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TITLE: IN-BORE RADIOGRAPHY FOR LARGE-CALIBER GUN

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IN-BORE RADIOGRAPHY FOR LARGE-CALIBER GUN

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State-of-the-art techniques for dense object radiography, fast-transient digitization, modern computation, digital averaging and enhancement of multifilm radiographs, and microwave interferometry have been combined to provide modern propulsion and launch diagnostics for large-bore gun shots. An in-bore multifilm radiograph of a rod and sabot assembly was taken using a 2.3-MeV flash x-ray system. The launch system was radiographed ~1 m from the muzzle end, where the gun tube walls are >1 in. thick. Excellent spatial resolution was achieved, and the straightness of the rod was determined to within 0.1 mm. A microwave interferometer produced in-bore position-vs-time measurements. External x-ray shadowgraphs were used to view yaw and sabot separation, and dynamic pressure measurements were compared with theoretical velocity profiles. The entire set of diagnostics comprises a self-consistent description of early projectile history.

Introduction

Significant advances have recently been made in armor. Reactive, spaced, composite, and other special armors have demonstrated performance far better than the old standard rolled homogeneous armor (RHA). One of the main weapons that has been relied on to defeat modern armor is the gun-launched long-rod penetrator. As armors improve, it is necessary to develop higher velocity and larger length-to-diameter ratio (L/D) rods. As L/D and velocity increase, the probability increases for system integrity failure. The diagnostics discussed in this paper were designed to help identify and solve the anticipated problems in rod and sabot failure.

Flash X Rays

The largest forces, and hence, the opportunities for failure, are applied to the launch system (rod and sabot) in the barrel; thus, the central diagnostic was an in-bore multifilm radiograph of the rod and sabot assembly taken with a 2.3-MeV Hewlett-Packard flash x-ray system. This standard system has a rated dose of 125 mR at 2 m and a spot size of 5 mm in diameter. Its rated pulse width is 40 ns. The x-ray diode was positioned 1.7 m from the axis of a 105-mm rifled gun tube and was centered 1 m from the muzzle end. The tube at this point was slightly more than 1 in. thick. The projectile used was the M833. This is a fielded, depleted-uranium rod round with no known deficiencies, which was given to Group M-8 for the development of these diagnostics.

Two major problems had to be overcome to produce a good radiograph. First, x-ray scattering was eliminated. With no shielding, a 2.3-MeV source generated significant fog on the film and yielded poor resolution, poor constrast, and density gradients. This we avoided by wrapping thick sheets of lead from the top of the barrel, around the back of the film cassette, to the bottom of the barrel. The second problem was insufficient x-ray intensity. The x-ray unit used was not designed to penetrate 2 in. of steel; thus film exposure was small. DuPont Cronex industrial NDT 75 film and ND 19 intensifier screens were used in screen/film/screen sets with 4-mil (0.1-mm) lead separating the sets. Four sets were used in a film pack and were indexed with pins to provide alignment. A bladder placed around the entire film pack was evacuated to ensure good screen-to-film contact. After development, the films were superimposed to improve effective exposure and signal-to-noise (S/N) ratio. Fine detail in the rod and sabot can be clearly observed, as can the rifling in the gun tube. A superposition of two films is shown in Fig. 1.

In addition, the best three of the four films were digitized on a scanning microdensitometer, then averaged. A reconstructed image in which density gradients have been removed and the contrast has been optimized to bring out features is shown in Fig. 2. Resolution on the reconstructed radiograph is 0.1 mm. The line across the center is an artifact of the digital processing. These processes were developed in Group M-4 of Los Alamos National Laboratory's (LANL's) Dynamic Testing Division for dense object radiography, in support of the nuclear weapons program.

The 2.3-MeV x-ray unit was triggered after an appropriate delay from a pulse generated by a pin inserted into the gun tube's bore evacuation holes. Three capped pins were used, along with a logic circuit that selected the first pin signal to arrive after a set delay from the round initiation time. This redundancy ensured proper triggering of the x-ray unit. Capped pins were required to avoid premature tripping that could result from hot ionized gas leaking past the obturator ring and shorting the uncapped pins. Capped pins produced a signal when they were crushed by the passage of the sabot connecting ring. Strain gages strapped

