

- [54] **METHOD AND APPARATUS FOR
DETECTING A PROJECTILE LEAVING THE
BARREL OF A GUN**
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Quebec, Ontario, Canada
- [73] Assignee: **Her Majesty the Queen, in right of
Canada as represented by the
Minister of National Defence of Her
Majesty's Canadian Government**
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[51] Int. Cl. **G01p 3/66, G04f 9/06, G01l 5/14**
[58] Field of Search **324/178, 179, 180; 73/167;
346/38**
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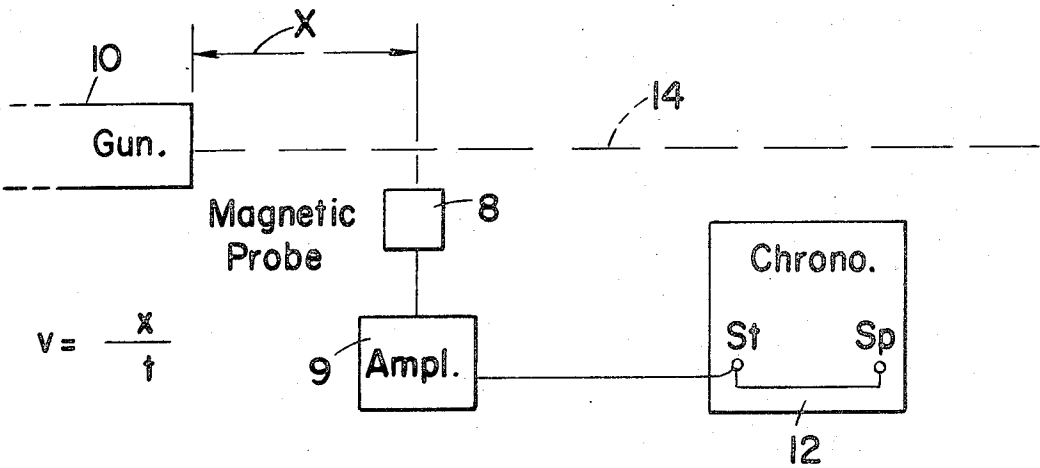
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Assistant Examiner—Rolf Hille
Attorney, Agent, or Firm—Edward J. Kelly; Herbert
Berl

[57] **ABSTRACT**

A method and apparatus for detecting a projectile leaving a gun using a permanent horse-shoe magnet located at or near the muzzle of the gun whereby the projectile cuts some of the magnetic lines of force of the magnet. Resultant voltage pulses from the separation of the projectile from the gun and from the passage of the projectile above the permanent magnet are induced in a pick up winding wound on the magnet and these are fed through an amplifier to an oscilloscope and/or a chronograph to provide an indication. The apparatus may also be utilized to measure the velocity of and to photograph the projectile as it leaves the muzzle of the gun.

8 Claims, 31 Drawing Figures



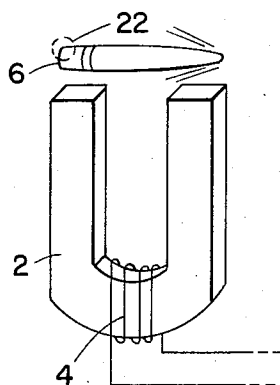


FIG. 1.

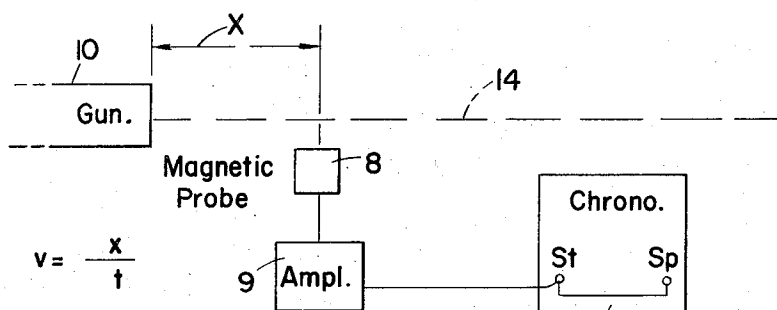
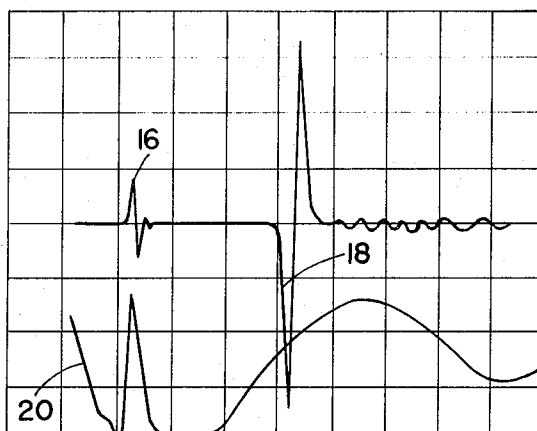


FIG. 2.



Vert: 20 mv / Div.
 Horiz: 200 μ sec / Div.

FIG. 3.

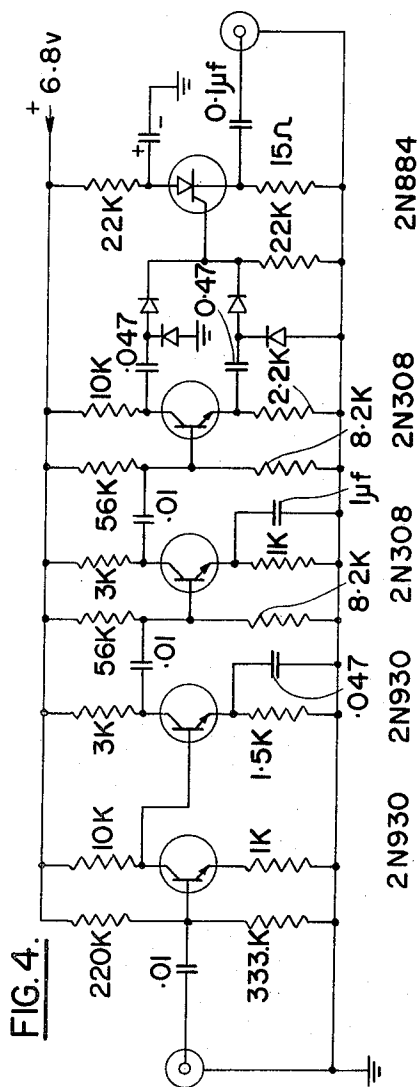


FIG. 5.

