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PORTABLE, FLASH X-RAY SYSTEMS: APPLICATIONS AND TECHNIQUES

SYSTÈMES PORTATIFS DE RAYONS X INSTANTANES: APPLICATIONS ET TECHNIQUES

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SUMMARY: Three energies of portable flash x-ray equipment are described, and applications such as jetting and high explosive studies, bullet impact and casting of lead experiments are given as well as techniques for triggering and protection of equipment and film.

RESUME : On décrit trois énergies d'un appareil portatif à l'irradiation par rayons x instantanés, et applications telles que des ètudes sur la formation de jet et sur des explosifs de hauté intensite, on donne les expériences d'impact des balles et de coulée du plomb de même que les techniques pour le déclenchement et la protection de l'appareil et du film.

I. INTRODUCTION

Flash x ray is a type of radiography that can be used to produce 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. Conventional radiography differs from flash x ray in that the object (a pipe weld or casting, for example) is motionless during the exposure to x rays. In image amplifier or vidicon radiography, the object can be in relatively slow motion, as when a briefcase passes through an airport security inspection station or a barium solution is on its way through one's digestive tract.

There are, however, 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 1.2 m for 480 kV. (3) The fastest possible film/screen combination is usually required and can result in poor resolution. (4) There is no opportunity to reradiograph if the first film turns out to be unusable. (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. In some exposures the film package in its protective holder may be located within 30 cm of 1 kg of high explosive.

II. EQUIPMENT

The three flash x-ray systems described here are portable and can be moved between various test sites. They are manufactured by the McMinnville Division of Hewlett-Packard, formerly Field Emission Corporation, and are discussed in the order of ascending x-ray energy.

A 180-kV system is shown in Fig. 1. Features in addition to those given in Table I include beryllium window and Kovar window x-ray tubes, 1- to 2.5-m useful target-to-film distance, and a pulser weight of only 54 kg.

The next system operates either at 430 kV with remote x-ray tubehead or at 600 kV when the x-ray tube is in the pulser. Figure 2 shows one of the pulsers, with its charging voltage and trigger cables, air and Freon lines, and grounding strap.

The equipment includes both beryllium and Kovar window x-ray tubes, a beryllium window electron-beam tube, useful target-to-film distance ranging from 2 to 8 m, and each pulser weighs 300 kg. See also Table I.

The system with the highest x-ray energy to be discussed here is a 2.0-MeV flash x-ray generator, the pulser shown in Fig. 3. There is a useful target-to-film distance ranging from 2 to 20 m. The huge pulser weighs 2700 kg and is 2.1 m high and 4.3 m long. Other characteristics are in Table I where the three systems are compared with LASL's PHERMEX, a large, fixed, 30-MeV flash x-ray facility. Figure 4 is a flow diagram showing how the systems work in which a power supply provides for charging of the pulser to 27.5 kV for 600-kV output, for example. The air-pressure control for spark gap switching allows gap spacing to remain fixed while the voltage is being adjusted. The main pulser column is insulated by Freon under pressure control. The trigger amplifier and pulse transformer provide the signal to discharge the pulser at the appropriate time.

TABLE I

COMPARISON OF FLASH X-RAY SYSTEMS

Max Energy of Equipment	180 kV	600 kV	2.0 MeV	30 MeV PHERMEX
Radiation Intensity at 1 m per Pulse:	1 mR	15 mR	2R	Up to 100 R
Focal Spot Size (mm)	1.8	5.0	5.0	0.5
Pulse Duration (ns):	20	20	20	200, 100, 40, or 6
Penetration: Capability:	2.5 cm Al at 1 m	5 cm Al at 4 m	7.75 cm Fe at 2 m	30.5 cm Fe at 2 m
Initial Cost ($k):	12.5 (1973)	22.5 (1971)	54.5 (1973)	4000 (1961)

Figure 5 is a photograph of a selection of radiation tubes used in flash x-ray systems. In the upper left is a beryllium window electron beam tube which can be used in the 600-kV pulsers. At the upper right is a Kovar window tube for the 2.0-MeV pulser. Both tubes have getters to help maintain the high vacuum required for good performance. In the lower right is an x-ray tube for a 600-kV pulser or a 480-kV remote tubehead. This particular tube has had heavy usage, and tungsten from the target has been deposited on the inside of the glass envelope. In the lower left are two tubes for the 180-kV tubeheads: a Kovar window tube, and, with the enlarged hood, a beryllium window tube.

