APTA STANDARDS DEVELOPMENT PROGRAM
RECOMMENDED PRACTICE
American Public Transportation Association
1300 I Street, NW, Suite 1200 East, Washington, DC 20005

APTA PR-M-RP-008-98, Rev. 2
First Published: March 26, 1998
First Revision: Feb. 13, 2004
Second Revision: Feb. 4, 2022

Commuter, Intercity and High-speed Rail
Mechanical Working Group

Passenger Rolling Stock Axle Design

Abstract: This document provides guidelines for the design of passenger rolling stock axles. These guidelines are based on service-proven performance design features.

Keywords: axles, axle, design

Summary: This document describes the design, manufacturing, and testing criteria for axles used on passenger rail vehicles.

Scope and purpose: This Recommended Practice provides guidance for the design of axles for passenger rail vehicles that operate on the general railroad system of transportation. This Recommended Practice can also be applied to passenger vehicle axles used in operations that are not on the general railroad system of transportation. These design recommendations have been developed based on industry best practices and proven-performance experience. The purpose of this document is to provide guidance for the design of passenger car axles, to encourage standardization of passenger car axle designs, and to promulgate the knowledge that has been gained through experience with such designs.

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Participants

The American Public Transportation Association greatly appreciates the contributions of the **Passenger Axle Design Task Group** of the APTA Commuter, Intercity and High-speed Rail Mechanical Working Group, which provided the primary effort in the drafting of this document.

At the time this standard was completed, the task group included the following members:

Glenn Brandimarte, ORX, *Task Group Lead*

Mohamed Alimirah, *Metra*
Frank Banko, *WSP*
Lee Barrington, *ORX (retired)*
David Bennett, *Capital Metro. Trans. Authority*
Eric Bisaillon, *Wabtec Corp.*
B.A. “Brad” Black, *Virginkar & Associates*
Greg Buzby, *SEPTA*
Joshua Coran, *Talgo Inc.*
Brian Creely, *Siemens Mobility, Inc.*
Richard Curtis, *Curtis Engineering Consulting*
Jasen Haskins, *Atkins Global NA*
Greg Holt, *Penn Machine Co.*
John Janiszewski, *Hatch LTK*
Robert Jones, *Stadler Rail Group*
Joe Kenas, *ALSTOM Transport*
Peter Klauser, *Vehicle Dynamics Group*
Karan Kothari, *Amtrak*
Tammy Krause, *Atkins Global NA*
Cameron Lonsdale, *Standard Steel, LLC*
Daniel Luskin, *Amtrak*
Frank Maldari, *MTA Long Island Rail Road*
Eloy Martinez, *Hatch LTK*
Francis Mascarenhas, *Metra*
Katie McCabe, *ORX*
William Minnick, *Omni Strategy*
Luke Morscheck, *Hatch LTK*
Eloy Munoz, *Hatch LTK*
James Pilch, *Standard Steel, LLC*
Brian Pitcavage, *Hatch LTK*
Vinay Tharigopula, *ORX*
Ron Truitt, *HTSI*
Gary Wagner, *Amsted Rail*
David Warner, *SEPTA*
Michael Wetherell, *McKissack & McKissack*
Kristian Williams, *Amtrak*
Todd Williams, *Penn Machine Co.*
Aleksey Yelesin, *ALSTOM Transport*
Kevin Young, *Axis, LLC*

At the time this standard was updated, the Commuter, Intercity and High-speed Rail Mechanical Working Group included the following members:

David Warner, SEPTA, *Chair*
Rudy Vazquez, Amtrak, *Vice Chair*
Paul Jamieson, retired, *Secretary*

Mohamed Alimirah, *Metra*
Carl Atencio, *American Rocky Mountaineer*
Frank Banko, *WSP USA*
Michael Barnes, *Jacobs*
Taft Bearden, *Atkins Global NA*
David Bennett, *Capital Metro. Trans. Authority*
Jonathan Bernat, *New York Air Brake*
Eric Bisaillon, *Wabtec Corp.*
B.A. “Brad” Black, *Virginkar & Associates*
Stephen Bonina, *WSP USA*
Glenn Brandimarte, *ORX*
Richard Bruss, *retired*
Greg Buzby, *SEPTA*
Dennis Cabigting, *STV Inc.*
Elvin Calderon, *Denver Transit Operators*
Paul Callaghan, *Transport Canada*
Gordon Campbell, *Crosslinx Transit Solutions*
Kevin Carmody, *STV Inc.*

David Carter, *New Jersey Transit*
Steve Cavanaugh, *Metrolinx (GO Transit)*
Steve Chrismer, *Amtrak*
Dion Church, *SNC-Lavalin Inc.*
John Condrasky, *retired*
Joshua Coran, *Talgo Inc.*
Michael Craft, *Paragon Robotics*
Brian Creely, *Siemens Mobility, Inc.*
Brendan Crowley, *New York Air Brake*
Ryan Crowley, *Atkins Global NA*
Richard Curtis, *Curtis Engineering Consulting*
Steven Dedmon, *Standard Steel LLC*
Joe Di Liello, *VIA Rail Canada Inc.*
David Diaz, *Hatch LTK*
Adam Eby, *Amtrak*
Phillippe Etchessahar, *ALSTOM Transport*
Gary Fairbanks, *Federal Railroad Administration*
Robert Festa, *MTA Long Island Rail Road*
Steve Finegan, *Atkins Global NA*
Gavin Fraser, *Jacobs*
Francesco Fumarola, *ALSTOM Transport*
Edward Gacsi, *New Jersey Transit*
Joe Gagliardino, *Arcosa*
Sebastien Geraud, *ALSTOM Transport*
Jeffrey Gordon, *Federal Railroad Administration*
Guillaume Ham-Livet, *ALSTOM Transport*
Eric Harden, *Knorr Brake Corp.*
Nick Harris, *Hatch LTK*
Jasen Haskins, *Atkins Global NA*
James Herzog, *Hatch LTK*
Kenneth Hesser, *Hatch LTK*
Lew Hoens, *MTA Metro-North Railroad*
Christopher Holliday, *STV Inc.*
Greg Holt, *Penn Machine Co.*
George Hud, *Hatch LTK*
John Janiszewski, *Hatch LTK*
MaryClara Jones, *Transportation Technology Center*
Robert Jones, *Stadler Rail Group*
Larry Kelterborn, *LDK Advisory, Inc.*
Joseph Kenas, *ALSTOM Transport*
Peter Klauser, *Vehicle Dynamics Group*
Christian Knapp, *Denver Transit Operators*
Karan Kothari, *Amtrak*
Heinz-Peter Kotz, *Siemens Mobility, Inc.*
Scott Kramer, *Arcosa*
Tammy Krause, *Atkins Global NA*
Pallavi Lal, *Hatch LTK*
Peter Lapre, *Federal Railroad Administration*
Nicolas Lessard, *ALSTOM Transport*
Cameron Lonsdale, *Standard Steel, LLC*
Daniel Luskin, *Amtrak*
Chris Madden, *Amtrak*
Francesco Maldari, *MTA Long Island Rail Road*
Brian Marquis, *Volpe Natl. Trans. Systs. Center*
Eloy Martinez, *Hatch LTK*
Francis Mascarenhas, *Metra*
Raynald Masse, *EXO*
Maria Mauri, *Wabtec Corp.*
Robert May, *Hatch LTK*
Ronald Mayville, *Simpson Gumpertz & Heger, Inc.*
Patrick McCunney, *Atkins Global NA*
Gerard McIntyre, *Knorr Brake Corp.*
Bryan McLaughlin, *New York Air Brake*
William Minnick, *Omni Strategy*
Luke Morscheck, *Hatch LTK*
Karl Mullinix, *Knorr Brake Corp.*
Joshua Munoz, *Hatch LTK*
Paul O'Brien, *Transit District of Utah*
Chase Patterson, *Voith Turbo, Inc.*
Joe Patterson, *Amsted Rail*
John Pearson, *Hatch LTK*
Martin Petzoldt, *Railroad Friction Products, LLC*
James Pilch, *Standard Steel, LLC*
Ian Pirie, *STV Inc.*
Brian Pitcavage, *Hatch LTK*
Brandon Reilly-Evans, *Hatch LTK*
Peter Reumueller, *Siemens Mobility, Inc.*
Danial Rice, *Wabtec Corp.*
Carol Rose, *STV Inc.*
Thomas Rusin, *Rusin Consulting*
Mehrdad Samani, *Hatch LTK*
Gerhard Schmidt, *Siemens Mobility, Inc.*
Martin Schroeder, *Jacobs*
Richard Seaton, *TDG Transit Design Group*
Frederic Setan, *ALSTOM Transport*
Patrick Sheeran, *Hatch LTK*
Melissa Shurland, *Federal Railroad Administration*
David Skillman, *Amtrak*
Benjamin Spears, *Hatch LTK*
Rick Spencer, *Knorr Brake Corp.*
Rex Springston, *AECOM*
Mark Stewart, *Hatch LTK*
Jonathan Sunde, *Strato Inc.*
Lukasz Szymsiak, *VIA Rail Canada, Inc.*
Mehdi Taheri, *Raul V. Bravo & Associates, Inc*
Ali Tajaddini, *Federal Railroad Administration*
Jeff Thompson, *SEPTA*
Matthew Todt, *Amsted Rail*
Michael Trosino, *Amtrak*
Ron Truitt, *HTSI*
Anthony Ursone, *UTC/Rail & Airsources, Inc.*
Frank Ursone, *UTC/Rail & Airsources, Inc.*
Gary Wagner, *Amsted Rail*
Michael Wetherell, *McKissack & McKissack*

Brian Whitten, *SNC-Lavalin Inc.*
Kristian Williams, *Amtrak*
Todd Williams, *Penn Machine Co.*
Nicholas Wilson, *Transportation Technology Center*
Tim Wineke, *Knorr Brake Corp.*
Reggie Wingate, *Knorr Brake Corp.*
Aleksey Yelesin, *ALSTOM Transport*
Kevin Young, *Axis, LLC*
Gregory Yovich, *NICTD*
Steven Zuiderveen, *Federal Railroad Administration*

Staff advisers
Narayana Sundaram, *American Public Transportation Association*
Nathan Leventon, *American Public Transportation Association*

Introduction

This introduction is not part of APTA PR-M-RP-008-98, Rev. 2, "Passenger Car Axle Design."

This recommended practice applies to all:

- railroads that operate intercity or commuter passenger train service on the general railroad system of transportation; and
- railroads that provide commuter or other short-haul rail passenger train service in a metropolitan or suburban area, including public authorities operating passenger train service.

This recommended practice does not apply to:

- rapid transit operations in an urban area that are not connected to the general railroad system of transportation;
- tourist, scenic, historic, or excursion operations, off the general railroad system of transportation;
- operation of private cars, including business/office cars and circus trains unless otherwise required by other standards or regulations;
- railroads that operate only on track inside an installation that is not part of the general railroad system of transportation

Historically, specifications for passenger car axles have referenced The Association of American Railroads (AAR)'s standards. However, these AAR standards do not specifically address passenger car axles, with the exception of a small portion of Amtrak axle designs. The AAR deals almost exclusively with freight car equipment. Pertinent aspects of modern passenger vehicles are completely absent from AAR specifications.

The strength of the AAR in relation to passenger car axle design is primarily in the area of materials specifications. The AAR's development of materials for freight car axles is applicable and valuable in the design of passenger car axles. Where the application of AAR specifications is valuable and applicable to passenger car axles, those specifications have been included. Additionally, other materials—most notably 4140 and 4130 steel grades, having been service-proven—are often better suited for passenger axles, and those materials are included in this standard.

> **NOTE:** This document includes end notes to provide additional background, history and insights to certain sections. The numbered end notes are found in Appendix A.

Passenger Rolling Stock Axle Design

1. Scope of this document

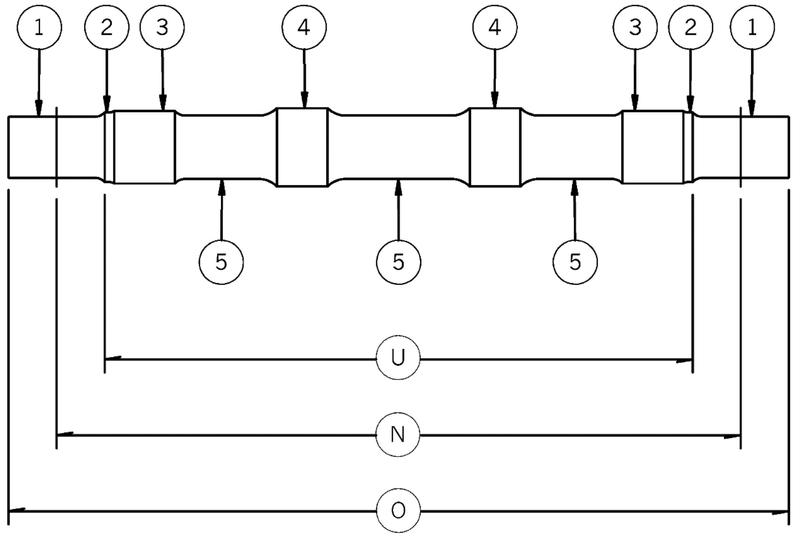
1. This recommended practice applies to steel axles intended for use on North American rail passenger vehicles other than high-speed rail vehicles. This includes axles for MU cars, coaches, non-passenger-carrying cars, and locomotives that are intended for use in passenger service.
2. This recommended practice applies to U.S. Department of Transportation Federal Railroad Administration speed classifications for Tier 1. This recommended practice may be applied to Tier 2 vehicles with appropriate engineering evaluation.
3. This recommended practice applies to single-piece steel axles on which two wheels are press-fitted.
4. This recommended practice applies to both inboard and outboard bearing axles.
5. This recommended practice applies to both powered and unpowered axles.
6. This recommended practice applies to both solid and hollow axles.
7. This recommended practice is not intended for application to independently rotating single- or two-wheel axles, e.g., stub axles and crank axles.
8. Axles designed prior to implementation of this recommended practice may be replaced as originally designed when they will be used on the vehicles for which they were original equipment.

2. Basic nomenclature for axles

1. **Body:** For an outboard bearing axle, the body is the portion of the axle between the wheel seats; the body of an inboard bearing axle is the portion of the axle between the two bearing shoulders.[1]
2. **Body segment:** Other than relief grooves, any part of the body of an axle onto which no component is fitted.[2]
3. **N-dimension:** The distance between the centerlines of the two axle bearings.
4. **O-dimension:** The overall length of an axle.
5. **U-dimension:** For outboard bearing axles, the distance between the inboard edges of the two axle bearing seat fillets. The U-dimension for inboard bearing axles is the distance between the two axle bearing shoulder faces.
6. **Relief groove:** A radiused groove between two adjacent seats or between a seat and a body segment.[3]

7. **Outboard bearing axle nomenclature (typical):** See **Figure 1**.

FIGURE 1
Outboard Bearing Axle with Two Brake Disc Seats

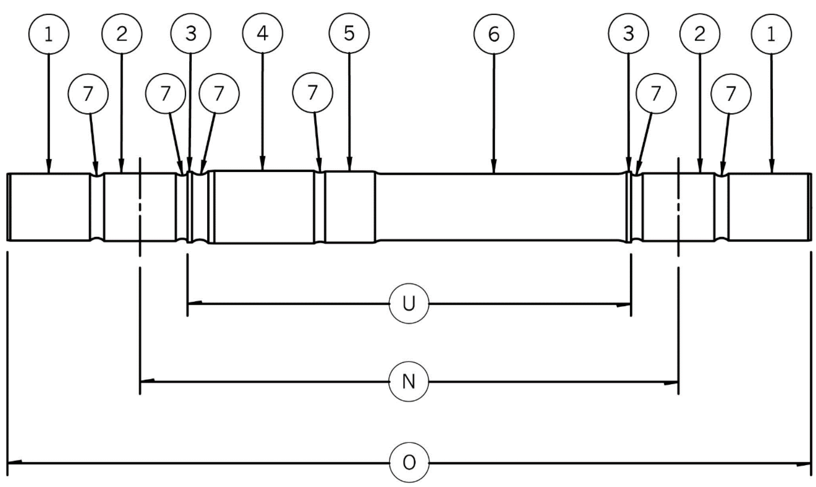


1: Bearing seat
2: Dust guard seat
3: Wheel seat
4: Brake disc seat
5: Body segment

U: Bearing location
N: Bearing centerline
O: Overall length

8. **Inboard bearing axle nomenclature (typical).** See **Figure 2**.

