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MASTER

ALUMINUM PULSE-ARC WELDING

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ABSTRACT

Necking (melting and severance of some of the individual strands) is a frequent problem in joining multistrand aluminum wires by means of pulse-arc welding. Erratic tungsten-electrode performance is another common problem. In addition, a nondestructive means of evaluating the effectiveness of the weld is not available, nor was there a suitable method of monitoring the weld current during the welding process established before this investigation. Experiments designed to determine the origin of the necking problem indicated that an oxide coating on the aluminum wire might be the cause of that problem. Preheating and post-heating of the cover gas, weld fixture, and piece part did not reduce the necking problem, but tended to make it more severe. A current-viewing-resistor (CVR) method of monitoring the weld current during the welding process provided an effective, nondestructive means of ensuring weld quality. Surface finish and the method employed in finishing the tungsten electrodes were shown to have significant effects upon electrode life and consistency of performance.

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SUMMARY

Problems have continued in pulse-arc welding of electrical terminations consisting of multistranded aluminum wire. The problem of major concern appears to be elongation and separation of the wire strands near the center of the weld bundle. The elongation and separation of these strands gives a necking appearance which reduces the cross-sectional area of the wire, thus causing a questionable electrical termination. In addition, electrode performance has not been consistent. Electrodes perform erratically; that is, they may make many satisfactory welds prior to failure, or fail after only a few welds. Presently, a statistical quality controlled method is being used for monitoring weld quality of pulse-arc welding. It was felt that an electronic in-process monitoring system would be advantageous as a quality control method.

Evaluations were performed in an effort to alleviate the above problems. A heated-weld system study was performed to determine if the elongation and separation of wire strands near the weld nugget could be reduced. The heated weld system was composed of heating the piece part, cover gas, and weld fixture before, during, and after the weld. In an effort to improve electrode consistency, an evaluation was performed by varying the electrode tip configuration and surface finish. Electrode configurations evaluated were conical and cylindrical tips. Four electrode surface finishes were evaluated to determine if they would improve electrode performance. Three of these surface finishes were obtained by mechanical grinding, the fourth was by electropolishing techniques.

A preliminary electronic process monitoring system was designed and fabricated to allow feasibility study of its capability. The monitoring system used a current-viewing resistor (CVR) method of monitoring the output-current waveform.

Previous effort has been expended in all of the above problem areas. A preliminary study was performed to determine the feasibility of the heated-weld system. The results were optimistic, thus prompting the more rigorous evaluation performed during this project. It was determined on PDO 6984216, Pulse-Arc Welding, that a 2-percent thoriated-tungsten electrode, with a 30° included-angle tip would produce the most consistent acceptable pulse-arc weld. Work on this project was directed at improving the performance of that configuration. Previously, a prototype electronic process monitoring system had been fabricated, utilizing a pulse current transformer. It was found that the pulse current transformer did not provide a faithful current-waveform reproduction.

It was concluded from this project that the heated weld system did not reduce the elongation and separation of the wire strands near the weld nugget. It

was also found that the electrode surface finish affects the electrode performance. The conical-tip electrode proved to be superior to the cylindrical tip, based on the results of this project. The CVR type of monitoring system was found to produce a reliable reproduction of the output-current waveform.

Upon evaluating the preliminary CVR monitoring system, it was determined that a more sophisticated monitoring system needed to be designed and fabricated before conclusive results could be obtained. It now appears that the investigations concerning the quality of aluminum wire needed to consistently produce high-quality welds are more complex than previously anticipated. It is believed that such an evaluation would be beyond the scope of this project.

It is recommended that future effort to reduce elongation and separation of wire strands near the weld nugget be alleviated by controlling the output pulse of the welder. This could be accomplished by the design and fabrication of a controlled-output pulse welder. It is planned that a welder of this type will be designed and fabricated on a future process development endeavor. In addition, a thorough investigation of aluminum wire should be completed. Work should continue in an attempt to improve electrode performance. Improved performance will require a thorough knowledge of arch phenomena. An evaluation should be planned to determine the value and accuracy of the CVR monitoring system. A correlation between weld quality and output-pulse parameters must be made to determine the effectiveness of this monitoring system.

