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WELD ENERGY MONITOR

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Abstract

A weld energy monitor has been developed to measure electrical energy delivered to resistance welds. The monitor combines the measurement of voltage, current, and time into an energy measurement with accuracy traceable to the National Bureau of Standards. The monitor has a range of 0 to 300,000 joules. Maximum weld voltage and current ranges are 0 to 5 volts and 6 to 30,000 amperes. Accuracy is better than ±2% of indication ±50 joules. The precise measurement of energy is required at the Savannah River Plant to help ensure the quality of production welds.

Introduction

A weld energy monitor has been developed to measure electrical energy delivered to 60 Hz alternating current resistance welds made at the Savannah River Plant. Precision measurement of weld variables such as voltage, current, time, and force are required to help ensure weld quality. The monitor combines the measurement of voltage, current, and time into an energy measurement with accuracy traceable to the National Bureau of Standards.

An energy monitor has been used with development welders for six months and two instruments will be built for production welders this year. The instrument is designed specifically for one type of welder, but it may also be used with other resistance welders.

Summary

The instrument measures energy over a range of 0 to 300,000 joules to an accuracy of ±2% of indication ±50 joules, and counts half-cycles of AC current delivered to a weld up to 99 with an accuracy of ±1 half-cycle. Weld voltage and current ranges are presently 0 to 5 volts and 6 to 30,000 amperes. A gain change in the input amplifiers will provide for input weld voltages from 5 to 28 volts and currents of 0 to 6,000 amperes. Specifications are outlined in table 1.

Figure 1 is a single-line diagram of the instrument. Signals proportional to and in phase with weld current and voltage are multiplied together to obtain instantaneous power. The power signal is integrated over the welding time to obtain energy. The integration time starts less than 1 millisecond after the weld begins and is adjustable from 1 to 99 half-cycles (1 half-cycle ≈ 8 milliseconds). After the weld has been completed, energy is displayed on a digital voltmeter which also serves as the integrator for the power signal. Weld half-cycles are counted during the weld and displayed digitally by the energy monitor.

Discussion

The operating principle was verified in the laboratory using a precision signal generator (to simulate weld current and voltage signals) and by work on development welders. When the instrument is connected to a welder, the voltage signal is taken between the welder electrode and the base plate (or between the two welder electrodes) and the current signal is obtained from a precision AC shunt (figure 2). The energy measured includes energy dissipated in the weld plus the fixture and interfaces between the fixture and the electrodes, since voltage drop is measured across the fixture and not just across the weld. The percentage of energy dissipated by current flow through the fixture is small since fixtures have low resistance compared to that at the weld point.

Figure 3 shows the sequence of signals through the instrument during a weld. The voltage signal across the piece being welded is coupled through an isolation amplifier to an analog multiplier. The current signal from the shunt is amplified and then multiplied by the voltage signal in the analog multiplier. The multiplier output signal represents the instantaneous product of voltage and current (power). The integrating digital voltmeter (IDVM) integrates the power signal over a period set by switches on the front panel. This period is set about 2 or 3 cycles longer than the weld duration expected so that additional energy will be indicated if the weld controller should fail and deliver increased current or additional weld cycles. The voltmeter displays energy in joules delivered to the weld (1.00 millivolt = 100 joules).

The first half-cycle of current initiates the integration "start" signal to the IDVM. As the first half-cycle begins, a high gain amplifier saturates in less than 1 millisecond to provide the start signal. The integration "stop" signal is generated by a circuit which counts pulses from a 120 Hz square wave generator and provides an output signal when the preselected number of pulses have occurred after the first half-cycle of weld current. An amplifier provides the signals to start and stop the IDVM.

Half-cycles are counted from the current waveform. The current signal is amplified and full-wave rectified to provide positive pulses for both positive and negative half-cycles. These pulses are converted to square pulses to provide the fast rise time pulse required by the counting circuit. Filtering prevents spurious counting of transients on the power line. A two-decade counter counts the pulses and provides a BCD output to an indicating tube driver circuit. The count is displayed on "Nixie" [trademark of Burroughs Corp.] digital indicating tubes.

INSTRUMENT COMPONENT AND PACKAGING

Precision components are used where necessary to provide required accuracy. Minimum operating controls simplify operation in production use. Major circuits are on printed circuit cards to simplify troubleshooting and repair. Figure 4 shows the front panel and component layout.

Solid state operational amplifiers provide signal amplification and conditioning. The amplifiers with associated components for each function (amplification, pulse shaping, etc.) are mounted on separate circuit cards to facilitate maintenance. Placing the amplifier input and feedback elements close to the amplifier connections provides stable operation. Figure 5 shows the layout of a typical card. The layout of cards for all amplifiers is identical (associated components are different).

The multiplier is a small encapsulated unit designed to precisely multiply two analog signals. It uses the variable transconductance characteristic of transistors to give good linearity with wide-band response; the result is low distortion multiplication. The multiplier is mounted on a card like the operational amplifiers. All cards are the same size and plug conveniently into connectors in a rack. Rack connections are made through wire-wrap terminals for high reliability.

Front panel controls include "Digiswitches" [trademark of Digitran Co.] for setting IDVM integration time, switches to reset the instrument to zero after a weld, switches to put calibration check signals into the voltage and current inputs, and zero and gain controls to adjust out small offset variations which may occur with time or temperature changes.

