

	<b>SURFACE VEHICLE RECOMMENDED PRACTICE</b>	<b>SAE</b> <b>J2551 SEP2013</b>
		Issued            2001-12 Cancelled        2013-09
		Superseding J2551 MAY2010
Recommended Practices for Fluid Conductor Carbon and Alloy Steel Tubing Applications		

RATIONALE

This recommended practice has been cancelled and replaced by SAE J2551-1, SAE J2551-2 and SAE J2551-3, making SAE J2551 now a three part recommended practice as follows: SAE J2551-1 is design and fabrication, SAE J2551-2 is performance requirements and SAE J2551-3 is for procurement.

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## FOREWORD

The SAE Recommended Practice is intended as a guide to consider when designing and fabricating metallic tubes and tube assemblies for fluid power and general applications. It is subject to change to keep pace with experience and technical advances. Experienced designers and users skilled in achieving proper results, as well as the less experienced may use this outline as a list of considerations to keep in mind.

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 may consult specialists such as experienced tube designers and fabricators. This guide may improve the communication process.

Following this document is highly recommended by the participating SAE/ISO organizations and their members. Adherence to these guidelines may assure the users they will create tube assemblies that can be efficiently manufactured, conveniently packaged/shipped, proficiently installed on their equipment, will perform adequately and safer to established industry standards and they will be using common practices and components that may be easily serviced anywhere globally.

**Safety Considerations**—These documents involve considerations to facilitate safer conditions when these products are in use; note these carefully during all phases of design and use of the tube assemblies. Improper selection, fabrication, installation, or maintenance of tube assemblies for fluid-power systems may result in serious personal injury or property damage. Adherence to these recommended practices could reduce the likelihood of component or system failure, thereby reducing the risk of injury or damage. The application of hydraulic tubing with fluids under pressure exposes users to risk due to mechanical or injection hazards and the environment to contamination from leakage. Users are reminded to consider the proper selection of components, fabrication of tubes, installation and maintenance procedures to address this potential risk.

## TABLE OF CONTENTS

1.	SCOPE.....	5
1.1	Purpose.....	5
1.2	Field of Application.....	5
2.	REFERENCES.....	5
2.1	Applicable Publications.....	5
2.1.1	SAE Publications.....	5
2.1.2	ISO Publications.....	6
2.1.3	EN Publications.....	6
2.2	Related Publications.....	7
2.2.1	SAE Publications.....	7
2.2.2	ISO Publications.....	8
2.2.3	ASTM Publications.....	9
3.	DEFINITIONS.....	9
3.1	Arc.....	9
3.2	Bend Die.....	9
3.3	Bend Radius.....	9
3.4	Bender (Tube).....	9
3.5	Boost.....	9
3.6	Buckling.....	9
3.7	Center to Center.....	10
3.8	Centerline Diameter.....	10
3.9	Centerline Radius (CLR).....	10
3.10	Clamp Die.....	10
3.11	Cold Bending.....	10
3.12	Compression.....	10
3.13	"D" of Bend.....	10
3.14	Degree of Bend (DOB).....	10
3.15	Distance Between Bends (DBB).....	10
3.16	Ductility.....	10

3.17	Elongation .....	10
3.18	Extrados .....	10
3.19	Flat Plane .....	10
3.20	Flash .....	11
3.21	Flattening .....	11
3.22	Fluid Power .....	11
3.23	Follower Die .....	11
3.24	Hump .....	11
3.25	Hydraulic Pressure Spike .....	11
3.26	ID .....	11
3.27	Inner Radius .....	11
3.28	Intrados .....	11
3.29	Mandrel .....	11
3.30	Minimum Wall Thickness .....	11
3.31	Neutral Axis .....	11
3.32	Nominal .....	11
3.33	Nominal OD .....	12
3.34	Nominal Wall .....	12
3.35	OD .....	12
3.36	Out-of-Plane .....	12
3.37	Outside Radius .....	12
3.38	Ovality .....	12
3.39	Over Bend .....	12
3.40	Plane of Bend (POB) .....	12
3.41	Press Die .....	12
3.42	Pressure Die .....	12
3.43	Pressure Die Assist .....	12
3.44	Radial Growth .....	12
3.45	Radius .....	13
3.46	Ram Die .....	13
3.47	Routing .....	13
3.48	Shoe .....	13
3.49	Spring-back .....	13
3.50	Tangent .....	13
3.51	Tangent Point .....	13
3.52	Tensile Strength .....	13
3.53	Tension .....	13
3.54	Throat Wall .....	13
3.55	Tube .....	13
3.56	Tube Assembly .....	13
3.57	Tube Assembly Drawing .....	13
3.58	Tube Failure .....	14
3.59	Tube Fitting or Fitting .....	14
3.60	Tube Service Life .....	14
3.61	Wall Factor .....	14
3.62	Wall Thickness .....	14
3.63	Wall Thinning .....	14
3.64	Wing Die .....	14
3.65	Wiper Die .....	14
3.66	Wrinkles .....	14
3.67	Yield Point .....	14
3.68	Yield Strength .....	14
4.	TUBE SIZING, TUBE CONNECTION SELECTION, AND ROUTINGS .....	14
4.1	Sizing .....	15
4.1.1	System Pressure and Fluid Velocity .....	15
4.1.2	Severity of Service .....	15
4.2	Tube and End Connection Selection .....	15
4.2.1	Tube Selection .....	15

4.2.2	End Connector Joining Methods.....	18
4.2.3	Tube Connection Selection.....	18
4.3	Environment.....	24
4.4	Routings.....	25
4.4.1	Accessibility of Joints for Assembly.....	25
4.4.2	Adequate Tube Supports.....	25
4.4.3	Maintenance and Access Constraints.....	26
4.4.4	Routings Between Fixed Points.....	26
4.4.5	Contact after Assembly.....	26
4.4.6	Clips and Clamps.....	26
4.4.7	Tightening Sequence Considerations.....	26
4.4.8	External Physical Abuse.....	26
4.4.9	Heavy-Duty Applications.....	27
5.	TUBE DESIGN, DIMENSIONING, TOLERANCES, AND INSPECTION.....	27
5.1	Tube Design.....	27
5.2	Tube Dimensioning.....	27
5.3	Maximum Recommended Tube Length.....	27
5.4	Tube Dimensional Tolerance.....	27
5.4.1	Hard Point versus Best Fit Inspection.....	27
5.5	Types of Inspection Methods.....	29
5.5.1	Hand Layout.....	29
5.5.2	Checking Fixtures (Machined and/or Fabricated Gauges).....	29
5.5.3	Vector Inspection (Articulating Arm Mechanism).....	29
5.5.4	Optical Inspection.....	30
6.	TUBE AND TUBE ASSEMBLY FABRICATION.....	30
6.1	Tube Bending.....	30
6.1.1	Minimum Bend Radii.....	30
6.1.2	Minimum Bend Angle.....	30
6.1.3	Maximum Bend Angle.....	30
6.1.4	Very Large Bend Radii.....	31
6.2	Tube End Cold Forming.....	31
6.3	Recommended Straight Lengths.....	31
6.3.1	Recommended End Straight Length for Bending and End Cold Forming.....	31
6.3.2	Recommended Straight Length Between Bends.....	32
6.3.3	Compound Bends.....	32
6.3.4	Common Bend Radii.....	32
6.4	Ovality and Flattening.....	32
6.5	Wall Thinning.....	32
6.6	Buckling.....	32
6.7	Marking.....	33
7.	TUBE CLEANLINESS.....	33
7.1	Compatibility of Process Coolants and Lubricants.....	33
7.2	Cleaning Compatibility.....	33
7.3	Contamination.....	33
7.4	Workmanship.....	33
7.4.1	Plating.....	33
7.5	Residual Magnetic Fields.....	34
8.	UNINTENDED USES.....	34
8.1	System Fluids Compatibility.....	34
8.2	Serviceability Issues.....	34
8.3	Mechanical Load Carrying Applications.....	34
9.	NOTES.....	34
9.1	Marginal Indicia.....	34