III. APPLICATIONS

Several applications of the flash x-ray technique are discussed in detail below. In addition, flash x ray has been used to make radiographs of electron beam welding of aluminum and of steel, [1] as well as of filament-wound pressings rotating at speeds as high as 18 000 rpm. It has also been used to irradiate electrical cabling, various types of detectors, and lasing environments.

First there is a setup of a 600-kV flash x-ray system (Fig. 6) where radiography was used to image bullets striking various ceramic armor samples. Figure 7 is a closeup of the target area, showing a trigger screen on the right and a boron nitride target sample mounted on a fiber glass backing plate in the center. A simple trigger circuit is located on the target face. Clip leads to layers of copper foil separated by Mylar complete the circuit through a battery, resistor, and capacitor to the delay trigger amplifier. The circuit is switched on when the bullet shorts the two copper sheets. To the left is a catch box for the spent bullet, and to the rear is a film holder. Figure 8 is a radiograph of a bullet striking the target with zero delay. Figure 9 shows bullets striking targets at various delay times. Debris can be seen at the front surface of the target, and there is deformation of the bullet and breakup of the targets.

An outdoor setup of the 600-kV flash x-ray system is shown in Fig. 10. The object of the experiment was to radiograph the particles of copper in the jet after detonation of a small shaped-charge device with a copper lining and 40 g of explosive, shown at the left of the picture along with the two elongated, upright film packages. The x-ray pulsers are positioned at 0° and 90°, as are the films. The two pulsers at the right operate in the 480-kV mode with remote tubeheads connected to the pulsers by high-voltage cables. The tubeheads are behind protective sandboxes which have Lexan windows to permit passage of the x-ray beam. The film holders are taped to 1.27-cm-thick Lexan to provide vertical support as well as protection against air blast and shrapnel. The experimental area is at the left behind another sandbox which protects both pulsers. Figure 11 is a radiograph of a jet from a demolition device identical to that just discussed. The jet in Fig. 11 has penetrated 7.6 cm of aluminum and was imaged with a 180-kV x-ray beam. The velocity of the jet is approximately 6 mm/μs. Note the individual particles of the jet, the rupture of the aluminum at the emergence hole, and the debris cloud going from the head of the jet back to the aluminum block.

In another application of flash x ray, we examined the bow-wave effects and jetting from the detonation of a 2.5-cm-diameter spherical explosive charge that was partially submerged in water. The setup for this type of experiment is shown in Fig. 12. Composite reproductions of the results of one of these experiments are shown in Fig. 13.

The images in Figs. 14-16 show at progressively later times the breakup of the metallic sphere of a small fragmentation device after detonation. The discontinuity in fragment distribution at the equator is evident, as well as the nonsymmetric expansion of fragments around the remainder of the envelope.

A recent application of flash radiography is the imaging of lead being cast into a graphite mold by a total of three flash x-ray generators, two 180 kV and one 600 kV. This is a preliminary experiment leading hopefully to the flash radiography of uranium castings in a vacuum furnace. We thereby hope to learn more about the formation of defects such as voids, cracks and segregation and their eventual elimination. Figure 17 is a closeup of the casting region showing from top to bottom the crucible where the lead is made molten, a graphite hemishell mold with three films behind at 0°, 60°, and 120° and lead bricks in front and at the sides to prevent exposure on a given film from more than one x-ray generator. A trigger circuit is mounted atop the mold riser consisting of a light beam and a photodiode, the signal coming from the light interruption from the falling, molten lead. Figure 18 is a 0° radiograph taken at 180 kV showing the molten metal striking the pole of the mold at 50 ms after zero time. Figure 19 is a 60° radiograph taken at 480 kV showing the molten metal striking the side wall of the concave portion of the mold at 75 ms after zero time with molten metal running up and down the side wall. Figure 20 is the 120° radiograph taken at 180 kV at 100 ms. All of the above flash radiographs were taken of a heated mold, the heating tape being imaged in the riser section of the mold.