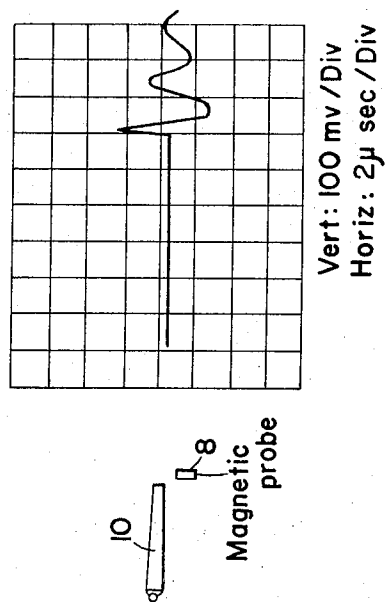
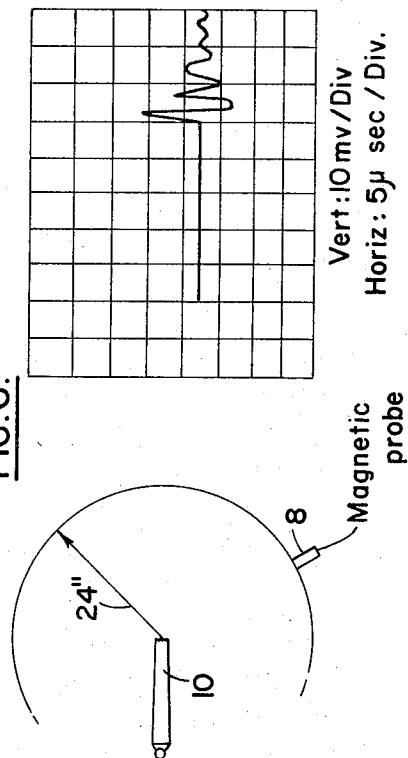
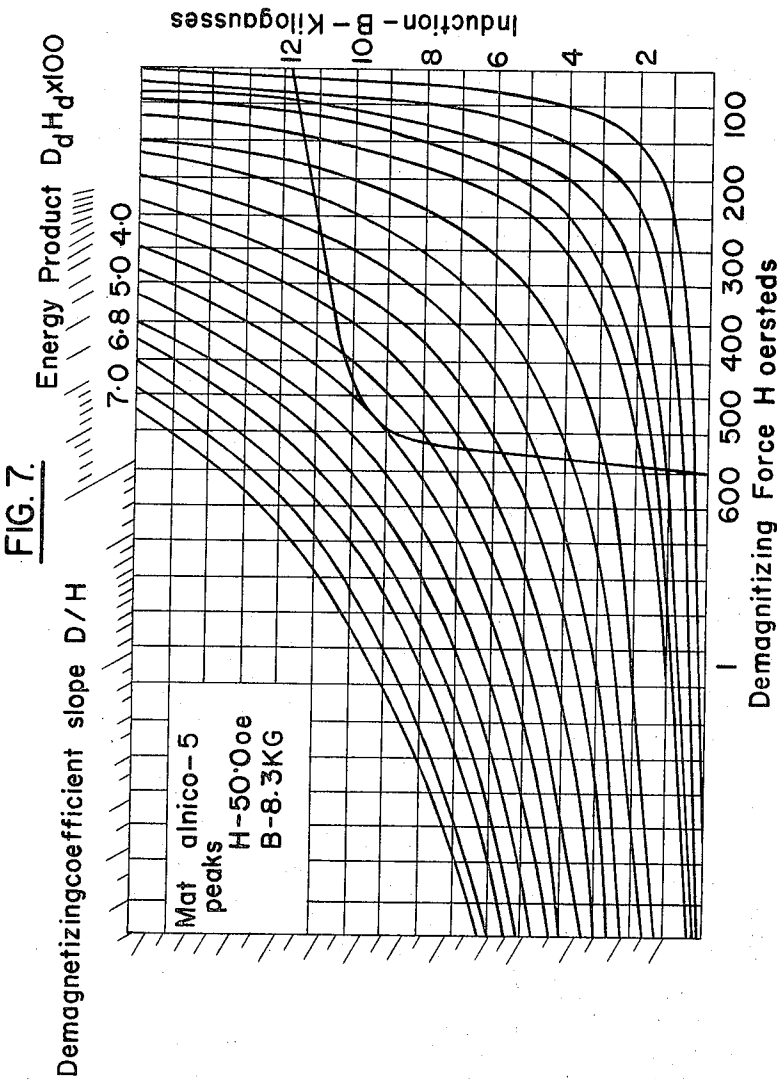


FIG. 6.





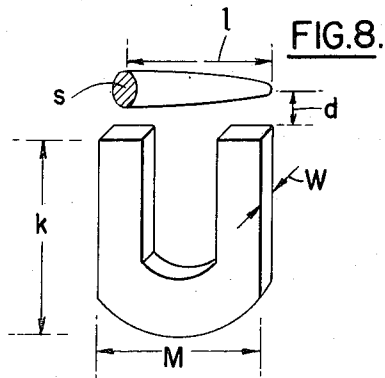
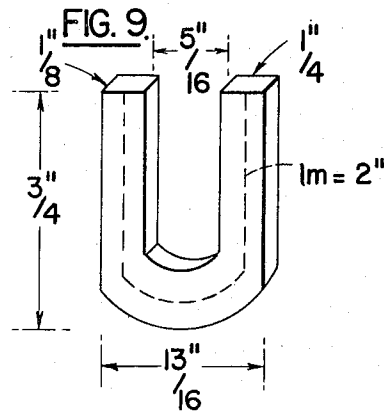
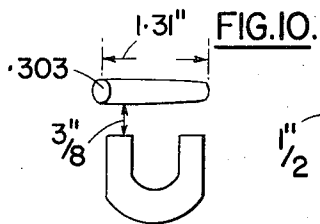
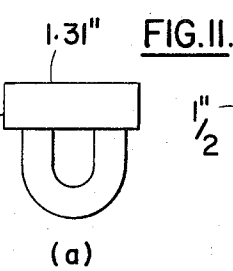
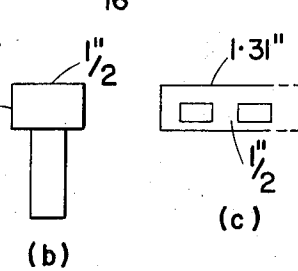
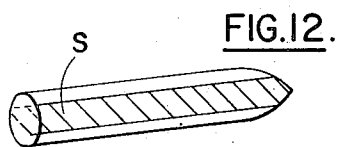
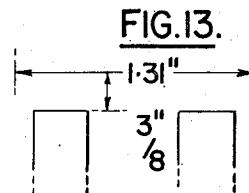
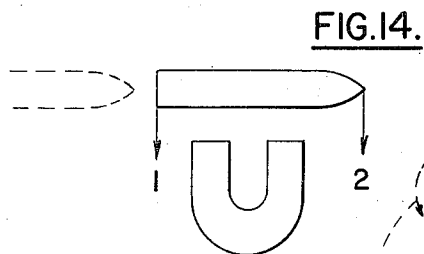
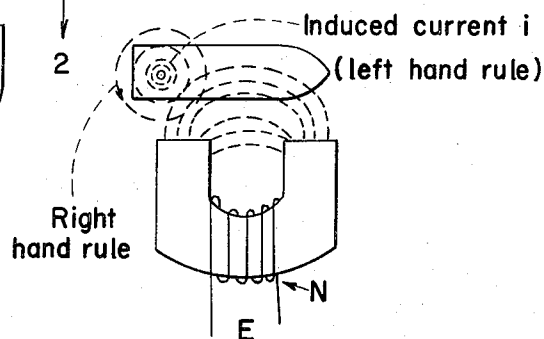


FIG. 16.