## 1. SCOPE

### 1.1 Purpose

These recommended practices provide general recommendations for designing and fabricating metallic tubes and 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.

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

For use of these recommended practices and connectors in conditions outside the pressure and temperature of limits specified, the manufacturers must be consulted. 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 Publications

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 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

SAE J512	Automotive Tube Fittings
SAE J514	Hydraulic Tube Fittings
SAE J518	Hydraulic Flanged Tube, Pipe, and Hose Connections, Four-Bolt Split Flange Type
SAE J533	Flares for Tubing
SAE J1065	Nominal Reference Working Pressures for Steel Hydraulic Tubing
SAE J1231	Formed Tube Ends for Hose Connections and Hose Fittings
SAE J1453-1	Specification for O-Ring Face Seal Connectors: Part 1—Tube Connection Details and Common Requirements for Performance and Tests
SAE J1453-2	Specification for O-Ring Face Seal Connectors: Part 2—Requirements, Dimensions, and Tests for Steel Unions, Bulkheads, Swivels, Braze Sleeves, Caps, and Connectors with ISO 6149-2 Metric Stud Ends
SAE J1453-3	Specification for O-Ring Face Seal Connectors: Part 3—Requirements, Dimensions, and Tests for Steel Unions, Bulkheads, Swivels, Braze Sleeves, Connectors, Caps, and Connectors with SAE J1926-2 Inch Stud Ends

SAE J2044	Quick Connect Coupling Specification for Liquid Fuel and Vapor/Emissions Systems
SAE J2593	Information Report for the Installation of Fluid Conductors and Connectors
SAE J2613	Welded Flash Controlled, High Strength Low Alloy Steel Hydraulic Tubing, Sub-Critically Annealed for Bending, Double Flaring, and Bending
SAE J2614	Welded and Cold-Drawn, High 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 and Flaring

### 2.1.2 ISO Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, [www.ansi.org](http://www.ansi.org).

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 for use at pressures of 3.5 MPa (35 Bar) to 35 MPa (350 Bar), DN 13 to DN127
ISO 6162-2	Hydraulic fluid power—Flange connectors with split or one-piece flange clamps and metric or inch screws—Part 2: Flange connectors for use at pressures of 35 MPa (350 Bar) to 40 MPA (400 Bar), DN 13 to DN 51
ISO 8434-1	Metallic tube connections for fluid power and general use—Part 1: 24° Compression connectors
ISO 8434-2	Metallic tube connections for fluid power and general use—Part 2: 37° Flared connectors
ISO 8434-3	Metallic tube connections for fluid power and general use—Part 3: O-ring face seal connectors
ISO 8434-4	Metallic tube connections for fluid power and general use—Part 4: 24° Cone connectors with o-ring weld-on nipples
ISO 10763	Plain-end, seamless and welded steel tubes—Dimensions and nominal working pressures
ISO 19879	Metallic tube connections for fluid power and general use—Test methods for hydraulic fluid power connections

### 2.1.3 EN Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, [www.ansi.org](http://www.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

## 2.2 Related Publications

The following publications are for information purposes only and are not a required part of this document.

### 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 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

SAE J246	Spherical and Flanged Sleeve (Compression) Tube Fittings
SAE J343	Tests and Test Procedures for SAE 100R Series Hydraulic Hose and Hose Assemblies
SAE J356	Welded Flash-Controlled Low-Carbon Steel Tubing Normalized for Bending, Double Flaring, and Beading
SAE J515	Specification for Hydraulic O-Ring Materials, Properties, and Sizes for Metric and Inch Stud Ends, Face Seal Fitting and Four-Screw Flange Tube Connections
SAE J524	Seamless Low-Carbon Steel Tubing Annealed for Bending and Flaring
SAE J525	Welded and Cold Drawn Low-Carbon Steel Tubing Annealed for Bending and Flaring
SAE J526	Welded Low-Carbon Steel Tubing
SAE J527	Brazed Double Wall Low-Carbon Steel Tubing
SAE J1273	Recommended Practices for Hydraulic Hose Assemblies
SAE J1290	Automotive Hydraulic Brake System—Metric Tube Connections
SAE J1677	Tests and Procedures for Steel and Copper Nickel 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 J2435	Welded Flash Controlled, SAE 1021 Carbon Steel Tubing, Normalized for Bending, Double Flaring, and Beading
SAE J2467	Welded and Cold-Drawn, SAE 1021 Carbon Steel Tubing Normalized for Bending and Flaring
SAE J2592	Carbon Steel Tubing for General Use—Understanding Nondestructive Testing for Carbon Steel Tubing

## 2.2.2 ISO Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, [www.ansi.org](http://www.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 3448	Industrial liquid lubricants—ISO viscosity classification
ISO 3457	Earth-moving machinery—Guards and shields—Definitions and specifications
ISO 3601	O-ring sealing devices for fluid carrier systems
ISO 4200	Plain end steel tubes, welded and seamless—General tables of dimensions and masses per unit length
ISO 4397	Connectors and associated components—Nominal outside diameters of tubes and nominal inside diameters of hoses
ISO 4399	Connectors and associated components—Nominal pressures
ISO 5598	Fluid power systems and components—Vocabulary
ISO 6072	Hydraulic fluid power—Compatibility between elastomeric materials and fluid
ISO 6149	Ports and stud ends with ISO 261 Metric threads and O-ring sealing
ISO 6150	Pneumatic fluid power—Cylindrical quick-action couplings
ISO 6163	Round flange, 8 and 12 screw connections
ISO 6164	Four-screw, one-piece square-flange connections
ISO 6605	Tests and test procedures
ISO 6743-4	Lubricants, industrial oils and related products (Class L)—Part 4: Family H (Hydraulic Systems)
ISO 7241	Quick action couplings
ISO 9974	Metric threaded ports and stud ends
ISO 10583	Test methods for tube connections
ISO 11926	Ports and stud ends with ISO 725 Inch threads and O-ring sealing
ISO 15171	Hydraulic couplings for diagnostic purposes
ISO 16028	Hydraulic flush face quick-action couplings

