93057

# ALMEN GAGE ACCURACY AND REPEATABILITY

Jack Champaigne
The Shot Peener
Electronics Incorporated, USA

## ABSTRACT

The Almen gage has been the dominant process control device for shot peening since its introduction in 1942. The ability of this gage to accurately determine shot stream intensity is related to its construction and maintenance. Attributes investigated included proper placement and wear of balls and indicator tip, and influence of indicator tip spring force upon the Almen strip. A new calibration block, flat on one side and curved on the other to represent .024 inch arc height, is defined. A procedure for checking Almen gage repeatability is described.

## KEYWORDS

Almen Gage, Almen Gauge, Shot Peening, Almen Gage Study

## INTRODUCTION

Since its introduction in the 1940's, the Almen gage has provided process control for the shot peening process. The blast stream energy is a very critical process variable and it can be measured with a small steel test strip and a test gage. The original gage design, invented by J. O. Almen, was described in his U.S. Patent Number 2,350,440 and it used two knife edges to support the test strip. One side of the test strip is exposed to the blast stream causing the strip to curve. The amount of curvature, as shown by the arc height, is a measure of the intensity of the blast stream.

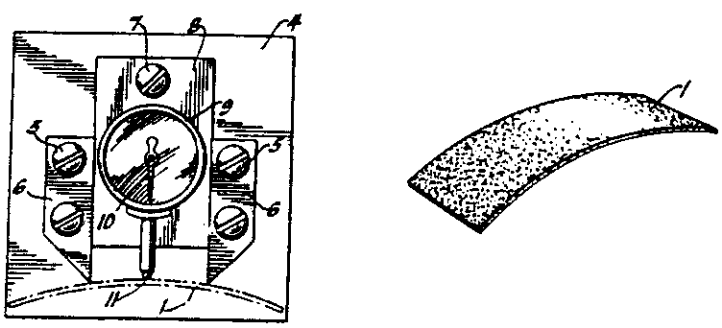


Figure 1. Original Almen Gage

This gage was later superseded by Almen Gage No. 2 which used four balls to support the strip during measurement. This approach accommodated the compound curvature exhibited by the strips (i.e., both span-wise and chord-wise curvature of the strip). For a more detailed explanation of the proper use of the Almen strip, block and gage see Society of Automotive Engineers publication J442 and J443.

