current, can be used for maintaining a desired open-circuit voltage. A shunt 27 is provided for measuring the load current, the output voltage across the shunt being used to control the frequency converter, as hereinafter described with reference to FIG. 2.

In the control circuit shown in FIG. 2, one terminal of the shunt 27 is connected to earth and the other terminal is connected to an amplifier 30 which amplifies the signal of the shunt 27 from a millivolt level to a volt level. The amplifier 30 is connected, via comparison

resistors 31, to a current adjusting device 32 in the form of a potentiometer, and to an amplifier 33 which serves as a level discriminator. The current adjusting device 32 serves to set the desired output current from the frequency converter. For setting the desired maximum output voltage from the frequency converter, there is provided a voltage adjusting device 35 in the form of a potentiometer which is connected, via comparison resistors 36, to the terminal 25 of the frequency converter and to an amplifier 37 which serves as a level discriminator. For controlling the states of the thyristors 15, 16 there is provided a sensing circuit comprising a transformer 38 whose primary is connected via diodes 39, 40 to the anodes A_1 , A_2 and the cathodes K_1 , K_2 of the thyristors 15, 16. One end of the secondary winding of the transformer 38 is earthed and the other is connected to a comparison circuit comprising two resistors 41, 42, the resistor 42 having one end connected to a constant negative voltage. The junction between resistors 41, 42 is connected to an amplifier 43 which serves as a level discriminator and the change-over point of which is determined by the resistors 41, 42 and said constant negative voltage. Each of the amplifiers 33, 37 and 43 is connected to a respective one of the inputs 45, 46, 47 of an AND gate 48 which operates in a known manner. Thus, the AND gate 48 can only provide an output signal when the output signal from the amplifier 33 is positive, i.e. when the load current measured by the shunt 27 is less than the value for which the adjusting device 32 is set. Correspondingly, it is necessary for the output signal from the amplifier 37 to be positive, i.e. for the load voltage on the terminal 25 to be less than the value set on the adjusting device 35. Finally, the output signal from the amplifier 43 must be positive, which means that the anode voltage of one of the thyristors 15 or 16 is negative in relation to its cathode, which in turn means that both thyristors 15 and 16 are de-energized.

The output of the AND gate 48 is connected to the input of a monostable flip-flop 50 which has a pre-determined pulse period corresponding to the recovery time of the thyristors 15, 16, for example 30 μ s. Thus, on the output Q of the flip-flop 50 there is obtained a positive voltage pulse for a period of time corresponding to the recovery time of the thyristors 15, 16. The pulse is applied to the trigger input T of a JK flip-flop 51, so that the JK flip-flop 51 changes the states of its outputs at the end of the pulse from the flip-flop 50. The outputs Q , $\bar{Q}$ of the JK flip-flop 51 are connected to the base electrodes of respective transistors 54, 55 via capacitors 52, 53. The emitters of the transistors 54, 55 are connected to earth while their collectors are connected to the primary winding of respective ignition transformers 56, 57 for the thyristors 15, 16. The other ends of the primary windings are connected to a terminal having a pre-determined positive potential. The signals from the outputs of the JK flip-flop 51 will alternately render the transistors 54, 55 conductive via the capacitors 52, 53, for a short period of time determined by the capacitors 52, 53, so that the thyristors 15, 16 alternately receive a short ignition pulse and thereby alternately supply current to the primary winding 18 of the transformer 17 to produce an alternating current whose frequency is determined by the input signals on the inputs 45, 46, 47 of the AND gate 48.

FIG. 3 shows the voltage U_{60} , U_{61} at points 60, 61 and the voltage U_{18} across the primary winding 18 of the transformer 17 with normal load on the output of the frequency converter shown in FIGS. 1 and 2. FIG. 3

also shows the output current I_{25} through the terminal 25 and the output currents I_{15} and I_{16} (the latter shown in dashed lines) from the thyristors. In FIG. 3 the reference t_1 indicates the point of time when the thyristor 15 is ignited, t_2 the point of time when the thyristor 15 is deenergised and obtains a voltage between its anode A_1 and cathode K_1 as a result of the resonant circuit formed by the primary winding 18 of the transformer 17 and the capacitors 19, 20; t_3 the point of time when the thyristor 16 is ignited; and t_4 is the point of time when the thyristor 16 is de-energised and its anode becomes negative as a result of said resonant circuit 18, 19, 20. The reference t_5 shows the point of time at which the thyristor 15 is re-ignited, whereupon the sequence is repeated provided that the load remains substantially unchanged.

FIG. 4 illustrates corresponding voltage and current curves, when the output current from the frequency converter is low and/or the output voltage high. Thus, it will be seen that, when the output current is low, a relatively long period of time is required to recharge the load capacitors 20, 19. This results in saturation of the transformer 17 with current surges therein as a result thereof. This is shown by the peaks at the trailing edges of the wave-forms showing the thyristors currents I_{15} , I_{16} . Such saturation always causes overshooting in the transformer voltage U_{18} with a resulting high voltage U_{61} across the capacitors 19, 20. Owing to the fact that the output voltage on the capacitors 19, 20 with the next following pulse (at t_3) is high, the next overshooting in the transformer voltage will be further increased, whereby an avalanche effect is obtained for the voltages U_{60} , U_{61} and U_{18} , resulting in the failure of a component of the frequency converter as a result of excessive voltage. It will therefore be understood that the frequency converter so far described is unable to deal with low currents and/or high voltages on the output thereof. The frequency converter can therefore not operate in the absence of a load when it is being used, for example, as a source of welding current.

To overcome these disadvantages, the frequency converter is provided with means for limiting the voltage across the primary winding of the transformer 17 and the load capacitors 19, 20 to a predetermined value above the voltage on the input lines 12, 13. In FIG. 1 this voltage-limiting means is shown to comprise two circuits, which include respectively zener diodes 62 and 63, current-limiting protective resistors 64 and 65, and diodes 66 and 67, the diodes 66, 67 blocking current in the forward direction of the zener diodes. The blocking voltage of the zener diodes 62, 63 is selected so as to be somewhat lower than the highest voltage by which the voltage U_{61} at point 61 may exceed the supply voltage on the lines 12, 13. Thus, when the voltage at point 61 exceeds the voltage on line 12 or falls short of the voltage on line 13 by an amount corresponding to the blocking voltage of the zener diodes 62, 63, current can flow through the circuit 64, 62, 66 from the point 61 to the line 12 and with opposite polarity at point 61 flow through the circuit 65, 63, 67 to the line 13. As indicated in dash lines in FIG. 1 the zener diodes 62, 63 may be replaced by varistors 68, 69. FIG. 7 illustrates an alternative embodiment of the voltage-limiting circuit included in FIG. 1. With this modification, the resistors 64, 65 are replaced by single resistor 70. Further the zener diodes 62, 63 are connected in series-opposition, while the diodes 66, 67 are arranged in the manner described with reference to FIG. 1. Further, as indicated in dashed lines, the zener diodes 62, 63 may be

replaced by a single varistor 71. As indicated by dashed line 72 in FIGS. 1, 7 and 10, the voltage-limiting circuits may alternatively be connected to a tapping of the primary winding 18 of the transformer 17.