AC SHUNT

Overall instrument accuracy is dependent on receiving two signals from the welder that are proportional to welding voltage and current. The voltage signal is the voltage drop across the piece being welded. An AC shunt was designed to SRP specifications by a commercial supplier [Holt Instrument Co., Oconta, Wisc] to provide a signal proportional to current and maintain the phase relationship with the voltage signal. Accuracy of the shunt is less than ±1%, 0 to 1000 Hz, 0 to 30,000 amperes. Figure 2 is a diagram of the shunt and table 2 gives shunt electrical specifications.

An AC shunt differs from a DC shunt in that it has little or no reactive component. It remains nearly a pure resistance even at high frequencies. The AC shunt uses a field cancellation technique to reduce mutual inductance and an external phase compensation network to reduce the small amount of self-inductance in the flat shunt plates. (Error without the compensating network would be about 2% of measurement.) Current flows in opposite directions in the two shunt plates to cancel the equal magnitude and opposite polarity signals which could be induced in the plates by the large electromagnetic fields present around the shunt when a weld is made. The phase compensation network is a resistor-capacitor combination that provides an equal and cancelling capacitive reactance for the small inductive reactance of the shunt.

The shunt is designed to fit between the base plate and a transformer secondary tap on a particular type of welder. Shunt resistance is only 10 micro-ohms; this additional resistance in the weld circuit has a negligible effect on weld current.

Shunt plates are made of manganin to achieve a very low temperature coefficient of resistance (0.01% per degree centigrade). Tests have shown that the temperature rise of the plates should be about 40°C for a 35,000 amp, 40-cycle weld; this would cause an error due to temperature rise of only about 0.4% of measurement. The temperature of the plates returns to ambient very quickly after a weld is made because of the heat sink which the large copper terminals provide. Duty cycle is rated at 0.5% or about one 40-cycle, 30,000 amp rms weld every two minutes. Shunt plates are sealed in epoxy to prevent surface contamination and consequent resistance changes.

NBS TRACEABILITY

Instrument accuracy can be made traceable to the National Bureau of Standards (NBS) by certifying the shunt and the instrument separately. Shunt resistance has been determined by measurements made with 1000 amps at 60 Hz by NBS and extrapolations made to certify the device to 30,000 amps. A technique has been established at SRP to periodically confirm the certification. The instrument can be certified at the plant by putting standard signals (traceable to NBS) into the current and voltage inputs, setting the integration time, and comparing the output displayed on the IDVM to the known value of $\int_0^T ei\ dt$. The integration time can also be certified by conventional methods.

LABORATORY TESTS

Tests were made on the first instrument to ensure accuracy and linearity. A dual output signal generator was used to simulate weld voltage and current signals. Accuracy and linearity of displayed measurements were within 1% of indication ±50 joules (the overall accuracy of ±2% ±50 joules quoted in table 1 is combined shunt and instrument accuracy). Table 3 shows indicated energy in joules for varying current and voltage. Error is plotted in figure 6. Data shown were taken with signals in phase. The instrument was also tested with phase angles from 0° to 180° between the signals, with equally accurate results.

The frequency spectrum of the weld current waveform was analyzed using a tunable bandpass filter to establish the required frequency response of the shunt and the instrument. The highest frequency components in the signal are about 1 kHz. Tests show that instrument accuracy is maintained up to 10 kHz.

The instrument was used to measure energy delivered to a length of 4/0 cable using a weld controller as a power source. A DC shunt was used for current signals since the AC shunts had not been received at that time. Tests were made over a time range of 10 to 40 half-cycles for 20 to 100% controller heat settings with each weld transformer tap setting. Absolute accuracy was not expected since the DC shunt was used but good linearity of energy versus time and good repeatability were indicated. A family of curves is shown in figure 7 and a sample of data is included in table 4.

The instrument and AC shunt are now being used on a developmental welder to establish the energy required for each of the production welds and the repeatability of indication.

WELDER OPERATION

AC resistance welds are made using solid-state phase heat controllers, "Powerstats" [trademark of Superior Electric Co. for its variable transformers], and variable tap current transformers to control the energy delivered to the welds. Figure 8 is a diagram of the basic arrangement.

The line voltage to the ignitron tubes is adjusted between 300 and 480 volts AC with the variable transformer, except for high current welds when the transformer is switched out and line (480 v) voltage is used. The phase angle of the 60 Hz voltage at which the ignitrons fire and the number of cycles they fire are controlled by the weld controller and are adjustable. The voltage from the ignitrons is stepped down to between 5 and 28 volts by the weld transformer.

CURRENT AND VOLTAGE WAVEFORMS

Figure 9 shows typical current and voltage waveforms for various welder controller heat settings. Neither is a pure sinusoid except at 100% heat settings, but both have waveforms with a 60 Hz fundamental component. The waveforms have higher frequency components but tests show that most of the energy is below 250 Hz. Phase relationship between current and voltage is a function of the inductance of the weld current loop and can change slightly when the physical arrangement of the loop is changed for different weld fixtures. However, they are never more than a few degrees out of phase.

