

PATENT SPECIFICATION

(11) 1 491 800

1 491 800

- (21) Application No. 25614/75 (22) Filed 16 June 1975 - F-D
 (31) Convention Application No. 479312
 (32) Filed 14 June 1974 in -> P-D
 (33) United States of America (US)
 (44) Complete Specification published 16 Nov. 1977
 (51) INT CL² G05F 1/02//1/04 1/08
 (52) Index at acceptance

G3R 1A 20 4 67 71 72N 72Y 73 74

- (72) Inventors WAYNE EDWARD HOFFMAN
 WILLIAM CHARLES DOWNING and
 KENNETH ANTHONY GOLONKA



(54) IMPROVEMENTS IN ARC WELDING POWER SOURCES

(71) We, THE LINCOLN ELECTRIC COMPANY, of 22801, St. Clair Avenue, Cleveland, Ohio 44117, U.S.A., a corporation organized and existing under the laws of the State of Ohio, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention concerns arc welding power sources and relates more particularly to a three phase, transformer-rectifier type variable voltage power source for d.c. manual and submerged arc welding.

Heretofore such power sources have been unsatisfactory for manual or submerged arc welding because the control circuits for the semiconductor controlled rectifiers (SCRs) used in the sources did not have the proper response characteristics for use in conjunction with the inductive choke required in the power leads for good welding. Accordingly, a choke smaller than that necessary to produce a smooth stiff arc had to be employed. Furthermore the SCRs had to have a maximum current rating much larger than the maximum rated welding current to prevent damage to the rectifiers due to short circuiting of the output either on starting the arc or during welding.

The present invention provides a three-phase transformer-rectifier type, variable voltage power source for d.c. welding which overcomes the difficulties of the prior art and provides a welder: having improved arc characteristics, e.g. yielding a smoother, less forceful arc which produces less spatter and has less tendency for pop outs, particularly with low hydrogen electrodes.

In accordance with the present invention, there is provided a three phase-transformer-rectifier type d.c. arc welding power supply apparatus including a transformer having three primary and three secondary windings, a full wave rectifier bridge including at least three SCRs having input terminals connected by leads to said secondary windings and a pair of d.c. output terminals for the connection of leads adapted to be connected to a welding electrode and to a workpiece, whereby welding current will in use flow in said leads, a choke in series with one of said output leads and a control circuit for said SCRs including a reactance in series with each of said secondary windings whereby the transformer has a drooping volt-ampere curve, means providing a d.c. feedback signal voltage proportional to the current in said secondary windings, and means for selecting a portion of said d.c. feedback signal voltage to control said firing circuit so that the power supply has a constant output current when a welding arc exists.

The present invention also provides a transformer-rectifier type d.c. arc welding power source including a transformer having three primary and three secondary windings, a full wave rectifier bridge including at least three main SCRs having input terminals connected by leads to said secondary windings and a pair of d.c. output terminals having leads adapted to be connected to a welding electrode and a workpiece whereby welding current will flow in said leads, a choke in series with one of said output leads; a current transformer in series with each secondary winding lead and having a secondary winding providing an output voltage proportional to the current in said lead, rectifier means associated with said current transformer secondary windings to provide a feedback signal, a choke and paralleled resistor in series with said feedback signal to provide a modified feedback signal, means for decreasing the induct-

ance of said choke with an increase in welding current, means for selecting a portion of said modified feedback signal, a control circuit for said main SCRs including an oscillator having a first transistor and a capacitor which when charged to a preset value turns on said first transistor, said oscillator including an energizing lead to a d.c. voltage proportional to the line voltage to said power source whereby the turn-on voltage of said first transistor varies proportionally to the line voltage, means controlling the charging of said capacitor including a first higher and a second lower resistance circuit energized from a fixed voltage source and means for controlling the maximum charging voltage of said capacitor through said second lower resistance circuit including a second transistor, means feeding said pre-selected portion of modified feedback signal to said second transistor whereby the conductivity of said second transistor is proportional to said portion of said modified feedback signal, short-circuit control means associated with said second transistor for causing said second transistor to become fully conductive including a third transistor energized by the total modified feedback signal and being turned on by a modified feedback signal resulting from welding currents in excess of a predetermined maximum current rating of said power supply apparatus, means delaying the turn on of a further SCR for a predetermined time period after the application of said short-circuit modified feedback signal voltage, a fourth transistor caused to become conductive by said turn-on of said further SCR, means delaying the rate of change of the conduction of said fourth transistor and means feeding the output of said fourth transistor to said second transistor for causing said second transistor to become conductive and increasing the charging time of said oscillator capacitor to a time that will reduce the conduction angle of the main SCRs so as to produce a safe output current.

The control circuit may include an iron cored choke in series with the signal voltage which acts to delay the rate of change of the input signal to the control circuit due to rapid changes in current through the rectifiers, the core of which choke is moved toward saturation by increasing arc currents whereby the rate of change of the input signal to the control circuit is more rapid at high welding currents than at low welding currents. This provides a faster control of the SCRs at the higher welding currents than at the lower welding currents.

Further in embodiments of the invention, varying percentages of the control signal are fed to the control circuit depending upon the preset output current of the machine, with greater percentages being fed to the control circuit at the lower currents. With such an arrangement, the ratio of short circuit to welding current at low current outputs is greater than at the higher current outputs. These ratios may be as desired but at the minimum output conditions a 4—1 ratio is desired while at the maximum rated output conditions, a ratio of 1.25—1 is desired.

Further in embodiments of the invention, the source, when a short circuit occurs, provides a short pulse of high current to the electrode to break the short and if such short is not broken in a predetermined time period, the SCRs are phased back at a controlled rate to prevent damage to the power components.