### 2.2.3 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](http://www.astm.org).

ASTM A 213/A 213M	Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
ASTM A 268/A 268M	Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing
ASTM 269-96	Seamless and Welded Austenitic Stainless Steel Tubing for General Service
ASTM 312A/A312M	Seamless and Welded Austenitic Stainless Steel Pipes
ASTM A 450/A 450M-96a	General Requirements for Carbon, Ferritic Alloy and Austenitic Alloy Steel Tubing
ASTM A 513	Standard Specification for Electric-Resistance-Welded Carbon and Alloy Steel Tubing
ASTM A 519	Standard Specification for Seamless Carbon and Alloy Steel Mechanical Tubing
ASTM A 554	Welded Stainless Steel Mechanical Tubing

### 3. DEFINITIONS

These explanations serve only to clarify this document and are not intended to stand alone. They are presented sequentially, with the former helping to explain the latter.

#### 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 will most often have 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 will reduce wall thinning of the outside wall and increase 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 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-degree bend for which the center to center distance will be equal to twice the centerline radius)

### 3.8 Centerline Diameter

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

### 3.9 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.

### 3.10 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.

### 3.11 Cold Bending

The bending of tube by cold working at ambient temperatures.

### 3.12 Compression

The forces that thicken the inside wall of the bend.

### 3.13 "D" of Bend

Centerline radius (CLR) divided by the tube diameter.

### 3.14 Degree of Bend (DOB)

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

### 3.15 Distance Between Bends (DBB)

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

### 3.16 Ductility

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

### 3.17 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.

### 3.18 Extradados

The outside arc of the bend.

### 3.19 Flat Plane

See Out-of-plane.

### 3.20 Flash

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

### 3.21 Flattening

See Ovality.

### 3.22 Fluid Power

Energy transmitted and controlled using pressurized hydraulic fluids or gases.

### 3.23 Follower Die

See Pressure die.

### 3.24 Hump

A rounded protrusion or bulge on the outside radius.

### 3.25 Hydraulic Pressure Spike

Rapid increase in system pressure that exceeds designed relief valve working pressure setting.

### 3.26 ID

The inside diameter of the tube.

### 3.27 Inner Radius

See Intrados.

### 3.28 Intrados

The inside arc of the bend.

### 3.29 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.

### 3.30 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.

### 3.31 Neutral Axis

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

### 3.32 Nominal

Used in reference to wall thickness, generally as a "mean" measurement.

### 3.33 Nominal OD

Usually refers to referenced pipe sizes, not actual OD.

### 3.34 Nominal Wall

The target measurement for the wall thickness.

### 3.35 OD

Outside diameter of the tube.

### 3.36 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.

### 3.37 Outside Radius

See Extradados.

### 3.38 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.

### 3.39 Over Bend

The amount that a tube has to be bent past the desired bend angle to compensate for residual stresses in the bend. This allows the tube to return to the desired bend angle after all external support from clamping has been removed.

### 3.40 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.

### 3.41 Press Die

See Ram die.

### 3.42 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.

### 3.43 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.

### 3.44 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.

### 3.45 Radius

See Centerline radius.

### 3.46 Ram Die

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

### 3.47 Routing

The path or shape of the tube required to move fluid from one point to another point.

### 3.48 Shoe

See Wiper die.

### 3.49 Spring-back

The movement of the bent tube toward the original straight configuration after release of the bending moment.

### 3.50 Tangent

A straight section of material on either end to the arc of a bend.

### 3.51 Tangent Point

The theoretical point at which the bend is started or ended.

### 3.52 Tensile Strength

The point at which material stretched beyond its yield will rupture.

### 3.53 Tension

The force which thins the outside wall of the bend.

### 3.54 Throat Wall

The inner half of the tube or the half undergoing compression during bending. The thickness of tubular material usually expressed as "nominal" or "minimum".

### 3.55 Tube

The carbon steel fluid conductor to be formed.

### 3.56 Tube Assembly

Tube with fittings and other components attached.

### 3.57 Tube Assembly Drawing

A visual representation of a tube assembly showing all of the components, end configuration method of manufacture, dimensions, functional tolerances, bend data information, reference 4 to 1 working pressure, internal wetted surface area, external surface coatings and part weight.

### 3.58 Tube Failure

Occurrence in which the tube stops meeting system requirements.

### 3.59 Tube Fitting or Fitting

Connector which is attached to the tube.

### 3.60 Tube Service Life

Length of time tube meets system requirements without needing replacement.

### 3.61 Wall Factor

The ratio of the tube outside diameter (OD) to its wall thickness.

### 3.62 Wall Thickness

The thickness of the material usually stated as a decimal or "Gauge".

### 3.63 Wall Thinning

The amount of reduction from original wall thickness of tube to the amount of wall thickness remaining in the extrados of a bend after forming.

### 3.64 Wing Die

Tool used in press or ram bending that forms the tube around the ram or bend die.'

### 3.65 Wiper Die

A die mounted on the bender used in rotary draw bending. It is located on the compressive side of the bend, adjacent to the bend die centerline. It supports the intrados and helps prevent it from buckling during bending.

### 3.66 Wrinkles

See Buckling.

### 3.67 Yield Point

The point at which material permanently deforms during bending.

### 3.68 Yield Strength

The stress at which a material exhibits a specified deviation from proportionality as a result of stress and strain.

## 4. TUBE SIZING, TUBE CONNECTION SELECTION, AND ROUTINGS

A wide variety of interacting factors influence tube service life and the ability of each fluid-power system to operate satisfactorily, and the combined effects of these factors on service life are often unpredictable. Therefore, these documents should not be construed as design standards.

Metallic tubing is specified in either millimeter or inch size designations. Availability and cost of millimeter or inch sizes are largely determined by local factors. Selection of millimeter or inch size tubing affects the selection and availability of related bending, flaring, and forming tooling, as well as the connectors specified. Millimeter size tubing and metric connectors are recommended to provide eventual ISO global standards.

Unusual applications—Applications not addressed by the fabricator or by industry standards may require special testing prior to selecting metallic tubing.

Carefully analyze each system. Then design routings and select tube and related components to meet system performance, capacity and tube-service-life requirements, and to minimize the risks of personal injury and/or property damage. The following factors should be considered.

#### 4.1 Sizing

Tube size should be determined by the proposed flow rate and pressure requirements of the fluid power system and the recommended design factors. Flow rate determines the fluid velocity in the system and is controlled by the outside diameter and wall thickness of the tube. Pressure determines the amount of force applied by the system fluids and the required strength of the tubing wall to conduct these pressures to the appropriate locations.

##### 4.1.1 System Pressure and Fluid Velocity

Industry practice is a design factor of 4 to 1, burst pressure versus working pressure. See SAE J1065 and ISO 10763 for nominal reference working pressures for specific types of steel tubing and sizes.

