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Recoil Motion Measurement

Army Test and Evaluation Command

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Provides a method for selecting instrumentation for weapon recoil motion measurements. Describes selection criteria; and characteristics, operation, and applicability of recoil potentiometer, time-displacement (drum) camera, photoelectric transducer, and high-speed camera systems as well as the seldom used revolving drum and slide wire resistance systems.

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U. S. ARMY TEST AND EVALUTION COMMAND
DEVELOPMENT TEST II (EP) - COMMON TEST OPERATIONS PROCEDURES

AMSTE-RP-702-102
*Test Operations Procedure 3-2-815 24 February 1975

RECOIL MOTION MEASUREMENT

SECTION I
GENERAL

1. Purpose and Scope. This TOP describes the selection, setup, and operation of the various instrumentation used for measuring recoil motion as part of weapon recoil system evaluation.

2. Background. A recoil system is the mechanism that absorbs the energy of recoil gradually when a weapon is fired, and thus averts the transmission of violent shock to the carriage and prevents extreme displacement of the gun and carriage assembly from the line of fire.

Recoil motion measurements are made to obtain a plot of the distance traveled by the recoiling parts under study versus their time of travel. This distance-time curve provides a graphic indication of recoil and counterrecoil mechanism performance including such faults as improper buffer action, slamming into battery, or hanging out of battery. The extent to which the curve is used is determined by the test requirements and test results. At times it may be necessary to include only the maximum recoil travel with the times of recoil and counterrecoil in the

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test report. If the performance of the system is unusual, it may be desirable to include the time-travel curve illustrating the irregularities. At other times, it may be necessary to show plots of the time-travel curve and plots of other curves with interrelated events (such as recoil pressure, rod pull, or trunnion reaction) drawn with a common time scale. This will present the sequence of events and illustrate any significant relationships. Designers of recoil systems also find that cross-plots of recoil pressure against recoil travel at common time are valuable indicators of system performance. Some requirements may include velocity and acceleration curves that can be obtained by successive differentiation of the time-travel plot. With proper care, the time-travel record becomes a powerful tool in analyzing the performance of a weapon.

3. Equipment and Facilities. The equipment and facilities required for each measurement system are described in the individual appendix.

SECTION II
TEST PROCEDURES

4. Selection of Measurement System. Before making a recoil motion measurement, consideration must be given to selecting the most appropriate measurement system for both the test requirements and the recoil system under test. The systems used for recoil motion measurement consist of three fundamental components: a detector, a timing device, and a recording device. The detector senses the position of the recoiling parts under study during a specified time interval. The timing apparatus establishes the interval of recoil motion and provides the timing base for the measurement. The recording system provides a simultaneous record of time and distance by accepting the detection and timing system outputs.

a. The instrumentation systems for collecting recoil time/travel data are described in appendixes B through D. The features of each system that should be considered before making a selection are:

(1) Recoil Potentiometer System. The recoil potentiometer (app. B) is an excellent all-purpose system that is very accurate. It requires electronic techniques for use, but it is applicable to all types of artillery. By using low temperature lubricants and by protecting the moving parts from frozen condensate, the system may be operated at temperatures down to -70° F.

(2) Time-Displacement (Drum) Camera System. The drum camera (app. C) is very accurate. It is useful only on smaller weapons with limited recoil movement (up to 2 feet). Photographic and limited electronic techniques are required. Tests must be conducted under controlled conditions of illumination, but may be run at temperatures down to -60° F with internal heaters installed in the camera. The recording film must be replaced after each firing sequence.

(3) Photoelectric Transducer System. The photoelectric transducer (app. D) is suited for all types of artillery and can be installed with relatively little effort. This type of transducer head and tape is satisfactory for the measurement of weapon recoil displacement at temperatures as low as -60° F.

(4) High-Speed Camera System. The high-speed camera system (app. E) is suited for all types of artillery and can be employed with relatively little effort. As with all photographic instrumentation, film processing is required and tests must be conducted under controlled conditions of illumination. Even with controlled illumination the system can be compromised by fog, smoke, etc.

(5) Revolving Drum System. The revolving drum system (app. F) is relatively simple to construct. Personnel with electronic training are not required for its operation and the resulting record may be easily evaluated in the field. However, the system is primarily applicable to heavy weapons that can accommodate the size and weight of the mechanism. In addition, it is not well suited for low temperature tests and it requires replacement of the recording paper between firings. This system is rarely used.

(6) Slide Wire Resistance System. The accuracy of the slide wire resistance system (app. G) is poor. Electronic techniques are required for operation. Although useful under extremely cold conditions, this system is rarely used.

b. The accuracy of the various measurement methods is dependent upon:

(1) Calibration. Calibration involves the relating of some point or points on the recorded time-travel curve to a known distance value. This establishes a ratio of actual travel distance to distance recorded for that travel.

(2) Linearity. A test of linearity is the possibility of straight line representation of the actual travel versus the recorded travel, regardless of whether the line passes through the zero or the maximum loci on the curve. Linearity is usually expressed numerically in tolerance limits where the number is the percentage of full scale of the maximum deviation (in terms of recorded travel) of the curve from the straight line. The interpolation accuracy of the system between its calibration points is dependent upon its linearity.

