AMERICAN NATIONAL STANDARD

Ball Screws

ANSI B5.48 - 1977

REAFFIRMED 2002

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REAFFIRMED 1994

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SECRETARIAT

SOCIETY OF AUTOMOTIVE ENGINEERS
SOCIETY OF MANUFACTURING ENGINEERS
NATIONAL MACHINE TOOL BUILDERS' ASSOCIATION
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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ERRATA

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Page 13. Paragraph A1.2 Symbols, *change* θ = helix angle, degrees *to read* θ = lead angle, degrees.

Page 13. Paragraph A1.3 Axial Angle Deflection Equations *change* $\theta = \tan^{-1} \frac{1}{\pi BCD}$ *to read* $\theta = \tan^{-1} \frac{L}{\pi BCD}$

(3/79)

FOREWORD

In order to obtain a consensus opinion relative to proposals for standardization of ball screw assemblies within the ISO/TC39 Sub-committee Working Group 7, a number of users within the machine tool industry and manufacturers of ball screws were assembled. It was determined by this group that there was a need for such standardization in the United States and application was made to AN Standards Committee B5-Machine Tools, for the organization of a technical committee for this work. Accordingly, TC43 was organized and a scope was approved by AN Standards Committee B5. The first meeting was held on July 22, 1971. The members of the committee represented manufacturers, users of ball screws, and others of general interest balanced according to ANSI requirements for such committees.

This document was approved as an American National Standard on April 7, 1977.

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AMERICAN NATIONAL STANDARD

BALL SCREWS

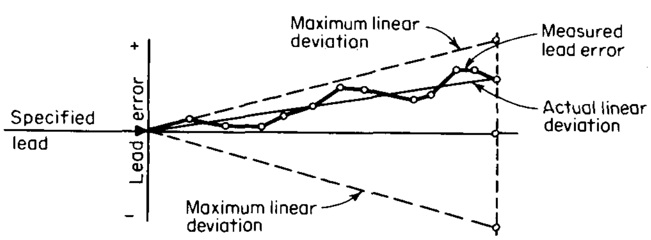
1.0 SCOPE

1.1 This standard covers definitions, classes of ball screws, recommended combinations of screw diameters and leads, recommended drawing format, and performance characteristics of ball screw and nut assemblies as applied to machine tools.

1.2 The values stated in U.S. customary units are to be regarded as the standard. Metric values are converted from the customary values per recommendations of "ASME Guide SI-1, ASME Orientation and Guide for Use of SI (Metric) Units".

2.0 DEFINITIONS

2.1 Actual Linear Deviation. The lead error rate, used as a reference line, for a ball screw assembly is determined by connecting the beginning and end points of the measured lead error.



2.2 Backdriving. Ability of screw or nut to rotate when thrust load is applied to the other member of the assembly.

2.3 Backlash. Axial free motion between the nut and screw.

2.4 Ball Nut. The member, containing the outer helical ball track of a ball screw assembly.

2.5 Ball Screw. The shaft member containing the inner helical ball track, of a ball screw assembly.

2.6 Ball Screw Assembly. A device consisting of ball nut, ball screw and balls.

2.7 Ball Track. Specially designed helical groove in a ball nut or ball screw which transmits the load reaction between the ball nut or ball screw and the balls.

2.8 Basic Load Rating. That constant axial load which a group of apparently identical ball screw assemblies can endure for a rated life of one million inches (25 400 m) of travel.

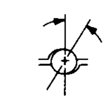
2.9 Basic Static Thrust Capacity. The static thrust load which will produce a permanent ball track deformation of 0.0001 times the ball diameter.

2.10 Circuit. A continuous closed path of recirculating balls.

2.11 Column Strength. Maximum compressive axial load that can be applied to a screw without resulting in permanent structural deformation.

2.12 Conformity Ratio. Ratio of the ball track radius to the ball diameter.

2.13 Contact Angle. Nominal angle between a plane perpendicular to the screw axis, and a line drawn between the theoretical points of tangency between a ball and the ball tracks and projected on a plane passing through the screw axis and the center of the ball.



2.14 Critical Speed. Rotational speed, of nut or screw, that produces resonant vibration of the ball screw assembly.

2.15 Drag Torque. The torque required to rotate the nut relative to the screw in the absence of an external load.

2.16 End Seals. Closure element(s) affixed to the nut and in slideable contact with the screw in a manner which will inhibit foreign objects from entering the ball nut assembly and/or provide retention of the lubricant.

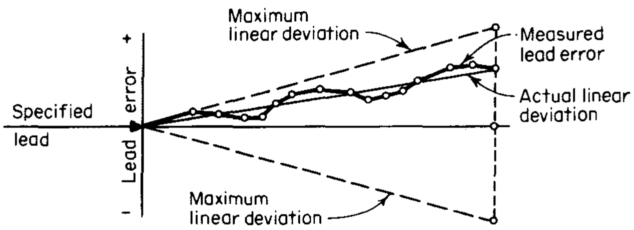
2.17 Equivalent Load. Mean load that will result in same life as a combination of varying loads.

2.18 Lead. Axial distance screw or nut travels in one revolution.

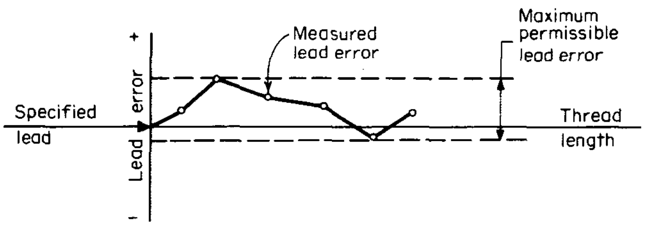
2.19 Lead Error (Deviation). The measured lead minus the specified lead.