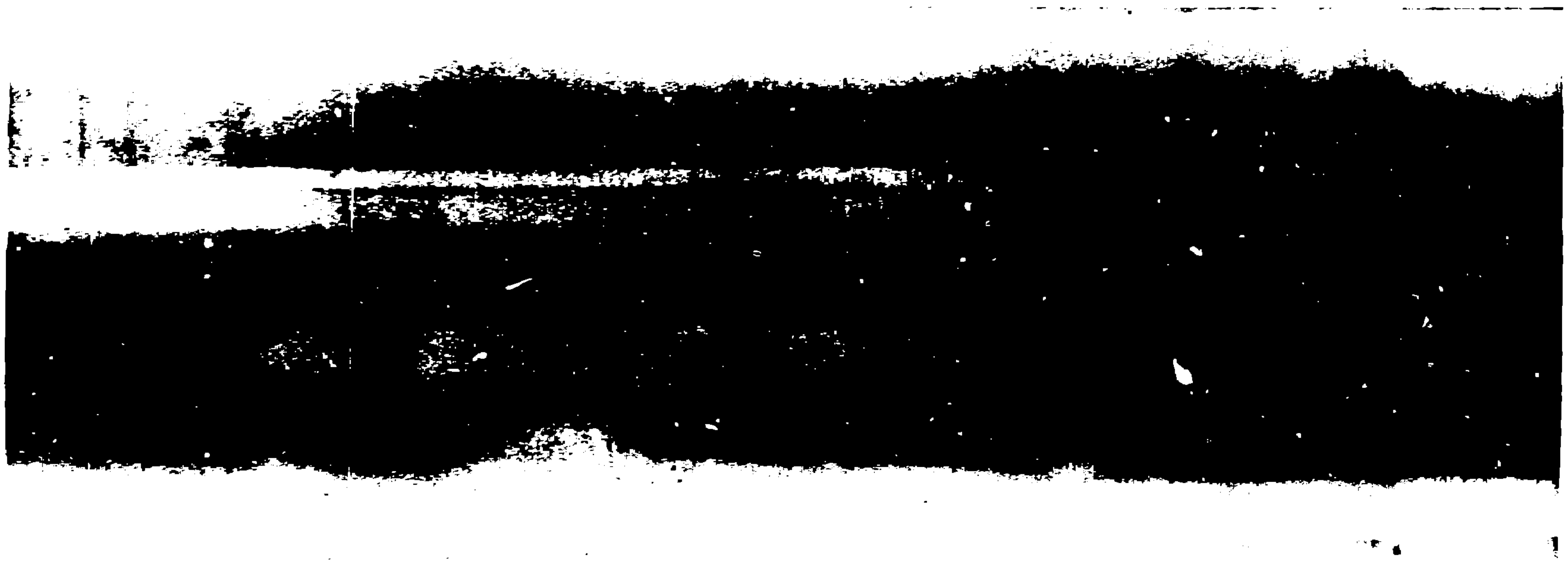

Fig. 1. M833 projectile inside 105-mm gun barrel.

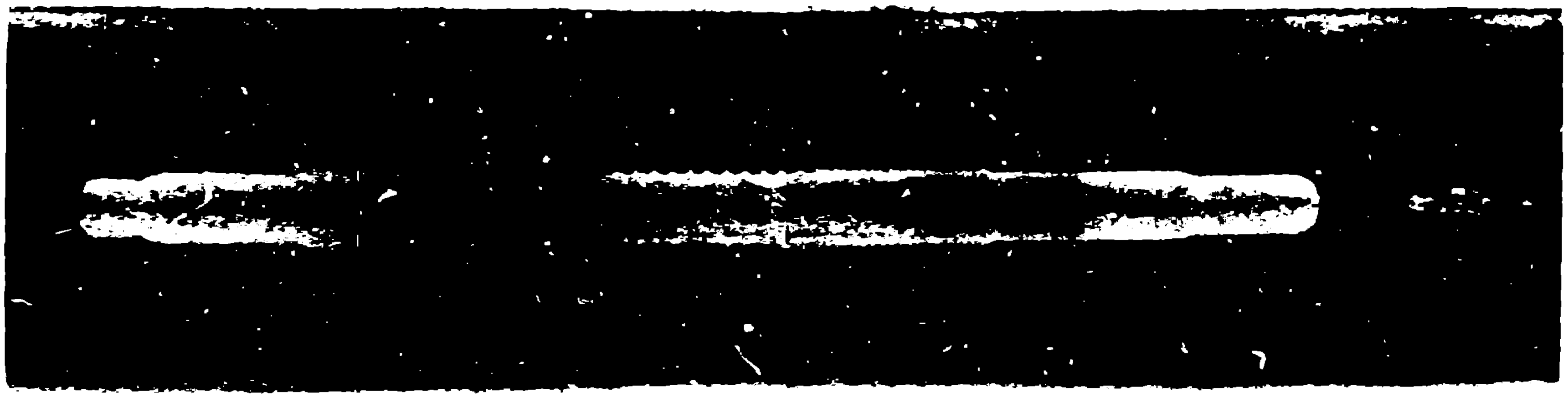

Fig. 2. Reconstruction of three radiographs of an M833 projectile inside a 105-mm gun barrel.

circumferentially onto the gun tube could also be used for triggering in the absence of pin access holes.