IV. TECHNIQUES

A. Films and Screens

All of the flash radiographs shown here are shadowgraphs and were obtained with the fastest film/screen combination that could be found for the energies involved at the time of these experiments. The film is Kodak Rapid-Process Royal (RPR) film, a 90-s processable medical film and a successor to the old Royal Blue and Type-F Kodak films. The screens are Radelin TI-2 calcium tungstate screens, manufactured by U. S. Radium Co.

We are continually evaluating possible high-speed film/screen combinations. Included are the more familiar calcium tungstate screens, as well as the newer rare-earth phosphor screens used with green light sensitive film. The radiographer is always searching for faster film/screen combinations that will allow use of greater target-to-film and object-to-film distances. Larger amounts of explosives can then be diagnosed, film-holder protection will be more assured, and better film definition will be achieved, or perhaps all three advantages can be realized.

B. Protection of Equipment and Films

A typical flash x-ray experiment requires protection not only of the film but of the expensive equipment. Both are in proximity to detonating explosives and the accompanying air overpressures, negative pressures, ground shocks and massive high-velocity and high-temperature shrapnel. The equipment, however, is usually 10 to 20 times farther from the detonation than is the film and is therefore easier to protect.

Some of the measures taken to protect equipment and film can be seen in Figs. 10 and 21. In Fig. 10, boxes of sand protected the equipment from shrapnel. The loose sand covering the ground served as an efficient shock attenuator. A 1.27-cm-thick layer of Lexan for protection of the film did suffer from overpressure shock, with resulting pressure marks on the film. In a later shot, film protection was improved by sandwiching the holder for film and screen between front and back Lexan sheets and front and back sheets of polyurethane foam (2.5 cm thick) which was compressed 50%.

A closeup of film holders and explosive in Fig. 21 shows the white circular explosive in place on the wooden shot stand and an electrical cable leading to the detonator. The two large steel plates adjacent to the wooden stand minimize explosive effects to the cylindrical film-holder pigs. The pigs are suspended on rigid foam inside the two saddles, and the aluminum lightproof film holders inside the pigs are suspended in slightly compressible foam.

In short, adequate blast and shrapnel resistance can usually be provided by distance, massive blast shields, aluminum or Lexan plates, and compressible and/or rigid foams.

C. Triggering Methods

Perhaps the most widely used method of providing a trigger signal to flash x-ray systems is the make trigger circuit, one version of which is shown in Fig. 7, and which consists of copper foils separated by a Mylar sheet. Other types of trigger circuits are break circuits (as opposed to make circuits), photoelectric devices, x-ray beam interruption, magnetic loop triggers, acoustic transducer triggers, precalculated time-delay triggers (from a zero time reference), microwave Doppler techniques, and capacitance triggers. [2]

V. NEW DEVELOPMENTS

Stereo flash radiography has been demonstrated statically, although not yet dynamically on a 21.6 cm diameter object at 480 kV. The setup geometry included 9.1 m target to film distance 2.1 m object to film distance and a 1.1 m tubehead centerline to tubehead center distance with the two images on two separate film loads. The pair of films, viewed on a stereo film viewer gives striking three dimensional relief. On an actual dynamic shot, simultaneous timing would be critically important.

To aid our various flash x-ray projects we have installed two Model M7A Kodak Medical X-Omats which give 150 second film processing and improved quality as compared to the manual processing of the very sensitive RPR film.