2.20 Load Ball. A ball which carries a portion of the load.

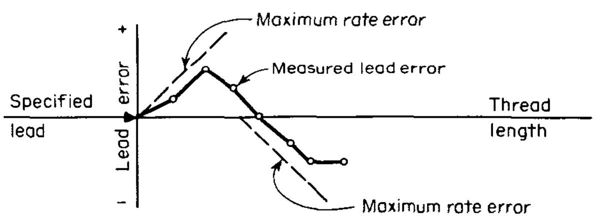
2.21 Maximum Linear Deviation. A maximum lead error rate applied to the total thread length.



2.22 Maximum Permissible Lead Error. The total allowable variation, peak-to-peak, in lead error over the total thread length.



2.23 Maximum Rate Error. The maximum permissible positive or negative slope, of the measured lead error line as plotted on a lead error versus thread length graph. It is normally specified in inches (mm) of error per 12 inches (300 mm) of thread length.



2.24 Measured Lead Error. The actual manufactured lead error including measurement error.

2.25 Multiple Circuit Nut. A ball nut with two or more closed paths of recirculating balls.

2.26 Multiple Start Screw. A ball screw in which the lead is an integral multiple of the pitch.

2.27 Nominal Lead. The lead chosen as a basic reference.

2.28 Ogival (or Gothic) Groove. A ball track cross-section shaped like a Gothic Arch.

2.29 Pitch. The distance from a point on a ball track to a corresponding point on the next track, parallel to the ball screw or ball nut axis.

2.30 Pitch (Ball Circle) Diameter. The nominal diameter of a theoretical cylinder passing through the centers of the balls when they are in contact with the ball screw and ball nut tracks.

2.31 Preload. The use of one group of ball grooves in opposition to another to increase stiffness and eliminate backlash in a ball nut assembly.

2.32 Rated Life. The length of travel that 90 percent of a group of ball screw assemblies will complete or exceed before the first evidence of fatigue develops. (L_{10})

2.33 Root Diameter. Diameter of the screw measured at the bottom of the ball track.

2.34 Screw Diameter. The outside diameter of the ball screw shaft.

2.35 Single Circuit Nut. A ball nut with only one closed path of recirculating balls.

2.36 Single Start Screw. A ball screw having the lead equal to the pitch.

2.37 Spacer Ball. A ball, an idler, smaller than the load balls.

2.38 Specified Lead. The prescribed theoretical lead from which tolerances are applied. The specified lead is generally expressed as the nominal lead, or the nominal lead plus or minus a specified cumulative variance per 12 inches (300 mm).

2.39 Spring Rate. A measure of stiffness equal to load per unit deflection.

2.40 Stiffness. Resistance to deflection.

2.41 Stops. Interference elements, effective at the end of nut travel, which prevent rotational motion between nut and screw. Stops are designed to prevent accidental disassembly, and/or prevent excessive travel.

2.42 Thread Length. Total axial distance of usable threads.

2.43 Travel. The axial distance traversed by screw or nut in one direction.

2.44 Turns. The number of revolutions that the nut ball track makes about the screw axis for one circuit.

2.45 Wobble Error. The total variation, peak-to-peak, in lead error for one revolution of the nut.

3.0 CLASSES OF BALL SCREWS

3.1 Preferred Classes

The preferred classes of machine tool screw assemblies are given in Table I.

Table I Class and Deviation

Class	Maximum Permissible Lead Error		Maximum Rate Error			Maximum Linear Deviation		Wobble Error Peak To Peak	
	Inch	μ m (5)	Inch / 12 inch	μ m / 300 mm	Acceptance Template	Inch	μ m	Inch	μ m
1	(2) (4) $0.0002 \times \frac{L_i}{12} \times T$	(3) (4) $5 \times \frac{L_{mm}}{300} \times T$						0.0002	5
2	$0.0002 \times \frac{L_i}{12} \times T$	$5 \times \frac{L_{mm}}{300} \times T$	±0.0002	±5	1	(1)	(1)	0.0002	5
3			±0.0002	±5	1			0.0002	5
4	$0.0005 \times \frac{L_i}{12} \times T$	$13 \times \frac{L_{mm}}{300} \times T$						0.0004	10
5	$0.0005 \times \frac{L_i}{12} \times T$	$13 \times \frac{L_{mm}}{300} \times T$	±0.0005	±13	2	(1)	(1)	0.0004	10
6			±0.0005	±13	2			0.0004	10
7			±0.001	±25	3			0.0004	10
8			±0.006	±150	4			0.0015	38

(1) Maximum linear deviation is to be determined by agreement between manufacturer and user.
(2) L_i = length of screw in inches
(3) L_{mm} = length of screw in millimeters
(4) T = value obtained in Table II
(5) μm = micrometer, 0.001 mm.
For maximum permissible runout, classes 1 through 7, see Table III. The full indicator movement for class 8 ball screw assemblies shall not exceed 0.020 (0.5 mm) for each 120 inches (3000 mm) or less of length.

For examples see Appendix A2; Figure A1 for classes 3, 6, 7, and 8; Figure A2 for classes 2 and 5; Figure A3 for classes 1 and 4.

Table I (a) Preferred Lead Error Measurement Interval—Inches

Lead—Inches	0.080	0.100	0.125	0.160	0.200	0.250	0.333	0.375	0.400	0.500	0.750	1.000
Integral No. of Leads	25	20	16	25	20	16	12	16	15	12	8	6
Measuring Interval—Inches	2.0	2.0	2.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	6.0	6.0

Table I (b) Preferred Lead Error Measurement Interval—SI (Metric)

Lead—mm	2	2.5	3	4	5	6	8	10	12	16	20
Integral No. of Leads	20	16	20	30	24	20	15	12	10	10	8
Measuring Interval—mm	40	40	60	120	120	120	120	120	120	160	160

3.2 Measured Lead

The measured lead shall be of a ball screw assembly, ie., the displacement of the ball nut relative to the ball screw.