Pin, strain gage, and velocity screen times were measured by means of DM10 time interval meters, and delays were generated by DM10 digital delay units. Both of these units were designed and built by M-8 personnel; they are 10-channel units with 1-ns resolution and range extending to 100 s.

Two sets of orthogonal 150-keV flash x rays were taken external to the gun tube to observe sabot separation and projectile yaw. They were centered at 2.55 m and 5.75 m from the muzzle. Use of such equipment is standard on well-equipped gun ranges. Proper system care of the system and film cassette can result in excellent radiograph quality, as shown in Fig. 3. These orthogonal views were taken at the 2.55-m position. Details such as fine screw threads and one bent fin are clearly visible.

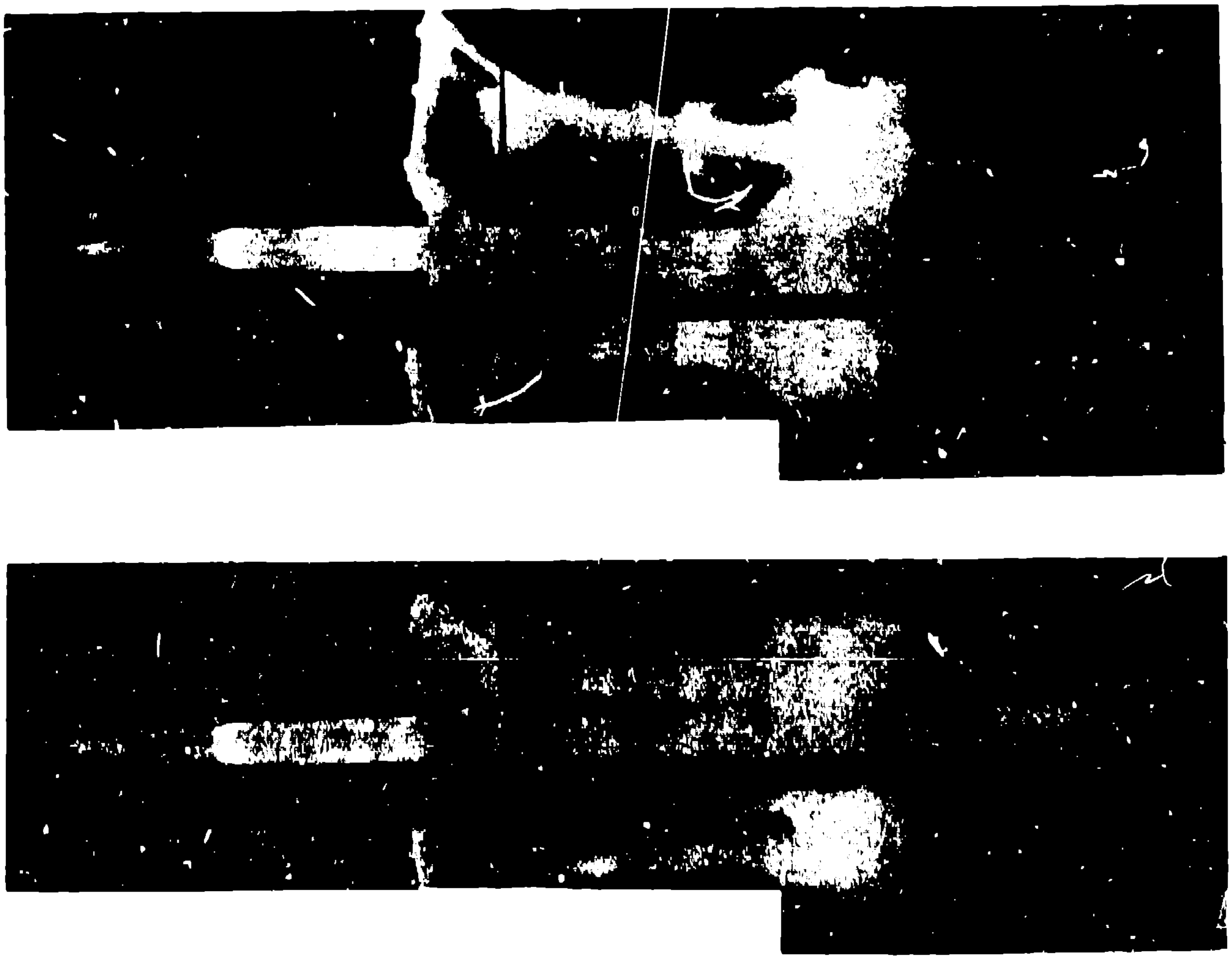

Fig. 3. Orthogonal 150-keV flash x rays of M833 round, 2.55m past the 105-mm gun muzzle.

Microwave Interferometer

The microwave system used an 8.3-GHz oscillator with separate horns for sending the signal down the gun tube and for receiving the reflected signal. Microwaves are reflected into the gun tube using a thin piece of small-cell polystyrene coated with aluminum foil. Use of quadrature hybrids, a signal divider, mixers, and a phase shifter in the circuitry produced two signals 90° out of phase. This redundancy was used to ensure acquisition of good data and to improve S/N by using only the zero crossings of both curves. With this