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A PORTABLE DIFFERENTIAL BALL GAUGE TO MEASURE THE INTERNAL FLARE ANGLE OF MC146 FLARED TUBING

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NASA

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ABSTRACT

The internal angle of MC 146 Revision D flared tubing is specified as 74° ± $1\frac{1}{2}$°. This angle is critical for correct mating with the male flare fitting. A considerable amount of effort has been expended for quality control purposes to measure this angle by a plaster or plastic cast method. Techniques to measure this angle are usually time consuming and costly.

This document describes a portable, differential ball gauge developed by the Manufacturing Engineering Laboratory to measure the internal flare angle accurately and speedily. The operational theory and pertinent mathematical derivations are included herein to demonstrate the principles of design of the Internal Flare Angle Gauge MR&T-sk-872. Potential error sources are discussed in order to evaluate their theoretical and practical impact on total accuracy. Tables and charts are included to short cut the design time of future ball gauges.

It is concluded that the differential ball gauge concept is a practical shop and inspection instrument which will quickly determine the average internal tube flare angle without waiting or relying heavily on operator judgement.

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MANUFACTURING RESEARCH AND TECHNOLOGY DIVISION
MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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A PORTABLE DIFFERENTIAL BALL GAUGE TO MEASURE THE INTERNAL FLARE ANGLE OF MC146 FLARED TUBING

INTRODUCTION

Separable tube joints have always presented a leakage problem. The sealing of high pressure joints for space work presents a particularly challenging problem because of the potential loss of precious gas during extended missions. For this reason, the Marshall Space Flight Center Design Standard MC 146 (Fig. 1) was created to upgrade the quality of the flared joint to the point that it would contain high pressure gas without leakage. Experience has shown that tube flares conforming to MC 146 would indeed perform the function, but the absence of means to fabricate and inspect the flares consistently to this stringent specification was very much in evidence. One of the more perplexing problems has been that of measuring the $74 \pm 1\frac{1}{2}$-degree internal angle of the flare. The only certified method at MSFC to date has been to make a plaster or plastic cast of the internal flare and inspect this cast on an optical comparator. For several reasons this method of inspection is not totally satisfactory:

1. It requires that the tube be vertical to make the mold.

2. It contaminates the flare, and clean flight hardware cannot be tested by this method.

3. It is time consuming and very impractical for calibrating or certifying a flaring machine setup when rapid measurements are desirable. At least $\frac{1}{2}$ to 3 hours time is required for a plastic mold to set before it can be inspected on an optical comparator.

4. Tubing installed on a flight vehicle cannot be inspected for the internal angle conformance.

One method proposed by elements of Quality Assurance Laboratory was to use precision tungsten carbide balls to measure the internal flare angle. This measurement is accomplished by placing a ball into the throat of the flare (Fig. 2) and measuring the distance, S_1, from the ball to an external reference point. A larger ball is then placed in the flare; the distance, S_2, is measured to the

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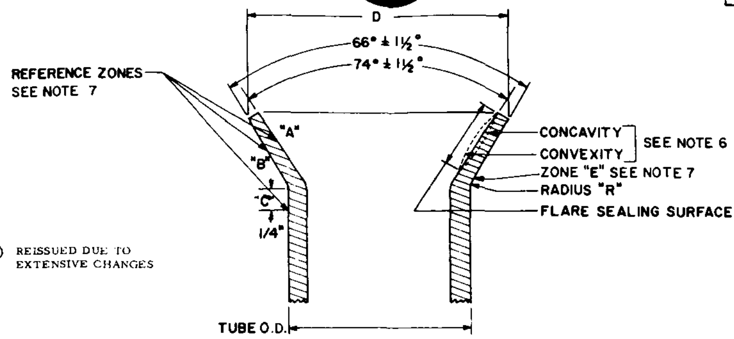
NONE



Ⓓ REISSUED DUE TO EXTENSIVE CHANGES

SECTION VIEW

TUBE O. D. NOMINAL	TUBE O. D. MAXIMUM △12	D DIA	D TOL	R RADIUS	R TOL	CONCEN-TRICITY △8	ROUNDNESS △9	THICKNESS CHANGE △10
1/8	.131	.230						
3/16	.194	.295				.0030	.0008	.0002
1/4	.256	.350	±.015	.032	±.010			
5/16	.319	.410						
3/8	.381	.475		.046		.0034	.001	.0003
1/2	.506	.645		.062	+.015			
5/8	.633	.760	±.020		-.010	.004	.0012	.0005
3/4	.756	.930		.078				
1	1.008	1.180		.093				
1 1/4	1.260	1.485						
1 1/2	1.510	1.720	±.030					
1 3/4	1.760	2.070			+.020	.005	.0015	.0007
2	2.010	2.335	±.040	.109	-.010			
2 1/2	2.512	2.840				.007	.002	.0015
3	3.016	3.320						

SIZES 1 1/4 THRU 3 ARE INACTIVE FOR NEW DESIGN AFTER 9-1-64

NOTES:

1. THIS DESIGN STANDARD ESTABLISHES THE REQUIREMENTS FOR THE GEOMETRIC CONFIGURATION OF FLARED TUBE ENDS, DESIGNED FOR USE WITH MC AND MF FLARED TUBE CONNECTORS.
2. THE FLARE SHALL BE FREE OF BURRS, SHARP EDGES, CHATTER MARKS, TOOL MARKS, EXCESSIVE OXIDES, FOREIGN MATERIAL, METALLIC FLAKES, AND SCRATCHES THAT FORM A LEAK PATH.
3. THERE SHALL BE NO PROTRUSION OF METAL BEYOND THE INTERSECTION OF THE TUBE I. D. AND THE FLARE SEALING SURFACE.
4. THE ROUGHNESS OF THE EXTERNAL ANGLE SURFACE IN BOTH RADIAL AND TANGENTIAL DIRECTIONS SHALL NOT EXCEED 63 CLA.
5. THE ROUGHNESS OF THE FLARE SEALING SURFACE, IN BOTH RADIAL AND TANGENTIAL DIRECTIONS, SHALL NOT EXCEED 16 CLA FOR ALUMINUM OR 10 CLA FOR ANY OTHER MATERIAL.
6. THE FLARE SEALING SURFACE PROFILE SHALL NOT EXHIBIT CONCAVITY; HOWEVER, IT MAY HAVE A CONVEX CONFIGURATION NOT TO EXCEED .001
7. REFERENCE ZONES FOR DETERMINING CONCENTRICITY, ROUNDNESS AND THICKNESS CHARACTERISTICS (SEE SKETCH):
   ZONE "A" IS THE APPROXIMATE MIDPOINT OF THE FLARE SEALING SURFACE;
   ZONE "B" IS THE APPROXIMATE MIDPOINT OF THE EXTERNAL ANGLE SURFACE;
   ZONE "C" IS APPROXIMATELY 1/4" FROM THE LINE OF TANGENCY OF THE EXTERNAL RADIUS "R" AND THE TUBE O. D.
   ZONE "E" IS ON THE EXTERNAL ANGLE SURFACE, APPROXIMATELY AT THE LINE OF TANGENCY WITH THE EXTERNAL RADIUS "R"
8. THE FLARE SEALING SURFACE (ZONE "A") AND THE TUBE O. D. (ZONE "C") SHALL BE CONCENTRIC WITHIN THE VALUES LISTED IN THE TABLE.
9. THE FLARE SEALING SURFACE (ZONE "A") SHALL BE ROUND, AS CHECKED ON THE RADIUS, WITHIN THE VALUES LISTED IN THE TABLE. THE CHANGE OF ROUNDNESS WITHIN ANY 30° OF ARC SHALL NOT EXCEED .0004.
10. THE CHANGE OF THICKNESS, MEASURED BETWEEN THE EXTERNAL SURFACE (ZONE "B") AND THE FLARE SEALING SURFACE (ZONE "A"), AS CHECKED ON THE RADIUS OF THE FLARE SEALING SURFACE, SHALL NOT EXCEED THE VALUES LISTED IN THE TABLE IN ANY 30° OF ARC.
11. THE FLARE THICKNESS IN ZONE "E" SHALL NOT BE LESS THAN 70% OF THE NOMINAL WALL THICKNESS FOR ALUMINUM AND NOT LESS THAN 80% FOR ALL OTHER MATERIALS.
12. THE MAXIMUM DIAMETER OF THE TUBE MEASURED APPROXIMATELY AT THE LINE OF TANGENCY WITH RADIUS "R", SHALL NOT EXCEED THE VALUES LISTED IN THE TABLE.
13. DIMENSIONS ARE IN INCHES.
14. THIS DESIGN STANDARD IS NOT TO BE USED AS A PART NUMBER.

APPROVED 1 JUN 61

REVISED Ⓐ 26 JUL 61 Ⓑ 7 MAR 63 Ⓒ 14 AUG 64 Ⓓ 13 JUN 66

CUSTODIAN	GEORGE C. MARSHALL SPACE FLIGHT CENTER Huntsville, Alabama	
PROCUREMENT SPECIFICATION NONE	TITLE TUBING END, FLARED, STANDARD DIMENSIONS FOR	DESIGN STANDARD MC146
COORDINATION STATUS MSFC ☒		SHEET 1 OF 1

MSFC - Form 1534-1 (May 1963) (OT)

FIGURE 1. MARSHALL TUBE FLARE SPECIFICATION MC 146

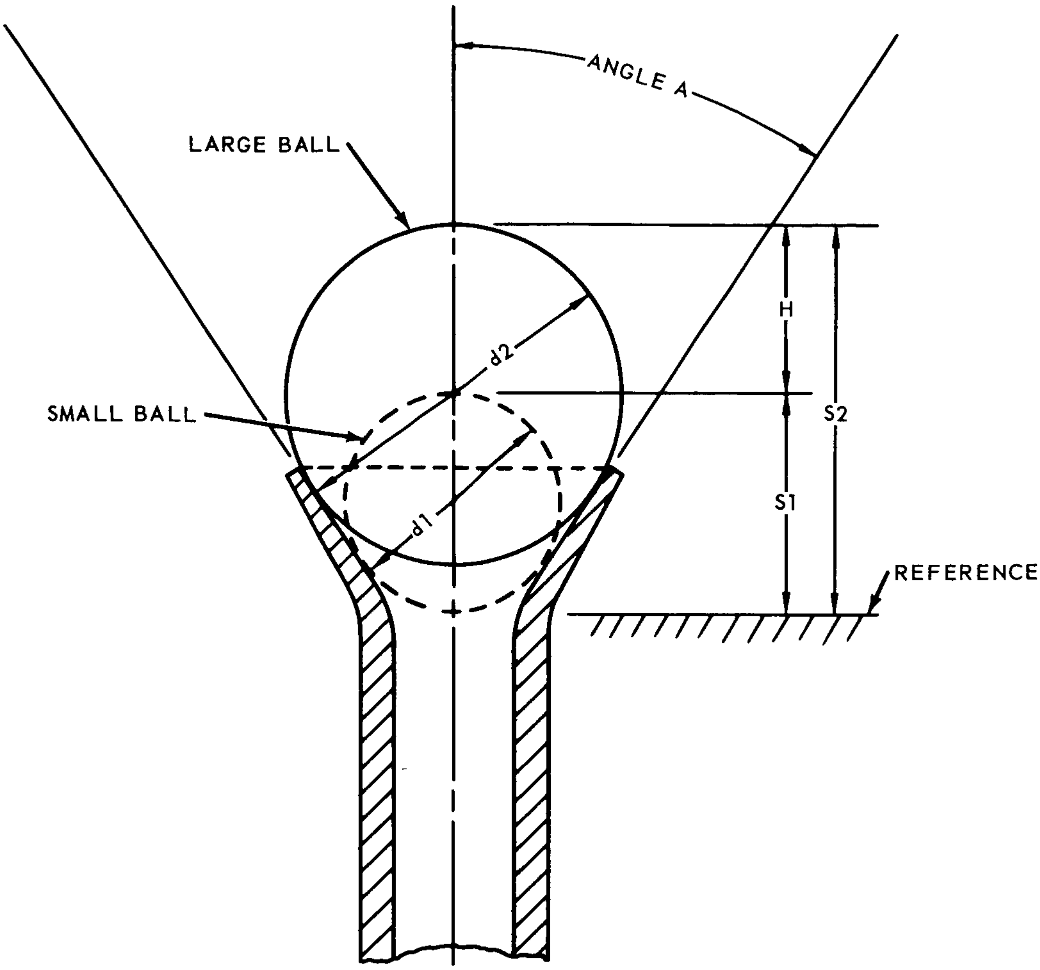


FIGURE 2. PRECISION BALL METHOD OF DETERMINING THE INTERNAL FLARE ANGLE

same reference point. The difference in distances (S_1-S_2) to the reference point, H, and the difference in diameters of the two balls d_1 and d_2 determine the average slope of the joint between the points of ball contact. Of course, precision is a function of the knowledge of the exact dimensions of the spheres and distances S_1 and S_2. In this case the required angle A can be determined by the following formula:[1]

$$\text{Cosec } \frac{A}{2} = \frac{2H}{d_2 - d_1} - 1$$

[1] Solving Gaging Problems with Master Balls, Industrial Tektronics, Inc., Technical Bulletin B-41, page 4.

