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TITLE: A SURVEY OF FLASH X-RAY TECHNIQUES AND APPLICATIONS

AUTHOR(S): Lawrence E. Bryant, Jr., and Jake P. Lucero

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A survey of flash x-ray techniques and applications*

Lawrence E. Bryant, Jr., and Jake P. Lucero

Nondestructive Testing Unit, Los Alamos National Laboratory
Mail Stop C914, P. O. Box 1663, Los Alamos, New Mexico 87545

Abstract

Flash x-ray diagnostics of high-speed dynamic tests need to be reliable as the test may be quite expensive and time-consuming.

Preparation for a first-time test can involve many partial or preliminary tests to verify adequacy of x-ray energy, x-ray exposure, film/screen combination, film-holder protection, flash x-ray-generator protection, triggering, and timing techniques.

Once these preparations have been successfully completed, very informative results are attainable for a variety of tests including jetting, welding, and casting.

Introduction

Flash x-ray is a form of radiography that can be used to produce either a single image or sequential images of dynamic events, such as a projectile in flight, an explosion, or any event in which there is rapid motion of metal, water, explosive by-products, or other materials.

There are certain limitations to the use of flash radiography.
(1) There can be no adjustment in exposure time or current flow, i.e., there is a fixed intensity for a given energy. (2) The total radiation per exposure is very low, for example, 10 mR total dose at 1m for 450 kV. (3) A fast film/screen combination is usually required and can result in poor resolution. (4) There is no opportunity to reradiograph if the first film results in an unusable image. (5) The proximity of the film package and x-ray source to the object being radiographed is such that film or x-ray generators can be ruined by shrapnel or other severe environmental conditions.

Techniques for flash x ray

Flash x-ray diagnostics are often performed at important facilities such as test fire sites, welding or casting labs or experimental areas that require efficient use. As such, it is frequently desirable to perform a number of preliminary tests to make sure the above listing of limitations has been adequately addressed in the flash x-ray techniques before final implementation.

It has been our experience in Los Alamos, that if a suitable static flash radiograph of the object to be dynamically imaged (or a simulated object representing a dynamic condition) can be obtained, then success is very likely. By radiographing the static object, one can choose the most suitable x-ray energy as well as determine the required exposure at the film. The latter choice depends mainly on selection of a beryllium window versus Kovar window tube, target to film distance, shielding material and thickness at the x-ray tubehead and/or film holder and choices of film/screen combination. Guidelines as to all of these choices can be found on technique curves as seen in Figure 1. By comparing this curve to curves for other energy flash x-ray generators, the most appropriate energy can be preselected for the given situation. Whereas this graph shows two materials, aluminum and steel with a range of thicknesses and five target-to-film distances ranging from 3 to 12m, it is also possible to plot additional curves for flash x ray tubes with different types of windows and different film/screen combinations.

Using this basic technique curve it is also possible to change to other film/screen combinations, using studies which give relative speeds for various combinations at differing x-ray energies. Copies of this study, jointly written by Los Alamos National Laboratory and Hewlett Packard are available from Hewlett Packard representatives at this meeting.

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Assuming one has a suitable static flash x-ray technique, it is possible to do preliminary tests on triggering and film/screen holder protection. Again, this preliminary work would more likely ensure success on a final, crucial test. Preliminary triggering tests carry the precaution that less than the full scale electrical environment could cause misleading confidence in the triggering arrangements. In addition to possible preliminary trigger tests, a final trigger test with as many realistic conditions as possible is recommended. This final trigger test should precede the actual test by as short an interval of time as is practical. One could do this just prior to placing the film/screen holders in position in order to verify time delay and use a dosimeter or laroid film to confirm x-ray output.

If survival of the film holder is in question due to blast or shrapnel, one could perform a simulated test, or even an overtest, to hopefully qualify the explosive resistant holder or at least learn what improvements are needed. Unfortunately, the reproducibility of explosive effects, and particularly shrapnel trajectories is not high, thus survival of the holder in a practice detonation is no guarantee of survival in an actual, crucial test.

