Electron Beam Welding Spike Suppression Using Feedback Control

Modification of previously developed system permits spike detector to operate from the top of the weld rather than the side

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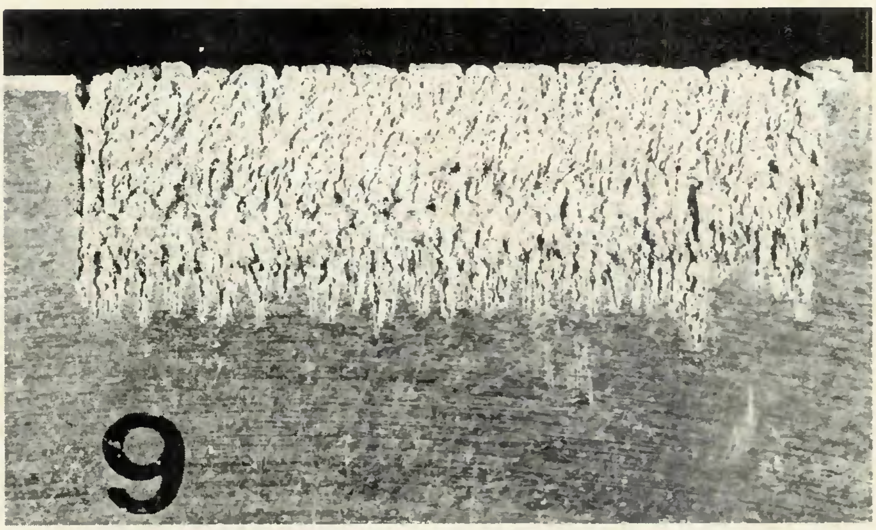

Fig. 1 — Typical partial penetration electron beam weld in 7075 aluminum. Spiking can be seen at the root of the weld X5, not reduced

ABSTRACT. An investigation was undertaken to determine the usefulness of a recently developed feedback control system (Ref. 1) for suppressing spiking during electron beam welding in aluminum. The principal objectives of the investigation were to determine whether or not the detector could be used in a top-looking position, and what maximum root depth could be monitored. The detector was successfully used in a top-looking position to suppress spiking. In addition, experimental evidence indicates that the system should be useful to root depths of 2.3 cm using a 50 kV beam, and to root depths of 7.5 cm using a 100 kV beam.

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Introduction

High energy density welding processes such as electron beam welding and laser welding have an associated defect known as spiking. The defect is illustrated in Fig. 1, a partial penetration weld between two aluminum blocks that have been broken apart to reveal the root of the weld. Spikes are the points of excessive penetration. Spike length increases with increasing penetration depths and power density. Variations in root depth due to spiking can be as great as 20 percent of the weld depth.

The causes of the spiking phenomenon include energy density levels, welding machine transients, and chemical composition of the welded material. To date, only one method has been developed to control spiking while making deep (greater than 5 mm), single pass electron beam welded joints in spike-susceptible aluminum alloys such as 7075. The method utilizes x-rays generated by the beam as it impinges on the welded metal. The detector portion of the system is sketched in Fig. 2. X-rays generated by the beam, including the x-rays generated at the root of the weld, travel in straight lines from their point of origin. The rays travel through the material and eventually leave the exposed surfaces of the weld members. The x-rays generated by the beam impinging upon metal at the root of the weld can be singled out from the x-rays generated at other points along the beam's path by means of a collimator. The collimator selects a single point of x-ray generation by shielding out any x-rays which are not collinear with the collimating axis.

As shown in Fig. 2, the previous system used two lead sheets mounted between the x-ray sensing element and the joint being welded. A small pinhole in each sheet (0.1 cm) formed a collimating axis which intersected the axis of the electron beam at the root of the weld. The x-ray sensing element used in the system was a sodium iodide crystal which converted the photons from x-ray wavelength (0.6 to 60 angstroms) to photons with wavelengths in the visible spectrum (4200 angstroms). A photomultiplier tube was used to detect the longer wavelength photons. This system provided an electronic signal in response to x-rays generated at the root of the weld. A complete description of the original feedback control system for suppressing spiking in electron beam welds can be found in the July 1974 issue of the *Welding Journal* (Ref. 2).

