



SURFACE VEHICLE RECOMMENDED PRACTICE

J2551™-1

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(R) Recommended Practices for Fluid Conductor Carbon, Alloy and High Strength Low Alloy Steel Tubing Applications-Part 1: Design and Fabrication

RATIONALE

The verbiage in this document has been modified to clarify the intent of the information presented. Information has been added to provide definitions and design guidance for side ports and pressure ratings.

FOREWORD

The May 2010 edition of SAE J2551 was published as a single document covering the design and fabrication of carbon, alloy and high strength low alloy tube assemblies. SAE J2551 has been organized into three sections as follows:

1. SAE J2551-1 - Recommended Practices for Fluid Conductor Carbon, Alloy and High Strength Low Alloy Steel Tubing Applications-Part 1: Design and Fabrication
2. SAE J2551-2 - Recommended Practices for Fluid Conductor Carbon, Alloy and High Strength Low Alloy Steel Tubing Applications-Part 2: General Specifications and Performance Requirements
3. SAE J2551-3 - Recommended Practices for Fluid Conductor Carbon, Alloy and High Strength Low Alloy Steel Tubing Applications-Part 3: Procurement

This SAE Recommended Practice provides guidelines for designing and fabricating carbon, alloy and high strength low alloy steel tube assemblies for fluid power and general applications. Experienced designers and users skilled in achieving proper results, as well as the less experienced, can use this outline as a list of recommendations to consider during the design and fabrication process.

Fluid power systems are complex and require extensive knowledge of both the system requirements and the various types of tube. Therefore, all-inclusive, detailed, step-by-step instructions are not practical and are beyond the scope of this document. Less experienced designers and users who need more information should consult specialists such as experienced tube designers and fabricators. The use and application of this Recommended Practice can improve the quality of the final product as well as the communication process.

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Documents
Document Sharing Hub

Adherence to the guidelines of this Recommended Practice can assist users to design, manufacture, procure, and install tube assemblies that can be:

- Designed to perform safely and adequately
- Designed and manufactured with common practices and components in accordance with established industry standards
- Easily procured and serviced globally
- Conveniently packaged/shipped
- Proficiently installed on their equipment

In an effort to standardize within a global market and ensuring that companies can remain competitive in an international market, it is the intent to convert to metric hex sizes which will:

- lead to one global system
- guide users to preferred system
- reduce complexity
- eliminate duplications

Safety Considerations

Improper selection, fabrication, installation, or maintenance of tube assemblies for fluid-power systems can result in serious personal injury or property damage. Adherence to this Recommended Practice can reduce the probability of component or system failure and thereby reduce the risk of injury or damage. Users shall consider the proper selection of components, fabrication of tubes, installation and maintenance procedures to address this potential risk.

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1. SCOPE

1.1 Purpose

These recommended practices provide general recommendations for designing and fabricating carbon, alloy and high strength low alloy steel tube assemblies for fluid power applications utilizing commonly available manufacturing methods and general guidelines for tube selection and application.

1.2 Field of Application

These recommended practices are intended for general application and hydraulic systems on industrial equipment and commercial products. Aircraft and Aerospace applications were not considered during the preparation of this document.

Because many factors influence the pressure at which a hydraulic system will perform satisfactorily, these recommended practices should not be construed as guaranteed minimums. For any application, sufficient testing should be conducted and reviewed by both the user and supplier to ensure that required performance levels are met.

The fabricator should be consulted for use of these recommended practices and connectors in conditions outside the pressure and temperature of limits specified. Both metric and inch tubing should be considered to accommodate hydraulic system design requirements. In the past, these requirements have been met predominantly with inch tubing; for new designs, metric tubing should be considered.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J356	Welded Flash-Controlled Low-Carbon Steel Tubing Normalized for Bending, Double Flaring, and Beading
SAE J512	Automotive Tube Fittings
SAE J514	Hydraulic Tube Fittings
SAE J518-1	Hydraulic Flanged Tube, Pipe, and Hose Connections, 4-Screw Flange Connection Part 1: 3.5 MPa to 35 MPa (Code 61)
SAE J518-2	Hydraulic Flanged Tube, Pipe, and Hose Connections, 4-Screw Flange Connection Part 2: 42 MPa (Code 62)
SAE J518-3	Hydraulic Flange Clamps, 2-Screw Flange Connections to be used with SAE J518-1 (Code 61) Connections where Only Low Pressure is Required
SAE J524	Seamless Low-Carbon Steel Tubing Annealed for Bending and Flaring
SAE J526	Welded Low-Carbon Steel Tubing Suitable for Bending, Flaring, Beading, Forming and Brazing
SAE J527	Brazed Double Wall Low-Carbon Steel Tubing
SAE J1065	Nominal Reference Working Pressures for Steel Hydraulic Tubing