Fluid velocity is a primary consideration when sizing tube for hydraulic systems. High fluid velocity can cause excess heat generation, turbulence and pressure drop in pressure lines. In suction lines, high velocity can lead to pump cavitation.

The following maximum fluid velocities are suggested initial design targets for hydraulic systems:

- a. Pressure Line—7.62 m/s (25 ft/s)
- b. Return Line—3.05 m/s (10 ft/s)
- c. Suction Line—1.22 m/s (4 ft/s)

High velocities and line restrictions create heat and pump problems, which have an adverse effect on system performance. Computer modeling and very often, trial and error testing are necessary to verify overall system performance and the determination of the need for coolers.

##### 4.1.2 Severity of Service

The recommended industry standard of 4 to 1 design factor, burst pressure versus working pressure, is adequate in systems with moderate mechanical and hydraulic shocks. When a system has known severe hydraulic shocks and mechanical strain, a design factor of 6 to 1, burst pressure versus working pressure, is recommended. In addition to hydraulic and mechanical shocks, high temperature also reduces the working pressure of the tube. When high operating temperatures are a system requirement, derating factors should be considered when calculating the working pressure of the tube. See tube manufacturer for derating factors.

#### 4.2 Tube and End Connection Selection

When selecting tube and end connections for specific applications, refer to applicable Standards listed as follows.

NOTE: When tubing information discrepancies between this document and associated tubing specifications occur, the current tubing and end connection specifications shall take precedence.

##### 4.2.1 Tube Selection

###### 4.2.1.1 Metric Tubing

See Table 1 for various types of steel metric size tubing used for various types of hydraulic systems. Refer to ISO 10763 for common tube OD'S, wall thickness and applicable 4 to 1 nominal reference working pressure ratings for carbon and alloy steel tubing.

TABLE 1 - TYPICAL APPLICATIONS OF METRIC SIZE HYDRAULIC STEEL TUBING LISTED IN ISO 10763

Metric Hydraulic Steel Tubing Standards	Tensile Strength Min MPa	Elongation Min	Hardness Max RKW	Typical 4 to 1 W.P. Ranges MPa	Typical System Applications
ISO 3304 Seamless Grade R28 Normalized	280	28%	* NA	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
ISO 3305 Welded Grade R28 Normalized	280	28%	* NA	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
ISO 3304 Seamless Grade R33 Normalized	320	25%	* NA	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
ISO 3305 Welded Grade R33 Normalized	320	25%	* NA	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
ISO 3304 Seamless Grade R37 Normalized	360	24%	* NA	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
ISO 3305 Welded Grade R37 Normalized	360	24%	* NA	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
ISO 3304 Seamless Grade R44 Normalized	430	22%	* NA	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
ISO 3305 Welded Grade R44 Normalized	430	22%	* NA	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
ISO 3304 Seamless Grade R50 Normalized	490	21%	* NA	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
ISO 3305 Welded Grade R50 Normalized	490	21%	* NA	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
EN 10305-2 Welded, Grade E155	270	28	* NA	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
EN 10305-2 Welded, Grade E195	300	28	* NA	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
EN 10305-2 Welded, Grade E235	340	25	* NA	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
EN 10305-2 Welded, Grade E275	410	21	* NA	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
EN 10305-2 Welded, Grade E355	490	22	* NA	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
EN 10305-4 Seamless, Grade E215	290	30	* NA	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
EN 10305-4 Seamless, Grade E235	340	25	* NA	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
EN 10305-4 Seamless, Grade E355	490	22	* NA	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid

- 1) Welded - This tubing is made from a single strip of steel shaped into a tubular form, the edges of which are joined and sealed by a suitable welding process.
- 2) ID Flash Controlled – The inside flash shall be of uniform contour free from saw-tooth peaks and controlled in height by seam-welding techniques or by cutting, but not by hammering or rolling.
- 3) DOM – After forming and welding, the tubing is subjected to further processing by drawing it over a mandrel to result in wall reduction to a specific OD size. As a result, the ID flash becomes virtually non-existent.
- 4) Seamless – This tubing is made by piercing and drawing a mass of steel to control the OD and ID.

## 4.2.1.2 Inch Size Tubing

See Table 2 for various types of steel inch size tubing used for various types of hydraulic systems. Refer to SAE J1065 for common tube OD'S, wall thickness and applicable 4 to 1 nominal reference working pressure ratings for carbon and alloy steel tubing.

TABLE 2 - TYPICAL APPLICATIONS OF INCH SIZE SAE HYDRAULIC STEEL TUBING LISTED IN SAE J1065

SAE Inch Hydraulic Steel Tubing Standards	Tensile Strength Min MPa	Elongation Min	Hardness Max RKW	Typical 4 to 1 W.P. Ranges MPa	Typical System Applications
SAE J356 Welded and ID Flash Controlled Tubing (See Notes 2) and 3)	310	35%	B65	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
SAE J524 Seamless Tubing (See Note 5)	310	35%	B65	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
SAE J525 DOM Tubing (See Note 4)	310	35%	B65	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
SAE J526 Welded Tubing (See Note 2)	290	14%	B65	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
SAE J527 Double Wall Tubing (See Note 1)	290	14%	B65	0 to 21	Implements, Powertrain, Controls, using Hydraulic Fluid, Fuel, Oil, Air
SAE J2435 Welded and ID Flash Controlled Tubing (See Notes 2) and 3)	415	25%	B75	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
SAE J2467 DOM Tubing (See Note 4)	415	25%	B75	21 to 30	Medium Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
SAE J2613 Welded and ID Flash Controlled Tubing (See Notes 2) and 3)	500	30%	B90	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
SAE J2614 DOM Tubing (See Note 4)	500	30%	B90	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
SAE J2832 Welded and ID Flash Controlled Tubing (See Notes 2) and 3)	690	15%	B100	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid
SAE J2833 DOM Tubing (See Note 4)	890	15%	B100	30 to 42	High Pressure Steering, Braking, Implements, Powertrain, Controls, using Hydraulic Fluid

- 1) Double Wall – This tubing is made from a single or double strip of steel shaped into the form of double wall tubing, the walls of which are secured by copper brazing in a controlled atmosphere.
- 2) Welded - This tubing is made from a single strip of steel shaped into a tubular form, the edges of which are joined and sealed by a suitable welding process.
- 3) ID Flash Controlled – The inside flash shall be of uniform contour free from saw-tooth peaks and controlled in height by seam-welding techniques or by cutting, but not by hammering or rolling.
- 4) DOM – After forming and welding, the tubing is subjected to further processing by drawing it over a mandrel to result in wall reduction to a specific OD size. As a result, the ID flash becomes virtually non-existent.
- 5) Seamless – This tubing is made by piercing and drawing a mass of steel to control the OD and ID.

#### 4.2.2 End Connector Joining Methods

See Table 3 for various types of methods used for various types of hydraulic steel tubing.