FIGURE 2
Inboard Bearing Axle with Gearbox and Ground Ring Seats

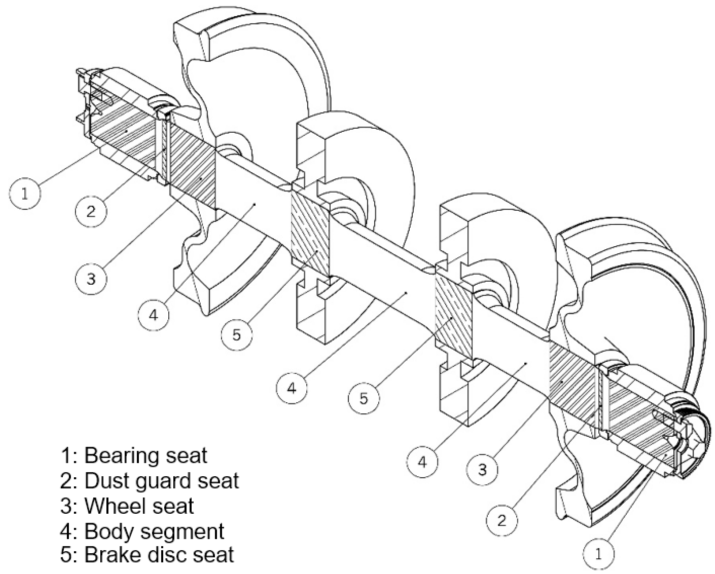


1: Wheel seat
2: Bearing seat
3: Bearing shoulder
4: Gearbox seat
5: Ground ring seat
6: Body segment
7: Relief groove

U: Bearing location
N: Bearing centerline
O: Overall length

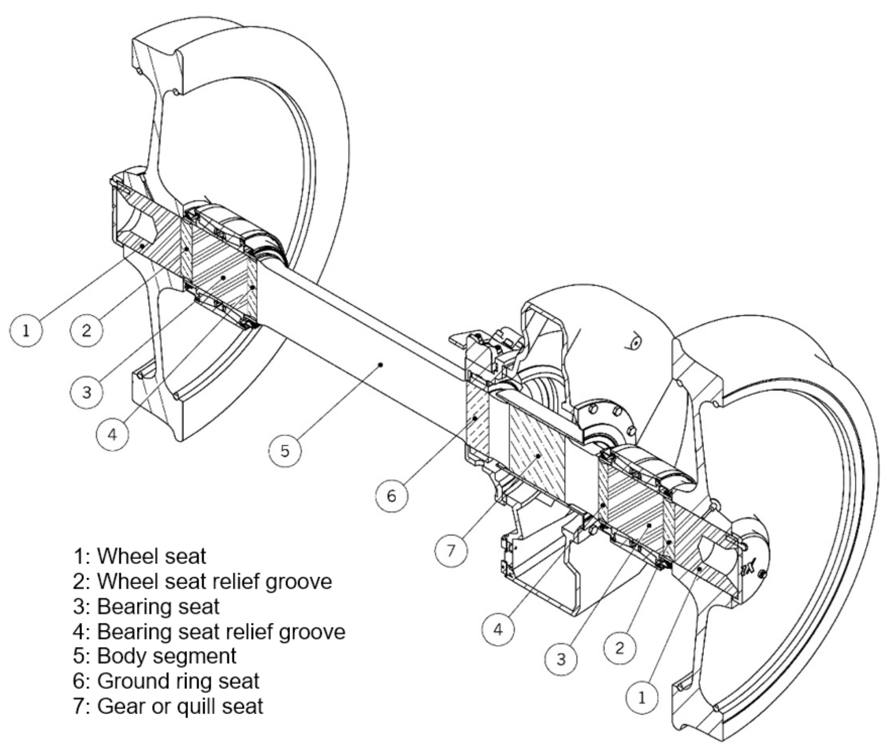
9. **Outboard bearing axle nomenclature, wheel set assembly view, with two axle-mounted brake discs.** See **Figure 3**.

FIGURE 3
Outboard Bearing Wheel Set Assembly with Two Brake Discs



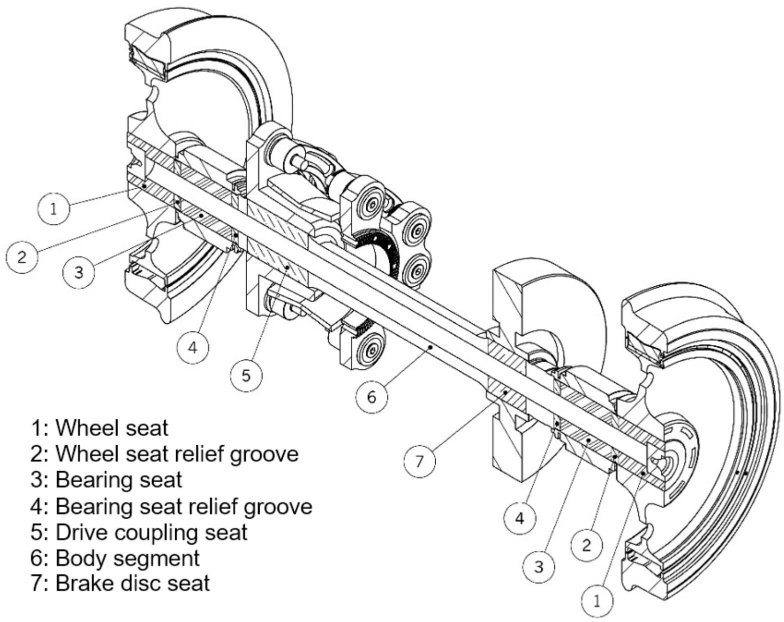
10. **Inboard bearing axle nomenclature, wheel set assembly view, with geared drive unit.** [4] See **Figure 4**.

FIGURE 4
Inboard Bearing Wheel Set Assembly with Geared Drive Unit and Ground Ring



11. **Inboard bearing axle nomenclature, wheel set assembly view, with drive coupling.** See **Figure 5**.

FIGURE 5
Inboard Bearing Wheel Set Assembly with Drive Coupling and Brake Disc



2.1 Axle diameter codes

The following codes[5] should be used to refer to axle diameters. Diameters are referenced with these codes using lower-case alphabetic characters.

These codes may be subscripted when more than one of the same code is used for an axle. For example, i_S could be used for the diameter of the wheel seat on the serial numbered side (S-side) of the axle, while i_T would be used to show the diameter of the T-side wheel seat. See **Table 1**.

TABLE 1
Diameter Code Descriptions

c	Coupling seat
d	Brake disc seat
e	Ground ring seat
f	Undercut
g	Axle bearing seat
h	Dust guard or bearing shoulder
i	Wheel seat
j	Motor support journal
k	Body segment (if multiple, then k_0 for middle segment when present, additional sections inboard to outboard on S and T sides, e.g., k_{S2}, k_{S1}, k_0, k_{T1}, k_{T2} for five segments)
p	Gear unit bearing seat

TABLE 1
Diameter Code Descriptions

q	Quill seat or bull gear seat
r	Radius
t	Threaded hole, nominal diameter and pitch
x	Chamfer or counterbore
y	Relief groove
z	Oil slinger seat

1. **Outboard bearing axle diameters**

FIGURE 6
Outboard Bearing Axle with Two Brake Disc Seats

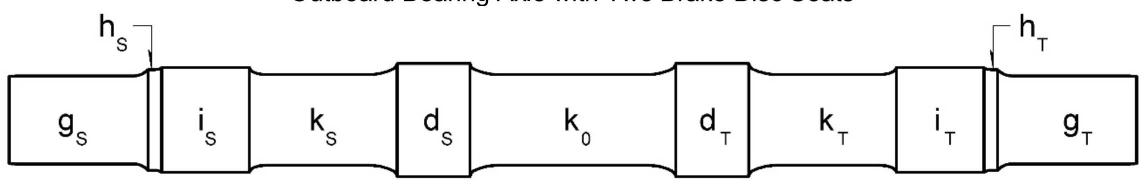


FIGURE 7
Outboard Bearing Axle with Plain Bearing Traction Motor Support Journals and Gear Seat

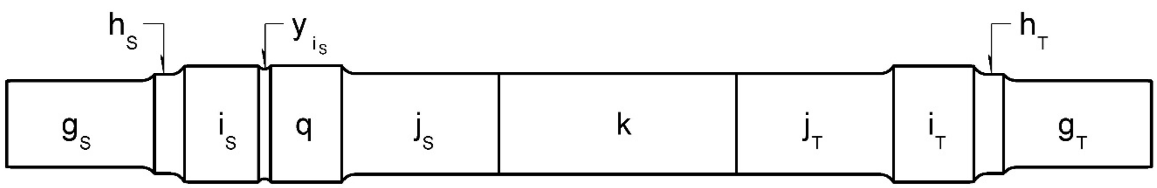


FIGURE 8
Outboard Bearing Axle with Drive Coupling Seat

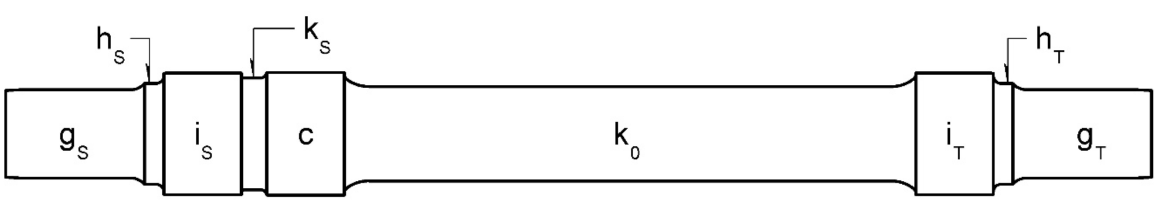
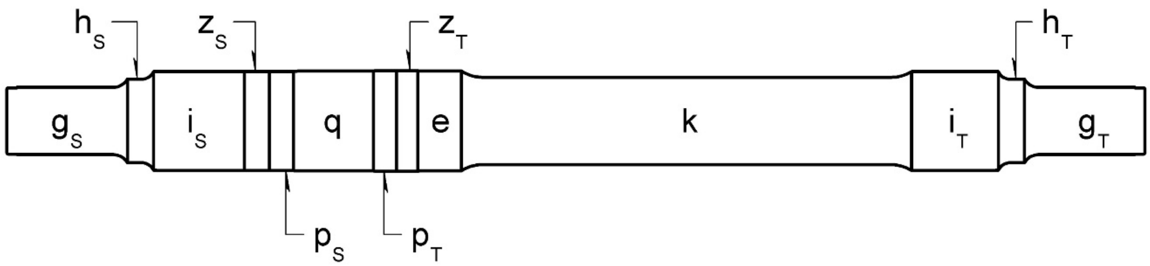


FIGURE 9

Outboard Bearing Axle with Gear Unit Components Seats and Ground Ring Seat



2. **Inboard bearing axle diameters**

FIGURE 10

Inboard Bearing Axle with Drive Coupling, Brake Disc, and Ground Ring Seats

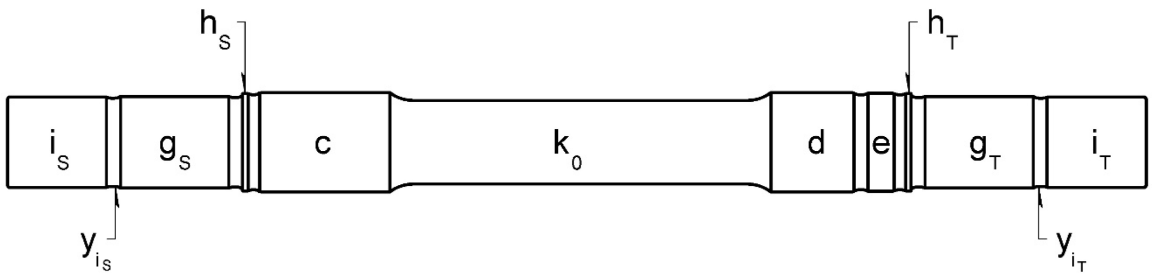


FIGURE 11

Detail View of Figure 10 Showing Bearing Seat Relief Groove, Short Body Segment, and Coupling Seat

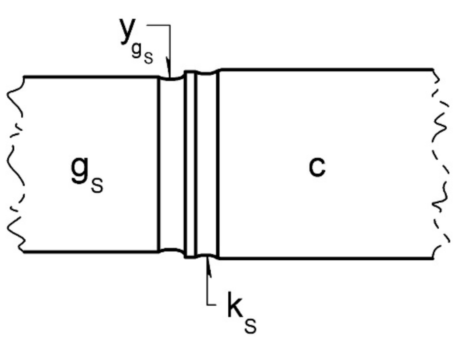


FIGURE 12

Detail View of Figure 10 Showing Bearing Seat Relief Groove, Short Body Segments, and Ground Ring Seat

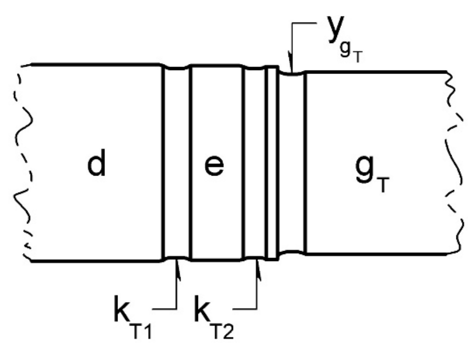


FIGURE 13

Inboard Bearing Axle with Gearbox and Ground Ring Seats

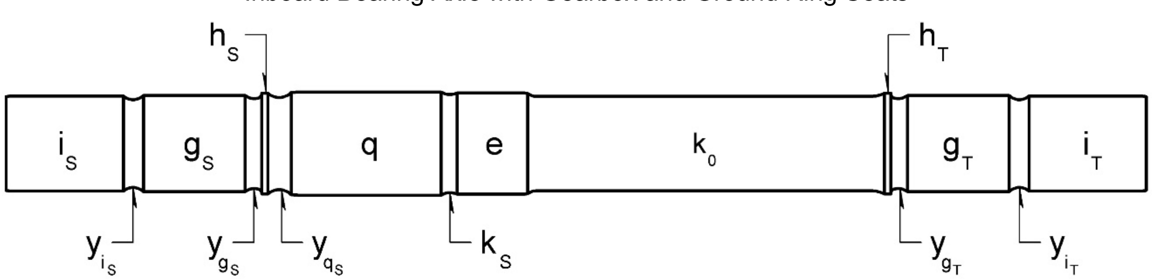


FIGURE 14
Inboard Bearing Axle with Gear Unit Components Seats and Ground Ring Seat

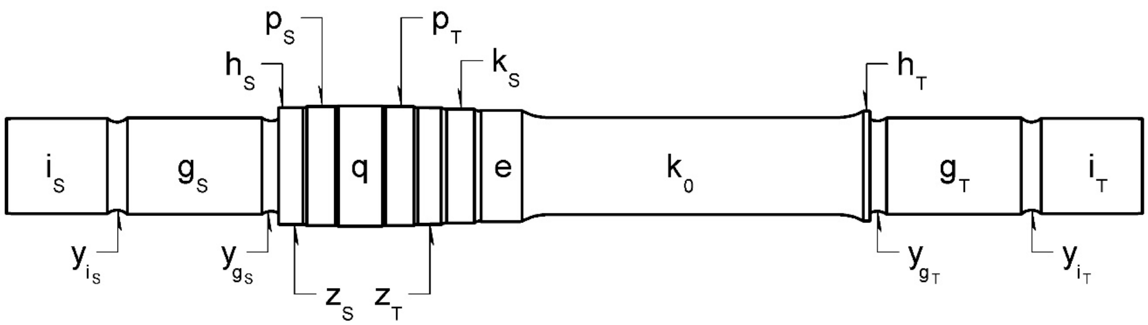
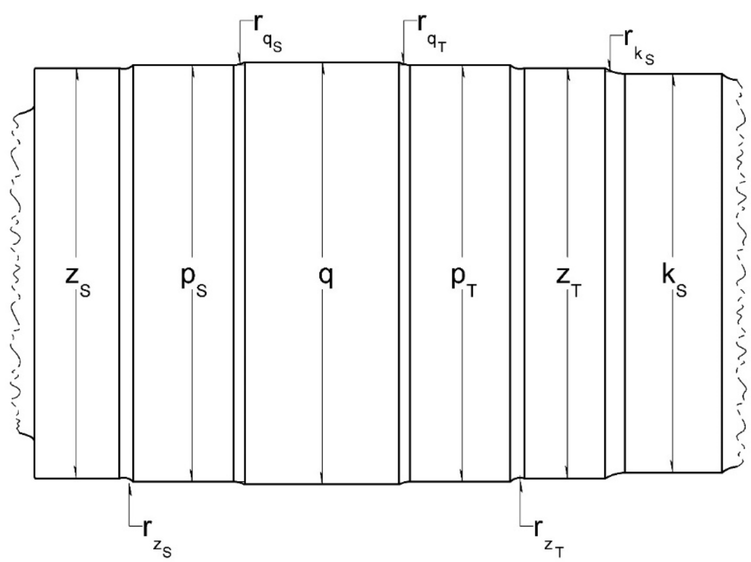


FIGURE 15
Detail View of Figure 14 Gear Unit Components Seats and Transition Radii



2.2 Axle length codes

The following codes should be used to refer to axle segment lengths. Lengths are referenced with these codes using upper-case alphabetic characters.

These codes may be subscripted when more than one of the same code is used for an axle. For example, G_S could be used for the length of the bearing seat on the serial numbered side (S-side) of the axle, while G_T would be used to show the length of the T-side bearing seat.