SAE J1231	Formed Tube Ends for Hose Connections and Hose Fittings
SAE J1273	Recommended Practices for Hydraulic Hose Assemblies
SAE J1453-1	Specification for O-Ring Face Seal Connectors: Part 1 - Tube Connection Details and Common Requirements for Performance and Tests
SAE J2044	Quick Connect Coupling Specification for Liquid Fuel and Vapor/Emissions Systems
SAE J2435	Welded Flash Controlled, SAE 1021 Carbon Steel Tubing, Normalized for Cold Forming, Welding and Brazing
SAE J2467	Welded and Cold-Drawn, SAE 1021 Carbon Steel Tubing Normalized for Bending and Flaring
SAE J2551-2	Recommended Practices for Fluid Conductor Carbon, Alloy and High Strength Low Alloy Steel Tubing Applications - Part 2: General Specifications and Performance Requirements
SAE J2551-3	Recommended Practices for Fluid Conductor Carbon, Alloy and High Strength Low Alloy Steel Tubing Applications - Part 3: Procurement
SAE J2593	Information Report for the Installation of Fluid Conductors and Connectors
SAE J2613	Welded Flash Controlled, High Strength (500 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Sub-Critically Annealed for Bending, Double Flaring, and Bending
SAE J2614	Welded and Cold-Drawn, High Strength (500 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Sub-Critically Annealed for Bending and Flaring
SAE J2832	Welded Flash Controlled, High Strength (690 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Stress Relieved Annealed for Bending and Double Flaring
SAE J2833	Welded and Cold-Drawn, High Strength (690 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Stress Relieved Annealed for Bending, Flaring, cold forming and brazing

2.1.2 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ISO 2566-1	Steel - Conversion of elongation values - Part 1: Carbon and low alloy values
ISO 3304	Plain end seamless precision steel tubes - Technical conditions for delivery
ISO 3305	Plain end welded precision steel tubes - Technical conditions for delivery
ISO 4406	Hydraulic fluid power - Fluids - Method for coding the level of contamination by solid particles
ISO 6162-1	Hydraulic fluid power - Flange connectors with split or one-piece flange clamps and metric or inch screws - Part 1: Flange connectors, ports and mounting surfaces for use at pressures of 3.5 MPa (35 bar) to 35 MPa (350 bar), DN 13 to DN 127
ISO 6162-2	Hydraulic fluid power - Flange connectors with split or one-piece flange clamps and metric or inch screws - Part 2: Flange connectors, ports and mounting surfaces for use at a pressure of 42 MPa (420 bar), DN 13 to DN 76
ISO 8434-1	Metallic tube connections for fluid power and general use - Part 1: 24 degree cone connectors
ISO 8434-2	Metallic tube connections for fluid power and general use - Part 2: 37 degree flared connectors

- ISO 8434-3 Metallic tube connections for fluid power and general use - Part 3: O-ring face seal connectors
- ISO 9227 Corrosion tests in artificial atmospheres - Salt spray tests
- ISO 10763 Hydraulic fluid power - Plain-end, seamless and welded steel tubes - Dimensions and nominal working pressures

2.1.3 EN Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

- EN 10305-2 Steel tubes for precision applications - Technical delivery conditions - Part 2: Welded cold drawn tubes
- EN 10305-4 Steel tubes for precision applications - Technical delivery conditions - Part 4: Seamless cold drawn tubes for hydraulic and pneumatic power systems

2.1.4 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

- ASTM B117 Operating Salt Spray (Fog) Apparatus
- ASTM D2247 Testing Water Resistance of Coatings in 100% Relative Humidity