This reporting activity was requested to design and develop a small, lightweight gauge which would utilize the ball gauge concept for measuring the tube flare internal angle. To minimize mistakes and to render the handling of the precision tungsten carbide balls easier, the decision was made to attach the spheres to either end of a stem which is properly marked to identify the correct tube size and readout table. Figure 3 pictures the finished gauge. Utilization of this differential technique vastly reduces the chances of error since it eliminates the need for gauge blocks, or the like, to make up the distance from a dial indicator to the surface of the sphere. Therefore, only a standard .0001-inch (.0025-millimeter) graduated dial indicator is required for readout. Since the trigonometric formula upon which this differential principle is based differs from the solution of the case illustrated in Figure 2, the following mathematical solution is offered to show how the angular readout formula for the differential ball gauge tables is derived.

FIGURE 3. FLARE ANGLE GAUGE MR& T-sk-872

THEORY OF DIFFERENTIAL BALL GAUGE MEASUREMENT

Figure 4 illustrates the small sphere, in solid line, of a differential ball gauge inserted in a tube flare. It also shows the reverse operation, in dashed line, where the large sphere is in the tube flare. If the small ball is inserted in the tube flare, distance from the point of contact, A, of the ball and flare to the actuator of the gauge is distance AM. Likewise, if the differential gauge is reversed, the distance from A to the gauge actuator now becomes AM_1.

By inspection of Figure 4,

$$AM = r_2 \sin \Theta + S + r_1, \tag{1}$$

and:

$$AM_1 = r_2 \sin \Theta + \frac{(r_1 - r_2)}{\sin \Theta} + S + r_2. \tag{2}$$

The critical dimension which finally determines the flare angle is d.

Again, by inspection of Figure 4,

$$d = AM_1 - AM \ . \tag{3}$$

Substituting Equations (1) and (2) into Equation (3),

$$d = [r_2 \sin \Theta + \frac{(r_1 - r_2)}{\sin \Theta} + S + r_2] - [r_2 \sin \Theta + S + r_1]$$

$$d = r_2 \sin \Theta + \frac{(r_1 - r_2)}{\sin \Theta} + S + r_2 - r_2 \sin \Theta - S - r_1.$$

Cancelling and combining terms, the required mathematical relationship becomes :

$$d = \frac{(r_1 - r_2)}{\sin \Theta} - (r_1 - r_2) . \tag{4}$$

The sample readout table, Table I, was calculated for differential ball gauges where the difference in ball radii is $(r_1 - r_2)$. Distance d is the reading obtained on a dial indicator as explained later.

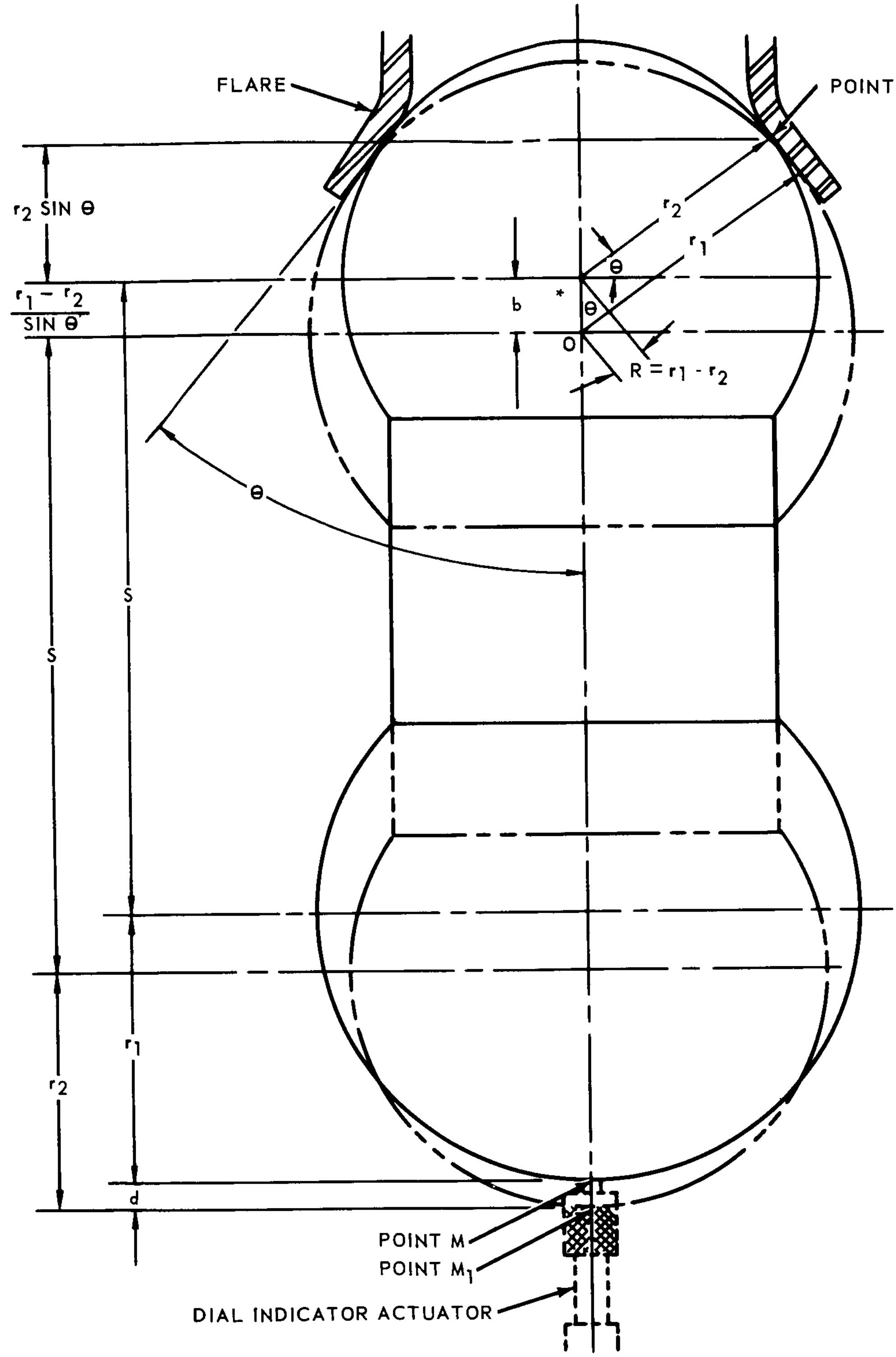


FIGURE 4. DIFFERENTIAL BALL GAUGE PICTORIAL DIAGRAM

TABLE I. SAMPLE READOUT TABLE ($r_1 - r_2 = 0.015625$)

DIAL INDICATOR DIFFERENTIAL READING "d"* IN.	INCLUDED FLARE ANGLE	FLARE ANGLE TO ℄	DIAL INDICATOR DIFFERENTIAL READING "d"* IN.	INCLUDED FLARE ANGLE	FLARE ANGLE TO ℄
.00920	78° - 03'	39° - 01.5'	.01045	73° - 38'	36° - 49'
.00925	77° - 50'	38° - 55'	.01050	73° - 28'	36° - 44'
.00930	77° - 38'	38° - 49'	.01055	73° - 18'	36° - 39'
.00935	77° - 27'	38° - 43.5'	.01060	73° - 08'	36° - 34'
.00940	77° - 16'	38° - 38'	.01065	72° - 59'	36° - 29.5'
.00945	77° - 05'	38° - 32.5'	.01070	72° - 49'	36° - 24.5'
.00950	76° - 55'	38° - 27.5'	.01075	72° - 40'	36° - 20'
.00955	76° - 44'	38° - 22'	.01080	72° - 30'	36° - 15'
.00960	76° - 33'	38° - 16.5'	.01085	72° - 20'	36° - 10'
.00965	76° - 22'	38° - 11'	.01090	72° - 11'	36° - 05.5'
.00970	76° - 12'	38° - 06'	.01095	72° - 11'	36° - 00.5'
.00975	76° - 01'	38° - 00.5'	.01100	71° - 52'	35° - 56'
.00980	75° - 5[illegible]'	37° - 55'	.01105	71° - 43'	35° - 51.5'
.00985	75° - 40'	37° - 50'	.01110	71° - 33'	35° - 46.5'
.00990	75° - 30'	37° - 45'	.01115	71° - 24'	35° - 42'
.00995	75° - 19'	37° - 39.5'	.01120	71° - 15'	35° - 37.5'
.01000	75° - 09'	37° - 34.5'	.01125	71° - 06'	35° - 33'
.01005	74° - 58'	37° - 29'	.01130	70° - 57'	35° - 28.5'
.01010	74° - 48'	37° - 24'	.01135	70° - 48'	35° - 24'
.01015	74° - 38'	37° - 19'	.01140	70° - 38'	35° - 19'
.01020	74° - 28'	37° - 14'	.01145	70° - 30'	35° - 15'
.01025	74° - 18'	37° - 09'	.01150	70° - 21'	35° - 10.5'
.01030	74° - 08'	37° - 04'	.01155	70° - 12'	35° - 06'
.01035	73° - 58'	36° - 59'	.01160	70° - 03'	35° - 01.5'
.01040	73° - 48'	36° - 54'	.01165	69° - 54'	34° - 57'

BALL GAUGE BLOCKS

Configuration

As stated earlier, the differential ball gauge blocks consist of a small tungsten carbide and a larger tungsten carbide ball attached to either end of a metal stem (Fig. 5). Tungsten carbide balls were selected because of their low temperature expansion coefficient, their resistance to corrosion, and their extremely hard 1 micro-inch surface finish. During fabrication, the balls are brazed to an oversize stem and the stem machined for .0005 inch (.013 millimeter) concentricity of the centerline of the stem and the spheres. Each ball gauge is then clearly marked for tube size, wall thickness range, and correct angular readout table.