Further in carrying out the invention, a voltage proportional to the line voltage may be fed to the control circuit to change the conduction angle of the SCRs and maintain the voltage output constant despite line voltage variations.

Further in preferred embodiments of the invention, the control circuit energizes the gates of the main SCRs with a high "back porch" voltage which ensures the turning on of the SCRs at the prescribed angle.

Further, in accordance with a preferred embodiment of the invention, a three legged three phase transformer is provided having a built in magnetic shunt dividing the legs into a close and a tight coupled portion with the primary winding being on the close coupled portion and the secondary windings being divided into two sections one on each leg portion whereby to provide a transformer having a drooping volt-ampere curve. Further the division of turns of the secondary is such as to provide equal voltage outputs from each secondary windings.

The principal advantage of the invention is that it provides an improved arc welding power source of the transformer-rectifier type which enables improved and easier manual welding.

Another advantage of the invention is that it provides a source of the type described wherein the three phase transformer is simple in construction and has a high intrinsic internal reactance.

Another advantage of the invention is that the transformer core design may be such that the laminations may be manufactured without producing scrap and the transformer may have a minimum physical size for a maximum power handling capability.

Another advantage of embodiments of the invention is that they include a con-

a port
cluding an
reset value
to a d.c.
ie turn-on
is control-
wer resist-
the maxi-
ce circuit
modified
cond trans-
ort-circuit
transistor
l modified
lting from
aid power
etermined
al voltage,
ther SCR,
istor and
or causing
ne of said
ain SCRs

the signal
rol circuit
choke is
nge of the
ian at low
r welding

he control
ent of the
lower cur-
ent at low
may be as
ile at the

uit occurs,
nd if such
back at a

ne voltage
SCRs and

energizes
the turn-

n, a three
it dividing
being on
vo sections
ping volt-
to provide

proved arc
roved and

type des-
has a high

n may be
the trans-
capability.
ide a con-

5
10
15
20
25
30
35
40
45
50
55
60
65

5
10
15
20
25
30
35
40
45
50
55
60
65

control for changing the conduction angle of the SCRs which automatically changes the number of conduction periods for the SCRs to reach steady state condition to correspond with the preset welding currents.

Another advantage of the invention is that embodiments thereof permit relatively high short circuit currents for a brief period of time and, if the short circuit is not broken within such time period, phase back the SCRs to low-current within a controlled number of conduction periods.

Another advantage of the invention is that arc welding power sources embodying the invention have a drooping volt-ampere output curve and that means are provided for varying the output so that the arc current will remain constant at a preset value.

Another advantage of embodiments of the invention is that the arc voltage is varied to maintain the output current constant and that provision is made for a brief high short circuit current to break a short circuit if the electrode should touch the workpieces, further in combination with means which will reduce the output of the source if the short circuit is not quickly broken.

Another advantage of embodiments of the invention is that they may include means for varying the conduction angle of the SCRs to compensate for line voltage variation.

Another advantage of embodiments of the invention is that they may include means for varying, in proportion to the arc welding current, the rate of change of current surges to the control circuit upon the occurrence of short circuits in the event of short circuiting of the electrode to the workpiece.

Another advantage of embodiments of the invention is that the ratio of short circuit current to welding current may be substantially reduced at the higher welding currents.

A preferred embodiment of the invention will be described in detail in this specification and illustrated in the accompanying drawings wherein:

Figure 1 is a schematic diagram of the main or power welding circuitry;

Figure 2 is a schematic view of the transformer core and winding arrangement;

Figure 3 is a schematic diagram of the firing control and overload protection circuits;

Figure 4 is a volt-ampere curve of the power source at minimum and maximum outputs; and

Figure 5 is a voltage-time curve showing the triggering voltages of the SCR firing circuit.

Referring now to the drawings which are for the purposes of illustrating a preferred embodiment of the invention only and not for purposes of limitation, Figure 1 shows a three phase transformer T having primary windings 20 and secondary windings S1, S2, S3 connected to a full wave semi-converter rectifier bridge circuit, a choke L1 in series with one d.c. output lead of the bridge, and a polarity reversing switch SW1 connected between the bridge and electrode and work terminals E, W, respectively. The output leads of the secondary windings each pass through a current transformer, CT1, CT2, CT3 the secondary windings of which are in a Y connection the purposes of which will be described hereinafter with reference to Figure 3. The other output lead of the bridge is linked with the core of an inductance L2 for purposes which will be described below with reference to Figure 3.

The rectifier bridge is comprised of three diodes D_A , D_B , D_C and three semiconductor controlled rectifiers SCR_A , SCR_B , SCR_C in a known semi-converter bridge circuit. The latter rectifiers will hereinafter be referred to generically as the main SCRs. A diode D_D is connected across the output of the bridge. As is known, by controlling the phase angle of firing pulses to the mains SCRs relative to the alternating voltages applied to the rectifier bridge, the conduction angles of the SCRs may be readily varied and the output voltage of the power source thus readily controlled.