TABLE 2
Length Code Descriptions

A	Brake disc centerline → brake disc centerline
B	Bearing shoulder → bearing centerline
C	Coupling seat

TABLE 2

Length Code Descriptions

D	Brake disc seat
E	Ground ring seat
F	Undercut
G	Axle bearing seat
H	Dust guard
I	Wheel seat
J	Motor support
K	Body segment
L	Inside of wheel seat → inside of wheel seat
M	Outside of wheel seat → outside of wheel seat
N	Bearing centerline → bearing centerline
O	Overall length
P	Gear box bearing seat
Q	Quill seat or bull gear seat
R	Radius
T	End bore
U	Bearing shoulder —> bearing shoulder (inboard axle) Edge of bearing seat —> edge of bearing seat (outboard axle)
V_d	Drilled hole, depth
V_t	Threaded hole, depth
W	End of axle → bearing shoulder
X	Chamfer or counterbore
Y	Relief groove
Z	Oil slinger seat

1. **Outboard bearing axle lengths**

FIGURE 16
Outboard Bearing Axle with Two Brake Disc Seats

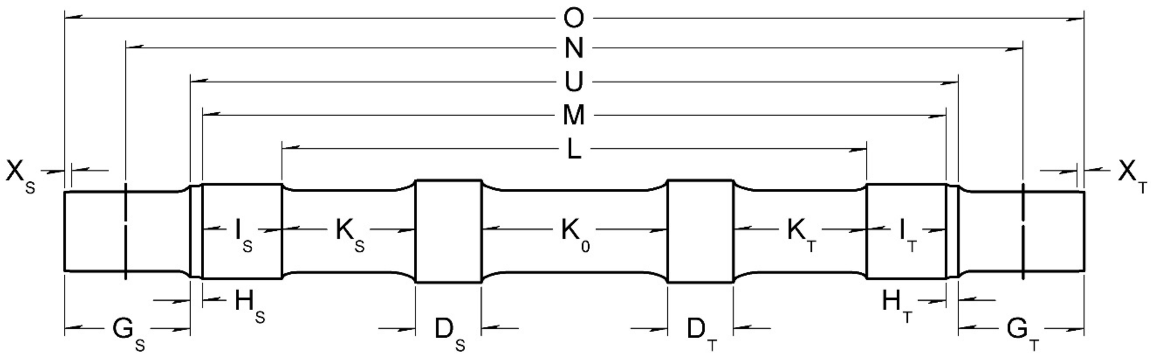


FIGURE 17
Outboard Bearing Axle with Plain Bearing Traction Motor Support Journals and Gear Seat

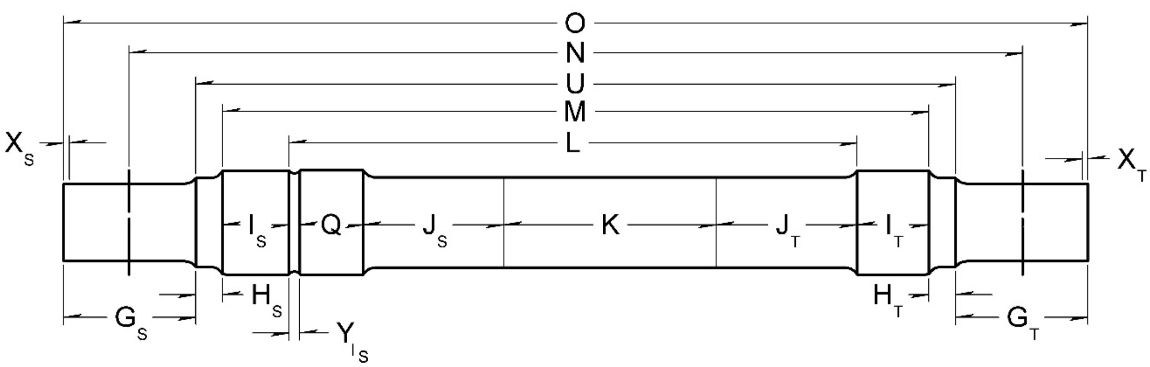


FIGURE 18
Outboard Bearing Axle with Drive Coupling Seat

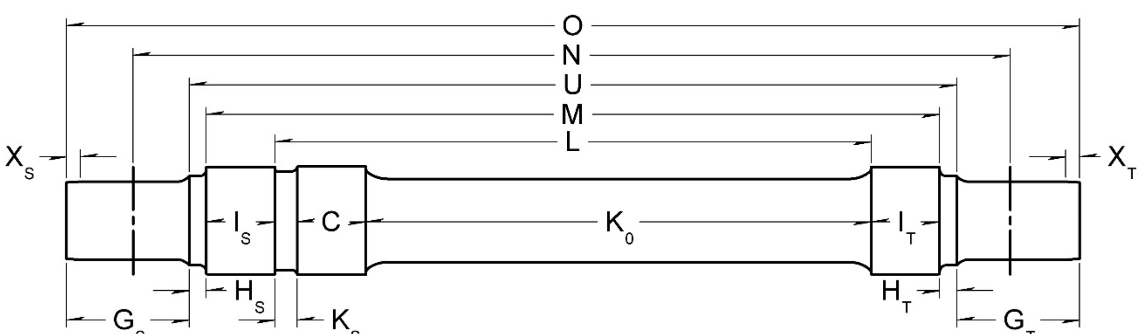
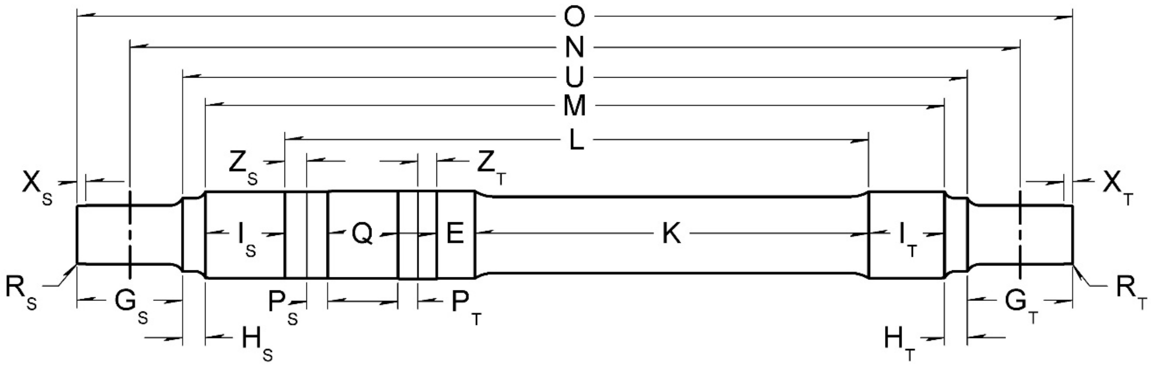


FIGURE 19
Outboard Bearing Axle with Gear Unit Components Seats



2. **Inboard bearing axle lengths**

FIGURE 20
Inboard Bearing Axle with Coupling, Brake Disc, and Ground Ring Seats

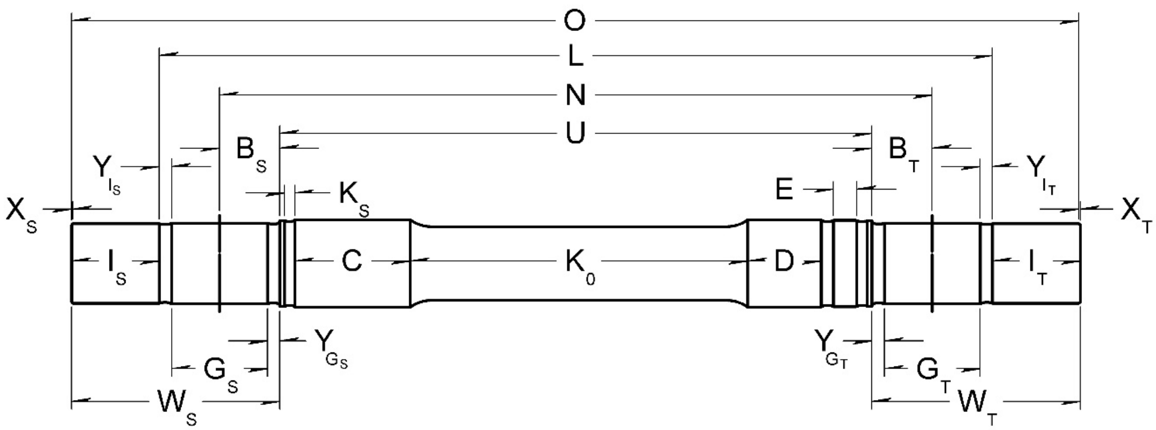


FIGURE 21
Detail View of Figure 20 Showing Bearing Seat Relief Groove, Short Body Segments, and Ground Ring Seat

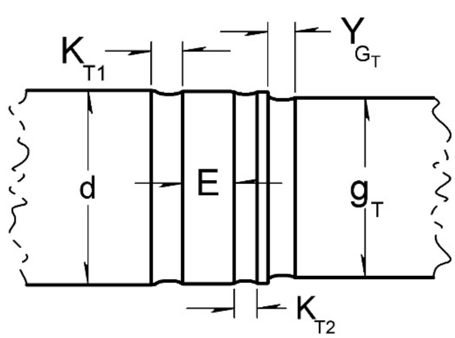


FIGURE 22

Inboard Bearing Axle with Gearbox Quill Seat and Ground Ring Seat

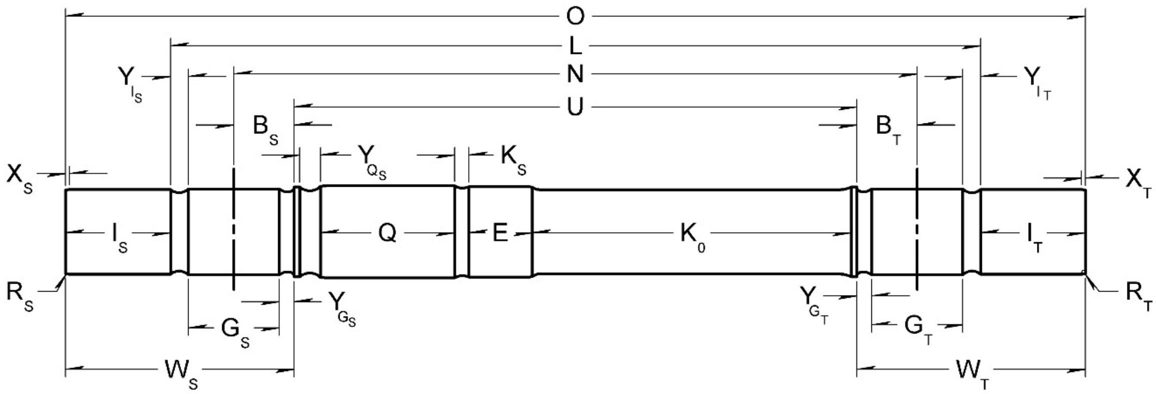


FIGURE 23

Inboard Bearing Axle with Gear Unit Components Seats and Ground Ring Seat

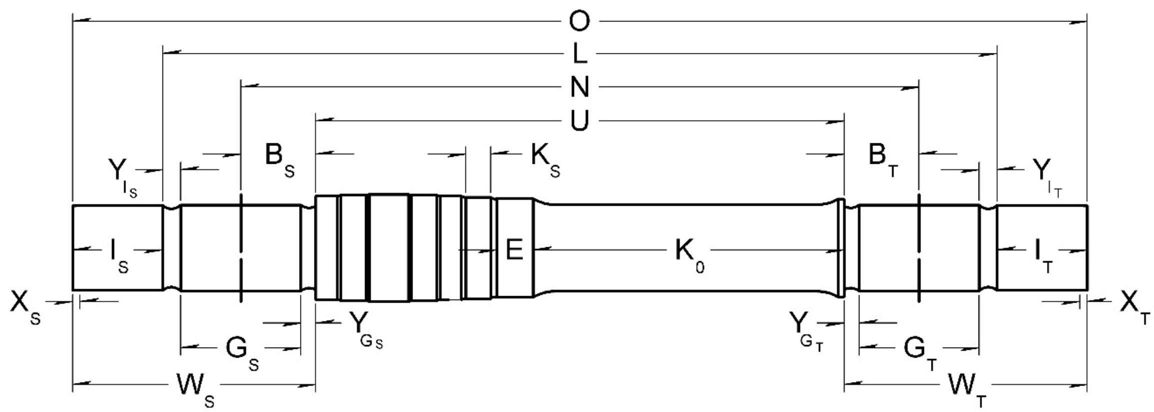
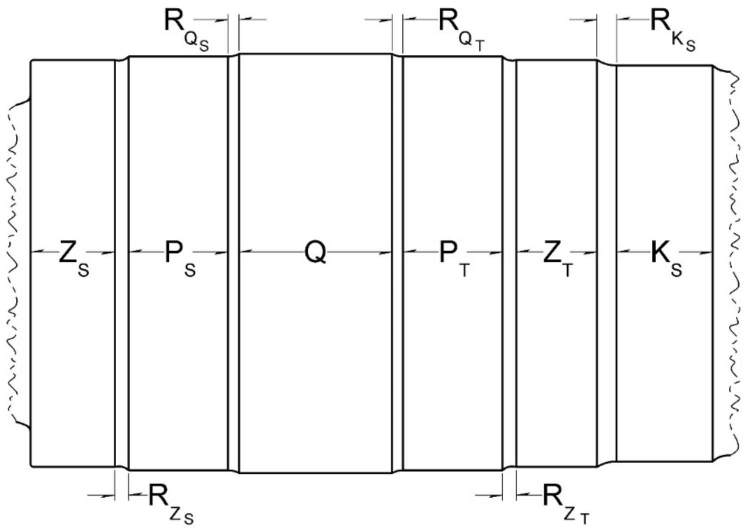


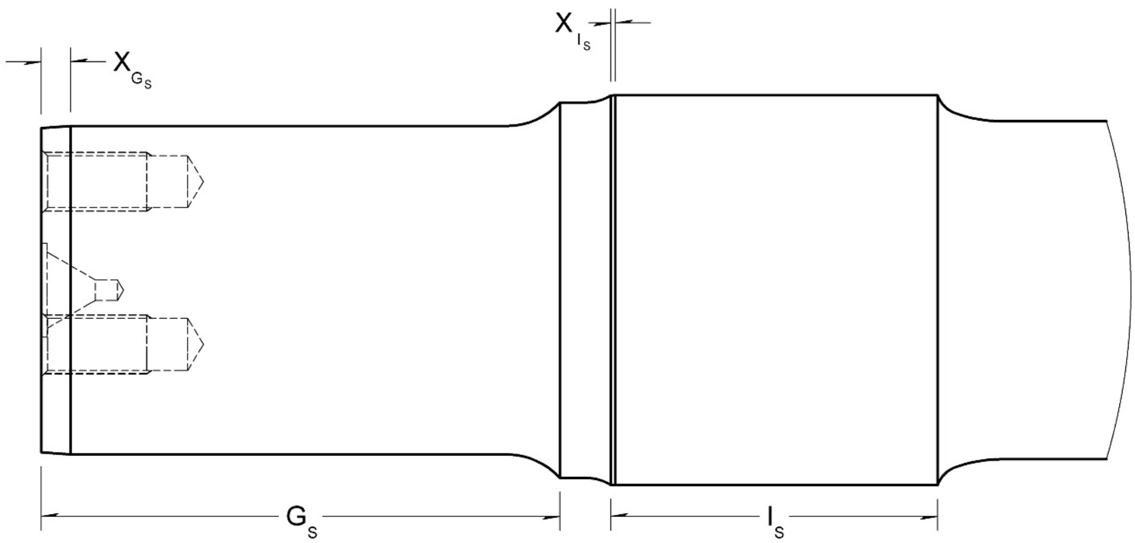
FIGURE 24

Detail View of Figure 23 Gear Unit Components Seats and Transition Radii



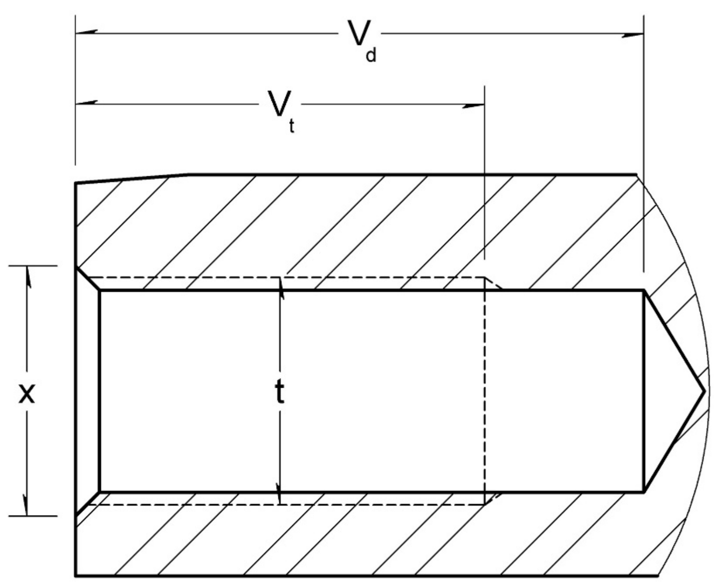
3. **Axle seat chamfer lengths (applies to inboard and outboard bearing designs, outboard bearing axle shown)**

FIGURE 25
Outboard Bearing Axle Showing Bearing Seat and Wheel Seat Chamfers



4. **Drilled and tapped hole depths and inside diameter (ID) chamfer**

FIGURE 26
Dimension Codes for Drilled and Tapped Holes



3. Manufacturing cycle

1. The manufacturing cycle for railroad axles consists of these steps:
   - manufacturing of raw steel
   - forging
   - heat treatment
   - final machining
   - cold-rolling when applicable
2. Steel is manufactured as ingots or blooms and supplied to the axle producer.
3. After dividing the ingot or bloom into appropriately sized blocks, the producer forges those blocks into billets or bars. Bars may be forged directly from the full-sized ingot or bloom:
   - Forging may be accomplished by a hammer.
   - Forging may be accomplished by rolling.
4. Hammer forging must reduce the cross-sectional area of the ingot or bloom by a factor of at least 3:1.
5. Roll forging must reduce the cross-sectional area of the ingot or bloom by a factor of at least 9:1.
6. The forged bar or billet must be heat-treated to attain its final physical properties.
7. The heat treated bar or billet must be machined to achieve its final dimensions.
8. Hollow axles must be manufactured by deep hole boring solid bars or rough-turned axles.

