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RECENT APPLICATIONS OF THE PIEZO-ELECTRIC MEASURING METHOD IN BALLISTICS

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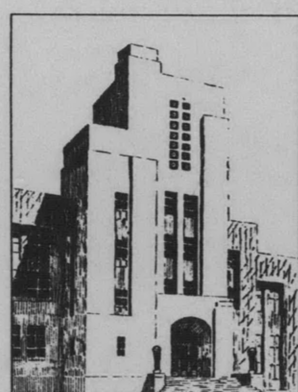

RESTRICTED

OCTOBER 1943

TRANSLATION 120

RECENT APPLICATIONS OF THE PIEZO-ELECTRIC MEASURING METHOD IN BALLISTICS

(NEUERE ANWENDUNGEN DES PIEZO-ELEKTRISCHEN MESSVERFAHRENS IN DER BALLISTIK)

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(Zeitschrift für technische Physik, Vol. 18, No. 11, November 1937)

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October 1943

Translation 120

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ABSTRACT

This paper describes the basic design of piezo-electrical equipment adapted to the study of phenomena in interior and exterior ballistics, and cites sources of error due to the mechanical structure of the gas pressure gage. It describes measurements of gas pressures in standard* guns, and devices to measure recoil forces in large and small guns. Piezo-electrical kick** data are compared with a curve derived by recoil measurement.

INTRODUCTION

It is a little-known fact that the piezo-electric method of measuring pressure, which has become very popular because of its wide range of application in mechanical engineering, was used at an early stage of its development for ballistic measurements. Although the attempt to employ the piezo-electric effect to measure rapidly varying pressures was first undertaken in the field of ballistics, this fact as well as the course of further development has scarcely become known beyond the most restricted professional groups. Therefore the present paper will report on this type of measuring apparatus as well as on the experience gained in numerous experiments during years intervening.

HISTORICAL BACKGROUND

The most important problem of internal ballistics consists in measuring the pressure-time relation when powder is burned in a gun. Since the pressure phenomena occur in periods of 10^{-3} and 10^{-2} second and pressures between 1000 and 4000 kg/cm^2 (14,223 and 56,893 lb/in^2) are produced, special measuring techniques are required, which cannot be supplied by mechanical equipment. Measurement was formerly restricted to maximum pressure, which was determined by crushing copper cylinders called crusher gages. Although this method has indisputable advantages because of its simplicity, it shows a number of basic errors which make determination of the true maximum pressure impossible.† The piezo-electric method of pressure measurement was first used in America in 1919 for ballistic measurements by W. Karcher. The mechanism transmitted the charge produced by the piezo-electric crystal to a highly sensitive ballistic galvanometer and recorded its deflection as a function of time.

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* Translator's Note: The guns referred to were of standard manufacture and had not been altered for testing purposes.

** See the definition of "kick" in the footnote on page 5.

† Editor's Note: Dr. J. Kirner, Stuttgart-Canstatt, has pointed out that he reported indicator diagrams of pressure phenomena in firearms, obtained by an optical method (Newton's color rings) in 1910, in Forschungsheft 88 of the VDI.

Differentiation of the recorded curve was necessary to determine the pressure curve itself.

At about the same time measurements on explosive phenomena in closed vessels were performed by Keys in England. At the suggestion of J.J. Thomson, Keys transmitted the charges produced by the piezo-electric tourmaline crystals directly to a cathode-ray oscillograph.

TEST SETUP

In 1931 the Zeiss Ikon A.G. in Dresden developed a piezo-electric indicator which was originally intended to measure the gas pressure curve in small arms, but which was later used for other pressure measurements in the field of ballistics.

The arrangement contains a pressure element whose quartz crystal is cut perpendicularly to the electrical axis. The direction of pressure coincides with the electrical axis. As a result of its compact design, the pressure element can be used in place of the usual counter-pressure screw used in an ordinary manometer. The charges produced by pressure effects are transmitted to a direct-current amplifier which is similar in principle to that described by Kluge and Linckh. The pressure curves are recorded by a cathode-ray oscillograph connected to a recording drum unit.

