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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Provides techniques for measuring projectile spin rate. Includes photographic method, paint smear method, pop-out-pin method, radio telemetry method, magnetic spin loop method (applicable to magnetizable projectiles), and flash radiography method (applicable primarily to aluminum sabots at time of emergence from gun tube). Includes spin rate computations for all methods.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-103 12 February 1976
Test Operations Procedure 4-2-811
AD No.

MEASUREMENT OF PROJECTILE RATE OF SPIN

1. SCOPE. This TOP describes the methods used at Army proving grounds to measure the rate of spin of projectiles. Photographic, mechanical, and electronic techniques are included.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENTS
Test site	Firing range with unrestricted view of, and access to, the targets.
Yaw card stands	To support yaw cards and other equipment items in the line of fire.
Detector loop support	Fabricated as illustrated under para 5.5.1.
Pop-out pins for projectiles	As described in para 5.3.1.

2.2 Instrumentation.

ITEM	MAXIMUM ERROR OF MEASUREMENT[1]
Photographic equipment (as described in para 5.1 and TOP/MTP 4-2-816)	Spin rate (rps); ±2%

[1]See note on p. 2.

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*This TOP supersedes MTP 4-2-811, 1 November 1966.

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ITEM	MAXIMUM ERROR OF MEASUREMENT[1]
Projectile velocity measuring equipment (as described in para 5.2 and TOP 4-2-805)	Up to 10,000 fps (3,048 m/s); ±0.1%
Radio telemetry equipment (para 5.4)	Spin rate (rps); ±2%
Signal conditioning and recording equipment (voltage amplifier, magnetic tape recorder, oscillograph, etc., as described in para 5.5.1).	Spin rate (rps); ±2%
Flash radiography instrumentation.	
Counter chronographs	Time resolution; ±1 μsec

[1] Values may be assumed to represent ±2 standard deviations; thus the stated tolerances should not be exceeded in more than 1 measurement out of 20.

3. PREPARATION FOR TEST.

a. Preparation of the projectiles and setup of equipment and instrumentation is described with the applicable method below.

b. For several of the methods, the spacing between targets or spin measuring devices is based on the anticipated distance that a projectile will travel during one revolution of spin. Assuming standard performance, one revolution of the projectile should occur in a distance equal to the design twist of the rifling. For example, the 90-mm gun M41 has a twist of one turn in 25 calibers (or 2250 mm) which is equivalent to 7.4 feet (2.25 m) for one revolution.

4. TEST CONTROLS.

a. All safety SOP's are observed throughout the measurement tests.

b. At least three rounds should be fired for each variable under consideration (e.g., muzzle velocity, band design, state of tube wear, projectile type).

5. SPIN RATE TESTS. Projectile spin measurements are made to verify that the projectile is spinning at a rate commensurate with design objectives. High rates of spin tend to stabilize the projectile and thus maintain its accuracy. Low spin rates are necessary to achieve the maximum effectiveness of shaped-charge rounds. Failure of fuzes or

other components may result from excessive spin velocity, whereas failure to arm may result from low spin velocity.

Spin measurements are most important in connection with tests to assure that rotating bands are engraving properly and maintaining their integrity, and in tests of projectiles that have sabots or carriers that are expected to impart a certain spin to the core of the projectile.

Spin rates are usually reported in terms of revolutions per second. Timing data are obtained either by direct recording of timing marks on film records or calibration of the time from velocity data obtained by conventional measurement of projectile velocities (TOP 4-2-805).

5.1 Photographic Method. The selection and deployment of photographic instrumentation depends on the test requirements and the anticipated performance of the test item. The various types of photographic instrumentation that can be used are described in TOP/MTP 4-2-816.

5.1.1 Procedure. Cameras are placed along the line of fire to obtain photographs of the projectile in flight at two or more points on the trajectory. A spiral pattern is painted (in contrasting color) on the projectile so that the change in the rotational position during the time elapsed between photographs can be determined. The time lapse is determined either from common-coded time impressed on the film or from the velocity of the projectile and the distances between cameras. The amount of rotation, expressed in revolutions, divided by the elapsed time, in seconds, gives the spin rate in revolutions per second.