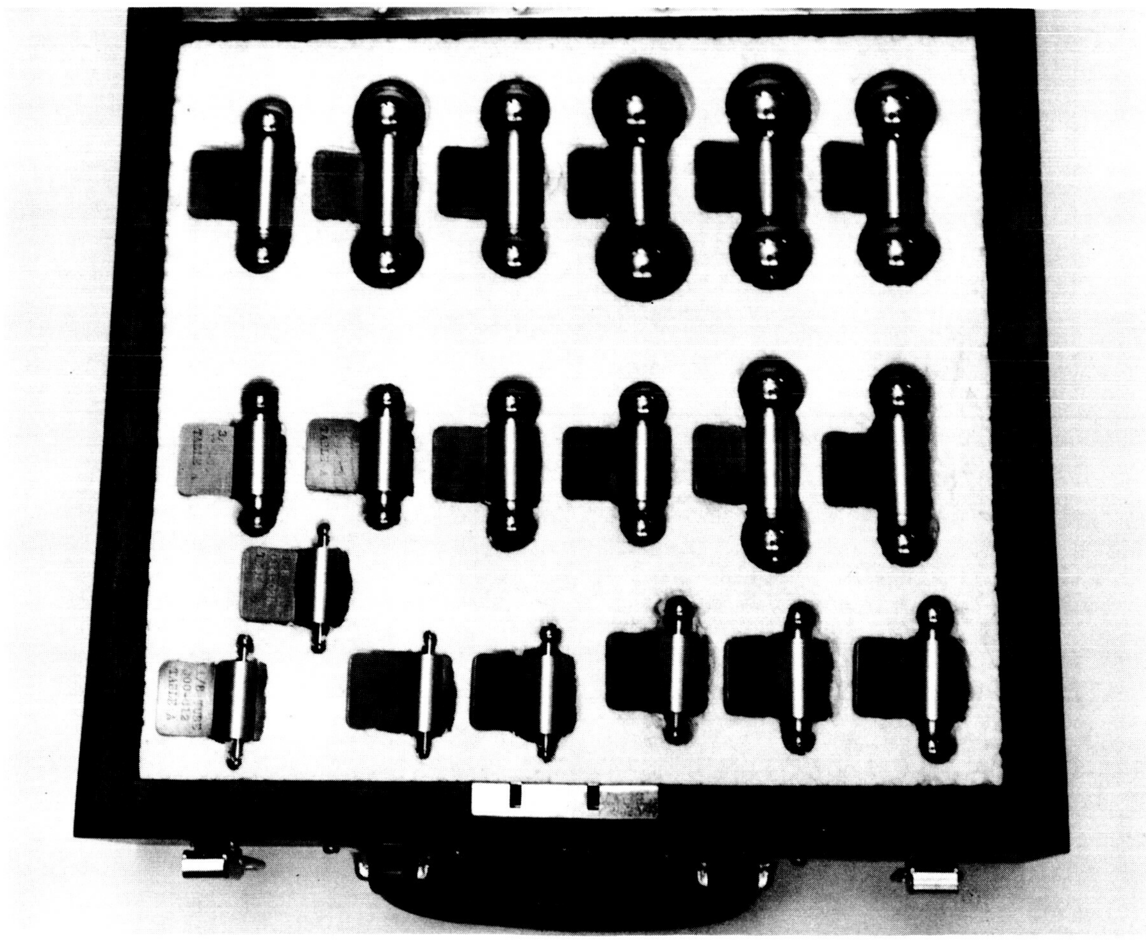


FIGURE 5. MR&T-sk-872 DIFFERENTIAL BALL GAUGE KIT

BALL GAUGE DESIGN CRITERIA

Extreme care must be exercised to ascertain that the spheres will always make contact only with the flat surface of the flare. Since a $\pm$ 10 percent variation is allowable in the tube wall thickness, this fact must be considered when the large and small balls for each gauge are being sized. Originally, large scale drawings were made for a given tube size and a given wall size in order to determine these two diameters. Because of the time consumed and the inherent inaccuracy of this method, a mathematical method to accomplish this task was felt necessary. Simply stated, the problem was to determine a formula for the smallest possible sphere and the largest possible sphere which would fit inside a given flare and at the same time rest only on the sealing surface of the flare. Formulas 9 and 21 of this document determine the required limits. Since variations of the tube wall thickness affect the width of the sealing surface, these formulas are based on tube tolerances found in MSFC Design Standard MC146, and Table III of MSFC-SPEC-131C, Figures 1 and 6 respectively.

OUTSIDE DIAMETER AND WALL THICKNESS TOLERANCES

Nominal dimensions (all wall thicknesses)	Permissible tolerance from specified dimensions		
Outside diameter (inch)	Outside diameter (inch)		Wall thickness range (percent of specified dimension)
	Average	Ovalness	
0 to 0. 5 incl.	+0. 004 -0. 000	0. 002	± 10
Over 0. 5 to 1. 5 incl.	+0. 005 -0. 000	0. 003	± 10
Over 1. 5	+0. 010 -0. 000	0. 005	± 10

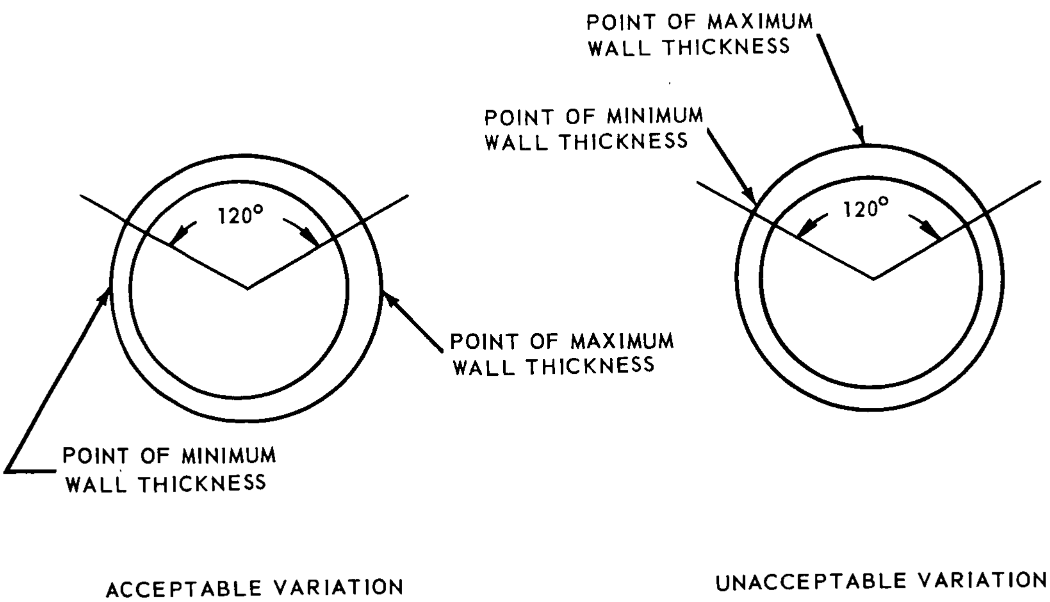


FIGURE 6. POINTS OF MINIMUM AND MAXIMUM TUBING WALL THICKNESS

DERIVATION OF SPHERE SIZES FOR BALL GAUGES

For the derivation of formulas to determine the ball diameters, refer to Figure 7.

Given: Overall diameter, D_0
Wall Thickness, t
Outside flare diameter, D
Arc Radius, R
Angles Θ and a
Segment AB and A'B' = .9t

Note: The term "0.9t" is an average thickness arrived at by a large sampling of MC 146 flares.

$\overline{EF}$ is parallel to $\overline{AB}$

Problem: Derive formulas expressing the diameter of smallest sphere which may be tangent to $\overline{AE}$ and $\overline{A'E'}$ and the diameter of largest sphere which may be tangent to $\overline{AE}$ and $\overline{A'E'}$ using only the given.

Let:

D_1 = throat diameter AA'	D_x = length of $\overline{EF}$
D_2 = length of FG or F'G'	D_L = length of $\overline{FB}$
D_3 = mouth diameter $\overline{EE'}$	D_s = length of $\overline{A'Q'}$
D_4 = length of BB'	D_r = length of $\overline{B'Q'}$

Determination of D_{min}

D_{min} = diameter of smallest sphere which may be tangent to $\overline{AE}$ and $\overline{A'E'}$.
Since acute angles whose corresponding sides are mutually perpendicular are equal,

Angle HAA' = SEE' = angle Θ;

Angle EFG = BCD = angle a;

$$D_{min} = D_1 \sec \Theta . \tag{5}$$

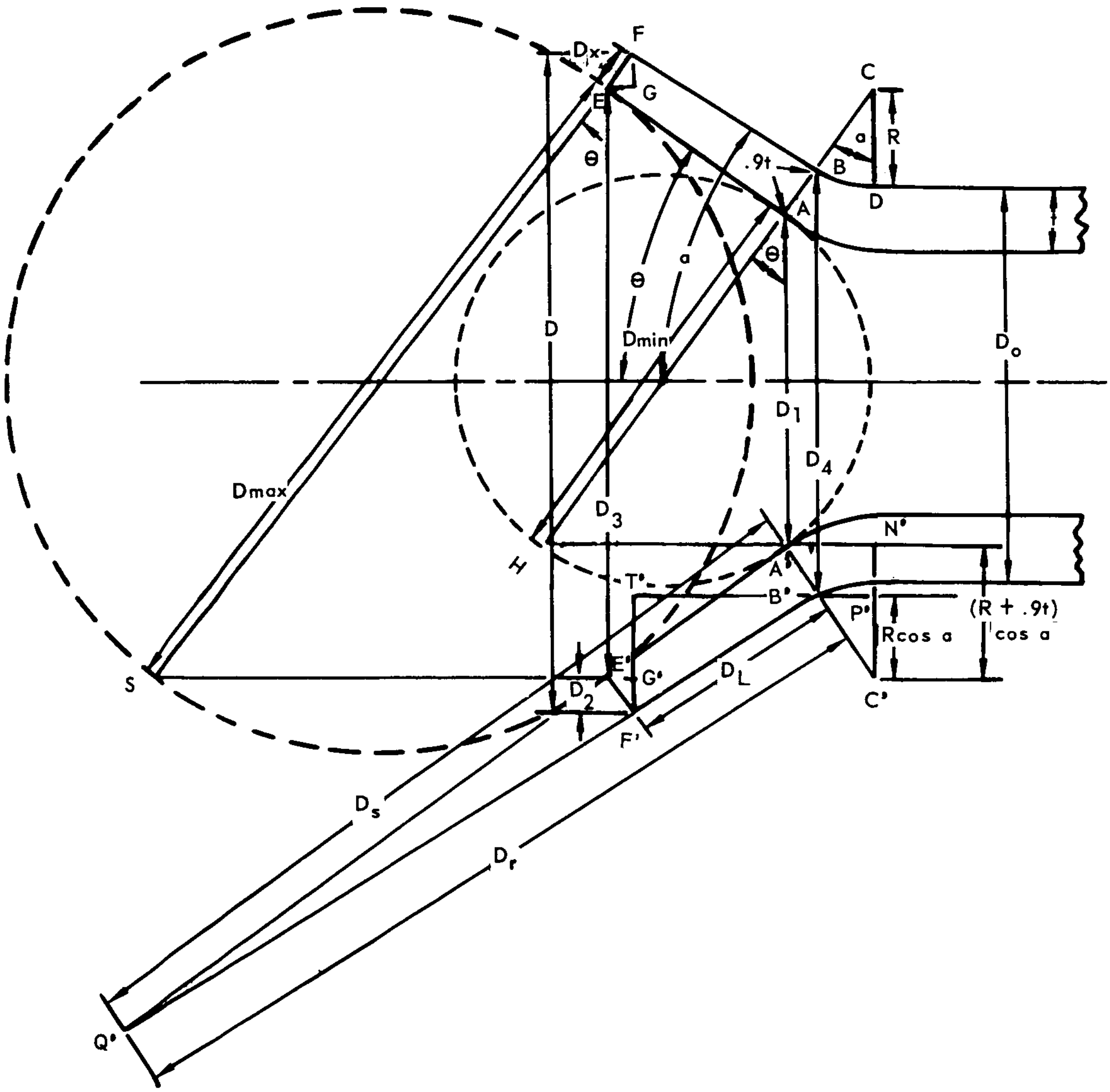


FIGURE 7. GEOMETRIC RELATIONSHIPS OF THE INTERNAL FLARE ANGLE

By inspection,

$$D_1 = D_0 + 2R - 2C'N' \tag{6}$$

but $\quad C'N' = (R + .9T) \cos a.$ (7)

Substituting the right side of (7) into (6), we find:

$$D_1 = D_0 + 2R - 2(R + .9T) \operatorname{Cos} a. \tag{8}$$

Substituting the right side of (8) into (5), we find:

$$D_{min} = [D_0 + 2R - 2(R + .9T) \operatorname{Cos} a] \sec \Theta. \tag{9}$$

Determination of D_{max}

D_{max} = diameter of largest sphere which may be tangent to AE and $\overline{A'E'}$.

