EXHIBIT "B"

MEASUREMENT OF THE PITCH OF RIFLING TWIST USING BALLISCAN PICTURES

General:

Rifling twist, as recorded on bullets, can be measured quite easily and with a high degree of accuracy using Balliscan photography and a good protractor. The technique is simple, but care must be exercised since certain types of errors tend to produce significant inaccuracies in the final result. These errors are avoidable and/or correctable, as will be seen.

Bullet Damage and Distortion:

A considerable amount of research has been done on rifling pitch measurement using bullets which have been damaged to a greater or lesser degree. Some basic rules can be stated with confidence, but much work needs to be done yet in this area.

The pitch measurement technique depends upon the availability of rifling shoulders or properly oriented striae spaced at substantially equal intervals around the bullet circumference. Any damage which prevents such measurement intervals reduces the accuracy of the end result, or makes the entire procedure impossible. As a rule of thumb, if one shoulder is not measurable but closely adjacent striae can be used, the results are accurate. If no nearby striae are usable, but the adjacent trailing shoulders can be measured and averaged, the results are close to being correct, but must be used with caution. If neither procedure is possible, pitch measurement should not be attempted.

Mushrooming or flattening of the ogive will not affect the accuracy of results. If the distortion extends down into the area of the rifling impression, the pitch may still be measured but care must be exercised to use only as much of the shoulder length as is undistorted. Generally, if 50 percent of the rifled area is intact, usable measurements can be made.

Equipment:

1. Balliscan camera

2. Photographic processing and enlargement printing equipment and supplies.

3. Engineer's drafting machine, or 24" steel straight-edge, two "C" clamps, and a portable protractor with a 5' vernier scale.

4. Masking tape or similar.

5. Drafting table or other flat surface.

6. Table of trigonometric functions in one minute increments.

Photographing the Bullet:

The driven shoulders are the most reliable pitch indicators. Therefore, bullets with right twist rifling should be photographed inverted to highlight these shoulders. Left twist bullets should be photographed erect.

Follow the procedures recommended in the Balliscan operator's manual, using particular care in setting the bullet up. Inaccuracy in the setup will have the following effects: Tilt - no effect on the pitch measurement results, but sharpness of focus will be degraded in parts of the pictures, thus reducing its value for other purposes. Eccentric rotation - Poor focus over substantial areas of the picture and a noncorrectable error in the pitch determination. If the eccentricity is small, this error may be ignored since it will be below the noise level. Poor focus - This is the most serious setup error since there is an acceleration factor in resulting dimensional errors. Fortunately, dimensional shifts due to focus error are detectable and correctable.

Focus Versus Geometry:

The Balliscan records at exactly twice the scale of the photographed object. The translation velocity of the object is precisely synchronized to film velocity when focus is correct. Focus error has a negligible effect on the vertical dimension of the object as recorded on the film, but it causes a major distortion of the horizontal dimensions. Example: A .45 caliber bullet in perfect focus measures, in circumference, on the film .45" x 3.1416 x 2 = 2.82744". A focus error of ±.010" equals an apparent diameter change of ±.020". The error on the film will be .020" x 3.1416 x 2 = ±.125664". Measurements, taken from an enlargement print, of circumference, land and groove widths, and pitch are all degraded by focus error. Since the true diameter of the bullet is known, these errors may be corrected mathematically. Pitch error corrections will be discussed later. Linear measurement errors are corrected as follows:

C = True diameter X 3.1416

L = Circumference as measured on the negative or print

A = Dimension, such as land width, as measured on the negative or print

X = True dimension

Formula:

$$\frac{C}{L} = \frac{X}{A}$$

Pitch Measurement Technique:

Enlargement Prints: It is desirable to use prints with the maximum enlargement possible; 20X over bullet scale is excellent. The high magnification enables more accurate pitch measurement, particularly on short bullets. Semi-matte paper, rather than glossy, is best since reflections are reduced. Trim the print so that it covers one full bullet circumference, plus one or two extra land and groove impressions.

Step I. Lay the print on the drafting table or desk with the bullet ojive up. Select a small or sharply pointed detail on the bullet near either end of the picture and circle it with a pencil or pen. Find the same point near the other end of the print and mark it. The vertical position of the point selected doesn't affect the results. If a line were drawn between these points, it would be perpendicular to the axis of rotation of the bullet when it was photographed.

Step II. (Using a fixed engineer's drafting machine.) Orient the straight edge to horizontal. Be sure that the vernier scale reads precisely 0° or 90°.

Place the print under the straight-edge and align it so that the two selected points are exactly on the edge of the ruler. Carefully fix the corners or ends of the print to the table with masking tape. Recheck the alignment of the selected points and the vernier reading. Any error in this phase of the process will carry over into the pitch measurement results and will not be apparent unless the entire procedure is repeated.