VI. CONCLUSIONS

Flash radiography can be performed with a variety of commercially available equipment, all of which is portable and many components of which are interchangeable. Application of flash radiography is some times easier and less expensive than high-speed photographic techniques and sometimes makes possible determination of otherwise unattainable data, such as internal integrity of dynamic assemblies and metallic jet analysis. Imaging techniques depend essentially on the fastest available screens and films. Protection of equipment and film is accomplished by judicious combinations of common materials such as aluminum and steel, compressible foams, and Lexan. The make circuit is the most commonly used of a variety of trigger techniques.

VII. REFERENCES

[1] BRYANT, L., "Flash Radiography of Electron Beam Welding," Materials Evaluation, Vol. XX1X, Issue 10 [1971] p. 237-280.

[2] ESPEJO, R., "Suggested Methods of Triggering Pulsed Radiation Systems," Field Emission Corp. Tech. Bulletin No. 730-8, April 16 [1969], p. 1-7.

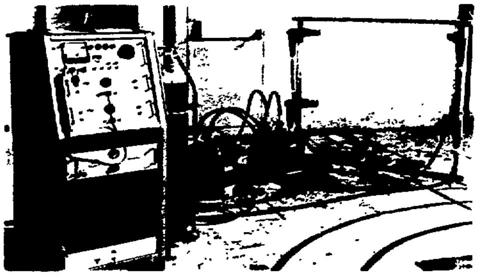

Fig. 1. 180-kV portable flash x-ray system.

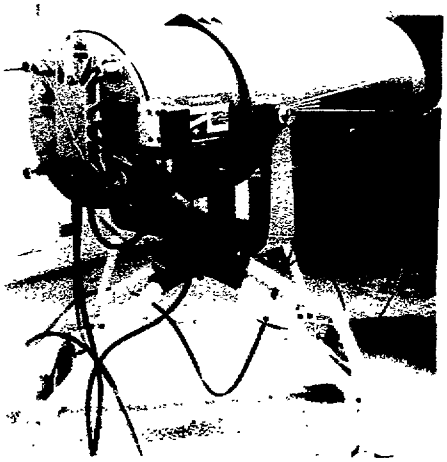

Fig. 2. Pulser for a 480-kV flash x-ray experiment.

Fig. 3. Pulser for 2.0-MeV flash x-ray system. (Photographic reproduction with permission of McMinnville Div., Hewlett-Packard.)

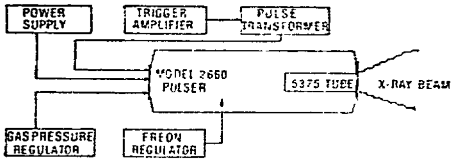

Fig. 4. Schematic diagram for flash x-ray system.

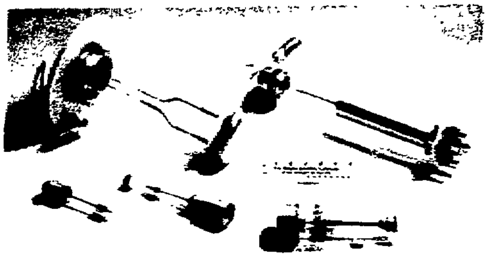

Fig. 5. Representative radiation tubes used in flash x-ray systems.

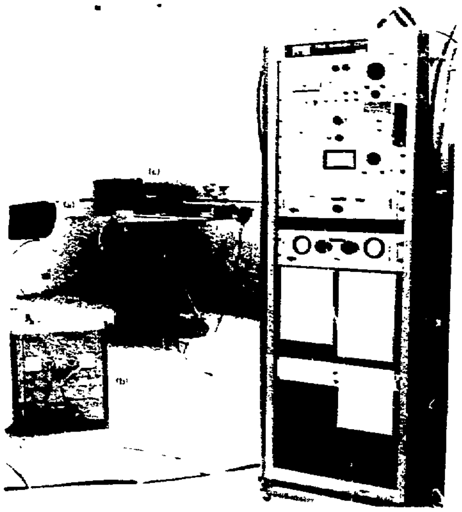

Fig. 6. Setup for a 600-kV experiment in which bullets are to strike ceramic armor samples. (a) Flash x-ray generator; (b) time-interval counter; (c) location of gun; (d) x-ray controls.