Maximum permissible lead error, maximum rate error and maximum linear deviation are normally measured in a plane passing through the screw axis and on one side of the screw over an integral number of revolutions. The preferred interval between measurements to be taken for lead error are given in Table I(a) for conventional units and Table I(b) for SI units.

Wobble error measurements are made over small angular rotations during one revolution. Their cyclical nature prevents them from appearing during maximum measurements of permissible lead error, maximum rate error and maximum measurements of linear deviation lead error. Measurements for wobble error, if required, should be taken for at least two revolutions and for as many positions along the screw as determined by agreement between manufacturer and user. Wobble error is in addition to lead error measurements for maximum permissible lead error, maximum rate error, and maximum linear deviation.

When maximum linear deviation is specified in classes 2 and 5, the vertical distance between the actual linear deviation line and the measured lead error line, in a chart plotting lead error versus screw length, must be transferred at each measured point to the abscissa before maximum permissible lead error, maximum rate error, and acceptance templates may be applied. See Figure A2 of Appendix A2 for illustration.

The measurement of runout for classes 1 through 7 shall be taken in the ball groove with the screw mounted on centers. Runout measurements for class 8 screws shall be taken on the outside diameter with the screw supported on a surface plate. When the ball nut is in close proximity to the screw bearing journals good concentricity of the screw threads and bearing journals is essential to protect the ball screw assembly from excessive forces. Figure 3, Note 1, shows a method of specifying this concentricity.

3.3 Templates

For screw classes 2, 3, 5, 6, 7, and 8, the templates shown in Figure 1 may be used to verify accuracy requirements. The template is superimposed and moved along the measured lead error line. The acceptance template may be moved vertically but may not be rotated. For every possible horizontal position of the template, there must be at least one vertical position where the template contains the entire measured lead error line. See Appendix A2 for illustration.

Table II Thread Length vs. "T" Factor for Classes 1, 2, 4 and 5

Thread Length		T
Inches	Millimeters	
12 to 18	300 to 450	1.0
18+ to 24	450+ to 600	0.85
24+ to 36	600+ to 900	0.7
36+ to 48	900+ to 1200	0.6
48+ to 60	1200+ to 1500	0.55
60+ to 72	1500+ to 1800	0.52
72+ to 84	1800+ to 2100	0.49
84+ to 96	2100+ to 2400	0.46
96+ to 120	2400+ to 3000	0.4
over 120	over 3000	0.5

Example (1):

75 inch long class 1 ball screw assembly

maximum permissible lead error equals:

$$0.002 \times \frac{75}{12} \times 0.49 = 0.0006125 \text{ inches } (15.5\ \mu\text{m})$$

Example (2):

1600 mm long class 4 ball screw assembly

maximum permissible lead error equals:

$$13 \times \frac{1600}{300} \times 0.52 = 36.05 \text{ micrometers } (0.00142 \text{ inches})$$

4.0 COMBINATIONS OF NOMINAL SCREW DIAMETER AND NOMINAL LEAD—INCH SERIES

4.1 General Plan

For preferred combinations, Table IV, the lead value is underlined. The combinations for which the lead value is not underlined should be used when it becomes necessary to deviate from the preferred combinations.

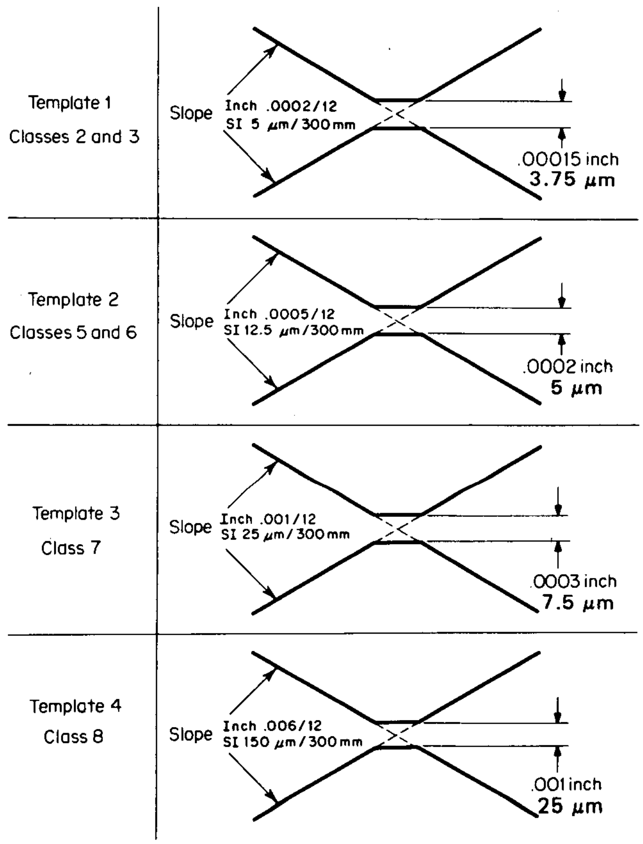


FIG. 1 ACCEPTANCE TEMPLATE CONSTRUCTION

5.0 COMBINATIONS OF NOMINAL SCREW DIAMETER AND NOMINAL LEAD–METRIC SERIES

5.1 General Plan

For preferred combinations, Table V, the lead value is underlined. The combinations for which the lead value is not underlined should be used when it becomes necessary to deviate from the preferred combinations.

6.0 SPECIFICATIONS AND DRAWING FORMAT

6.1 Figure 2 is a machine design engineer's guide to convey requirements to the ball screw manufacturer. Each item indicated is to be the responsibility of the designer, the manufacturer, or both.

6.2 Figure 3 illustrates the method required to specify a ball screw assembly. Technical data is presented in the prescribed format.