When using any one of the protective circuits illustrated in FIGS. 1 and 7, the voltage and current wave forms shown in FIG. 5 are obtained with a low load, i.e. a low output current and/or high output voltage on the output terminals 24, 25 of the frequency converter. As shown in FIG. 5, the voltage U_{61} occurring at point 61 does not avalanche, but is substantially restricted to a single value which exceeds the voltage lying on the line 12 or 13 by an amount which corresponds to the blocking voltage U_z of the zener diodes 62, 63, with the exception of a relatively low voltage peak of short duration which originates from the voltage drop across the associated protective resistor 64, 65 or 70. It will thus be understood that the current and voltage pulses will not change with time in the avalanche manner shown in FIG. 4.

FIG. 8 shows a further modification of the protective circuit. In the FIG. 8 embodiment the protective circuit is connected solely across the primary winding 18 of the transformer 17. In a manner corresponding to that indicated in dashed lines 72 in FIGS. 1 and 7, the protective circuit shown in FIG. 8 may alternatively be connected across only part of the primary winding 18. The circuit shown in FIG. 8 includes a current-limiting resistor 73 and two zener diodes 62, 63 connected in series-opposition. As indicated by dashed lines, the zener diodes may be replaced by a varistor 71. The blocking voltage of the zener diodes or the varistor may be selected taking into account the highest voltage which should be permitted to occur across the primary winding 18. By means of this arrangement avalanche-like voltage and current surges are avoided with low output currents and/or high outputs voltages on the output terminals 24, 25 of the frequency converter, since, each time the thyristors 15, 16 are ignited the capacitors 19, 20 are rapidly discharged down to the blocking voltage of the zener diodes 62, 63 or the varistor 71 immediately the voltage across the primary winding exceeds said blocking voltage. In this way voltage and current wave forms such as those shown in FIG. 6 are obtained, in which U_z' is equal to the blocking voltage of the zener diodes 62, 63 or the varistor 71.

In the modification shown in FIG. 9, the protective circuit is connected to the end terminals of an additional secondary winding 74 of the transformer 17, the number of turns of the additional winding being equal to or somewhat lower, e.g. 0-30%, than the number of turns of the primary winding 18. The ends of the winding 74 are connected via a rectifier bridge 75-78 and a current limiting resistor 79 to a respective one of the input lines 12, 13. By means of this arrangement, avalanche-like voltage and current surges are avoided with low output currents and/or high output voltages on the output terminals 24, 25 of the frequency converter, since each time the thyristors 15, 16 are ignited, the winding 74 at excessive voltage at point 61 limits the transformer voltages by substantially loss-free backfeeding of current to the lines 12, 13. In this way voltage and current wave forms such as those shown in FIG. 6 are obtained, in which U_z' is equal to the voltage difference between lines 12, 13 multiplied by the ratio between the number of turns of the primary winding 17 and the number of turns of the additional secondary winding 74. The relatively low voltage peak of short duration above U_z'

originates from the voltage drop across the protective resistor 79.

The voltage limiting means according to FIG. 10 comprises two circuits, each including a diode 66 or 67 and a thyristor 80 or 81. The circuits further comprise a common current limiting resistor 82. Each thyristor 80 or 81 is associated with an ignition circuit comprising a current limiting resistor 83 or 84 and a zener diode 85 or 86. The zener diodes 85, 86 may be replaced by varistors. The blocking voltage U_z'' of the zener diodes 85, 86 is selected so as to be somewhat lower than the highest voltage by which the voltage U_{61} at point 61 may exceed the supply voltage on the lines 12, 13. Thus, when the voltage at point 61 exceeds the voltage on line 12 or falls short of the voltage on line 13 by an amount corresponding to the blocking voltage of the zener diodes 85, 86, the thyristor 80 or 81 is ignited so that current can flow from the point 61 through the circuit 82, 80, 66 to line 12 and with opposite polarity at point 61 can flow through the circuit 82, 81, 67 to line 13.

When using the protective circuits illustrated in FIG. 10, the voltage and current wave forms shown in FIG. 11 are obtained with a low load, i.e. a low output current and/or high output voltage on the output terminals 24, 25 of the frequency converter. As shown in FIG. 11, the voltage U_{61} occurring at point 61 does not avalanche, but is substantially restricted to a value which exceeds the voltage on line 12 or 13 by an amount which corresponds to the blocking voltage U_z'' of the zener diodes 85, 86, with the exception of a relatively low voltage peak of short duration which originates from the voltage drop across the associated protective resistor 82. It will thus be understood, that the current and voltage pulses will not change with time in the avalanche manner shown in FIG. 4.

What we claim is:

1. A frequency converter of the series-capacitor type having small internal damping and comprising switching elements in the form of thyristors, said converter further comprising a transformer having a primary winding and at least one secondary winding, said primary winding being connected in series to at least one load capacitor, and a voltage limiting means for limiting the voltage across the transformer and said at least one load capacitor to a predetermined voltage value exceeding the supply voltage.

2. A frequency converter as claimed in claim 1, wherein the voltage limiting means comprises circuits connected between the common point of the capacitor circuit and the primary winding of the transformer and means for making said circuits conductive at a voltage which is equal to the difference between said predetermined voltage value and the supply voltage (FIGS. 1, 7 and 10).

3. A frequency converter as claimed in claim 2, wherein said means for making the circuits conductive comprise at least one zener diode or varistor in said circuits.

4. A frequency converter as claimed in claim 2, wherein each said circuit comprises a thyristor and means for igniting the thyristor at said predetermined voltage value.

5. A frequency converter as claimed in claim 4, wherein said ignition means comprises a zener diode or varistor connected between an input line of the supply voltage and the gate of the thyristor.

6. A frequency converter as claimed in claim 1, wherein the voltage limiting means comprises a circuit

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connected between terminals or points on one of the transformer windings, and means for making said circuit conductive at said predetermined voltage value.

7. A frequency converter as claimed in claim 6, wherein the voltage limiting means comprises a circuit 5 connected in parallel with at least part of the primary winding of the transformer, and means for making said circuit conductive at said predetermined voltage value.

8. A frequency converter as claimed in claim 7, wherein said means for making the circuit conductive 10 comprises two zener diodes connected in series opposition or a varistor in said circuit.

9. A frequency converter as claimed in claim 6, wherein said voltage limiting means comprises an additional secondary winding having a number of turns 15 which is equal to or less than the number of turns of the primary winding, and wherein the end terminals of the additional secondary winding are connected via a rectifying bridge to a respective one of the input lines of the supply voltage.

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10. A frequency converter as claimed in claim 1, wherein the voltage limiting means comprises circuits connected between a point on the primary winding of the transformer and a respective one of the input lines of the supply voltage and means for making said circuits conductive at a voltage which is equal to the difference between said predetermined voltage and the supply voltage (FIGS. 1, 7 and 10).

11. A frequency converter as claimed in claim 10, wherein said means for making the circuits conductive 20 comprise at least one zener diode in said circuit.

12. A frequency converter as claimed in claim 10, wherein each said circuit comprises a thyristor and means for igniting said thyristor at said predetermined voltage value.