3.1 Axle material

1. Axles must be manufactured from the following steel classes:
   - AAR M-101 F with restricted manganese content
   - ASTM A29/A29M 4140 with restricted sulfur content
   - ASTM A29/A29M 4130 with restricted sulfur content
2. Axle steel grades other than those listed above are acceptable if approved by the end user of the axle.

3.2 Axle producers

1. Axle billets and bars must be produced by entities having an AAR-approved M-1003 quality assurance certification or having an equivalent quality assurance program.
2. Axle producers must be approved by the AAR for the production of axles.
3. Axle producers other than those approved by the AAR are acceptable if approved by the end user.
4. The following factors should be considered in the evaluation for acceptance of non-AAR approved producers.
   - Existence of a formal quality assurance program equivalent to AAR M-1003
   - Periodic independent audits of quality assurance system
   - Experience in the production of railway axles
   - Service proven performance levels
   - Compliance with applicable internationally recognized industry standards

3.3 Heat treaters and heat treatment

1. Final heat treatment of axle material must produce the mechanical properties prescribed in this recommended practice .
2. Grade F axles must be normalized and tempered. It is not necessary to double normalize.
3. Grade G axles must be quenched and tempered.
4. Grade H axles must be normalized, quenched, and tempered.
5. Axle manufacturers are responsible for the selection and monitoring of subcontracted heat treatment facilities and for heat treatment meeting the requirements specified herein.
6. Axle manufacturers utilizing subcontracted heat treaters must quality audit those facilities at least once every five years.

7. For heat treatment of APTA 1052 class material (Table 3) by AAR-approved axle producers, the heat treatment processing must be made in accordance with AAR M-101, provided that the mechanical properties specified in this standard are attained:
    - For heat treatment made by AAR-approved axle producers, double normalizing is not required. A single normalizing treatment is sufficient as long as the required properties are obtained.
    - For heat treatment made by AAR-approved axle producers, the AAR record-keeping requirements of M-101 must be maintained.
8. For heat treaters other than AAR-approved axle producers, heat treatment processes must comply with AMS H-6875 or AMS 2759, as appropriate:[6]
    - For heat treaters other than AAR-approved axle producers, heat treating pyrometric equipment, i.e., thermal processing equipment, temperature sensors, and instrumentation, must comply with AMS 2750.
    - For heat treaters other than AAR-approved axle producers, records must include identification of the specific material heat-treated in each charge, a temperature log versus time for the duration of the charge, and the equipment used to process the charge.

3.4 Axle manufacturers

1. The axle manufacturer is responsible for manufacturing axles in accordance with the specifications provided by the purchaser of those axles.
2. Axle manufacturers must be approved by the AAR for the manufacture of axles.
3. Axle manufacturers other than those approved by the AAR may be acceptable when approved by the end user of the axle.
4. The following factors should be considered in the evaluation for acceptance of non-AAR approved manufacturers.
    - Existence of a formal quality assurance program equivalent to AAR M-1003
    - Periodic independent audits of quality assurance system
    - Experience in the manufacturing of railway axles
    - Service proven performance levels
    - Compliance with applicable internationally recognized industry standards

3.5 Material chemical compositions (classes)

1. APTA 1052, shown in Table 3, is a steel class compatible with all AAR steel material requirements. APTA 1052 chemistry requirements meet fully the requirements of AAR M-101 for all three AAR classes, F, G, and H.
2. APTA 1052 has chemical restrictions that are not specified in AAR M-101. Those restrictions, though, fall within permissible ranges of AAR M-101.
3. APTA 1052 restricts carbon content to 0.45 - 0.59 ppm, the same as that for AAR class F, allowing it to meet the AAR requirements for all three M-101 classes, F, G, and H. AAR M-101 classes G and H have no carbon restriction whatsoever.
4. APTA 1052 restricts manganese content to 0.70 - 0.90 ppm, allowing it to meet the AAR requirements for all three AAR M-101 grades, F, G, and H. AAR class F permits a manganese content of 0.70 - 1.00 ppm. AAR classes G and H allow a manganese content of 0.60 - 0.90 ppm.
5. APTA 1052 restricts vanadium to 0.02 - 0.08 ppm, the same as that for AAR class F, allowing it to meet the AAR requirements for all three M-101 classes, F, G, and H. AAR M-101 classes G and H have no vanadium restriction whatsoever.

6. APTA 1052 restricts the maximum silicon content to 0.50 ppm. The AAR material classes have no restriction for maximum silicon content.
7. ASTM steel material classes 4140 and 4130 must meet the requirements of ASTM A29/A29M except that the sulfur content must be restricted to a maximum of 0.015%. ASTM 4140 and ASTM 4130 with the sulfur restriction will be referred to as APTA 4140 and APTA 4130.
8. APTA 1052 chemical composition must be as specified in **Table 3**. All values are mass percents.

TABLE 3
APTA 1052

	C	Mn	P	S	Si	V
MIN →	0.45	0.70	0.000	0.000	0.15	0.02
MAX →	0.59	0.90	0.045	0.050	0.50	0.08

9. APTA 4140 chemical composition must be as specified in **Table 4**. All values are mass percents.

TABLE 4
APTA 4140

	C	Mn	P	S	Si	Cr	Mo
MIN →	0.38	0.75	0.000	0.000	0.15	0.80	0.15
MAX →	0.43	1.00	0.035	0.015	0.35	1.10	0.25

10. APTA 4130 chemical composition must be as specified in **Table 5**. All values are mass percents.

TABLE 5
APTA 4130

	C	Mn	P	S	Si	Cr	Mo
MIN →	0.28	0.40	0.000	0.000	0.15	0.80	0.15
MAX →	0.33	0.60	0.035	0.015	0.35	1.10	0.25

3.6 Material mechanical properties (grades)

1. APTA steel classes 1052, 4140, and 4130 must be heat treated to attain the mechanical properties defined in **Table 6**. All values are minimums. Ultimate tensile strength (UTS) and yield strength (YS) are psi. Elongation, and reduction of area (ROA) are percents.

TABLE 6
Material Mechanical Properties

Grade	UTS	YS	Elongation	ROA
F	88,000	50,000	20	35
G	85,000	50,000	20	39
H1	105,000	65,000	18	35
H2	115,000	75,000	16	35
J	reserved	reserved	16	35

K	reserved	reserved	16	35

2. APTA steel grades must be specified with both a material chemistry and one of the heat treatments shown in Table 6, e.g., APTA 1052-F, APTA 1052-G, APTA 4140-H1, APTA 4130-H1.[7]

3.7 Residual compressive stresses

1. Residual compressive stress may be introduced into the axle either by cold-rolling or by heat treatment, specifically subcritical quenching.
2. The advantage of cold-rolling is that it imparts the residual stresses directly into the finished axle diameters while machining is required after subcritical quenching. That machining removes the highest compressive stresses imparted by the heat treatment, i.e., those at the surface.
3. Both methods produce residual stresses which are greater at the surface and decrease with depth below the surface.

3.8 Cold-rolling

1. Cold-rolling produces residual compressive stresses by plastic deformation of axle surfaces.
2. Cold-rolling is effected by using a hardened roller or ball to mechanically compress the surface over which it is passed, after which residual compressive stresses remain.
3. The shape of the roller and the force for compression should be designed so as to produce a Hertzian stress of approximately 5000 MPa (725,000 psi) at the contact surface. This will produce a compressive stress of approximately 500 MPa (72,500 psi) tangentially and 1000 MPa (145,000 psi) axially at the surface.[8]
4. Cold-rolling as described above should increase the surface hardness by approximately 15% when using Brinell hardness values. This value can be used as a quality control measurement.
5. Leeb scale hardness testing may be used. Such testing must comply with ASTM A956.[9]
6. Cold-rolling should be conducted in a manner that prevents upsets where radii meet cylindrical surfaces. Generally, when rolling radii, it is preferable to roll down from larger diameters to smaller diameters.
7. The effectiveness of the cold-rolling process in imparting residual compressive stresses may be evaluated using a hole-drilling strain gage technique in accordance with ASTM E837.

3.9 Subcritical quenching

3.9.1 Description

1. Subcritical quenching of axles must be performed only when specifically required by the purchaser.
2. This subcritical quenching procedure was originally developed for the treatment of hollow axles.
3. Subcritical quenching is a heat treatment process based on heating the axle below the tempering temperature and the pearlite-to-austenite phase transformation temperature, and then quenching in water.
4. Subcritical quenching must be performed on rough-turned axles, i.e., axles not machined to their finished dimensions.
5. Because finish machining of subcritically quenched axles removes material from the surface of the axle, the most highly beneficial residual compressive stresses are removed.
6. Finish machining of subcritically quenched axles may exhibit a non-uniform stress profile so that it is possible for these axles to deform when the relative high mounting forces of components are pressed onto them, resulting in increased radial and axial runouts.

3.9.2 Procedure

1. Axles must be rough machined not more than 3⁄16 inch (5 mm) over the finished diameters for the full length of the axle, including all seats, fillets, relief grooves, and axle body diameters.
2. Axles must be heated uniformly in a vertical position, i.e., with the length of the axle oriented up and down, to minimize distortion.
3. Axles must be heated to a temperature between 50 °F and 100 °F below the tempering temperature at which the axles were produced or heat-treated previously.
4. Axles must be quenched in a vertical position in water at an initial temperature between 60 °F and 80 °F.
5. Axles must remain in the quench medium, i.e., the water, until they reach a uniform temperature of 100 °F.
6. The quench water must be circulated during the quenching cycle.

4. Testing

1. The results of all testing required by this recommended practice must be supplied to the purchaser.

4.1 Chemical analysis

1. Chemical analysis must be reported for each heat of manufactured steel used to produce axles.
2. Chemical analysis must be in accordance with ASTM E350 or in accordance with AAR Specification M-101, Section 8.0, Ladle Analysis.

4.2 Tensile testing

1. Tensile testing must be reported for each heat treatment batch.
2. Tensile testing must be performed after final heat treatment.
3. Tensile testing for ultimate tensile strength, yield strength, elongation, and reduction of area must be in accordance with ASTM A370.
4. Samples for tensile testing must be taken from finished axles or from prolongations of billets or bars after forging.
5. Prolongation diameters must be of the same diameter as the forged diameter immediately inboard of the prolongation.
6. Samples for tensile testing must be taken at mid-radius of the smallest finished axle diameter.
7. When samples for testing are taken from prolongations, the test results must be at least 5% greater than the values specified in Section 3.6 for tensile strength and yield strength.

4.3 Impact testing

1. Charpy impact testing must be in accordance with ASTM A370 or ASTM E23.
2. When impact testing is required by the axle manufacturer or the purchaser, the testing must be performed on the material after final heat treatment.
3. Charpy testing must be made using at least one prolongation from each final heat treatment batch of axles.
4. Impact testing and acceptance criteria must be specified by the axle manufacturer or purchaser.

4.4 Nondestructive UT testing

1. Axles must be ultrasonically tested both radially and axially.
2. When practical, axial ultrasonic testing (UT) should be performed on the flat end faces of axles prior to machining of holes and centers in those faces.
3. Axial UT may be performed from the flat portions of the end faces of axles after machining of holes and centers in those faces.

4. The surface finish of axle end faces must not exceed an R_a of 125 µ-inches (3.2 µ-m) for axial UT.
5. Axles produced from billets must be ultrasonically tested (UT) radially and axially in accordance with Section 16 of AAR Specification M-101.
6. Axles produced from bars must be radially UT tested in accordance with ASTM E2375 Class B or in accordance with Section 16 of AAR Specification M-101.
7. Axles produced from bars must be axially UT tested in accordance with AAR Specification M-101.
8. Radial testing for hollow axles may be performed from the axle bore or from the axle outside diameter.

4.5 Material cleanliness testing

1. When material cleanliness testing is required, the testing must meet the specifications of this section.
2. Steel cleanliness testing must be performed in accordance with ASTM E45.
3. Cleanliness results must meet the requirements of **Table 7**.
4. All values shown in **Table 7** are maximum acceptable severity levels.
5. The DS column is single globular types.
6. The D SULF column is circular oxide sulfide.

TABLE 7
Cleanliness Requirements

REF	SERIES	A	B	C	D	B+C+D	DS	D SULF
1	Heavy	2.0	1.5	1.5	1.5	3.0	1.5	1.5
2	Thin	2.0	2.0	2.0	2.0	4.0	n/a	n/a

5. Gas content

1. Steel used for the manufacture of axles must be vacuum degassed.
2. Gas content must be as prescribed in **Table 8**. All values are parts per million.
3. Gas content measurement must be made in accordance with ASTM E1019 for nitrogen and oxygen, and in accordance with ASTM F1113 for hydrogen.

TABLE 8
Gas Content

Ref.	Element	Symbol	Min.	Max.
1	hydrogen	H_2	0	2.5
2	oxygen	O_2	0	24
3	nitrogen	N_2	0	90

6. Grain size

1. Steel for axles must have a uniform, fine-grained structure of grain size 5 or finer.
2. Grain size measurement must be made in accordance with AAR Specification M-101, Section 13.

7. Surface finishes

1. Seats for press-fitted components, relief grooves, transition radii, and hollow axle bores must have surface finish R_a values not exceeding the values shown in **Table 9**.
2. The values shown in the U.S. column must be used when R_a values are specified in U.S. customary units. U.S. values are µ-inch.

3. The values shown in the Metric column must be used when R_a values are specified in metric units. Metric values are μ-m.

TABLE 9
Maximum Surface Finish R_a Values

Ref.	Area	U.S.	Metric
1	Wheel seat	63	1.6
2	Axle bearing seat	50	1.3
3	Brake disc seat	63	1.6
4	Gearbox (quill) seat	63	1.6
5	Drive coupling seat	63	1.6
6	Bull gear seat	63	1.6
7	Gear unit bearing seat	63	1.6
8	Gear unit slinger seat	63	1.6
9	Relief groove	32	0.8
10	Body and body segment diameters	125	3.2
11	Body transition radius	32	0.8
12	Hollow axle bore	125	3.2
13	Seat chamfer	63	1.6

Measurements of R_a values must be taken with a cutoff setting of 0.030 or 0.100 inch (0.8 or 2.5 mm). Generally, cutoffs should be chosen so as to include at least four times the spacing of periodic irregularities.[10]

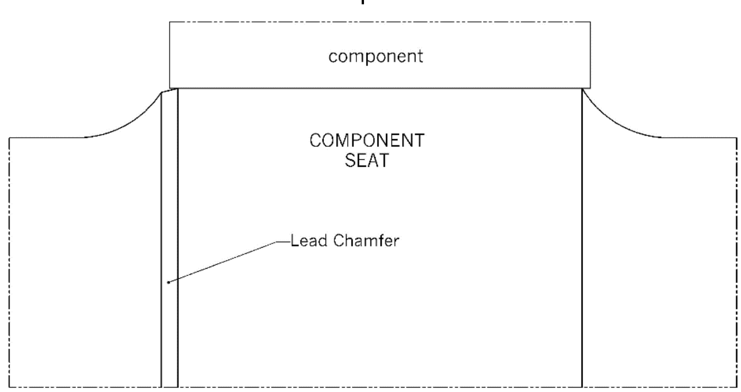
Surface finishes must be tested in accordance with ASME B46.1.

The surface condition of all axles must meet the requirements of AAR Specification M-101, Appendix A, "Interpretation of Defects Considered Injurious in Axles."