Table III Full Indicator Movement†
Classes 1 through 7

Thread* Length		Pitch Diameter											
		inch	mm	inch	mm	inch	mm	inch	mm	inch	mm	inch	mm
inch	mm	0.25 to 1.0	6 to 25	1.0+ to 1.25	25+ to 32	1.25+ to 2.0	32+ to 50	2.0+ to 3.0	50+ to 75	3.0+ to 4.5	75+ to 115	4.5+ to 8.0	115+ to 200
12	300	0.003	0.075	0.002	0.05	0.002	0.05	0.0015	0.038	0.0015	0.038	0.0015	0.038
18	450	0.004	0.1	0.003	0.075	0.003	0.075	0.002	0.05	0.002	0.05	0.002	0.05
24	600	0.005	0.125	0.004	0.1	0.004	0.1	0.004	0.1	0.004	0.1	0.003	0.075
36	900	0.006	0.15	0.006	0.15	0.006	0.15	0.006	0.15	0.006	0.15	0.004	0.1
48	1200			0.008	0.2	0.007	0.175	0.007	0.175	0.007	0.175	0.005	0.125
60	1500			0.010	0.25	0.008	0.2	0.008	0.2	0.008	0.2	0.006	0.15
72	1800			0.012	0.3	0.009	0.225	0.009	0.225	0.008	0.2	0.007	0.175
84	2100					0.010	0.25	0.010	0.25	0.009	0.225	0.008	0.2
96	2400					0.011	0.275	0.011	0.275	0.009	0.225	0.009	0.225
120	3000					0.011	0.275	0.011	0.275	0.009	0.225	0.009	0.225
144	3600					0.012	0.3	0.012	0.3	0.010	0.25	0.010	0.25
192	4800					0.015	0.375	0.015	0.375	0.012	0.3	0.012	0.3
240	6000							0.020	0.5	0.020	0.5	0.020	0.5
360	9000									0.040	1	0.040	1
480	12000											0.060	1.5

†Ref. Note 2, Figure 3.
*Linear interpolation may be employed for thread lengths between those listed.

Table IV Diameter and Lead Combinations—Dimensions in Inches

Nominal Screw Diameter	Nominal Lead											
0.250	0.080	0.100										
0.3125		0.100	0.125									
0.375		0.100	0.125	0.160								
0.500		0.100	0.125	0.160	0.200							
0.625		0.100	0.125	0.160	0.200	0.250						
0.750			0.125	0.160	0.200	0.250	0.333	0.375				
0.875			0.125	0.160	0.200	0.250	0.333	0.375				
1.000				0.160	0.200	0.250	0.333	0.375	0.400			
1.250				0.160	0.200	0.250	0.333	0.375	0.400	0.500		
1.500				0.160	0.200	0.250	0.333	0.375	0.400	0.500		
1.750					0.200	0.250	0.333	0.375	0.400	0.500		
2.000					0.200	0.250	0.333	0.375	0.400	0.500	0.750	
2.250						0.250	0.333	0.375	0.400	0.500	0.750	
2.500						0.250	0.333	0.375	0.400	0.500	0.750	1.000
3.000							0.333	0.375	0.400	0.500	0.750	1.000
3.500							0.333	0.375	0.400	0.500	0.750	1.000
4.000							0.333	0.375	0.400	0.500	0.750	1.000
4.500								0.375	0.400	0.500	0.750	1.000
5.000									0.400	0.500	0.750	1.000
6.000									0.400	0.500	0.750	1.000
8.000									0.400	0.500	0.750	1.000

Table V Diameter and Lead Combinations—Dimensions in Millimeters

Nominal Screw Dia.	Nominal Lead										
6	2	2.5									
8		2.5	3								
10		2.5	3	4							
12		2.5	3	4	5						
16		2.5	3	4	5	6					
20			3	4	5	6	8				
25				4	5	6	8	10			
32				4	5	6	8	10	12		
40					5	6	8	10	12		
50					5	6	8	10	12	16	
63					5	6	8	10	12	16	20
80						6	8	10	12	16	20
100							8	10	12	16	20
125								10	12	16	20
160								10	12	16	20
200								10	12	16	20

FIG. 2 BALL SCREW SPECIFICATION SHEET

Purchaser ball screw #______________________ Vendor #______________

▽ To be specified by purchaser

⬡ To be specified by vendor

▽ ⬡ To be agreed upon between vendor and purchaser

SCREW AND NUT SPECIFICATIONS:

▽ Screw diameter ______________________ inches or mm

▽ Lead ______________________ inches or mm

▽ Pitch ______________________ inches or mm

▽ Class ______________________

▽ Maximum lead error: ______________________ inch per 12 inches screw thread

______________________ μm per 300 mm screw thread

______________________ inches in full travel

______________________ μm in full travel

▽ Type nut: (   ) single
(   ) double
(   ) other ______________________ (Specify)

▽ Squareness or parallelism nut mounting surface to screw axis

______________________ F.I.M. per inch (per 25.4 mm)

⬡ Number of effective turns per circuit ______________________

⬡ Number of circuits/nut ______________________

⬡ Balls per circuit ______________________

⬡ Nominal ball dia. ______________________ inches or mm.

⬡ Spacer balls ______________________

LOAD SPECIFICATIONS:

▽ Maximum speed ______________________ RPM: Screw rotating (   ); nut rotating (   )

▽ Axial dynamic load, L_{10} load rating, 10^6 inches of travel-lbf (25 400 meter-Newton)

⬡ Axial static load capacity, non-brinelling ______________________ lbf or N

FIG. 2 (CONT'D)

PRELOAD SPECIFICATIONS: (or backlash limitations)

▽ Preload________ to________ lbf or N________ tension;________ compress

⬡ ▽ Axial spring constant nut to screw______________ lbf/inch or N/mm

If different in (+) and (-) directions, specify both

Maximum drag torque at __________ RPM:

▽ With wipers____________ lb. in. or N•m

⬡ Without wipers____________ lb. in. or N•m

⬡ ▽ Variations____________ lb. in. or N•m

GENERAL

Unusual environment–(Describe)________________________

▽ Straightness–see Drawing Fig. 3

▽ Screw mounting attitude:________ Vertical;________ Horizontal;________ Incline

▽ Return tube location:________ Top;________ Bottom;________ Side

⬡ ▽ Wipers:________ One end (Specify)________ Both Ends________ Type

TO BE SHOWN ON DRAWING:

▽ Nut mounting hole pattern and configuration (clearance holes, tapped holes, etc.)