At least three cameras are required to provide adequate data. The first camera is usually placed as close as possible to the weapon, but not so close as to risk obscuration by smoke or flame. The second camera is so located that less than one complete rotation of the projectile (para 3b) will occur between it and the first camera. The third camera is placed downrange at a distance that permits about five revolutions of the projectile between it and the first camera. Additional cameras may be used to increase the accuracy and precision of measurement. The distances between the cameras are measured to the nearest 0.05 foot (0.015 meter). All cameras are aligned so that their optical axes are perpendicular to the trajectory.

Spin rates are most frequently measured by the use of "smear" cameras, which have their lateral fields of view restricted by an internal slit. These cameras must have a film velocity approximately equal to the velocity of the image, and must be located so that the direction of film travel in the camera will be opposite that of the projectile to compensate for image reversal by the optical system. If motion picture cameras are used, the shutter speeds and framing rates should be adequate to provide relatively sharp images. Supplemental lighting may be obtained with flash lamps.

Still cameras must be used in darkness, in inclosed ranges, or in "dark boxes." Microflash techniques may be used to obtain adequate lighting under these conditions. The projectile is momentarily illuminated as it passes through the camera field, and the shutter opening is synchronized with the illumination. By using cameras with self-processing film, immediate examination of the photograph is possible.

The spiral pattern mentioned above must go completely around the projectile, and the ends of the pattern must be plainly marked to be visible in all rotational positions of the projectile. The change in rotational position occurring between two camera stations can be inferred from the change in the appearance of the spiral pattern in the photographic image. The progression of the spiral, as seen in the photograph, is usually measured with respect to the longitudinal axis of the projectile, and a complete revolution appears as a complete longitudinal progression of the spiral. For ease of data reduction the spiral should be designed so that the amount of rotation is proportional to the amount of progression of the spiral. A spiral stencil suitable for use on the cylindrical portion of a projectile can be simply designed by cutting from paper or other flexible material a right triangle with one leg equal to the circumference of the projectile and the other slightly shorter than the length of the cylindrical portion. The latter side is placed parallel to the longitudinal axis and the triangular piece wrapped around the cylinder. (Fig. 1 illustrates such a pattern.) The pattern should be as long as possible to give better precision of the measurement of rate of spin.

5.1.2 Spin Rate Computation.

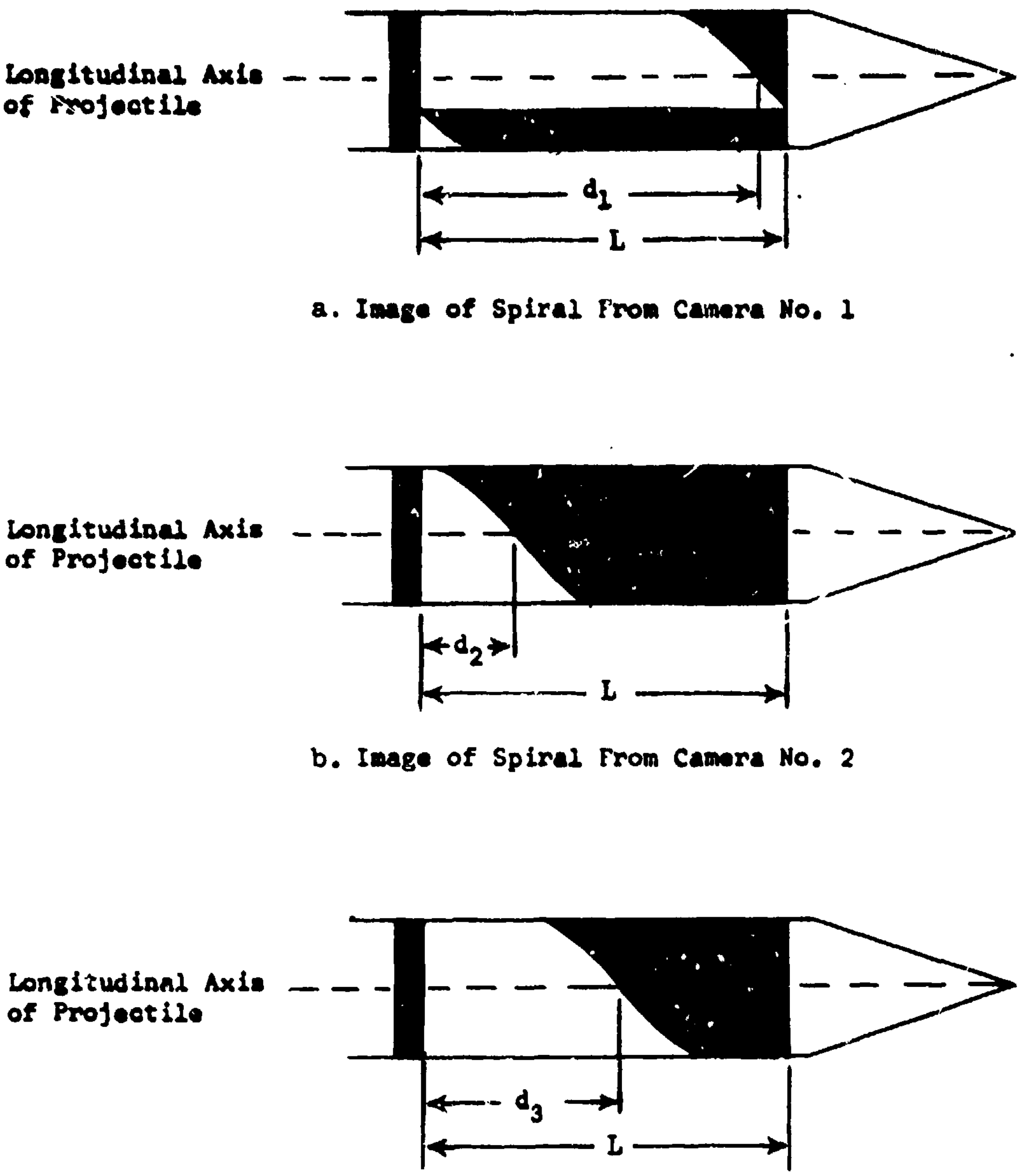
5.1.2.1 Spin Rate from Camera Observations: A first approximation of the spin rate is obtained from observations made by the two cameras so placed that less than one revolution of the projectile occurs between them. The partial revolution is calculated by determining the difference in the spiral positions recorded by the two cameras. Figure 1 (a and b) illustrates the appearance of the spiral as recorded by cameras 1 and 2, camera 1 being nearer the weapon. Assuming clockwise rotation of the projectile, the partial revolution, ΔR, is given by the equation:

$$\Delta R = \frac{d_1 - d_2}{L}$$

The spin rate, r, in revolutions per second, is given by the equation:

$$r = \frac{\Delta R}{\Delta t},$$

where Δt (seconds) is the time between the two observations.



a. Image of Spiral From Camera No. 1

b. Image of Spiral From Camera No. 2

c. Image of Spiral From Camera No. 3

Figure 1. Views of Painted Spirals from Three Cameras.

A more precise determination of the spin rate is had by combining data from the third camera (c, fig. 1) with data from the first two. Because the expected error of measurement (random error) varies inversely with Δt, use of the longer time between the observations made by cameras 1 and 3 (or 2 and 3) improves the accuracy of the measurement of rate of spin. Calculations are as follows:

The elapsed time between observations by cameras 1 and 3 is denoted by $\Delta' t$. The number of complete revolutions, n, is found by multiplying the spin rate calculated from cameras 1 and 2 by $\Delta' t$ and discarding the fractional portion of that product. The appropriate fraction of a revolution, $\Delta' R$, is obtained from measurements of the photographs taken by cameras 1 and 3 (fig. 1).

$$\Delta' R = \frac{d_1 - d_3}{L} .$$

The spin rate is then calculated as

$$r = \frac{n + \Delta' R}{\Delta' t} .$$

This procedure is easily extended for application to a situation in which more than three cameras are used. The accuracy obtained by these photographic methods is within about 2 percent, depending on the sharpness and contrast in the film image.

5.1.2.2 Theoretical Spin Rate: It is sometimes of interest to compare the measured spin rate with the theoretical spin rate for monobloc projectiles. Consider the 90-mm gun of paragraph 3b (which gave a spin distance of 7.4 feet (2.25 m) for one revolution). If a velocity of 3000 fps (914.4 m/s) is assumed, the rate of spin for a monobloc projectile would theoretically be 3000/7.4 (914.4/2.255) or 405.4 revolutions per second when the projectile emerges from the tube.

5.2 Paint Smear Method.

5.2.1 Procedure. The spin rates of projectiles fired from rifled tubes may be obtained with a relatively simple setup. This method, which has yielded satisfactory spin data for 90-mm guns, requires minimal data reduction and is comparatively inexpensive.