The transformer T is of a construction wherein high internal leakage reactance is achieved through the use of an iron shunt path in the lamination assembly which separates a portion of the secondary windings from the primary windings. In the embodiment shown in Figure 2, the lamination assembly is made up of four T-shaped iron sections; a right-hand section 10, a left-hand section 11, a central top section 12 and a central bottom section 13. The right-hand and left-hand sections are identical to each other and the central top and bottom sections are also identical to each other. The cross bar portions of the four T-shaped sections are all arranged in a rectangle with the legs of the T's on the inside of the rectangle. The ends of the legs of the top and bottom sections abut each other, while the sides of these legs are positioned between and spaced from the ends of the leg portions of the right-hand and left-hand sections. These latter leg portions form a magnetic shunt path and the resulting core

5
10
15
20
25
30
35
40
45
50
55
60
65

5 has three vertical legs with a portion of each leg below the shunt path and a portion of each leg above the shunt path. A primary winding 20 is placed below the shunt section on each of the three vertical legs formed by the four iron sections. The secondary windings S1, S2, S3, are each divided into a tightly coupled portion 21 placed one on each of the three vertical legs below the shunt path, and thus adjacent to the primary windings, and a loosely coupled portion 22 placed on the vertical legs above the shunt path. The transformer thus has an intrinsic leakage reactance resulting in a drooping volt-ampere output curve, the slope of which can be determined in advance by the design of the shunt air gap, lamination stack length and the ratio of turns in the loosely and tightly coupled portions of the secondary windings.

10 With the configuration of the magnetic shunting path shown, the central loosely coupled secondary windings will have approximately half the flux linkage with the primary windings as compared to the outside loosely coupled secondary windings. The central secondary winding must therefore have a distribution of loosely and tightly coupled secondary turns which is different from that of the outside secondary windings. The distribution must be such that when the loosely and tightly coupled windings on each leg are connected in series, the resultant output is balanced, reflecting the summation of the individual coils. In the preferred embodiment, the total number of secondary turns in each winding is the same, with the central tightly coupled secondary winding containing, 70—75% of the total secondary turns as compared to 40—42% of the secondary turns on the two outside tightly coupled windings.

15 The described transformer provides internal magnetic shunts in a three phase scrapless lamination. This produces a high reactance transformer, yet maintains a lamination stack length, leg height and coil configuration that results in efficient use of materials. Because of the internal reactance in the transformer, the main SCR's can also be operated near maximum conduction angle to achieve the maximum output of the power source. This enables the SCR's to operate at the lowest possible RMS current for a given conduction angle.

20 The d.c. output filter choke L1 reduces the ripple voltage at low output current and the following criteria have been found desirable for power sources of different current ratings:

	Rated Maximum Current Amperes	Inductance, mH	Flux density lines/in ²	Amperes
35	300	8.4	81,000	at 45
	400	6.7	84,000	50
	500	5.5	90,000	60

40 The choke iron section is a toroid wound from 14 gauge low carbon, hot rolled steel. This toroid iron section is then cut in two places, 180° apart, and a helical coil is placed around the iron section. The iron section is then closed with air gap spacers inserted at the two cuts and the sections welded in place.

The inductance of the choke is unusually large for a three phase power source and provides excellent arc stability and reduces pop-outs.

45 The control circuits control the SCR's of the power source to give a voltage output curve from the transformer-rectifier combination such as to overcome the difficulties on starting or short circuiting which such high inductance might otherwise cause.

50 Welding tests have revealed that the SCR control circuit must be capable of providing the power source with a response time of 10 milliseconds. This response is needed to achieve a step function response to a change in loading without having any substantial overshoot. This means that as the electrode shorts momentarily during normal arc transfer, the transient short circuit current will not exceed that of a steady-state short circuit of the same resistance path.

55 Snubber circuits provided for the main rectifier bridge are composed of resistor and capacitor networks that reduce rapid changes in voltage with respect to time, (dv/dt). There are four separate networks: Ra, Ca; Rb, Cb; Rc, Cc, which protect the main SCR's and Cd, Rd which protects the three phase bridge as a whole. Diode D_p protects the bridge from reverse polarity transients and aids in the commutation of the main power SCR's.

60 The output current control circuit shown in Figure 3 receives a control signal from the secondaries of the current transformers, CT1, CT2 and CT3 which are in a Y connection. Six diodes D20 to D25 form a three-phase bridge which rectifies the voltage across these secondaries to provide a control signal. This signal from the cur-