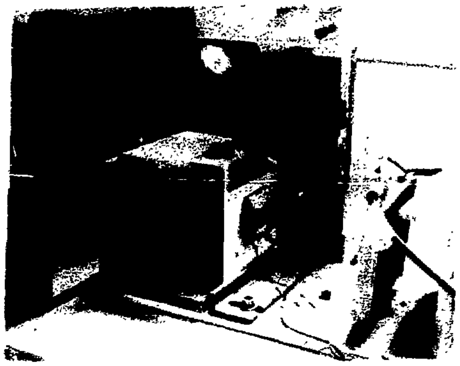

Fig. 7. Closeup of target area for 600-kV experiment of Fig. 6, showing armor sample and film holder.

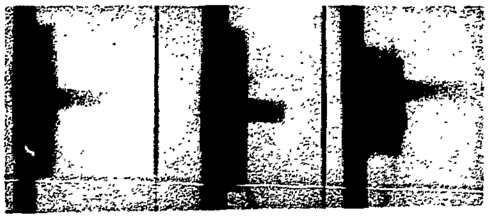

Fig. 9. Positive radiographs of bullets striking target at increasing delays in x-ray pulse. Boron nitride targets, left and center; aluminum oxide target, right. Note debris from target and deformation of bullet and target.

Fig. 8. Positive radiograph of bullet striking boron nitride target (zero delay in x-ray pulse).

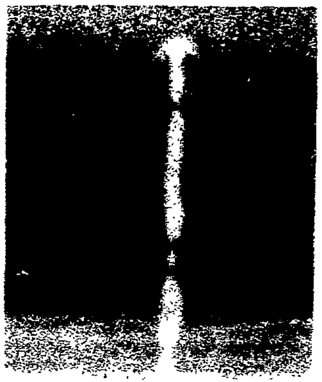

Fig. 11. Radiograph (180 kV) of jet from a demolition device. Jet has penetrated 7.6 cm of aluminum after a pulse delay of 58 μs.

Fig. 10. Setup for 480-kV flash x-ray experiment, showing protected firing bunker in background.

Fig. 12. Setup for a 600-kV experiment in which a spherical explosive charge (not visible) was detonated while partially submerged in a pool of water (sandbagged structure). Film is on derricklike structure suspended above the water.

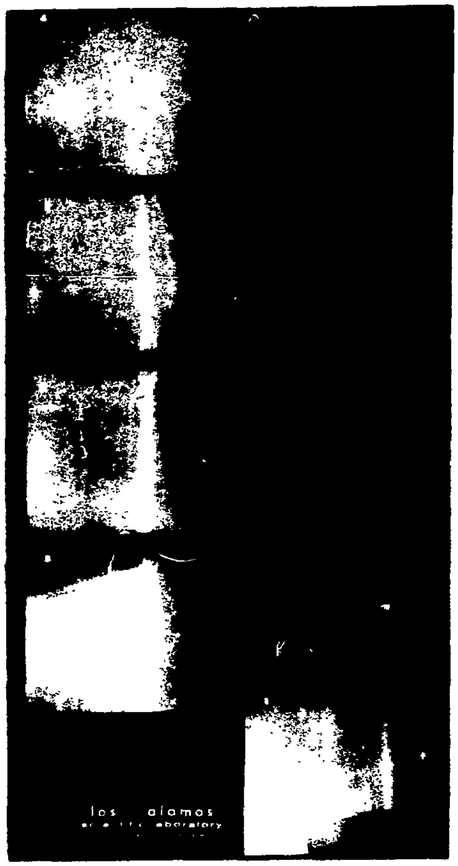

Fig. 13. Composite radiographic reproductions of 600-kV images obtained from setup of Fig. 12. Note the vertical jet of water.