The division of the measuring unit into three principal parts, i.e., pressure element, amplifier, and recording gear, has been retained for all subsequent ballistic pressure measuring instruments because it has a number of advantages. In addition to ready adaptability of the instrument to the pressures to be measured and to ease of calibration of the device, the pressure measuring portion can be set up at a distance from the recording unit. This is an indispensable requirement, especially in the measurement of gas pressures in heavy ordnance. The arrangement permits simultaneous recording of additional points on the curve, by which the time necessary for the firing pin to traverse its course, the exit of the projectile from the barrel, as well as the initial velocity of the projectile, can all be measured. Figure 1 shows a pressure curve plotted for small arms from data obtained by the piezo-electric device.

Figure 1 - Gas Pressure Curve of a Rifle Cartridge

The numerous pressure measurements made on small arms with this type of indicator show a number of remarkable results which will be described in greater detail.

The maximum pressures recorded by the piezo-electric method are regularly higher than those derived by copper cylinders, sometimes by as much as 25 per cent. These variations are attributable to the fact that the crusher-gage method gives values which are too low when peak pressures are of such brief duration.

SOURCES OF ERROR

Special emphasis was placed upon adaptability to existing gun gas pressure gages in the development of the piezo-electric indicator. A few additional noteworthy phenomena occurred in performing detailed quantitative measurements by this method. These phenomena, which had not been observed previously, are attributed to the design of the pressure transmission in the manometer.

In one of the manometers used, which is considered as a standard design, the pressure transmission piston was mounted in a bore which led directly from the detonating chamber to the pressure element. Records obtained with this arrangement show an incomplete return of the pressure curve after peak pressure has been attained. This singular phenomenon is caused by jamming of the moving plunger, which is produced by deformation of the bore during the pressure rise. Since the plunger must fit snugly in the bore to assure good sealing against escaping gas, the jamming effects can not be prevented in practice.

Another gas pressure gage commonly used houses the plunger guide in a cone seated in a conical hole drilled into the barrel and held fast by a thumb screw. This arrangement permits easy replacement of the plunger. However, jamming also occurred when measurements were made with this gage. They were evident in a step-like rise and fall of the curve. A detailed investigation of this phenomenon showed that the inherently easy-fitting piston guide became deformed when the cone was pressed tight and that the piston jammed even before the pressure developed in the barrel. The pressure transmission arrangement shown in Figure 2 was designed to eliminate these difficulties.

The actual plunger guide lies in the cylindrical part of the removable cone and cannot cause jamming of the plunger by tightening of the cone nor by the deformations occurring during the pressure rise. A grease packing between the combustion chamber and the plunger permits a hydrostatic transmission of the pressure without falsifying results, as was determined by numerous tests.

Since the point where pressure measurements are made for small arms commonly is in the cartridge chamber, the cartridge case used for the gas pressure measurements is provided with a drilled hole 1.5 mm (0.059 inch) in diameter. Gas pressure curves recorded with this type of cartridge showed an irregular

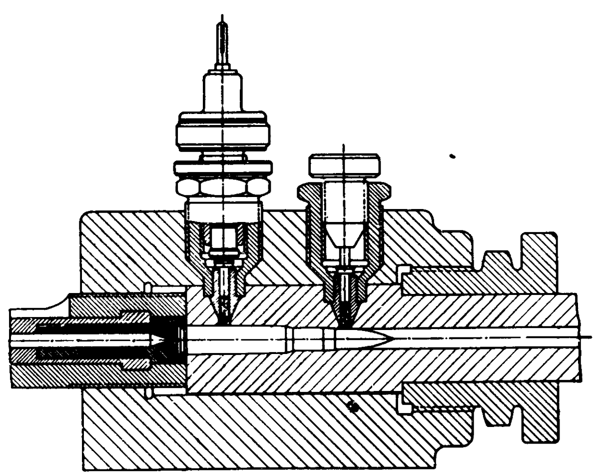

Figure 2 - Section of a Gas Pressure Gage for Piezo-Electrical Pressure Measurements

pressure rise which was not in accord with the expected pressure curve. At the same time the rate of rise in the pressure seemed subject to rapid fluctuations. By tests under various conditions this disturbance was identified as a throttling effect of the hole drilled in the cartridge. At the same time the unavoidable dead space outside the cartridge had the effect of a vibratory structure. By drilling larger holes in the cartridges this defect was completely obviated.