By inspection,

$$D_4 = D_0 + 2R - 2C'P' \tag{10}$$

But $\quad C'P' = R \operatorname{Cos} a.$ (11)

Substituting the right side of (11) into (10), we find:

$$D_4 = D_0 + 2R - 2R \operatorname{Cos} a = D_0 + 2R (1 - \operatorname{Cos} a). \tag{12}$$

In triangle B'T'F,

$$\sin a = \left(\frac{\frac{D - D_4}{2}}{D_L} \right) ;$$

therefore,

$$D_L = \frac{D - D_4}{2 \sin a} . \tag{13}$$

By inspection,

Angle B'Q'A' = $(\Theta - a)$

$$D_s = \frac{.9t}{\sin(\Theta - a)} \tag{14}$$

$$D_r = D_s \cos(\Theta - a) \,. \tag{15}$$

Substituting the right half of (14) into (15), we have

$$D_r = .9t \cot(\Theta - a) \,. \tag{16}$$

Since corresponding parts of similar triangles are proportional, in triangles B'Q'A' and F'Q'E',

$$\frac{D_x}{.9t} = \frac{D_r - D_L}{D_r}$$

$$D_x = \frac{.9t(D_r - D_L)}{D_r} \tag{17}$$

$$D_2 = D_x \cos a \tag{18}$$

$$D_3 = D - 2\,D_2 \tag{19}$$

$$D_{max} = D_3 \sec \Theta \,. \tag{20}$$

A solution is derived by assimilating the equations as follows:

1. Substitute the right half of (16) and (13) into (17);
2. Substitute the right half of (17) into (18);
3. Substitute the right half of (18) into (19);
4. Substitute the right half of (19) into (20).

The equation derived is:

$$D_{max} = \sec \Theta \left\{ D - 2(\cos a) \left[.9t \left(\frac{.9t \cot(\Theta - a) - \dfrac{D - D_0 - 2R(1 - \cos a)}{2 \sin a}}{.9t \cot(\Theta - a)} \right) \right] \right\} \,. \tag{21}$$

It can now be shown that D_{min} formula (9) and D_{max} formula (21) are straight line formulas; thus a simplified graphical solution is possible.

SIMPLIFIED GRAPHICAL SOLUTION FOR BALL GAUGES

If wall thickness t and D_{min} (or D_{max}) are used as coordinates in a rectangular system, a straight line graph is formed. Thus, for any given tube size, it is possible to determine D_{min} (or D_{max}) for any given wall size t without the solving formulas (9) and (21).

MATHEMATICAL EXPLANATION OF GRAPHICAL SOLUTION

From Equation (9): $D_{min} = \sec \Theta \; [\; D_0 + 2R - 2\;(R + .9t)\;(\cos a)\;]$.

D_0, R, sec Θ and cos a are all constants for any one given tube size, and t is the only variable. This equation may be rearranged in the following manner:

$$D_{min} = \sec \Theta \;\; [D_0 + 2R - 2\;(R + .9t)\;\cos a\;]$$

$$D_{min} = \sec \Theta \;\; [D_0 + 2R - 2R \cos a - 1.8t \cos a\;]$$

$$D_{min} = D_0 \sec \Theta + 2R \sec \Theta - 2R \cos a \sec \Theta - 1.8t \cos a \sec \Theta$$

$$D_{min} = (-1.8 \cos a \sec \Theta)\, t + (D_0 \sec \Theta + 2R \sec \Theta - 2R \cos a \sec \Theta). \tag{22}$$

The last equation is in the form y = mx + b, the graph of which is a straight line.

Likewise, equation (21) for D_{max} is:

$$D_{max} = \sec \Theta \left\{ D - 2 \cos a \left[.9t \left(\frac{.9t \cot(\Theta - a) = \dfrac{D - D_0 - 2R(1 - \cos a)}{2 \sin a}}{.9t \cot(\Theta - a)} \right) \right] \right\} .$$

D, D_0, R, cos a, sec Θ, cos (Θ -a), and sin (Θ -a) are all constants for any given tube size, and t (the wall thickness) is the only variable. Equation (21) can thus be rearranged into the following form:

$$D_{max} = (-1.8 \cos a \sec \Theta)\, t + \frac{[D - D_0 - 2R(1 - \cos a)]\, 2 \cos a \sec \Theta}{2 \sin a \cot (\Theta - a)} + D \sec \Theta \,.$$

Equation (22) is also in the form y = mx + b, and therefore its graph is also a straight line.

As a result of this mathematical conclusion, plots of Equations (22) and (23) are included as Figures 8 through 15 for tube sizes of 1/8 to 1-inch (3.175 - 25.4 millimeter).

USE OF BALL GAUGE SIZING GRAPHS

Problem:

Determine the minimum diameter sphere to use with 0.25-inch(6.35-millimeter) by 0.020-inch (0.508-millimeter) wall tubing.

Solution:

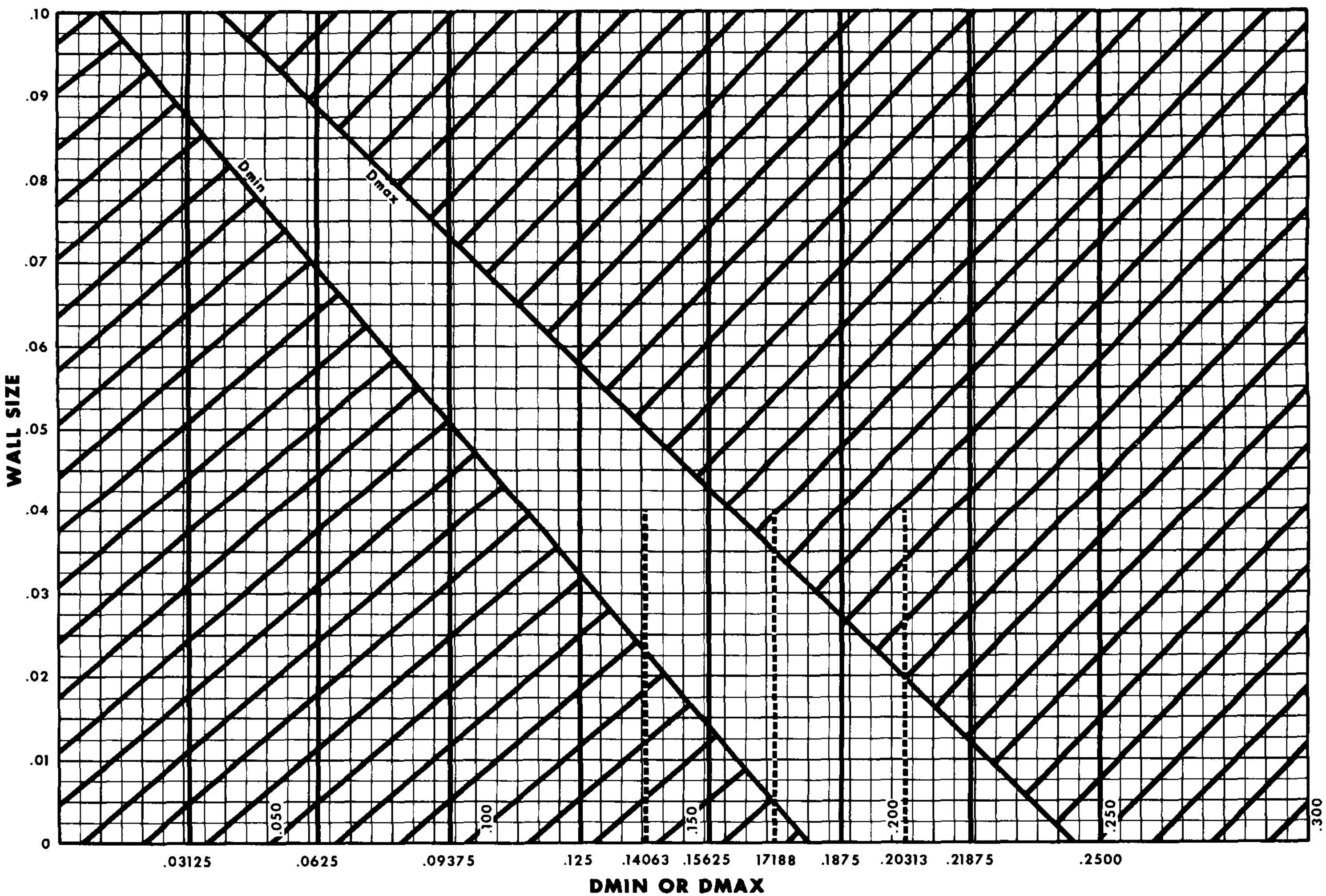
1. Refer to graph in Figure 9.

2. Locate the wall size (in this case 0.020-inch or 0.508-millimeter) in the left margin marked "WALL SIZE" and read straight across to the diagonal line marked "D_{min}." Proceed straight down and read the answer, 0.3035 inch (7.7 millimeters).

3. The number 0.3035 inch (7.7 millimeters) may now be rounded to next higher even thirty-second of an inch (0.792 millimeter). The vertical lines on the graph indicate these increments because the production of even 1/32-inch (0.792 millimeter) precision balls is standard.