8. Axle seats

1. Seats for interference fitted components, other than bearings, should be designed so the bore of the fitted component overhangs the edges of fitted length of the seat as shown in **Figure 27**.[11]

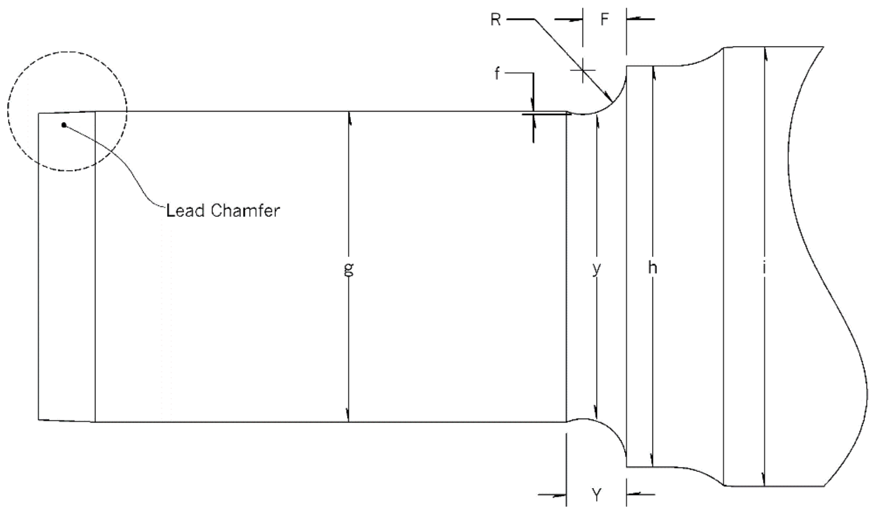
FIGURE 27
Axle Component Seat



2. Bearing seats for outboard bearing axles may be designed so that the inboard cone's inner ring overhangs an undercut radius, such as the radius shown in **Figure 28**.[12]

FIGURE 28

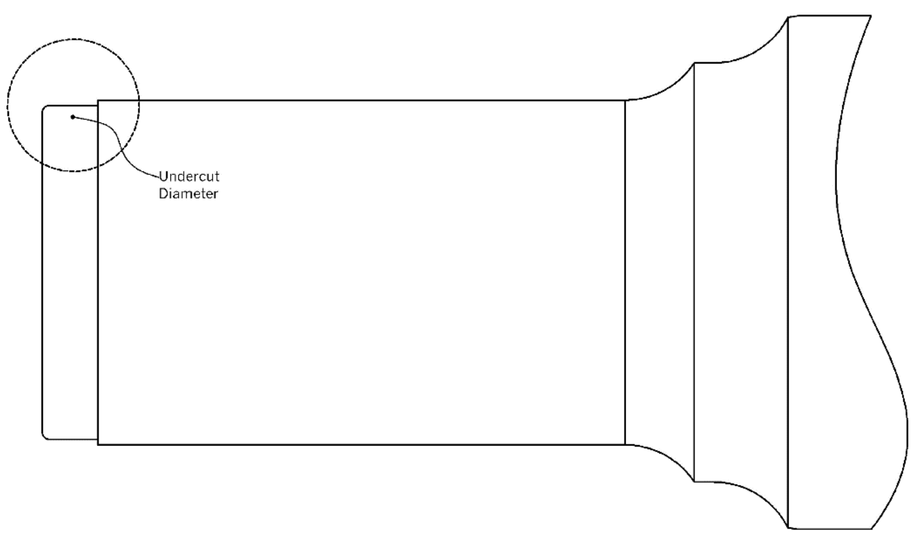
Undercut Radius (on the Right) and Lead Chamfer (on the Left)



3. Outboard bearing seats for press-fitted AAR-style bearings must have a tapered lead chamfer as shown in **Figure 28**.
4. Lead chamfers for each bearing class of outboard bearings must be as specified in AAR Specification M-101, Appendix B.
5. Undercut diameters at the outboard end of outboard bearing seats are prohibited for use with press-fitted AAR-style bearings. See **Figure 29**.[13]

FIGURE 29

Bearing Seat Undercut Diameter



6. For wheels used on both inboard and outboard bearing axles, it is not necessary that the front (outboard) edge of the wheel hub overhang the outboard edge of its wheel seat.
7. The L-dimension (inside of wheel seat to inside of wheel seat) for outboard bearing axles should be 49.500 inches, +0.040 inch, −0.000 inch That L-dimension will provide an overhang of the back wheel hub over its seat. This overhang will be present for both new and secondhand wheel seat diameters when the following tolerances are maintained.
   - The wheel back-to-back dimension is 53.250 to 53.375 inches
   - The back hub projection is 2.500 to 2.520 inches
   - The back hub bore chamfer or radius is 0.060 to 0.250 inch
   - The hub length is 6.980 to 7.020 inches
8. When measured relative to the datum of the two axle bearing seats, the total runout for wheel seats must not exceed 0.004 inch.
9. When measured relative to the datum of the two axle bearing seats, the total runout for seats other than wheel seats must not exceed 0.004 inch.
10. When measured relative to the datum of the two axle bearing seats, the total runout for body segments must not exceed 0.006 inch.

9. Tapered seats

1. Tapered seats for press-fitted components should follow the guidelines of this section.
2. The full angle conical taper is the difference between the nominal major diameter (D) and the nominal minor diameter (d), divided by the length (L) of the seat, i.e., (D − d) / L.
3. Tapered wheel seats should have a nominal full-angle conical taper of 1:150 or 1:300.
4. Tapered seats for other components should have a full-angle conical taper of 1:50, 1:100, 1:150 or 1:300.
5. Tapered seat locations must be referenced relative to the major diameter of the tapered seat.
6. Tapered seat diameters must be referenced relative to the major diameter of the tapered seat.
7. Chamfers and edge breaks must be located outside of the defined length and major diameter of the taper.

10. Outboard bearing AAR D-11 axle designs

NOTE: Specifications for N-dimensions (bearing centerlines) in this section assume a track gage of 56.50 inches. Appropriate modification to this dimension must be made for other track gages.

1. For AAR D-11 outboard bearing axle designs,[14] wheel seat and bearing seat diameters must be as shown in **Table 10**.[15,16] Dimensions are inches.
2. Class L, K, M and 2G designs utilize bearings that minimize the supported load moment and are recommended for new designs.

TABLE 10

Outboard Bearing AAR D-11 Axles (all dimensions in inches)

Bearing Class	Axle Design	Bearing Seat (min.)	Bearing Seat (max.)	Wheel Seat (min.)	Wheel Seat (max.)	Bearing Centerline
L	L825	5.6910	5.6920	8.250	8.251	78.000
K	K850	6.1910	6.1920	8.500	8.501	79.000
K	K875	6.1910	6.1920	8.750	8.751	79.000
M	M850	6.5035	6.5045	8.500	8.501	79.000
M	M875	6.5035	6.5045	8.750	8.751	79.000

M	M925	6.5035	6.5045	9.250	9.251	79.000
2G	2G925	7.0035	7.0045	9.250	9.251	79.000
2G	2G950	7.0035	7.0045	9.500	9.501	79.000

3. Axle Design L825 axles are intended for use with AAR class L bearings.
4. Axle Design K850 and K875 axles are intended for use with AAR class K bearings. Class K bearings have proven to reduce axle fretting in comparison with class F bearings.
5. Axle Design M850, M875, and M925 axles are intended for use with AAR class M bearings. Class M bearings have a reduced load bearing moment in comparison with class G bearings.
6. Axle Design 2G925 and 2G950 are intended for use with short cup Class 2G diameter bearings. These bearings are very similar to AAR Class G bearings but have a reduced centerline dimension that results in a load bearing moment shorter than that of a standard AAR Class G bearing.
7. For all outboard bearing axle designs, seats for axle body fitted components must be larger than the wheel seat diameters specified in **Table 10**.

11. Outboard bearing AAR D-12 axle designs

NOTE: Specifications for N-dimensions (bearing centerlines) in this section assume a track gage of 56.50 inches. Appropriate modification to this dimension must be made for other track gages.

1. **Table 11** shows AAR D-12 outboard bearing axle designs.[17]
2. These are legacy designs that utilize longer supported load moments than AAR D-11 designs.
3. These D-12 legacy designs have been used successfully in the past, and many of them are being used on vehicles currently in service.
4. Whenever possible, AAR D-11 axles should be used in lieu of D-12 axles.
5. For AAR Class D-12 outboard bearing axle designs, wheel seat and bearing seat diameters must be as shown in **Table 11**. Dimensions are in inches.

TABLE 11
Outboard Bearing AAR D-12 Axles (all dimensions in inches)

Bearing Class	Axle Design	Bearing Seat (min.)	Bearing Seat (max.)	Wheel Seat (min.)	Wheel Seat (max.)	Bearing Centerline
CC	CC750	5.0035	5.0045	7.359	7.360	76.000
DD	DD775	5.5035	5.5045	7.562	7.563	77.000
EE	EE825	6.0035	6.0045	8.250	8.251	78.000
FF	FF875	6.5035	6.5045	8.750	8.751	79.000
D	D775	5.1910	5.1920	7.562	7.563	77.000
E	E825	5.6910	5.6920	8.250	8.251	78.000
F	F875	6.1910	6.1920	8.750	8.751	79.000
G	GFF875	6.5035	6.5045	8.750	8.751	79.000
G	G875	7.0035	7.0045	8.750	8.751	79.000
G	G925	7.0035	7.0045	9.250	9.251	79.000
G	G950	7.0035	7.0045	9.500	9.501	79.000

6. Axle Design CC750 axles are used on New York City Transit Authority subway vehicles and are unique to that application.
7. Axle Design DD775 axles are intended for use with appropriately sized AAR-style bearings.
8. Axle Design EE825 axles are intended for use with appropriately sized AAR-style bearings.
9. Axle Design FF875 axles are intended for use with appropriately sized AAR-style bearings.
10. Axle Design D775 axles are intended for use with AAR class D bearings.
11. Axle Design E825 axles are intended for use with AAR class E bearings.
12. Axle Design F875 axles are intended for use with AAR class F bearings.
13. Axle Design GFF875 axles are intended for use with appropriately sized AAR-style bearings.
14. Axle Designs G875, G925 and G950 axles are intended for use with AAR class G bearings.

12. Outboard bearing double brake disc designs

1. The axle designs in this section show three different standard brake disc spacings.
2. These designs use press-fitted brake discs.
3. These designs use brake discs with nominal bores of 228 mm.
4. These designs use brake discs with nominal disc widths of 110 mm.
5. These designs use brake discs with nominal outside diameters of 27.50 inches.
6. **Figure 30** shows design dimensions detailed in **Table 12**.[18]

FIGURE 30
Double Brake Disc Axle Design

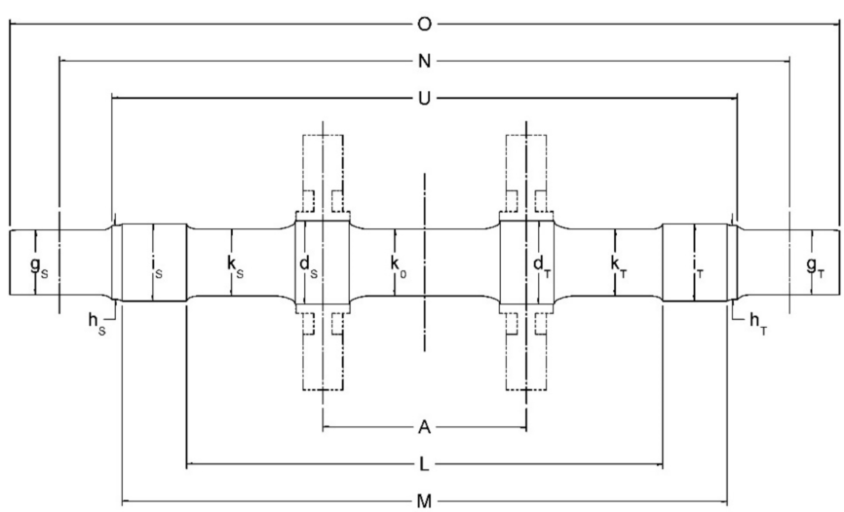


TABLE 12
Dimensions for Three Standard Brake Disc Spacings (all dimensions in inches)

Design	Class	N	A	O	U	g	i	d
F875-2D-A	F	79.000	39.000	89.625 89.687	66.125 66.187	6.1910 6.1920	8.750 8.751	8.9871 8.9882
K875-2D-A	K	79.000	39.000	87.094 87.156	69.294 69.356	6.1910 6.1920	8.750 8.751	8.9871 8.9882
G875-2D-A	G	79.000	39.000	89.250 89.312	67.125 67.187	7.0035 7.0045	8.750 8.751	8.9871 8.9882

TABLE 12

Dimensions for Three Standard Brake Disc Spacings (all dimensions in inches)

Design	Class	N	A	O	U	g	i	d
M875-2D-A	M	79.000	39.000	87.000 87.062	69.500 69.562	6.5035 6.5045	8.750 8.751	8.9871 8.9882
F875-2D-B	F	79.000	22.000	89.625 89.687	66.125 66.187	6.1910 6.1920	8.750 8.751	8.9871 8.9882
K875-2D-B	K	79.000	22.000	87.094 87.156	69.294 69.356	6.1910 6.1920	8.750 8.751	8.9871 8.9882
G875-2D-B	G	79.000	22.000	89.250 89.312	67.125 67.187	7.0035 7.0045	8.750 8.751	8.9871 8.9882
M875-2D-B	M	79.000	22.000	87.000 87.062	69.500 69.562	6.5035 6.5045	8.750 8.751	8.9871 8.9882
F875-2D-C	F	79.000	31.500	89.625 89.687	66.125 66.187	6.1910 6.1920	8.750 8.751	8.9871 8.9882
K875-2D-C	K	79.000	31.500	87.094 87.156	69.294 69.356	6.1910 6.1920	8.750 8.751	8.9871 8.9882
G875-2D-C	G	79.000	31.500	89.250 89.312	67.125 67.187	7.0035 7.0045	8.750 8.751	8.9871 8.9882
M875-2D-C	M	79.000	31.500	87.000 87.062	69.500 69.562	6.5035 6.5045	8.750 8.751	8.9871 8.9882

13. Inboard bearing axle designs

1. Axle designs should have a minimum of 2 inches of clearance from all axle-mounted components on the inboard side of the axle bearing shoulder to allow for efficient removal of the axle bearing.[19]
2. Wheel seat and bearing seat diameters for inboard axles must be as shown in **Table 13**. All dimensions are in inches.
3. Inboard bearing wheel and axle seats may be designed for use with AAR-type short cup bearings, sE and sF, as shown in **Table 13**. Short cup bearings consist of two cone assemblies, a cup, a cone spacer, two seal rings and two seals.[20]
4. Inboard bearing axles may be designed for use with AAR class L and K bearings. Class L and K bearings feature improvements over previous AAR class bearings. Some AAR Class L and Class K bearings consist of just two cone assemblies, a cup, a cone spacer and two seals, the designs having eliminated the two separate seal ring components.[21]
5. Note that, for L and K bearings, the stack lengths shown in the Stack column include a backing ring.[22]

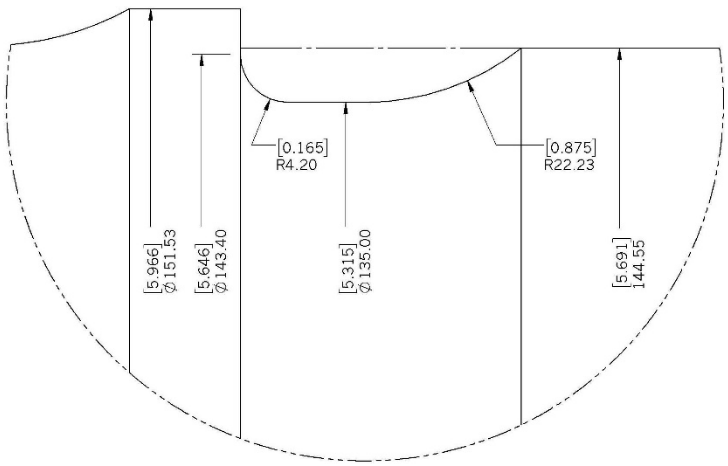
TABLE 13

Inboard Bearing AAR-Style Axle Classes (all dimensions in inches)

Class	Bearing Seat (Min)	Bearing Seat (Max)	Wheel Seat (Min)	Wheel Seat (Max)	Stack	Cup OD	Cup L
D513	5.1910	5.1920	5.130	5.131	8.430	8.1875	6.000
sE563	5.6910	5.6920	5.630	5.631	8.000	8.6614	5.512
sF613	6.1910	6.1920	6.130	6.131	9.500	9.8375	6.300
L563	5.6910	5.6920	5.630	5.631	7.700	8.6614	5.512
K613	6.1910	6.1920	6.130	6.131	8.460	9.8375	6.300

6. For inboard bearing axles, the bearing seat relief groove may be machined as shown in **Figure 31**.
7. The vertical flat portion of the bearing shoulder must extend to a diameter equal to the minimum bearing seat diameter less 0.040 inch (1.00 mm). In other words, radii that form the relief groove must not extend into the bearing shoulder above this diameter.
8. Axle bearing seat relief grooves are as shown in **Figure 31**.