▽ Nut lubrication–specify quantity and grade

▽ Return tube clearance dimensions, inches or mm

▽ Stop dogs

▽ Stroke and location on screw

▽ Vendor and purchaser part number, serial number marking location

⬡ ▽ Heat treatment: ends to be purchaser specification. Ball thread area commensurate with load life ratings

▽ Shipping instructions–crating and preserving instructions

⬡ Material: Nut____________; Screw____________

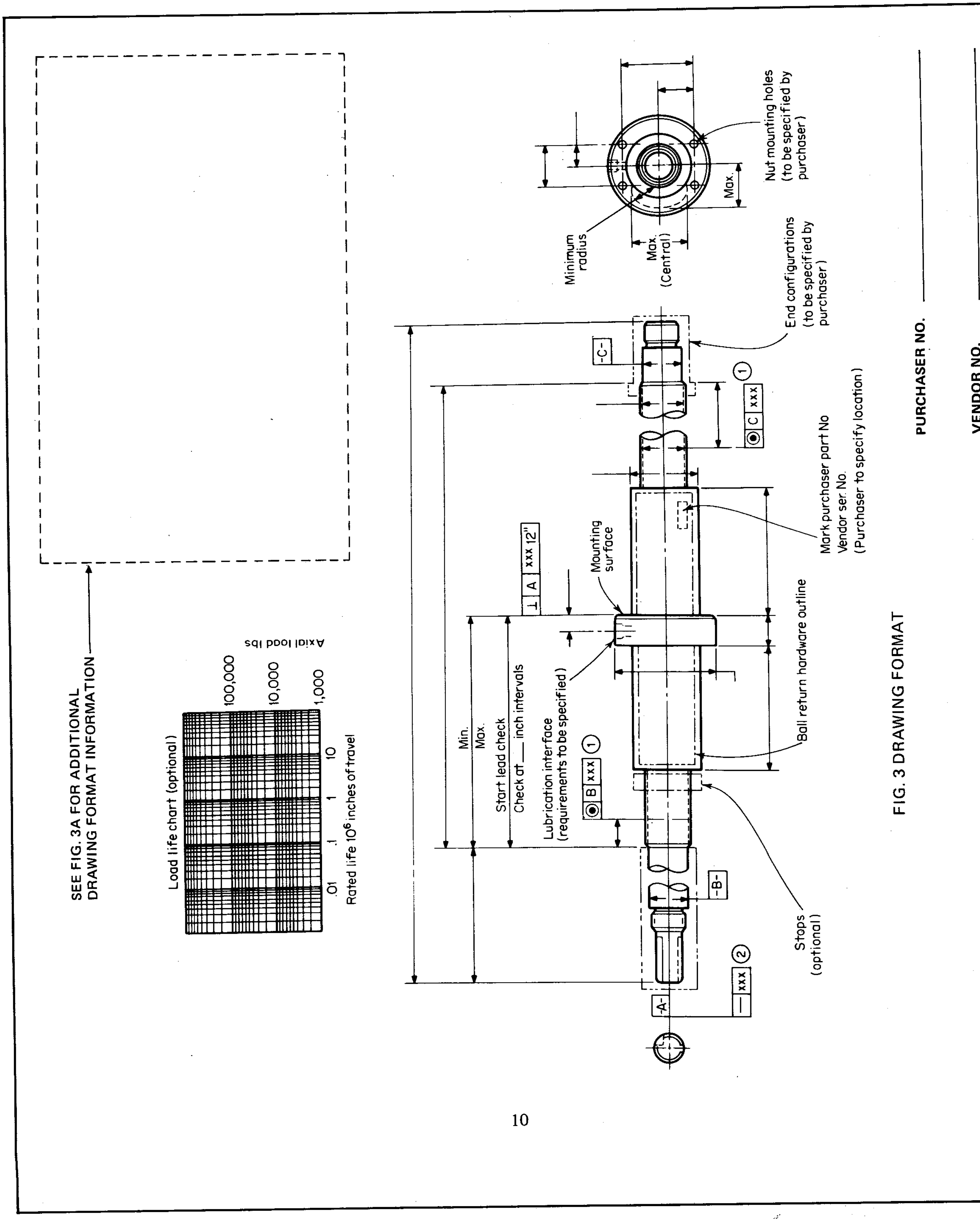


FIG. 3 DRAWING FORMAT

SCORE AND NUT SPECIFICATIONS

Ball Screw Diameter________

Lead______ ______R.H.________L.H.

Pitch______

Screw and Nut Class________

Max. Lead Error______per 12" Screw

______in Full Travel

Number of Effective Turns per Circuit________

Number of Circuits/Nut________

Balls per Circuit________

Nominal Ball Diameter________

Spacer Balls________

LOAD SPECIFICATIONS

Maximum Speed______RPM Screw Rotating ( )

Nut Rotating ( )

Axial Dynamic Load L_{10} Load Rating 10^6 Inches of Travel

Each Direction__________Lb.

Axial Static Load Capacity Non-Brinelling_______Lb.

PRELOAD SPECIFICATIONS (OR BACKLASH LIMITATIONS)

Method of preloading to be specified

Preload______to ______Lb.

Axial Spring Constant Nut to Screw_____Lb./Inch

If different in (+) and (-) directions, specify both.

MAX. DRAG TORQUE At______RPM

With Wipers______Lb. In.

Without Wipers______Lb. In.

Variation______Lb. In.

