Ballistic Breakthrough

A new method has been developed for taking very accurate internal measurements of projectile velocity, acceleration, and relative pressure from the same test firing by the use of nuclear radiation

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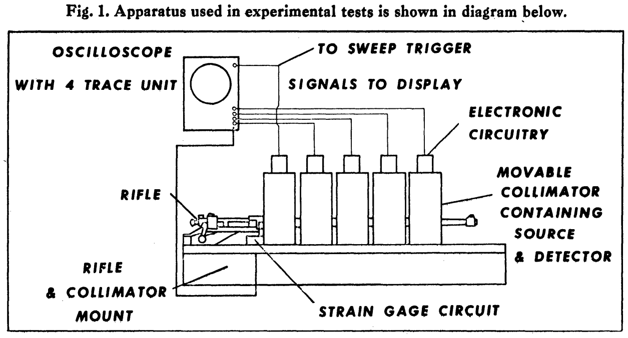
A NEW method for obtaining internal ballistic measurements by the use of nuclear radiation has been developed. This method makes it possible to obtain internal ballistic measurements that are difficult or impossible to obtain by conventional means. Through the use of gamma radiation, our knowledge of internal ballistics can be improved, and this improvement can result in increased efficiency and reliability of weapons and ammunition.

Internal ballistic measurements such as the determination of the velocity or acceleration of the projectile and the chamber pressure in a weapon as a function of projectile travel down the bore are important to designers of weapons and ammunition. Such measurements allow the designer of a weapon system to obtain the maximum efficiency and accuracy from the system.

Internal ballistic measurements are difficult to obtain because of the short time interval in which a projectile is accelerated within a rifle or cannon barrel. The magnitude of this problem is readily evident when one considers that in a modern high-velocity small arm the projectile is accelerated from zero velocity to a velocity of about 3,000 feet a second within a time interval of only one-thousandth of a second.

Fig. 1. Apparatus used in experimental tests is shown in diagram below.



In spite of the inherent difficulties in obtaining internal ballistic data, methods have been developed for acquiring some of these measurements. Chamber pressures have been measured in the past by the use of a copper "crusher" cylinder which is compressed by the pressure in the chamber of the weapon. This method gives approximate values of maximum chamber pressure, and for most reliable measurements is restricted to use in a special test-gun barrel that has been prepared for such a device.

Some other methods, such as the use of a piezoelectric gage, have been used to obtain pressure information, but these suffer from some of the disadvantages of the crusher-cylinder technique.

Procedures for the measurement of the acceleration and/or velocity of projectiles within gun bores have also been developed. Some methods have involved the use of wires, etc., that were inserted into the gun bore to detect the passage of the projectile. Ultrasonic or electromagnetic waves can be reflected from the projectile out the muzzle to give information on bullet travel versus time.

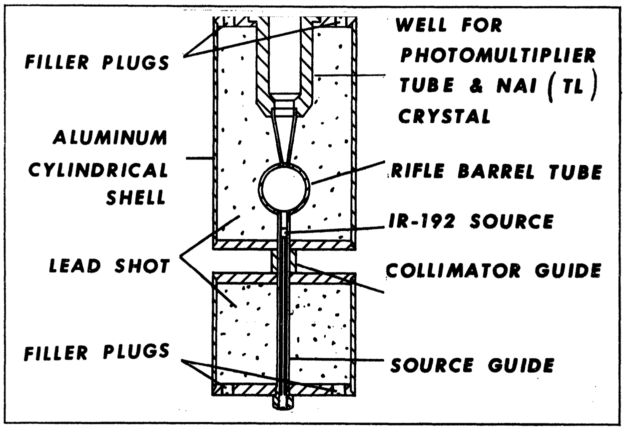


Fig. 2. Diagram shows cross section of aluminum collimating cylinder.

These methods may require modification of the barrel that is being tested. The main disadvantage is that none of the methods described give data simultaneously on both the chamber pressure and bullet position as a function of time.

THE new nuclear radiation method does not have the disadvantages and limitations that are inherent in previous techniques. Furthermore, the new method provides information that cannot be obtained with the methods in current use, and therefore the method is considered to be an experimental "breakthrough."

Using nuclear radiation it is possible to obtain accurate projectile velocity and acceleration information based on the distance the projectile has traveled down the gun bore. During the same firing, pressure information related to the travel of the projectile down the gun bore also can be obtained through the use of strain gages combined with nuclear radiation.