FIGURE 31
Relief Groove Detail

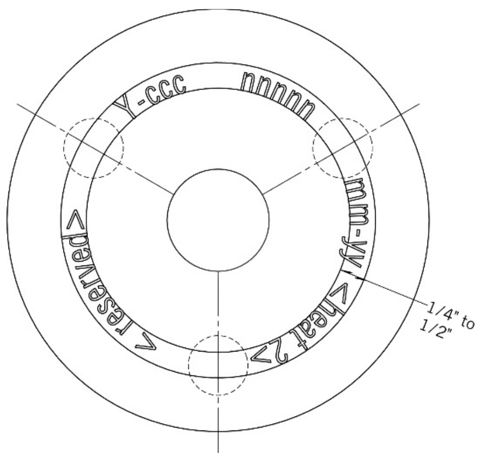


14. Marking

1. Axles must be marked by cold stamping or laser etching.
2. Axle markings must be clear and legible and able to remain so under the environmental conditions in which they operate.
3. Characters must be at least 0.25 inch in height and not more than 0.50 inch in height.
4. For axles with more than one asymmetrical seat, the S-end of the axle will be determined by the hierarchical existence of the following seats:
    - gear seat
    - gear unit seat
    - gearbox seat
    - coupling seat
    - brake disc seat
    - grounding device seat
5. The end of the axle opposite the S-end is referred to as the T-end.

6. Axle marking for the S-end of the axle must include the following information arranged as shown below and in **Figure 32**:
    - Axle manufacturer’s AAR shop code preceded by Y-.
    - Axle manufacturer’s serial number.
    - Axle manufacturer’s date of manufacture, preferably in the format mm-yy.
    - When applicable, manufacturer’s secondary heat treatment batch identification.

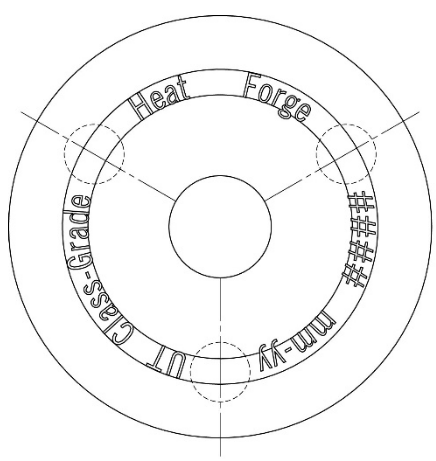
FIGURE 32
Axle Manufacturer’s Markings on S-End of Axle



Axle Manufacturer Information Markings	
Y-ccc	Axle manufacturer AAR shop code preceded by Y-
nnnnn	Axle manufacturer’s serial number
mm-yy	Axle manufacture month-year
<heat 2>	Secondary heat treatment (if none, XXXXX)
<reserved>	Reserved for customer request

7. Axle marking for the T-end of the axle must include the following information arranged as shown below and in **Figure 33**.
    - axle producer (forge) heat
    - axle producer (forge)
    - forge sequence
    - axle producer month and year of production in the format mm-yy
    - R, marking for radial UT
    - A, marking for axial UT
    - steel grade

FIGURE 33
Forge’s Markings on T-End of Axle

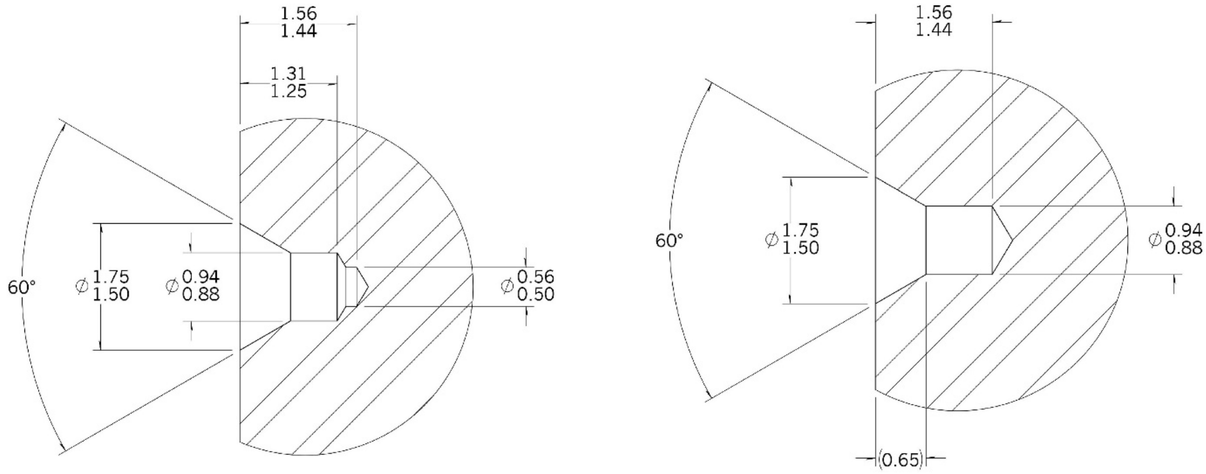


Forge Information Markings	
Heat	Forge heat
Forge	Forge AAR code
####	Forge sequence
mm-yy	Forge month - year
UT	A, R or AR (A=axial, R=radial)
Class-Grade	Material grade (e.g., APTA 1052-G, APTA 4140-H1)

15. Axle centers

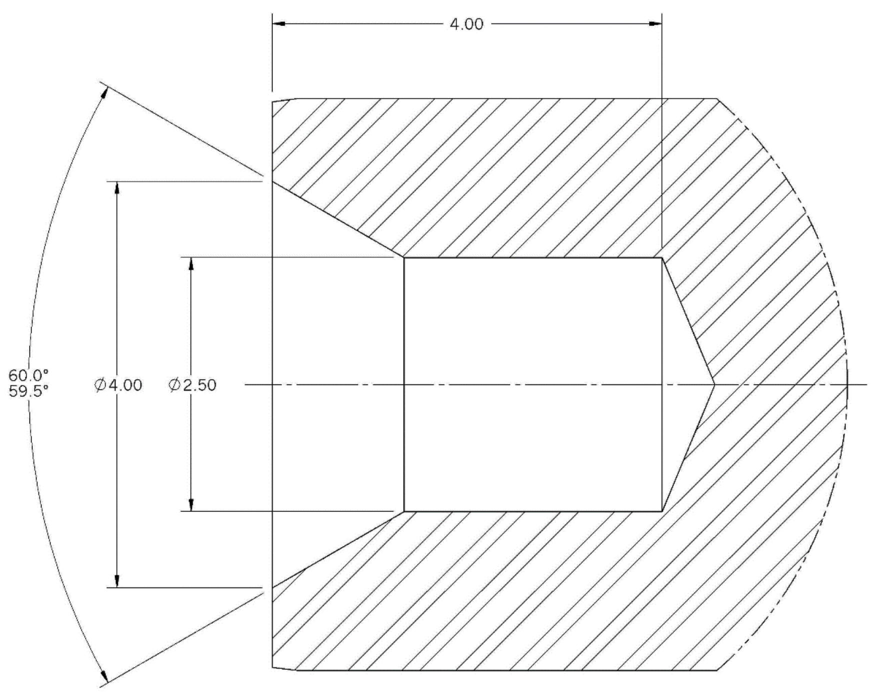
1. Axle centers may be as specified in AAR Specification M-101, Appendix B, figure B.5 for passenger roller bearing axles.
2. Alternate axle centers may be as shown in **Figure 34**.

FIGURE 34
Alternate Axle Centers



3. Axle centers for under-floor wheel truing machines should be as shown in **Figure 35**.

FIGURE 35
Axle Centers for Under-Floor Wheel Truing Machines



4. When measured relative to the datum of the two axle bearing seats, the total runout for axle centers must not exceed 0.002 inch.

16. Threaded holes

1. Internally threaded holes may be formed by drilling and tapping or by rolling.
2. The threads of all internally threaded holes must conform to ASME B1.1 Class 2 B for unified inch screw threads.
3. The threads of all internally threaded holes must conform to ASME B1.13M Class 6H/6g for M-profile metric threads.

17. Axle calculation

1. This axle calculation[23] must be carried out for all new axle designs and for all new applications of existing axle designs.
2. There are three steps required for the calculation.
    - stress calculation
    - selection of applicable maximum permissible stresses (MPSs)
    - acceptance or rejection of design
3. For outboard bearing axles, the stress calculation must be performed in accordance with EN 13103-1.
4. For inboard bearing axles, the stress calculation must be performed in accordance with CEN/TS 13103-2.
5. Deviations to the process described in these either of these standards, EN 13103-1 for outboard axles or CEN/TS 13103-2 for inboard bearing axles, must be approved by the purchaser and the end user.
6. For the stress calculations, care should be taken to ensure that worst-scenario stresses are calculated. Consequently, the following assumptions must be made:
    - Wheels are of maximum diameter.
    - Axle diameters are minimums.
    - Component locations and lateral force directions are chosen so as to maximize bending moments.
7. For the axle bearing supported mass, referred to as m_1 in the axle calculation standards, use the prescribed load specified in the technical specification of the vehicle for which the calculation is made. Apply that load to the calculation for passenger vehicles or locomotives as appropriate.
8. No safety factors should be applied to the stress calculations. The maximum permissible stresses shown in the tables below include the safety factors required by the EN standards. The safety factors are shown for reference in the last column of the tables, Safety.
9. Unless the precise value of such credits can be shown based on empirical testing, no credit is permitted for additional surface treatments such as cold-rolling, shot-peening or subcritical quenching.
10. For each axle design, the calculated stresses for all zones must be less than or equal to the maximum permissible stresses shown in the appropriate table.
11. Zone definitions in the EN standards are numbered, not lettered; however, the EN zones are not numbered in a consistent manner. To provide consistency and avoid confusion, the stress zones have been defined using letters in **Table 14**.[24]

TABLE 14
Zone Definitions

Zone	Inboard Bearing Axle	Outboard Bearing Axle
σA	All axle body segments All plain bearing journals All transition fillets All bases of relief grooves	
σB	All seats for D/d ≥ 1.12	All seats except bearing seats
σC	Not applicable	Bearing seats
σD	All seats for D/d < 1.12	Not applicable
σE	All hollow axle bores	

12. For zones σB and σD in the table, D/d is the ratio of the diameter of the area of interest on the axle to the diameter of the adjacent axle sections.

    CAUTION: There are two D/d ratios in the EN standards.

    - The D/d ratio in this section is not the same as the D/d ratio used to calculate stress concentrations.
    - The D/d ratio in this section is used for the selection of calculation zones.

13. For inboard bearing hollow axles, use the MPSs for hollow style axles whenever the smallest seat diameter to bore diameter ratio is less than the value specified in the axle calculation specification, CEN/TS 13103-2. Whenever this condition is not met, use the σA, σB, σC and σD MPSs for solid style axles and the óE MPS for hollow style axles.
14. For outboard bearing hollow axles, use the MPSs for hollow style axles whenever any of the following conditions are met. Whenever none of the conditions are met, use the σA, σB, σC and σD MPSs for solid style axles and the óE MPS for hollow style axles.
    - The ratio of the bearing seat diameter to axle bore diameter is less than the value specified in the axle calculation specification, EN 13103-1.
    - The ratio of the wheel seat diameter to axle bore diameter is less than the value specified in the axle calculation specification, EN 13103-1.
    - The ratio of any other seat diameter to axle bore diameter is less than the wheel seat limiting value specified in the axle calculation specification, EN 13103-1.
15. For the steel grades specified in Section 3.5, paragraph 1, **Table 15** through **Table 22** show the stress limits for each zone. The values shown are psi units. The factor of safety is a ratio with no units. It is labeled "Safety" in the table.
16. For steel grades not specified in this standard, the maximum permissible stresses must be calculated based on fatigue testing carried out per EN 13103-1. The method for fatigue testing defined in that standard applies to both inboard and outboard bearing axles.
    - Fatigue limits must be established for notched and unnotched small-scale specimens and for full-scale axles.
17. In lieu of the definitions for powered, non-powered and guiding axles in the EN specifications, in the tables, use the following definitions for the columns labeled "Type":[25]
    - Drive axles, both direct and indirect, are axles subjected to a tractive torque.
    - Idler axles are axles not subjected to tractive torque.

18. In the table column labeled “TT” (Tractive Torque), the following definitions apply.
    - “Direct” applies to axles for which there is an interference-fitted driving gear or gearbox quill.
    - “Indirect” applies to axles for which there is an interference-fitted coupling, i.e., for which the driving torque is not transmitted directly to the axle by the driving device.
    - “None” applies to axles for which there is no driving device.

TABLE 15
Grade F Solid Axles

F	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	solid	direct	22,800	13,600	13,600	11,300	n/a	1.41
2	drive	solid	indirect	26,300	15,700	15,700	13,100	n/a	1.22
3	idler	solid	none	26,700	16,000	16,000	13,300	n/a	1.20

TABLE 16
Grade F Hollow Axles

F	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	hollow	direct	22,800	12,500	10,700	11,300	9,100	1.41
2	drive	hollow	indirect	26,300	14,400	12,300	13,100	10,400	1.22
3	idler	hollow	none	26,700	14,600	12,500	13,300	10,700	1.20

TABLE 17
Grade G Solid Axles

G	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	solid	direct	19,300	11,600	11,600	9,700	n/a	1.60
2	drive	solid	indirect	22,200	13,300	13,300	11,200	n/a	1.39
3	idler	solid	none	24,100	14,500	14,500	12,000	n/a	1.28

TABLE 18
Grade G Hollow Axles

G	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	hollow	direct	19,300	10,600	9,100	9,700	7,700	1.60
2	drive	hollow	indirect	22,200	12,200	10,400	11,200	8,800	1.39
3	idler	hollow	none	24,100	13,200	11,300	12,000	9,700	1.28

TABLE 19

Grade H1 Solid Axles

H1	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	solid	direct	23,800	14,400	14,400	11,900	n/a	1.60
2	drive	solid	indirect	27,600	16,500	16,500	13,800	n/a	1.39
3	idler	solid	none	29,700	17,800	17,800	14,900	n/a	1.28

TABLE 20

Grade H1 Hollow Axles

H1	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	hollow	direct	23,800	13,100	11,200	11,900	9,600	1.60
2	drive	hollow	indirect	27,600	15,100	12,900	13,800	11,000	1.39
3	idler	hollow	none	29,700	16,400	14,100	14,900	11,900	1.28

TABLE 21

Grade H2 Solid Axles

H2	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	solid	direct	26,100	15,700	15,700	13,100	n/a	1.60
2	drive	solid	indirect	30,200	18,100	18,100	15,100	n/a	1.39
3	idler	solid	none	32,600	19,600	19,600	16,200	n/a	1.28

TABLE 22

Grade H2 Hollow Axles

H2	Type	Style	TT	σA	σB	σC	σD	σE	Safety
1	drive	hollow	direct	26,100	14,400	12,300	13,100	10,400	1.60
2	drive	hollow	indirect	30,200	16,500	14,200	15,100	12,000	1.39
3	idler	hollow	none	32,600	18,000	15,400	16,200	13,100	1.28

References

NOTE: References shown are documents used in the development of this standard. They are listed with the revisions in place at the time that this standard was developed. The documents listed are not included as *referenced* documents in that they are not necessarily referenced within the standard.