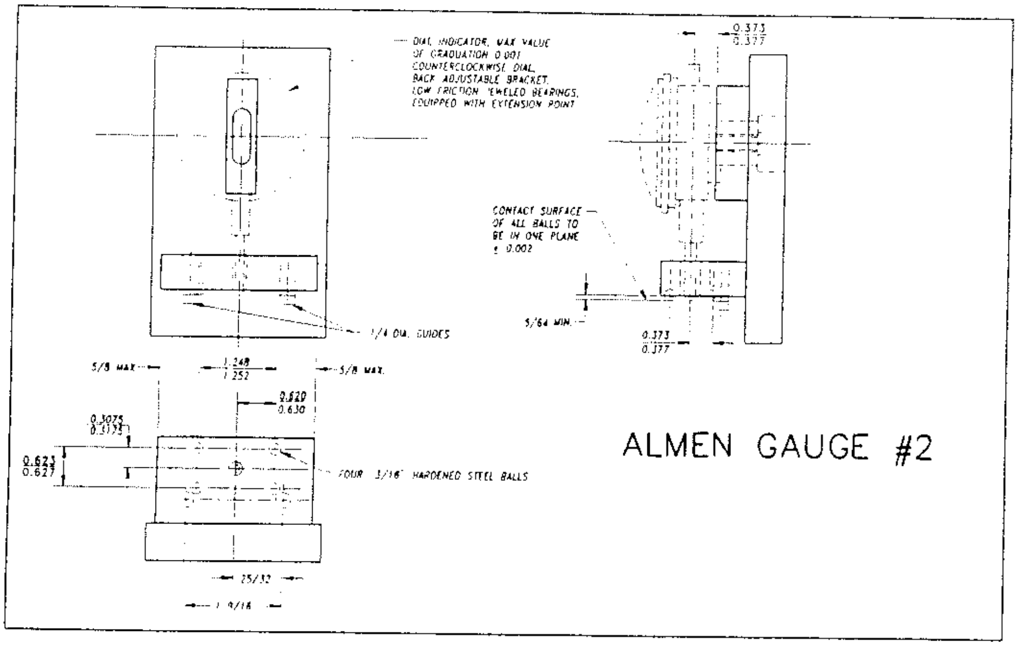



Figure 2. SAE J442 Reference Drawing

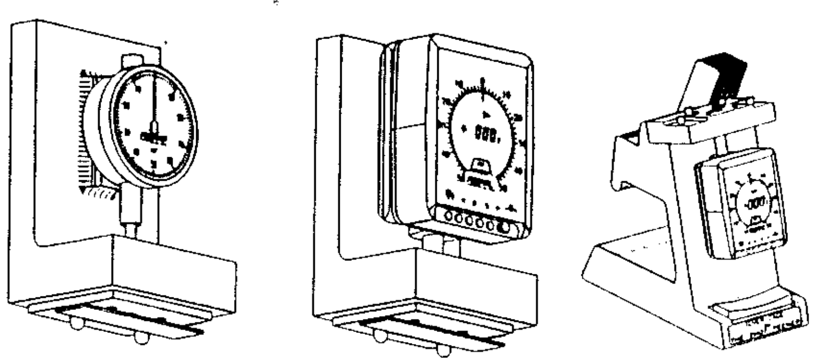
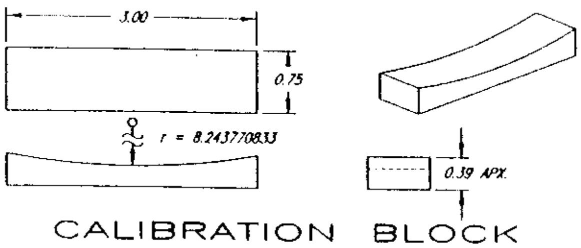


Figure 3. Modern Almen Gages

Calibration Block

A special calibration block was designed to facilitate the investigation of Almen gage accuracy. The block was made by precision grinding to provide a flat surface on one side and a curved surface on the opposite side. The curvature was set to represent the shape of an Almen strip having a deflection of .024". This value was chosen because it is the maximum value expected in usage. For A-strip intensities or arc heights greater than .024" the C-strip is supposed to be used. See Appendix A.




| Arc | Radius |
|---|---|
| 0.005 | 39.15875 |
| 0.010 | 19.63000 |
| 0.015 | 13.12208 |
| 0.020 | 9.86938 |
| 0.025 | 7.91875 |
| 0.030 | 6.61917 |
| 0.035 | 5.69161 |

Figure 4. Calibration Block

Almen Gage Accuracy

Areas of concern regarding Almen gage accuracy are adherence to design (construction) and deterioration of components (maintenance). Unless noted otherwise all measurements refer to the calibration gage block which provides an arc height of .024". Allowable deviation refers to Almen gage construction that does not cause more than .0001" error in measurement. The drawings and dimensions shown in SAE document J442 are used for reference.

Construction

1. Indicator Accuracy
2. Support Ball Placement
3. Support Ball Plane Flatness
4. Indicator Tip Placement
5. Indicator Tip Force

1. Indicator Accuracy

The accuracy of the indicator device is intuitive and doesn't need much comment. There is presently a trend to require resolution of .000l inch when recording arc height measurements. This requirement can best be achieved by digital indicating devices if the measurement range is greater than .020 inch. Mechanical type indicators are not suited for high resolution readings over a large range.

## 2. Support Ball Placement

The tolerance specified for ball placement is +/-.002".

The influence of ball placement was studied by calculating the error due to relocation of the balls along the span-wise axis (3 inch axis). See Appendix B.

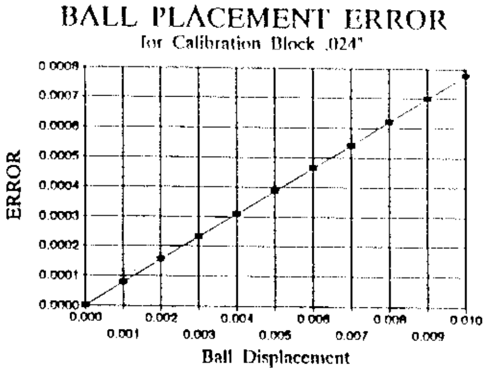



Figure 5. Ball Placement Effects

## 3. Support Ball Plane Flatness

The tolerance specified for ball plane flatness is +/-.002".