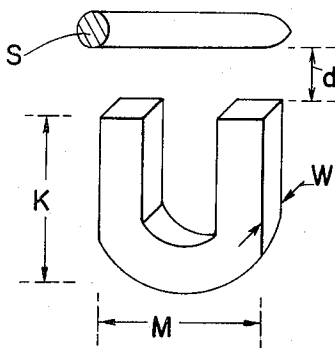


FIG. 18.

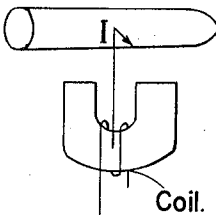


FIG. 19.

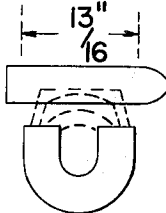


FIG. 17.

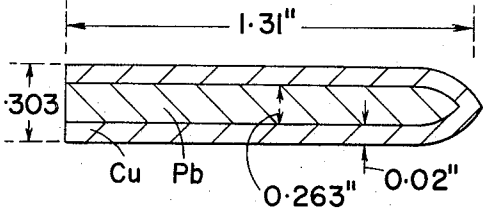


FIG. 20.

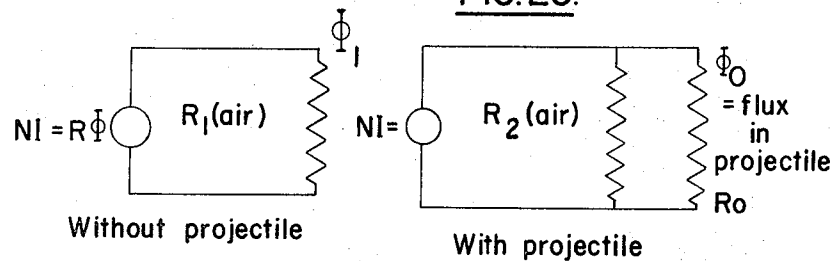


FIG. 21.

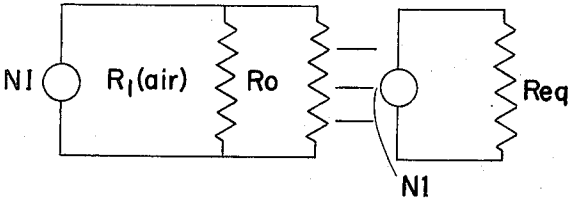


FIG. 22.

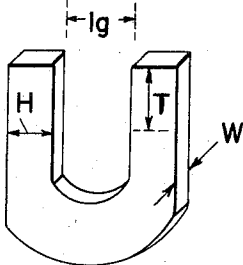
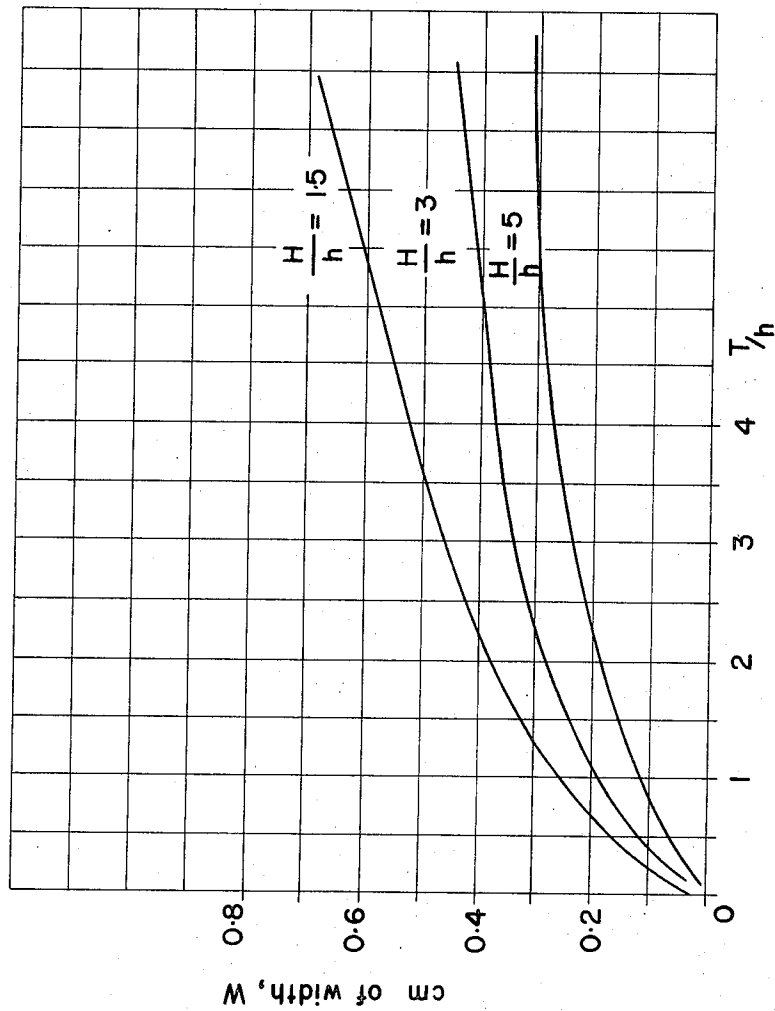
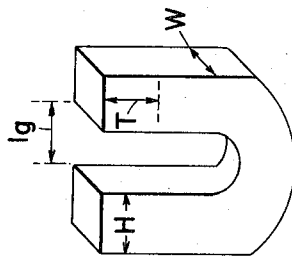


FIG. 23.



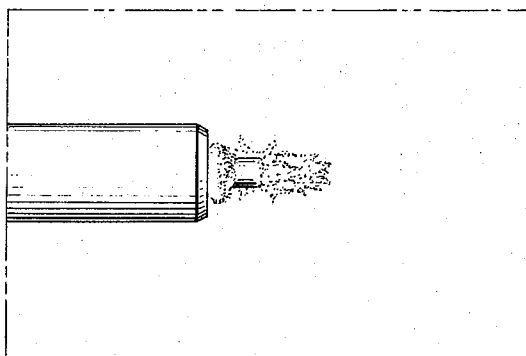


FIG. 24.