TABLE 3 - END CONNECTOR JOINING METHODS

Type of Tubing See Table 1 and Table 2 Notes	1) Braze	1) Weld	Single Flare	Double Flare	Compression Fitting	SAE J1231 Bead	Plain End
1) Double Wall	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2) As Welded	Yes	Yes	No	Yes	Yes	Yes	Yes
3) ID Flash Controlled	Yes	Yes	No	Yes	Yes	Yes	Yes
4) DOM	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5) Seamless	Yes	Yes	Yes	Yes	Yes	Yes	Yes

1) Brazing and welding may compromise the structural integrity of the tube material due to the degradation of the areas affected by the thermal effect applied to the tubing and therefore require qualification testing in accordance with ISO 19879 - Metallic tube connections for fluid power and general use -- Test methods for hydraulic fluid power connections. Cold forming avoids this systemic testing by not compromising the tube material structural integrity.

#### 4.2.3 Tube Connection Selection

There are many types of hydraulic tube connections available for hydraulic systems. The type of connection used should be based on the following criteria:

- a. System peak and working pressure
- b. Number of potential leak paths or joints in the connection
- c. Ease of assembly and repair
- d. Temperature – See connector standards for operating temperatures
- e. Compatibility of fluid being conveyed

NOTE: Elastomerically sealed end connections are preferred for hydraulic systems

Connection types should be selected from the specifications shown in Figures 1 through 7. Specific maximum working pressures and performance capabilities are listed for most common connectors in each of the various specifications. See SAE J2593 Information Report for the Installation of Fluid Conductors and Connectors for installation guidance, recommended assembly sequence and recommended tightening torque values.

## 4.2.3.1 SAE J1453/ISO 8434 Part 3 - ORFS Connection

See Figure 1.

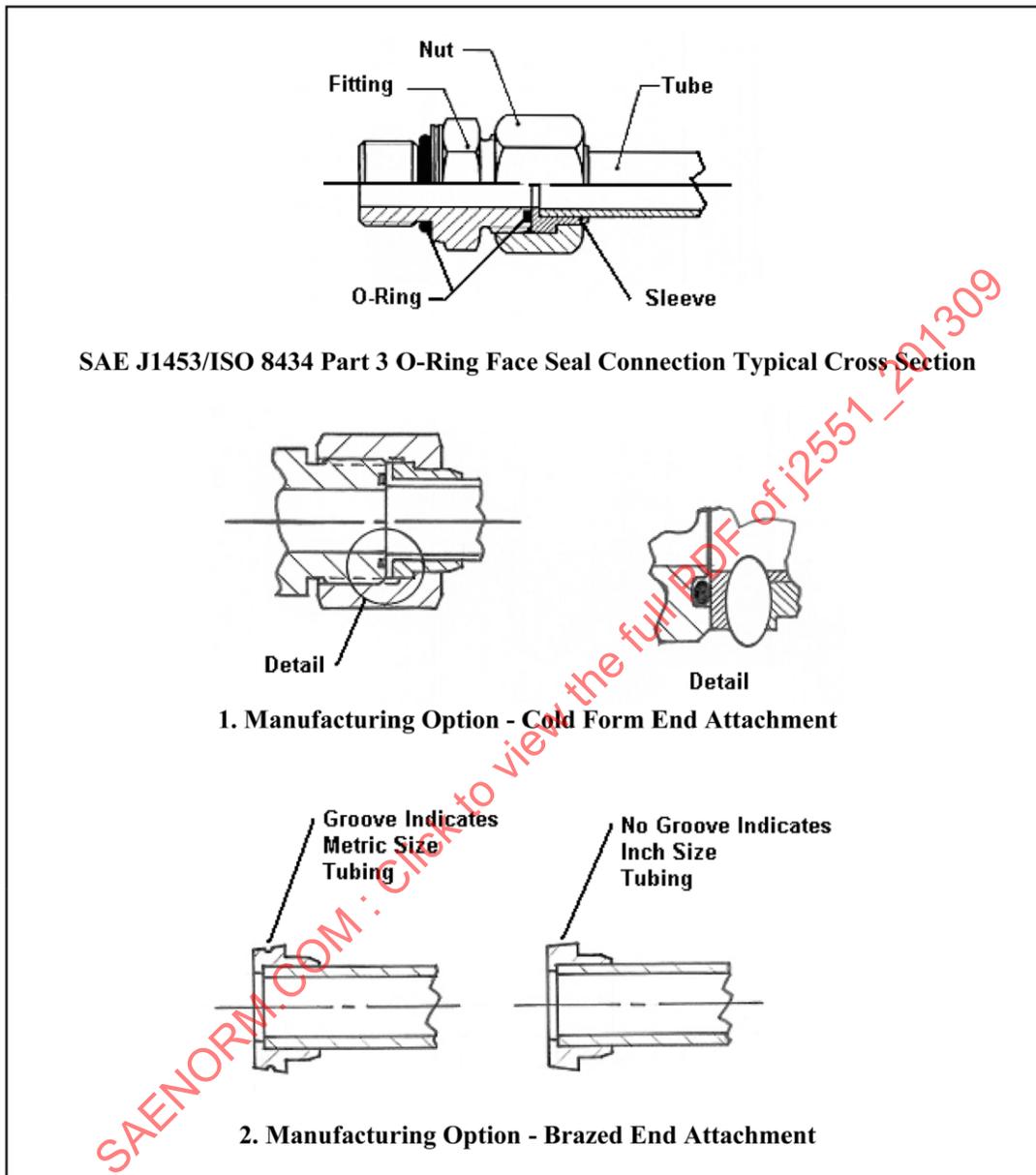


FIGURE 1 - SAE J1453/ISO 8434 PART 3 O-RING FACE SEAL CONNECTION AND OPTIONAL MANUFACTURING METHODS. FOR USE IN SYSTEMS UP TO 63 MPA (9000 PSI), SEE ISO 8434 PART 3 FOR WORKING PRESSURES, O-RING SEAL INTERFACE HELPS PROVIDE LEAK FREE CONNECTIONS

## 4.2.3.2 SAE J514/ISO 8434 Part 2 - 37 Degree Flared Connections

See Figure 2.