The original system was modified for the present work by redesigning the detector case to permit the positioning of the detector above the workpieces. A few of the electronic components in the feedback control circuit were also modified to improve response time. The purpose of the present work was to:

1. Determine whether the detector could be used in the top mounted position
2. Determine to what depths of penetration the system could sense spiking in 7075 aluminum

The components of the modified system are shown in Figs. 3 and 4. In order to position the detector in the area bordered by the electron beam and weld member surface, a nose-cone shaped collimator was machined. The detector was made insensitive to lateral misalignment of the collimating axis and the beam axis by combining a horizontal slit and pinhole rather than two pinholes. This arrangement continued to provide vertical discrimination of the x-rays. Vertical discrimination was necessary to single out the x-rays generated at the root of the weld. The electronic signal from the photomultiplier tube was amplified and used to drive a light emitting diode. The light from the diode was channeled along a plexiglass rod which extended into the high voltage tank of the welding machine. The high voltage tank contains circuitry which controls the bias on the grid cup. The grid cup in turn controls the electron beam.

Since the grid cup circuitry floats at cathode potential (−150,000 volts), the tank is filled with an insulating dielectric oil. Normally the grid cup is controlled by varying the voltage on the primary side of a high voltage isolation transformer. The transformer's response time, however, is too slow for feedback control, making it necessary to control the grid cup by the L.E.D./photodiode optic-electronic isolater. The photodiode signal controls a vacuum tube which in turn controls the biasing potential on the grid cup.

In operation, the x-ray detector is adjusted to sense x-rays generated at a point just below the desired depth of penetration. In the event of a spike formation, a signal is sensed by the detector. The signal is relayed through the feedback control chain to the grid cup of the electron gun which decreases the beam current. The decreased beam current is unable to sustain the previous depth of penetration. Since the beam no longer reaches the previous depth, the generation of x-rays at the depth is terminated. When the x-ray detector no longer senses the generation of x-rays, beam current is allowed to return to its previous level.

The ability of the system's detector to sense x-rays generated at the root of the weld is dependent upon the sensitivity of the photomultiplier amplifier, and upon the attenuating effect which the weld members have on the x-rays. In addition, the percent spiking or amount of suppression which occurs is dependent upon the speed with which the feedback control chain can respond to the signals.

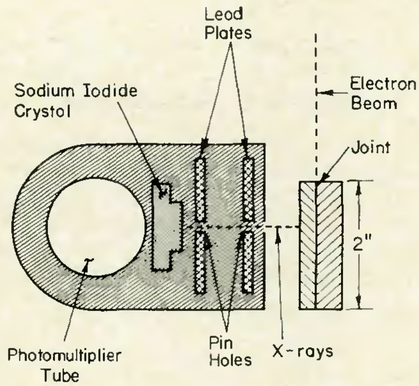

Fig. 2 — Sketch of detector used with previous system

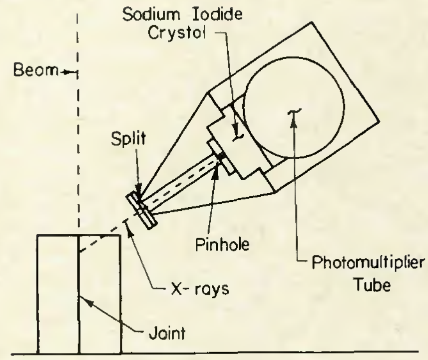

Fig. 3 — Sketch of new detector

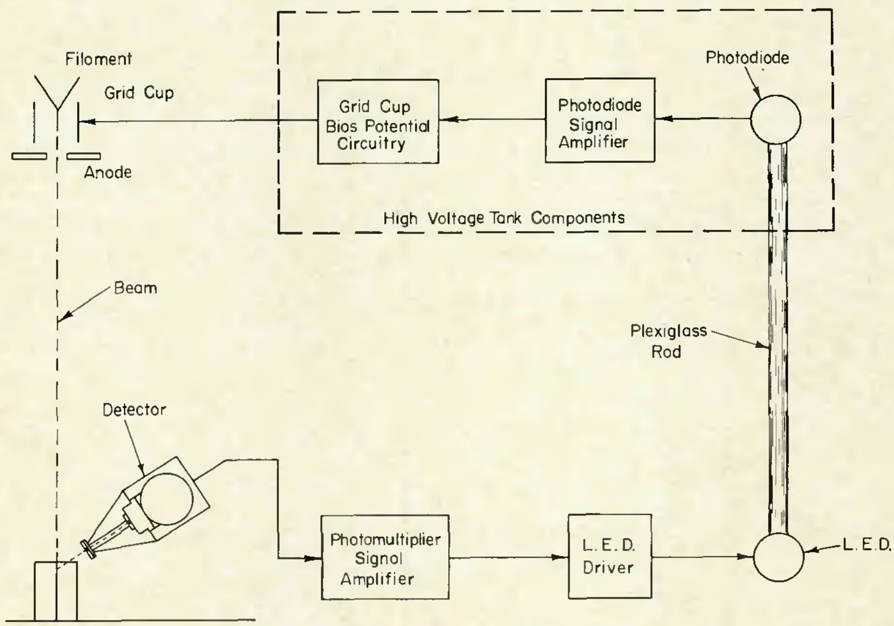

Fig. 4 — Components of the feedback control chain

In order to study the effect of attenuation, a step wedge calibration procedure was used. This procedure determined the intensity and attenuation coefficient for the x-rays produced by an electron beam impinging upon weld metal. Measurements of the electronic response time were also made to relate percent spiking to signal delay time.