13. A frequency converter as claimed in claim 12, wherein said ignition means comprises a zener diode connected between an input line of the supply voltage and the gate of the thyristor.

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[54] CURRENT UNIT FOR ARC WELDING

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[52] U.S. Cl. 219/130.21

[58] Field of Search 219/130.1, 130.21, 130.31,
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[57]

ABSTRACT

An a.c. operated arc welding current supply unit comprises a frequency converter of the series capacitor type and operating with a half period which is substantially less than the average duration of the current and voltage transients caused by short circuits through droplets of weld material during welding. The frequency converter is connected to welding electrodes through a transformer in series with a rectifier to provide direct current for the welding electrodes, and the frequency converter is associated with a control device for controlling the operating frequency of the converter in a manner such that it is substantially inversely proportional to the square of the input voltage of the current supply unit, thereby maintaining the power output of said unit substantially unchanged irrespective of changes in load caused by the welding operation and irrespective of variations in said input voltage.

1 Claim, 3 Drawing Figures

Fig. 3

CURRENT UNIT FOR ARC WELDING

This is a divisional application of Ser. No. 795,501, filed May 10, 1977, now abandoned.

The present invention relates to an arc welding current supply unit which is arranged to be fed with alternating current and to provide direct current for welding electrodes.

An object of the invention is to provide a novel and useful welding current supply unit which will facilitate welding operations so that an acceptable weld can be made by relatively unskilled persons and which will also enable more satisfactory welding operations to be carried out than was hitherto possible, with the use of conventional welding current units operating at main frequencies.

To this end it is suggested in accordance with the invention that an arc welding current supply unit of the aforementioned type includes a controlled frequency converter operating with a half-period which is less than the average duration of the current and voltage transients caused by short circuits through droplets of the weld material, e.g. less than 3 milliseconds and preferably less than 1.5 milliseconds, and adapted to be connected to the welding electrodes through a transformer in series with a rectifier, and also includes a control device which is adapted to control the converter in a manner such that the arc power remains substantially unchanged irrespective of changes in load caused by the welding operation, wherein said converter is of the series-capacitor type converter, i.e. the primary winding of the transformer is supplied from a d.c. voltage intermediate stage by controlled alternating discharge of one or more capacitors connected in series with said primary winding, and wherein the voltage of the a.c. supply applied to the unit is substantially constant, the control device may be adapted to control the converter in a manner such that it operates at a constant frequency which can be adjusted to a desired value. On the other hand, the control device is arranged to control the operating frequency of the converter so that it is substantially inversely proportional to the square of the voltage of the a.c. supply or the voltage applied to the capacitor or capacitors.

With such a welding current supply unit there is obtained a particularly stable and quiescent arc, irrespective of small variations in the distance between electrode and work piece. In addition, in the event of a short circuit caused by droplets of welding material, the arc will be smoothly re-ignited with small dynamic effect on the molten material.

So that the invention will be more readily understood and optional features thereof made apparent, an embodiment thereof will now be described with reference to the accompanying schematic drawings, in which:

FIG. 1 is a circuit diagram of an a.c. operated arc welding current supply unit having a frequency converter of a type which can be used to advantage in conjunction with the present invention;

FIG. 2 is a circuit diagram of a control circuit intended for use with the current supply unit of FIG. 1;

FIG. 3 illustrates curves denoting voltages and currents which occur during the normal operation of the current supply unit.

The current supply unit shown in FIG. 1 is connected at 10 to a 3-phase a.c. network. The input current is rectified in a six-element full-wave rectifier 11, the recti-

fied output voltage on lines 12, 13 being smoothed by a buffer capacitor 14 and applied to a frequency converter having—as a consequence of the shown arrangement of elements 11 to 14—a low input impedance.

With the illustrated embodiment the switching elements of the frequency converter comprise thyristors 15, 16 which are controlled so as to be alternately energized. The frequency converter is associated with a transformer generally shown at 17 and the primary winding 18 of which is connected in series with load capacitors 19, 20 forming parts of the frequency converter. The secondary winding 21 of the transformer 17 is connected via a bridge rectifier 22 and a choke 29 to welding electrode terminals 24, 25, which terminals are capable of being connected to a winding electrode holder and a work piece to be welded. With the illustrated embodiment there is connected between the terminals 24, 25 a capacitor 26 which is used to maintain a desired open-circuit voltage. A shunt 27 may also be arranged for measuring the load current.

In the case of a fluctuating supply voltage and a constant converter frequency, the desired converter provides a power output which varies substantially proportionally to the square of the supply voltage U_{10} between the terminals 10. If the power output from the current unit is to remain substantially constant irrespective of fluctuations in the supply voltage, the frequency of the converter must be varied in proportion to $1/U_{10}^2$.

In FIG. 2, there is shown a control device which is adapted to control the frequency converter in a manner such that the arc power remains substantially constant irrespective of changes in load caused by the welding operation and by changes in input voltage. This control device includes a potentiometer 33 and an oscillator 34, said potentiometer being adapted to control the operating frequency of the oscillator 34. The potentiometer 33 is connected between earth and a negative voltage source which varies substantially inversely proportional to the square of the voltage applied to the frequency converter.

In the shown embodiment, the control device further includes a fixed negative potential 335 and a load resistor 331 connected in series with the potentiometer 33. The supply voltage U_{10} is applied to the primary of a transformer 334 the secondary of which is connected through a bridge rectifier 333 to a smoothing capacitor 332 and said load resistor 331. The values of the components are chosen so that the voltage across the resistor 331 is approximately twice that of the voltage across the power adjusting device 33. The voltage across the resistor 331 will therefore vary in proportion to U_{10} which in turn means that the voltage across the power adjusting device 33 will vary approximately in proportion to $1/U_{10}^2$ as long as the variations of the supply voltage are small, e.g. not more than $\pm 5\%$. The frequency of the oscillator 34 controlled by the voltage adjusting device 33 will thus also vary in proportion to $1/U_{10}^2$. Instead of using U_{10} as the control voltage signal, it is of course possible to use the voltage applied to the converter capacitor 19, 20.

The oscillator 34 includes an integrating circuit comprising an amplifier 340, resistors 341 and 342, and a capacitor 343. The oscillator also includes a level discriminator 344 with associated comparison resistors 345, 346, the resistor 345 being connected to the output of the integrating circuit and the resistor 346 being connected to a voltage source having a fixed negative voltage. The amplifier 340 is controlled in the positive

sense by control signals from the potentiometer 33 and in the negative sense by signals from the $\bar{Q}$ -output of a monostable flip-flop 50 hereinafter described. A voltage adjuster 35 in the form of a potentiometer is provided for adjusting the desired maximum output voltage from the current supply unit, which voltage adjuster 35 is connected via comparison resistors 36 to the terminal 25 of the current supply unit and to an amplifier 37 which serves as a level discriminator.