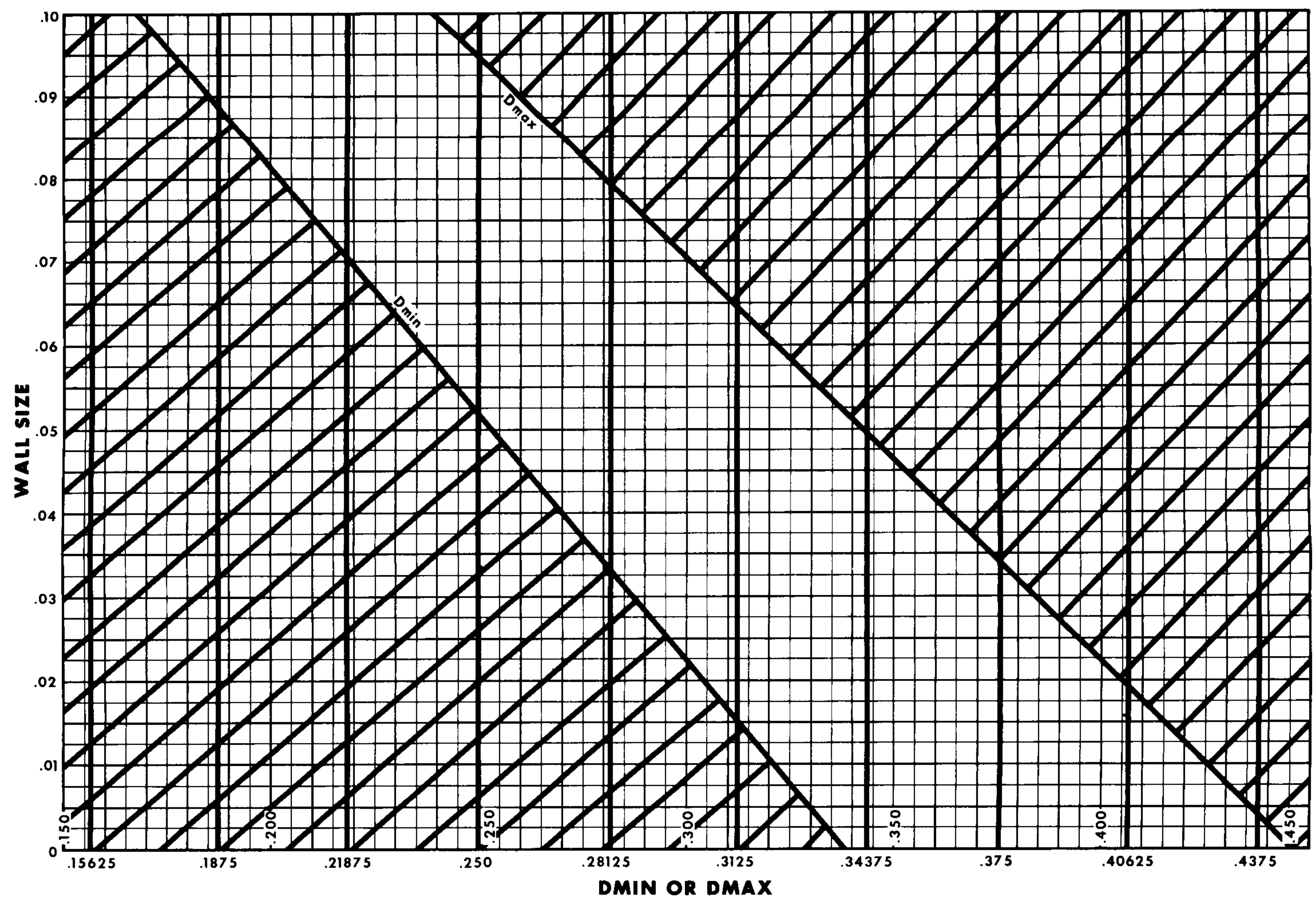
Problem:

Determination of maximum diameter sphere to use with 0.25-inch (6.35 millimeters) by 0.020-inch (0.508 millimeter) wall tubing.



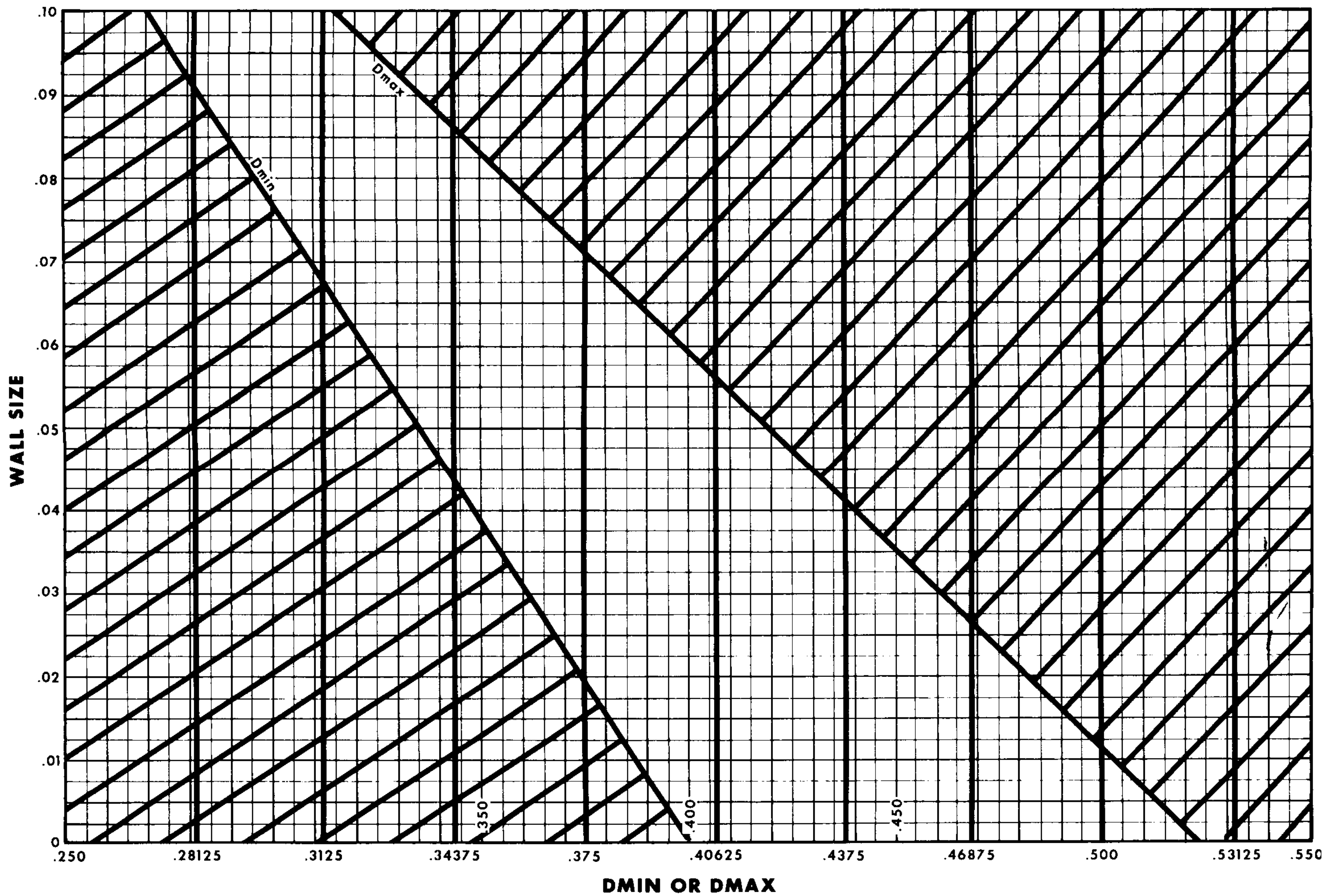
FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 8. BALL GAUGE SIZING GRAPH FOR 1/8-INCH (3.175-MILLIMETER) DIAMETER TUBING



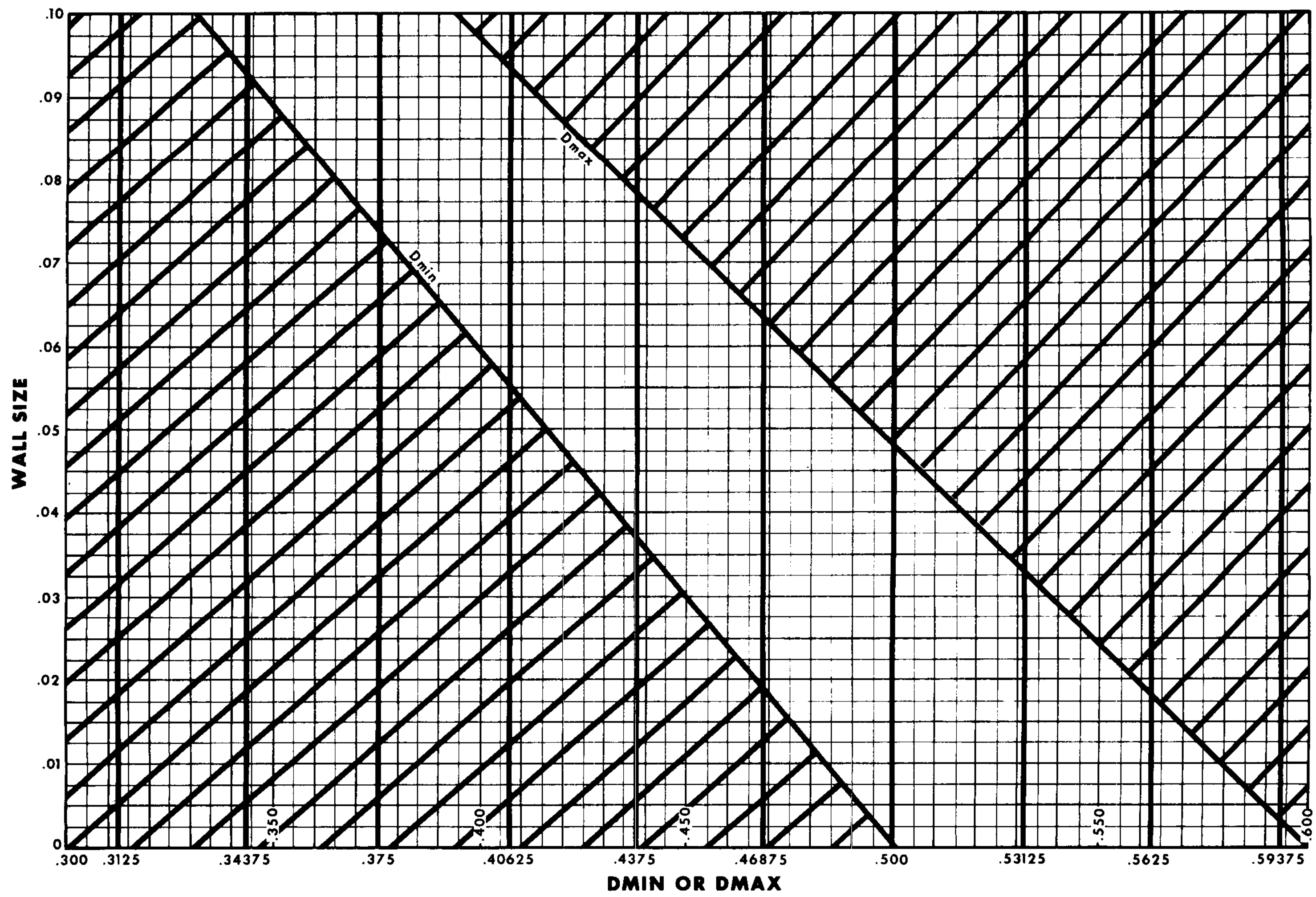
FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 9. BALL GAUGE SIZING GRAPH FOR 1/4-INCH (6.350-MILLIMETER) DIAMETER TUBING