(3) Resolution. Detector resolution is the length of the smallest movement that can be sensed by the detector. It is usually expressed in fractions of an inch or, in more general terms, as the percentage of total detector output. Reading resolution is the smallest increment that can be read from the record. It is dependent upon the

quality of the record, but the width of the recording tract with respect to the trace displacement generally determines the resolution at any given point (e.g., a graph drawn by crayon would have to be drawn to a much larger scale to be read to the same accuracy as that drawn with a pen).

5. Setup of Selected System. Setup requirements vary with the system selected. Individual system setups and calibration requirements are given in the appropriate appendix.

6. Recoil Motion Measurement. Recoil motion is measured as part of the recoil system evaluation described in TOP/MTP 3-2-600. Regardless of the measurement system used, the length of travel versus the time of travel is plotted for each recoiling part under study. Plotting techniques applicable to the individual measurement systems are described in the appendixes.

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APPENDIX A
REFERENCE

Yeager, J. G., Jr, "Improved Instrumentation for Measuring Gun Recoil Travel-Velocity," Aberdeen Proving Ground, Md., Report DPS-2363, June 1967.

APPENDIX B
RECOIL POTENTIOMETER SYSTEM

1. Description. The use of an electromechanical device to convert the position of the recoiling mechanism into an electrical voltage is the basis of the potentiometer system detector. A minimum of electrical circuitry is required since the potentiometer consists of a continuous variable resistance that divides the voltage across it proportionally to the angular position of its rotating shaft. The shaft is directly coupled to a pinion gear that is actuated by the movement of a rack attached to the recoiling part (figs. 1 and 2).

The output voltage of the potentiometer and a timing signal are simultaneously applied to the input circuit of an FM magnetic tape recorder. The recorded signals are then played back through a galvanometer oscillograph using direct print recording paper. A reduced playback speed is used to provide a time expansion record.

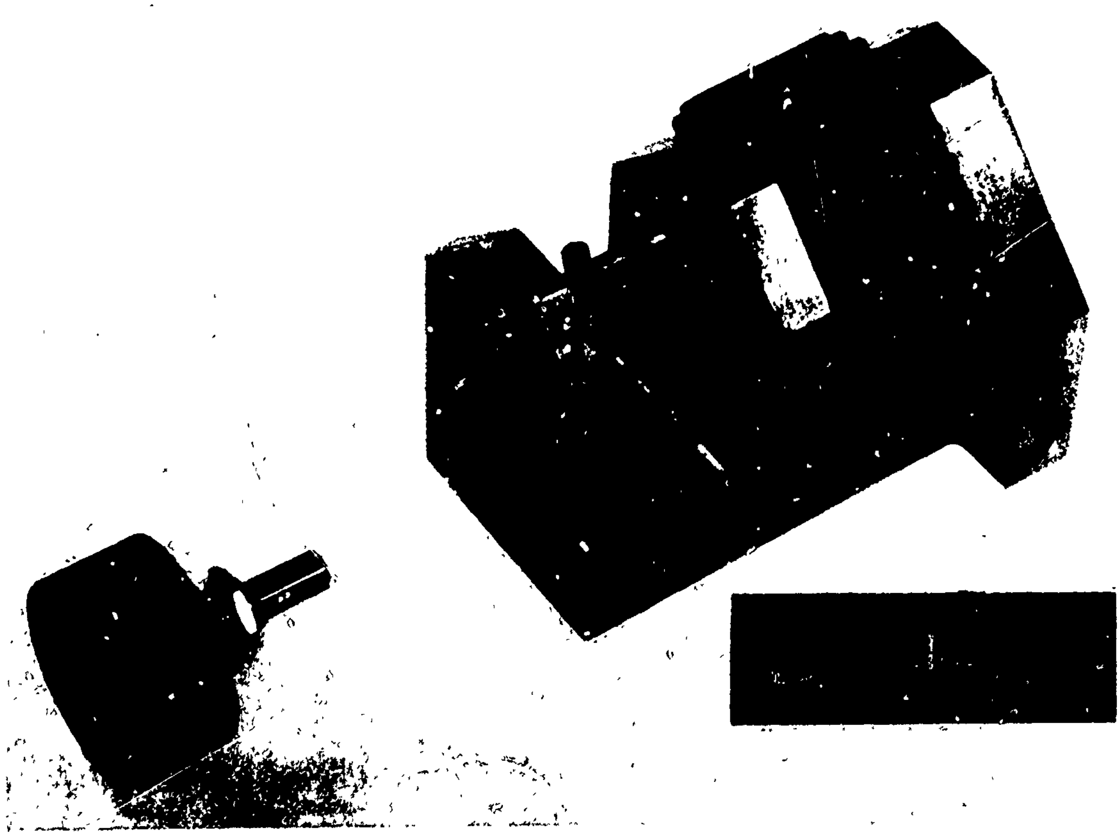

Figure 1. Recoil Potentiometer and Pinion Gear Assembly.