	4	5	1,491,800	5
a portion of the shunt			rent transformers is proportional to the load current of the main transformer and performs two separate functions.	
The second 21 placed	5	5	The first function of this rectified signal is to control the output of the welder by the amount of feedback fed into the main SCR firing circuits. This feedback will determine the conduction angle or phase-back angle of the main SCR's. The time the SCR's are turned on during a forward biased condition is the conduction angle. The time the SCR's are turned off during a forward biased condition is the phase-back angle.	5
cent to the legs above			As to the first function, there are two current dial selections A and B selected by ganged switches SW3, SW4, SW5, all shown in the B position. Dial "A" expands the rotational adjustment for the lower third of the current range. Dial "B" is a fairly linear adjustment of the entire range of current of the machine.	
ulting in a in advance	10	10	Control of the output is performed by two groups of elements: one group for Dial "A" and a second group for Dial "B" with some elements common to both dials.	10
urns in the			Output control elements that are common to both dials are resistors R33 and R37, capacitor C20, diodes D26, D33, D34 and D35, resistors R1 and R3, choke L2, diodes D1, D2 and ganged switches SW3, SW4, SW5. Output elements exclusive to "B" dial are diodes D27, D28, and resistor R20. Output control elements exclusive to the "A" dial are diodes D30 and D31, and resistors R35, R34, R36, R4 and R5.	
tral loosely	15	15	For Dial "B" the feedback voltage from the current transformers is developed across resistor R1 and filtered by choke L2. This filtered voltage is then fed into potentiometer R3, the current control rheostat, which is connected in parallel with R33 by way of switch SW5 and diode D2. The feedback is taken between leads 205 and 204 and is clamped by diodes D27 and D28 so an excess of feedback voltage does not enter the firing circuit. Resistor R20 is an adjustable resistor (trimmer) that sets the calibration of the "B" scale. Its function is to distribute load points evenly over the rotation of the current control rheostat adjustment. The purpose of diode D26 is described in the subsequent explanation of fault protection arrangements. Capacitor C20 is an R.F. by-pass filter capacitor.	15
e with the dings. The			For Dial "A" the feedback voltage from the current transformers is developed across resistors R1 and R4 and filtered by choke L2. This filtered voltage is then fed into potentiometer R3, the current control potentiometer. This potentiometer, in series with R5 is in parallel with R33. The feedback is taken between leads 205 and 204 and is clamped by resistor R35 and diodes D30 and D31. The addition of resistors R4 and R35 provides more feedback voltage for a given low value of current set on Dial "A" than on Dial "B". The remainder of the circuit consists of resistors R34 and R36. Resistor R36 is an adjustable resistor (trimmer) which in conjunction with resistor R34, which is connected in shunt with the upper limb of potentiometer 3, sets the calibration of the expanded low current Dial "A". Diodes D1, D2 prevent interaction between the "A" and "B" dials. Resistor R5 limits the maximum current adjustment of the expanded low current dial "A". Capacitor C20 is an R.F. bypass filter common to dials "A" and "B". Switch SW3, 4, 5 is the selector switch for Dial "A" or Dial "B". The switch switches the components that are exclusive to Dial "A" or Dial "B" into the circuit.	
nd tightly	20	20	Diodes D33, D34 and D35 maintain feedback to the firing circuit if the current dial selector is switched under load.	20
ary wind-pled wind-			The output of the current control is fed to the base of transistor Q40, one of which is included in each of three SCR firing circuits of which one only is shown, by wire 205.	
lecting the number of	25	25	In operation the feedback voltage or signal is proportional to the load current and is generated by the current transformers in each of the three legs of the three phase transformer secondaries S. It is then rectified by diodes D20—D25 and filtered by choke L2 which is arranged to be affected by the load current. The choke L2 is iron cored and has a nominal inductance of ten henries and a resistance of 17 ohms. The d.c. welding current lead 5 is linked with the iron core by passing through it to aid in the saturation of the choke thus reducing its inductance at the higher welding currents. The choke L2 also has a resistor R37 in shunt with it for allowing rapid changes in welding current to feed a portion of the signal into the control circuit without any time delay. At low currents it takes twice as long as at high currents for the main SCR's to reach a new steady state value. This system of choke L2 employing variable inductance, with resistor R37 in shunt with it, allows enough filtering to eliminate any substantial overshoot on feedback, to provide a good damping factor, and at the same time, to introduce proper system response, i.e. changes in output of the main SCR's, to cause the proper system dynamics for good constant current welding. This choke system filters the small conduction angle signals that are generated at the low cur-	25
led second-				
ed to 40—	30	30		30
a three				
maintains	35	35		35
efficient use				
main SCR's				
sum output				
sible RMS				
ut current				
if different				
res				
5				
0				
0				
hot rolled				
helical coil				
ap spacers				
wer source				
voltage out-				
the diffi-				
otherwise				
ble of pro-				
response is				
having any				
rily during				
of a steady				
of resistor				
it to time,				
ich protect				
ole. Diode				
mmutation				
ontrol signal				
ch are in a				
ectifies the				
m the cur-				

rents. As the welding load current increases, the inductance and thus the effect of choke L2 becomes less and less. This is important as it ensures good tracking of the three main SCR's. Tracking is the ability of all three SCR's to conduct at the same conduction angle.

5 The response of the system is extremely important in starting of the electrode and the stability of the arc under the dynamics of arc welding. At minimum welding current it takes three SCR conduction periods to achieve a steady state value from open circuit to short circuit. Each succeeding pulse is phased further back until steady state is achieved.

10 When the short-circuit is broken, at minimum output current settings, it takes six to seven SCR conduction periods to reach open circuit. Each pulse increases the conduction angle until the open circuit condition is established. This is due to the choke L2 in the signal conditioning section of the circuit. To get from open circuit to a load condition other than a short-circuit, the response is one to two conduction periods of the SCR's.

15 At higher current settings of the current control potentiometer R3, a smaller percentage of the feedback signal is used for controlling the output. At these higher current levels, since the choke L2 is saturated it takes two SCR conduction periods to get to steady state on short circuit and it takes only three conduction periods of the SCR's to return to open circuit from a short circuit.

20 The second function of the signal from the current transformers is to sense the magnitude of the output current and to reduce the conduction angle after a specific duration of overload. This reduction in conduction angle will reduce the output of the power source until the overload is removed from the transformer. This protects the components of the power source from overstress due to excessively long overloads.

25 As to the second function under overload conditions, the overload protection circuit will decrease the conduction angle of the main SCR's at a controlled rate. Once an overload condition is established, the divider network, resistors R30, R31, R29 and filter capacitor C26 will switch on transistor Q21. Zener diode DZ21 sets the switching voltage and trimmer potentiometer R31 sets the percentage of feedback voltage to trigger the transistor Q21. Once transistor Q21 turns on, capacitor C24 charges through resistor R27 with a fixed R-C time constant. Once capacitor C24 charges to the switching voltage of the silicon unilateral switch (SUS), the switch SUS will trigger and will in turn fire SCR₁. Once SCR₁ fires, capacitor C25 will discharge through resistor R23 and will supply the holding current for SCR₁.