Flash x-ray applications

Casting

A typical application of flash x-ray is the imaging on x-ray film of molten lead being poured into a graphite mold. The setup for this experiment, is shown in Figure 2. Arrow A indicates an electrically heated crucible to melt the lead. Underneath is a hemispherical mold to receive the molten metal, (Arrow B). On top of the mold is a ring, (Arrow C), containing a narrow, beamed light source and a light-detecting photocell. This is the trigger circuit. The falling, molten lead will interrupt the light beam, giving a "zero time" electrical signal, which is sent to three trigger amplifiers for this experiment. In this case, 50, 75, and 100 milliseconds were chosen, to view three phases of the casting.

Behind the mold are three film holders (labeled 1, 2, 3). The lead bricks in front of the graphite mold and to either side of it serve as collimation for the three flash x-ray generators with respect to the three film holders.

Figures 3, 4, and 5 show the x-ray images at 50, 75, and 100 milliseconds. In Fig. 3, the falling molten lead is just beginning to strike the inner, polar region of the graphite mold and to spray horizontally. In Fig. 4, 25 milliseconds later, the molten lead continues to fall on the polar region and the sideward spray has reached the outer wall of the mold. Rivulets of and down the sidewalls. Finally, in Fig. 5, at 100 milliseconds, the mold is partially filled, although one portion of the bottom rim is only beginning to receive the first droplets of molten lead.

Jetting

Figure 6 shows a static radiograph of a small shaped charge device aimed at a 2mm thick uranium plate. The static, pretest, radiograph is a useful verification of setup geometry, adequacy of flash x-ray technique and satisfactory functioning of all equipment; triggering, x-ray generator exposure, film handling, and film processing. Figure 7 is an early time, dynamic radiograph of the setup showing formation of the jet and Figure 8 is a later time radiograph made at 90° showing jet penetration of the plate as well as cracking of the charge case. The setup for this type of shot is shown in Fig. 9 where two remote, 450 Kv tubeheads are placed in protective stands with adjustable platform and slitted apertures for x-ray beam emergence. The two blast resistance cassettes are seen near the shot stand.

Welding

We have used a 600-pkV flash x-ray system to obtain dynamic radiographs of electron beam welds. By "dynamic", we mean a series of instantaneous, random radiographs of the weld cavity during the welding process.

This experiment was to investigate several welding energies and to compare the relative cavity shapes, depths, and anomalies.

A schematic of the flash radiographic setup is shown in Fig. 10. The stage, the bar to be welded and the film holder move together. The stage travel direction, electron beam axis and x-ray beam axis are orthogonal. The port to the left of the chamber normally contains a lead glass observation window. An adapter was fabricated with O-ring seals at either end so that the x-ray beam emerged from the pulser face directly into the evacuated welding chamber. The cylindrical section of the adapter was intentionally made of a small diameter pipe [1.5 in. ID (38.1 mm)] to serve as a radiation beam collimator.

By collimating the x-ray beam, as well as employing multiple starts and stops of the sample stage and welder, it was possible to accomplish up to six exposures per 17-in. (43.2 cm) length of film package, thus minimizing the number of vacuum pumpdowns.

The welding was merely a bead-on-plate type with no attempt to join the pieces of material. The height of the bar was 3/4 in. (19.0 mm) and the maximum penetration was planned to be no greater than about 5/8 in. deep (15.9 mm).

The experimental setup is shown in Fig. 11. The x-ray pulser is the large cylindrical object; an x-ray shield is shown to the right of the pulser, and to the right of the shield is the welding operator's station.

The original radiographs were studied by the metallurgist with whom this project was coordinated. He then sketched representative cavities from which drawings were made. The darkened portion of each drawing (Fig. 12) represents the weld cavity. The stage was moving from right to left and the weld beam location was stationary; thus, in effect, the weld was progressing from left to right. The image referred to as cavity is probably just that, not molten metal but essentially a void, perhaps containing plasma or vaporized metal with molten melt undoubtedly surrounding the cavity at the sides and bottom.

The sketch for 20 kV (Fig. 12A) shows the weld penetration with the highest power input per unit volume due largely to the slower stage travel. The amount of metal made molten is greater than that of the other weld energy, although the penetration is less than the higher energy.

The drawing for 27.5 kV (Fig. 12B) consists of the results for flash radiography of aluminum welds performed at relatively high energy. This produced high depth-to-width ratio welds with a resulting high incidence of cold shuts and root porosity.

Conclusion

Those organizations and individuals who have been involved in flash x-ray work for some time have probably evolved similar or more advanced approaches for establishing techniques. The range of applications for flash x-ray is extensive and once again, it is likely that many people in this audience could give equally or even more interesting examples.