One ball was moved to create an offset of .010" at one of the ball contact points. This action caused the flat calibration block to tilt and achieve contact with only three of the four balls. The indicator was zeroed and readings were made with the calibration block tilted in both directions. The tilting action did not change the zero reading.

The reason for this is explained by visualizing a line drawn from the offset support ball to the diagonally opposite ball and with the indicator tip at the midpoint of this line. Tilting the calibration block would allow it to rotate around this line. Since the end points of the line do not change, then the midpoint of the line will not change. Therefore the indicator tip will not change its position and the indicator reading will not change.

Note: The above analysis is valid if, and only if, the indicator tip is not flat. It must act like a point contact on the line of rotation, otherwise the tilting action will show an offset.

Readings of strips peened to arc height deflections of .005,.010, .015, .020, and .025 were made with a standard specification ball plane flatness of .002" and repeated with one ball offset .010". The readings taken with the offset were not different than the standard set-up. We therefore concluded that ball plane flatness specification was not a critical factor in Almen gage accuracy.

4. Indicator Tip Placement

The tolerance specified for placement of the indicator tip is +/-.005".

The influence of indicator tip placement was studied by calculating the error due to tip displacement (no rotation). See Appendix C.

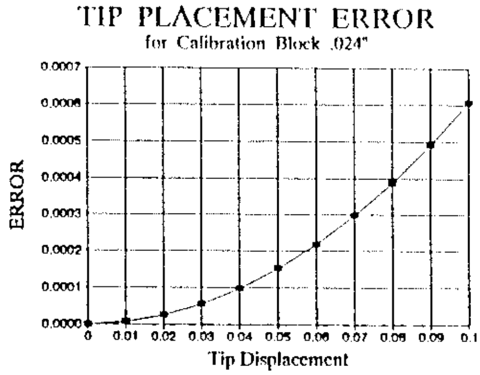



Figure 6. Indicator Tip Placement Effects

5. Indicator Tip Force

The extension force of the indicator tip will tend to bend the strip and might change the reading. A survey of several commercial indicators, both mechanical and digital electronic, showed the following extension tip force:

| | Type | Force |
|---|---|---|
| (1) | mechanical | 75 grams |
| (2) | mechanical | 45 grams |
| (3) | digital | 93 grams |
| (4) | digital | 155 grams |
| (5) | digital | 20 grams |

The extension force necessary to deflect various types of strips by 0.0001" is shown below:

| Strip | Force |
|---|---|
| 'A' | 300 grams |
| 'N' | 50 grams |

These values were obtained by using a commercial force gage and first measuring the indicator tip force and recording this value for reference. Next, the force gage was placed against the Almen strip directly opposite the indicator tip. The force exerted on the strip was increased until the indicator showed .0001" deflection. The value shown in the table is the exertion force minus the indicator reference force for a net value.

Maintenance

Component deterioration includes indicator tip wear and ball wear.

1. Indicator Tip Wear

The tolerance for indicator tip wear is not specified.

As the indicator stem becomes flat, the indicator is not allowed to drop its full distance prior to contacting the curved strip. This gives an under-size reading.

The indicator tip radius is not specified. A survey of several Almen gages indicates that various sizes are in use, with the most common size being .125" radius. Since the equivalent radius of a strip peened to .024" arc height is over 8", then just about any tip radius would be acceptable. This would hold true as long as the tip is not worn flat. See Appendix D.