30 Resistor R25 and capacitor C21 form a snubber circuit for SCR₁ to prevent false triggering and capacitor C23 and resistor R26 protect the gate of the SCR from false triggering in the presence of R.F. interference. Once SCR₁ is fired, a voltage drop is developed across resistors R22, R32, R24 and R28. The voltage across resistors R22 and R32 charges capacitor C22 which provides a time constant that will gradually turn on transistor Q20. Zener diode DZ20 clamps the voltage across resistors R22, R32 and R24 so the time constant is repeatable. Zener diode DZ22 protects the circuit from voltage transients. Once transistor Q20 turns on, a current flows through resistors R20 and R21 that is a function of the total feedback voltage. This is compared with the partial voltage supplied by the divider network of potentiometer R3. Diode D26 is used to prevent current from flowing through the adjusted resistance of potentiometer R3. Once the total feedback from the current transformer CT is fed into the firing circuit by wire 205, minimum output is obtained. Since the only power supply for the circuit comes from current feedback, to reset the circuit, current must stop flowing, i.e. the load must be broken. This will reset the overload protection circuit as SCR₁ will turn off.

35 The fault protection circuit has several advantageous features. When the overload or fault circuit is activated after a time delay predetermined by the R27, C24 time constant, the controlled feedback is gradually raised by the time constant provided by C22, R24 and R28 to the 100% value which yields maximum phase back of the SCR's and a preset minimum output. This is necessary to avoid a shoot through condition that will cause one of the main SCR's to carry maximum current. A fault condition is defined as an accidental short-circuit of the power supply lasting for one second. An overload condition is a load exceeding the rating of the power supply for two to three seconds. In both cases, there is a gradual, 500 milliseconds typical, decrease in phase back after the initial time duration of the overload or fault.

40 The signal conditioning of the control circuit and feedback elements is extremely critical. Too much filtering causes unstable operation due to poor response time. Too little filtering causes too rapid a change in feedback which will yield unstable operation dynamically.

the effect of
firing of the
at the same

the electrode
in welding
value from
back until

As it takes
increases the
due to the
open circuit
conduction

smaller per-
centage higher
in periods
of the

to sense the
at a specific
input of the
protects the
overloads.

protection cir-
cuit. Once
it, R29 and
the switch-
back voltage
24 charges
24 charges
SUS will
discharge

to prevent false
from false
voltage drop is
resistors R22
gradually
resistors R22,
the circuit
ough resis-
compared
R3. Diode
istance of
CT is fed
only power
current must
protection cir-

the overload
C24 time
provided by
lack of the
rough con-
fault con-
ing for one
supply for
ds typical,
ult.

extremely
time. Too
ble opera-

The firing circuits supply the energy to trigger the main SCR's with the timing required to obtain the desired conduction angle for any output of the welder. The firing circuits also compensate for line voltage variations when the welder is loaded. There are three symmetrical firing circuits one for each of the three main SCR's, SCR_A, SCR_B, SCR_C, but for simplicity only one will be described in detail and as shown in Figure 3.

Diode D40 provides half wave rectification from an a.c. source in phase with the voltage input to the respective main SCR. This voltage is supplied from auxiliary windings (not shown) on transformer T. Resistor R40 is a current limiting resistor for the Zener voltage-regulating diode, DZ40. Capacitors C40 and C49 are transient voltage and R.F. suppression capacitors. Diode D43 is a blocking diode that prevents capacitor C43 discharging through the Zener diode DZ40. Capacitor C43 filters the timing circuit voltage and also supplies the triggering power pulse to the respective main SCR. Resistor R64 and capacitor C58 comprise the snubber network for the pilot SCR, SCR₂. Capacitor C55 protects the gate of the main SCR_A from R.F. Capacitor C53 and diode D52 protect the gate of the pilot SCR from R.F. and resistor R82 provides a leakage path to line 204 for the anode to gate leakage current. Resistor R67 is the emitter load resistor and limits the current through SCR₂. Resistors R67 and R79 limit the gate current of the main SCR. Capacitor C61 protects the input to the circuits from R.F. interference and transients. Resistor R76 is in parallel with resistor R40 once SCR₂ turns on. This supplies sufficient "back porch" energy to trigger the main SCR. D49 blocks current through resistor R76 until SCR₂ is turned on.

The remainder of the components, transistor Q43, capacitor C46 and resistors R58 and R61 generate the timing signal that triggers SCR₂ to produce a desired output. These components make up a conventional relaxation oscillator.

The unijunction transistor Q43, triggers when the voltage across capacitor C46 reaches the triggering point of the unijunction transistor. This value is the voltage from base 1 to base 2 times the intrinsic stand-off ratio of the unijunction device. Resistor R61, the base 2 resistor, is connected ahead of resistor R43 and the voltage which it receives is therefore not regulated by the Zener diode DZ40. This will raise or lower the voltage VB1-VB2 between base 1 and base 2 of unijunction transistor Q43, with increases or decreases in line voltage, thus yielding line voltage compensation.

There are two paths for charging current to flow into capacitor C46. The first path is that through resistors R55 and R73 and produces a voltage 50 (see Figure 5) that increases progressively with time. This is a ramp voltage. The second path is through resistor R49, diode D46 and resistor R52. This path, a low resistance path, will charge the capacitor C46 very rapidly to a point determined by the divider network formed by a resistor R49, transistor Q40, and resistors R70 and R46. This network provides a pedestal function of voltage as shown at 51. The change in conduction angle is produced by a change in the pedestal function and is controlled by the current of the welder. The current feedback will control the magnitude of the pedestal function by varying the voltage between collector and emitter of the transistor Q40. This is done by introducing the feedback signal on lead 205 into the base circuit of transistor Q40. The signal introduced into the base circuit will reduce the collector to emitter voltage of Q40 and increase the time before triggering of unijunction transistor Q43 occurs.