Through the proper selection of a radiation source, this nuclear method can be utilized to obtain internal ballistic measurements from guns of almost any caliber. The tests that were conducted to develop and verify the feasibility of this method were made with a model 1903/A3, .30/'06 Springfield rifle. These tests were sufficient to show that nuclear radiation can be applied to internal ballistic measurements on larger guns.

The radiation technique developed with the .30/'06 Springfield rifle utilized nuclear radiation from the radioisotope iridium 192 and suitable radiation detectors. Iridium 192 emits gamma rays that are capable of penetrating matter in the same manner as the more familiar X-rays.

This radioisotope has been used in radiographic work and it is readily available from commercial suppliers as well as from the U. S. Atomic Energy Commission at a relatively moderate cost.

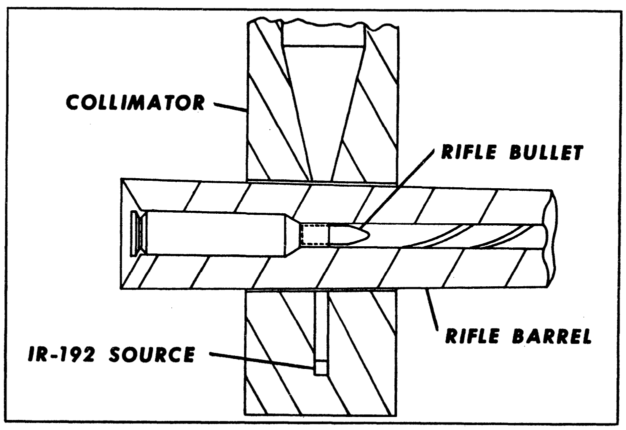
A diagram of the apparatus used in the experimental tests is shown in Figure 1. The equipment consists of a rifle, five radiation collimating cylinders, a mount for the rifle and the collimators, five iridium 192 gamma radiation sources, five radiation detectors and the associated electronic circuitry, two strain gages, a strain-gage circuit, an oscilloscope, and a camera.

The rifle and collimator mount serves two basic functions: it secures the rifle, preventing motion from recoil, and it provides a base and guide for the collimating cylinders which can be moved to any desired positions along the rifle barrel.

The collimating cylinders are aluminum casings filled with lead shot. They each contain an iridium 192 radiation source and a radiation detector. A diagram of the cross section of a collimator is shown in Figure 2. The collimator casing is cylindrical, and the iridium 192 gamma source is located in a source guide at the bottom of the collimating cylinder. A large hole through each collimator at right angles to the axis of the cylinder permits the rifle barrel to be slipped through the collimator. The collimating cylinder contains a funnel-shaped insert so that virtually all the gamma radiation intersecting the bore is incident upon the radiation detector.

The radiation detector consists of a scintillation crystal and a photomultiplier. The nuclear radiation signal is detected by the crystal, and the signal is passed to the photomultiplier tube. The photomultiplier tube is attached

Fig. 3. Sectional diagram shows relationship of first collimator to rifle bullet.



to a preamplifier mounted on top of the collimating cylinder. The output of the photomultiplier tube and preamplifier is fed to an integrating circuit.

AFTER passing to the integrating circuit, the output of the photomultiplier tube located closest to the breech of the rifle also is fed to the external trigger input on an oscilloscope. The oscilloscope is capable of simultaneously displaying four voltage traces.

The output of each of the other photomultiplier tubes is fed first to an integrating circuit and then to one of the four inputs on the oscilloscope. A camera is used to record the display on the oscilloscope.

The two strain gages used to obtain pressure measurements are attached around the chamber section of the rifle barrel and are connected to an electronic circuit whose output is displayed as one of the traces on the oscilloscope.

The first collimator is located so that when a cartridge is seated in the chamber of the rifle, the lead core of the projectile intersects and attenuates the beam of gamma radiation from the iridium 192 radiation source. Figure 3 shows a cross section of the rifle chamber and the first collimator, indicating the relationship of the bullet and the gamma beam.