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

- SAE J246 Spherical and Flanged Sleeve (Compression) Tube Fittings
- SAE J343 Test and Test Procedures for SAE 100R Series Hydraulic Hose and Hose Assemblies
- SAE J515 Specification for O-Ring Materials Used with Hydraulic Connectors
- SAE J525 Welded and Cold Drawn Low-Carbon Steel Tubing Annealed for Bending and Flaring
- SAE J533 Flares for Tubing
- SAE J1290 Automotive Hydraulic Brake System - Metric Tube Connections
- SAE J1453-2 Specification for O-Ring Face Seal Connectors: Part 2 - Requirements, Dimensions, and Tests for Steel Unions, Bulkheads, Swivels, Braze Sleeves, Braze-on Tube Ends, Caps, and Connectors with ISO 6149-2 Metric Stud Ends and ISO 6162 4-Bolt Flange Heads
- SAE J1453-3 Specification for O-Ring Face Seal Connectors: Part 3 - Requirements, Dimensions, and Tests for Steel Unions, Bulkheads, Swivels, Braze Sleeves, Caps, and Connectors with SAE J1926-2 Inch Stud Ends
- SAE J1677 Tests and Procedures for Carbon Steel and High Strength Low Alloy Steel Tubing

SAE J1926-1	Connections for General Use and Fluid Power - Ports and Stud Ends with ASME B1.1 Threads and O-Ring Sealing - Part 1: Threaded Port with O-Ring Seal in Truncated Housing
SAE J1926-2	Connections for General Use and Fluid Power - Ports and Stud Ends with ASME B1.1 Threads and O-Ring Sealing - Part 2: Heavy-Duty (S Series) Stud Ends
SAE J1926-3	Connections for General Use and Fluid Power - Ports and Stud Ends with ASME B1.1 Threads and O-Ring Sealing - Part 3: Light-Duty (L-Series) Stud Ends
SAE J2094	Vehicle and Control Modifications for Drivers with Physical Disabilities Terminology
SAE J2592	Carbon Steel Tubing for General Use - Understanding Nondestructive Testing for Carbon Steel Tubing
SAE J2682	Connections for General Use and Fluid Power - Test Methods-Threadless Connections
SAE J2832	Welded Flash Controlled, High Strength (690 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Stress Relieved Annealed for Bending and Double Flaring
SAE J2833	Welded and Cold-Drawn, High Strength (690 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Stress Relieved Annealed for Bending and Flaring

2.2.2 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ISO 272	Fasteners - Hexagon products - Widths across flats
ISO 273	Fasteners - Clearance holes for bolts and screws
ISO 2944	Fluid power systems and components - Nominal pressures
ISO 3304	Plain end seamless precision steel tubes - Technical conditions for delivery
ISO 3305	Plain end welded precision steel tubes - Technical conditions for delivery
ISO 3448	Industrial liquid lubricants - ISO viscosity classification
ISO 3457	Earth-moving machinery - Guards and shields - Definitions and specifications
ISO 3601-1	Fluid power systems - O-rings - Part 1: Inside diameters, cross sections, tolerances and designation codes
ISO 3601-2	Fluid power systems - O-rings - Part 2: Housing dimensions for general applications
ISO 3601-3	Fluid power systems - O-rings - Part 3: Quality acceptance criteria
ISO 3601-4	Fluid power systems - O-rings - Part 4: Anti-extrusion rings (back-up rings)
ISO 3601-5	Fluid power systems - O-rings - Part 5: Specification of elastomeric materials for industrial applications
ISO 4200	Plain end steel tubes, welded and seamless - General tables of dimensions and masses per unit length
ISO 4397	Fluid power connectors and associated components - Nominal outside diameters of tubes and nominal hose sizes
ISO 4399	Fluid power systems and components - Connectors and associated components - Nominal pressures