The windshield or ogive of the projectile is painted with a slow drying oil paint (red, blue, or green) as shown in figure 2.

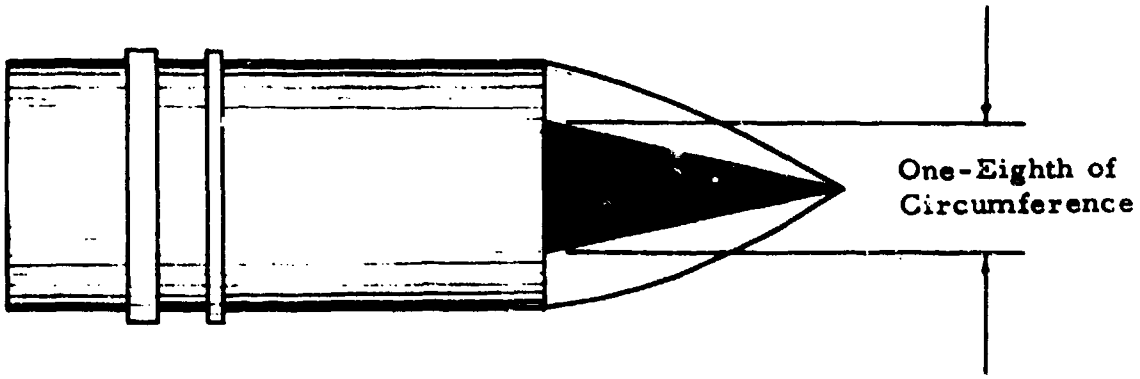


Figure 2. Painting of the Projectile Ogive.

Three cloth panel targets 4 feet square, and velocity coils or sky screens (TOP 4-2-805) are positioned as shown in Figure 3. Spacing should be controlled to within 0.05 foot. Dimension a (gun to first coil) and dimension f (first to second coil) may be selected to suit the velocity determination. Dimensions c and d are limited to encompass slightly less than one revolution (para 3b) between panels 1 and 2 and slightly less than two revolutions between panels 2 and 3. Dimensions b and e are not critical and may be varied to facilitate the test setup.

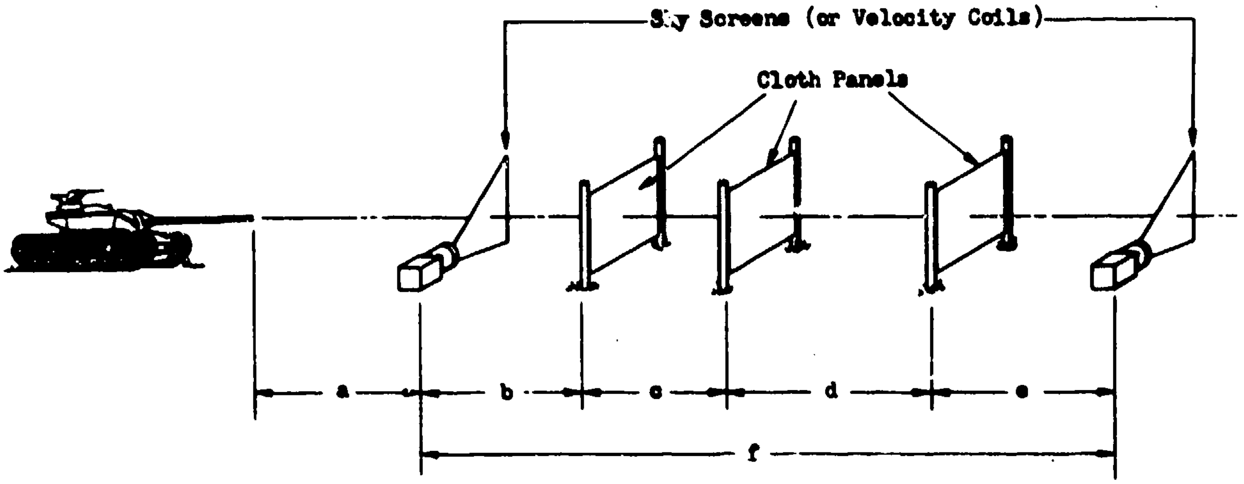


Figure 3. Target Spacing.

At least three rounds are fired for each variable under consideration: i.e., muzzle velocity, band design, state of tube wear, projectile type, or other feature. Velocity should be determined for each round.