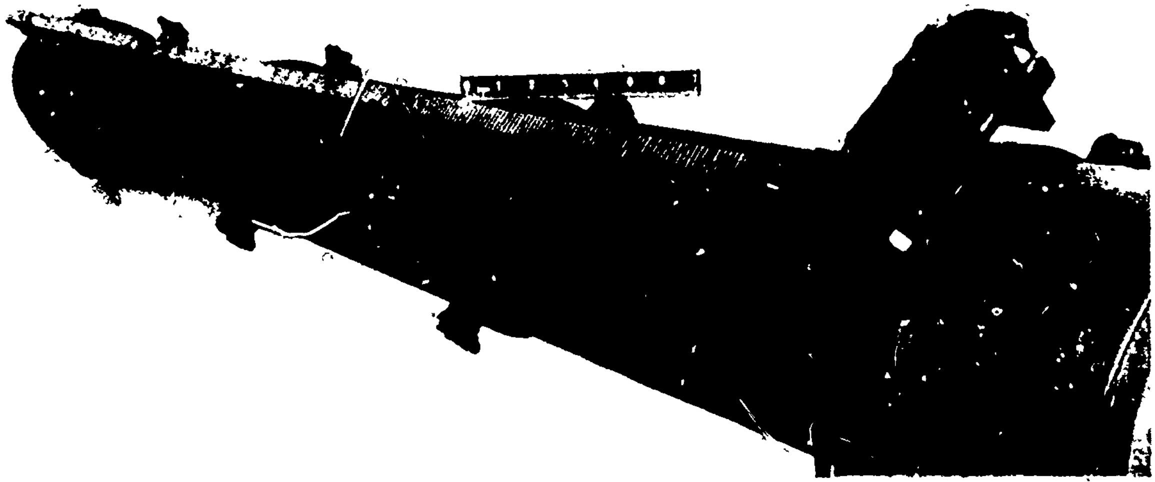

Figure 2. Recoil Potentiometers Mounted on Weapons. (Note rack and pinion.)

2. Setup Requirements. The rack-and-pinion gear selected for use with the recoil potentiometer must be compatible with the recoil system being tested. In addition to the machining of mounting hardware, the design and fabrication of the rack and pinion should produce easy-to-read results. For example, if the

pinion gear attached to the potentiometer shaft has 18 teeth and the rack attached to the recording part has 6 teeth per inch, when the rack moves 3 inches the motion of the pinion gear rotates the potentiometer shaft through one revolution. As the potentiometer shaft is rotated through successive revolutions, its voltage output varies from zero to maximum in each revolution. At the point where the wiper, within the potentiometer, crosses the opening between the high and low ends of the resistance winding, the voltage abruptly changes from maximum to zero.

Recoil potentiometer systems require 115-v, 60-cycle alternating current for the electronic equipment. The recording equipment must be placed in a weatherproof shelter and located a sufficient distance from the weapon to safeguard the electronic equipment from the effects of blast.

3. System Accuracy.

3.1 Calibration. This system is self-calibrating, with calibrations occurring each time the potentiometer shaft rotates the wiper through a crossover point. The physical dimensions of the mechanical actuator must be known.

3.2 Linearity. The standard linearity deviation for potentiometers used as detectors is ±0.5 percent. The deviation of the magnetic tape/oscillograph recording system is a function of scaling the calibration step signals on each record.

3.3 Resolution. Most of the commonly used potentiometers have a resolution equal to about 0.15 percent of the pinion gear circumference.

4. Precautions. It is essential that the rack gear be restrained by a floating spring loaded against the pinion gear; otherwise, the gear will bind or disengage during recording. The potentiometer shaft must be locked to the pinion shaft so that no slippage occurs. The potentiometer must be kept free from dirt. If the record shows discontinuities, remedial measures should be taken in the following order:

a. Increase the spring loading of the potentiometer wiper.

b. Lightly sand the contact portion of the resistance winding (rub the contact surface against extra fine sandpaper placed face up on a flat surface).

c. Increase the diameter of the pinion gear to decrease the angular velocity of the potentiometer.

NOTE: The electrical load of the potentiometer and slide wire resistor should be maintained at 100 times the detector resistance, or greater. A detector load (usually consisting of the input impedance of the associated amplifier) of this magnitude will introduce an error of 0.5 percent at 67 percent of full output. This is in addition to the error attributable to linearity tolerance discussed in 3.2 above.