The firing circuit is designed to yield preferably a four to one ratio of short-circuit to welding current under minimum output conditions. This is accomplished by adjusting resistor R70 which sets the level to which the pedestal voltage on transistor Q43 will drop under minimum output load conditions. The drop in pedestal voltage sets the amount of phase back of the main SCR's. For output currents above minimum, the ratio of short-circuit current to welding current is reduced. As an example, at the power supply rating, the ratio of short-circuit current to welding current is reduced preferably to 1.25:1.

The above is accomplished by the adjustment of the firing circuit and the control and feedback conditioning section of the circuit. At minimum output of the machine, one hundred percent of the feedback is used to phase back the output of the main SCR's. This phase-back condition reduces the output voltage of the main SCR's. As a result, a small change in current will yield a large change in feedback voltage which in turn will produce a large change in phase back angle.

As the welding current is increased, by adjusting the current control potentiometer R3, the percentage of feedback voltage is decreased. Thus for a given change in current, a smaller percentage of feedback is fed into the firing circuit, yielding a

smaller change in conduction angle. This change in percentage of feedback is an advantageous way of changing the ratio of short-circuit current to welding current as the output current is increased.

The change in ratio of short-circuit current to welding current is one of the features that make the present embodiment such a good power supply for normal and submerged-arc welding. If the slope of the output characteristic were vertical, the same or nearly the same ratio of short-circuit current to welding current would result at all values of current and the electrode would tend to stick. If the slope were strictly reactive, i.e. a small change in voltage for a change in current, the short-circuit current would be too high at the higher current settings and too low at the lower current settings. Therefore, the invention provides a dual slope machine that has the capability of selecting the short-circuit current for a given welding current.

The firing circuit has two adjustments. One adjustment is to set the maximum possible phase back angle, using resistor R73, and the second is to set the short circuit current value at minimum output, using resistor R70.

Two other features of the firing circuit are line voltage compensation and a "back porch" circuit. The line voltage compensation is accomplished by not clamping the voltage, taken from the junction of resistor R40 with resistor R43, which is applied to base 2 of the unijunction transistor Q43, so that this voltage varies with changing line voltage. The back porch circuit is a circuit, fed from the junction of D40 with resistor R40, that supplies more than enough half wave supply-frequency energy, properly phased, to the main SCR, to turn it on. Once SCR₂ fires, a large pulse of energy is supplied to the gate of the respective main SCR. If there is a phase shift between the anode voltage applied to the main SCR's and the gate signal, as happens under large current changes, the main SCR will not get a gate pulse at the proper time and it will not turn on. To preclude this problem arising, there is enough "back porch" signal applied through diode D40, resistor R76, SCR₂, and resistor R79 to turn on the main SCR. The "back porch" energy follows the initial gate pulse and is there for the remainder of the half cycle and applied to the gate of the main SCR to turn it on if the initial firing pulse fails to do so.

It will thus be seen that the described control circuit will change the firing angle of the main SCR's quickly enough to compensate for the large inductance of the choke L1 in the event of short circuiting of the electrode to the workpiece and yet overloads are prevented both by the phasing back of the SCR's and the inherent drooping volt-ampere curve of the transformer T.

Preferably the transformer has a maximum open circuit voltage of 70—100 volts so that the main SCR's need operate at a maximum phase back angle no greater than 20° to meet the maximum output requirements of the power source.

Figure 4 shows typical output curves of the described power source at maximum and at minimum output, it being noted that at short circuit conditions the maximum current is self limiting. The main SCR's may thus be of a current rating corresponding thereto.

At the minimum output currents, it will be noted that the volt-ampere curve is quite steep but gradually decreases in slope at or close to short circuit conditions. This improves on the operation at low welding currents.

For completeness, the values of the various components are listed as follows:

	μ F		
Ca, Cb, Cc—	.68 400 V	D40, D43, D46,	
Cd	1.0 400 V	D49, D52	1 AMP
C20	.022	D20 to D35	1 AMP
C21	.22	DZ20 to DZ40	20 V.
C22	100	DZ21	6.2 V.
C23	.047	DZ22	.82 V.
C24	100	DZ40	20 V. 1 W.
C25	30		
C26	50		
C61	.022		
C43	4.7		
C46	.1		
C52	.1		
C49	.047		
C55	.022		
C58	.22		

back in
ing current

one of the
normal and
vertical, the
ould result
were strictly
cuit current
current set-
e capability

maximum
e short cir-

tion and a
not clamp-
3, which is
varies with
junction of
y-frequency
res, a large
e is a phase
e signal, as
pulse at the
e is enough
resistor R79
e pulse and
main SCR

firing angle
of the choke
at overloads
oping volt-

—100 volts
greater than

t maximum
e maximum
correspond-

re curve is
itions. This

follows:

MP
AP
V.
V.
1 W.

Ra, Rb, Rc

Rd

R20

R21

R22

R23

R24

R25

R26

R27

R28

R29

R30

R31

R32

R33

R34

ohms.

47 2 W.

27 2 W.

500 1/4 W.

100

2700

330

27000

10

100

39000

2700

10000

1000

500 1/3 W.

6800

500 5 W.

1500

R35

R36

R37

R40

R43

R46

R49

R52

R55

R58

R61

R64

R67

R70

R73

R76

R79

R82

SCR₁—SCR₂

SUS

Q20—Q21

Q40

Q43

ohms.

27

500 1/4 W.

330

500 5 W.

27

150

3300

150

47000

47

680

10

47

500 1/4 W.