DISCUSSION

SCOPE AND PURPOSE

A problem of major concern has been the elongation and separation of the wire strands near the center of the weld nugget. This problem has existed since the original concept of the wire-bundle pulse-arc weld. Because other problems were prevalent with this weld, such as porosity and inconsistent visual results, the elongation and separation was not thought to be the problem at that time. The porosity and visual inconsistency have been eliminated, thus shedding more light on the elongation and separation or "necking" appearance. The necking appearance, which reduces the cross sectional area of the wire strands as it joins the weld nugget, not only causes a higher resistance junction, but also causes a questionable mechanical joint. It appears that possible expansion and contraction due to temperature environments could cause the wire to pull apart at the weld nugget.

Electrode performance has not been as consistent as desired. All electrodes are prepared by the same process in an effort to promote consistency of performance. It has been found, however, that this does not yield the consistency need for pulse-arc welding. Electrodes perform erratically; that is, given a standard configuration, one electrode may weld up to 25 satisfactory welds, while another may only make one or two satisfactory welds.

A statistical quality control method is being used at present in pulse-arc welding. This consists of welding a number of samples, then visually and metallurgically examining them. If a specified number of welds are visually and metallurgically acceptable, the process is said to be consistent and in control. In addition, samples are welded daily prior to and after production welding to confirm, on a daily basis, the consistency of the processes. This method is satisfactory; however, it is a statistical-type method, and one can only speculate with some degree of certainty that a specific weld is acceptable. With this shortcoming in mind, it is felt that some type of in-process monitoring system would be advantageous. The monitoring system would determine if a weld made at that point in time is of acceptable quality.

PRIOR WORK

A preliminary study of the heated weld system was performed to determine if it would be possible to make welds under a heated-system condition. Several difficulties were encountered in the first attempt. Problems consisted of inadequate heat transfer to the argon cover gas and lack of a heated weld fixture. Enough data was accumulated to justify a more extensive evaluation.

An evaluation was performed on PDO 6984216, Pulse-Arc Welding, to determine the effects of the included angle on a conical-tipped electrode and the thoria content in a tungsten electrode. Electrodes having 30° and 60° included-angle tips were evaluated. Five different tungsten compositions were evaluated. The compositions were pure tungsten, 1-percent and 2-percent thoriated tungsten, zirconia tungsten, and stripped tungsten. All of the tungsten evaluated was Linde brand material. It was concluded from this evaluation that a 30°-angle tip would produce the most consistent pulse-arc weld. Additionally, the 2-percent thoriated tungsten performed better than the other compositions.

ACTIVITY

It was originally thought that the necking appearance was a result of rapid heating and cooling of the weld nugget during the actual weld.

A possible solution to the necking problem might be to heat and cool the weld nugget during welding. That could be accomplished by use of a preheated and postheated weld system. Since the cover gas, the electrode, and the weld fixture are intimately related to the weld, it would be necessary to preheat and postheat all three of those system components.

Heating the cover gas was accomplished by passing the argon over a nichrome heater, then allowing it to flow through the nozzle and electrode assembly, thereby heating those parts. Because of the slow response of the heating system to temperature change, the argon was allowed to flow continuously until a stable temperature was obtained. The weld fixture also contained a nichrome heating element. The current through each heating element was controlled by a separate variac.

A temperature range of 400 to 700°F was used in this evaluation. Sample welds were made at 400, 500, 600, and 700°F. Other samples were welded at room temperature to provide a control set to which preheated welds could be compared. Results were judged by visual and metallurgical cross-section examinations.

An effort to improve electrode consistency was performed by examining various electrode surface finishes and tip configurations. It was thought that the type of abrasive used to grind the electrode might be a determining factor on its performance. Therefore, three different abrasive wheels were used to obtain the mechanically-ground surface finishes. The roughness of the surface finish was maintained at 32 RMS or better.

By maintaining a constant surface roughness or RMS finish, it was thought that the only variable involved would be the type of abrasive wheel used to grind the surface. Two aluminum-oxide abrasive wheels of 120-grit and

240-grit were used to prepare a group of electrodes. Additional electrodes were prepared by using a 320-grit diamond-abrasive wheel. It was also theorized that an electropolishing technique might be used to prepare electrode finishes. Electropolishing consists of electrically and chemically etching the surface of the electrode after it has been ground mechanically. A number of sample welds were made using these various electrode finishes, with varying results. When the number of electrodes versus the number of acceptable welds per electrode was plotted on a graph it was noted that the aluminum-oxide-prepared surface finishes had similar distributions. The electrodes prepared by electropolishing and diamond-abrasive grinding had dissimilar distributions. In addition, these distributions were different from the aluminum-oxide-prepared electrodes. All the surface finishes were examined with a scanning electron microscope. The mechanically-ground electrodes all had similar surface conditions. The electropolished electrode had a significantly different appearance.