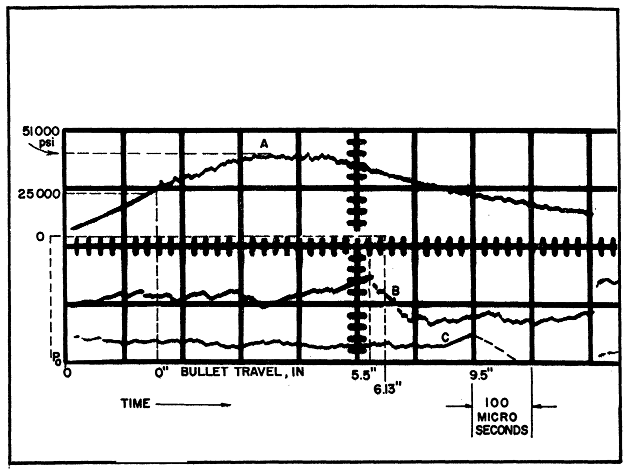


Fig. 5. Chamber pressure and bullet position after primer firing and ⅛-inch of initial bullet movement (at T_0) with detectors at 0, 5.5 and 9.5 inches shown above.

When the rifle is fired, pressure builds up behind the projectile from combustion of the primer and propellant and forces the projectile out of the cartridge case and down the bore of the rifle.

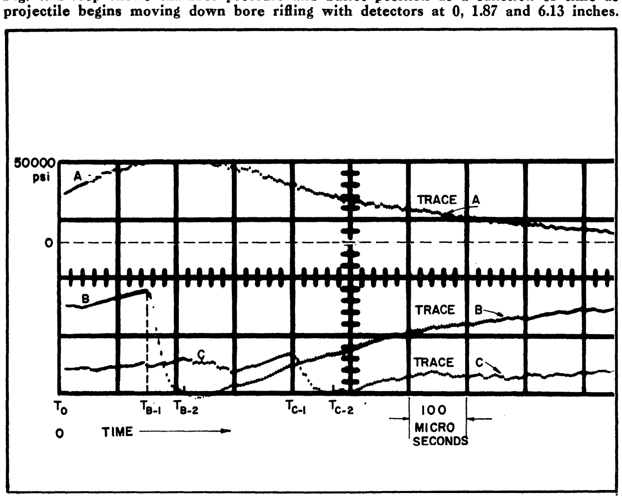
As soon as the projectile has moved approximately one-quarter of an inch, the gamma beam is no longer attenuated by the projectile. This change in attenuation results in a voltage signal being fed into the external trigger on the oscilloscope. This voltage rise triggers the sweep of the oscilloscope.

As the projectile continues down the rifle bore, it is accelerated due to the combustion of the powder in the cartridge. The projectile successively intersects the gamma beams of the other collimators located down the barrel. Corresponding voltage changes are indicated on the oscilloscope display of the traces of the successive collimators.

The distance between any two pulses, multiplied by the time-scale factor used on the oscilloscope, gives the time required for the projectile to travel between the corresponding two gamma beams. Since the distances between the gamma beams are known, a displacement-versus-time curve can be obtained. The distance between the collimators and their location along the rifle barrel can be adjusted so that any segment of the barrel can be studied.

In order to obtain a trace of both chamber pressure and bullet travel as a function of time, one of the four-trace plug units is supplied with the input from the strain-gage circuit. After the cartridge is fired, the pressure in the rifle chamber rises, producing a strain on the surface of the barrel and a voltage change in the strain-gage circuit. This voltage change is

Fig. 4. Sweep shows chamber pressure and bullet position as a function of time as projectile begins moving down bore rifling with detectors at 0, 1.87 and 6.13 inches.



displayed on the oscilloscope and indicates the instantaneous pressure in the chamber of the rifle.

By use of equations describing the voltage change in terms of strain and strain in terms of chamber pressure, the voltage curve from the strain-gage sweep can be converted to pressure and is found to be directly proportional. (See Figures 4 and 5.)

ONE feature of the experimental "breakthrough" consists of the development of a method for precise determination of time zero, T_o, which is the time when the bullet has moved ⅛-inch from the cartridge case. At this instant the high-speed oscilloscope is triggered by a beam of gamma radiation.

The scope makes a single sweep in one millisecond (1/1,000-second) and displays the voltage change in strain gages used to measure pressure. The sweep of the oscilloscope time scale has fifty subdivisions, indicating that each subdivision measures the changes produced in 20 microseconds (20 millionths of a second). Three traces are shown: A, B, and C. Trace A is of chief interest.