Control of the state of the thyristors 15, 16 is effected by means of a sensing circuit comprising a transformer 38, the primary side of which is connected via diodes 39, 40 to the anodes A_1 , A_2 and cathodes K_1 , K_2 of the thyristors 15, 16. One end of the secondary winding of the transformer 38 is earthed and the other end is connected to a comparison circuit which comprises two resistors 41, 42, the resistor 42 having one end thereof connected to a constant negative voltage. The junction between the resistors 41, 42 is further connected to an amplifier 43 which serves as a level discriminator and the change-over point of which is determined by the resistors 41, 42 and the aforementioned constant negative voltage. Each of the amplifiers 34, 37 and 43 is connected to a respective input 45, 46, 47 of an AND gate 48, which operates in a known manner. Thus, in order for the AND gate 48 to emit an output signal, it is necessary for the output signal obtained from the amplifier 34 to be positive. Correspondingly, it is necessary for the output signal from the amplifier 37 to be positive, i.e. for the load voltage on the terminal 25 to be less than the value for which the adjuster 35 is set. Finally, the output signal from the amplifier 43 must be positive, which means that the anode voltage of one of the thyristors 15 or 16 is negative in relation to the cathode, which in turn means that both the thyristors 15 and 16 are de-energized.

The output of the AND gate 48 is connected to the input of the monostable flip-flop 50 which has a pre-determined pulse period corresponding to the recovery time of the thyristors 15, 16, for example 30 μ s. Thus, on the output Q of the flip-flop 50 there is obtained a positive voltage pulse for a period of time corresponding to the recovery time of the thyristors 15, 16. This pulse is transmitted through the resistor 342 to the amplifier 340 and is also transmitted to the trigger input T of a JK flip-flop 51, so that the JK flip-flop 51 changes the status of its outputs at the end of the pulse obtained from the flip-flop 50. The outputs Q , $\bar{Q}$ of the JK flip-flop 51 are connected to the base electrodes of respective transistors 54, 55 via capacitors 52, 53. The emitters of the transistors 54, 55 are connected to earth while their collectors are connected to the primary windings of respective ignition transformers 56, 57 for the thyristors 15, 16. The other ends of the primary windings are connected to a terminal having a pre-determined positive potential, and the ends of the secondary windings are connected to the cathode K_1 or K_2 and the gate G_1 or G_2 of a respective thyristor 15 or 16. The signals from the outputs of the JK flip-flop 51 will alternatively render the transistors 54, 55 conductive via the capacitors 52, 53, for a short period of time determined by the capacitors 52, 53, so that the thyristors 15, 16 alternately receive a short ignition pulse and thereby alternately supply current to the primary winding 18 of the trans-

former 17 to produce an alternating current whose frequency is determined by the signals on the inputs 45, 46, 47 of the AND gate 48. With this arrangement a desired substantially constant arc power can be set solely by a corresponding adjustment of the potentiometer 33.

FIG. 3 shows the voltages U_{60} , U_{61} at points 60, 61 and the voltage U_{18} across the primary winding 18 of the transformer 17 with normal load on the output of the current supply unit shown in FIGS. 1 and 2. FIG. 3 also shows the output current I_{25} through the terminal 25 and the output currents I_{15} and I_{16} (the latter shown in dash lines) from the thyristors 15, 16. In FIG. 3 the reference t_1 illustrates the point of time when the thyristor 15 is ignited, t_2 the point of time when the thyristor 15 is de-energized and obtains a negative voltage between the anode A_1 and cathode K_1 as a result of the resonant circuit formed by the primary winding 18 of the transformer 17 and the capacitors 19, 20, t_3 the point of time when the thyristor 16 is ignited, and t_4 the point of time when the thyristor 16 is de-energized and obtains a negative anode voltage as a result of said resonant circuit 18, 19, 20. The reference t_5 shows the point of time at which the thyristor 15 is re-ignited, whereupon the sequence is repeated provided that the load remains substantially unchanged.

The invention is not limited to the frequency converter illustrated and described, but may be used in conjunction with other frequency converters, for example frequency converters having forced commutation or d.c. controlled intermediate stages. If larger fluctuations in supply voltage U_{10} than e.g. $\pm 5\%$ are likely to occur, there may be added to the varying negative voltage source described with reference to FIG. 2 a multiplying circuit which generates across the resistor 331 a voltage which is truly proportional to $1/U_{10}^2$.

I claim:

1. An arc welding current supply unit arranged to be fed with alternating current voltage and to provide direct current for welding electrodes, said unit including a controlled frequency converter operating with a half period which is less than the average duration of the current and voltage transients caused by short circuits through droplets of the weld material and adapted to be connected to the welding electrodes through a transformer in series with a rectifier, a control device for controlling said converter in a manner such that the arc power remains substantially unchanged irrespective of changes in load caused by the welding operation, wherein current pulses are formed in the secondary winding of the transformer by alternately charging and discharging at least one capacitor which is connected in series with said primary winding of said transformer and which is discharged therethrough, and said at least one capacitor being charged by a direct current voltage intermediate source and being connected to said source by a number of thyristors equal in number to the number of said capacitors, said thyristors being connected to said control device, and wherein said control device further comprises means for alternately making said thyristors conductive at a frequency which is substantially inversely proportional to the square of said voltage applied to said current supply unit.

* * * * *

United States Patent [19]

Hedberg

[11]

4,117,303

[45]

Sep. 26, 1978

[54] ARRANGEMENT IN ELECTRICAL WELDING APPARATUS

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[58] Field of Search 219/131 R, 131 WR, 135,
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[57]

ABSTRACT

An a.c. operated arc welding apparatus comprises a controlled frequency converter which substantially increases the frequency of the alternating current and the output of which is connected to the welding electrodes via a transformer and a rectifier. The connection between the rectifier and the welding electrodes includes a shunt capacitance having an impedance low enough to attenuate the alternating current components of the welding current to a level acceptable from the acoustic aspect, the said connection further comprising means for preventing the capacitor from adversely affecting the rectifier and frequency converter and also comprising a choke arranged between the capacitor and the electrodes to prevent the capacitor from adversely affecting the welding properties.

5 Claims, 2 Drawing Figures

Fig. 1 *Fig. 2*

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ARRANGEMENT IN ELECTRICAL WELDING APPARATUS

The present invention relates to arc welding apparatus of the kind in which the welding electrodes are supplied with pulsating direct current derived from an a.c. supply by means of a controlled frequency converter which substantially increases the frequency of the alternating current, and which is connected to the welding electrodes through a transformer and a rectifier.

Such apparatus has the advantages of low weight, easy control of the welding parameters, low manufacturing costs and high efficiency. A serious disadvantage with such apparatus, however, is that, as a result of the transformation of the alternating current to a higher frequency, e.g. 500 - 1500 Hz or even higher, e.g. up to 15,000 Hz, in the frequency converter, the pulsating d.c. current fed to the welding electrodes during welding gives rise to sound oscillations of such intensity as to exceed normally acceptable sound levels, e.g. 85 dBA at frequencies up to 16,000 Hz, 95 dB in the frequency range of 16,000 to 20,000 Hz and 105 dB in the frequency range of 20,000 to 50,000 Hz. Hitherto this has prevented such apparatus from being used in practice.

An object of the present invention is to provide such apparatus in which the aforementioned disadvantages are substantially eliminated whilst retaining the advantages afforded by such apparatus.