Aerospace Materials Specifications, 2750, *Pyrometry*

Aerospace Materials Specifications, 2759, *Heat Treatment of Steel Parts, General Requirements*

Aerospace Materials Specifications, H-6875, *Heat Treatment of Steel Raw Materials*

Association of American Railroads, *Manual of Standards and Recommended Practices, Section G, Specification M-101*, September 29, 2020

Association of American Railroads, *Manual of Standards and Recommended Practices, Section J, Specification M-1003*, October 14, 2019

ASTM International, A29, *Standard Specification for General Requirements for Steel Bard, Carbon and Alloy, Hot-Wrought*

ASTM International, A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM International, A956, *Standard Test Methods for Leeb Hardness Testing of Steel Products*

ASTM International, E23, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*

ASTM International, E45, *Standard Test Methods for Determining the Inclusion Content of Steel*

ASTM International, E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron*

ASTM International, E837, *Standard Test Methods for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method*

ASTM International, E1019, *Standard Test Methods for Determinations of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Fusion Techniques*

ASTM International, E2375, *Standard Practice for Ultrasonic Testing of Wrought Products*

ASTM International, F1113, *Standard Test Methods for Electrochemical Measurement of Diffusible Hydrogen in Steels*

European Committee for Standardization, EN 13261:2020, *Axles - Product Requirements*

European Committee for Standardization, EN 13260:2020, *Railway applications - Wheelsets - Product requirements*

European Committee for Standardization, EN 13103-1:2017, *Design method for axles with external journals*

European Committee for Standardization, CEN/TS 13103-2:2020, *Design method for axles with internal journals*[26]

The American Society of Mechanical Engineers, B1.1, *Unifies Inch Screw Threads*

The American Society of Mechanical Engineers, B1.13M, *Metric Screw Threads: M Profile*

The American Society of Mechanical Engineers, B46.1, *Surface Texture*

Definitions

AAR-style bearings: Unitized roller bearings consisting of two bearing cones, a single-piece outer cup that includes the outer raceways for the two cones, a spacer between the cones used to adjust the axial end play, and sealing components at both ends of the bearing unit.

axle: A fully-finished, ready-for-assembly component of a wheel set assembly onto which wheels, bearings and other components are mounted.

axle heat treater: The entity that heat-treats the axle to attain its mechanical properties.

axle manufacturer: The entity which machines the axle to its finished condition ready for use.

axle producer: The entity that forges a block from an ingot or bloom into an axle shape ready for heat treatment and machining; the axle producer is also referred to as the forge.

bar: A roll-forged steel product with a long length relative to its cross-sectional area.

bearing centerline: The centerline of the load zone for a bearing.

bearing shoulder: For inboard bearing axles, the flat surface against which the bearing seats; for outboard bearing axles, the largest diameter of the radius against which the bearing seats.

bearing stack length: The sum of the lengths of bearing components, or fractions thereof, subjected to axial clamping forces.

billet: A hammer-forged steel product.

block: A piece of steel cut from an ingot or bloom, sometimes referred to as a “mult.”

bloom: a continuously cast steel product, somewhat equivalent to an ingot but manufactured by continuous casting (concasting) with an open mold that allows molten steel to cool and take a solid shape as it passes through the mold.

deep hole boring: The machining of holes where the depth-to-diameter ratio (D/d) is large, typically greater than or equal to 10.

end user: The authority having jurisdiction ultimately responsible for the operation and use of the products defined in this recommended practice.

final heat treatment: All heat treating processes except for subcritical quench.

forging: A steel product whose shape is produced by hammering, pressing or rolling.

gearbox: An enclosed, power-transmitting, unitized assembly of gears used to drive the axle directly by means of a press fit or indirectly through a coupling fitted to the axle.

gear unit: A power-transmitting assembly of gears for which the bull gear is press-fitted or heat shrink–fitted directly to the axle with other components of the unit assembled subsequently.

heat treatment batch: For batch-processed heat treatment, all the material subjected to the same heat treatment conditions, i.e., processed in the same furnace or oven simultaneously. For continuous heat treating lines, all the material subjected continuously to the same heat treating conditions.

heat treatment charge: For batch-processed heat treatment; "charge" has the same meaning as "batch."

ingot: A steel casting from a mold.

journal: A cylindrically shaped portion of an axle on which a plain bearing is supported.

lead chamfer: A tapered portion at the entry edge of a seat designed to facilitate the start of a press fit.

material class: The chemical composition of the steel used to manufacture axles, often referred to as chemical composition, or simply "chemistry."

material grade: The mechanical properties of the steel used to manufacture axles.

purchaser: The entity that specifies and places an order for purchase.

quill: The component of a gearbox onto which a bull gear is secured. The quill may be press-fitted directly to the axle or connected to the axle through a coupling press-fitted to the axle. Quills that are not press-fitted directly to the axle and that transmit power to the axle through a coupling are referred to as "hollow shafts."

S-end: The end face of an axle on the same side of an axle as any asymmetrically located seat. For bilaterally symmetric axles, the designation of the S-end is at the discretion of the axle manufacturer.

S-side: The axial half portion of an axle containing the S-end of the axle.

safety factor: The ratio of the maximum design stress to the expected operational stress.

seat: Any cylindrical or conical portion of an axle onto which a component is assembled by press-fitting or heat-shrinking.

steel manufacturer: The entity which manufactures the raw steel ingot or bloom that is subsequently forged, heat-treated and machined to produce a manufactured axle.

T-end: The end face of an axle opposite its S-end.

T-side: The axial half portion of an axle containing the T-end of the axle.

undercut diameter: Relative to any given diameter, an adjacent smaller diameter.

undercut radius: A radius offset tangentially so as to produce a reduced diameter on a cylindrical shape.

Acronyms

AAR	Association of American Railroads
AMS	Aerospace Materials Specifications
APTA	American Public Transportation Association
ASME	The American Society of Mechanical Engineers
ASTM	ASTM International (formerly American Society for Testing and Materials)
BS	British Standard
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
EN	European Norms
ETSI	European Telecommunications Standards Institute
FRA	Federal Railroad Administration
MPS	maximum permissible stress
MU	multiple unit
NATSA	North American Transportation Services Association
ROA	reduction of area
UT	ultrasonic testing
UTS	ultimate tensile strength
YS	yield strength

Summary of document changes

- Document formatted to the new APTA standard format.
- Sections have been moved and renumbered.
- "Summary" and "Scope and purpose" moved to the front page.
- Definitions, abbreviations and acronyms moved to the rear of the document.
- Two new sections added: "Summary of document changes" and "Document history."
- Some global changes to section headings and numberings resulted when sections dealing with references and acronyms were moved to the end of the document, along with other changes, such as capitalization, punctuation, spelling, grammar and general flow of text.
- Participants updated.
- Previous revision only consisted of diagrams for outboard bearings, BX service, outboard roller bearings with raised wheel seats, axle centers, and table of new and limiting dimensions for inboard roller bearing axles. All other content is new.

Document history

Document Version	Working Group Vote	Public Comment/ Technical Oversight	Rail CEO Approval	Policy & Planning Approval	Publish Date
First published	—	—	—	—	Mar. 26, 1998
First Revision					Feb. 13, 2004
Second Revision	May 20, 2021	Sept. 1, 2021	Oct. 22, 2021	Jan. 28, 2022	Feb. 4, 2022

Appendix A: End notes

NOTE: This appendix has been added to provide background information, history and insight to selected sections of this recommended practice. The items in this appendix are not requirements of this recommended practice. Rather, they are included to aid the reader in understanding the requirements, to show the origins of the requirements, and generally to pass to the next generation of railroad engineers the knowledge gained from previous generations.

1. The body of an axle is the central section in the middle of the axle between the wheel seats for outboard bearing axles and between the bearing shoulders for inboard bearing axles. It is the portion of the axle inside the wheels and bearings. The term was originally defined by the AAR for the central section of a freight car axle, a section that did not contain any seats for fitted components. Because it is often necessary to refer to this portion of the axle, whether it has seats for fitted components or not, the body of the axle has been defined by its location, rather than by its function. Consequently, the body of an axle may have fitted components.

2. A body segment is any portion of the axle, other than relief grooves, which does not contain a seat for a fitted component. For an axle with only two wheels and two bearings, the body of such an axle is a body segment.

3. Relief grooves are common on inboard bearing axles between the outboard wheel seat and its adjacent bearing seat, and between the bearing seat and the shoulder against which the bearing seats to establish its location on the axle. For these axles, the groove between wheel seat and bearing seat is referred to as the wheel seat groove, while the groove between the bearing seat and its locating shoulder is referred to as the bearing seat groove.

   Relief grooves are commonly used between seats in other applications where two press fitted components abut each other, e.g., between a gear seat and a wheel seat of an outboard bearing locomotive axle. Grooves in this location have been shown to substantially reduce fatigue cracks that can develop.

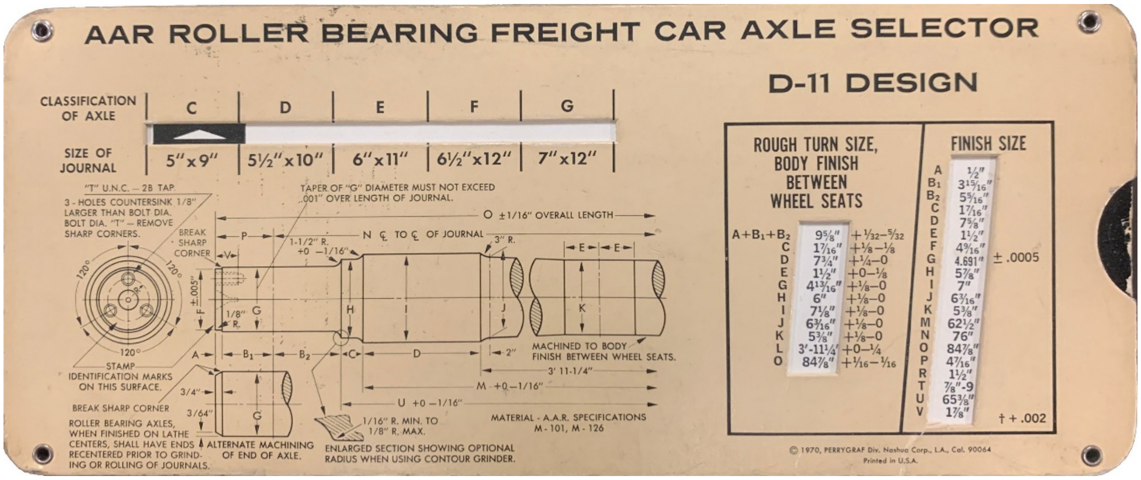
4. **Figure 4** shows a geared reduction drive wheel set assembly. Because the gear is not present in the sketch, it could be a gear unit or a gear box. Consequently, the drive unit's seat is labeled as a gear or quill seat. It would be a quill seat for a gearbox. It would be a gear seat for a gear unit. See the Definitions section for the difference between the two. The astute reader may notice that the construction of the gear case in the figure would not allow for assembly of components around a press-fitted gear since the gear case is not split and doesn't have an opening large enough to accept a gear. Actually, the way it is drawn, it is a gearbox and the seat is a quill seat. For illustrative purposes, though, the ambiguity was maintained.

5. These axle diameter codes were developed to standardize communication when discussing axle designs. The codes have their roots in the dimensional nomenclature developed by the AAR many years ago. Some of this AAR nomenclature is routinely used for axles—e.g., U-dimension and N-dimension—but many of the other dimensions are not.

   AAR standard axles are all outboard bearing designs with no brake discs, couplings, ground rings or driving devices—no mounted components on the bodies of the axles. Developing lettered conventions for all the various dimensions prevalent in modern, diversified axle designs was challenging. As much as possible, this recommended practice attempts to use the same letters as those used by the AAR. See **Figure 36** and **Figure 37**.

FIGURE 36

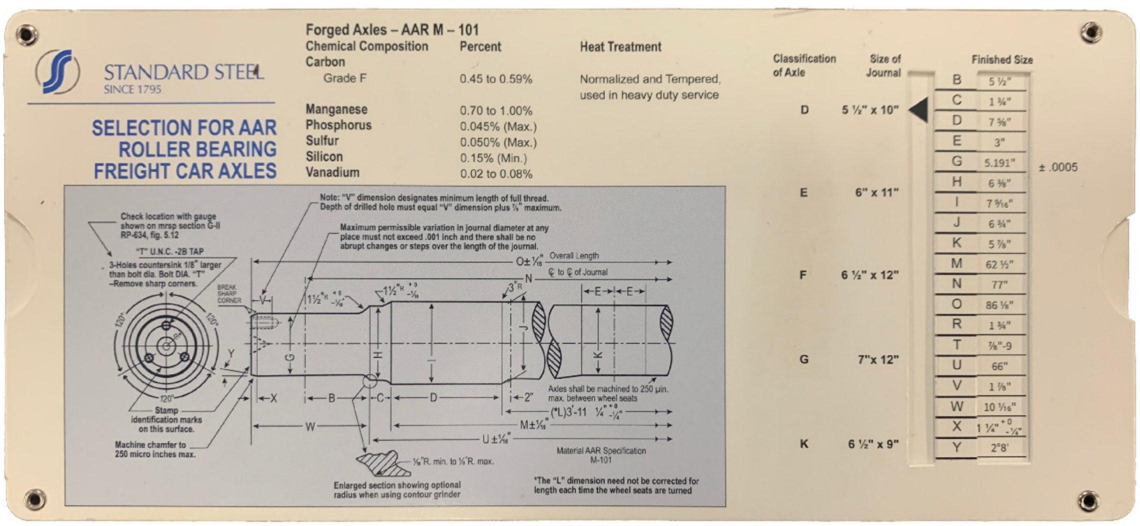
AAR's Dimension Lettering Schema, 1960s



"Slide rule" from the 1960s showing the then-current AAR roller bearing axle designs with AAR's dimension lettering schema

FIGURE 37

AAR's Dimension Lettering Schema, Current



21st-century slide rule attesting to the usefulness of the AAR axle design coding schema.

6. AMS H-6875 applies to steel raw materials, while AMS 2759 applies to parts. That is how those specifications define their scopes. In simpler terms, H-6875 applies to heat treating by steel producers, while 2759 applies to post-production heat treating. Steel producers are equivalent to axle producers, as that term axle producers, is defined in the Definitions section.

   Both of these specifications refer to another specification, AMS 2750, which defines furnace classes based on temperature uniformity. The furnace class defines accuracy levels for temperature control, temperature sensors, etc. The furnace class defines the specifications for not only the furnace, but for all heat treating equipment used in a particular heat treating process.

H-6875 and 2759 define the furnace class for various processes, e.g., normalizing, quenching and tempering, applicable to a given material. The material in this specification falls into the category "Others, under 220 ksi" for 6875, and "Carbon and low alloy below 220 ksi UTS" for 2759.

7. The AAR defines its steel grades with specifications for both chemical and mechanical properties for each of its grades: F, G and H. For its G and H grades, the AAR defines multiple sets of mechanical properties based on the diameter of the axle bearing seat.

   For AAR grades of steel, both the chemical and mechanical properties are fully defined by specifying the grade with a single letter, e.g., AAR grade H, though it is necessary to provide the diameter of the purchased material's bearing seat in order to determine which set of mechanical properties applies. This can lead to confusion.

   The AAR specifies two sets of mechanical properties for AAR grade H material. This recommended practice has separated those into two separate grades, H1 and H2, based on the differing mechanical properties, irrespective of the bearing seat diameter of the axle for which they will be used.

   APTA 4140 and APTA 4130 steels can be specified as either grade H1 or grade H2 depending on the properties required, e.g., APTA 4140-H1, APTA 4140-H2, APTA 4130-H1, APTA 4130-H2. These two 41xx grades of steel can easily meet the H1 and H2 mechanical properties, and they are good choices for axles that are of relatively constant diameter, e.g., inboard bearing axles.

   All the AAR steel grades, F, G and H, were originally developed for outboard bearing axles. Those grades have performed well in outboard bearing applications, where there is typically a large difference in axle seat diameters, specifically between bearing seats and wheel seats.

   The AAR provides three sets of properties for its grade G axles, again based on the diameter of the axle's bearing seat. One of the divisions is for axles with bearing seats 4.00 inches. or less. It is likely that no AAR producer has made an axle in this size in over 60 years. This size axle was an AAR standard at one time, used almost exclusively on the lightest weight cabooses.

   The second and third AAR classifications of G grade axles, greater than 4.00 inches and not greater than 7.00 inches, and greater than 7.00 inches and not greater than 10.00 inches, have the same values for yield strength and ultimate tensile strength. They differ only minimally in their specification for elongation and reduction of area. This third category of AAR G grade axles, greater than 7.00 inches and less than 10.00 inches, covers axles that were used primarily for steam locomotives. No modern AAR-style bearings require seats greater than 7.00 inches.

   This recommended practice consolidates the three AAR G grades into one, using the values for 4.00 to 7.00 inches. This range has more restrictive elongation and reduction of area (ROA) requirements than the larger 7.00 to 10.00 inch range.

8. This specification was developed by a European carbuilder. Prior to the development of this performance-based criteria, cold-rolling was defined by the technique and tooling to be used with no measurement of the outcome.

9. The 15% increase in hardness specified here is achievable, though that may not always be the case for all axle material. More experience with this method of testing for cold-rolling is needed to refine the requirement of this paragraph. Note that Leeb hardness testers and Leeb hardness values are especially convenient for doing the hardness testing. When Leeb hardness (or other hardness scale)

measurements are used, they must be converted to equivalent Brinell hardness values for evaluation of the 15% requirement.

10. In general, roughness (and waviness) cutoffs should be chosen so as to be at least four times the spacing of regularly occurring irregularities in the surface profile. These regularly spaced irregularities are referred to as "waves." The spacing of these waves for axles turned on a lathe is equal to the feed rate at which they are machined. This feed rate can be greater, in certain instances, than 0.008 inch, making a cutoff of 0.030 inch. insufficient for accurate determination of the roughness.

    While the results obtained using a 0.030 inch. (0.8 μ-m) cutoff will usually vary only slightly from the results obtained by using a 0.100 inch. (2.5 μ-m) cutoff, that may not always be the case. Most (relatively) inexpensive R_a measurement devices do not allow for selection of the cutoff length, and nearly all these instruments use a fixed cutoff length of 0.030 inch.

    The ASME specification for surface texture measurement (B46.1) allows the cutoff to be specified by the designer or engineer. Care should be taken when making R_a measurements when the cutoff could be a factor in the accuracy of the result.

11. This component overhang design moves the edge-generated stresses from the press-fitted joint into the relatively low-stress areas of the fitted component, i.e., at the outboard edges of the hub of the fitted component.