If you are not involved in flash x-ray or are only beginning, perhaps these ideas will be helpful. Please remember the national laboratories, of which Los Alamos is one, are a national resource. If we at Los Alamos can be of assistance to you in radiography, flash x-ray, high speed videography, or high speed radiography to mention only a few of our capabilities, feel free to contact us.

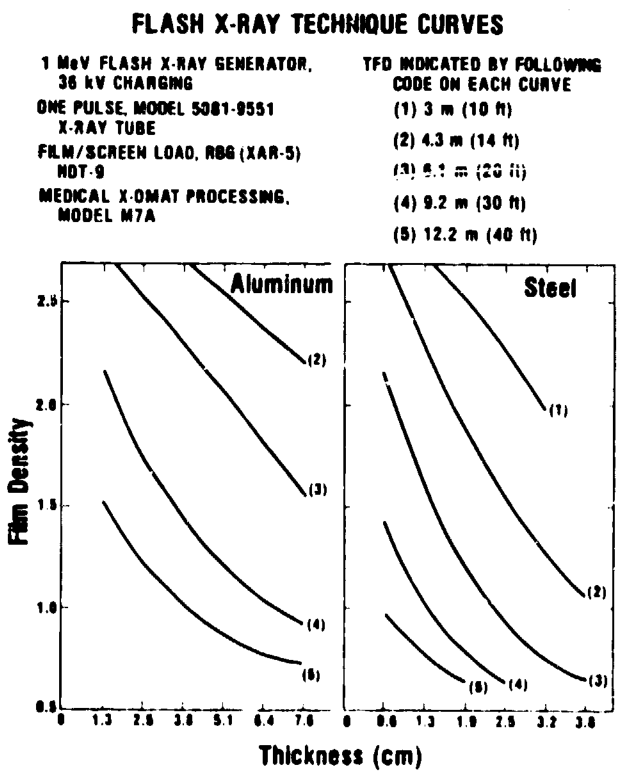

Figure 1.

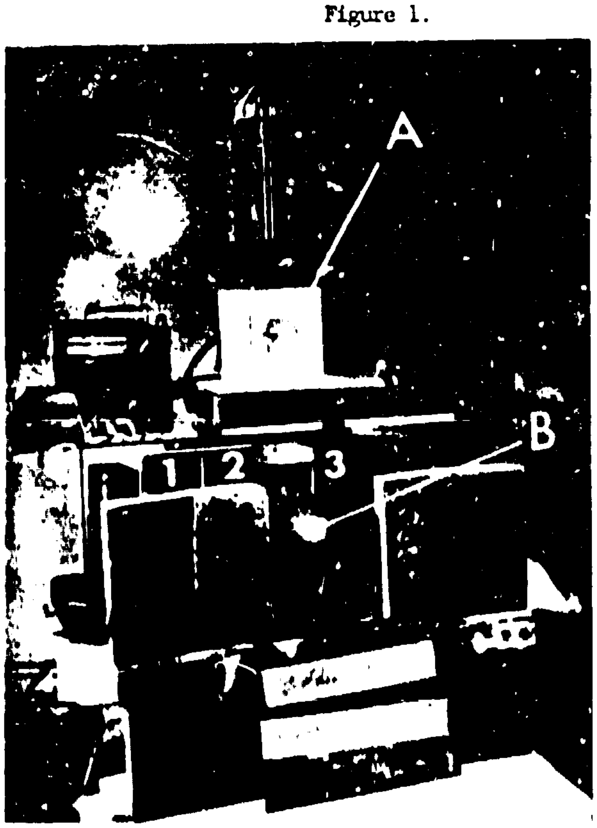

Figure 2. Setup for flash x-ray/casting experiment.

Figure 3. Casting at 50 milliseconds after zero time.

Figure 4. Casting at 75 milliseconds after zero time.

Figure 5. Casting at 100 milliseconds after zero time.

Figure 6. Radiograph (450 kV) of small-shaped-charge device before detonation.

Figure 7. Radiograph taken shortly after detonation of device shown in Fig. 6.

Figure 8. Radiograph of device shown in Fig. 6 after interaction with 2-mm-thick metal plate.