5. Data Record. The recoil potentiometer record has a saw-toothed appearance as shown in figure 3.

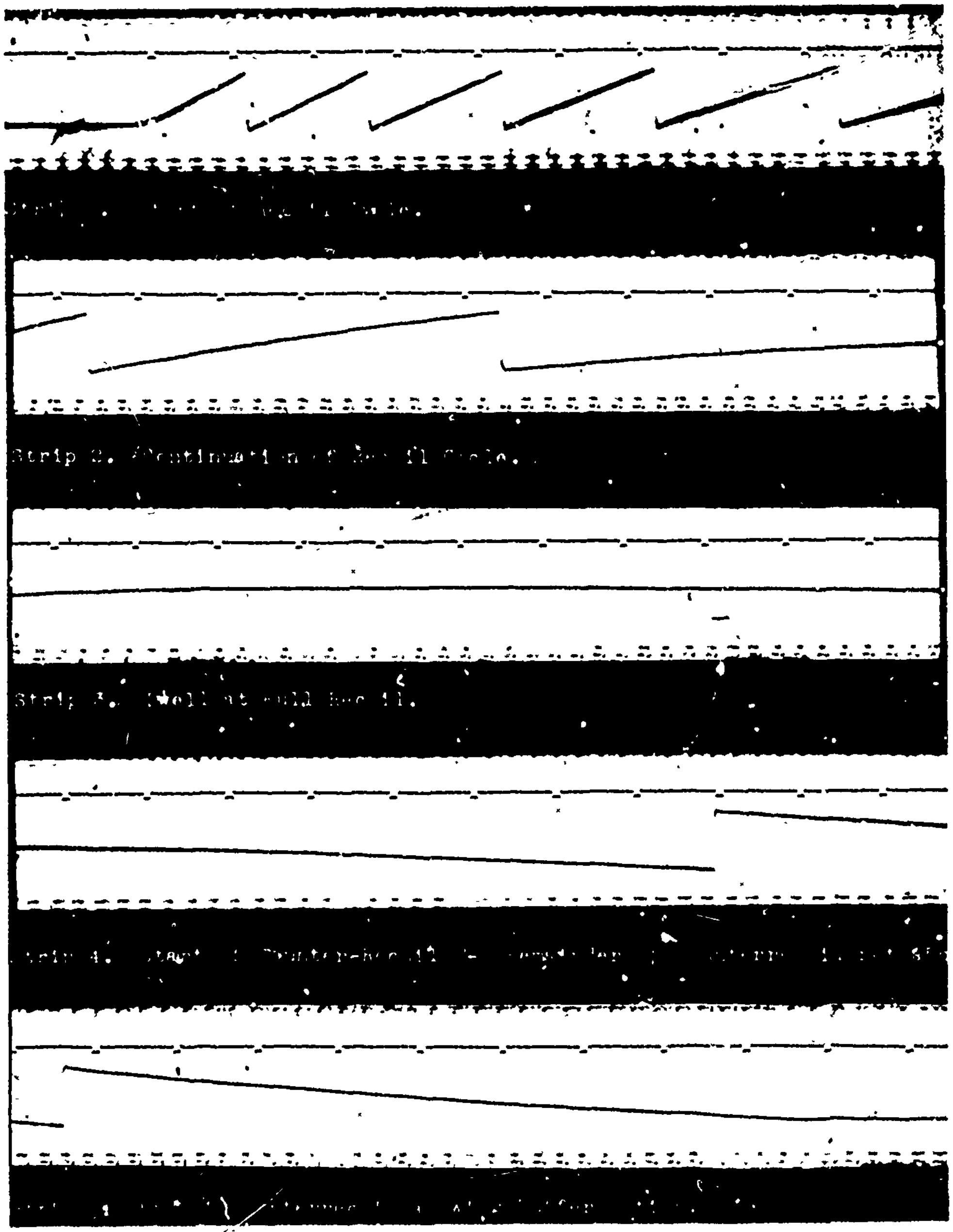

Figure 3. Recoil Potentiometer Record.

APPENDIX C
TIME-DISPLACEMENT (DRUM) CAMERA SYSTEM

1. Description. The detector in the time-displacement apparatus is a small cylindrical reflector mounted on each moving part under study (fig. 4). A source of parallel light is directed at the cylindrical reflector. The reflected light appears as a line that passes through the lens of the time-displacement camera, is condensed into an intense spot of light by a cylindrical lens, and impinges upon photo-sensitive paper attached to the surface of a revolving drum within the camera mounting. The optics of the system dictate that the axis of rotation of the revolving drum be parallel to the path of the moving reflecting cylinder, and that the longitudinal axis of the reflector be normal to a plane intersecting this path and the axis of rotation of the revolving drum. Precise time markers are supplied by a neon lamp within the camera, which is focused on the recording paper and is pulsed 1000 times a second by a timing standard. The camera shutter is synchronized by the timer or by contacts on the revolving drum so that it is open for only one revolution of the drum. The number of recoil cycles recorded is dependent upon the drum speed, which may be regulated by using a variable voltage source.

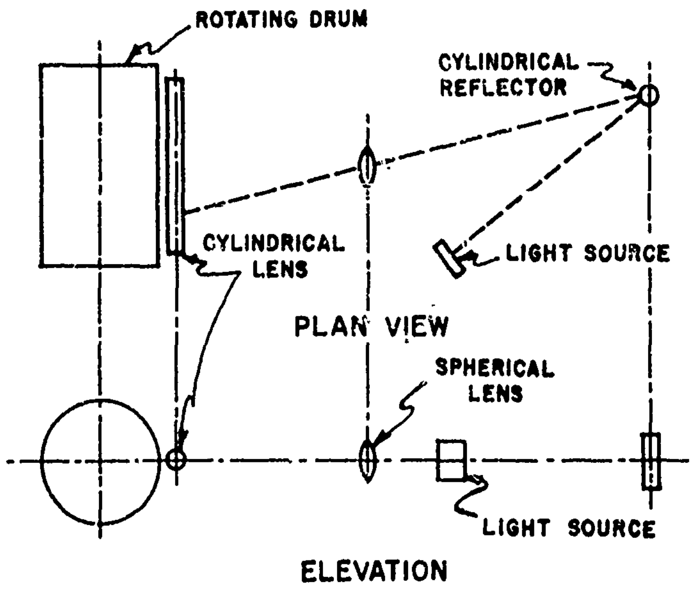

Figure 4. Time-Displacement Camera Setup.