Experimental Procedure

The new detector is illustrated in Fig. 3. The remainder of the components which make up the feedback control chain can be seen in Fig. 4. The photomultiplier tube used in the detector is an RCA 931-A. The amplifier has an F.E.T. input stage along with a parallel connected variable input impedance. Optimum response time for the tube is obtained by using low amplifier input impedance and high gain. The voltage signal output from the amplifier cannot be used directly for driving the light emitting diode since the diode is a nonlinear power dissipating device. Instead, the amplifier output, which is directly proportional to x-ray intensity or flux, is used to drive the L.E.D. through a voltage to current converter.

The light from the L.E.D. passes through the plexiglass rod and illuminates the photodiode at the receiving end. The signal from the photodiode is amplified approximately 300 times, providing a negative 160 volt potential to control the high-voltage on the grid cup supply. Although a linear relationship between the L.E.D. signal and beam current was desired, the circuitry was only capable of providing on-off control. At intermediate signal levels, a high frequency oscillation of the beam current developed. The beam current control on the welding machine was used to set the "beam-on" current level.

Figure 5 is a sketch of the experimental setup for the attenuation experiment. The target block shown in the figure was machined from the material being welded, 7075-T6 aluminum. The step wedge attenuating the x-rays was also machined from 7075-T6 aluminum. These conditions simulated the case of an actual weldment in which radiation is being generated and attenuated by the same material.

Response time of the feedback control chain was measured by pulsing the beam. A pulse signal was applied to the L.E.D. driver, while the voltage output from the photomultiplier tube amplifier was monitored. Square-wave pulses ranging from 20 microseconds to 500 milliseconds at frequencies ranging from 100 Hz to 20 kHz were used.

Results and Discussion

The results of the attenuation experiment are summarized in Fig. 6, a plot of the necessary sensitivity to detect x-radiation attenuated by various thicknesses of 7075 aluminum. The beam current used for the tests was 0.5 milliamp at all voltages. The photomultiplier tube was operated at 700 volts with a 300 kilo-ohm load (input impedance to the amplifier). For the system used in this investigation, the maximum sensitivity of the photomultiplier amplifier was 0.01 microamp. This maximum sensitivity would theoretically permit this system to detect x-rays attenuated by 2.3 cm of material for a 50 kV beam or for 7.5 cm of material for a 100 kV beam. If an amplifier with greater sensitivity than 0.01 microamp were used, the depth could be increased. In addition, if the amount of beam current impinging on the target increases, the depth could be increased.

The rise and fall times for a 50 microsecond square wave input pulse were measured to be less than 25 microseconds each. This compares with a rise time of 20 microseconds and fall time of 80 microseconds associated with the previous electronic circuitry. The lag time for the present system was 40 microseconds. No lag time measurements were made for the previous system. Work by Mara (Ref. 3) has shown that an electron beam can penetrate aluminum at rates of 5.6 meters per second. At these rates, a 50 microsecond lag would allow the beam to penetrate 57 mils in 40 microseconds. The spiking which occurred in the feedback controlled welds had lengths about half of this value, indicating that the penetration rate at the root of the weld is perhaps somewhat less than 5.6 m/s or that the forma-