    Designs that have the seat protruding from the edges of the press-fitted hub concentrate the joint's edge stresses into the axle seat. The axle seat is a more critical structure than the component mounted to it. Additionally, because the axle has a longer useful life, it is preferable to avoid the accumulation of stresses that it would be subjected to when those stresses are concentrated in the axle seat rather than in the component's hub.

12. The technique described using an undercut radius at the edge of the inboard bearing cone is helpful in reducing or eliminating the axle fretting that tends to occur at this location. However, over the years, at least some bearing manufacturers have modified the design of the inner rings of their bearing cones so as to reduce or eliminate axle fretting on bearing seats without undercut radii.

13. The undercut diameter (not the undercut radius described above) shown in **Figure 29** was originally developed for roller bearing axles that used cylindrical bearings. These designs used an inner ring heat-shrink fitted to the bearing seat. This type of bearing was used in many passenger and locomotive axle designs from the 1950s into the 1970s.

    These cylindrical bearings used the face of the axle as a thrust surface. The cylindrical bearings were housed in a relatively large box with a brass thrust face that contacted the end of the axle to control axial movement of the wheel set assembly within the truck. Because there was thrusting contact against the end faces of the axle, axle identification stamping was not permitted on the faces of the axle. The undercut shown in the drawing was created for stamping of axle identification information.

    With the development of AAR-style unitized bearings, manufacturers designed their bearings so they could be fitted directly to these older-style seats. It was necessary to simply drill and tap three holes into the ends of the axles for attachment of the AAR-style bearings' end caps.

Engineering drawings were created to show conversion of the axle for AAR-style bearings. The addition of the three drilled and tapped holes on the ends of the axles were added with no other changes. Over the years, these conversion drawings were copied and used for the purchasing of new axles for use with AAR-style bearings. These axles would never use the cylindrical bearings that required the undercut for axle identification stamping.

Keeping the undercut diameter is not good for press-fitting of AAR-style bearings. A taper is strongly preferred. Because their application does not require contact with the ends of the axle, AAR-style bearings allow for the stamping of axle identification information on the ends of the axles. The undercut diameter is no longer needed and it is detrimental to proper assembly of press-fitted bearings.

14. The classification code D-11 (and D-12 in Section 11) is an arbitrary designation with no special meaning. D-11 axle designs utilize the shorter load bearing moment bearings that have gained widespread acceptance and utilization since their introduction circa 2010.

    The codes "D-11" and "D-12" are borrowed from an old designation once used by the AAR to differentiate between axles with plain bearing journals (termed "D-12" by AAR) and axles with roller bearing seats (termed "D-11" by AAR). Since the AAR plain bearing axle designs have been obsolete for many years, the AAR no longer uses these designations. The two terms have been recycled here to differentiate between modern axle designs and legacy axle designs.

15. The bearing seat diameters, both minimums and maximums, defined in this recommended practice are 0.0005 inch. larger than current AAR designs for the same bearing seats. This increase in bearing diameters has been adopted to reduce the scrapping of axles when they are processed for reuse as secondhand axles. "Secondhand" is an AAR term that has been used for nearly 100 years. It refers to material that has been used in service, i.e., used material.

    Current AAR acceptance for bearing seats is the same for both new and secondhand axles.

    Secondhand material, axles in particular, is processed in wheel shops for reuse. APTA PR-M-S-019-17, "Passenger Wheel Set Assembly," covers the reuse and assembly of both new and secondhand axles.

    Secondhand axles are cleaned, inspected dimensionally and tested non-destructively to qualify them for reuse. Because abrasive media are commonly used to clean axle seats prior to dimensional inspection, axles may be scrapped for undersized seats, particularly bearing seats, the first time they are processed for reuse. This can be the case when axles were originally manufactured at or near acceptable minimum limits.

    A thorough analysis, based on extensive experience over many years, of the effect of the small increase in bearing seat diameters determined that doing so would not negatively impact either the assembly process or the performance of AAR-style bearings. Furthermore, the analysis determined that bearing remanufacturing procedures would not be impacted, in that current remanufacturing specifications for determination of bearing spacer sizing to achieve the required axial clearance of mounted bearings need not be changed.

    NOTE: This increase in bearing seat diameters applies to all designs contained in this recommended practice and not only those in Section 10, where it first appears. This note will not be repeated for each of the applicable sections, which also include Sections 11, 12 and 13.

16. The wheel seat diameters provided in **Table 10** for D-11 designs allow for 0.250 inch reduction of wheel seat for maintenance purposes. Wheel seats are typically machined with a light "skim cut" when wheels are replaced. This skim cut reduces the diameter of the wheel seat by about 0.015 inch each time wheels are changed.

    APTA's (and AAR's) standard for wheel set assembly maintenance allows wheel seats to be reduced in diameter by 0.250 inch before the axle must be scrapped. The D-11 axle designs in this recommended practice have wheel seat diameters that will allow for the cutting of wheel seats when wheels are replaced. D-11 wheel seat diameters allow for maintenance machining of wheel seats so that the wheel seat condemning diameter is greater than the diameter of the axle dust guard seat.

17. The classification code D-12 (like D-11 in Section 10) is an arbitrary designation with no special meaning. D-12 axle designs utilize AAR-style bearings with longer load bearing moments. Since circa 2010, the AAR has approved new bearing designs that shorten the load bearing centerline moment. Axle designs described in this recommended practice that use these new bearings are designated D-11. The D-12 axle designs are legacy designs that, as of 2021, make up the overwhelmingly large share of axles in use at that time. For that reason the D-12 designs have been included in this recommended practice .

    The codes "D-11" and "D-12" are borrowed from an old designation once used by the AAR to differentiate between axles with plain bearing journals (termed "D-12" by AAR) and axles with roller bearing seats (termed "D-11" by AAR). Since the AAR plain bearing axle designs have been obsolete for many years, the AAR no longer uses these designations. The two terms have been recycled here to differentiate between modern axle designs and legacy axle designs.

18. The axle design identification schema in **Table 12** is Bnnn-2D-Z:

    - B is the AAR bearing class, determined largely by the bearing seat diameter.
    - nnn is the nominal wheel seat diameter in 0.01 inch.
    - 2D denotes two discs.
    - Z is a sequential alphabetic character (A, B, C) to differentiate the three standard axle designs.
    - The A designation for character Z was chosen because Amtrak Viewliner cars use this design.
    - The B designation for character Z was chosen because vehicles in use at New Jersey Transit and MARC use this design on vehicles from a carbuilder whose first letter is "B."
    - The C designation for character Z was chosen because some Chicago Metra coaches use this design. This C design is also used in LIRR and MARC vehicles.

19. The clearance requirement described here is to facilitate removal of the bearing from the axle. The use of short cup bearings on inboard bearing axles results in only a small part of the bearing (approximately 0.030 inch) protruding above the diameter of the axle's bearing shoulder. The use of short cup bearings in this manner has been prevalent since the 1970s.

    While removal of the bearings with such a limited available area of contact is possible, it can require expensive tooling or destruction of the bearing during removal when mounted components do not permit sufficient room for adequate bearing removal fixtures.

    The clearance requirement in this section allows for tooling that can slip over the axle bearing shoulder and pull on the minimally exposed area of the bearing. For short cup bearings, the exposed area is on the seal ring. This 2.00 inch clearance requirement is minimal. Whenever possible, allowing more room in this area is highly beneficial for maintenance of bearings and wheel set assemblies.

Short cup bearings were a modification of standard AAR bearings, the modification being effected as described in note 22 of this appendix. The recent addition of improved performance AAR bearing classes L, K and M make them ideal choices for inboard bearing applications. These L, K and M bearings are actually shorter than the older style short cup bearings as a result of the elimination of the two seal ring components. Additionally, the exposed area of these bearings available for bearing removal is much larger. The exposed portion of L, K and M bearings is the inner bearing cone's inner ring.

20. As described in note 22 of this appendix, short cup bearings were a modification of standard AAR bearings for AAR bearing classes E and F. Since these bearings were never an AAR standard in their shortened cup form, they never received an AAR class designation. They have been referred to with various names to designate the modification—short cup E, compact E, etc. This recommended practice assigns the prefix "s" to short cup bearings for easier identification.

21. Class L and K bearings are AAR standard designs, so their designations clearly define them. When considering axle designs, note that L and K bearings have stack heights that are even less than the stack heights of short cup bearings. This is a consequence of the elimination of seal rings. Seals for L and K bearings are mounted directly to the inner ring of the bearing, the inner ring having been lengthened somewhat to accommodate the seal. Even with the lengthened inner rings, though, these bearings are still significantly shorter than short cup bearings, offering the axle designer increased flexibility in addition to the improved performance of L and K designs.

22. The design class designation follows the schema Annn:

    - A is the AAR-type bearing class, basically the size of the bearing.
    - nnn is the diameter of the wheel seat in 0.01 inch.
    - For example, an sE563 axle is designed to use an AAR-style class sE short cup bearing with a nominal new wheel seat diameter of 5.63 inches.

    NOTE: Short cup bearings are not AAR standards because they are not used in freight car applications. They differ from AAR standard bearings only in that their cup lengths and cone spacer widths have been shortened to provide the compact envelope needed for inboard axles.

    The L and K classes are ideally suited for inboard applications since not only do they feature a reduced centerline load moment (in comparison to sE and sF bearings), they also have the added benefit of having a backing ring to facilitate bearing removal. As of the writing of this recommended practice , L and K bearings have not yet been used in inboard applications in North America, but any new vehicle design should consider their use.

23. The purpose of this section is to simplify the "axle calculation" defined in an EN (European) standard. This calculation is often required by the specification for new passenger vehicle designs. The axle calculation originally required the use of four standards, an EN standard for the axle calculation for outboard bearing axles, a BS (British) standard for the axle calculation for inboard bearing axles, and two EN standards, one for axle design and one for wheel set assembly. The EN and BS standards adopted a two-step calculation for the maximum permissible stresses for various axle zones.

The outboard bearing standard and the inboard bearing standard were originally authored by disparate technical groups—BS (British), EN (European) and CEN (European). There are inconsistencies in nomenclature due to the information being spread over four different standards. These four standards have undergone consolidation over the past five years. The two standards that covered inboard versus outboard bearing axles have been recently consolidated into two parts of a single standard, EN 13103-1 for outboard bearing axles and CEN/TS 13103-2 for inboard bearing axles. Even so, the inconsistencies in nomenclature between inboard and outboard axles remain.

Taking the above history into consideration, this APTA recommended practice attempts to consolidate those four standards, adapt them to steel commonly used in the U.S. and specified in this recommended practice , and create a single-step axle calculation while maintaining the spirit of the original EN standards. This involved the creation of new maximum permissible stress tables for the steel grades covered in this recommended practice . To eliminate the inconsistency in nomenclature, axle calculation zones have been redefined using letters instead of the numbers used in the EN zone definitions.

24. From the newly updated EN standards, EN 13103-1 and CEN/TS 13103-2, consider these calculation zone definitions.

    - Zone 3 is the axle bearing seat for outboard axles in 13103-1
    - Zone 3 is the axle bore for inboard hollow axles in 13103-2
    - Zone 4 is the axle bore for outboard hollow axles in 13103-1

    The fact that Zone 3 is the bore of a hollow axle in one standard while Zone 3 is a bearing seat in the other standard was determined to be confusing, especially when including all types of axles in one unifying recommended practice, as this recommended practice does.

    Using numbers, even consistently defined numbers, to designate the calculation zones could have led to further confusion, so this document adopts letters for the definitions of the various zones. Note that the definitions of the zones have not been changed from the EN standards. Only the nomenclature used to refer to them has been altered.

25. The axle calculations specified by EN 13103-1 and CEN/TS 13103-2, and required by this recommended practice , determine acceptance of a given design based on whether or not axle loads generate stresses that exceed maximum permissible stresses applicable to five specific axle zones.

    The maximum permissible stresses are a function of the fatigue limit of the steel grade used. The two EN (CEN) axle standards, one for outboard bearing axles and one for inboard bearing axles, specify the MPSs for standard EN steels for five zones of the axle. Furthermore, those standards specify the magnitude and method for application of forces to those five zones.

    The EN axle calculation specifications define a method for determination of MPSs for materials other than standard EN axle grades. That method has been followed to establish MPSs for the axle grades contained in this document. Those MPSs are shown in **Table 15** through **Table 22**.

    To determine MPSs for the four steel grades in this recommended practice , it is necessary to know the empirically determined fatigue limit for those grades for full-sized test samples. Additionally, it is necessary to know the empirical fatigue limits for small-sized tests of notched and unnotched samples. Those three fatigue limits are provided in the EN specifications for EN steel grades, but not for other grades of steel.

Empirical testing was available for three of the APTA steel grades covered by this recommended practice , AAR grade F, AAR grade H1 and APTA 4140-H2. It was necessary to estimate fatigue limits for the other steel grades included in this document. That was accomplished in the following manner.

The EN-specified fatigue limits for each of the five calculation zones were compared to the minimum values for ultimate tensile strength for each of two EN materials, EA1N and EA4T. For each axle zone, a ratio of the fatigue limit to the UTS of the material was determined. The values for EA1N were slightly more conservative than those for EA4T. The zonal fatigue limit-UTS ratios for EA1N are shown in **Table 23** as percents.

TABLE 23

Zonal Fatigue Limit-UTS Ratios

EA1N	A%	B%	C%	D%	E%
1	36	20	17	18	15

The minimum UTS values for the four steel grades specified in **Table 6** were multiplied by these ratios to establish full-size fatigue limits for APTA steel grades for each of the five axle zones. These fatigue limits are *not* the maximum permissible stresses. The MPSs must be calculated using fatigue limits in combination with a safety factor.

The safety factor is calculated using the ratio of the unnotched sample fatigue limit to the notched sample fatigue limit for empirically tested small-size test pieces. This ratio is referred to as "q." Fatigue limit test results were available for AAR grade F, AAR grade H1 and APTA 4140 grade H2.

The q ratios shown in **Table 24** were available from empirical tests of those three steel grades. The "qtest" column shows the actual ratios from the fatigue testing. The fatigue values from the tests, one for unnotched specimens and one for notched specimens for each grade, were reported to two decimal places. The fatigue limits for the unnotched (RfL) samples and the notched (RfE) samples are shown in MPa units. The calculated q ratios are shown to seven decimal places in the qtest column. Because the q values for H1 and H2 were so similar, those two were averaged to obtain a single safety factor for both H grades. The "qAPTA" column shows the q values used to calculate the MPSs in the tables in Section 17.

TABLE 24

Empirical Tests of Three Steel Grades

Grade	qAPTA	qtest	RfL	RfE
AAR F	1.38	1.3783293	273.75	198.61
AAR H1	1.57	1.5692189	386.42	246.25
APTA 4140-H2	1.57	1.5762004	377.50	239.50

The safety factor for each grade of steel is calculated using the ratio of the q ratio determined for a particular steel grade to the q ratio for EA1N. This is a ratio of ratios, i.e., a q divided by the qEA1N number. The ratio of ratios q/qEA1N is then multiplied by the safety factors for EA1N as specified in the EN specifications for three separate axle types to determine the safety factor for the APTA steel grades. The EA1N safety factors are published in the EN specifications for axle calculations. A minimum safety factor of 1.20 is required, so whenever a calculated safety factor was less than 1.20, the value 1.20 was used.

Empirical test results were not available for APTA grade G. Consequently, its q value and safety factor could not be determined. The q value for grade G was set to the same as that for grades H1 and H2, i.e., 1.57. The reason for using this value, rather than the value for grade F, is that it provides a more conservative, higher safety factor. **Table 25** summarizes the q values and safety factors (SF) used to establish the MPSs for APTA steel grades.

TABLE 25
Summary of Factors Used to Establish APTA Steel MPSs

Type	TT	SF_{EA1N}	q_{EA1N}	q_F	q_G	q_{H1}	q_{H2}	SF_F	SF_G	SF_{H1}	SF_{H2}
drive	direct	1.50	1.47	1.38	1.57	1.57	1.57	1.41	1.60	1.60	1.60
drive	indirect	1.30	1.47	1.38	1.57	1.57	1.57	1.22	1.39	1.39	1.39
idler	none	1.20	1.47	1.38	1.57	1.57	1.57	1.20	1.28	1.28	1.28

26. This standard was originally a British Standard, British Standards Institution, BS 8535:2011, Railway Applications – Wheel sets and bogies – Powered and non-powered axles with inboard bearings – Design method. EN standards are technical standards drafted and maintained by one of three organizations: CEN, CENELEC and ETSI. The standard CEN/TS 13103-2:2020, "Design method for inboard axles," is an updated revision of an original British BS standard.

    EN standards are used by European Union railroads. EN standards provide a comprehensive set of standards for European railways. Prior to 2020, there was no EN standard for the design method for inboard bearing axles. The only recognized European standard for inboard bearing axle designs was the British Standard, BS 8535.

    CEN/TS 13103-2:2020 was used to develop this APTA recommended practice for the "axle calculation" required in Section 17. In that section, maximum permissible limits based on endurance limits for the steel materials defined in Section 3.1 have been provided for use in the axle calculation. See end note 23 for more details on this subject.