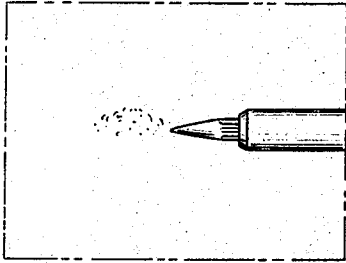


FIG. 25.

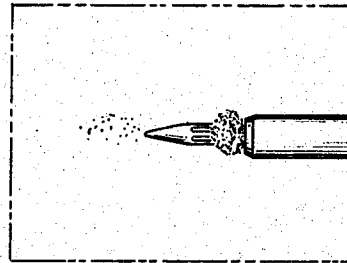


FIG. 26.

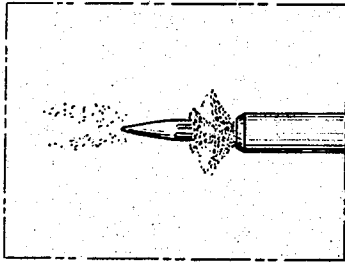


FIG. 27.

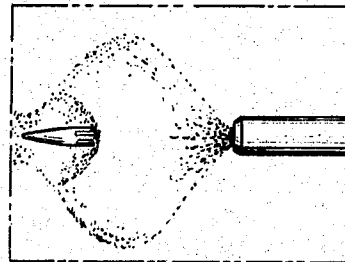


FIG. 28.

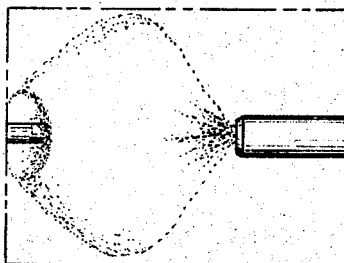


FIG. 29.

METHOD AND APPARATUS FOR DETECTING A PROJECTILE LEAVING THE BARREL OF A GUN

This invention relates to a method and apparatus for detecting a projectile leaving the barrel of a gun.

In ballistic research it is often desired to determine the exact instance at which a projectile leaves the barrel of the firearm in order that a determination of the velocity of the projectile can be facilitated and/or muzzle exit photographic equipment can be triggered at or near the muzzle of the firearm. This is particularly important with small arm calibre projectiles where the exact time at which the round leaves the muzzle and the muzzle velocity of the round are two important parameters that have to be known. These parameters have previously been determined with limited accuracy and success mainly due to the disturbing effects of the blast, smoke and flash around the ordnance. It will be understood that the term small arm calibre projectiles is normally considered to cover all types of ammunition used for rifles, pistols, carbines, machine carbines and machine guns. There is no definite ruling as to calibre but a maximum calibre of one inch is taken as a convenient standard although, it will be appreciated, that the present invention does not appear to be restricted to such small arm calibre projectiles.

Some previous systems associated with muzzle exit photography on small calibre projectiles have been constructed so as to trigger the camera by an electrostatic detector mounted on the gun itself but these systems have proved to be somewhat unreliable because the electrostatic detector waveform is sometimes affected by the weather, environmental conditions and wear of the gun barrel. Another system has used an optical detector located at the proximity of the gun and adapted to trigger a camera but the optical detector waveform has been found to be very much affected by the smoke and flash around the ordnance.

It is an object of the present invention, from one aspect, to provide a method of detecting a projectile leaving the barrel of a gun which is not as affected by its environment, etc., as the above-mentioned previous systems.

According to this aspect there is provided a method of detecting a projectile leaving the barrel of a gun comprising the steps of firing the gun and directing its projectile across at least one pole of a permanent magnet having a pick up winding wound thereon, feeding the resultant voltage induced in said winding to the input of an amplifier and feeding the output of the amplifier to an indicating means.

From another aspect it is an object to provide apparatus for detecting a projectile leaving the barrel of a gun which is not subject to all the disadvantages of the above-mentioned previous systems.

From this aspect, the present invention provides apparatus for detecting a projectile leaving the barrel of a gun comprising a permanent magnet locatable at the muzzle of the firearm and having a pick-up winding wound therearound, an amplifier having its input connected to said pick-up winding and indicating means connected to the output of said amplifier to provide an indication when a projectile is detected.

Previous systems have also been used to determine the velocity of a projectile fired from a gun by providing a pair of spaced-apart screens in line with the path of the projectile. The time taken for the projectile to

travel from one screen to the next was then measured and the velocity of the projectile was then calculated. However, it will be appreciated that that velocity is not the true velocity of the projectile as it leaves the muzzle, even though the screens may be located in the vicinity of the muzzle. Thus the required extrapolation of the muzzle velocity, which is a calculated value, is not as accurate as would be a measured value obtained at the muzzle. A magnetic system according to the present invention, as described and illustrated, responds to the arc discharge at the precise instance at which the projectile leaves the gun barrel and also responds to the projectile itself. The present system may be utilized as a single detector muzzle velocity system whereby the muzzle velocity of the projectile can be obtained with greater accuracy. The magnetic system, i.e., the probe, is unaffected by the environment around the ordnance. The electromagnetic radiation, referred to as arc discharge, produced by the separation of the projectile from its launcher, i.e., the gun barrel, is the precise instance at which the projectile leaves the gun barrel and since this is detectable by the magnetic probe or system according to the present invention, a convenient trigger for muzzle exit photography can be obtained. It does not appear to be affected by the weather, environment of the wear of the gun barrel.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings in which:

FIG. 1 is a diagrammatic representation showing a projectile passing over a horse-shoe shaped permanent magnet used in accordance with the present invention;

FIG. 2 is a diagrammatic representation of a magnetic probe according to the present invention located at a distance 'x' from the muzzle of a gun;

FIG. 3 diagrammatically illustrates the waveforms obtained using the system of FIG. 2;

FIG. 4 is a diagrammatic representation of a typical amplifier for use in the system of FIG. 2;

FIG. 5 is a diagrammatic representation of the probe located at the gun muzzle and showing the corresponding oscilloscope trace for the arc discharge;

FIG. 6 is a diagrammatic representation showing the possible location of the magnetic probe at a distance of 24 inches from the muzzle of the gun and also showing the corresponding oscilloscope trace for the arc discharge;

FIG. 7 is a typical graphical representation of the demagnetization and energy-product curve for cast Alnico 5 DG;

FIG. 8 is a representation showing dimensions of the magnet for use in the empirical design thereof;

FIG. 9 is an illustrative drawing for the solid angle approach of the empirical design;

FIG. 10 is a dimensional figure for use in respect of the volume approximation in the empirical design calculation;

FIG. 11a, b and c is also used in the said volume approximation;

FIGS. 12 through 23 are further figures which are utilized in the empirical design description; and

FIGS. 24 through 29 are representations of photographs taken as a bullet leaves the muzzle of a gun.