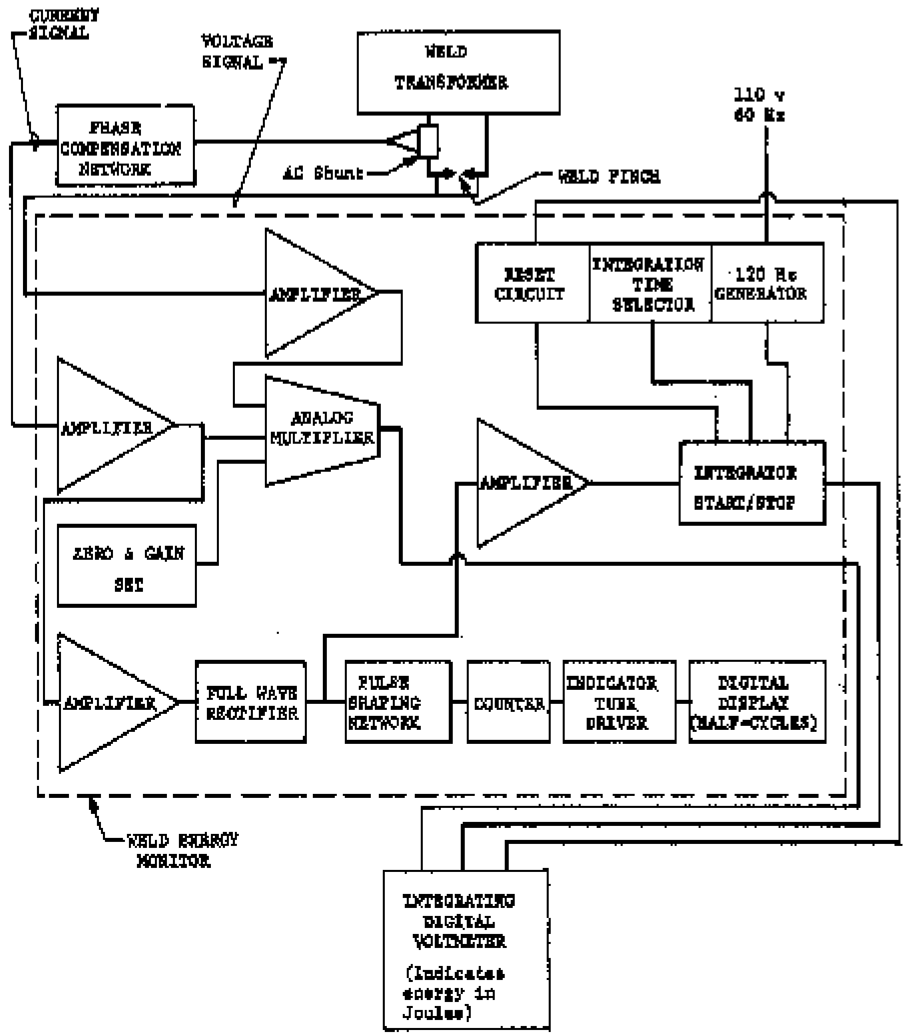

FIGURE 1. WELD ENERGY MONITOR

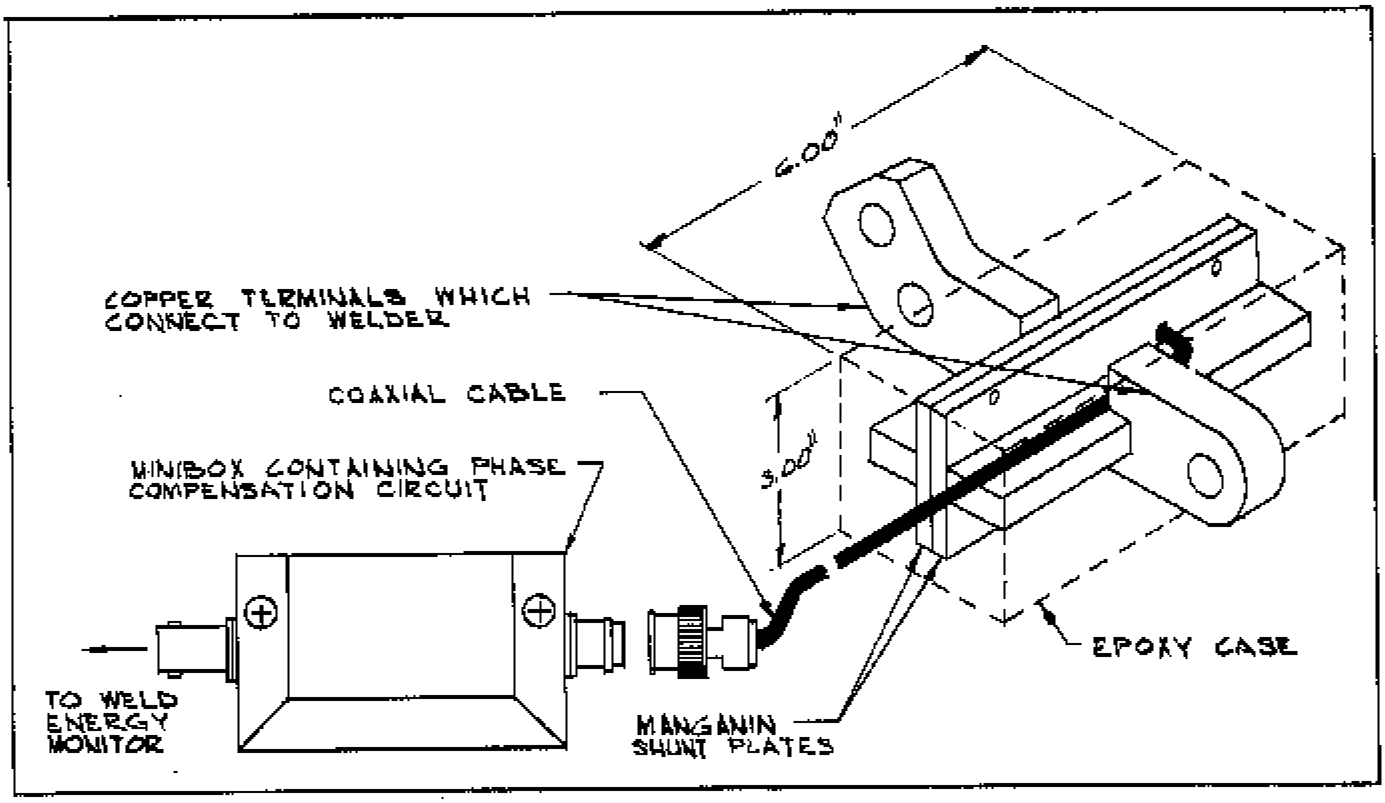

FIGURE 2. PRECISION AC SHUNT

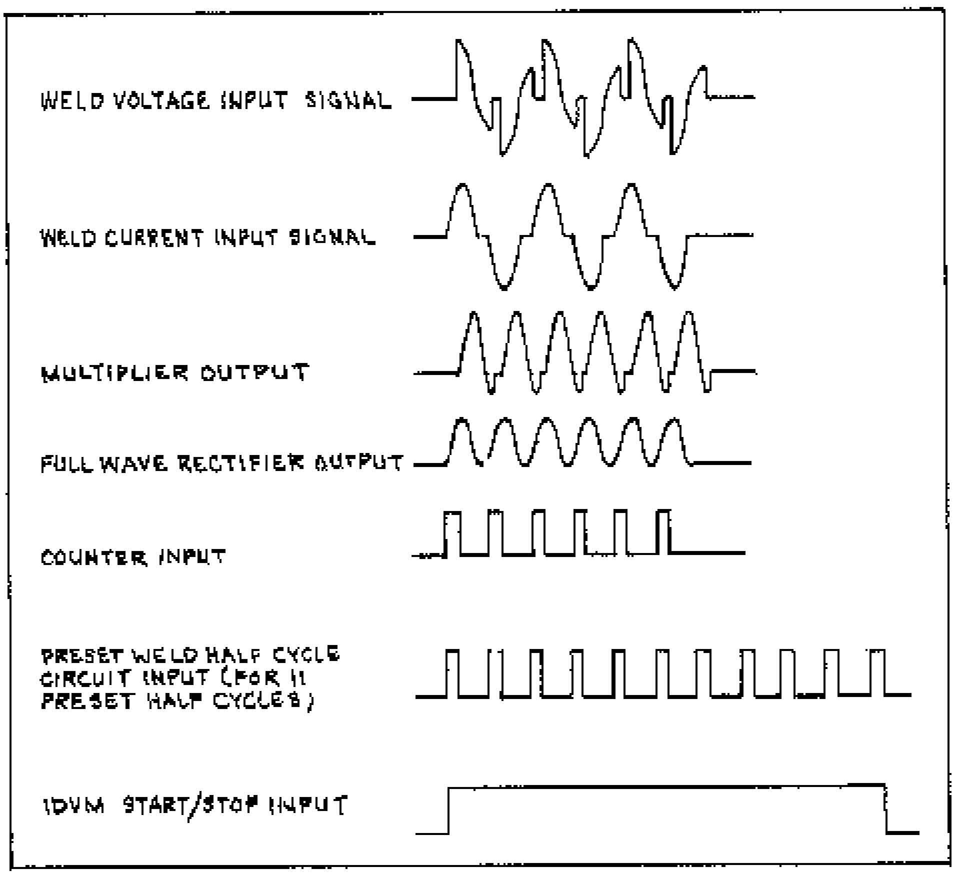

FIGURE 3. TYPICAL WELD ENERGY MONITOR WAVEFORMS FOR 3-CYCLE WELD

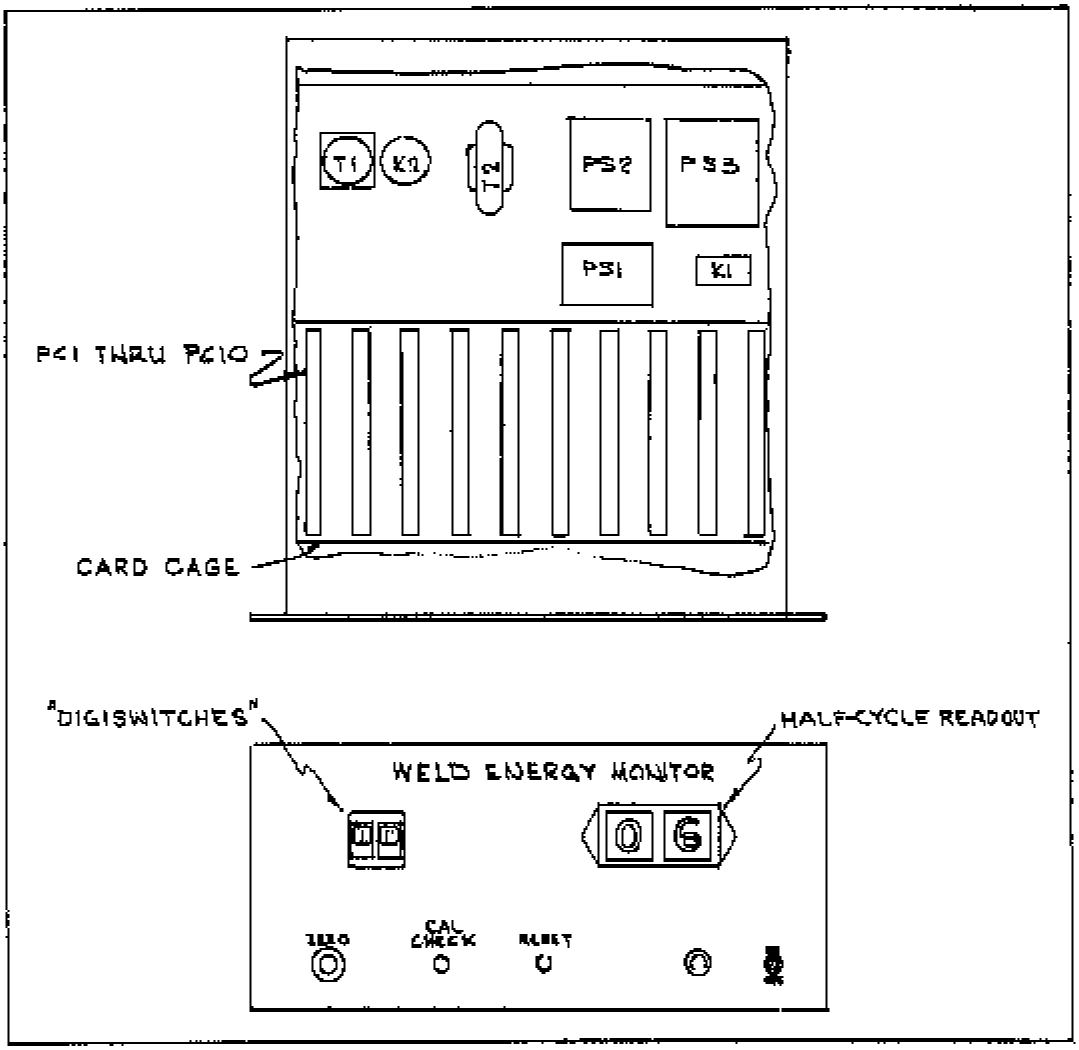

FIGURE 4. FRONT PANEL AND COMPONENT LAYOUT

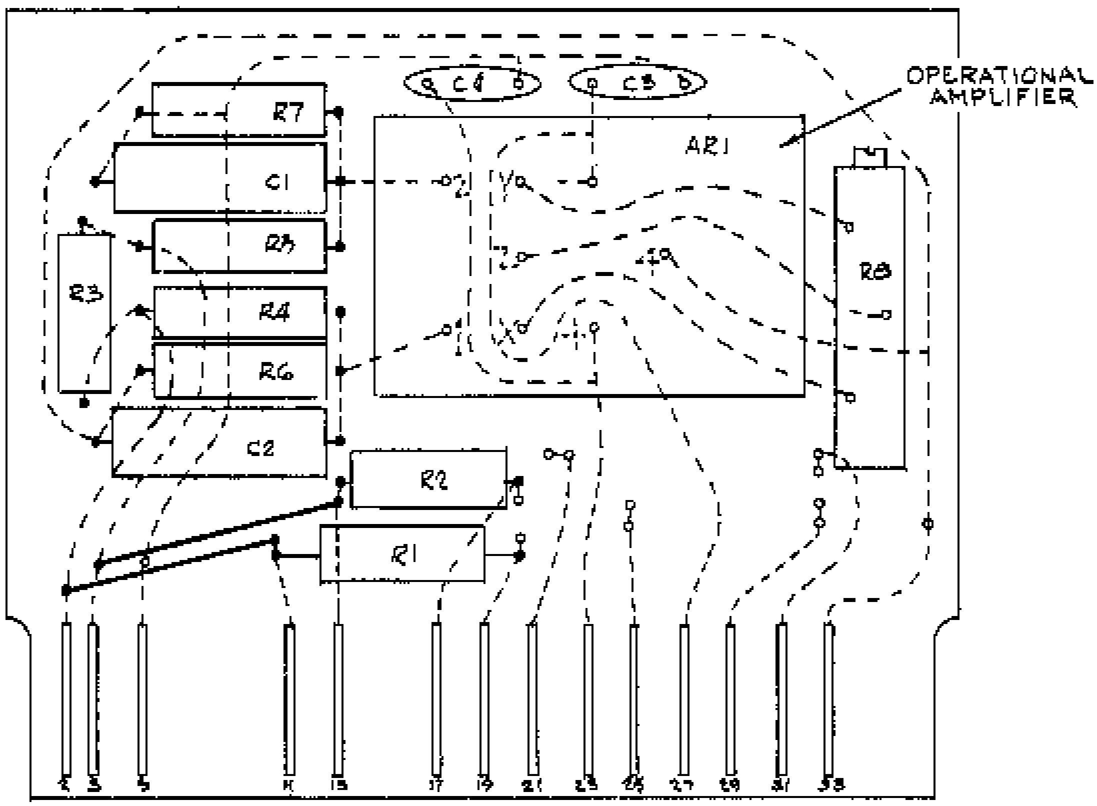

FIGURE 5. TYPICAL PRINTED CIRCUIT LAYOUT

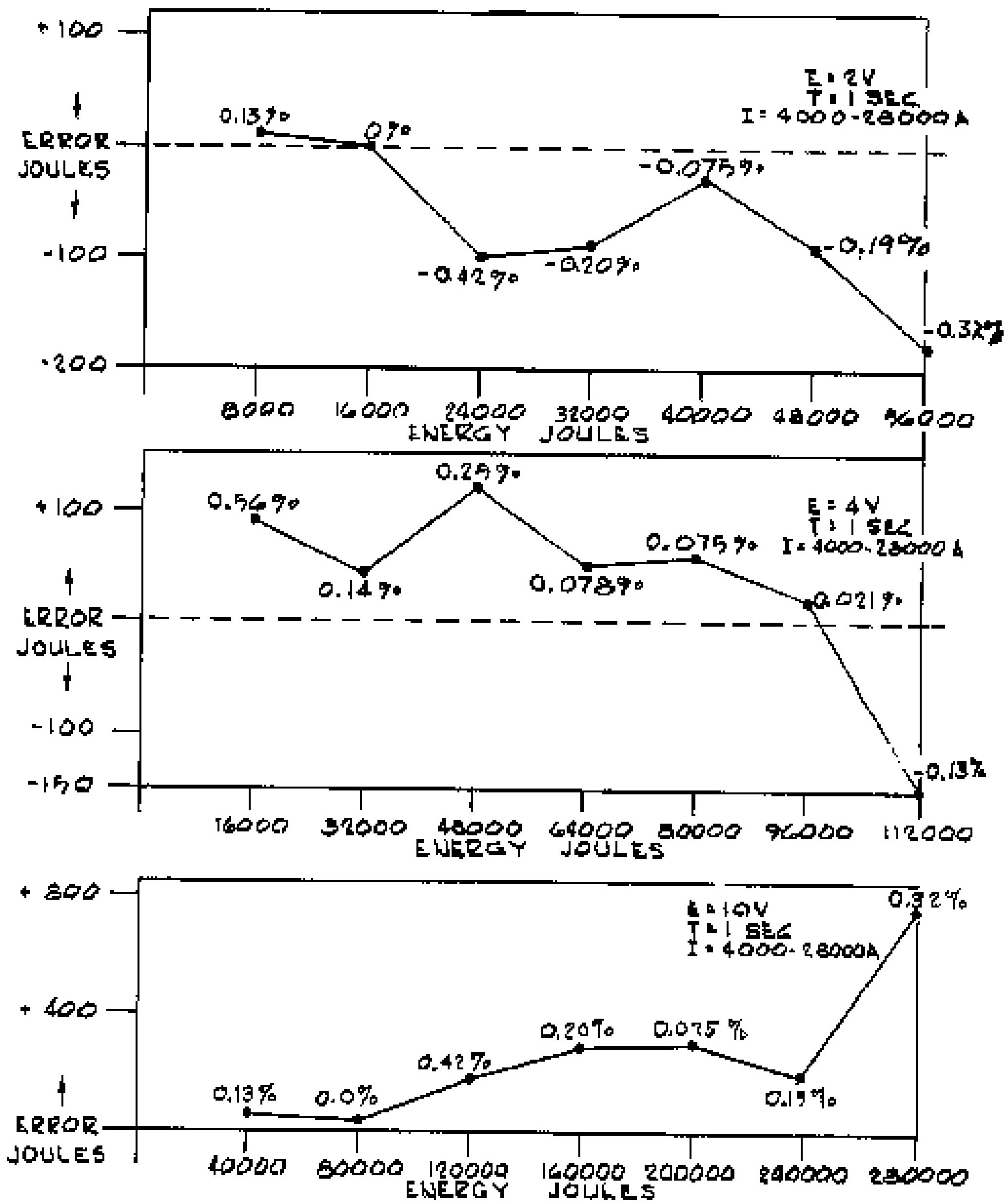