As the round passes through the cloth target, a clear red, blue, or green area will be stenciled on the cloth by the painted portion of the ogive. The angular orientation will change from target to target because of the spin of the projectile, as indicated in figure 4.

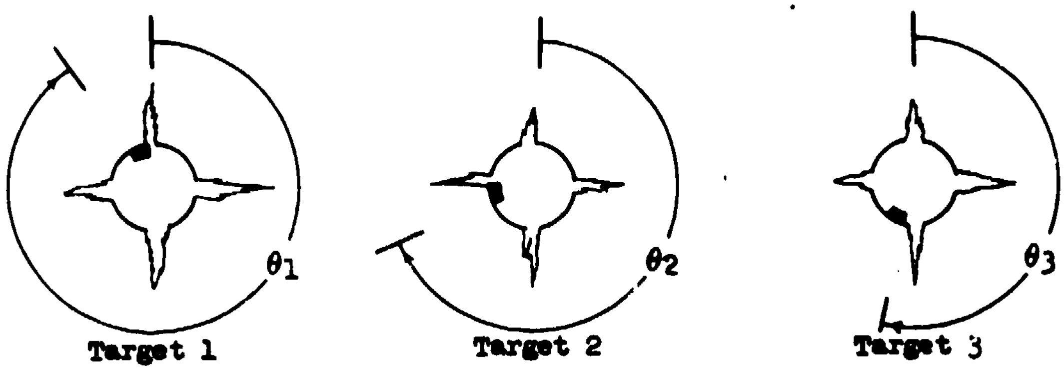


Figure 4. Stenciled Target.

5.2.2 Spin Rate Computation. In computing spin, the projectile rotation (θ) between panels is determined first by means of a protractor, where for clockwise rotation $\theta = \theta_2 - \theta_1$. (If the algebraic sum is negative, add 360°.)

The distance between targets in feet (or meters) (d) divided by the velocity of the projectile between the coils (v_c) gives the time of flight (t_d) between the targets in seconds.

The rate of spin (rps) is equal to the number of revolutions the projectile makes between the targets divided by the time of flight between those targets. The rate of spin between panels 1 and 2, 2 and 3, and 1 and 3 should check and may be averaged. The longer time base between panels 1 and 3, however, should produce the more reliable data.

When spin measurements are made at some distance from the muzzle of the gun, the assumption must be made that there is a linear relationship between projectile spin rate and velocity. Since the decrease in spin rate and velocity from drag forces may not be proportional, the measurements made at considerable distances downrange are not reliable for predicting initial rate of spin. In general, if measurements are made within several hundred feet of the muzzle, the rate of spin will not be appreciably affected.

5.3 Pop-Out-Pin Method.

5.3.1 Procedure. A method that is occasionally used to determine spin rate involves the use of a modified projectile fitted with pop-out pins. Centrifugal force causes these pins to extend beyond the normal circumference of the round and to notch yaw cards as the round passes through them. The test setup is the same as that used for the paint smear method (para 5.2) except that cardboard yaw cards are used in the line of flight instead of cloth panels. The angular change of notch orientation from target to target and the velocity of the projectile determine the spin rate.

5.3.2 Spin Rate Computation. Spin rate computation is the same as that described for the paint smear method (para 5.2).

5.4 Radio Telemetry Method.

5.4.1 Procedure. An electrical system for measuring spin rate that may be used when other methods are not suitable is a spin-sonde operating in the very high frequency radio range. This method is particularly suited for measurement of continuous or terminal spin rates. The airborne portion of the system consists simply of a miniature radio transmitter and a polarized transmitting antenna. The antenna is usually a small loop although a dipole may be used. The receiving antenna is usually oriented to collect the maximum signal from the transmitter. Assuming that the receiving antenna is polarized in the horizontal plane, the maximum signal will be received when the transmitter antenna is also polarized horizontally. Minimum signals will be received when the antenna are out of phase. An AM receiver, tuned to the transmitter frequency, will pick up a signal varying in strength and modulated by the spinning antenna of the transmitter. This signal is recorded by magnetic tape and/or oscillograph for data reduction purposes. The projectile spin rate is directly related to the signal from the radio receiver, the actual spin rate being one-half the demodulated audio frequency.

5.4.2 Spin Rate Computation. The spin rate data recorded on magnetic tape are processed through an analog computer to determine the audio frequency. The spin rate of the projectile is equal to one-half the demodulated audio frequency. Spin rate can also be determined by developing and processing the oscillographic record.