A cylindrical-tipped electrode was also evaluated. It was thought that a small, cylindrical tip on the end of a larger electrode cone would cause the tip to reach a higher temperature during welding, thus burning off any contaminates or impurities on the electrode surface. After viewing the high-speed photographs, it was noted that the cylindrical tip did, in fact, glow slightly brighter than the conical tip. Results from the weld samples made did not indicate an improvement over the conical tip.

It was hypothesized that two parameters which might be related to weld quality in pulse-arc welding are peak output current and output pulse length. A preliminary attempt was made to monitor these parameters by the use of a pulse current transformer. It was later found that the pulse current transformer would saturate under certain conditions and, therefore, could not provide a faithful reproduction of the current waveform. The electronics of the system performed satisfactorily, but since the transformer was inadequate. acceptable data could not be obtained with this system.

It was suggested that a current-viewing resistor (CVR) might be used to monitor the peak output current and output pulse length. A preliminary investigation of this method proved to be optimistic. By inserting a CVR in the output of the pulse-arc welder and viewing its output on an oscilloscope, it was concluded that the CVR did give a faithful reproduction of the output waveform.

ACCOMPLISHMENTS

From the results of this project, the following may be concluded.

The heated welding system neither eliminates nor decreases the elongation and separation of wire strands near the weld nugget; in fact, the necking is somewhat worse at elevated temperatures. By comparing the photomicrographs of joints welded at 600°F (Figure 1, A and B) to those of joints welded at room temperature (Figure 1, C and D), it may be noted that necking exists in both samples. Visual appearance of the heated-system welds was degraded, also.

It was found that electrode surface finish does affect the weld quality. Results indicate that grinding the electrode tip with an aluminum-oxide abrasive wheel degrades electrode performance, i.e., on the average, fewer acceptable welds were obtained with $al_2 0_3$-abrasive-ground electrodes than with the diamond-abrasive-ground or electropolished electrodes. A slight improvement in electrode performance was obtained with the diamond-abrasive-ground electrodes. All electrodes used for production pulse-arc welding are now prepared by grinding the tip surface with a 320-grit diamond abrasive as determined on this project.

The current-viewing-resistor method of monitoring the output waveform was proved to be an accurate method of monitoring the weld-current waveform. The preliminary monitoring system used an oscilloscope to display the current waveform. Figure 2 is a schematic of the CVR monitoring system. Additional electronics will be required to read the peak current and pulse length with digital instruments. Figure 3 compares the CVR waveform to the pulse current waveform. It is evident that the CVR provides the true current waveform, whereas the pulse current transformer saturates early in the pulse.

A list of aluminum-wire alloys was compiled for a weldability evaluation using pulse-arc welding. Eleven alloys and three different wire sizes were selected. After considering the quantity of weld samples needed, manpower required, and long procurement time, it was determined that the weldability evaluation planned was beyond the scope of this project. A meaningful and thorough evaluation was more complex than originally anticipated.