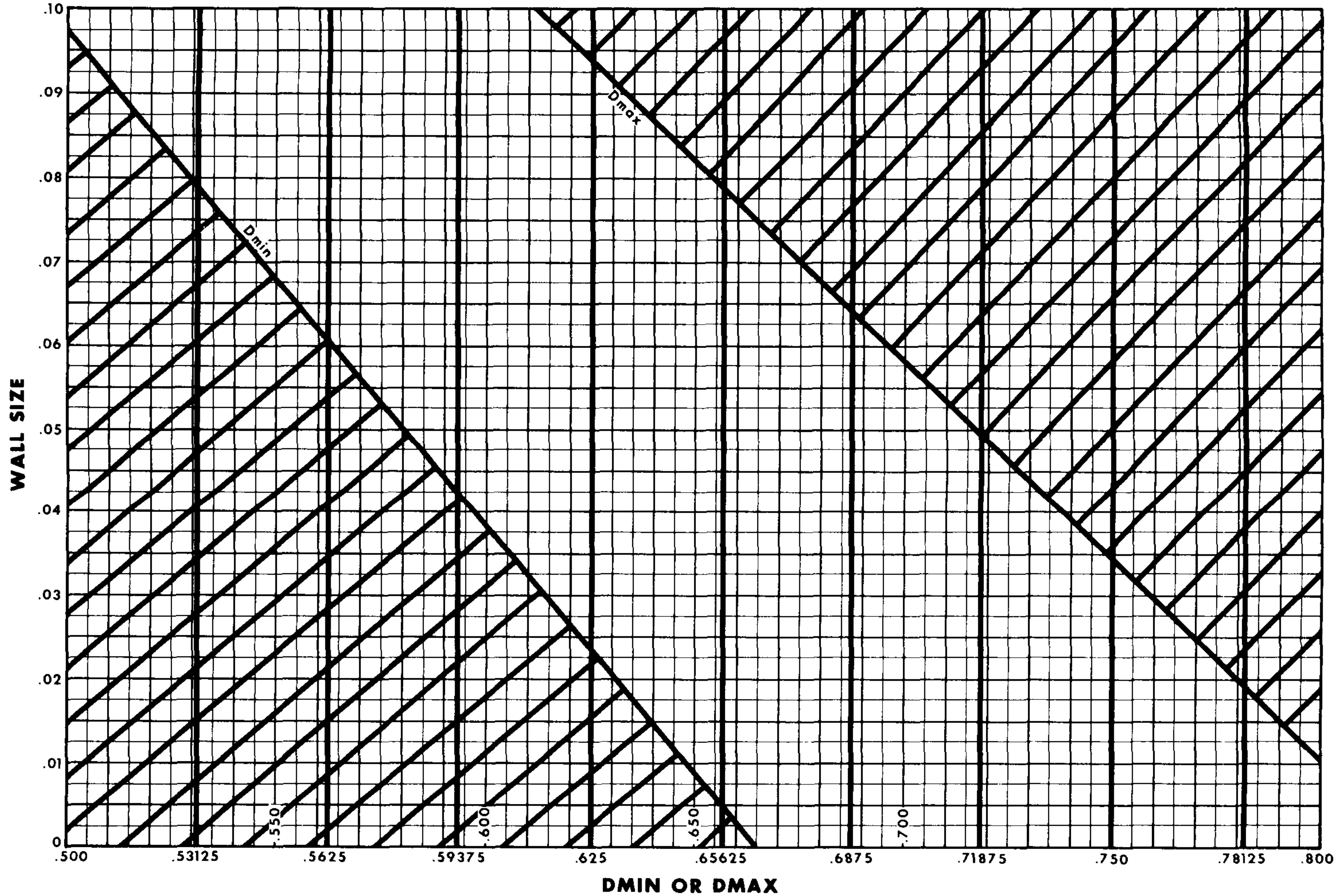
FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 10. BALL GAUGE SIZING GRAPH FOR 5/16-INCH (7.9375-MILLIMETER) DIAMETER TUBING



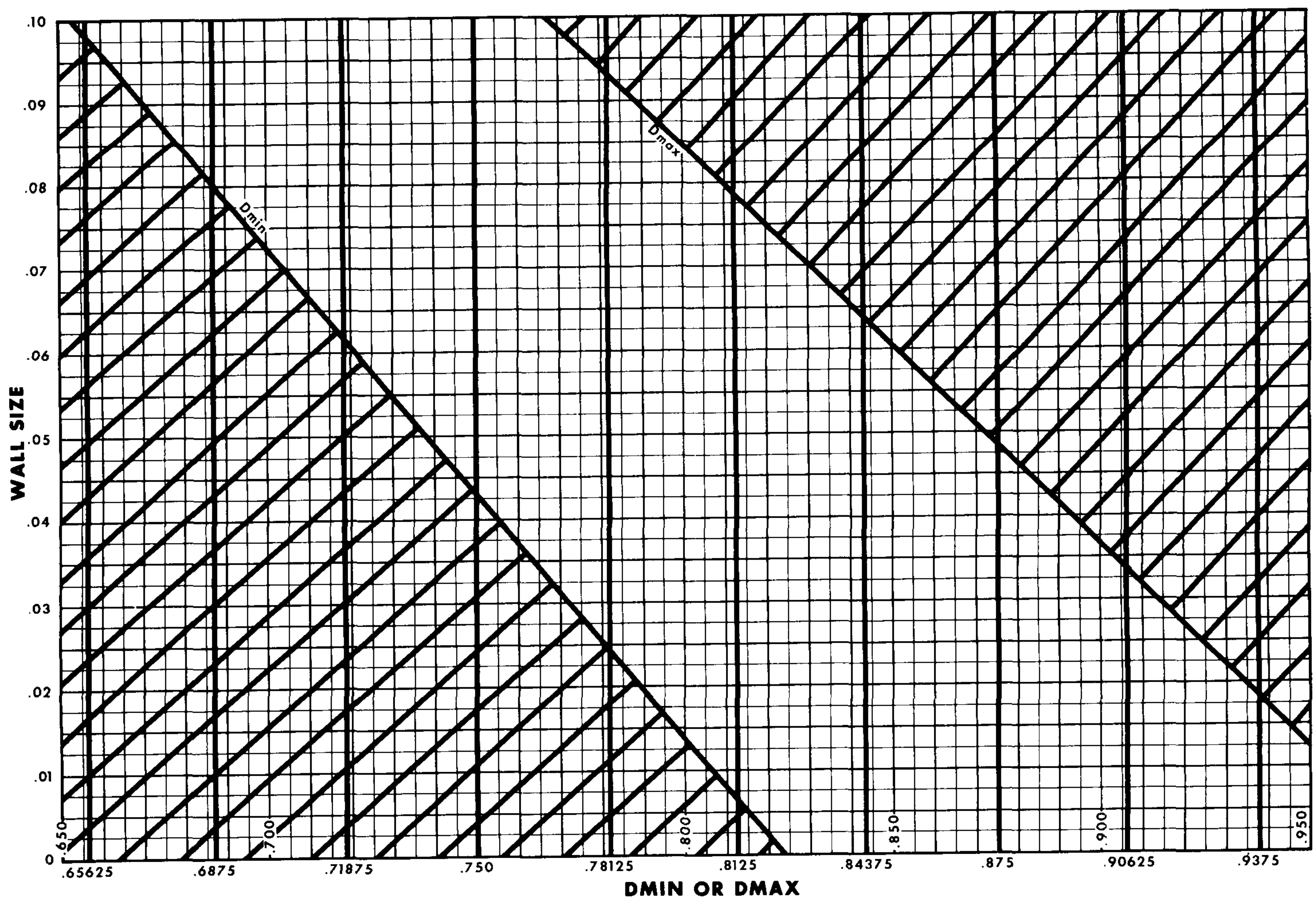
FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 11. BALL GAUGE SIZING GRAPH FOR 3/8-INCH (9.525-MILLIMETER) DIAMETER TUBING



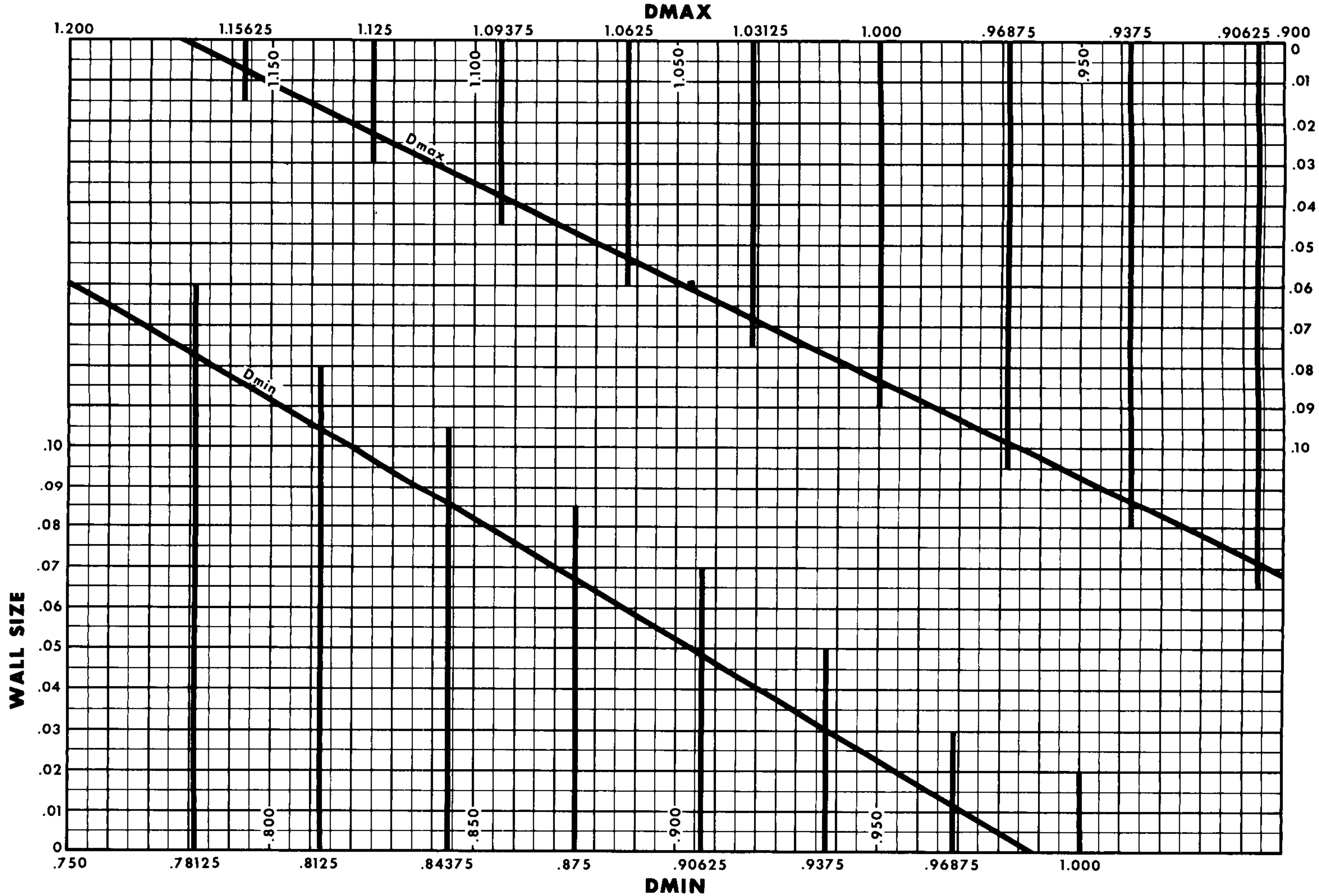
FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 12. BALL GAUGE SIZING GRAPH FOR 1/2-INCH (12.700-MILLIMETER) DIAMETER TUBING