2. Setup Requirements. Recoil motion measurements made with the time-displacement camera must be conducted indoors where illumination can be controlled. The installation of the cylindrical reflectors on the recoiling parts must be precise with respect to the camera installation.

The angle of motion should be as nearly horizontal as is feasible; the mounting hardware for positioning of the weapon and instrumentation must therefore be adequate.

The facility must be equipped with 60-cycle alternating current to provide electrical power for the camera, lights, and timer.

3. System Accuracy.

3.1 Calibration. Although not self-calibrating, the time-displacement camera is easily calibrated by using a bar that provides multiple calibration steps depending upon the spacing of reflectors on the bar.

3.2 Linearity. The linearity is totally dependent upon the optics of the system. A linearity tolerance of less than ±0.5 percent is commonly achieved by systems now in use.

3.3 Resolution. Since the system is optical and continuous, the resolution is excellant, depending upon the capability of the reading equipment. Use of 10-inch-wide photographic paper and a 1:1 reduction provides a very readable record for small arms testing.

4. Precautions. Proper alignment of all components must be accomplished for the time-displacement camera to produce a meaningful record. The axis of the revolving drum, the path of the moving deflector, the parallel light source, and the camera lens must be kept in a common plane. Lamp life is increased and a better photo record produced if the light source is "over-voltaged" during intervals of recording and "under-voltaged" between firings.

5. Data Record. Presentation of the data from this system is accomplished by duplicating the original record, as shown in figure 5.

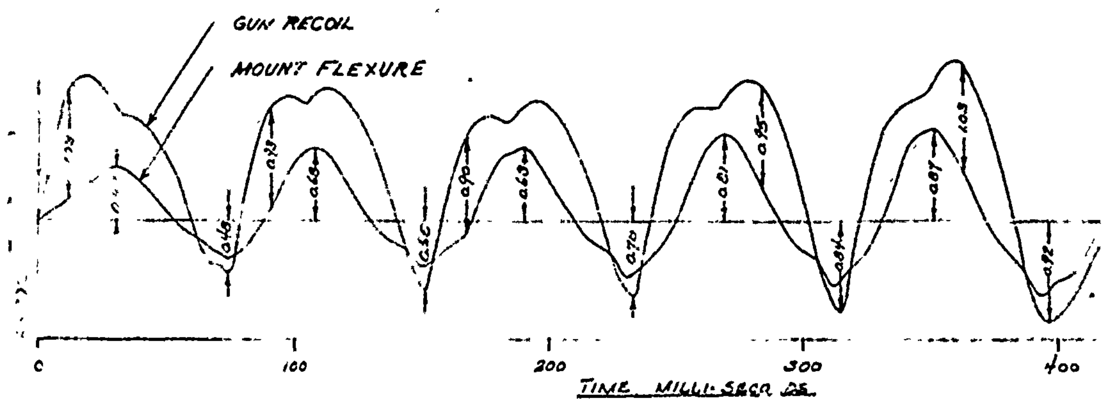

Figure 5. Time-Displacement Camera Record.

APPENDIX D
PHOTOELECTRIC TRANSDUCER SYSTEM

1. Description. This system uses the photoelectric principle to measure displacement. The system consists essentially of a photoelectric transducer head (light source and photovoltaic cell) through which a narrow tape is moved having alternate opaque and transparent transverse bands. A miniature lamp illuminates an aperture or gage in the opaque mask, and the illumination passing through the gate impinges on the photovoltaic cell which produces a voltage proportional to the transparency of the tape. As the tape is moved through the transducer head, a triangular-shaped pulse is generated and recorded. Permanent records of the amplifier output may be made on either a magnetic tape recorder or a galvanometer oscillograph. A view of the photoelectric displacement transducer is shown in figure 6.