To this end it is proposed in accordance with the invention that the connection between the rectifier and the welding electrodes should include a shunt capacitor having an impedance low enough to attenuate the alternating current components of the welding current to a level acceptable from the acoustic aspect, the said connection further comprising means for preventing the capacitor from adversely affecting the rectifier and frequency converter and also comprising a choke arranged between the capacitor and the electrodes to prevent the capacitor from adversely affecting the welding properties.

Preferably said means for preventing the capacitor from adversely affecting the rectifier and frequency converter has the form of a further choke arranged upstream of the capacitor, preferably between the rectifier and the capacitor.

So that the invention will be more readily understood and further features thereof made apparent, an exemplary embodiment of the invention will now be described with reference to the accompanying drawing, in which

FIG. 1 is a block schematic circuit diagram showing the principal component of welding apparatus supplied by alternating current; and

FIG. 2 is a circuit diagram showing the additional components to be included in the apparatus of FIG. 1 in accordance with a preferred embodiment of the invention.

In FIG. 1 there is shown an arc welding apparatus comprising an a.c. generator 1, e.g. an a.c. mains supply (250/380 V, 50 Hz), a frequency converter 2, a transformer 3, and a rectifier 4, connected in cascade so as to supply direct current to a load 5 which is in the form of a welding arc.

The output frequency of the converter 2 is controlled, and the converter may comprise a rectifier connected in series with an a.c. inverter circuit of the series

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capacitor type, the conductivity of the current control devices of the inverter being controlled with the aid of pulses obtained from a control unit 6 which operates in dependence upon the current through, and the voltage across, the load 5. To this end the control unit 6 may comprise an oscillator which delivers control pulses alternately to the current control devices of the inverter at a suitable timing to obtain the desired welding current. This current comprises a pulsating current of relatively high frequency, e.g. in the order of magnitude of 1000 - 3000 Hz or even higher, e.g. up to 30,000 Hz, and would, if no other measures were taken, give rise to harmful high frequency noise, such as noise in a range of about 95 dBA with a welding current of 250A.

As will be seen from FIG. 2 there is provided, for the purpose of preventing disturbing noise during a welding operation, a capacitor 9 which is permanently connected across the line leading to the welding electrodes, said capacitor preferably being of the order of magnitude of at least 1000 μ F in the case of an apparatus having an output capacity of 375A.

When the welding apparatus is to be used in different welding current ranges, conveniently a capacitor 9 of variable capacitance is used to enable said capacitance to be modified in respect of the particular field of use, and in order that the level of sound is lowered, the capacitor shall be so constructed and so connected in the circuit that the parallel arm containing the capacitor shall have as low an a.c. impedance as possible, which means that the resistance and inductance of the parallel arm shall be very small. The connection of the capacitor 9 alone would, however, make it impossible to effect a welding operation, owing to the fact that the capacitor would be discharged momentarily with each short circuit in the weld zone, for example through droplets of welding material during an arc welding operation, due to which the arc welding would be extinguished during the time required to recharge the relatively large capacitor. Further, the capacitor would act to present a short-circuit to the frequency converter and therewith cause high current peaks, which would disturb the operation of the frequency converter and, moreover, act adversely on the components arranged upstream of the capacitor. To eliminate these disadvantages, the apparatus is provided with means for preventing such current peaks. Said means may be constructed and arranged in many different ways upstream of the capacitor and may, for example, be of the resistive type. It is preferred, however, that said means has the form of a choke, such as that shown at 12 in FIG. 2, the choke being placed immediately upstream of the capacitor 9. Further, there is arranged between the capacitor 9 and the electrodes a further choke 13 having an inductance of sufficient magnitude to support the arc during the recharge of the capacitor subsequent to a short circuit caused through droplets of welding material. The inductances of chokes 12 and 13 are selected in dependence upon, inter alia, the capacitance of the capacitor 9 and the internal capacity of the apparatus and, with the aforesaid values of the capacitor, and the output capacity of the welding apparatus, both may suitably be of the order of magnitude of 50 μ H.

I claim:

1. Welding apparatus of the type wherein the welding electrodes for producing an arc are supplied with pulsating direct current derived from an a.c. current supply by means of a controlled frequency converter which substantially increases the frequency of the alternating

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current, the output of said converter being connected through a transformer and a rectifier to the welding electrodes, wherein the connection between the rectifier and the welding electrodes includes a shunt capacitance having a preselected impedance which is of a low value so as to attenuate the alternating current components of the welding current to an audio level of at most 85 dB at frequencies up to 16,000 Hz, 95 dB in the frequency range of 16,000 to 20,000 Hz and 105 dB in the frequency range of 20,000 to 50,000 Hz, the said connection further comprising means for preventing the capacitor from adversely affecting the rectifier and frequency converter and a choke arranged between the capacitor and the electrodes to support the arc during recharge of the capacitor but for allowing discharge

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thereof during short circuit periods caused by droplets of molten welding material.

2. Apparatus as claimed in claim 1, wherein said means for preventing the capacitor from adversely affecting the rectifier and frequency converter has the form of a further choke arranged upstream the capacitor.