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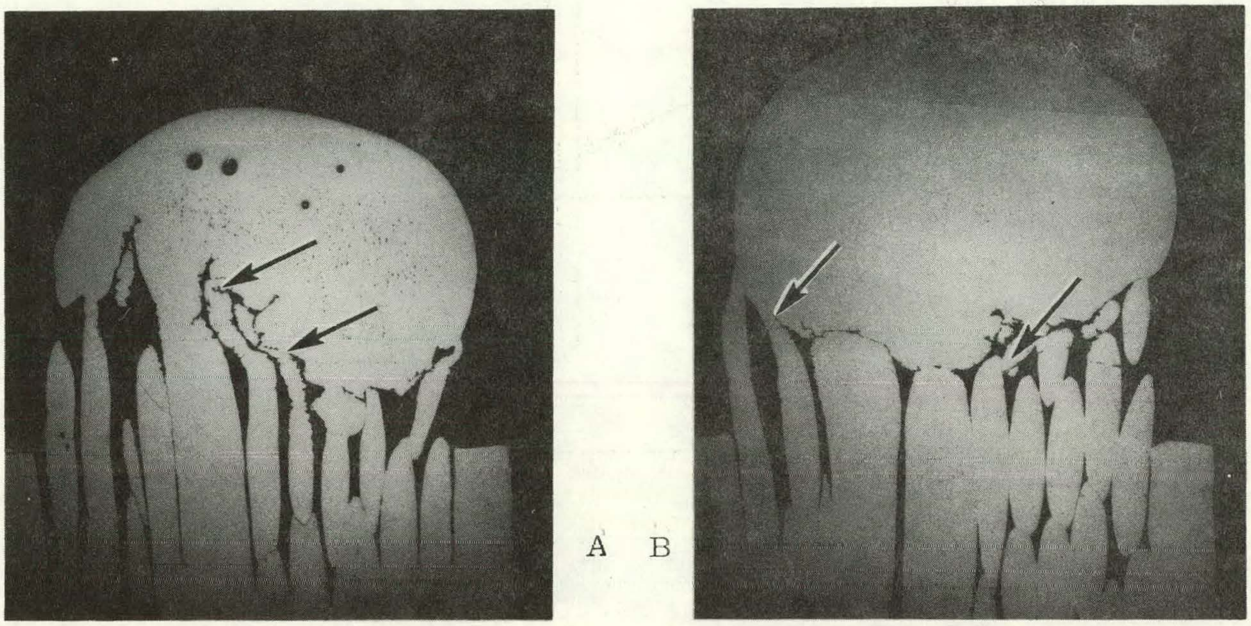
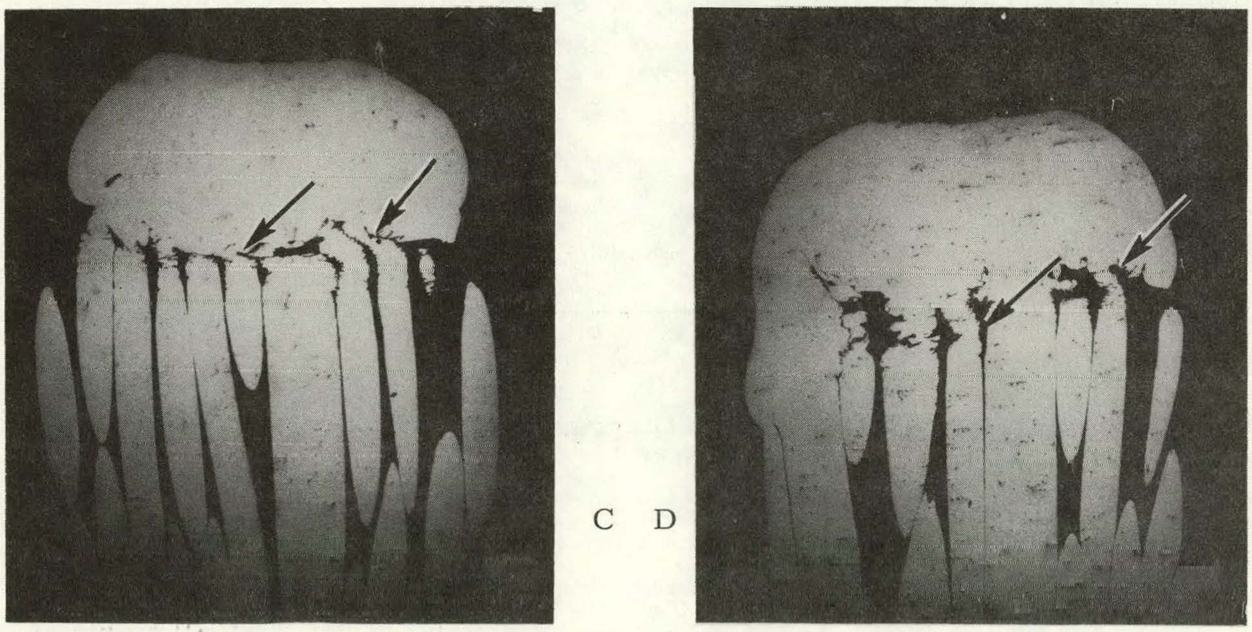


Necking Effects in Joints Heated to 600°F Before Welding



Necking Effects in Joints Welded at Room Temperature

Figure 1. Photomicrographs, 25X, of Metallurgical Cross-Sections of Pulse-Arc Welded Aluminum-Wire Joints