5.5 Magnetic Spin Loop Method. The magnetic spin loop is an economical, reliable, and accurate method of obtaining spin data on magnetizable projectiles having a velocity/spin ratio of less than 50 feet per revolution (15.24 m/rev).*

5.5.1 Procedure. Spin rate is obtained using a transversely magnetized projectile and a detector loop (fig. 5) consisting of a single loop of wire supported along the line of fire. Support for the loop is provided by two parallel beams (two-by-fours) that are supported aboveground by vertical uprights or yaw card stands. The projectile is fired parallel to and approximately 1 foot above the detector loop. As the projectile travels over the loop, a spin signal is induced in the loop by the magnetic field of the spinning projectile. This signal is fed to a voltage amplifier whose output is recorded on magnetic tape along with a timing signal on a second channel of the tape. The recorded signals are played back to a galvanometer oscillograph using direct-point recording paper. A reduced playback speed is used to provide a time-expanded plot (fig. 6) for measurement.

5.5.2 Spin Rate Computation. Spin rate is determined from the oscillographic record (fig. 6) of the time-expanded signals. Spin is recorded as a continuous sine wave with the distance between each peak representing one revolution of spin. The revolutions of spin are compared with the recorded timing signal to obtain the time per revolution which is then converted to revolutions per second.

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*Savage, Michael R., "Study to Improve Spin Data Acquisition," Jefferson Proving Ground, Madison, IN, Report MTD-I-1-74, TECOM Project 9-CO-004-000-005, June 1974 and Report MTD-I-4-75, TECOM Project 9-CO-014-000-007, May 1975.