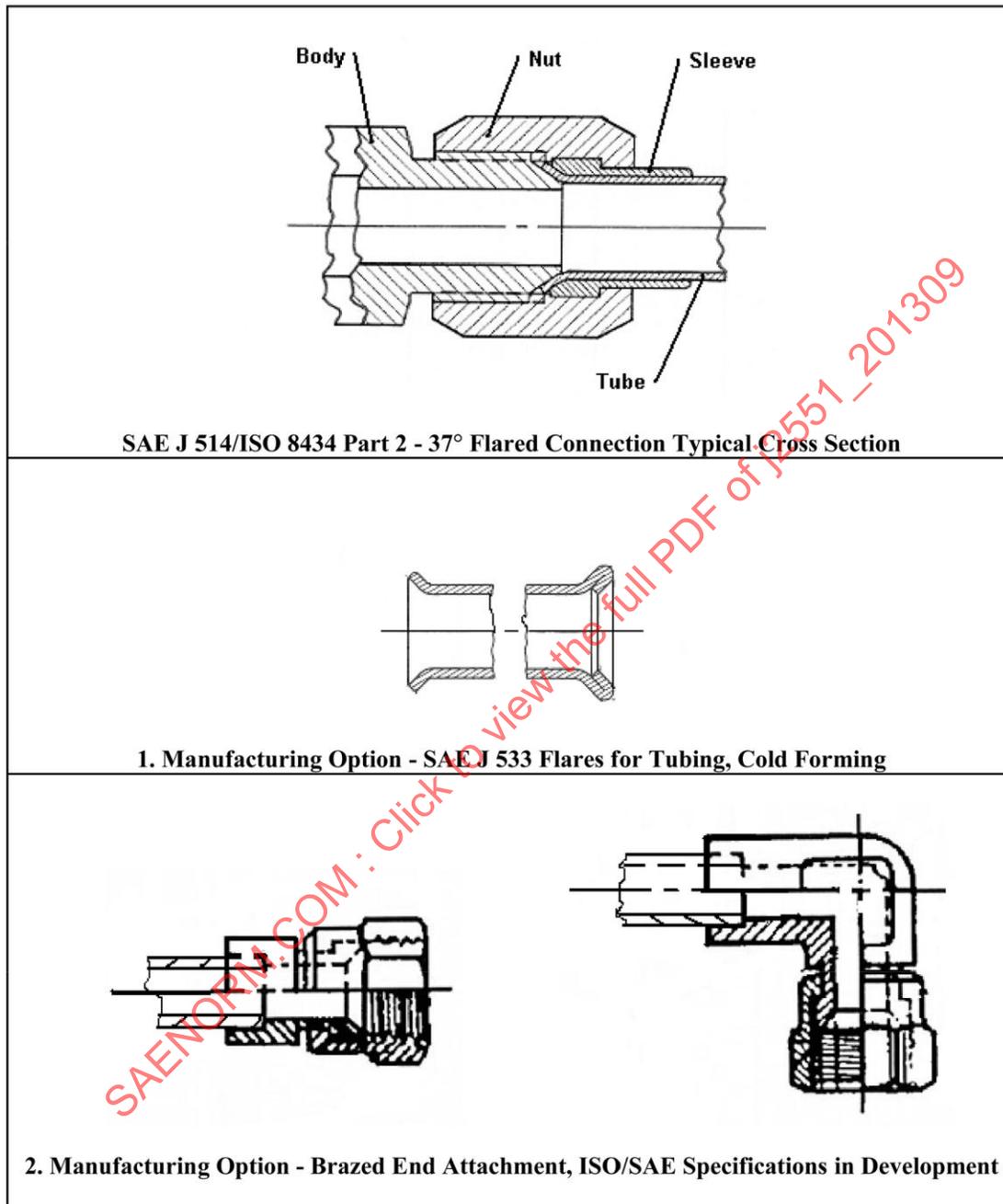


FIGURE 2 - SAE J514/ISO 8434 PART 2 - 37 DEGREE FLARED CONNECTION AND OPTIONAL MANUFACTURING METHODS. FOR USE IN SYSTEMS UP TO 35 MPA (5000 PSI), SEE ISO/SAE J514/8434 PART 2 FOR APPLICABLE WORKING PRESSURES FOR VARIOUS TUBE SIZES, METAL TO METAL SEALING INTERFACE

## 4.2.3.3 SAE J512 45 Degree Inverted Flare Connections

See Figure 3.

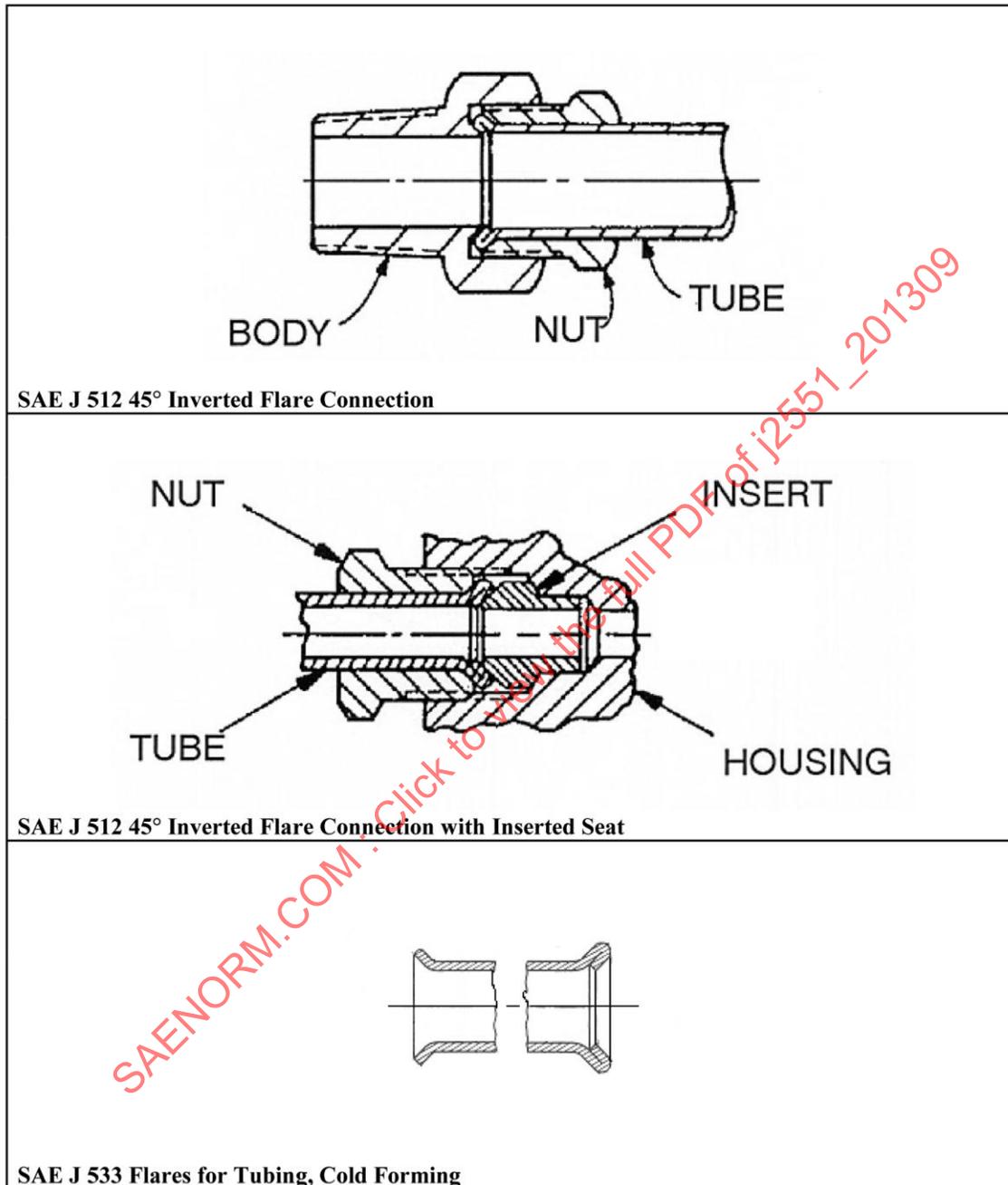


FIGURE 3 - 45 DEGREE FLARED CONNECTION TYPICALLY USED FOR AIR BRAKE SYSTEMS, CONTACT SUPPLIER FOR WORKING PRESSURE, METAL TO METAL SEALING INTERFACE

## 4.2.3.4 SAE J1231 Formed Tube Ends for Hose Connections

See Figure 4.