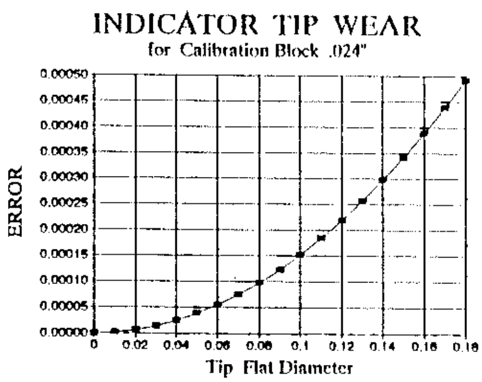



Figure 7. Indicator Tip Wear Effects

2. Ball Wear

Ball wear introduces a complex error on Almen gage accuracy. The contact point for a flat strip is at the bottom of the ball. As strip curvature increases the contact points shift, following the curvature of the ball. As the balls wear flat, the effective ball contact points for a curved strip increase their chord length. This motion effectively allows the strip to drop and gives a high reading. The degree of error depends upon the flatness of the balls and also the curvature of the strip. See Appendix E.

The following graph was generated using Almen strips of various arc heights which were positioned on balls having various degrees of flatness.

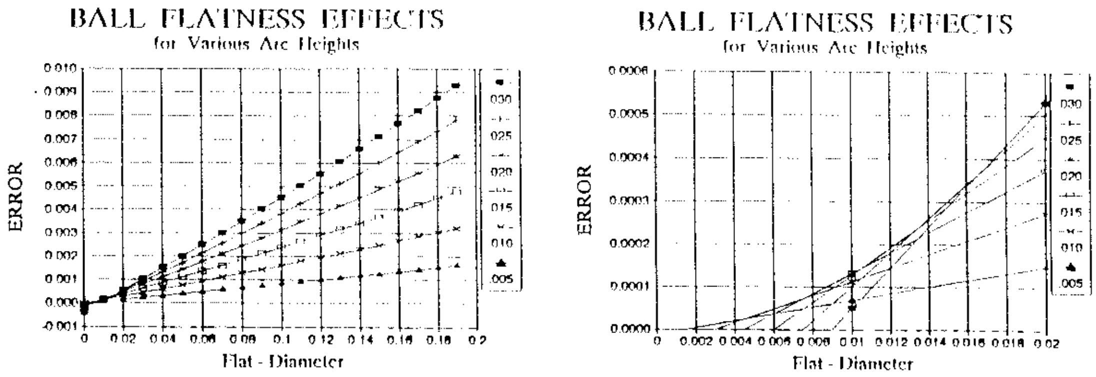



Figure 8. Ball Wear Effects

## Summary - Almen Gage Accuracy

| Attribute | Specification | Allowable* | Figure |
|---|---|---|---|
| Ball Placement | +/-.002 | +/-.0013 | 7 |
| Ball Plane Flatness | +/-.002 | N/A | - |
| Tip Placement | +/-.005 | +/-.041 | 8 |
| Tip Force | None | 50 grams | - |
| Tip Wear | None | .081" dia | 9 |
| Ball Wear | None | .009" dia | 10 |

* Allowable tolerance with .0001 indicated error

## Almen Gage Repeatability and Reproducibility

Suppose your shot peening specification calls for an intensity range of 14 to 16A (.014-.016A). How much of this range (tolerance) is consumed by Almen gage errors or variations in readings? Greater than 30% variation is generally unacceptable and you must either increase the tolerance or improve your gage. Less than 10% variation is considered desirable.

Almen gage **repeatability** is the variation in measurements obtained with one gage when used several times by one operator while measuring one set of parts.

Almen gage **reproducibility** is the variation in the average of the measurements made by different operators using the same gage when measuring one set of parts.

A standard industrial practice for evaluating gages provides a means of showing equipment variation (EV), appraiser variation (AV) and their combined effects known as repeatability and reproducibility (R&R).

Procedure:

Select an individual to administer the test. The administrator selects 10 pre-peened Almen strips. These should be representative of a particular peening machine or process. However, any collection of strips will suffice, but the curvatures should be restricted to a range of .005 to help prevent the operator from memorizing the readings and introducing bias. The strips are then individually identified and numbered one through ten.

The administrator presents one strip at a time (in a random sequence) to the appraiser for measurement being careful not to disclose to the appraiser which strip is being measured. The appraiser measures the strip and tells the administrator the value. The administrator records the value, being careful not to let the appraiser see the record. This procedure prevents operator bias. After all ten strips are measured, a second appraiser repeats the process.

When all three appraisers have measured the strips, the strips are then randomly re-ordered and the first appraiser again measures each of the ten strips. This process is repeated until each appraiser has completed three trials each.