GENERAL

Screw Mounting Attitude______Vertical________Horizontal

________Inclined

Return Tube Location_____Top______Bottom______Side

Wipers_____One End (Specify)________Both Ends

______Type

No deviations from these specifications will be accepted without written authorization from purchaser.

Vendor to list exceptions if any to Ball Screw Standard #________

Notes: Stiffness drag torque preload and life are inter-related. The requirements are to be agreed upon between the vendor and customer as they effect the specific application.

1. pitch diameter concentricity with journals
2. full indicator movement (straightness)
   (For tolerance values—see Table III)

> This drawing illustrates typical features which should be considered.
>
> Specific configurations of nuts, journals, mounting tolerances, capacities, etc., should be shown on a working drawing.

FIG. 3A (TO BE A PART OF DRAWING FORMAT)

7.0 PERFORMANCE CHARACTERISTICS

7.1 General

The following equations for the basic load rating and static thrust capacity are included to enable the user of this standard to determine the approximate size ball screw assembly necessary to meet requirements. The ball screw rating method is similar to that used by the AFBMA to evaluate multiple row ball bearings. The equations have been modified in accordance to the experience of various manufacturers. Certain limiting conditions have been placed on these equations due to the simplifying assumptions made during their development.

7.2 Limiting Conditions on Equations 7.4, 7.5 and 7.6; 7.8, 7.9 and 7.10

The contact angle must be equal to or greater than 45 degrees.

The conformity ratio must be within the range of 0.53 to 0.62.

The ratio of the pitch diameter to the ball diameter must be within the range of 4:1 to 16:1.

The basic load rating tends to be increasingly conservative as the total number of turns of balls exceeds 7.

The values for the basic load rating and the basic static thrust capacity are valid for ball screws as commonly designed and manufactured and made of hardened steel of Rockwell C Scale, 56 minimum.

7.3 Imperial (Inch) System Symbols

P_i = Basic load rating (1 000 000 inches rated life), lbf
P_{ix} = Rated load at x inches rated life, lbf
T_i = Basic thrust capacity, lbf
LI_i = 1 000 000 inches rated life, inches
LI_{ix} = X inches rated life, inches
d_i = Ball diameter, inches
n = Number of ball turns under a unidirectional load, turns
L_i = Lead, inches/revolution
Z = Number of load carrying balls per turn, balls/turn

7.4 Basic Load Rating (1 000 000 Inches Rated Life)

$$P_i = 4500\, Z^{2/3} d_i^{1.8} n^{0.86} L_i^{1/3}, \text{ lbf}$$

7.5 Basic Static Thrust Capacity (Imperial)

$$T_i = 10\,000 n Z d_i^2, \text{ lbf}$$

7.6 Load Rating at Other Than One Million Inches of Travel

$$P_{ix} = P_i \left(\frac{LI_i}{LI_{ix}}\right)^{1/3} \text{ lbf.}$$

7.7 SI Symbols

P_m = Basic load rating (25 400 meters rated life), newtons
P_{my} = Rated load at Y meters rated life, newtons
T_m = Basic thrust capacity, newtons
LI_m = 25 400 meters rated life, meters
LI_{my} = Y meters rated life
d_m = Ball diameter, millimeters
L_m = Lead, millimeters/revolution
n and Z = Same as in 7.3

7.8 Basic Load Rating (25 400 Meters Rated Life)

$$P_m = 20.16\, Z^{2/3} d_m^{1.8} n^{0.86} L_m^{1/3}, \text{ newtons}$$

7.9 Basic Static Thrust Capacity (Metric)

$$T_m = 68.95 n Z d_m^2 \text{ newtons}$$

7.10 Load Rating at Other Than 25 400 Meters of Travel

$$P_{my} = P_m \left(\frac{LI_m}{LI_{my}}\right)^{1/3} \text{ newtons}$$

7.11 The Equivalent Load for Ball Bearing Screw Assemblies

If the load on a ball screw assembly varies and the magnitudes are known together with the time in percent of the total time that the loads will be effective, the equivalent load

$$P = \sqrt[3]{\frac{C_1 P_1^3 + C_2 P_2^3 + \cdots C_n P_n^3}{100}}$$

where C_1, C_2, C_3, C_n are percentages in which P_1, P_2, P_3, P_n are effective, respectively. The equation is valid for both inch and metric systems if units are kept consistent with each other.

APPENDIX A1

A1.1 GENERAL

The axial deflection between the ball nut and screw under load and the drag torque are frequently considerations in the design of machine tool ball screws.

Different methods of calculating deflection have been proposed in technical literature. The method found to most closely parallel test results is found in *Analysis of Stresses and Deflections,* A. B. Jones.

A summary based on this work is included in this appendix. No. allowance for manufacturing variations is included in this analysis.

When deflection is not critical, an estimated value may be obtained by using the approximate method shown below.

The maximum drag torque equation is included to provide the user with an approximate no-load torque allowance for his drive system. Lubrication, ball track design, the quantity and size of balls, etc., have a great effect on the amount of drag torque. Preload, therefore, cannot be determined from drag torque.

A1.2 SYMBOLS

- a_i = screw I.D., inches
- a_o = effective inner diameter of nut, inches
- B = conformity ratio
- BCD = pitch diameter, inches
- b_i = effective outer diameter of screw, inches
- b_o = nut O.D., inches
- C_δ = deflection factor (See Chart A1)
- d = ball diameter, inches
- E = modulus of elasticity, psi
- f = race conformity ratio
- n = number of ball turns under a unidirectional load, turns
- K = deflection constant
- k = compliance factor, in./lb.
- L = lead, inches/revolution
- $\int$ = axial length of ball track engaged by balls, inches
- P_D = diametral clearance between nut, balls and screw, inches
- r = ball track radius, inches
- T = thrust load, pounds
- T_p = preload, pounds
- y = diametral expansion or contraction of ball nut or screw, inches
- Z = number of load carrying balls per turn, balls/turn
- β = contact angle with diametral lash removed, but with no measurable force applied
- β_o = contact angle with axial lash removed, but with no measurable force applied
- β_i = contact angle with axial load
- θ = helix angle, degrees
- δ = Poisson's ratio

NOTE

The subscripts o and i applied to dimensions indicate nut and screw ball tracks, respectively (does not apply to β).