Referring to FIG. 1, it will be seen that there is diagrammatically illustrated a horse-shoe shaped permanent magnet 2 having a pick up winding 4 wound therearound as shown. A projectile, e.g., a bullet, 6 is shown

in position passing the poles of the permanent magnet so as to interrupt the magnetic field around the permanent magnet and cause a voltage to be induced in the pick up winding 4.

As mentioned above, the magnetic probe according to the present invention will function adequately at any one of a number of distances from the muzzle of the gun. By way of example, FIG. 2 is a diagrammatic representation of a magnetic probe device 8 located at a distance x from the muzzle of a gun 10. The magnetic probe 8 is, of course, of the type illustrated in FIG. 1 comprising a permanent magnet 2 and pick up winding 4. The pick up winding 4 is connected to the input of an amplifier 9 whose output is connected to an indicating means 12 which is, in this case, a chronograph device.

In one practical arrangement of FIG. 2, the magnetic probe 8 was located at 18 inches from the muzzle of gun 10 and five-eighth inch below the line of sight 14 for typical 0.303 rounds of ammunition. An oscilloscope was also connected to the output of amplifier 9 and, with these conditions, the oscilloscope showed traces corresponding to FIG. 3. The leading pulse 16 on the upper trace of FIG. 3 represents the arc discharge resulting from the round being fired from the gun 10 whilst the second pulse 18 represents the projectile passing near to the detector magnetic probe 8. The lower beam waveform 20 in FIG. 3 was used to trigger the oscilloscope.

The chronograph 12 of FIG. 2 will give the difference in time between the arc discharge and the projectile, i.e., between the traces 16 and 18 of FIG. 3 and thus the velocity of the projectile can be readily calculated since the distance x of the magnetic probe 8 from the muzzle of gun 10 is known. Thus:

$$\text{Velocity } v = x/t;$$

where t is the time between detection of the arc discharge and the passage of the projectile, i.e., the time between the oscilloscope pulses 16 and 18 of FIG. 3.

The instant of arc discharge can be readily determined since it corresponds to the pulse 16 of FIG. 3 and that pulse can conveniently be used to trigger photographic equipment to photograph the arc discharge. Several positions were again found suitable for the location of the magnetic probe 8 and this will be further discussed below.

The amplifier 9 (FIG. 2) used in one constructed embodiment had a circuit substantially as shown in FIG. 4 and had the following characteristics:

Sensitivity: 5mv

Output rise time: 1 μ sec

Delay time: 2 μ sec for negative input, 5 μ sec for positive input

The chronograph 12 of FIG. 2 used in one series of trials was a Transistor Specialties Inc. (TSI) Solid State Universal Counter, Model 361, with a time base of 1 μ sec and an accuracy of $\pm$ one count.

The oscilloscope used in the above-mentioned trials was a general purpose 27 MHz dual-beam oscilloscope.

In the above-mentioned practical embodiment of the present invention, tests were carried out using a 0.303 rifle because of its well known performance and an evaluation of the constructed magnetic probe was performed for the arc discharge and the detection of the projectile. It was found that the arc discharge could be

detected by the probe when it was located either at the gun muzzle, as in FIG. 5, or at a distance up to 24 inches, for small arms, in any one direction as represented in FIG. 6. The repeatability of the arc discharge was also checked by taking pictures of various 0.303 and 50 calibre rounds as they left the gun muzzle. A variation in time of 6 μ sec was observed between the arc discharge produced by several rounds of the same type and these small variations could, for example, be caused by:

- a. The arc discharge occurring around the point 22 (FIG. 1) of the round. This position may vary slightly from round to round, as will be appreciated;
- b. A variable delay occurring in the SCR stage of the amplifier;
- c. A delay in the flash unit system.

Careful measurements were made of all possible delays in the system and these showed that a constant delay was present in the amplifier and this can therefore be ignored. However, a variable (jitter) delay was present in the flash triggering unit up to 6 μ sec. and thus it is believed that any small variation in the arc discharge detection could well be caused by the flash unit jitter and/or by the breaking point on the projectile.

In considering the use of the probe for the detection of a projectile, it was found that erratic results could be obtained if the probe 8 was located too close to the gun muzzle 10. This was due to spurious signals altering the projectile detected waveform and experiments have shown that the above-mentioned horizontal range of 18 inches to 24 inches and a vertical distance up to five-eighth inch below the line of sight was the most suitable for projectile detection.

One further point should be mentioned in that whenever the gun was electromechanically fired, the magnetic probe 8 picked up the firing pulse so as to give a pre-triggering of the system. Therefore in these cases unless an electromagnetic detector is used, it should be kept in mind that velocity measurements could be inaccurate.

The exclusive characteristic of the magnetic probe 8 in detecting the arc discharge and also the projectile 6 permits the described system to be used as a single detector muzzle velocity system, as shown in FIG. 2, as compared with the previously mentioned prior velocity system requiring two detectors (screens). The 24 inch-base experimental set up which was tried was successful and the velocities were additionally computed from photographs using a telereader. It will be appreciated that electronic circuitry could conveniently be used in place of the telereader for velocity computation.

The facility of the magnetic probe 8 in detecting arc discharge is of particular importance in ballistic photography and permits the triggering of a camera located near the gun 10 so as to obtain muzzle photography of the projectile. This enabled the study of the performance and behavior of the round whilst leaving the gun 10, as well as its study several micro-seconds afterwards by using a delay time. for wave investigation on the back of the models being fired. Tests were made using different rounds.

Two types of error, namely, Systematic and Random, could alter the accuracy of the system when used for velocity measurements:

A. Systematic Errors:

These errors can apparently affect all measurements in a series. They can be subdivided into four different categories:

1. The minimum resolution of the chronograph 12, which is 1 μ sec for a 1 MHz counter.
2. The position of the round 6 in the "sensitive" area of the magnetic probe 8 when the amplifier 9 is triggered. This exact triggering time was checked during several 0.303 and 50 calibre firings and, in some cases, it was found that the amplifier was triggered when the nose of a 0.303 projectile reached the center of the probe 8.
3. Possible variation in delay from one amplifier to another. This was carefully measured for amplitude and duration with different input signals covering all the working ranges of the amplifier.
4. Surveying and estimating the length of the trajectory. This error should not be more than one-sixteenth of an inch on a 24-inch-base.

B. Random Error:

The chronograph 12 used (TSI Model No. 361) had a random error of 1 μ sec on start and stop.

If we assume all errors are additive, the accuracy of the system can be calculated from the formula:

$$\Delta v/v \% = [(\Delta s + \Delta t \cdot v) 100/s - \text{projectile length}]$$

Where

Δs = Inaccuracy in surveying

Δt = Inaccuracy from the chronograph 12

v = Velocity in ft/sec

s = Base length

For a typical velocity of 2,400 ft/sec, an overall accuracy in the order of 0.65 percent was possible with this system using the magnetic probe 8 to detect both the arc discharge and the projectile on a 24-inch-base. This system differed only by 0.2 percent from the standard system used in the same trial.