The data collected provides insightful information. Evaluation of range errors from each appraiser can identify "good" or "bad" appraiser performance (repeatability). Evaluation of average values from one appraiser to the next can disclose another type of bias (reproducibility).

Typical data collection is shown in Figure 9.

| | A-> | | | | B-> | | | | | C-> | | | | | Parts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | Range | 1 | 2 | 3 | Range | | 1 | 2 | 3 | Range | | Xp |
| 1 | 0.0080 | 0.0080 | 0.0080 | | 0.0070 | 0.0080 | 0.0080 | 0.0010 | 1 | 0.0080 | 0.0075 | 0.0080 | 0.0005 | 1 | 0.0078 |
| 2 | 0.0070 | 0.0060 | 0.0065 | 0.0010 | 0.0060 | 0.0060 | 0.0065 | 0.0005 | 2 | 0.0065 | 0.0065 | 0.0065 | | 2 | 0.0064 |
| 3 | 0.0070 | 0.0070 | 0.0070 | | 0.0070 | 0.0070 | 0.0070 | | 3 | 0.0070 | 0.0070 | 0.0070 | | 3 | 0.0070 |
| 4 | 0.0065 | 0.0080 | 0.0070 | 0.0015 | 0.0070 | 0.0070 | 0.0070 | | 4 | 0.0075 | 0.0075 | 0.0075 | | 4 | 0.0072 |
| 5 | 0.0080 | 0.0080 | 0.0080 | | 0.0080 | 0.0070 | 0.0080 | 0.0010 | 5 | 0.0080 | 0.0080 | 0.0080 | | 5 | 0.0079 |
| 6 | 0.0050 | 0.0060 | 0.0065 | 0.0015 | 0.0065 | 0.0070 | 0.0070 | 0.0005 | 6 | 0.0065 | 0.0065 | 0.0060 | 0.0005 | 6 | 0.0063 |
| 7 | 0.0085 | 0.0090 | 0.0090 | 0.0005 | 0.0080 | 0.0085 | 0.0075 | 0.0010 | 7 | 0.0085 | 0.0090 | 0.0085 | 0.0005 | 7 | 0.0085 |
| 8 | 0.0060 | 0.0070 | 0.0075 | 0.0015 | 0.0060 | 0.0070 | 0.0070 | 0.0010 | 8 | 0.0075 | 0.0070 | 0.0075 | 0.0005 | 8 | 0.0069 |
| 9 | 0.0080 | 0.0080 | 0.0080 | | 0.0075 | 0.0075 | 0.0075 | | 9 | 0.0075 | 0.0075 | 0.0075 | | 9 | 0.0077 |
| 10 | 0.0090 | 0.0090 | 0.0090 | | 0.0090 | 0.0090 | 0.0090 | | 10 | 0.0090 | 0.0090 | 0.0090 | | 10 | 0.0090 |
| | | | | | | | | | | | | | | Rp | 0.0027 |
| | Ra 0.00060 | | | | Rb 0.00050 | | | | | Rc 0.00020 | | | R = | | 0.00043 |

Figure 9. Data Collection

The formulas in Appendix F and G will calculate the appraiser variation (AV) and the equipment variation (EV). Lower numbers are better, since this represents variations in measurement. These numbers are presented separately to allow remedial action in either (or both) areas. To get an overall performance index (R & R) the results are combined and shown in Appendix H.

It is important to note that when gage R&R is stated as a percentage, then the basis for comparison needs to be stated. Table 3 shows a table of percentages based upon three of the more prominent shot peening intensity tolerances, namely +/-.001, +/-.002, and +/-.005 for tolerance ranges of .002, .004, and .010.

| | | | +/- .001 | +/- .002 | +/- .005 |
|---|---|---|---|---|---|
| *If the (total) Peening Tolerance = --->* | | | *0.002* | *0.004* | *0.010* |
| ***Equipment Variation*** | *EV=* | ***0.001322*** | ***66.1%*** | ***33.0%*** | ***13.2%*** |
| ***Appraisor Variation*** | *AV=* | ***0.000533*** | ***26.6%*** | ***13.3%*** | ***5.3%*** |
| ***Repeatability and Reproducibility*** | ***R&R=*** | ***0.001425*** | ***71.3%*** | ***35.6%*** | ***14.3%*** |