A1.3 AXIAL DEFLECTION EQUATIONS

$$f_o = \frac{r_o}{d} \qquad f_i = \frac{r_i}{d} \qquad B = (f_o + f_i - 1)$$

$$\cos\beta_o = \cos\beta - \frac{P_D}{2Bd}$$

$$a_o = BCD + \frac{d}{2} \qquad b_i = BCD - \frac{d}{2}$$

$$K = \left[\frac{B \times 10^6}{7.8107\,(C_{\delta_o} + C_{\delta_i})}\right]^{3/2}$$

See chart A1 for values of C_{δ_o} and C_{δ_i}.

$$\theta = \tan^{-1}\frac{1}{\pi BCD}$$

$$k = \frac{1}{\pi E}\left[\frac{1}{\int_o}\left(\frac{b_o^2 + a_o^2}{b_o^2 - a_o^2} + \delta_o\right) + \frac{1}{\int_i}\left(\frac{b_i^2 + a_i^2}{b_i^2 - a_i^2} - \delta_i\right)\right]$$

β_i can be found by the trial and error solution of the following equation. Assume values of β_i and solve for T.

$$T + \frac{2BD \sin^{1/3} \beta_i T^{2/3}}{(nZd^2 K \cos\theta)^{2/3} k} = \frac{2Bd}{k} \sin\beta_i \left[\frac{\cos\beta_o}{\cos\beta_i} - 1\right]$$

$$y_o = \frac{T}{\pi E \int_o \tan\beta_i} \left[\frac{b_o^2 + a_o^2}{b_o^2 - a_o^2} + \delta_o\right]$$

$$y_i = \frac{T}{\pi E \int_i \tan\beta_i} \left[\frac{b_i^2 + a_i^2}{b_i^2 - a_i^2} - \delta_i\right]$$

axial deflection

$$= Bd \left(\tan\beta_i \cos\beta_o - \sin\beta_o - \frac{(y_o + y_i)\tan\beta_i}{2}\right)$$

A1.4 APPROXIMATE DEFLECTION

The following equation may be used as a guideline for calculating an average deflection between the nut and the screw for ball screw assemblies as commonly designed. The more complex analysis shown above should be used for applications where deflection is critical.

$$= \frac{T}{2 \times 10^6 + 3 \times 10^6 (BCD - 1/2)}$$

$$1/2 < BCD \leqslant 4$$

A1.5 DRAG TORQUE (MAXIMUM)

$$= 0.007\ T_p \text{ lb. in.}$$

A1.6 LENGTH VS. PITCH DIAMETER RELATION

For ease of manufacturing, it is recommended that the length of the screw not exceed forty times pitch diameter of the screw.