FIGURE 6. ERROR PLOT – SIMULATED INPUT SIGNALS

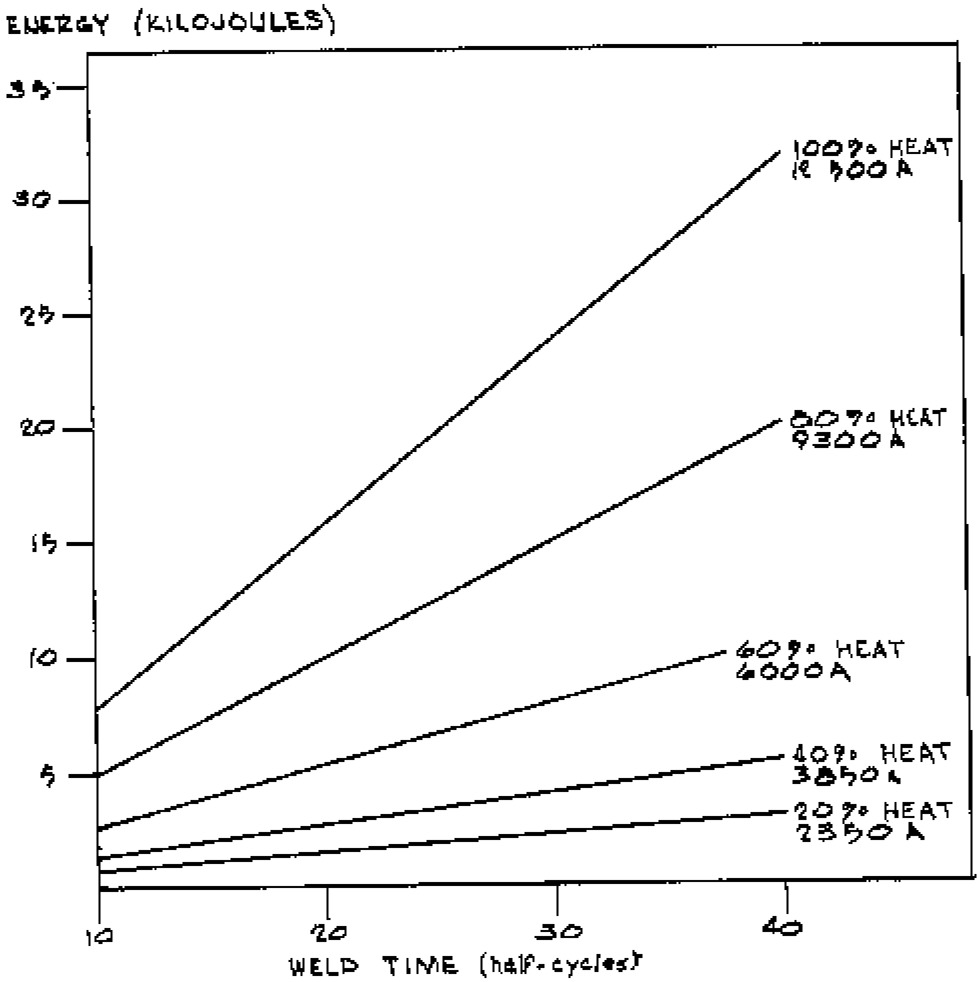

FIGURE 7. WELD ENERGY MONITOR ENERGY - TIME LINEARITY TEST MADE ON WELTRONIC WELDER

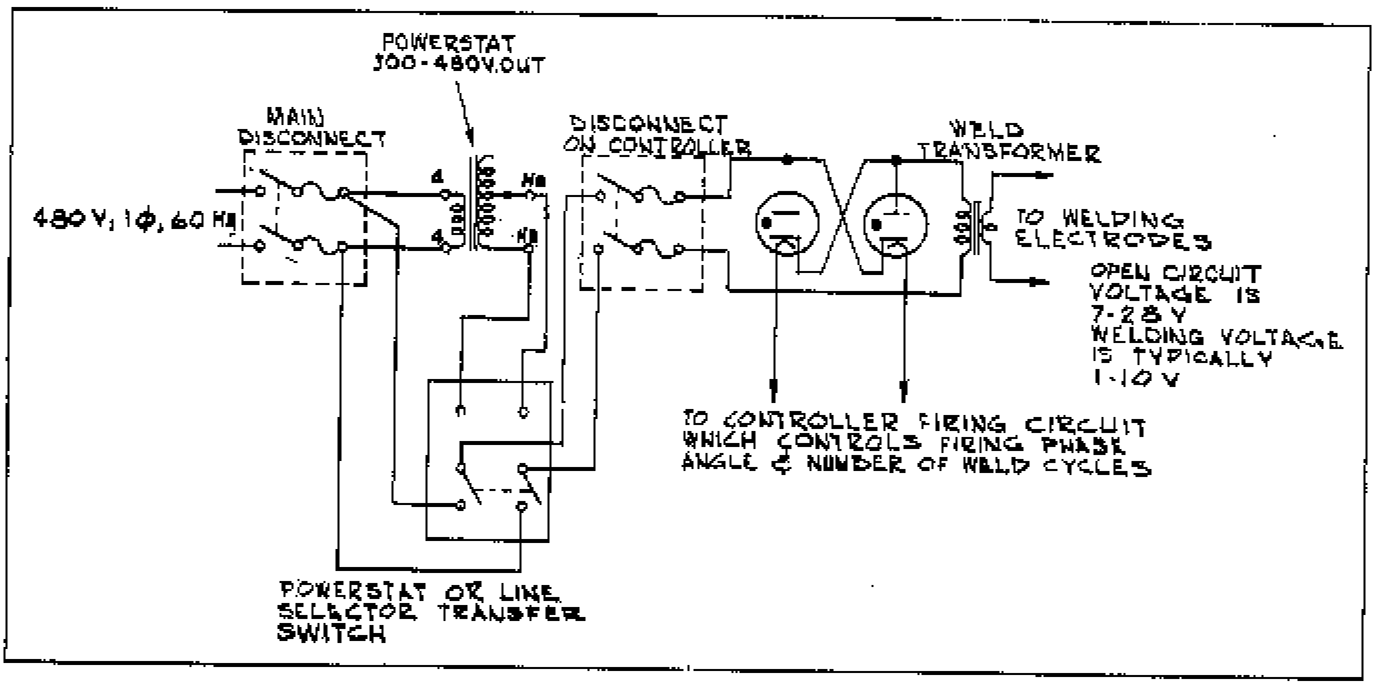

FIGURE 8. WELDER POWER DIAGRAM

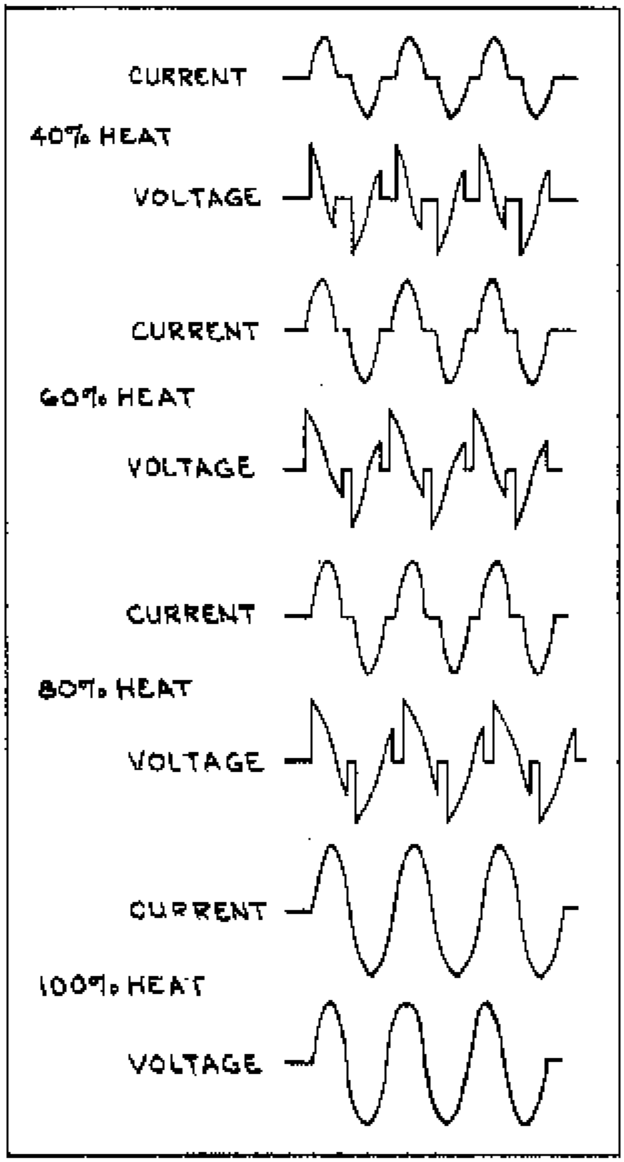

FIGURE 9. WELD CURRENT AND VOLTAGE WAVEFORMS

TABLE 1
WELD ENERGY MONITOR SPECIFICATIONS

Weld voltage range	0 - 28 volts
Weld current range	0 - 30,000 amperes
Energy range	0 - 300,000 joules