RESULTS OF MEASUREMENT

Measurements on pressure flasks have also been made recently with a piezo-electric indicator. Experiences gained with the gas pressure gage for rifles were used to improve the test setup. Certain difficulties in sealing the cone were removed by installing packing caps.

Naturally, measurement of the gas pressure curve in heavy ordnance is of special interest. In principle the same setup can be used as for the rifle pressure gages. A hole is drilled into the loading chamber of the cannon barrel, into which a plunger guide and a pressure element are fitted in the manner previously described. Several such devices have been constructed but they could not be used in practice because drilling a hole in the barrel decreases its strength.

The final design of the measuring device contains a piezo-electrical element which, including its plunger guide, is secured in the base of the cartridge case as a so-called piezo-electrical "capsule-gage." This design requires no modification of the gun and therefore permits the measurement of gas pressures in any gun. The electrical connection of the element with the feed cable of the amplifier is effected by an insulated wire running in a groove on the outside of the base of the cartridge. This wire is carried from the loading chamber through the breechblock so that it is freely movable, and is connected to the fixed feed cable. The remaining features of the indicator correspond in many ways to the device used for determining the gas pressures in rifles. In this case a number of markings are scribed on the record which permit the pressure at the muzzle as well as the initial velocity of the projectile to be determined. Figure 3 shows a gas pressure curve recorded in a 3-inch anti-aircraft gun.

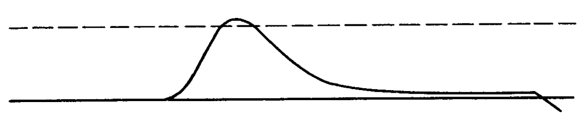

Figure 3 - Curve of Pressure in an Anti-Aircraft Gun

By measurement of the gas pressure curve in large guns a number of unsolved problems can now be solved by test methods. It is possible to check the accuracy of Heydenreich's standard curve by gas pressure curves recorded in tests and to make any necessary corrections. Furthermore, the problems of Vieille's pressure waves in the barrel, as well as the determination of the portion of the charge participating in the acceleration of the barrel are now brought closer to their solution.

In addition to the measurement of the pressure curve in internal ballistics, the piezo-electric measuring method is also of great importance for the measuring of forces which occur outside the weapon. An example of this use is the measurement of the "kick"* of a rifle on the shoulder. Much attention has been devoted to this problem in the past. Some of the previous experimental methods showed such great deviations from practical conditions that there could be no question of a direct measurement of kick on the shoulder. It was only very recently that Cranz and Kutterer attempted to solve the problem of the kick of a rifle held against the shoulder by recording its recoil. This practical test technique unfortunately has the disadvantage that a double differentiation of the resultant time-travel curve is necessary for a final analysis. To check the testing methods to be described here, Cranz's and Kutterer's experiments were repeated and the recoil was recorded by slow-motion photography. Figure 4 shows a section of a slow-motion film from such a test.

The problem of kick can be investigated in an exceptionally simple manner by piezo-electric pressure measurements. Figure 5 shows a kick element designed as a butt plate for a rifle and mounted on it. The first tentative measurements made with this device were merely intended to show whether the element was functioning properly. However, even these tests gave the following noteworthy results.