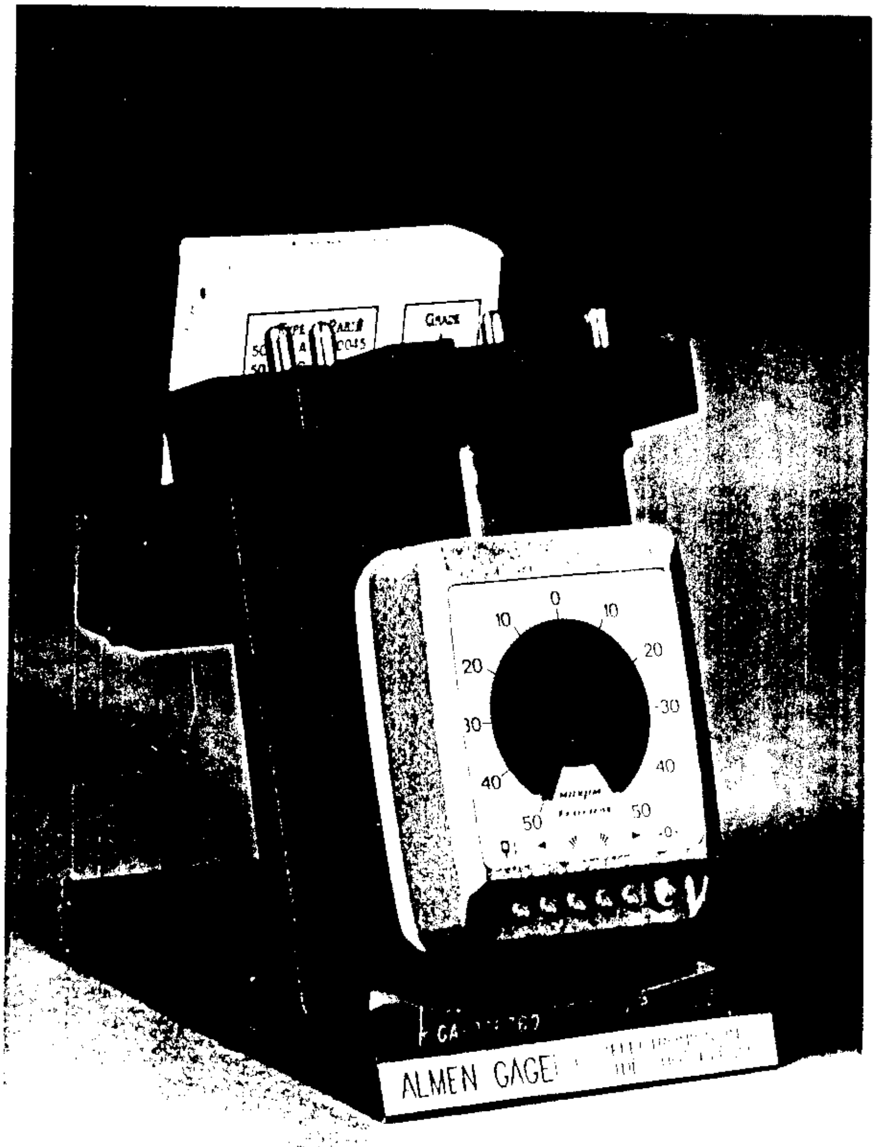
Figure 10. Table of Percentages

From the table in Figure 10 you can see that the performance level of the Almen gage must be appropriate for the specified peening tolerance. If, for example, your peening process requires a range of .002 or 14A -16A intensity, then to have gage variations consume 10% or less of the tolerance, the gage must have a R&R rating of .0002. If you find that your gage R&R is greater than .0006, then you are contributing over 30% variation to the measuring process.

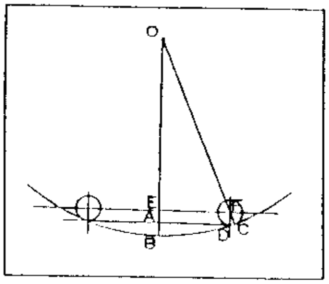
If you want to keep your process under control and accurately report the peening intensity, then you must insure that your Almen gage doesn't contribute substantial (more than 10%) variation to the measurement process.