phase-sensitive detection system, resolution is about 1% of a wavelength or 0.36 mm. The system output was signal phase vs time, where phase is proportional to projectile position in the gun tube. System output was digitized and stored with a Lecroy system capable of 200-MHz digitization rate. Useful data are typically over about 28,000 points of the available 64,000 points and only every sixth point is used. Position-vs-time data are shown in Fig. 4, where only every hundredth point is plotted for clarity.

Differentiating these data once, with respect to time, gives velocity, which is plotted vs position in Fig. 5. The curve is described by a running least-squares fit using 50 data points. As expected, differentiation adds some noise to the result. The muzzle velocity from the microwave data, extrapolated to the end of the gun tube, is 1485 m/s, which agrees well with the advertised velocity of 1495 m/s for the M833 round. The quality of data is remarkably good, considering the complex shape of the projectile-reflecting surface and large dynamic range of velocities observed.

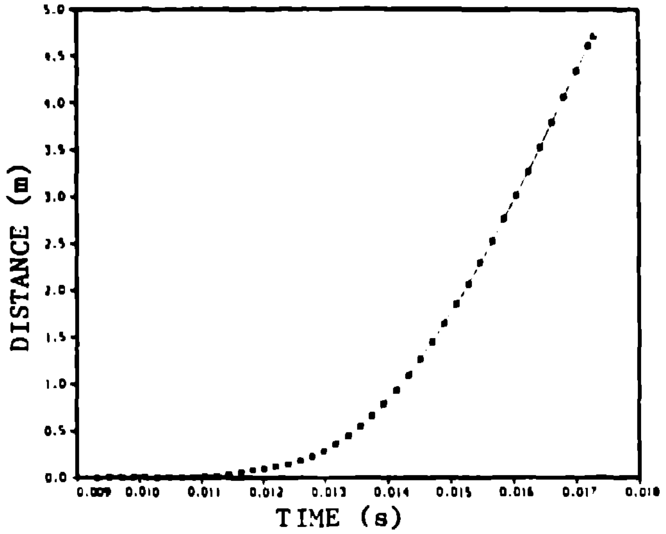

Fig. 4. Position as a function of time of an M833 projectile in a 105-mm gun barrel, as measured by an 8.3-GHz microwave interferometer.

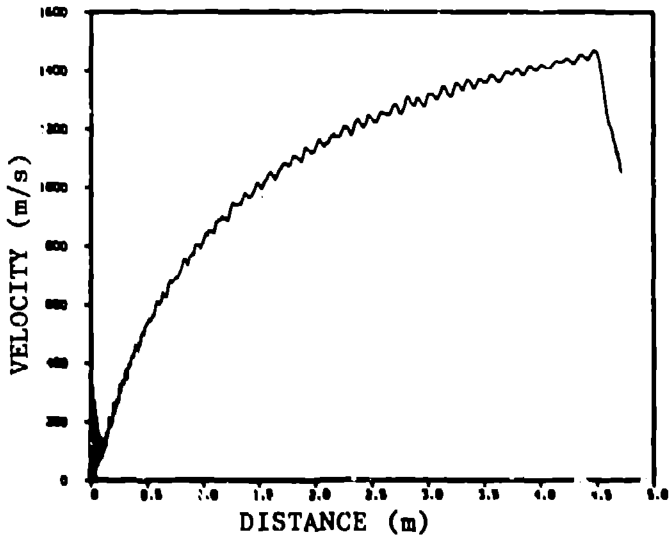

Fig. 5. Velocity as a function of position of an M833 projectile in a 105-mm gun barrel, calculated from the first derivative of the microwave interferometer data.