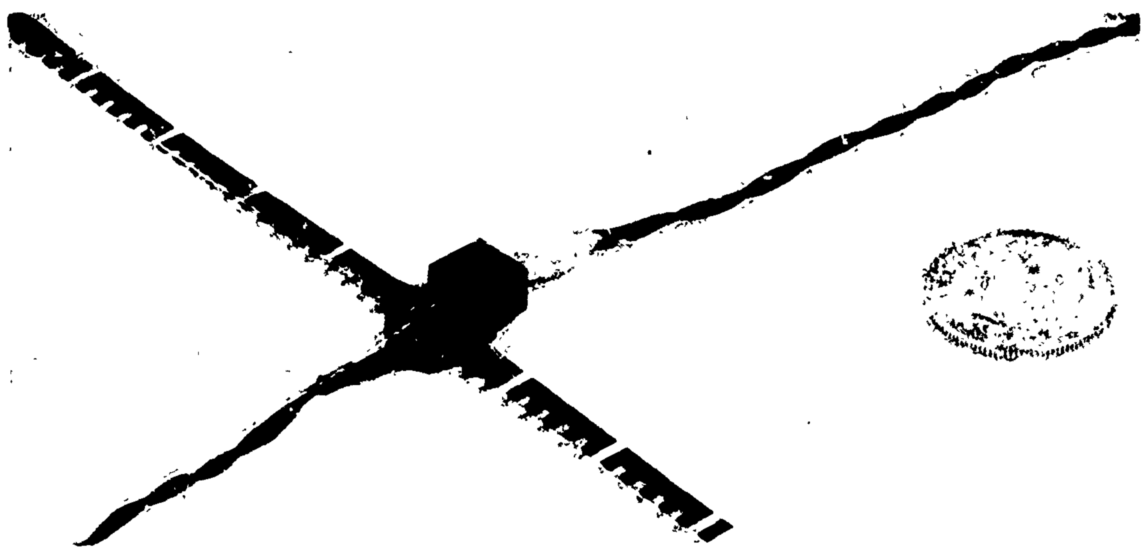

Figure 6. Photoelectric Displacement Transducer.

2. Setup Requirements. The photoelectric transducer requires 60-cycle alternating current for the opeation of the electronic equipment. The transducer is cemented to a small piece of sheet metal which is affixed to the mount by a pressure-sensitive tape commonly known as gun tape. The transducer tape is then fastened at each end to aluminum blocks or spacers held by gun tape so the transducer tape is suspended approximately 1/4 inch above the breechblock. The tape is aligned with the slot in the transducer head so that it will not bind as it moves through the slot during recoil.

3. System Accuracy.

3.1 Calibration. This instrument is self-calibrating in that the tape is premarked at regular intervals and the initial relative positions of the head and tape are of no consequence.

3.2 Linearity. The transducer in the system is linear and therefore the linearity is the same at all points along the record or recoil travel.

3.3 Resolution. Tapes with a resolution of 0.05 inch are standard equipment. However, tapes with a higher resolution can be obtained.

4. Precautions. The brackets must be mounted carefully to ensure their rigidity. The unit containing the solid-state amplifier and the power supply for the lamp should not be attached to the weapon. This will eliminate any shock effects. The transducer head must be shielded from external light such as the sun. Caution should also be taken to ensure that the tape is securely fastened.

5. Data Record. The photoelectric transducer record has a typical calibration trace which is obtained with the filmstrip displacing at a constant rate as shown in figure 7. The trace shows good linear relationship between the filmstrip travel and trace displacement.