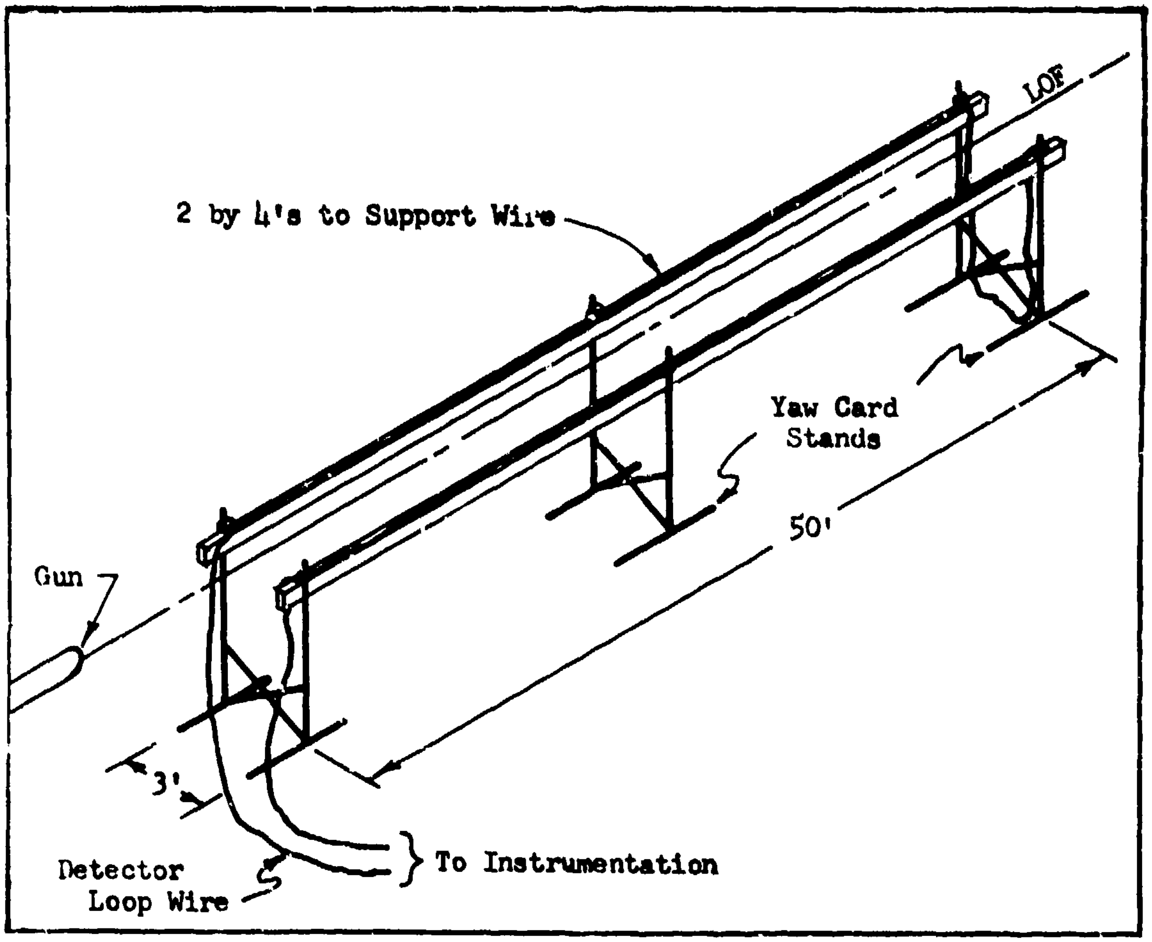

Figure 5. Typical Detector Loop Support.

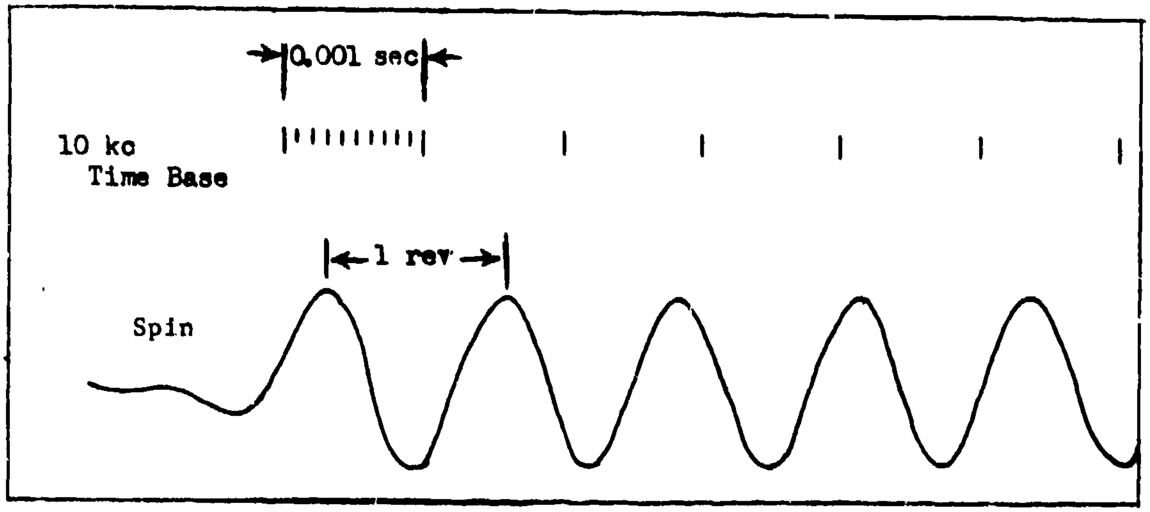

Figure 6. Typical Spin Loop Record.

5.6 Flash Radiography Method. Flash radiography (TOP/MTP 4-2-825) is used primarily for measuring the rate of spin of aluminum or other nonmagnetic sabots just as they emerge from the gun tube. (The nonmagnetic metal and the obscuration from muzzle flash prevent the use of other methods.) If subprojectile spin must also be measured, a magnetic spin loop may be used.

5.6.1 Procedure. A small lead pin is inserted off center in the base of the sabot, and the complete round is loaded in the chamber of the weapon. The projectile is oriented so that the twist of the rifling will cause the pin to be positioned on the longitudinal axis of the round as it exits the tube. The rotational position of the pin is recorded with respect to time by two X-ray units located along the flight path near the muzzle. One unit is positioned to record the pin location when the round is approximately 2 inches from the muzzle, and the second unit is positioned so that one-quarter of a revolution of the round (para 3b) will occur between it and the first X-ray unit. Triggering of the X-ray units is initiated by a strain gage on the tube of the weapon with successive pulses controlled by a time-delay network. Time-delay settings are calculated from muzzle velocity data. A counter chronograph is used to record the time between the X-ray unit triggering pulses.

5.6.2 Spin Rate Computation. The time for one revolution of spin is determined from the angle through which the pin has rotated (as viewed on the X-ray film) during the recorded time between triggering pulses. This value is then converted to revolutions per second.

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