Trace A shows the chamber pressure (measured by strain gages) versus time, from the time the projectile has moved ⅛-inch until the projectile has left the muzzle. In this trace, the pressure is about 25,000 p.s.i. when the projectile has moved ⅛-inch and enters the rifling. The pressure reaches a maximum of about 51,000 p.s.i. about two-tenths of one-thousandth of a second later. The pressure then starts to drop and is only a few thousand p.s.i. when the projectile has reached the muzzle.

Traces B and C are the respective signals from detector B located 1.87 inches and detector C located 6.13 inches down the barrel from the bullet base at the initial bullet position in the cartridge. As the bullet passes detectors B and C, a drop in the signal is produced starting at $T_{B\text{-}1}$ and ending at $T_{B\text{-}2}$ for the detector B and beginning at $T_{C\text{-}1}$ and ending at $T_{C\text{-}2}$ for the second detector C. The pulses from these detectors make it possible to determine the time intervals required for the bullet to reach position B and C down the barrel. This provides velocity information and a pressure-versus-time curve all for a single firing.

The three traces shown in Figure 4 permit many analyses to be made. The pressure curve versus time is proportional to the acceleration versus time if we include a correction for the energy expended in bullet engraving, bore-friction, and other lost work.

One integration of the acceleration-time curve will give a curve proportional to the velocity-versus-time curve. Integration of the velocity-time curve will give the distance of projectile travel versus time.

Two distance of travel measurements are given by detectors B and C which permit evaluation of the factors to convert the integral of the pressure-time curve to the velocity-time curve. Cross plots also permit construction of pressure and velocity curves versus distances of projectile travel. Thus from a single firing, the entire family of internal ballistic relationships for that load combination can be obtained.

Figure 5 shows a negative of another oscilloscope photograph. In this figure the sweep was started at an initial pressure of a few hundred p.s.i. (estimated at about 20 microseconds after the time when the chamber pressure begins to rise from zero). The pressure curve again is indicated by the sweep labeled A in Figure 5.

The slightly curved pressure line from the left-hand edge of the oscilloscope grid to the point indicated as T_o is the oscilloscope sweep and was not drawn by calculation or estimation. During the period in which the pressure builds up in the cartridge chamber from zero pressure, at P_o, to the bullet entrance into the rifling, at T_o, the oscilloscope sweep gives a smooth curve of pressure rise as shown by sweep A in Figure 5.

After the bullet begins to travel, the pressure sweep shows minor oscillations through the remainder of the sweep.

Sweeps B and C in Figure 5 are from radiation detectors located 5.5 and 9.5 inches down the barrel in this firing. The sweeps from the detectors always show continuous irregularities because of background radiation.

It should be noted that the zero pressure scale does not occur at the same point on each oscilloscope photograph and is determined by location of zero voltages in the strain-gage circuit. Therefore, to superimpose the curves, the heavy oscilloscope grid scale must be disregarded, and in the case of sweep A the curves of Figure 4 may be superimposed by alignment of the zero pressure scale in sweep A for the photograph to give correct vertical alignment. Horizontal alignment then is obtained by aligning identical distances of travel on the time scale.

The same powder charge, powder type, primers, bullets, and cases were used in both of the firings shown in Figures 4 and 5.

Numerous additional firings similar to that shown in Figure 5 have been made since the preparation of the first draft of this manuscript. In most observations the oscilloscope sweep showing pressure rise is a smooth curve until a pressure similar to the discontinuity at 25,000 p.s.i. of Figure 5 is reached. Then the sweep oscillates and the data show that a definite period of oscillation occurs of the order of 10 to 20 microseconds. This corresponds to the order of magnitude for the time period required for sonic vibration in steel to travel from the bore of the rifle throat to the strain gage.

It is believed that this signal is produced by the impact of the bullet on the rifling of the barrel and that at time, T_o, as shown in Figure 5, the bullet has traveled about ⅛-inch from its initial position to contact the rifling.

ALTHOUGH a distance of ⅛-inch of bullet travel would seem to be a small factor it actually corresponds to about 100 microseconds of time because of low initial bullet velocity. If this correction is made to the distance-versus-pressure curve for this load, the bullet begins to move when the pressure is about 12,000 p.s.i. and travels ⅛-inch to the rifling while the pressure rises to about 25,000 p.s.i. Obviously much is to be learned by further study.

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