ISO 5598	Fluid power systems and components - Vocabulary
ISO 6072	Rubber - Compatibility between hydraulic fluids and standard elastomeric materials
ISO 6149-1	Connections for hydraulic fluid power and general use - Ports and stud ends with ISO 261 metric threads and O-ring sealing - Part 1: Ports with truncated housing for O-ring seal
ISO 6149-2	Connections for hydraulic fluid power and general use - Ports and stud ends with ISO 261 metric threads and O-ring sealing - Part 2: Dimensions, design, test methods and requirements for heavy-duty (S series) stud ends
ISO 6149-3	Connections for hydraulic fluid power and general use - Ports and stud ends with ISO 261 metric threads and O-ring sealing - Part 3: Dimensions, design, test methods and requirements for light-duty (L series) stud ends
ISO 6149-4	Connections of hydraulic fluid power and general use - Ports and stud ends with ISO 261 metric threads and O-ring sealing - Part 4: Dimensions, design, test methods and requirements for external and internal hex port plugs
ISO 6164	Hydraulic fluid power - Four-screw, one-piece square-flange connections for use at pressures of 25 MPa and 40 MPa (250 bar and 400 bar)
ISO 6605	Hydraulic fluid power - Tests methods for hoses and hose assemblies
ISO 6743-4	Lubricants, industrial oils and related products (class L) - Classification - Part 4: Family H (Hydraulic systems)
ISO 7241	Hydraulic fluid power - Dimensions and requirements of quick-action couplings
ISO 9974-1	Connections for general use and fluid power - Ports and stud ends with ISO 261 threads with elastomeric or metal to metal sealing - Part 1: Threaded ports
ISO 9974-2	Connections for general use and fluid power - Ports and stud ends with ISO 261 threads with elastomeric or metal to metal sealing - Part 2: Stud ends with elastomeric sealing (type E)
ISO 9974-3	Connections for general use and fluid power - Ports and stud ends with ISO 261 threads with elastomeric or metal to metal sealing - Part 3: Stud ends with metal-to-metal sealing (type B)
ISO 9974-4	Connections for general use and fluid power - Ports and stud ends with ISO 261 threads with elastomeric or metal to metal sealing - Part 4: Dimensions, design, test methods and requirements for external hex and internal hex port plugs
ISO 15171-1	Connections for fluid power and general use - Hydraulic couplings for diagnostic purposes - Part 1: Coupling not for connection under pressure
ISO 15171-2	Connections for fluid power and general use - Hydraulic couplings for diagnostic purposes - Part 2: Coupling with M16 x 2 end for connection under pressure
ISO 16028	Hydraulic fluid power - Flush-face type, quick-action couplings for use at pressures of 20 MPa (200 bar) to 31,5 MPa (315 bar) - Specifications
ISO 19879	Metallic tube connections for fluid power and general use - Test methods for hydraulic fluid power connections

2.2.3 EN Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

EN 10305-3 Steel tubes for precision applications - Technical delivery conditions - Part 3: Welded cold sized tubes

2.2.4 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM B117	Operating Salt Spray (Fog) Apparatus
ASTM A213/A213M	Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
ASTM A268/A268M	Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service
ASTM A269/A269M	Seamless and Welded Austenitic Stainless Steel Tubing for General Service
ASTM A312/A312M	Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
ASTM A450/A450M	General Requirements for Carbon and Low Alloy Steel Tubes
ASTM A513/A513M	Electric-Resistance-Welded Carbon and Alloy Steel Mechanical Tubing
ASTM A519/A519M	Seamless Carbon and Alloy Steel Mechanical Tubing
ASTM A554	Welded Stainless Steel Mechanical Tubing
ASTM D2247	Testing Water Resistance of Coatings in 100% Relative Humidity

2.2.5 American Welding Society Publications

Available from American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, Tel: 800-443-9353, www.aws.org.

AWS D1.1/D1.1M	Structural Welding Code - Steel
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3. DEFINITIONS

The following terms and definitions apply to this Recommended Practice.

3.1 ARC

The curved portion of the bend.

3.2 BEND DIE

A wheel-shaped die with a groove in the outer circumference that conforms to half the tube circumference. It most often has a straight section used as half of the clamp set for holding the tube against the die. This type of die is used in rotary draw or compression bending to generate the bend radius.

3.3 BEND RADIUS

See Centerline Radius.

3.4 BENDER (TUBE)

A mechanical device capable of forming a bend in a straight length of material.

3.5 BOOST

Device or system to apply a longitudinal positive force in the direction of the bend by either clamping or pushing on the end of the tube being bent. This force reduces wall thinning of the outside wall and increases the compression and thickness of the inside wall.

3.6 BUCKLING

Definite folds, creases, or wrinkles formed on the surface of the tube during the bending operation.

3.7 BURST PRESSURE

Pressure at which a component or tubing fails and fluid begins to escape (typically equal to 4X the System Working Pressure designated on the tube assembly drawing).

3.8 CENTER TO CENTER

The distance between the theoretical or calculated centers of adjoining bends. Also used for diametric measurement between the centerlines of two tangent points of a bend, (i.e., 180° bend for which the center to center distance is equal to twice the centerline radius).

3.9 CENTERLINE DIAMETER

The distance from the centerline axis of the tube across to the other centerline of a 180° bend.

3.10 CENTERLINE RADIUS (CLR)

The distance on a bend forming tool from the center of curvature to a point corresponding to the centerline of the tubular shape when mounted in the bend-forming tool - nominal CLR.

3.11 CLAMP DIE

A tool used in rotary draw and compression bending to clamp the tube against the bend die to prevent the tube from slipping during bending.