To summarize, it would thus appear that:

- a. The magnetic probe 8, according to the present invention, can be used in muzzle velocity systems for small calibre ammunition without being affected by the environment around the ordnance.
- b. An absolute accuracy of 0.65 percent and a relative accuracy of 0.2 percent when compared with standard systems was obtained during typical trials.
- c. Because of its exclusive characteristic of detecting the arc discharge as well as the projectile, a single detector muzzle velocity system is possible as illustrated in FIG. 2.
- d. The system can also be used as a trigger in Ballistic Photography to study the performance and behavior of models being fired:

1. While leaving the gun

2. With variable delays for wake investigation on models.

- e. Whenever the gun is electromechanically fired the electromagnetic detector should be used.

A method and apparatus have been described above for detecting a projectile leaving the barrel of a gun and some consideration will now be given to the principle of operation of the apparatus and the design thereof. As will be appreciated, a greatly simplified system of muzzle velocity measurement has been obtained which simultaneously may be used for shot ejection measurement as well as for triggering projectile photography. Since the separation arc discharge produces electromagnetic radiation, and most rounds of ammunition are made of either conductive or magnetic material (or

both), the magnetic sensing type of probe is ideally suitable. However, the two phenomena being detected call for opposing characteristics in the detection for optimum performance with either signal and thus a compromise design may be required as is disclosed below. The principle of the magnetic probe is based on the possibility of modulating the magnetic field of an open magnetic path magnet by partially and momentarily closing the path with a moving projectile passing near-by. The projectile can be made of conductive but non magnetic material, conductive and magnetic or simply magnetic.

As a first approximation, it follows from Faraday's Law that the voltage induced in the pick up winding is numerically equal to the rate of change of the magnetic flux through the circuit. For an idealized model, the voltage is given by:

$$\epsilon = N(\Delta\Phi/\Delta t)$$

$$\Phi = \beta A = \mu HA = (NI)/(l/\mu A) = (NI/R)$$

$$\therefore \epsilon = N(\Delta/\Delta t)(NI/R)$$

Where

ϵ = Voltage induced in the winding; volts

N = Number of turns in the winding

NI = Equivalent amp-turns from the magnet

R = Reluctance of the magnetic path

An empirical design procedure based on the variation of the reluctance of the magnetic path and which has given satisfactory results in the case of 20, 303 and 50 calibre projectiles is described below and it is believed that the same procedure could be used for other projectile calibres. However, it should first be mentioned that the arc discharge is an electromagnetic phenomenon which requires a low impedance detector. On the other hand, the signal coming from the passage of the projectile is a function of the variation of the magnetic flux which is a function of NI . Therefore, for optimum results, NI should be as large as possible. However for design convenience, " I " has to be kept very low which makes N very large. This produces a high impedance which prevents detection of the arc discharge.

To get around these difficulties, a horse-shoe shaped permanent magnet with a suitable pick up winding was designed (see empirical design below). The constant unpowered field of permanent magnets is an inherent advantage over electromagnets and was a major factor in the design of a suitable detector.

Three classes of permanent magnet materials were considered, namely brittle metallic, ductile metallic and ceramic. Cast Alnico 5 DG which is of the brittle metallic family was selected on the following grounds:

- a. Highest energy product $B_d H_d$ (see FIG. 7); this is required to have a low impedance for detecting the arc discharge and still have a suitable signal from the projectile when passing near-by.

- b. The least susceptible to reversible remanence.

- c. Practically unaffected magnetically by shock or vibration.

EMPIRICAL DESIGN

Electromotive Force (ϵMF) induced by a moving projectile above a magnet probe.

This describes an empirical design method used in the development of the magnetic probe 8 (FIG. 2). It is divided into three parts:

1. From $\epsilon = N(\Delta\Phi/\Delta t)$ and for a specified ϵ $\Delta\Phi/\Delta t$ is approximated by the solid angle approach, seen by the magnet with and without the projectile and N is calculated accordingly. This is established for all non-magnetic projectiles in general.

2. An empirical formula $(\Delta\Phi/\Phi) = \alpha (l s k/M W d^2)$ is then determined which takes into account the various dimensions of the magnet employed with the jacket and core of the projectiles, as shown in FIG. 8.

It is first used with projectiles made of conductive but non-magnetic material and the constant α is determined experimentally using the number of turns N computed in part I.

3. The method is then extended to projectiles made of magnetic material.

PART I — SOLID ANGLE APPROACH — SEE FIG. 9.

Material:

Alnico 5 DG

Cross section = $1/32$ in²

Operating $pt = B = 8.3$ KG

$H = 520$ oe

Assumed velocity = 2,400 ft/sec

Signal required ≈ 60 mv

From magnetic circuit theory

$MF = R_T \Phi$

MF = Magnetomotive force

R_T = Total reluctance of the path

$= R_{mag} + R_{air}$

The energy in a magnetic field produced by a coil = W_{mag}

$$W_{mag} = \frac{1}{2} L i^2 = \frac{1}{2} R_T \Phi^2$$

From

$$\epsilon = N (\Delta \Phi / \Delta t)$$

and

$$\epsilon = L (\Delta i / \Delta t) \rightarrow N (\Delta \Phi / \Delta t) = L (\Delta i / \Delta t)$$

and

$$N \Phi = Li + \text{a constant}$$

since $\Phi = 0$ when $i = 0$

$$N \Phi = Li \rightarrow L = N \Phi / i = N (\beta A / i)$$

From Ampere's Law,

$$H = Ni/l \rightarrow i = H l / N$$

$$\therefore W_{mag} = \frac{1}{2} L i^2 = \frac{1}{2} (N \beta A N / H l) \times H^2 l^2 / N^2 = \frac{1}{2} \beta \frac{H A l}{H A l}$$

and Al = volume v of the magnetic circuit

$$\therefore W_{mag} = \frac{1}{2} \beta H v$$

Initial Reluctance

To find the initial reluctance of the System, we have to deal with the magnetic energy of the System.

$$W_{mag} = \frac{1}{2} R_T \Phi^2 = \frac{1}{2} \beta H v \rightarrow R_T = \beta H v / \Phi^2$$

$\Phi = \beta A = 1.67 \times 10^3$ maxwells at the operating pt

$$R_T = \beta H v / \Phi^2 = 1.55 v$$

$$\therefore R_T = 1.55 v$$

Volume Approximation (in CGS System)

$$v = v_{magnet} + v_{air}$$

$$v_{mag} = 1.02 \text{ cm}^3$$

v_{air} is based on the dimensions of the projectile (FIG. 10)

We suppose that the majority of the lines of flux are passing within a volume that we assume to be 1.3 inches $\times$ $\frac{1}{2}$ inch $\times$ $\frac{1}{2}$ inch (see FIG. 11)

$$v_{air} = 5.4 \text{ cm}^3$$

$$v_T = v_{mag} + v_{air} = 6.5 \text{ cm}^3$$

From

$$R_T = 1.55 v \rightarrow R_T = 10.1$$

5 $R_T = 10.1$ total initial reluctance

The reluctance depends on the magnetic path length and on the area through which the lines are passing. Here the length = a constant because the projectile considered is no magnetic conductor. We can then assume that the variation of the reluctance is $\propto$ to the variation of the surface seen by the magnet with and without the round. Therefore the variation in the reluctance is proportional to the variation of the solid angle seen by the magnet with and without the projectile.