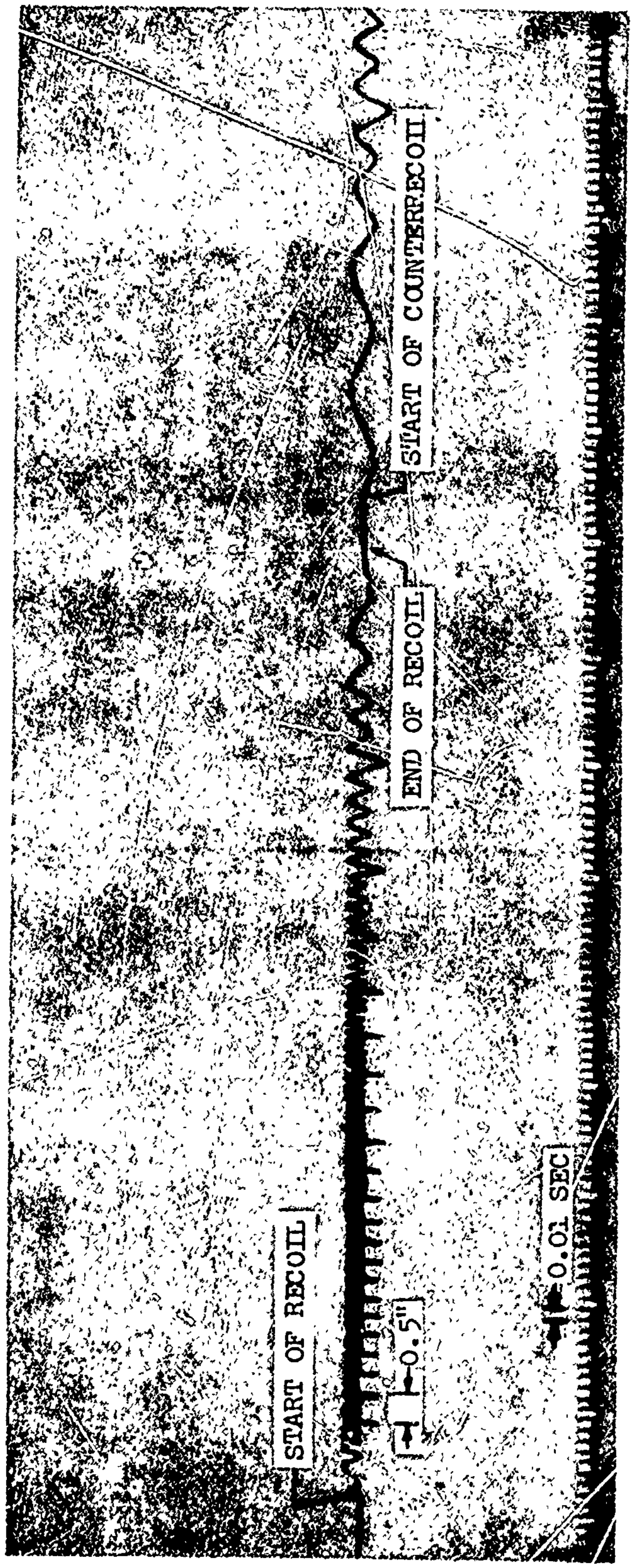

Figure 7. Photoelectric Transducer Record.

APPENDIX E
HIGH-SPEED CAMERA SYSTEM

1. Description. In this system, a 35-mm shutterless camera (smear or streak camera) or a high-speed framing camera (Fastax) records recoil motion data by photographing the recoiling parts (i.e., gun tube) which have been marked with reference lines. The displacement of these reference lines during the recoil/counterrecoil cycle is compared with fixed reference lines on the gun carriage (nonrecoiling part of mount assembly) or on the mobile carriage if the weapon is vehicle mounted. When using the framing camera, a scale may be substituted for the reference lines. Both cameras are equipped with a precise timing system to provide timing marks on the film. A detailed description of these cameras is contained in TOP/MTP 4-2-816.

2. Setup Requirements. The reference lines must be capable of withstanding weather and shock and be spaced a known distance apart. When a scale is used, suitable brackets must be fabricated for mounting the scale on the recoiling part. If the reference lines (or scale) are not in the same vertical plane as the recoiling part being measured, the recorded measurement must be adjusted by a scale factor to compensate for optical parallax error. The camera-to-subject and camera-to-reference distances are required to determine this scale factor.

The camera must be positioned in its mount so that the direction of film travel and the optical axis are perpendicular to the direction of recoil motion. To minimize distortion, the camera lens and reference lines (or scale) should be kept in a common horizontal plane.

3. System Accuracy.

3.1 Calibration. Calibration is achieved by the measured distances between reference lines or, when applicable, the scale graduations. Data reduction is simplified if the reference lines are equally spaced.

3.2 Linearity. Linearity of the data curve is directly proportional to the speed of the film and the motion of the recoiling parts.

3.3 Resolution. Both systems are optical and continuous, and detector resolution should therefore be excellent if the system is properly set up. Optimum reading resolution can be achieved by measuring the film record accurately.

4. Precautions. Firing of the weapon must not influence the camera by means of muzzle blast or muzzle flash. The camera is started immediately before a round is fired and stopped immediately after.

5. Data Record.

5.1 Smear or Streak Camera. The smear or streak camera record shows a continuous trace of both fixed and recoiling part reference lines during the recoil/counterrecoil cycle. Trace displacement versus time is obtained from the timing marks on the film.

5.2 High-Speed Framing Camera. The high-speed framing camera record shows a number of stop-action photographs from which the displacement of the recoiling parts can be read by means of the reference lines or scale. The timing interval between events is determined by the camera framing rate.

APPENDIX F
REVOLVING DRUM SYSTEM

1. Description. This system of recoil time/travel measurement employs a revolving cylinder which rotates at a speed dependent upon the power line frequency. The detector is a spring-loaded stylus (pencil or ball-point pen) that slides along guides aligned parallel to the axis of drum rotation. The sliding crosshead carrying the stylus is rigidly attached to the recoiling part for which the relative motion is to be determined. As the motion occurs, the stylus traces the travel on recording paper which covers the drum surface and is propelled by the drum rotation. The synchronous speed of the drum provides the time base necessary to complete the system. Figure 8 shows a typical revolving drum recorder with the recording paper removed.