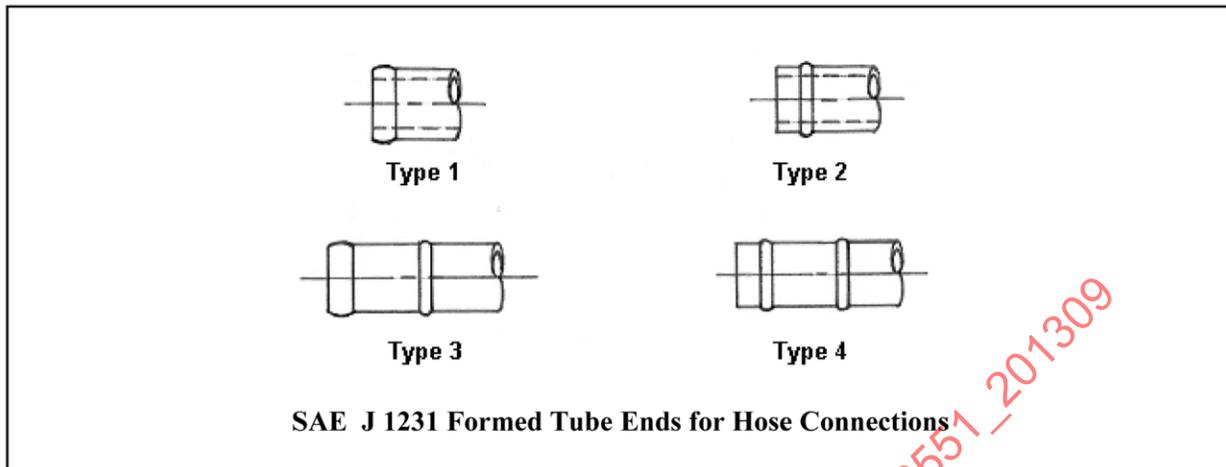


FIGURE 4 - SAE J1231 FORMED BEADED TUBE ENDS TYPICALLY USED FOR SUCTION LINES, CONTACT SUPPLIER FOR PERFORMANCE REQUIREMENTS

## 4.2.3.5 ISO 8434 Part 4 - 24 Degree Cone Welded Nipple Connections

See Figure 5.

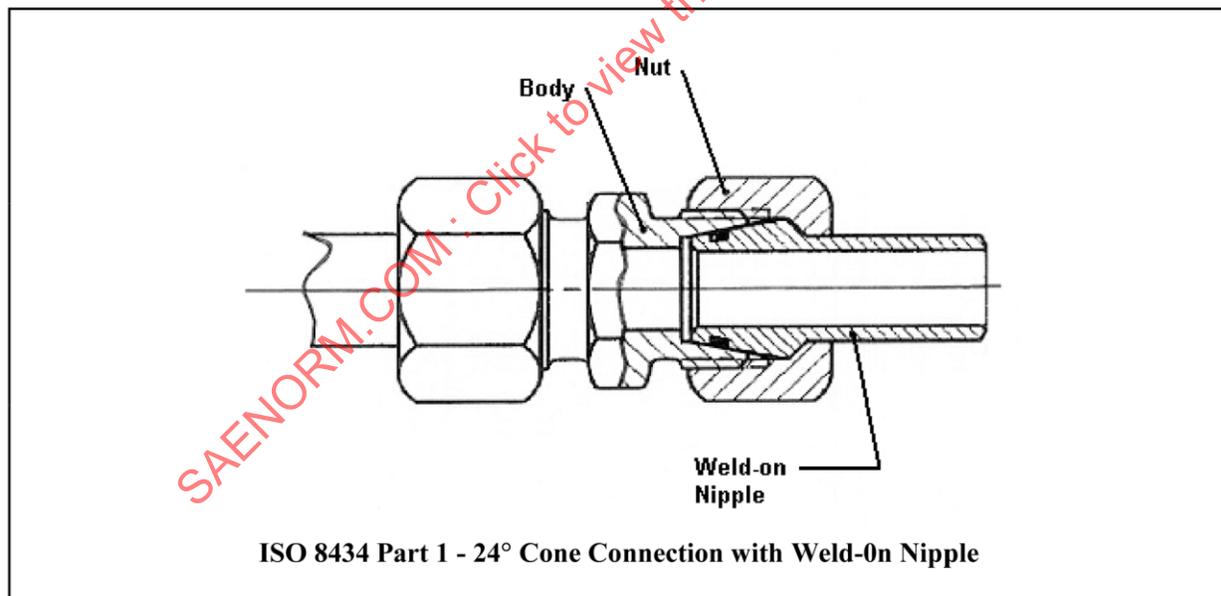


FIGURE 5 - ISO 8434 PART 4 - 24 DEGREE CONE CONNECTION WITH WELD-ON NIPPLE FOR USE IN SYSTEMS UP TO 63 MPA (9000 PSI), SEE ISO 8434 PART 4 - FOR APPLICABLE WORKING PRESSURES FOR VARIOUS TUBE SIZES, METAL TO METAL AND ELASTOMERIC SEALING INTERFACE HELP PROVIDE LEAK FREE CONNECTIONS

## 4.2.3.6 ISO 8434 Part 4 - 24 Degree Cone Compression Connections

See Figure 6.