15 i.e.

$$\Delta R \approx (\Delta \omega / \omega) \times R_{air}$$

ω_1 = solid angle without the projectile

$$\omega_1 = 2 \pi$$

S = equivalent bullet area seen by the magnet (see FIG. 20 12)

For 0.303 bullet

$d = 0.303$ inch

$l = 1.31$ inch

$$\therefore S = 2.57 \text{ cm}^2$$

Mean distance of the round to the center of the magnet (see FIG 13) — by numerical integration this distance is 2.1 cm.

$$\therefore \omega_2 = 2\pi - 2.57/(2.1)^2$$

$$30 \Delta \omega = \omega_1 - \omega_2 = 0.56$$

$$\Delta \omega / \omega = 0.089$$

we found

$$R_T = 10.1 = R_{mag} + R_{air}$$

$$R_{mag} = l/\mu A = 1.53$$

35

$$\therefore R_{air} = 8.57$$

and

$$\Delta R_{air} \approx (\Delta \omega / \omega) R_{air} = 0.77$$

40 and $\Delta R_{mag} = 0$ because the μ of the magnet is practically constant

$$\therefore \Delta R_T \approx \Delta R_{air} \approx \Delta \Phi = 0.77$$

Evaluation of Δt — see FIG. 14

45 Δt = time taken by the round to move from 1 to 2 = 1.31 inches

assuming a velocity of 2,400 ft/sec

$$\Delta t = 45 \mu \text{ sec}$$

so

$$\Delta \Phi = 0.77$$

50 $\Delta t = 45 \mu \text{ sec}$ } from $\epsilon = N \Delta \Phi / \Delta t \times 10^{-8}$ we find N required $\epsilon = 60$ mv

$$N = \epsilon \Delta t \times 10^8 / \Delta \Phi = 354 \text{ turns}$$

55 $N = 354$ turns and 36 was chosen

PART II — PROJECTILE MADE OF CONDUCTIVE BUT NON-MAGNETIC MATERIAL — See FIG. 15

The projectile when passing near the magnet cuts a certain number of magnetic lines which cause a current i to flow in the projectile. This generates a magnetic field which tends to oppose the magnetic field variations seen by the round (Lenz's Law) and induces a voltage ϵ in the pick up winding N . We want to evaluate this voltage ϵ .

65 Number of Flux Lines Cut By the Projectile (Flux Plotting Method)

1. All flux lines and equipotential lines must be mutually perpendicular at each point of intersection.

2. Each figure bonded by two adjacent flux lines and two adjacent equipotential lines must be curvilinear square.

Empirical Formula — see FIG. 16

$$\Delta\Phi/\Phi = \alpha (l s k/M W d^2)$$

$$D = 3/8'' + 0.303 \text{ inch}/2 = 0.526 \text{ inch}$$

$$l = 1.31 \text{ inches}$$

$$S = (\pi/4) (0.303)^2$$

$$K = 0.75 \text{ inch}$$

$$M = 0.813 \text{ inch}$$

$$\alpha = \text{Proportionality constant}$$

All dimensions must be in MKS or CGS

The constant α was determined experimentally with a 0.303 bullet passing at 3/8 inch above the magnet.

$$\Delta\Omega/\Omega = \alpha [\dots] = 2.53\alpha$$

$$l = \text{length of projectile if } < 2M \text{ if not, we take } l = 2$$

$$M \rightarrow \text{based on flux plotting method}$$

$$\Phi = \beta A = 1.67 \times 10^{-5} \text{ webers (Alnico 5 DG)}$$

$$\Delta\Phi = 4.23 \times 10^{-5}\alpha$$

The projectile cuts a number of flux lines in a certain time Δt , velocity is taken as 2,400 ft/sec. $\Delta t = 45 \mu \text{ sec}$

$$\Delta\Phi/\Delta t = 0.96\alpha$$

$$\therefore \Delta\Phi/\Delta t = 0.96\alpha \text{ seen by the projectile}$$

we have to find $\Delta\Phi/\Delta t$ in the coil

From

$$\oint E dl = \epsilon = \Delta\Phi/\Delta t$$

$$E = \Delta\Phi/\Delta t \Delta l = 39\alpha \text{ where } \Delta l = \text{circuit path length of the current} \approx \pi D$$

$$\therefore E = 39\alpha \text{ in the projectile}$$

$$I = E/R$$

where I = current/unit length

R = resistance of the projectile

$$R = \rho l/A$$

and

$$\rho = 1.6 \times 10^{-5} \text{ for } C_u$$

$$\rho = 1.25 \times 10^{-5} \text{ for } Pb$$

$$A_{Pb} \approx 0.263 \times 1$$

Referring to FIG. 17:

$$R_{Cu} = 3.6 \times 10^{-5} \Omega$$

$$R_{Pb} = 0.57 \times 10^{-5} \Omega$$

and those two "resistors" are in parallel

$$\therefore R_{eq} = 0.53 \times 10^{-5} \Omega$$

Therefore

$$I = E/R = 0.75 \times 10^7 \alpha$$

The induction β produced by a current I in an element Δl located at a distance r for I parallel to Δl and perpendicular to r is given by:

$$\Delta\beta = \mu_0 I \Delta l / 4 \pi r^2 \text{ (Biot Law)} - \text{see FIG. 18}$$

$$r = 1.15 \text{ inches}$$

$$r^2 = 1.32 \text{ in}^2$$

$$l = 0.303 \text{ in}$$

$$\mu_0 = 4\pi \times 10^{-7}$$

$$\Delta\beta = 5.2\alpha$$

$$\therefore \Delta\beta = 5.2\alpha \text{ in the Coil}$$

$\Delta\Phi = \Delta\beta A$ = flux variation in the coil

A = cross section of the coil

$\Delta t = 45 \mu \text{ sec}$ evaluated previously

$$\therefore \Delta\Phi/\Delta t = 2.4\alpha \text{ in the coil}$$

$$\epsilon = N (\Delta\Phi/\Delta t) \text{ and using } N = 354 \text{ computed in part I}$$

I

we found ϵ experimentally to be 80 mv

$$\therefore \alpha = \epsilon / 2.4 N = 80 \times 10^{-3} / 850 \approx 10^{-4} \\ \approx \alpha \approx 10^{-4}$$

5 knowing the constant to be $\approx 10^{-4}$, one can compute the number of turns required on the magnet for any desired voltage ϵ .