## Conclusion

Almen gage accuracy depends on its construction and maintenance. The manufacturer's certification should be carefully checked for new and refurbished gages. Intermediate checking can be performed with a precision calibration block. The use of a special design calibration block will check multiple aspects of the Almen gage for accuracy. Periodic Almen gage studies should be performed to assure continued accuracy.



## APPENDIX A. *CALIBRATION BLOCK RADIUS*

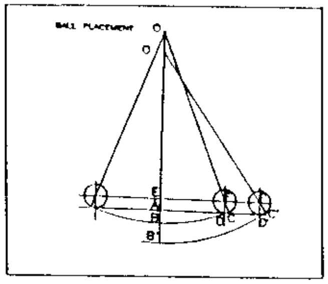


Given: EF = .625
EA = .09375
AB = Arc Height

Find r = OB = radius

1. $r = OB = OC$ But $OC = OA + AB$
2. $OB = OF + FC$
3. $OB = OF + FD$ But $FD = EA$
4. $OB = OF + EA$
5. $OB = OE + EA + AB$
6. $OF + EA = OE + EA + AB$ [From 4]
7. $OF = OE + AB$
8. $OE = OF - AB$
9. $(OF)^2 = (OE)^2 + (EF)^2$
10. $(OF)^2 = (OF - AB)^2 + (EF)^2$ [From 8]
11. $(OF)^2 = (OF)^2 - 2 \cdot (OF) \cdot (AB) + (AB)^2 + (EF)^2$
12. $2 \cdot (OF) \cdot (AB) = (AB)^2 + (EF)^2$
13. $OF = \dfrac{(AB)^2 + (EF)^2}{2 \cdot AB}$
14. $OB = OF + EA$
15. THEN $OB = \dfrac{(AB)^2 + (EF)^2}{2 \cdot AB} + EA$

## APPENDIX B. *BALL PLACEMENT*



Move Ball From F to F'

Given: EA = Ball Radius = .09375
AB = Arc Height = .024
EF = Ball Span = .625
r = OB = 8.243770833

Error = BB'

$r = OB = OC = O'B' = O'C'$

$OC = OF + FC$
$OC = OF + FD$
$OC = OF + EA$

$OF = OC - EA$
Also $OO' + O'E = OE$
$OO' = OE - O'E$ But $OO' = BB'$
Thus $BB' = OE - O'E$

$(OF)^2 = (OE)^2 + (EF)^2$
$(OF)^2 = (OO' + O'E)^2 + (EF)^2$
$(OF)^2 = (BB' + O'E)^2 + (EF)^2$
$(BB' + O'E)^2 = (OF)^2 - (EF)^2$

$BB' + O'E = \sqrt{(OF)^2 - (EF)^2}$

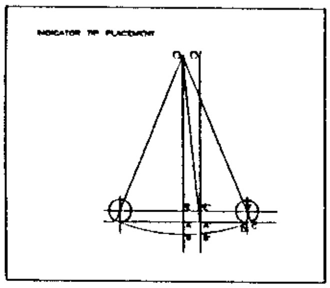
$BB' = \sqrt{(OF)^2 - (EF)^2} - O'E$

Also $(O'E)^2 + (EF + FF')^2 = (O'F')^2$
$(O'E) = \sqrt{(O'F')^2 - (EF + FF')^2}$

$BB' = \sqrt{(OF)^2 - (EF)^2} - \sqrt{(O'F')^2 - (EF + FF')^2}$

$BB' = \sqrt{(OC - EA)^2 - (EF)^2} - \sqrt{(OC - EA)^2 - (EF + FF')^2}$

## APPENDIX C. *INDICATOR TIP PLACEMENT*



Move Indicator From OB to O'B'
Original Arc = AB
Find New Arc = A'B'

Given: EA = Ball Radius = .09375
AB = Arc Height = .024
EF = Ball Span = .625
r = OB = O'B' = OB'
r = 8.24370833"

Find Error = OB - O'B'