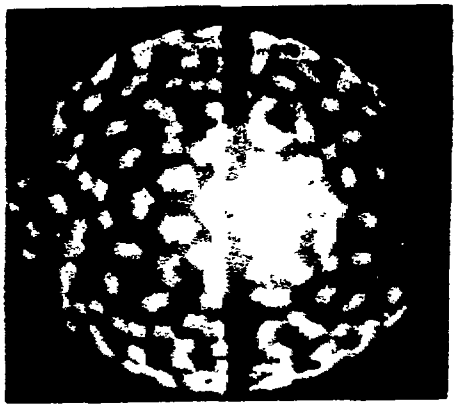

Fig. 14. Double exposure (480 kV) of small spherical fragmentation device before detonation and after a pulse delay of 45 μs.

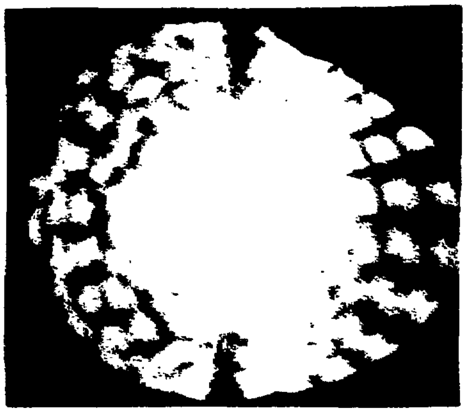

Fig. 15. Radiograph of small spherical fragmentation device after a pulse delay of 60 μs.

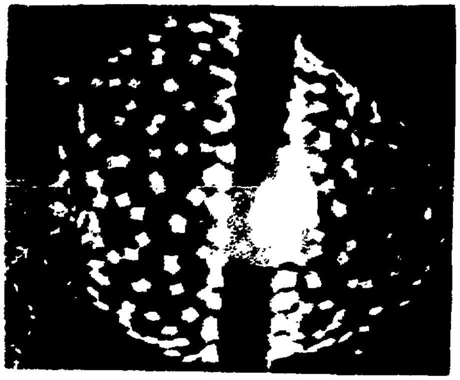

Fig. 16. Radiograph of small fragmentation device after a pulse delay of 75 μs.

Fig. 17. Lead Casting Setup.

Fig. 18. 180 kV image of molten lead pour with 50 ms delay.

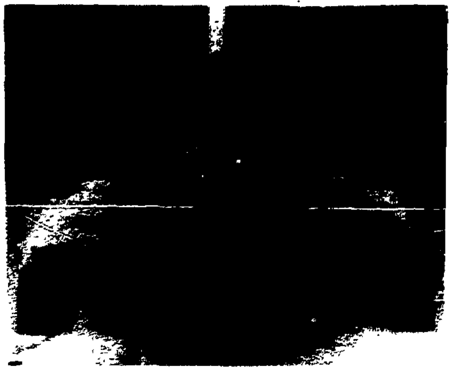

Fig. 19. 600 kV image of molten lead pour with 100 ms delay.

Fig. 20. 180 kV image of molten lead pour with 250 ms delay.

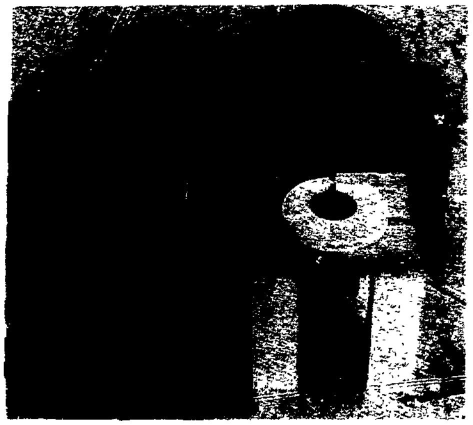

Fig. 21. Closeup of protective film holders and explosive.