PART III — PROJECTILE MADE OF MAGNETIC MATERIAL

10 The flux lines cut by the non-magnetic projectile of the preceding case, are now concentrated in the magnetic projectile because the reluctance of the magnetic round is smaller than the reluctance of air. Therefore a flux variations is produced which induces a voltage in the coil.

From $\Delta\Phi/\Phi = \alpha (l s k/M W d^2) = 2.53 \times 10^{-4}$ as computed previously, we have the flux line proportion passing through the round as shown in FIG. 19.

$$20 \Delta t = (13 \text{ inches}/16)/(2,400 \times 12) = 28 \mu \text{ sec}$$

From Electrical Analogy we can refer to FIG. 20.

NI = Constant (Magnet)

$$NI = R \Phi = 1.67 \times 10^{-5} \times R$$

25 $R1^{(air)}$ is calculated from the effective air-gap permeance and flux distribution in space and is determined graphically (FIG. 23)

$$R1^{(air)} = 68.6 \times 10^7$$

$$R \Phi = NI = 114.5 \times 10^2$$

30 $NI = R_o \Phi_o$ but Φ_o = flux in the projectile due to $\Delta\Phi$

$$\therefore \Phi_o = \Delta\Phi,$$

and

$$35 \Delta\Phi/\Phi = 2.53 \times 10^{-4}$$

$$\Phi = 1.67 = 10^{-5}$$

$$\therefore \Phi = 4.22 \times 10^{-9}, \text{ and}$$

therefore

$$40 R_o = N I / \Phi_o = 27.2 \times 10^{11}$$

because this reluctance is $\gg$ than $R_1(\text{air})$ we can approximate

$$R_2(\text{air}) = R_1(\text{air})$$

45 hence we have the situation of FIG. 21.

$$R_{eq} = 68.6 \times 27.2 \times 10^7 / 27.2 + 0.00686$$

and

$$\Delta = R1^{(air)} - R_{eq}$$

$$50 \Delta R = 209 \times 10^3$$

we want

$$\Delta\Phi, R\Phi = NI = \text{Constant}$$

$$\Delta(R\Phi) = 0 \rightarrow R\Delta\Phi + \Phi\Delta R = 0$$

$$55 \therefore \Delta\Phi = \Phi/R \Delta R = 0.51 \times 10^{-8}$$

$$\epsilon = N \Delta\Phi/\Delta t$$

and

$$\Delta t = 28 \mu \text{ sec}$$

$$60 N = 354$$

$$\therefore \epsilon = 64 \times 10^{-3} = 64 \text{ mv}$$

$$\epsilon \text{ calculated} = 64 \text{ mv}$$

$$\epsilon \text{ measured} = 75 \text{ mv}$$

65 Graphic calculation for $R1^{(air)}$ — see FIG. 22.

Given

$$l_g = 5/16 \text{ inch}$$

$$h = 1/2 l_g = 5/32 \text{ inch (By def)}$$

$T = 5/16$ inch
 $H = 1/4$ inch
 $W = 1/8$ inch

$$T/h = (5/16)/(5/32) = 2$$

$$H/h = 1/4/5/32 = 1.6$$

From the graph of permeance for magnet air-gap, as shown in FIG. 23:

P/cm of $W = 0.36$
 $W = 0.3157$ cm

$$\therefore \text{Permeance } P = 0.36 \times 0.3175 = 0.116$$

$$\text{Reluctance} = 1/P = 1/0.116 = 8.65 = R_1^{(air)}$$

NB: It should be noticed that this reluctance was found to be 8.57 by the volume approximation technique in Part I which cross checks very well.

$$\text{In MKS } R_1^{(air)} = 68.6 \times 10^7$$

$$\therefore R_1^{(air)} = 68.6 \times 10^7$$

From the above it will further be appreciated that the magnetic probe can pick up the arc discharge which gives a unique and reliable trigger for ballistic photography at the muzzle. This is particularly advantageous because of the inherent simplicity of the system and consequently its relatively low cost, and also due to the avoidance of some problems which arise using separate pick-ups and separate processing circuits.

FIGS. 24 through 29 are representations of typical photographs for different rounds of 0.303 calibre (FIGS. 25 through 29 being with different delays during the flight of the bullet for wake investigation and thus effectively corresponding to successive instants of time during the flight of the bullet). They illustrate the accuracy of using the arc discharge, with and without delay, as a trigger in ballistic photography.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of detecting a projectile leaving the barrel of a gun comprising the steps of: locating a permanent magnet with a pickup winding thereon at a distance "X" from the muzzle of a gun, firing said gun and directing its projectile across at least one pole of said permanent magnet, obtaining a first voltage from said pickup winding when the arc discharge from the gun is

detected and a second voltage as the projectile passes across the permanent magnet, feeding the resultant voltages induced in said winding to the input of an amplifier and feeding the output of the amplifier to an indicating means, obtaining the time "t" between said first and said second voltages and calculating the velocity of the projectile as it leaves the muzzle of the gun from the formula $v=x/t$.

2. Apparatus for detecting a projectile leaving the barrel of a gun comprising a permanent magnet located at a distance "x" from the muzzle of the gun and having a pick up winding wound therearound, an amplifier having its input connected to said pick up winding and indication when a projectile is detected, whereby, the permanent magnet pick up winding provides a first voltage when the arc discharge from the gun is detected and a second voltage is provided as the projectile passes across the permanent magnet to affect the magnetic field therearound, and said indicating means provides an indication of the difference in time "t" between said voltages, whereby, the velocity "v" of the projectile as it leaves the muzzle of the gun is given by the formula $v=x/t$.

3. Apparatus according to claim 2 wherein said permanent magnet is a horse-shoe permanent magnet.

4. Apparatus according to claim 2 wherein said indicating means is a chronograph.

5. Apparatus according to claim 2 wherein said indicating means is an oscilloscope.

6. Apparatus according to claim 2 wherein said permanent magnet is at a horizontal distance from the muzzle of the gun between 18 inches and 24 inches and approximately 5/8 inch below the line of sight of the gun muzzle.

7. Apparatus according to claim 2 wherein said permanent magnet is at a horizontal distance from the muzzle of the gun between 18 inches and 24 inches and approximately 5/8 inch below the line of sight of the gun muzzle.

8. Apparatus according to claim 2 wherein ballistic photographic means is provided and the magnet is utilized to pick up the arc discharge to trigger said ballistic photographic means and facilitate ballistic photography at the muzzle of the gun.

* * * * *

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