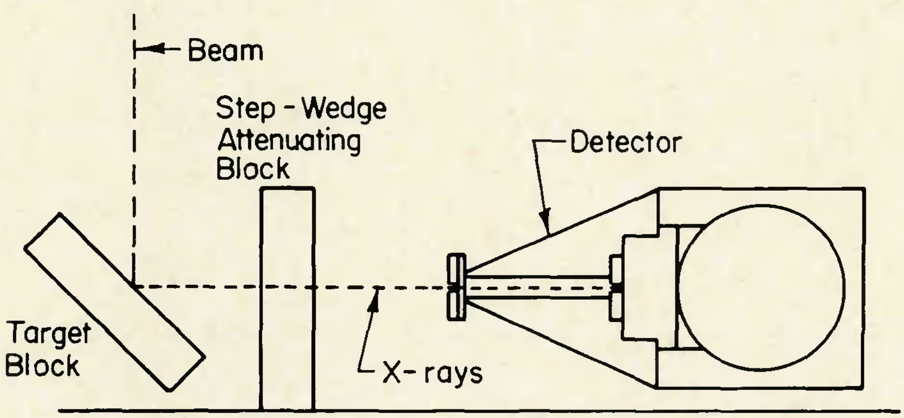

Fig. 5 — Experimental setup for attenuation experiment

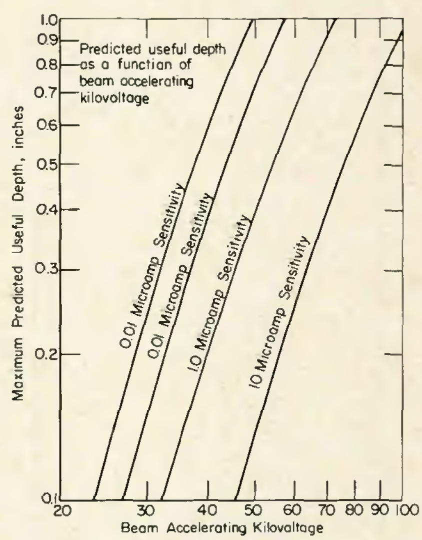

Fig. 6 — Maximum predicted useful depth of penetration for feedback control system. Depth depends upon amplifier sensitivity and accelerating kilovolts

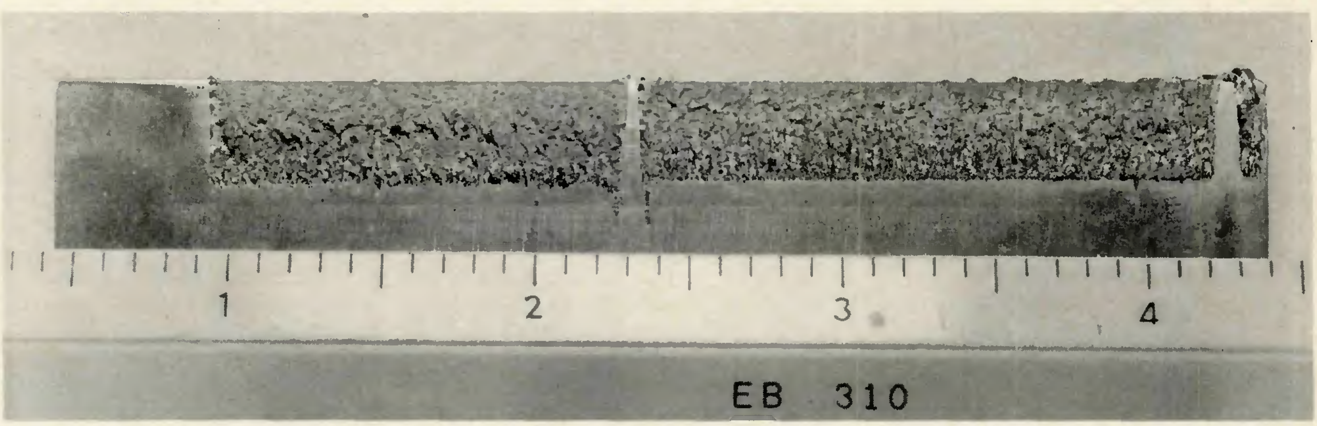

Fig. 7 — Partial penetration electron beam weld with feedback control (right) and without feedback control (left). X1.6 as shown

tion of a spike begins with a slow increase in penetration.

A comparison of feedback suppression using the present equipment and using the previous equipment can be illustrated by two samples. Figure 7 is a photograph of two weld passes made in succession, without feedback control on the right, and with feedback control on the left. All other conditions remained constant. The depth of the weld was 0.92 cm max, 0.87 cm min with a 5.7 percent spiking figure. This compares to 8.1 percent spiking figure from the best sample made with the previous system in a 0.71 cm deep weld. The improvement in control is believed to be due to the increased response speed of the new circuitry.

The major conclusions reached on the basis of this work have been:

1. The feedback control method of spike suppression in welding 7075 Al can be accomplished using a top-mounted feedback control detector.

2. Using presently available equipment, penetration in welds to depths of 1 in. or more can be controlled in aluminum with a 50 kV beam.

References

1. O'Brien, T. P., "The Suppression of Spiking in Partial Penetration Electron Beam Welding Using Feedback Current Control," Master's Thesis, The Ohio State University, 1973.

2. O'Brien, T. P., "Suppression of Spiking in Partial Penetration EB Welding With Feedback Control," *Welding Journal,* 53 (8) Aug. 1974, Res. Suppl., pp 332-s to 338-s.

3. Mara, G. L., "Penetration Mechanism of Electron Beam Welding and the Spiking Phenomenon," *Welding Journal,* 53 (6) June, 1974, Res. Suppl., pp 248-s to 251-s.