3. Apparatus as claimed in claim 2, wherein said further choke is arranged between the rectifier and the capacitor.

4. Apparatus as claimed in claim 2, wherein the inductance of said choke and of said further choke is about 50 μ H.

5. Apparatus as claimed in claim 1, wherein the capacitance of said capacitor is at least about 1000 μ F.

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APPENDIX D

Breadboard Schematics

LAST USED	SKIPPED
C17	
CR16	
R35	
Q1	
T4	
U8

APPENDIX E

Final Schematics

CONTRACT NO.		DATE	
APPROVALS		DATE	
DRAWN		E-AC-80	
CHECKED			
REVIEW			
USED ON			
APPLICATION			

cyclo-matic		SAN DIEGO-CA-USA	
SCHEMATIC, INTERCONNECT WIRING			
SIZE	CODE IDENT NO	DRAWING NO	REV
16 422	800520	A

APPENDIX F

DETAILED COST BREAKDOWN PS-25 POWER SOURCE

Part Number	Qty	Description	Unit Cost	Total Cost
SK942	1	POWER CIRCUIT	—	—
800011	1	CIRCUIT BREAKER	19.00	19.00
800004-101	3	DIODE, RECT. 800V60a STD.	5.50	16.50
800004-201	3	DIODE, RECT. 800V60a REV.	5.50	16.50
IN5626	4	DIODE, RECT. 600V 3a	.80	3.20
800005	2	DIODE, RECT. 400V 250a	15.00	30.00
IN5624	6	DIODE, RECT. 200V 3a	.38	2.28
800013	4	SCR, 600V, 63 AMP 25 usec	10.00	40.00
800002	3	CAP. A.C., .22 uf 600V	.30	.90
800000	5	CAP. POLYPROP. .068 uf 600V	.54	2.70
800001-1	4	CAP. ALUM.ELEC. 1300 uf 200V	4.50	18.00
800001-2	5	CAP. ALUM.ELEC. 600 uf 100V	3.00	15.00
800003	4	CAP. SCR COM 5 uf 600V	4.00	16.00
430102GO25SJ1 (SPR)	2	CAP. ALUM.ELEC. 1000 uf 25V	1.14	2.28
430502GO16KL1 (SPR)	1	CAP. ALUM.ELEC. 500 uf 16V	1.06	1.06
800012	2	RESISTOR 220W .5 ±10%	1.10	2.20
RW67-V-153	4	RESISTOR 5W 15K ±5%	.37	1.48
RE-75N-10R0	5	RESISTOR, NON IND.	1.30	6.50
RC TYPE	5	RESISTOR, CARB., 100 1/4w	.036	.18
RC TYPE	4	RESISTOR, CARB., 10K 1w	.067	.27
V47ZA2	2	VARISTOR, 47 V	.73	1.46
8XXXXX	1		1.50	1.50
800006	2	INDUCTOR, DI/DT LIMITER	.40	.80
800008	1	INDUCTOR, OUTPUT FILTER	2.40c 4.68s .50h	7.58
800007	1	INDUCTOR, OUTPUT SMOOTHING	1.50c 3.09s .50h	5.09
800009	1	TRANSFORMER, CONTROL	2.80c 6.43s .50h	9.73
800010	1	TRANSFORMER, MAIN	6.40c .75h 11.70s	18.85
8XXXXX	1	TRANSFORMER, CURRENT	1.50 core .15 copper	1.65
(E.L.E.-SW)	1	SWITCH 600V, 20 AMP	12.00	12.00
	1	FAN	25.00	25.00
	1	FUSE 3 AMP	.28	.28
	1	FUSE HOLDER	.32	.32
	1	SHUNT, 400A 100mv	1.50	1.50
	1	POWER RECEPTACLE	2.04	2.04
		TOTAL		281.85

DETAILED COST BREAKDOWN PS-25 POWER SOURCE

Part Number	Qty	Description	Unit Cost	Total Cost
SK950-2	1	SCR CONTROLLER DRIVER	—	—
UA78M05UC	1	I.C. VOLTAGE REG.	.70	.70
UA3302PC	1	I.C.	.75	.75
CD4093BE	1	I.C.	.60	.60
CD4098BE	1	I.C.	.60	.60
CD4013BE	1	I.C.	.60	.60
UDN5707A	1	I.C.	1.20	1.20
4N37	1	I.C. OPTO. ISO.	.75	.75
MPS-A05	1	TRANS. NPN	.25	.25
1N914	4	DIODE	.08	.32
1N4733	2	DIODE, ZENER	.75	1.50
1N4757	1	DIODE, ZENER	.75	.75
1N47 TYPE	1	DIODE, ZENER	.75	.75
1N4934	4	DIODE	.27	1.08
1N4002	4	DIODE	.13	.52
T110A105M035A	2	CAP. TANT. 1 uf 35V	.16	.32
T110 TYPE	1	CAP. TANT. 10 uf 35V	.40	.40
C330C104Z1UCA	3	CAP. CERAMIC .1 uf	.11	.33
C320C333K5R5CA	1	CAP. CERAMIC .033 uf	.11	.11
C312C102K1R5EA	6	CAP. CERAMIC .001 uf	.11	.66
6113X7R101KA100	4	CAP. CERAMIC 100 pf	.11	.44
RC TYPE	25	RES., CARB. 1/4 W	.036	.90
RC TYPE	2	RES. CARB. 1/2 W	.041	.08
RC TYPE	3	RES., CARB. 1W	.067	.20
RN TYPE	5	RES., M.F. 1/10 W	.09	.40
8XXXXX	4	TRANSFORMER, PULSE	.50	2.00
		TOTAL		16.21

DETAILED COST BREAKDOWN PS-25 POWER SOURCE

Part Number	Qty	Description	Unit Cost	Total Cost
SK988	1	PROCESS CONTROL LOGIC	—	—
MC14584BCP	1	I.C.	.60	.60
MC14001BCP	1	I.C.	.40	.40
8748 (or 8048)	1	I.C. MICROPROCESSOR	15.00	15.00
8253	1	I.C. PROG TIMER	10.00	10.00
AD571JD	1	I.C. A/O CONVERTER	15.00	15.00
LF13508	1	I.C. MUX	2.80	2.80
MC14503BCP	2	I.C.	.60	1.20
MA747PC	4	I.C. OP. AMP.	.75	3.00
MA7805UC	1	I.C. VOLTAGE REG. 5V	1.00	1.00
UA78M12UC	1	I.C. VOLTAGE REG. +12V	.80	.80
MA79M12UC	1	I.C. VOLTAGE REG. -12V	.80	.80
IN5240	1	DIODE ZENER, 10V	.75	.75
IN4002	2	DIODE	.13	.26
MPSA05	3	TRANSISTOR	.25	.75
T110A105M035AS	6	CAP. TANT. 1 uf 35 f	.16	.96
C330C104K1R5CA	10	CAP. CERAMIC .1 uf	.11	1.10
C320C103KUR5CA	7	CAP. CERAMIC .01 uf	.11	.77
C320C220K2G5CA	2	CAP. CERAMIC 22 pf	.11	.22
	1	CRYSTAL	1.03	1.03
RN TYPE	26	RESISTOR, MF, 1/10 W	.09	2.34
RC TYPE	16	RESISTOR, CARB. 1/4 W	.036	.57
3299W-1-103	1	RESISTOR, VARIABLE 10 K	1.07	1.07
#387	3	LAMP	.26	.78
LH89/1TC35RT2	1	LAMP, INDICATOR (RED)	1.20	1.20
LH89/1TC35GT2	1	LAMP, INDICATOR (GREEN)	1.20	1.20
LH89/1TC35YT2	1	LAMP, INDICATOR (YELLOW)	1.20	1.20
8803K10	1	SWITCH	1.20	1.20
8800K16	1	SWITCH	1.20	1.20
RV4NAYSD102A	2	POT. 1K $\pm$ 10%	1.20	2.40
7467	1	PLUG, INLET	2.04	2.04
		TOTAL		71.64

APPENDIX G

In-Plant Testing

Unit Under Test — PS-25 (SN 001)

Equipment — 460VAC 3 ϕ supply mains.
 — KW transducer (FW Bell Mdl. PR 24015)
 — KVAR transducer (FW Bell Mdl., QR 24015)
 — Meters 4 required (Data Precision Mdl. 935)
 — Load bank with selections within .065 ohm to .30 ohm range
 — Shunt 100mv output at 400 amps

Test Set-up — The unit under test is connected to the supply mains. The KW and KVAR transducer monitors input KW and KVAR which is read out on meters. The load bank is connected to the output of the unit under test output voltage and current are monitored by meters.