3.12 CMM (Coordinate Measuring Machine)

An accurate measurement device that measures the geometrical attributes and dimensions of an object. Measurements are obtained by the use of a probe that interacts with the sample part. Examples of probes include (but are not limited to): mechanical, optical, laser, or white light.

3.13 COLD BENDING

The bending of tube by cold working at ambient temperatures.

3.14 COMPRESSION

The forces that thicken the inside wall of the bend.

3.15 COMPOUND BEND

A condition that exists where there is insufficient straight length between a bend and an adjacent bend.

3.16 CUSTOMER

An individual or company that purchases goods or services.

3.17 "D" OF BEND

Centerline radius (CLR) divided by the tube outside diameter.

3.18 DEGREE OF BEND (DOB)

The angle expressed in number of degrees, to which the bend is formed.

3.19 DESIGNER

A person who conceives and executes detailed plans for metallic tube assemblies.

3.20 DISTANCE BETWEEN BENDS (DBB)

The actual length of the straight section between the tangent points of two adjoining bends.

3.21 DUCTILITY

The ability of the material to deform plastically without fracture, as measured by elongation or reduction of area in a tensile test.

3.22 ELONGATION

The increase in length of a test specimen at failure in a tensile test, expressed as a percentage of the original length. The increase in length of material fiber during bending, expressed as a percentage of the original length.

3.23 EXTRADOS

The outside arc of the bend.

3.24 FABRICATOR

An individual or company that makes parts and tube assemblies.

3.25 FLAT PLANE

See Out-of-Plane.

3.26 FLASH

The excess material created at the weld joint when the tube was produced.

3.27 FLATTENING

See Ovality.

3.28 FLUID POWER

Energy transmitted and controlled using pressurized hydraulic fluids or gases.

3.29 FOLLOWER DIE

See Pressure Die.

3.30 HUMP

A rounded protrusion or bulge on the outside radius.

3.31 HYDRAULIC CIRCUIT

A system of interconnecting parts that transport liquid to move and control energy.

3.32 HYDRAULIC PRESSURE SPIKE

Momentary rapid increase in system pressure.

3.33 ID

The inside diameter of the tube.

3.34 INNER RADIUS

See Intrados.

3.35 INTRADOS

The inside arc of the bend.

3.36 MANDREL

A tool device used to provide internal support to the tube to prevent excessive flattening, collapse or wrinkling during rotary draw bending. The mandrel is supported by a mandrel rod that runs through the tube ID and is held in location at the bend die.

3.37 MINIMUM WALL THICKNESS

The wall thickness specified on the fabrication drawing or computed in accordance with the applicable specification as the minimum acceptable for the design criteria.

3.38 NEUTRAL AXIS

That portion of the tube that is neither in compression nor in tension.

3.39 NOMINAL OD

Target measurement for tubing OD.

3.40 NOMINAL WALL

The target measurement for the wall thickness.

3.41 OD

Outside diameter of the tube.

3.42 OUT-OF-PLANE

The deviation of the horizontal plane of a single bend between its tangent points, based on the theoretical centerline of the bend.

3.43 OUTSIDE RADIUS

See Extrados.

3.44 OVALITY

The distortion of the cross section of tube from its normal (round) shape usually expressed as a percentage of the difference between the major and minor axes of the starting material compared to the OD before bending.

3.45 OVER BEND

The amount that a tube has to be bent past the desired bend angle to compensate for spring-back in the bend. This allows the tube to return to the desired bend angle after all external support from clamping has been removed. Also see Spring-Back.

3.46 PLANE OF BEND (POB)

The plane of a bend in relation to the axis of the straight section preceding it. Used specifically for changes of plane in successive bends.

3.47 PRESS DIE

See Ram Die.

3.48 PRESSURE DIE

A tool used in rotary draw bending that holds the tube against the die as the bend and clamp die rotate with the tube. Pressure dies can be of the static or follower type. Also used in compression bending to form the tube around the bend die.

3.49 PRESSURE DIE ASSIST

A system that generates a longitudinal force on the tube during bending. The amount of force generated is dependent on the friction occurring in the interface of the pressure die and the tube.

3.50 PRESSURE RELIEF VALVE

A type of valve designed to limit or control the pressure in a hydraulic circuit.

3.51 USER

End user of the finished tube assembly.

3.52 RADIAL GROWTH

The difference between the actual CLR and the bend die CLR of a tubular shape after all external forces that restrained it are removed.

3.53 RADIUS

See Centerline Radius.

3.54 RAM DIE

A type of bend die used in a press or ram bender to form the bend.