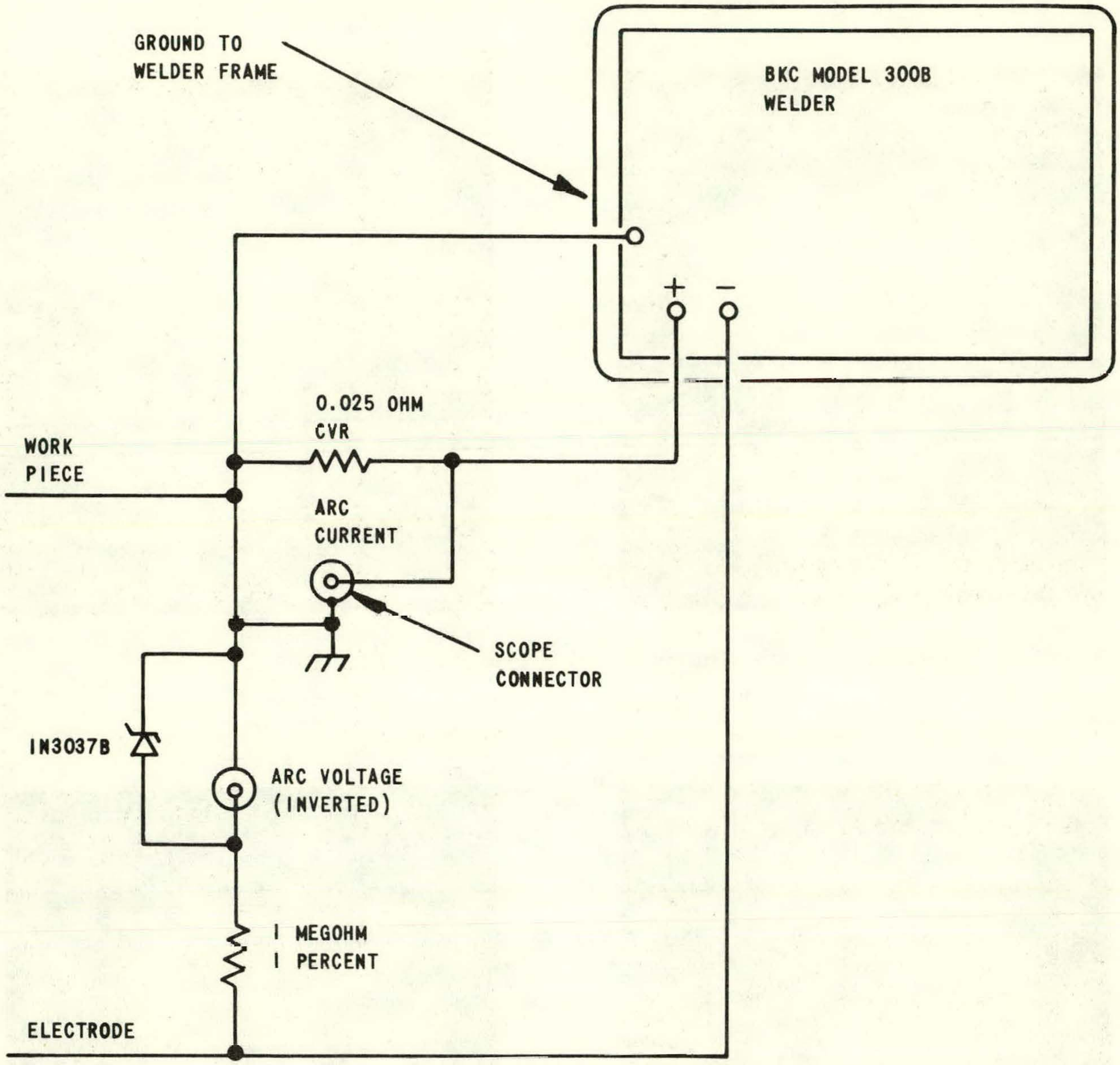
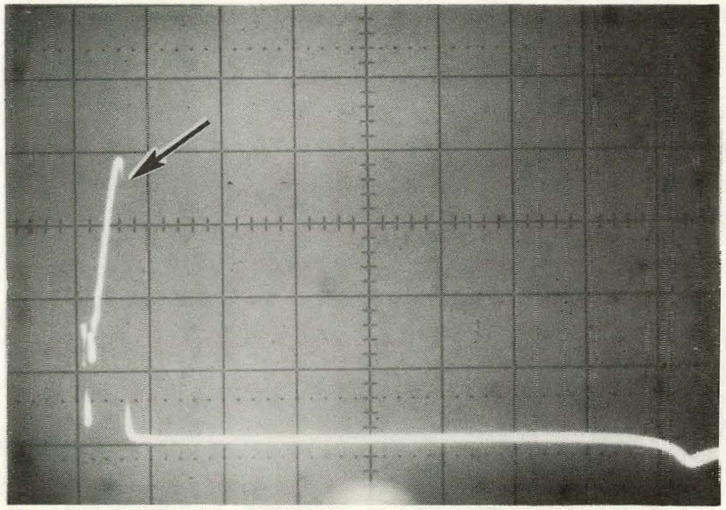
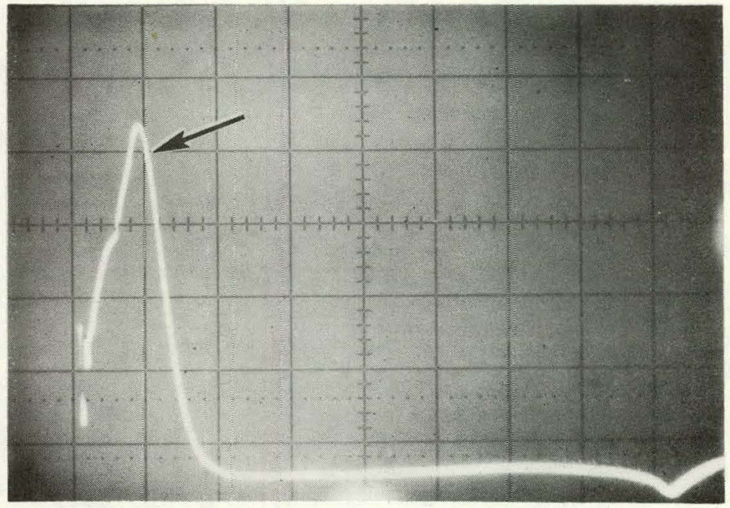