Data Taken — Tables G1 and G2 — Input KW, output volts and output amps are measured. Output KW and operating efficiency are calculated as follows:

Output KW = output voltage x output current

Operating Efficiency = output power $\div$ input KW

— Table G3 — Input KW, output KVAR, output volts, and output amps are measured. Power factor is calculated as follows:

Power factor = $\cos[\tan^{-1}(\text{input KVAR} \div \text{input KW})]$

Condition		Input KW	Output Volts	Output Amps	Output KW	Operating Efficiency
Setting	Load Res					
20	.136	1.29	12	72	.86	62.9
	.166	1.28	12.5	64	.80	62.5
	.211	1.28	14	60	.84	65.6
	.300	1.26	17.5	48	.84	66.8
40	.136	3.88	23	152	3.50	88.9
	.166	3.85	25	136	3.40	87.1
	.211	3.80	27.5	120	3.30	84.4
	.300	3.12	33	100	3.30	87.3
60	.136	7.15	32	212	6.78	94.8
	.166	7.01	34	192	6.53	93.1
	.211	6.86	37.5	168	6.30	91.8
	.300	6.56	45	136	6.12	93.2
80	.136	*	*	*	*	*
	.166	10.09	41	228	9.35	92.6
	.211	9.77	45	204	9.18	93.9
	.300	8.13	50	152	7.60	93.4
100	.136	*	*	*	*	*
	.166	10.43	42	236	9.91	95.0
	.211	9.55	44	200	8.80	92.1
	.300	7.99	50	152	7.60	95.1

*Data not available

Table G1
PS-25 In-plant Test for Operating Efficiency

Condition		Input KW	Output Volts	Output KW	Output KW	Operating Efficiency
Setting	Load Res					
50	.136	1.06	6.5	46.8	.30	28.6
	.166	1.11	7.5	46.4	.35	31.3
	.211	1.17	9.7	46.0	.45	38.1
	.300	1.35	11.3	45.2	.51	37.8
100	.136	2.08	15	93.6	1.40	67.5
	.166	2.28	16	93.2	1.49	65.4
	.211	2.57	18	92.4	1.66	64.7
	.300	3.28	28	90.8	2.54	77.5
150	.136	4.20	21	151.2	3.18	75.6
	.166	4.73	25	150.4	3.76	79.4
	.211	5.52	31	149.2	4.63	83.7
	.300	7.47	47	146.8	6.90	92.3
200	.136	6.66	27	196.8	5.31	79.7
	.166	7.56	33	196.4	6.48	85.7
	.211	8.98	41	196	8.04	89.4
	.300	11.88	60	187.2	11.23	94.5

Table G2
Conventional Power Source In Plant Operating Efficiency Test

Power Source	Condition		Input KW	Input KVAR	Output Volt	Output Amps	Power Factor
	Setting	Load Res.					
Conventional	100	.065	1.54	1.81	6.7	101.6	.65
		.118	1.98	2.20	12.0	100.4	.67
		.166	2.37	2.40	16.6	99.6	.70
		.211	2.71	2.54	20.7	98.4	.73
Conventional	200	.065	4.23	5.77	13.4	202	.59
		.118	5.98	6.40	23.3	200	.68
		.166	7.53	6.60	33.4	198.4	.75
		.211	9.15	6.51	42.0	197.2	.81
PS-25	35	.065	3.40	.55	13.4	202	.987
		.118	3.27	.53	18.2	152	.987
		.116	3.21	.51	21.4	127.6	.987
		.211	3.18	.51	24.0	114	.987
PS-25	70	.065	8.65	1.33	21.8	326.8	.988
		.118	8.03	1.26	29.2	245.6	.987
		.166	7.70	1.20	34.5	205.2	.988
		.211	7.50	1.18	38.5	182.4	.987

Table G3
In-Plant Power Factor Data

Comparative Testing (Energy Efficiency)

- Unit Under Test — PS-25 (SN 005), CP-250, SRH303
- Equipment/Materials — 460 VAC 3 ϕ supply mains
 — KW transducer (FW Bell Mdl. PR 24015)
 — KVAR transducer (FW Bell Mdl. QR 24015)
 — Meters 4 required (Data Precision Mdl. 935)
 — Shunt 100mv @ 400 amps
 — Scorpion Wire Feeder (with Model 612 chuck)
 — Various welding electrodes, wire, gases
 — 1/4" and 3/8" thk. steel cut to 12 inch lengths for weld samples
- Test Set-up — The unit under test is connected to the supply mains. The KW and KVAR transducers monitor input KW and KVAR which is read out on meter. The unit under test output is connected to the weld torch or electrode. Output voltage and current are monitored.
- Data Taken — Tables G4 and G5 — Input KW, input KVAR, output volts, output KW, output amps and idle power is measured. Line amps, power factor, operating efficiency, and effective efficiency are calculated as follows:

$$\text{Output KW} = \text{output volts} \times \text{output amps}$$

$$\text{Line amps} = \frac{\sqrt{\text{input KW}^2 + \text{input KVAR}^2}}{\sqrt{3} \times (.46)}$$

$$\text{Power Factor} = \cos [\tan^{-1} (\text{input KVAR} \div \text{input KW})]$$

$$\text{Operating Efficiency} = \text{output KW} \div \text{input KW}$$

$$\text{Effective Efficiency} = \frac{\text{output KW}}{\text{input KW} + 4X(\text{idle power})}$$

PS-25 COMPARATIVE WELD DATA

WELD APPLICATION	Input KW	Input KVAR	Output V	Output I	Output KW	P.F.	Line Amps	Operating Efficiency	Effective Efficiency
SMAW E6011 1/8 DIA	3.49	0.0	28.1	116	3.26	1.0	4.38	93.3	87.4
SMAW E6011 3/16 DIA	4.75	.11	25	180	4.50	.999	5.96	94.7	90.2
SMAW E7018 1/8 DIA	3.55	.25	23	140	3.22	.997	4.46	90.7	85.0
SMAW E7018 5/32 DIA	5.16	.01	23.5	200	4.70	.999	6.47	91.0	87.0
SMAW E6013 3/16 DIA	6.23	.24	26	225	5.85	.999	7.82	93.9	90.4
SMAW E7028 3/16 DIA	9.00	.17	33.5	252	8.44	.999	11.20	93.7	91.3
GMAW E705-6 .035 DIA	2.68	.14	19.5	124	2.42	.998	3.36	90.2	82.9
GMAW E705-6 .035 DIA	3.60	.01	21	152	3.19	.999	4.52	88.6	83.1
GMAW E705-6 .045 DIA	3.85	.02	22.5	160	3.60	.999	4.83	93.5	88.0
GMAW E705-6 .045 DIA	5.25	.01	23	200	4.30	.999	6.59	87.6	83.7
FCAW E70T-1 .052 DIA	5.21	.05	22	200	4.40	.999	6.54	84.0	80.7
FCAW E70T-1 .052 DIA	7.75	.08	23.5	288	6.77	.999	9.72	87.3	84.7