100 1/4 W.

330 5 W.

5.1

100

4A., 300 V.

2N4989

2N5679 PNP

2N2393 NPN

D5E43UJT

4A., 300 V.

WHAT WE CLAIM IS:—

1. A three phase-transformer-rectifier type d.c. arc welding power supply apparatus including a transformer having three primary and three secondary windings, a full wave rectifier bridge including at least three SCR's having input terminals connected by leads to said secondary windings and a pair of d.c. output terminals for the connection of leads adapted to be connected to a welding electrode and to a work-piece, whereby welding current will in use flow in said leads, a choke in series with one of said output leads and a control circuit for said SCR's, including a reactance in series with each of said secondary windings whereby the transformer has a drooping volt-ampere curve, means providing a d.c. feedback signal voltage proportional to the current in said secondary windings, and means for selecting a portion of said d.c. feedback signal voltage to control said firing circuit so that the power supply has a constant output current when a welding arc exists.

2. A power supply apparatus in accordance with claim 1 wherein said transformer has a core composed of three parallel spaced legs including two outer and one centre leg and members bridging both ends of all said legs to form closed magnetic loops, a magnetic shunt between adjacent legs intermediate the ends of said legs dividing each of said legs into a closely-coupled and a loosely-coupled section, each primary winding being on one of said close-coupled sections, each secondary winding being on one of said legs, a portion of each said secondary winding being on the closely-coupled section and a further portion on said loosely-coupled section.

3. A power supply apparatus in accordance with claim 2 wherein the number of secondary turns on the closely-coupled sections of the outer legs is 40—42% of the total and the number of secondary turns on the closely-coupled section of the centre leg is 70—75% of the total, said secondary windings all having an equal total number of turns.

4. A power supply apparatus in accordance with claim 1, 2 or 3 wherein said means for producing a feedback signal is a current transformer in series with each secondary winding lead and said rectifier means.

5. A power supply apparatus in accordance with claim 1, 2 or 3 including a choke having an iron core connected in series with said d.c. feedback signal, said core being magnetically coupled to one of said bridge output leads whereby welding current contributes to the magnetic saturation of said core.

6. A power supply apparatus in accordance with claim 5 wherein a resistor is connected in parallel with said iron core choke, said resistor and choke modifying the rate of change characteristics of said feedback signal voltage applied to said control circuit.

7. A power supply apparatus in accordance with any one of claims 1—6 wherein



272

		ohms.			
	Ra, Rb, Rc	47 2 W.	R35	27	
	Rd	27 2 W.	R36	500 1/4 W.	
5	R20	500 1/4 W.	R37	330	
	R21	100	R40	500 5 W.	5
	R22	2700	R43	27	
	R23	330	R46	150	
	R24	27000	R49	3300	
10	R25	10	R52	150	
	R26	100	R55	47000	10
	R27	39000	R58	47	
	R28	2700	R61	680	
	R29	10000	R64	10	
15	R30	1000	R67	47	
	R31	500 1/3 W.	R70	500 1/4 W.	15
	R32	6800	R73	100 1/4 W.	
	R33	500 5 W.	R76	330 5 W.	
	R34	1500	R79	5.1	
20			R82	100	
			SCR ₁ —SCR ₂	4A., 300 V.	20
			SUS	2N4989	
			Q20—Q21	2N5679 PNP	
			Q40	2N2393 NPN	
25			Q43	D5E43UJT	
				4A., 300 V.	25

WHAT WE CLAIM IS:—

1. A three phase-transformer-rectifier type d.c. arc welding power supply apparatus including a transformer having three primary and three secondary windings, a full wave rectifier bridge including at least three SCR's having input terminals connected by leads to said secondary windings and a pair of d.c. output terminals for the connection of leads adapted to be connected to a welding electrode and to a work-piece, whereby welding current will in use flow in said leads, a choke in series with one of said output leads and a control circuit for said SCR's, including a reactance in series with each of said secondary windings whereby the transformer has a drooping volt-ampere curve, means providing a d.c. feedback signal voltage proportional to the current in said secondary windings, and means for selecting a portion of said d.c. feedback signal voltage to control said firing circuit so that the power supply has a constant output current when a welding arc exists.
2. A power supply apparatus in accordance with claim 1 wherein said transformer has a core composed of three parallel spaced legs including two outer and one centre leg and members bridging both ends of all said legs to form closed magnetic loops, a magnetic shunt between adjacent legs intermediate the ends of said legs dividing each of said legs into a closely-coupled and a loosely-coupled section, each primary winding being on one of said close-coupled sections, each secondary winding being on one of said legs, a portion of each said secondary winding being on the closely-coupled section and a further portion on said loosely-coupled section.
3. A power supply apparatus in accordance with claim 2 wherein the number of secondary turns on the closely-coupled sections of the outer legs is 40—42% of the total and the number of secondary turns on the closely-coupled section of the centre leg is 70—75% of the total, said secondary windings all having an equal total number of turns.
4. A power supply apparatus in accordance with claim 1, 2 or 3 wherein said means for producing a feedback signal is a current transformer in series with each secondary winding lead and said rectifier means.
5. A power supply apparatus in accordance with claim 1, 2 or 3 including a choke having an iron core connected in series with said d.c. feedback signal, said core being magnetically coupled to one of said bridge output leads whereby welding current contributes to the magnetic saturation of said core.
6. A power supply apparatus in accordance with claim 5 wherein a resistor is connected in parallel with said iron core choke, said resistor and choke modifying the rate of change characteristics of said feedback signal voltage applied to said control circuit.
7. A power supply apparatus in accordance with any one of claims 1—6 wherein



said control circuit includes means responsive to large values of modified feedback signal voltages caused by short-circuits or source overloads for decreasing the conduction angle of said SCR's to a safe value, including means for delaying the actuation of said means for a predetermined time period after the beginning of said short-circuit or overload.