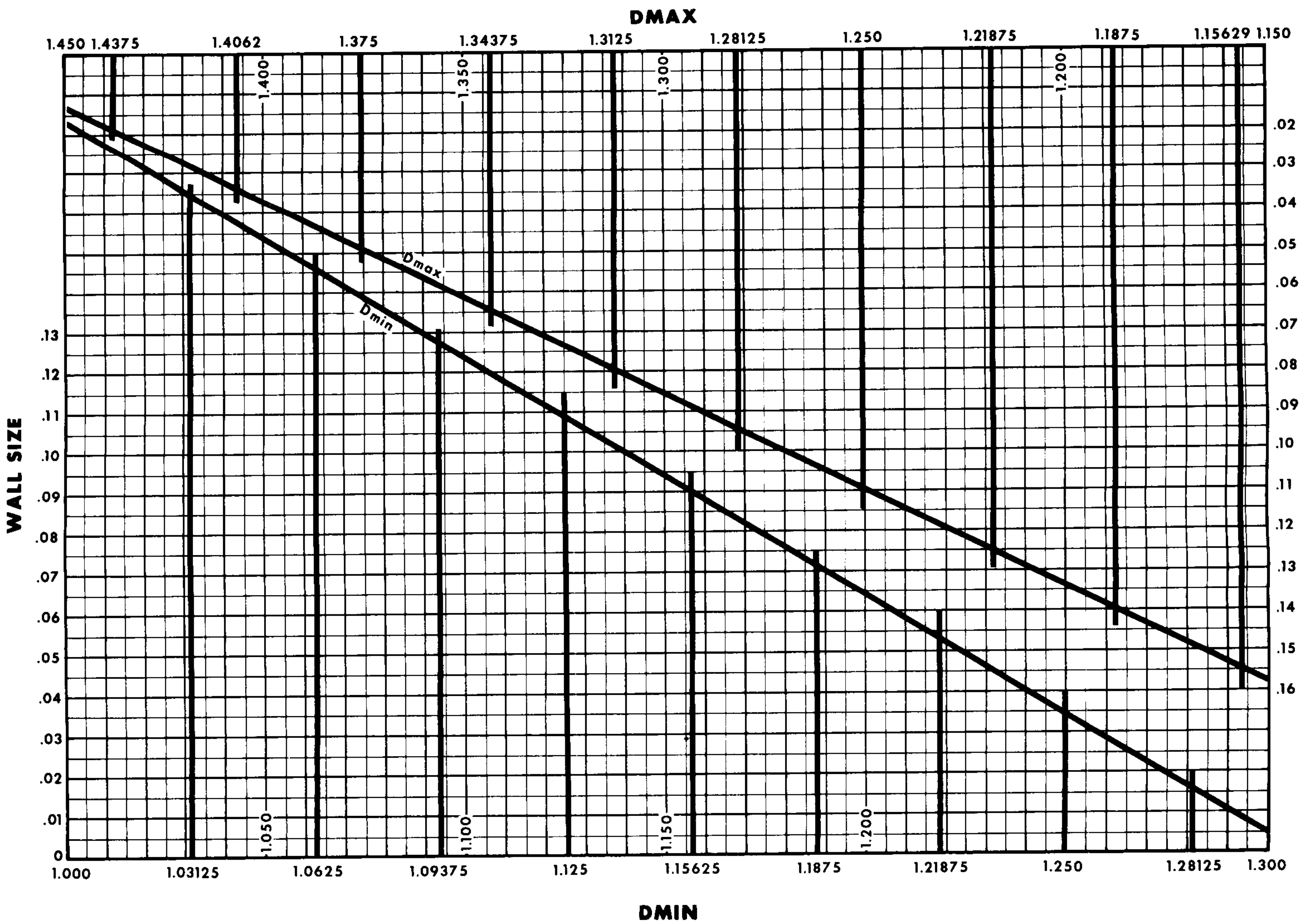
FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 13. BALL GAUGE SIZING GRAPH FOR 5/8-INCH (15.875-MILLIMETER) DIAMETER TUBING



FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 14. BALL GAUGE SIZING GRAPH FOR 3/4-INCH (19.050-MILLIMETER) DIAMETER TUBING



FOR DIMENSIONS IN MILLIMETERS MULTIPLY INCHES x 25.4

FIGURE 15. BALL GAUGE SIZING GRAPH FOR 1-INCH (25.4-MILLIMETER) DIAMETER TUBING

1. Refer to graph in Figure 9.

2. Locate the wall size (in this case 0.020 inch or 0.508 millimeter) in the left margin marked "WALL SIZE" and advance straight across to the diagonal line marked "D_{max}." Proceed straight down and read the answer, 0.404 inch (10.26 millimeters).

3. This answer, 0.404 inch (10.26 millimeters), may now be rounded to the next lower even 32nd (0.792 millimeter) of an inch.

NOTE: When the graphs are used for 0.75-inch (19.05 millimeters) and 1-inch (25.4 millimeters) tubing, the right margin marked "WALL SIZE" is used for determining the diameters of the large spheres. To find the desired wall size, proceed straight across to the diagonal line marked "D_{max}" and thence straight up to read the answer.

The above example illustrates how the diameters of the two spheres used with 0.25-inch (6.35 millimeters) tubing and 0.020 (0.508 millimeters) wall ball gauges may be calculated. Although these two sphere diameters may be adjusted as indicated in step 3 of both examples, the diameter of the small sphere must always be less than the diameter of the large sphere. If pre-calculated values for m and b are available, a simplified mathematical check is also easily made. An explanation of this method follows.

SIMPLIFIED MATHEMATICAL METHOD TO DETERMINE BALL SIZES

Given: Tube size and wall size.

Find: Diameter of small sphere and/or large sphere.

Procedure: 1. In Table II below, locate m or b across from given tube size and desired sphere.

TABLE II. TYPICAL VALUES OF m AND b FOR 0.125-INCH TO 1-INCH TUBING

Tube Size[1]	Sphere	m	b
0.125 (3.175)	Small	1.89202	.180188
	Large	1.88852	.243440
0.25 (6.35)	Small	1.89202	.337751
	Large	1.88852	.445880
0.3125 (7.94)	Small	1.89202	.416532
	Large	1.88852	.522930
0.375 (9.52)	Small	1.89202	.501175
	Large	1.88852	.600770
0.5 (12.7)	Small	1.89202	.665440
	Large	1.88852	.820470
0.625 (15.9)	Small	1.89202	.824266
	Large	1.88852	.975970
0.75 (19)	Small	1.89202	.988534
	Large	1.88852	1.173590
1 (25.4)	Small	1.89202	1.309937
	Large	1.88852	1.477050

[1] Size is given in inches with millimeters in parentheses.

2. Use m and b in the following formulas:

Minimum diameter of small sphere (D_{min}) = b - m (.9t) (24)

Maximum diameter of large sphere (D_{max}) = b - m (1.1t) (25)

Where: t = tube wall thickness in inches.

3. D_{min} may be increased to any convenient size and D_{max} lowered to any convenient size; but D_{max} must always be greater than D_{min}, preferably by a minimum of 0.0666 inch (1.584 millimeter).

This simple solution is possible because D_{min} and D_{max} may be expressed in the form y = mx + b. For any given tube size, m and b are constant and need not be recalculated each time.

EXAMPLE 1:

To determine the minimum diameter of the small sphere used with 0.25-inch (3.175 millimeters) tubing and 0.020-inch (0.508 millimeter) wall:

1. From Table II: m = 1.89202, b = .337751

2. Using formula (23):

Minimum Diameter of Sphere (D_{min}) = .337751 - 1.89202 (.9) (.020)

= .337751 - 1.89202 (.018)

= .337751 - .034056

= .303691 inch (7.7 millimeters)

3. The answer, .303691, may now be increased to a more convenient size if desired.

EXAMPLE 2:

To determine the maximum diameter of large sphere used with 0.25-inch (3.175 millimeters) tubing and 0.020-inch (0.508 millimeter) wall:

1. From Table II: $m = 1.88852$, $b = .445880$

2. Using formula (24):

Maximum Diameter of Large Sphere (D_{max}) $= .44588 - 1.88852(1.1)(.020)$

$= .44588 - 1.88852\ (.022)$

$= .44588 - .041547$

$= .40433$ inches (10.25 millimeters)

3. The answer, .40433, may now be decreased to a more convenient size if desired.

NOTE: Examples 1 and 2 above demonstrate how the two spheres for 0.25-inch (3.175 millimeters) tubing and 0.020-inch (0.508 millimeter) wall are calculated. Although these two sphere diameters may be adjusted as indicated in step 3 of both examples, the diameter of the small sphere must always be less than the diameter of the large sphere.

The product of our development was Internal Flare Angle Gauge, MSFC drawing MR&T-sk-872. Figure 3 illustrates the gauge housing which consists of the Main Block -1, Dial Indicator -2, a Gross Movement Adjustment Screw -3, "V" Block -4, Tube Clamping Ring -5, and an assortment of Split Sleeves -6 to clamp the specimen to be measured. A sample differential Ball Gauge -7 is also pictured. The Main Block -1 is made of a special tool quality aluminum to minimize warpage and weight. Clamping of the tube sample is convenient since the spring cone inside the Clamping Ring -5 is free to rotate. The Split Sleeve -6 slides into the spring cone and hand rotation of -5 quickly clamps and aligns the tube specimen.

FLARE ANGLE MEASUREMENT

For a measurement, the tube specimen is first clamped in the Main Block, and the proper differential ball gauge selected and placed in the "V" Block with the small sphere in the tube flare. The Gross Adjustment Screw is then used to adjust the dial indicator until its hand is off the mechanical limit. The indicator is zeroed with its regular rotating dial -8 until the hand is zeroed, Figure 16. Next, the zero setting is checked by assuring that the small sphere

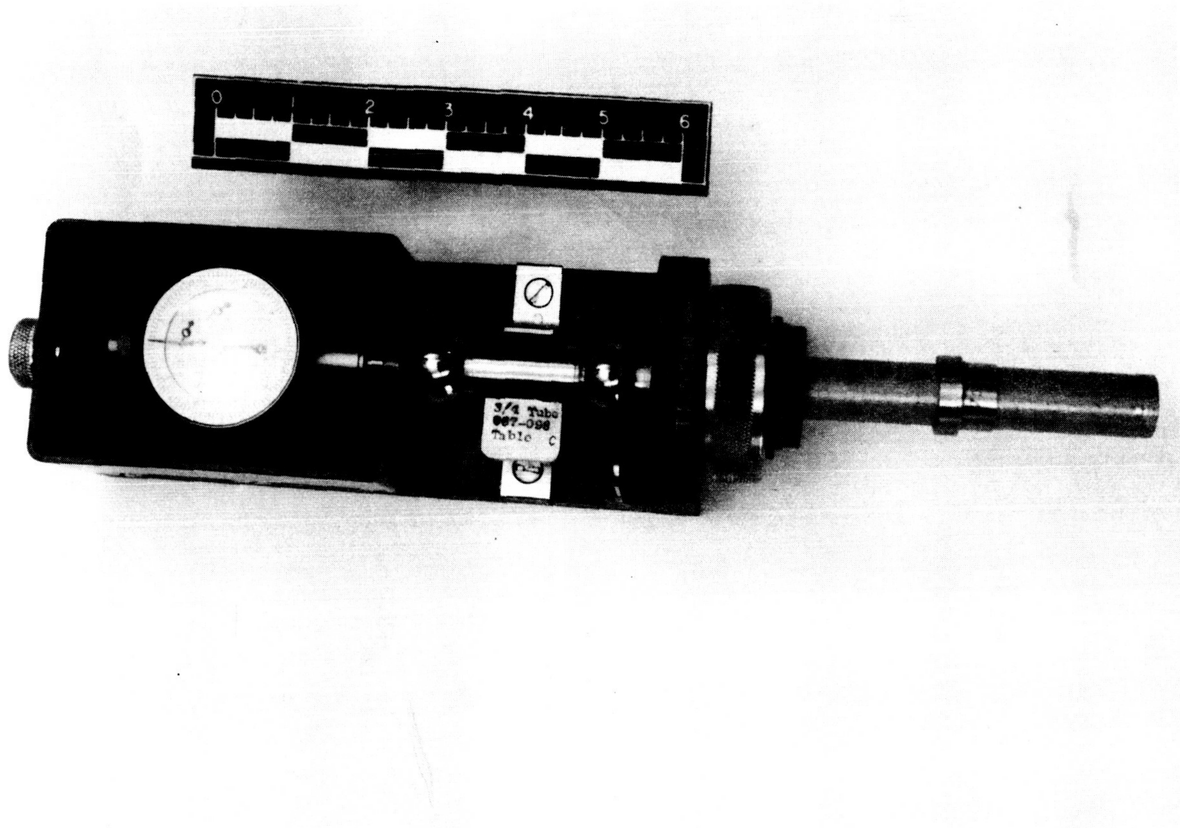


FIGURE 16. GAUGE DIAL ZEROED AND READY TO MAKE MEASUREMENT

is snug in the flare. After the check for snugness and zero, the ball gauge is reversed, Figure 17, placing the large sphere in the flare. The dial indicator will now read distance "d." To determine the flare angle, refer to the Readout Table etched on the tab of the ball gauge. A sample readout table is illustrated in Table I. The procedure should be repeated several times until a consistent reading is obtained. Usually, two or three minutes is sufficient time to complete a measurement.