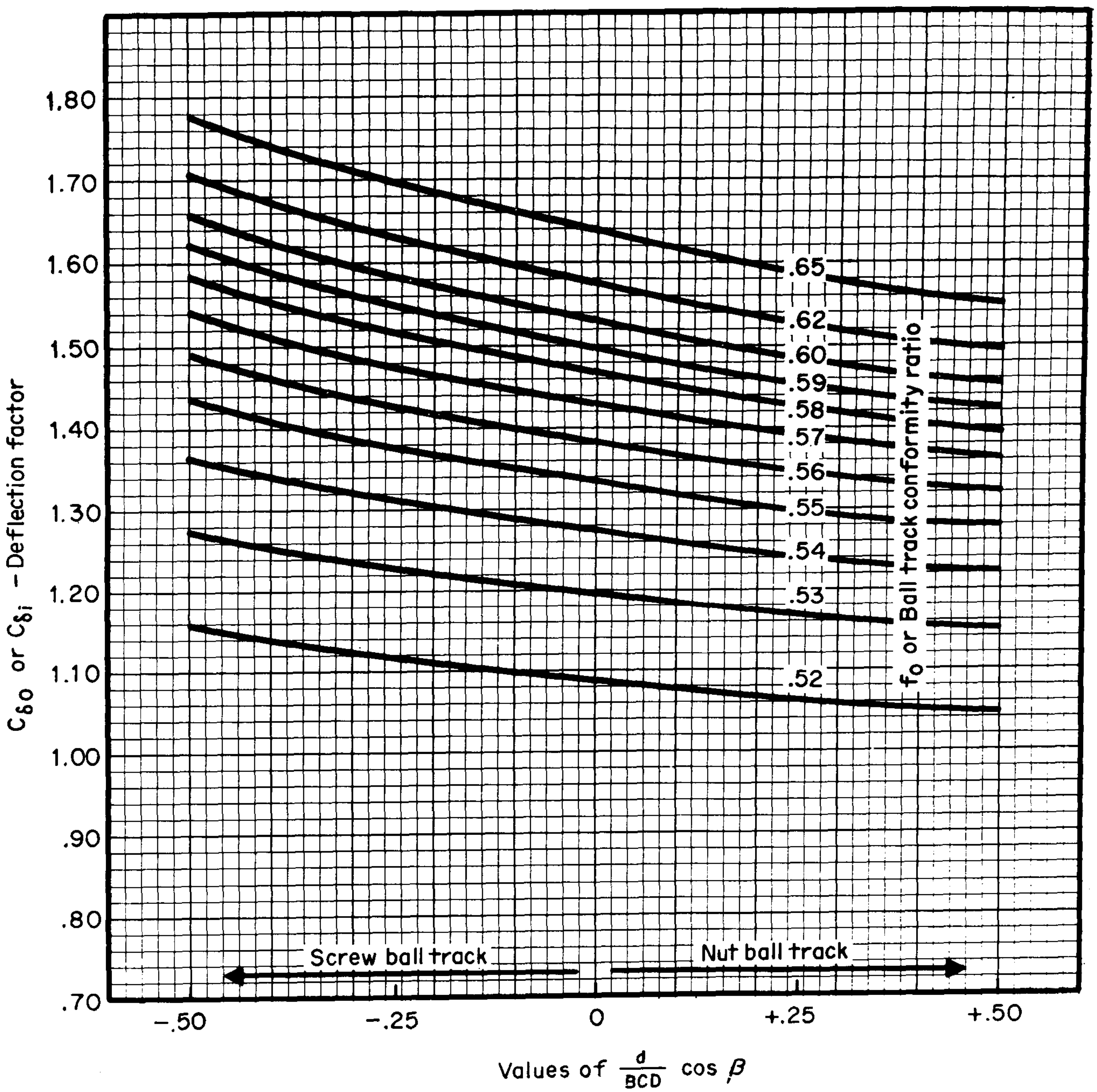

1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
$C_{\delta o}$ or $C_{\delta i}$ – Deflection factor
.65
.62
.60
.59
.58
.57
.56
.55
.54
.53
.52
f_o or Ball track conformity ratio
Screw ball track
Nut ball track
–.50
–.25
0
+.25
+.50
Values of $\frac{d}{BCD}$ cos β

CHART A1

APPENDIX A2

The use of the acceptance template, Figure 1 of Section 3, is demonstrated below. Only eight inch checks are demonstrated for a 48 inch long, class 3 assembly. The point at the 24 inch length does not meet the lead error requirements.

This is an example of a class 3 ball screw assembly. Examples of ball screw assemblies of class 6, 7, and 8 are similar. The permissible lead error is proportional to the screw length. Only acceptance template tests must be passed. Wobble error is in addition to measured lead error.

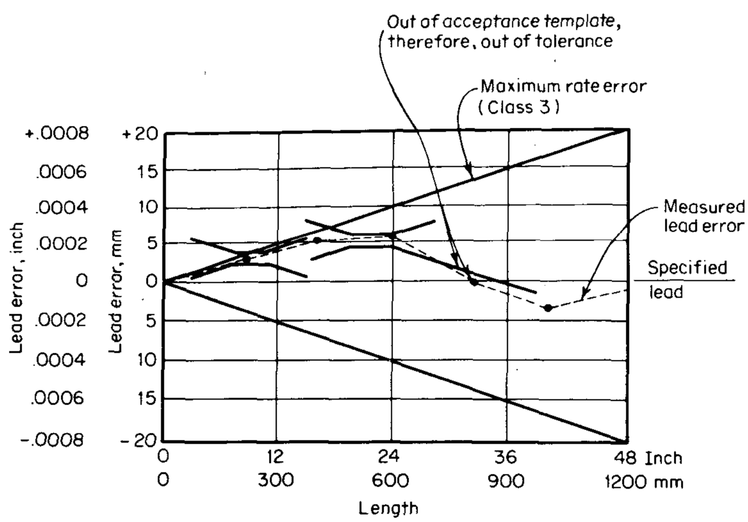


FIG. A1 MAXIMUM RATE ERROR AND ACCEPTANCE TEMPLATE USE—CLASSES 3, 6, 7, AND 8

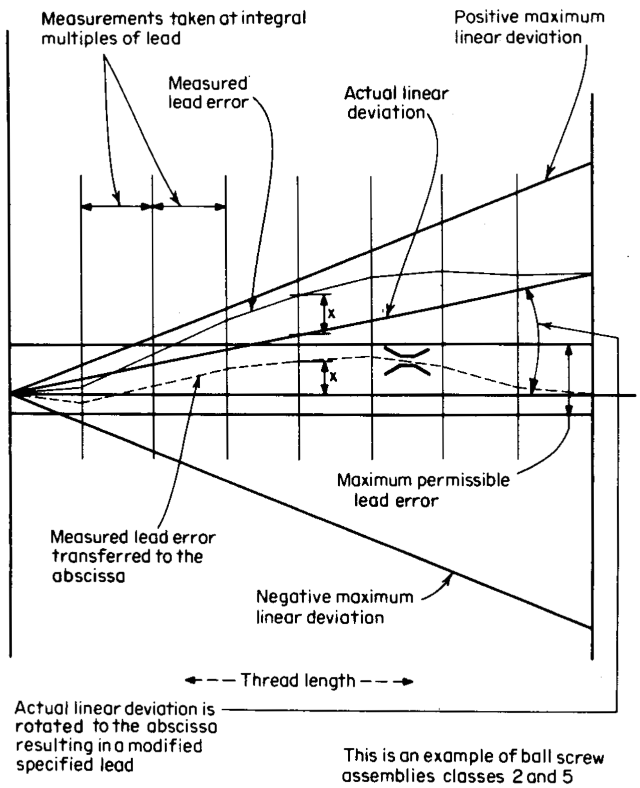
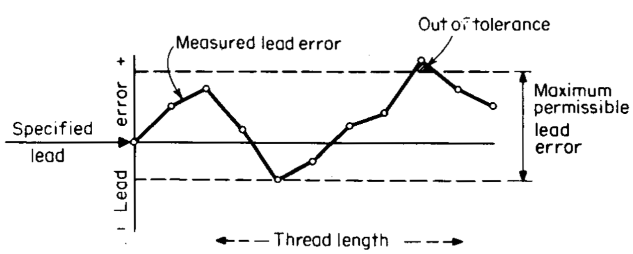


FIG. A2 MAXIMUM LINEAR DEVIATION—CLASSES 2 AND 5



Measured lead error line can be any slope within maximum permissible lead error limits and either all (+) or all (-). No rate error specified or acceptance template used. Wobble error is in addition to maximum permissible lead error.

FIG. A3 MAXIMUM PERMISSIBLE LEAD ERROR—CLASSES 1 AND 4