Step II (Using a portable protractor). Lay the print on the table at the near edge, ojive up. Place the straight edge on it and carefully align the top edge with the selected points. Draw a line along the bottom of the straight edge and then move the top edge down to this line. The purpose of this is to move the straight-edge below the rifling so that the entire length of each driven shoulder is revealed and usable. Therefore, repeat the straight-edge movement process, if necessary. Next, using the two "C" clamps, clamp the straight-edge down and then tape the print corners down. Recheck the straight edge alignment since this is crucial to accurate results.

NOTE: Drafting machines, protractors, and straight-edges must be calibrated accurately to ensure useful results!

Step III (Drafting Machine). Unlock the protractor and lay the ruler very accurately along the driven shoulder on the extreme left side of the point. (Note: It is helpful to identify each driven shoulder on the print by numbering them 1, 2, 3, etc. Measurement values can then be jotted down on a scratch pad and then later rechecked, if necessary.) Frequently, fine structure can be seen in the shoulder area, which helps to refine the alignment. If the shoulder is damaged or obscured, look for properly oriented striae close to the shoulder and use these for alignment. If this is necessary, try to find one on each side of the shoulder and close to it and use the average of the two values. If there are no reliable striae near a damaged driven shoulder, measure the two adjacent trailing shoulders and use the average of these measurements. Remember, however, that the key to accurate pitch measurement is to make a series of equally spaced angular measurements around the circumference of the bullet. When averages must be used, as suggested above, the final result may be degraded, although it should be usable. When the straight-edge is correctly aligned, lock the protractor and read the value. This may vary according to the drafting machine model, but it will be either 90° or 0° plus or minus some number of degrees and minutes, usually less than ten. If your machine reads plus or minus 90°, subtract 90 from each result. This number represents the amount that the measured shoulder deviates from the axis of rotation. Record the value and then repeat the process until all driven shoulders around the bullet circumference have been measured. Each measurement should be read to, at most, five minutes of arc and smaller if possible.

Step III (Portable Protractor). Unlock the protractor and place one straight-edge against the clamped straight-edge. Align the other protractor straight-edge with the selected driven shoulder. Follow the same techniques as used with the drafting machine. Use particular care that the protractor is kept firmly against the clamped straight-edge.

Step IV. When all driven shoulders have been measured, it is normal to find a spread of readings over a degree or more. The variance is due to the bullet being set up slightly off vertical when it was photographed. This divergence is corrected in this step of the process. Add all of the measurement readings and divide the result by the number of measurements. The resulting value is the pitch of the rifling expressed in degrees and minutes. This figure can be converted into pitch in inches if desired.

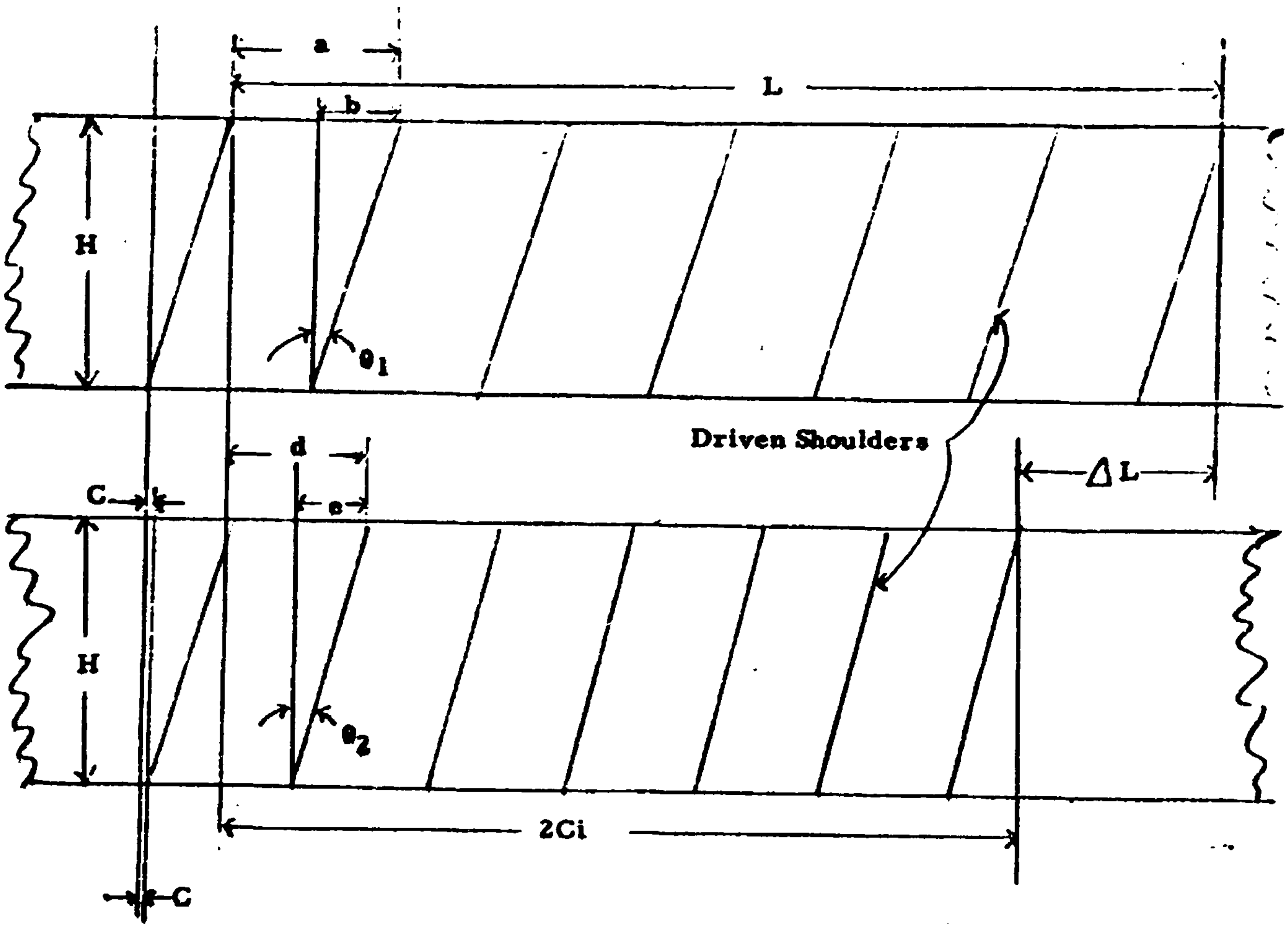
Step V. As pointed out above, inaccuracy in focusing the camera, even though the error may be small, produces a distortion in circumferential measurements. It also changes the apparent pitch of the rifling impressions. This change may be insignificant, but often it is large enough to be important. In order to determine the magnitude of the error and correct it, use the following procedure:

1. Measure the caliber of the bullet and multiply it by 3.1416 x 2. Check this value against the circumference of the bullet as shown on the Balliscan negative. If the results are identical, no error exists. If they differ, subtract the negative circumference value from the actual circumference times two.

2. Figure 1 illustrates the linear and angular changes which occur when circumferential error exists in Balliscan photography. The upper part of the figure represents the Balliscan picture, while the lower part is a drawing of the true dimensions of the bullet. For this example, an error of +25% in circumference is used in order to make the effect of such errors visually apparent. (In practice, an error of this magnitude cannot occur.) Significant dimensions are annotated.

Figure 1

Linear Scale Change vs. Apparent Pitch



L = Bullet circumference measured on Balliscan negative.

2Ci = Actual bullet circumference times 2 = 2X caliber x 3.1416.

ΔL = Difference in length due to linear scale change

n = Number of rifling lands (6 in this example)

a = Distance between driven shoulders = $\frac{L}{n}$

θ_1 = Apparent pitch measured on Balliscan photo in degrees and minutes

θ_2 = True pitch of rifling impressions on bullet

H = Height of rifling impressions (measured on photo)

b = H tangent θ_1

c = $e - b = \left(\frac{b}{a}\right) \times \left(\frac{\Delta L}{n}\right)$ = change in e due to ΔL

d = $\frac{2Ci}{n}$

e = H tangent θ_2

3. At this point in the procedure, the following values have been determined: 2Ci; L; θ_1; n. 2Ci was found using the measured caliber of the bullet. L was measured on the Balliscan negative. θ_1 is the average of the individual pitch measurements. n is the number of rifling lands. Several simple measurements, plus reference to the trigonometric tables, will complete the process and reveal the true pitch of the rifling twist.

4. In Step I above, the difference between the true bullet circumference times 2 and the apparent circumference measured on the negative was determined. Multiply this by the enlargement factor of the projection print as compared to the negative. This figure is ΔL. It will be a plus or minus value depending on whether the circumference measured on the negative is larger or smaller than the bullet circumference times 2.

5. Measure the bullet circumference on the enlargement point and divide this by the number of rifling lands. This value is a.

6. Measure the height of tha rifling impressions on the print. Since these may vary from land impression to land impression, use the smallest one. This value is H.

7. Determine b using the following equation.

b = H times the tangent of the pitch angle (θ_1) as previously measured on the enlargement print.

8. Determine c as follows: $c = \left(\frac{b}{c}\right) x \left(\frac{\Delta L}{n}\right)$. It may be either a plus or a minus value.

9. Determine e as follows: e = b + c.

10. Determine θ_2 as follows: $\frac{e}{H}$ = tangent of θ_2

θ_2 is the true pitch angle of the rifling.

11. In summary:

2Ci-L times enlargement factor = ΔL

$L + n = a$

$b = H \tan \theta_1$

$c = \frac{b}{a} \times \frac{\Delta L}{n}$

$e = b + c$

$\frac{e}{H} = \tan \theta_2$

12. This correction procedure may appear to be complex and time consuming. However, it is simple to use. Furthermore, the examiner will be able to judge, with experience, when the correction procedure must be followed and conversely, when the linear error is small enough to be ignored.

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