Analytical Photography of Electron Beam Welding

A new technique for photographing minute details of electron beam welding indicates that the pictures obtained are repeatable and of acceptable quality for welding analysis.

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ABSTRACT. A successful technique for photographing electron beam welding has been developed by the Technical Photography Group at the Lawrence Radiation Laboratory, Livermore. The pictures produced are repeatable and of acceptable quality for welding analysis.

Background

A technique has been developed for photographing electron beam welding and hardware has been constructed and tested. Development test runs were made intermittently during the past 18 months between normal uses of the welder. A full-size mock vacuum-tank bulkhead was also used as an aid in lens testing and set-up photography.

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Optics and related hardware were designed for use on an electron beam welder and the equipment was made for easy removal from the welding chamber.

In addition to the average problems of high-speed photography, the following environmental conditions had to be dealt with:
1. photography in vacuum vessel
2. x-ray radiation shielding for protection of film and operator
3. vacuum-vessel warpage and hardware alignment
4. evaporation deposition on mirrors and optics
5. radiant-heat damage to equipment.

Hardware

Two access ports into the vacuum chamber were made on the end opposite the main chamber door. Two independent tube assemblies with turning mirrors and vacuum-seal windows were made and fitted through the welding chamber ports.

One assembly is used to direct high intensity light from outside the vacuum chamber to the point of interest inside; a lens focuses the light at the welding point. The light source used during the development of this project was a commercial 200W, high pressure mercury vapor lamp. This lamp unit is mounted outside the vacuum tank.

The second tube assembly contains the optical system for relaying the weld puddle image to the camera, which is also located outside the vacuum chamber. We used a 400-ft reel camera on a heavy duty adjustable mounting.

Both assemblies mount rigidly to the internal vacuum-chamber bulkhead with no solid connection to either the camera or the lamp house. In this fashion, no mechanical vibrations produced by the camera are amplified through the optical system. Sufficient radiation shielding was made by adding a \(\frac{1}{4}\)-in. thick lead sleeve over each of the tube assemblies inside the vacuum chamber. Light losses and optical problems were kept at a minimum by having all windows and lenses perpendicular to the lines-of-sight, as opposed to looking through windows at oblique angles. The turning mirrors previously mentioned are the means by which both light and camera lines-of-sight converge to the weld puddle inside the chamber (see Fig. 1).

The problem caused by evaporation deposition on the mirrors and optics was solved in the following fashion. A motor-driven clear film window unit was installed on each of the turning mirror-boxes; these units move 70-mm wide clear film at a rate of approximately 2 in./sec in front of both the light source and camera view mirrors (see Figs. 2 and 3). The film in these units would warp from radi-
Optics

Earlier tests indicated that lighting requirements for acceptable pictures are approximately 250,000 ft-c (foot-candles) over an area \( \frac{1}{2} \) in. in diameter at the welding puddle. Figure 4 shows the light-focusing lenses, turning mirror, and film shield; an additional approximately 6-deg angle was given to the illumination turning mirror to prevent glare from being reflected from the welding sample through the photographic line-of-sight. The surface finish of the metal being welded also contributes to this glare; glass bead or sand blasting of weld samples dulls the surface finishes and helps reduce the glare.

The photographic optics for the project are achromatic doublet (achromats), which are versatile and have high resolution qualities; they are objective quality lenses and are antireflection coated. Two 19\( \frac{1}{2} \) in. focal-length lenses of this type positioned as shown in the camera schematic (Fig. 5) produce a 1-to-1 image-to-object ratio. Since the area of interest on the weld is approximately the same as full-frame (16 mm), no change in magnification is necessary. By substituting lenses of different focal ratios, image sizes can be varied. The distance between the two 19\( \frac{1}{2} \) in. lenses can be varied to suit different setups on other types of welding machines.

The depth of field became a critical factor when the weld was viewed at an oblique angle. The focal ratio for the system used during this project was calculated to be F11, which seemed to be a good balance between light transmission and depth of field. Most general types of commercial photographic lenses are not suitable for conjugates of 1-to-1 at this working distance. An image rotator (shown in Fig. 5) was used to orient the weld image squarely to the camera frame. A Pechan prism was used as an image rotator because of its ability to accept the converging rays of light.

As mentioned before, a 400-ft reel camera was used with high speed, 16-mm color film, ASA 120. The film was force developed to ASA 640. The best framing rate seems to be in the region of 10,000 fps (frames/second). Durations of runs at this speed are 2.3 sec, with only the last 0.6 of a second averaging 10,000 fps. Average welding energies used on aluminum was 130 kV at 25 mA, with table speeds of 1 in./sec.

Mechanical requirements for the camera mounting call for X, Y and Z movements, plus angular control to square the camera with the rigid mounting of the optics on the vacuum chamber. The camera mounting shown in Fig. 6 has tripod screws in the base to handle vertical motion. A rotary table with X and Y travel was installed on the base pedestal, which is
r-45-deg Turning Mirror
3-in. d
1/2-in. Focal Length Achromat
Adjustable Diaphragm
High-Speed Camera

Fig. 5—Schematic drawing of side view of camera tube with turning mirror and camera attached, as mounted through the access port into vacuum chamber.

Chemical Imaging System
X and Y Rotary Table
Elevating Screws

Fig. 6—Schematic drawing showing vacuum chamber and camera mounting, together with the camera optical system.

combined with a fabricated "tilt" plate; all the motions necessary for correct camera alignment can thus be completed. The mounting must be rigid, yet movements must be precisely controlled. In both the setup photographs and in Fig. 6, light shields in the form of tubes are used between the optical assembly and the camera. These tubes also serve as an aid in camera positioning but, to prevent vibration transmission into the optics system, do not connect mechanically to the camera. The 200W high pressure mercury vapor lamp unit has a complete internal condenser lens system and focus ability, and it has an iris diaphragm.

For system alignment, a light source is placed behind the eyepiece on the camera and an image of the ground glass finder is projected through the optical system and focused on the weld sample in the chamber. A reference mark on the weld sample is used as the common target for alignment of the light source, camera line-of-sight and electron beam.

Experience gained with the vacuum chamber enabled us to make the gross compensation for warpage with the turning mirrors. After the chamber was under vacuum, minor corrections for image centering in the camera were made by tightening or loosening the window port flange bolts. The viewing angle of approximately 37 deg from vertical has given good analytic photographs. Viewing angles can be varied to suit specific interests in the welding analysis.

Future Work
The following future improvements to the equipment are being studied:
1. Variable position vacuum chamber access ports
2. Reduction in the optical tube diameter, as an aid to variable positions
3. Possibility of an optical system for photography coming through the top of the vacuum vessel, similar to the present operator's viewing-light system.

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