8. A power supply apparatus in accordance with claim 7 wherein said responsive means also includes means for controlling and slowing the rate of decrease of the conduction angle of the SCR's after said time period.

9. A power supply apparatus in accordance with claim 6 including means for preselecting a portion of said modified feedback signal voltage and feeding same to said control circuit whereby the output voltage of said power source will be controlled to provide a constant welding current.

10. A power supply apparatus in accordance with claim 9 including means for feeding the total modified feedback signal voltage to control means responsive to large values of modified feedback signal voltage caused by short-circuits or source overloads and means associated with said control circuit for decreasing the conduction angle of said SCR's to a safe value when said means respond, including means for delaying the response of said responsive means for a predetermined time period after the beginning of the short circuit or overload.

11. A power supply apparatus in accordance with claim 10 including means for reducing the rate of decrease of the conduction angle of the SCR's after said responsive means become operative.

12. A power supply apparatus in accordance with any one of claims 1-11 wherein said control circuit includes an oscillator for each SCR firing in phase with the anode voltage on said SCR, means for delaying the firing signal to decrease the conduction angle of said SCR, and means for feeding an unclamped pulsed d.c. voltage proportional to the line voltage from said source to said oscillator to adjust the firing thereof upon a change of line voltage to compensate the output of said power source for line voltage variation.

13. A power supply apparatus in accordance with claim 6 wherein said control circuit includes an oscillator for each SCR firing in phase with the anode voltage of said SCR means for delaying the firing signal to decrease the conduction angle of said SCR's, said oscillator including a transistor and a capacitor and first and second parallel resistive paths for charging same to the firing potential of said transistor, said first path including a relatively high resistance, said second path including a relatively low resistance and means controlling the maximum voltage of charging through said second path including a second transistor, the conductivity of which is proportional to the preselected portion of said modified feedback signal voltage.

14. A transformer-rectifier type d.c. arc welding power source including a transformer having three primary and three secondary windings, a full wave rectifier bridge including at least three main SCR's having input terminals connected by leads to said secondary windings and a pair of d.c. output terminals having leads adapted to be connected to a welding electrode and a workpiece whereby welding current will flow in said leads, a choke in series with one of said output leads; a current transformer in series with each secondary winding lead and having a secondary winding providing an output voltage proportional to the current in said lead, rectifier means associated with said current transformer secondary windings to provide a feedback signal, a choke and paralleled resistor in series with said feedback signal to provide a modified feedback signal, means for decreasing the inductance of said choke with an increase in welding current, means for selecting a portion of said modified feedback signal, a control circuit for said main SCR's including an oscillator having a first transistor and a capacitor which when charged to a preset value turns on said first transistor, said oscillator including an energizing lead to a d.c. voltage proportional to the line voltage to said power source whereby the turn-on voltage of said first transistor varies proportionately to the line voltage, means controlling the charging of said capacitor including a first higher and a second lower resistance circuit energized from a fixed voltage source and means for controlling the maximum charging voltage of said capacitor through said second lower resistance circuit including a second transistor, means feeding said pre-selected portion of modified feedback signal to said second transistor whereby the conductivity of said second transistor is proportional to said portion of said modified feedback signal, short-circuit control means associated with said second transistor for causing said second transistor to become fully conductive including a third transistor energized by the total modified feedback signal and being turned on by a modified feedback signal resulting from welding currents in excess of a predetermined maximum current rating of said power supply apparatus, means delaying the



29

-10

11

1,491,800

11

and feed back
the conduction
actuation of
short-circuit

5

5

is responsive
of the con-

means for
ing same to
be controlled

10

10

means for
ive to large
source over-
conduction
means for
period after

15

15

means for
aid respon-

20

claims 1—11
phase with
decrease the
d d.c. volt-
adjust the
said power

25

said control
voltage of
conduction angle
and second
transistor, said
line a rela-
ing through
is propor-

30

35

ing a trans-
ifier bridge
leads to said
to be con-
t will flow
transformer
providing
associated
al, a choke
dified feed-
increase in
k signal, a
transistor and
transistor, said
line voltage
varies pro-
apacitor in-
om a fixed
f said capa-
stor, means
d transistor
portion of
said second
including a
armed on by
a predeter-
elaying the

40

45

50

55

60

65

turn on of a further SCR for a predetermined time period after the application of said short-circuit modified feedback signal voltage, a fourth transistor caused to become conductive by said turn-on of said further SCR, means delaying the rate of change of the conduction of said fourth transistor and means feeding the output of said fourth transistor to said second transistor for causing said second transistor to become conductive and increasing the charging time of said oscillator capacitor to a time that will reduce the conduction angle of the main SCR's so as to produce a safe output current.

5

15. Power supply apparatus in accordance with any one of claims 1—13 wherein the series reactance is built into and is a part of the transformer winding-core arrangement.

10

16. Power supply apparatus in accordance with any one of claims 1—13 wherein the output volt-ampere curve of the transformer-reactance combination has an open circuit voltage of 70—100 volts and requires the SCR's to operate at a phase back angle of no greater than 20° to meet the maximum output requirements of the power source.

15

17. A d.c. arc welding power supply apparatus substantially as described with reference to the drawings.

A. A. THORNTON & CO.,
Chartered Patent Agents,
Northumberland House,
303/306 High Holborn,
London, W.C.1.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1977
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
which copies may be obtained.