Idle power measured .06 KW

Table G-4

CONVENTIONAL COMPARATIVE WELD DATA

WELD APPLICATION	Input KW	Input KVAR	Output V	Amps Output I	Output KW	Line Amps	Power Factor	Operating Efficiency	Effective Efficiency
*SMAW E6011 1/4 DIA	3.98	6.75	24.2	115	2.78	9.72	.51	69.9	41.4
*SMAW F6011 3/16 DIA	6.75	9.90	26.5	183	4.85	14.96	.58	72.9	51.6
*SMAW E7018 1/8 DIA	4.70	8.10	24	142	3.41	11.75	.50	72.5	45.8
*SMAW #7018 5/32 DIA	6.50	10.10	24	200	4.80	15.10	.54	73.8	51.9
*SMAW E6013 3/16 DIA	8.10	12.10	26.5	226	5.99	18.40	.56	73.9	55.3
*SMAW E7028 3/16 DIA	10.40	13.30	31	260	8.06	21.19	.62	77.5	61.3
**GMAW E705-6 .035 DIA	3.09	2.08	20	124	2.48	4.67	.83	80.2	60.3
**GMAW E705-6 .035 DIA	4.15	2.85	21.5	152	3.27	6.32	.82	78.7	63.2
**GMAW E705-6 .045 DIA	4.35	3.00	22.5	166	3.73	6.63	.82	85.8	69.5
**GMAW E705-6 .045 DIA	5.68	3.90	23.5	200	4.70	8.64	.82	82.7	70.1
**FCAW E70T-1 .052 DIA	5.44	3.80	22	200	4.40	8.33	.82	80.9	68.1
**FCAW E70T-1 .052 DIA	7.85	5.40	23.5	280	6.58	11.95	.82	83.8	74.2

*Constant current type, idle power — .685 KW (Miller SRH-303)

**Constant potential type, idle power — .255 KW (Miller CP 250)

Table G-5

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WELDING EQUIPMENT INDUSTRIAL GASES

August 8, 1980

DIVISION OFFICE: 2424 - 6th ST.
BERKELEY, CALIFORNIA 94710

P.O. BOX 1510, 94701
(415) 843-3993

Mr. J. M. Thommes
Cyclomatic Industries, Inc..
7520 Convoy Court
San Diego, CA 92111

Dear Jim:

Referencing your letter of July 24, 1980 requesting comparable performance information on the PS-25 vs various other power supplies:

1. GMAW .035 CO2 - PS-25 compared to CP-300

In general, the results with the PS-25 are less desirable. We experienced difficulty in obtaining good wetting action which could lead to lack of fusion or cold lapping. Spatter levels were higher.

2. GMAW .035 AR/CO2 - PS-25 compared to CP-300

Results considerably better than with CO2 gas. Still below results achieved with CP-300. Spatter levels higher than CP-300. Arc initiation at higher current levels more difficult.

3. FCAW 1/16 CO2 - PS-25 compared to CP-300

Acceptable, very similar and comparable both flat and vertical.

4. GMAW .035 & .045 Steel - Pulsed Spray Argon/CO2
3/64 Aluminum - Argon - PS-25 only

The only comparable machine capability would be the Pulse-Arc manufactured by Airco. In general, the Airco machine has a higher ratio (approximately 8 or 10-1) between the peak and the background voltage. We believe the PS-25 to be approximately 4-1 ratio. The PS-25 could be used successfully on what is considered standard spray welding but when trying to do out of position work on steel or aluminum, it was

August 8, 1980

Mr. J. M. Thommes
Cyclomatic Industries, Inc.

....Page 2

necessary to increase wire speeds beyond the ability to handle it out of position in order to get the proper arc characteristics. Arc initiation is a real problem which we believe is due to the high inductance.

5. SMAW E6010 - PS-25 compared to SRH-303 & POW PAK

Results comparable to SRH-303. Somewhat better than POW PAK, particularly, on small diameter electrodes. Had no problems maintaining arc transfer.

6. SMAW E7018 - PS-25 compared to SRH-303 & POW PAK

Results comparable to both units. Good results obtained with all sizes of electrodes. The ability to adjust arc force when using electrodes is certainly a PLUS in the PS-25's favor. This feature compares very favorably to the old style motor generators.

7. General Marketability

Assuming performance characteristics can be made comparable to conventional power supplies. There is a very desirable feature in the ability of the PS-25 to have constant current/constant voltage. If the pulsed spray can also be perfected, this would add a very strong additional feature. The existing noise levels being emitted are very high even when compared to the POW PAK. It is also very difficult to adjust in mig welding. The terminology on the dials does not correspond with conventional machines.

I hope this information will be beneficial and if I can be of any further assistance, please do not hesitate to contact me.

very truly yours,

Roy H. Palmer
Executive Vice President

RHP:el

APPENDIX H

GLOSSARY OF TERMS

- base metal** — Any metal of a weldment which was originally that of the parts being welded together. See "filler metal" for contrasting definition.
- BJT** — Bipolar Junction Transistor. A solid state semiconductor device which can be used as an electronic switch.
- effective efficiency** — The energy efficiency of a welding power source taking into account idle power consumption as well as energy input during non-idle or operating situations.
- FCAW** — Flux Core Arc Welding. A welding process with a continuous, consumable wire for an electrode. The wire is tubular with welding fluxes contained in the hollow core of the wire.
- filler metal** — Any metal of a weldment which is added to the weld area in the form of a welding wire or electrode. See "base metal" for contrasting definition.
- GMAW** — Gas Metal Arc Welding. A welding process with a continuous, consumable solid wire electrode with an inert gas shield.
- GTAW** — Gas Tungsten Arc Welding. A welding process with a nonconsumable tungsten electrode with an inert gas shield; filler wire may be added.
- idle power** — Power consumed by a welding power source when it is turned "on" yet in an idle mode not delivering power to a welding arc.
- KVARH** — Kilo-Volt-Ampere-Reactive Hours. A measurement unit for imaginary energy consumption. KVARH is the reactive or imaginary component of total apparent volt-ampere-hours (KVAH).
- KWH** — Kilo-Watt Hours. A measurement unit for energy consumption. KWH is the real component of total apparent volt-ampere-hours (KVAH).
- operating efficiency** — The energy efficiency of a welding power source only during the operation of an electric welding arc. Operating efficiency does not take into account idle power consumption.
- power factor** — The ratio of real energy (KWM) to total apparent energy (KVAH). The ideal power factor (1.0) indicates that all of the apparent energy usage is in the form of real energy. The following diagram illustrates the relationship between power factor, KWH, KVARH and KVAH.

$$\begin{aligned}
 \text{power factor} &= \text{KWH} \div \text{KVAH} \\
 &= \cos \theta \\
 &= \cos [\tan^{-1}(\text{KVARH} \div \text{KWH})]
 \end{aligned}$$

- Primary energy conversion** — Conversion of a primary energy source such as coal or oil to electrical energy.
- PRM** — Pulse Repetition Modulation. A method of TRC employing a controlled pulse repetition rate of fixed pulse widths.
- PWM** — Pulse Width Modulation. A method of TRC employing a controlled pulse width at a fixed repetition rate.
- SCR** — Silicon Controlled Rectifier. A solid state semiconductor device which can be used as an electronic switch.
- Short Arc** — A mode of GMAW whose arc voltage oscillates between a short circuit (electrode contacts work) and an arc mode. Metal is transferred from electrode to work during a shorting period.
- SMAW** — Shielded Metal Arc Welding. A welding process with a solid shield coated consumable electrode.
- Spray Arc** — A mode of GMAW whose arc voltage is stable in an arc mode. Metal deposition is sprayed from the electrode to the workpiece.
- Switch mode** — A means of electric power control which utilizes electronic switch devices in a rapid on and off operation. Power level is determined by TRC.
- TRC** — Time Ratio Control. A method of power control using switch type devices. Control is accomplished by varying the "on time" to "off time" ratio of the controlling switch device.