The true kick effect first appears a considerable time after the projectile has left the muzzle; it is produced by the braking effect of the weapon recoiling

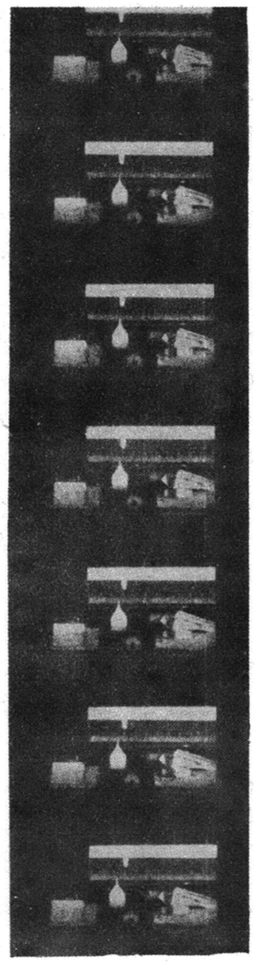

Figure 4 - Slow Motion Film of the Recoil Action of a Rifle

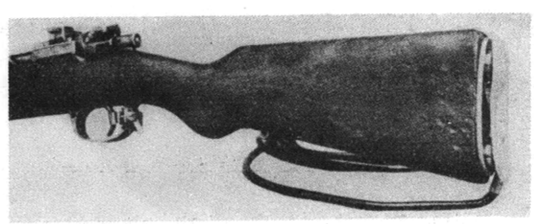

Figure 5 - Rifle with a Built-in Piezo-Electric Pressure Element

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* Translator's Note: The author distinguishes between "Rückstoss," i.e., the recoil impact, which is translated here as "kick," and "Rücklauf," i.e., the distance traveled by the gun in recoil, which will be translated simply as "recoil."

on the shoulder. On the other hand the recoil movement, insofar as it occurs while the projectile is in the gun, produces no perceptible kick on the shoulder of the rifleman. Comparative tests, performed by several riflemen and in various positions, showed that kick depended greatly on the manner of holding the gun on the shoulder.

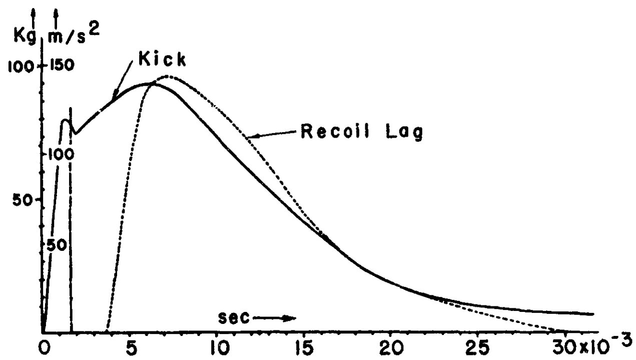

Figure 6 - Recoil Curve and the Recoil Lag of a Rifle fired from the Shoulder

The vertical line at 1.8 times 10^{-3} second corresponds to the exit of the bullet from the muzzle

To check the correctness of the measurements, after double differentiation, the recoil movements recorded by slow-motion photography were compared with the piezo-electrical pressure curve. The curve in Figure 6 shows a satisfactory quantitative and qualitative agreement. However, a final explanation of the problem of recoil will still require extensive tests under various test methods and under varying conditions.

A knowledge of recoil forces is also very important for large guns. In this case experiments apply to the forces which act on the trunnion or on the recoil brake. Whereas it was possible to build piezo-electric pressure elements for maximum loads of some six tons, in which the quartz crystals pick up the total recoil force, a hydraulic force-reducing device was successfully used to measure still greater forces up to 50 tons. In this device the force to be measured impinges upon a piston of large cross-sectional area which is located in a chamber filled with liquid, while a piston of small cross-sectional area acts upon the attached piezo-electric pressure element with correspondingly small forces. Although a decrease of the natural frequency of such a measuring element cannot be prevented, the natural frequency is still sufficient for conditions in actual practice.

The application of the piezo-electric measuring method in the field of ballistics is by no means exhausted by the examples quoted. It is not restricted to the direct determination of forces, but its range extends to the determination of acceleration. As a result of the acceleration peaks, some of which are quite high and of short duration, the fabrication of measuring devices presents difficulties. Methods can however be found to solve these problems satisfactorily.