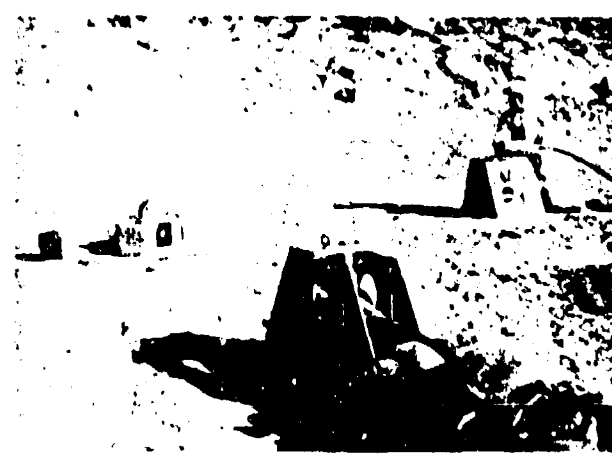

Figure 9. Two tubeheads (450 kV) in place for 0° and 30° flash radiography. Fild holder and explosive are at left center.

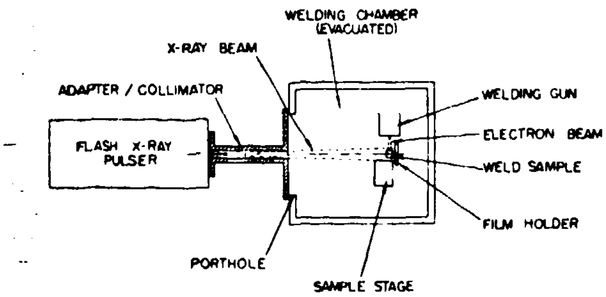

Figure 10. Schematic setup for flash radiography during electron beam welding.

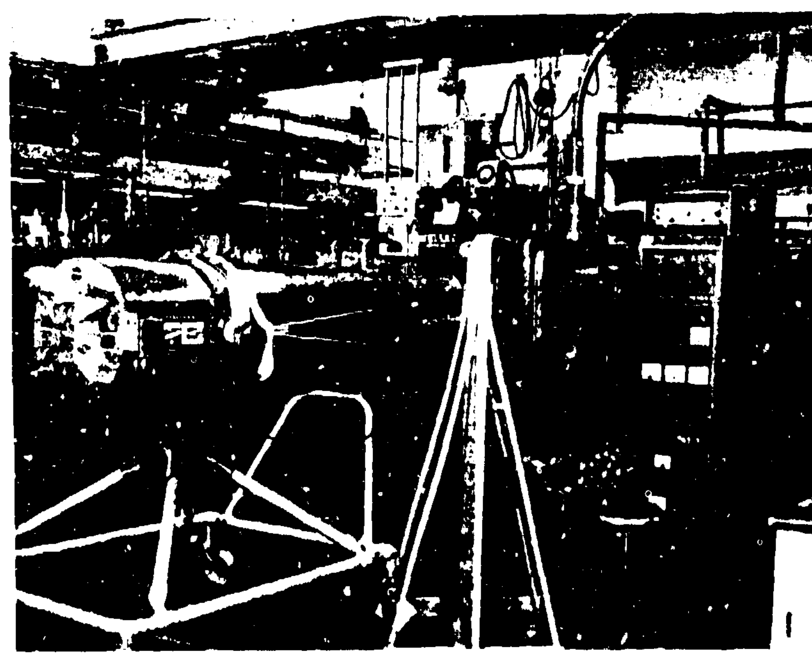

Figure 11. Flash X-ray/electron beam welding experiment: pulser to left, welding chamber and controls to right.

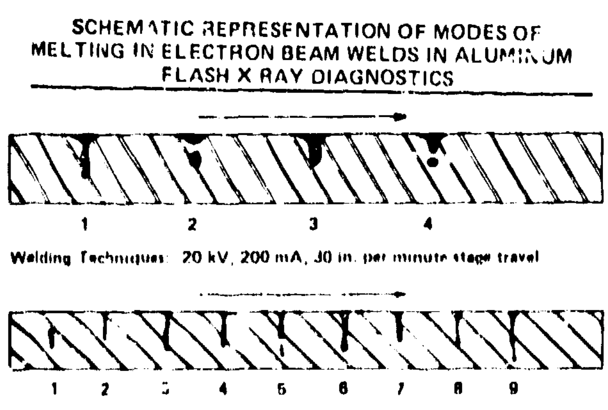

Figure 12.