The recoil position data are superimposed on the raw in-bore velocity data. These recoil data appear as a low-frequency modulation of the phase-vs-time curve because a component of the microwave is reflected off the gun tube end. These low-frequency data agree well with other recoil data. With this gun system, about one cycle or 36 mm of recoil is observed by the time the projectile exits the gun tube.

When a nylon obturator ring, also designed to act as a clutch, is used in a rifled tube, hot ionized gases can leak past the seal, thus changing the dielectric constant in the tube. If significant leakage occurs, good data will not be acquired down the entire length of the gun tube. Data from systems with smooth-bore gun tubes or projectiles with nonclutching firmly sealed obturator rings will be consistently high quality. The data of Figs. 4 and 5 show that the obturator ring sealed quite well on this particular round. Other M833 seals have been observed to fail at ≤2m from the muzzle; thus the microwave system also serves as an obturator diagnostic.

Interior Ballistics Burn Code

The interior ballistics code IBHVG2.229 was brought from the U.S. Army Ballistic Research Laboratory and was adapted to run on the CRAY computers at LANL. The code has the usual inputs for frictional resistance; gun-tube geometry; projectile and heat-loss variables; and recoil, primer, and propellant data. Like most codes, this assumes instantaneous ignition and laminar burning of the grains. This code has the added capability to use varying properties of the propellant grains during the burn. The output includes a table with the travel, acceleration, and velocity of the projectile, the mean pressure and temperature of the gas, and the fraction of the propellant burned every 0.1 ms. The conditions at maximum pressure and when the projectile exits, and the energy balance are summarized.

Pressure transducers were placed 0.97, 1.10, 1.98, and 3.06 m from the breech end in the gun tube. Transducer output was digitized with a Nicolet 4094A digital oscilloscope and the data were analyzed and plotted with an in-house Macintosh program. A typical result for the first transducer is shown in Fig. 6. Since the M833 round has a steel case, breech pressure could not be measured. Thus, Fig. 6 shows a delay from propellant initiation, followed by a sharp rise as the obturator ring passes the transducer port. Pressure transducer data, position-vs-time measurements from the microwave system,

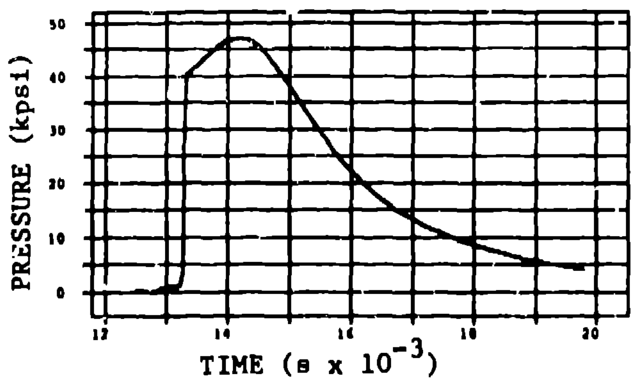

Fig. 6. Pressure vs time data at 0.97m from the breech end of the gun tube.

and measured muzzle velocity agreed well with the burn code.

Conclusions

The in-bore flash x ray and microwave interferometer have been shown to be excellent internal ballistics diagnostics. For experimental systems that are experiencing rod or sabot failure, the radiograph could be used to view the region where the structural break or bend is occurring. Design solutions would then be far more direct and would not rely on the hit-or-miss technique. Similarly, the microwave interferometer can identify gun tube positions where seal failure occurs or positions where the velocity abruptly changes because of projectile system failure. Combined with the other more standard diagnostics used, the M-8 range can provide an excellent data base for internal ballistics.

The results from many of these diagnostics will soon be used in support of work on a doctoral thesis. Long-rod systems will be fired down 120-mm gun tubes that are within and at the limits of manufacturing straightness tolerances. Experimentally observed rod distortion and projectile system failure will be compared with model predictions. The result should significantly affect future weapon designs.

Acknowledgments

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