$(OB')^2 = (OO')^2 + (O'B')^2$

$(O'B')^2 = (OB')^2 - (OO')^2$

$O'B' = \sqrt{(OB')^2 - (OO')^2}$

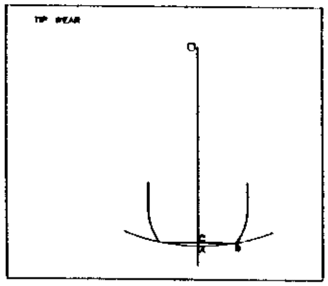
Error $= OB - O'B'$

$= OB - \sqrt{(OB')^2 - (OO')^2}$

Sub $r = OB = OB'$

Error $= r - \sqrt{r^2 - (OO')}$

## APPENDIX D. *INDICATOR TIP WEAR*



Flatten The Indicator Tip
To Form C-B

Error = AC = OA - OC

Let r = OB = OA

$(OB)^2 = (OC)^2 + (CB)^2$

$(OC)^2 = (OB)^2 - (CB)^2$

$OC = \sqrt{(OB)^2 - (CB)^2}$

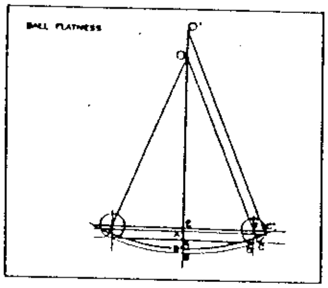
Error $= OA - OC$

$= r - OC$

Error $= r - \sqrt{(OB)^2 - (CB)^2}$

Error $= r - \sqrt{r^2 - (CB)^2}$

## APPENDIX E. *BALL FLATNESS*




Given: EF = .625
EA = .09375
AB = .024

Flat= Circle Diameter Caused By Wear on Ball Bottom

Let Error=A'B' - A B

$$A'C' = AD + \frac{FLAT}{2} = EF + \frac{FLAT}{2}$$

$r = OB = OC = OE + EA + AB =$ radius
$r = O'B' = O'C' = O'E + EA' + A'B' =$ radius
$A'B' = r - (O'E + EA')$
Also $(O'E + EA')^2 + (A'C')^2 = r^2$ Let $X = O'E + EA'$

$$X^2 + (A'C')^2 = r^2$$
$$X = \sqrt{r^2 - (A'C')^2}$$
$$A'B' = r - x$$
$$A'B' = r - \sqrt{r^2 - (A'C')^2} \qquad \text{But } A'C' = EF + \frac{FLAT}{2}$$
$$A'B' = r - \sqrt{r^2 - (EF + \frac{FLAT}{2})^2}$$

And Error $= A'B' - AB$

$$\text{Error} = r - \sqrt{r^2 - EF + \frac{FLAT}{2}} - AB$$

Valid For $A'C' > AC$

## APPENDIX F. *APPRAISOR VARIATION*

$XDIFF = \max \bar{x} - \min \bar{x}$
$XDIFF = .00756 - .00735$
$XDIFF = .00021$

$$AV = \sqrt{(XDIFF \times 2.70)^2 - (EV^2/nr)}$$
$$AV = \sqrt{(.000210 \times 2.70)^2 - (.001322^2/30)}$$
$$AV = \sqrt{(3.266 \times 10^{-7}) - (5.8227 \times 10^{-8})}$$
$$AV = \sqrt{2.6839 \times 10^{-7}}$$
$$AV = 5.1806 \times 10^{-4}$$
$$AV = .000518$$

## APPENDIX G. *EQUIPMENT VARIATION*

$$\bar{R} = \frac{(Ra + Rb + Rc)}{3} = \frac{(.00060 + .00050 + .00020)}{3} = .00043$$

$EV = \bar{R} \times 3.05$
$= .00043 \times 3.05$
$= .001322$

## APPENDIX H. *REPEATABILITY AND REPRODUCIBILITY*

$$R\&R = \sqrt{EV^2 + AV^2}$$
$$R\&R = \sqrt{.00132^2 + .000518^2}$$
$$R\&R = \sqrt{2.0151 \times 10^{-6}}$$
$$R\&R = 1.4196 \times 10^{-3}$$
$$R\&R = .001420$$