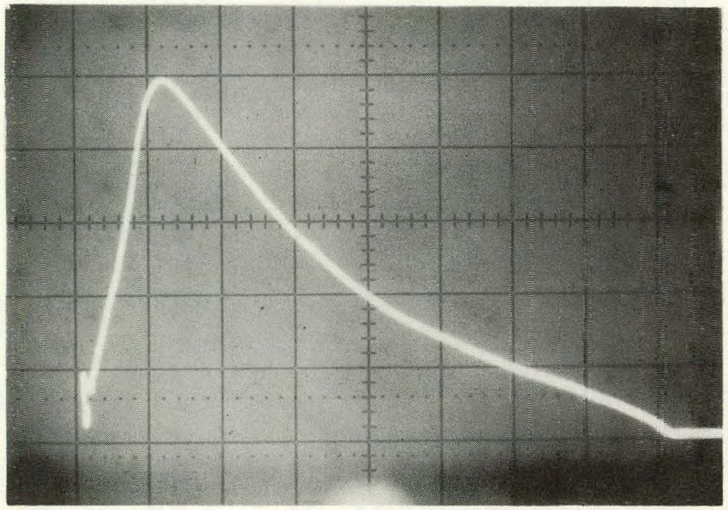
Figure 2. CVR Monitoring System Diagram



A

B





C

A and B show saturation resulting from use of Pearson Models 110 and 310 pulse current transformers.

C illustrates the true output-current waveform derived by use of the current-viewing-resistor (CVR) method

Figure 3. Current-Waveform Traces for Three Joints Welded With the Same Pulse-Arc Weld Schedule

FUTURE WORK

Since electrode inconsistency still exists in some degree, future effort should be directed toward a better understanding of pulse-arc phenomena, and evaluations should be conducted to determine the causes of electrode failure.

The quality of aluminum wire used in welded assemblies should be evaluated fully. In addition to weldability, the physical properties of the wire should be evaluated.

The current-viewing-resistor monitoring method should be implemented, using a digital-readout measuring system. Such a digital-readout system would have to be designed and fabricated to enable the value of the output-waveform monitoring concept to be determined.

A variable-output pulse-type power supply might provide a means of eliminating, or at least reducing, the necking problem. It would be necessary to design and fabricate a prototype variable-output pulse power supply for such an investigation.

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