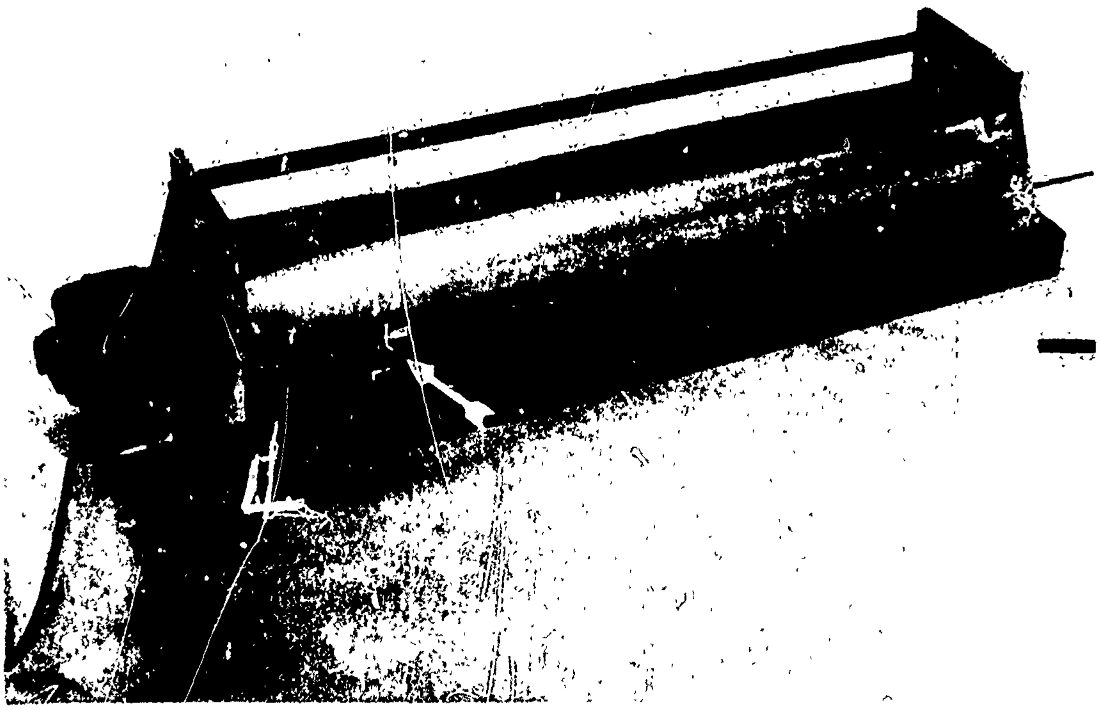

Figure 8. A Typical Revolving Drum Recorder. (Arrow indicates the stylus.)

2. Setup Requirements. The revolving drum recorder requires 60-cycle alternating current for the operation of the synchronous motor. Suitable brackets must be fabricated to properly position the drum with respect to the recoiling part. The point of zero travel must be capable of being adjusted to the desired point on the recording paper.

A roofed facility is necessary to protect the recording paper from the effects of precipitation during periods of inclement weather.

3. System Accuracy.

3.1 Calibration. Stylus calibration is not required for the revolving drum system since the direct mechanical linkage between the recoiling part and the stylus provides a 1:1 ratio of actual travel to recorded travel. A determination of the recording paper travel versus time is required, however.

3.2 Linearity. Backlash is eliminated in this system by the stylus' being held rigidly. The revolving cylinder drive motor is directly coupled to the revolving shaft so that linearity is absolute.

3.3 Resolution. Detector resolution for this system is determined by the width of the stylus trace. The stylus pressure must be adjusted to the point where it is just able to produce a continuous, legible trace. Optimum reading resolution (compared to other systems) is the result of the width of the recording paper.

4. Precautions. Care must be taken to see that the stylus holder slides freely upon the guides at all positions of the recoil cycle. The firing of the weapon must not subject the drum assembly to undue torsional or racking stresses. The springloaded pencil or ballpoint pen must have enough loading to scribe a distinct line without undue wear on the point or tearing of the paper. The paper itself must have enough stiffness that it cannot easily be torn and must be smooth enough to prevent excessive wear of the scribing point. The synchronous motor is started immediately before a round is fired and stopped immediately afterward. There must be no backlash in the pencil holder assembly.

5. Data Record. The revolving drum trace is replotted to a suitable scale. The new curve is made continuous by the successive displacements of the time scale by a distance corresponding to the period of one drum revolution. The direction of drum rotation produces a positive slope of the helix-like stylus trace in recoil and a negative slope in counter-recoil.

APPENDIX G
SLIDE WIRE RESISTANCE SYSTEM

1. Description. A simplified version of the recoil potentiometer is the cylindrically wound slide wire resistor. It has a sliding contact affixed to the recoiling part of the weapon. As the recoiling motion takes place, the voltage output varies linearly with the position of the contact along the winding. The output voltage of the resistor is fed into a magnetic tape/oscillograph recording system as in the case of the recoil potentiometer.

2. Setup Requirements. Arrangements for the slide wire resistance system are the same as those required for the recoil potentiometer except that the detector equipment is more easily installed since it does not entail the machining and physical alignment required by the rack and pinion gear used with the recoil potentiometer.

3. System Accuracy.

3.1 Calibration. Calibration is not an inherent factor in the slide wire resistance system. It must be obtained by displacing the slider a known distance and measuring the apparent displacement of the recording trace. This can be accomplished by measuring the total length of recoil by some other method and relating this distance to the maximum displacement of the time-travel curve. The system can also be calibrated by electrically simulating the end points of the resistance winding.

3.2 Linearity. The uniformity of the slide wire resistance winding determines its linearity. With care, windings can be wound within linearity tolerances of ±0.1 percent. The large voltage outputs available from the slide wire resistor simplify amplifier design and tend to improve system linearity.

3.3 Resolution. Decreasing the electrical contact width tends to improve the resolution of the detector.

4. Precautions. To maintain a desirable level of system accuracy, backlash and binding of the slide wire resistance system moving parts must be kept to a minimum. Contact pressure of the sliding wiper must be great enough to prevent "hopping" during recording intervals.

5. Data Record. The slide wire resistance record provides a continuous curve. Presentation of the data is accomplished by duplicating the original record.