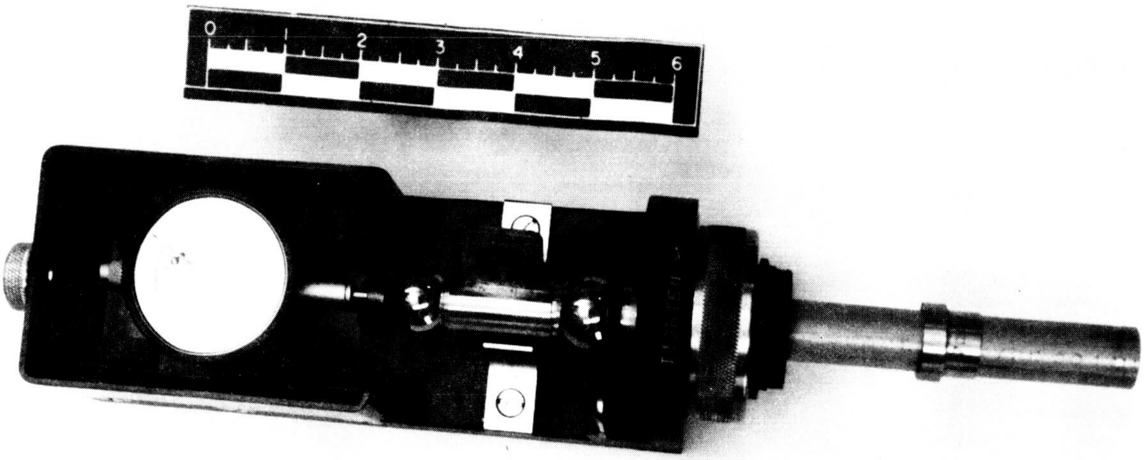


FIGURE 17. BALL GAUGE IN READOUT POSITION

POTENTIAL ERROR SOURCES

Of course, there are potential error sources associated with this inspection approach, but most have been eliminated or minimized through design of the gauges. Those sources minimized through design will be discussed first.

1. Source: The known diameter and roundness of the tungsten carbide spheres.

Solution: This has been minimized by specifying precision balls below 0.75 inch (19.05 millimeters) in diameter to ± 0.00001-inch (0.000254-millimeter) tolerance and balls 0.75 inch (19.05 millimeters and above to ±0.00005-inch (0.00127-millimeter) tolerance. The degree of readout error is inversely proportional to the difference in diameters of the balls; i.e., the larger the difference of ball diameters, the more accurate the internal flare angle can be measured. Under the worst conditions with the precision spheres specified, the maximum error due to ball diameter could range from ± 2 to ± 7 minutes of arc depending on many parameters. Tungsten carbide precision ball bearings with the stated tolerances are available commercially.

2. Source: The alignment of the centerline of the gauge with respect to the centerline of the tube.

Solution: This problem has been minimized by specifying that the flats of the "V" block in which the differential ball gauge rests be parallel to the centerline of the tube clamp within ± 0.001 inch (0.254 millimeter). Actually, a certain amount of cocking of the ball gauge in the "V" block can be tolerated. Up to 1.5 degrees of non-parallelism will not materially affect the readout. Alignment of the tube in the gauge is a factor of the precision of the clamping means; therefore every precaution was taken to specify precision tube alignment for gauge MR&T-sk-872.

Measurement Error Sources:

1. Source: Concentricity, eccentricity, and finish of the sealing surface of the tube flare.

Comment: Tube flares made to MC146 present no problem due to the above listed factors. The allowable eccentricity, concentricity and sealing surface finish of MC146 precludes a smooth, uniform sealing surface. A slight pressure on the ball gauge should be sufficient to seat the differential gauge in the flare adequately.

2. Source: Convexity of the tube flare sealing surface. MC146 allows + 0.001-inch (0.0254-millimeter) convexity and zero-inch concavity of the sealing surface.

Comment: Convexity of the sealing surface is potentially the greatest source of readout error. MC146, Figure 18 pictures a flare with dashed convexity. Further, MC146 states that "The flare sealing surface shall not exhibit concave areas, but may have a convex configuration of a concentric nature not to exceed 0.001 as indicated in drawing." Close inspection of triangle AOB will show that side AB is the error introduced into the dial indicator reading "d" if the small ball makes contact at 0 on the sealing surface and the large ball makes contact at F. The error distance introduced by the convexity would be:

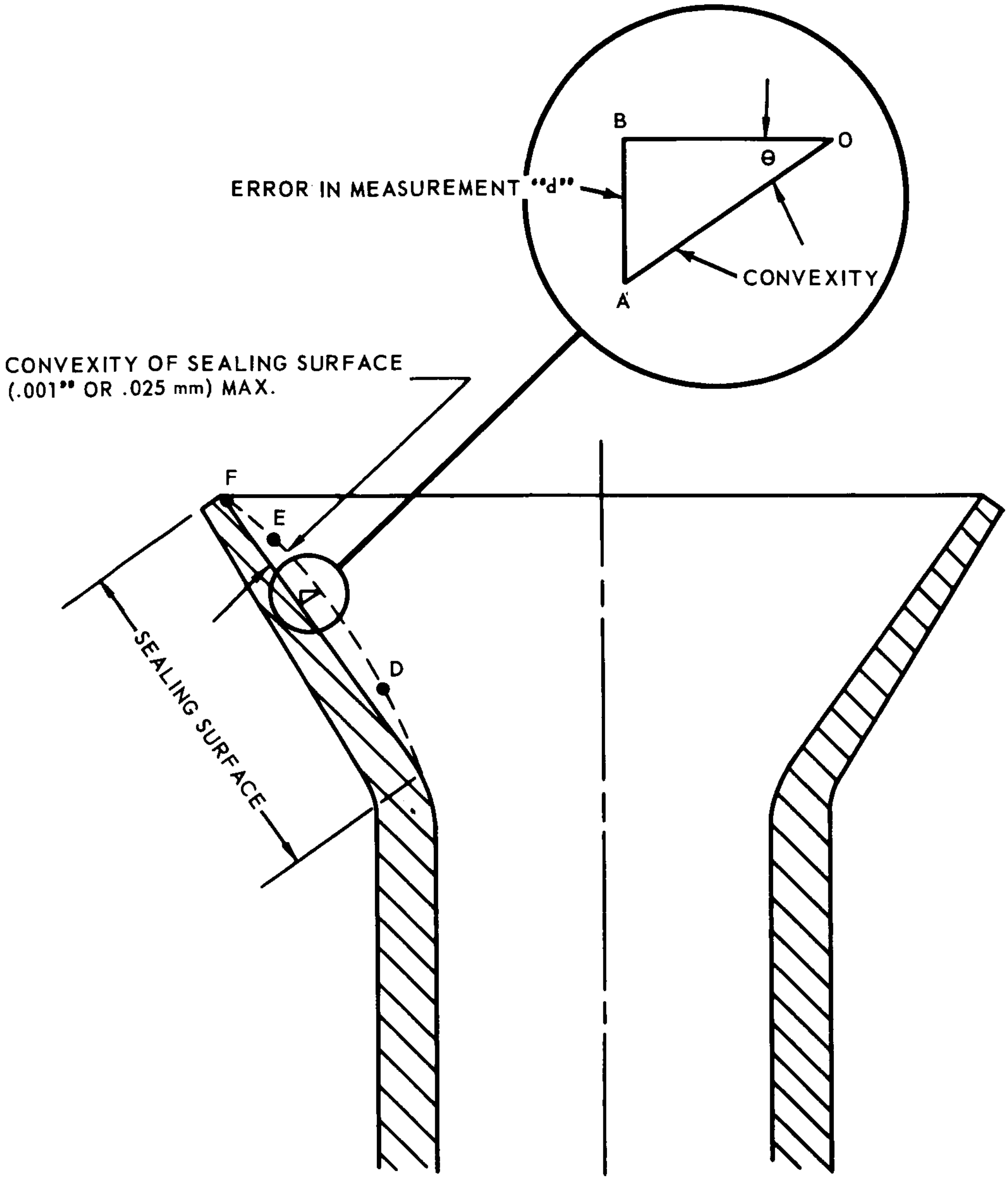


FIGURE 18. CONVEXITY ERROR DIAGRAM

Error distance = (Convexity) (sin Θ)

where: $\Theta \approx \dfrac{\text{Internal flare angle}}{2}$.

Of course, the smaller the maximum convexity of the sealing surface, the less the probability of error. Also, if the amount of convexity were the same at the two points of contact, such as points D and E in Figure 18, the readout error caused by the convexity of the sealing surface would be zero because of cancellation. Thus, to minimize readout error due to convexity of the sealing surface, the balls should be sized to make contact as near the ends of the sealing surface as possible. A check of a large sampling of flares indicated that the probability of a large error caused by the convexity of the sealing surface is very remote. A maximum of ± 3 to ± 7 minutes of flare angle arc would normally be sufficient allowance for convexity error in a borderline case.

ACCURACY

Based on experience and probability factors, it is estimated that total angular readout error for ball gauges sized to a specific tube size and wall thickness would range from 0 to ± 7 minutes of arc. On the other hand, ball gauges sized for a specific tube size and range of wall thicknesses present a probability of error ranging from 0 to ± 12 minutes of arc. It then becomes obvious that a decision based on cost of additional gauges versus accuracy is a definite application consideration.

PATENT STATUS

A joint patent on gauges MR&T-sk-774 and MR&T-sk-872, a second generation design, has been applied for by Mr. W. A. Wall and Mr. N. D. Elder of the Marshall Space Flight Center.

CONCLUSIONS

The differential ball gauge method of measuring the internal flare angle of an MC146 flare is concluded to be a valid method. Speed, accuracy, reliability, maintainability and simplicity of this gauge renders it a reliable, workable, shop type, measuring instrument. Repeatability of the reading from gauge to gauge is an outstanding feature. It has been proved that the same reading, within reason, may be obtained on any gauge manufactured ot the same tolerances as gauge MR&T-sk-872. In addition, this gauge is portable and can make equally accurate readings in the field or on the bench. Of importance, frequent calibration is not required.

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A PORTABLE DIFFERENTIAL BALL GAUGE TO MEASURE THE INTERNAL FLARE ANGLE OF MC146 FLARED TUBING

By David Cleghorn, William A. Wall, and J D Bennight

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This report has also been reviewed and approved for technical accuracy.

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