Accuracy	±2% of indication ±50 joules
Weld duration range	0 - 99 half-cycles
Accuracy	±1 half-cycle
Energy readout	Digital indicating
Weld duration readout	Digital indicating
Operating temperature	75° ± 15°F
Operating voltage	115 volts ± 10 volts at 60 Hz

TABLE 2
SHUNT SPECIFICATIONS

Current range	0 - 30,000 amperes
Time	0 - 1.0 second
Duty cycle	0.5% (max)
Frequency	60 Hz - 1 kHz
Shunt impedance	10 micro-ohms
Impedance change due to temperature rise, self-inductance, mutual inductance, skin effect, etc.	Less than ±1% of nominal
Phase shift caused by shunt	4° at 1 kHz

TABLE 3
WELD ENERGY MONITOR LABORATORY EVALUATION DATA

I,[a] amps	Energy, joules				
	E = 2 v	E = 4 v	E = 6 v	E = 8 v	E = 10 v
4,000	8,010	16,090	24,050	32,067	40,061
8,000	16,000	32,044	48,150	64,049	80,036
12,000	23,900	48,120	72,180	96,010	120,190
16,000	31,910	64,050	95,998	128,210	160,291
20,000	39,970	80,060	120,380	159,960	200,290
24,000	47,910	96,020	144,400	192,790	240,220
28,000	55,820	111,850	168,260	244,720	280,800

[a] Signal equivalent to currents indicated provided by signal generator. Integration time was 1 second for all data.

TABLE 4
SAMPLE OF DATA TAKEN ON WELDER

Auxiliary Counter Time, half-cycles	Energy Monitor Time, half-cycles	Energy, joules				
		20% Heat	40% Heat	60% Heat	80% Heat	100% Heat
10	10	713	1,344	2,651	5,030	7,850
20	20	1,408	2,644	5,272	10,050	15,860
30	30	2,084	3,956	7,893	15,100	23,870
40	40	2,770	5,175	10,507	20,060	31,660

APPENDIX I

Drawing Title	Current Number	Former Number
Weld Energy Monitor Printed Circuit Cards	S3-2-326	SSK3-7-260
Weld Energy Monitor Schematic Diagram	S5-2-5333	SSK5-7-1298
Weld Energy Monitor PC Component Layout	S5-2-5336	SSK5-7-1299
Weld Energy Monitor Component Layout	S5-2-5335	SSK5-7-1300
Weld Energy Monitor Chassis Layout	S5-2-5334	SSK5-7-1301

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