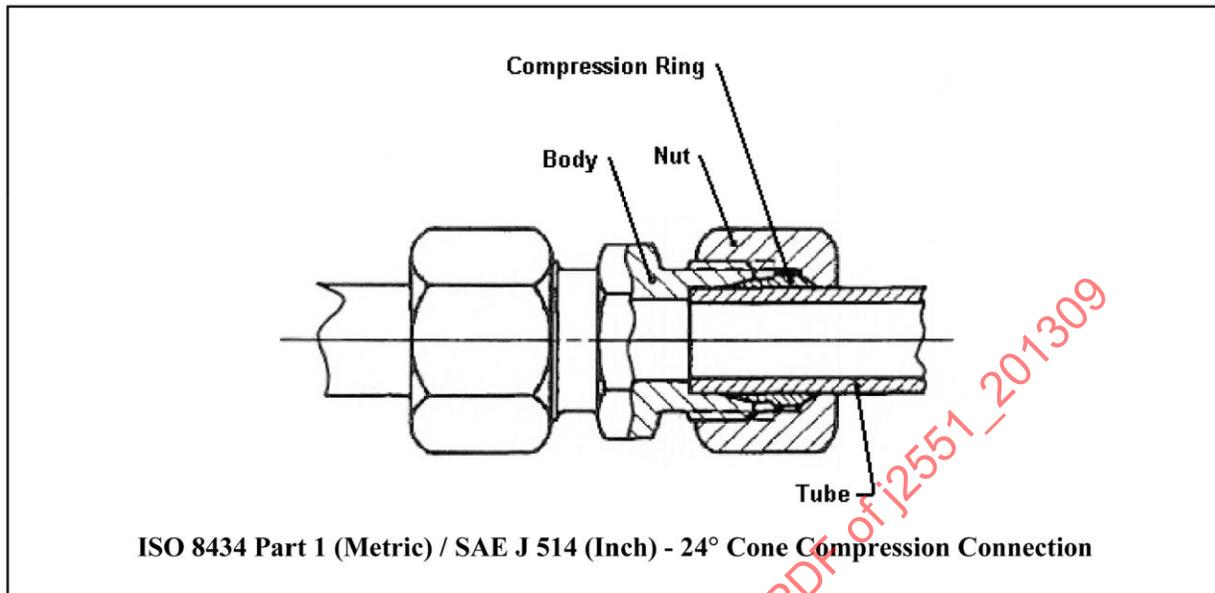


FIGURE 6 - ISO 8434 PART 1/SAE J514 - 24 DEGREE CONE COMPRESSION CONNECTION - FOR USE IN SYSTEMS UP TO 63 MPA (9000 PSI), SEE ISO 8434 PART 1/SAE J514 FOR APPLICABLE WORKING PRESSURES FOR VARIOUS TUBE SIZES. METAL TO METAL SEALING INTERFACE

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## 4.2.3.7 SAE J518/ISO 6162 - 4-Bolt Flange Connections

See Figure 7. (Replaced lock washers with flat washers)

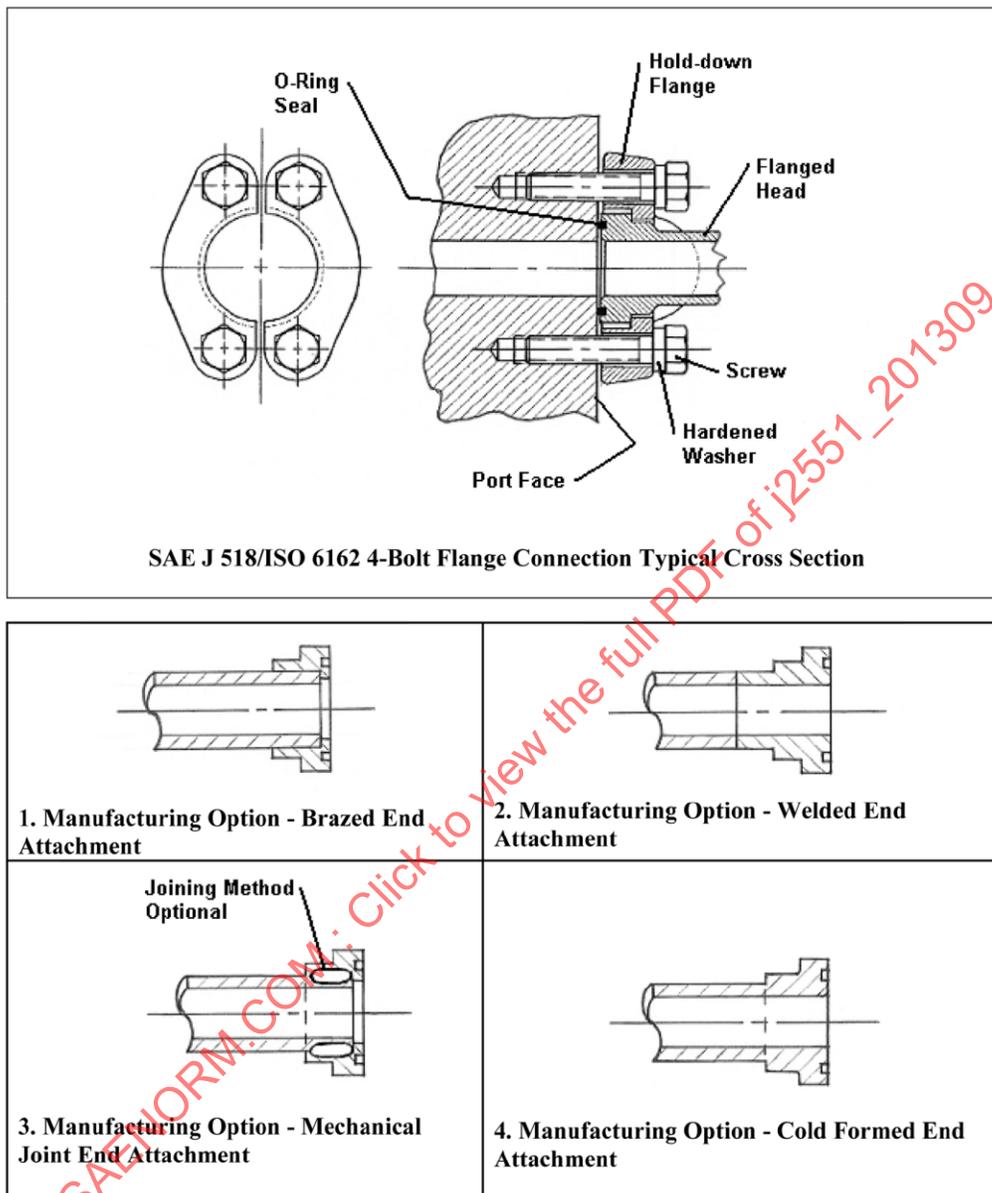


FIGURE 7 - SAE J518/ISO 6162 4-BOLT FLANGE CONNECTION, FOR USE WITH SPLIT OR CAPTIVE 4-BOLT FLANGES IN SYSTEMS UP TO 41.4 MPA (6000 PSI), SEE ISO 6162/SAE J518 FOR WORKING PRESSURES FOR VARIOUS TUBE SIZES. ELASTOMERIC SEAL INTERFACE HELPS PROVIDE LEAK FREE CONNECTIONS

## 4.3 Environment

Carbon steel tube in itself offers little or no corrosion resistance. Appropriate coatings for the usage environment should be specified per the application. Coatings such as, phosphate, zinc plating and painting may be available. Because of the potential for galvanic interaction, consider the compatibility of the tube material and the related components and adapters.

#### 4.4 Routings

Proper fluid carrier routings are essential for ease of assembly, overall efficiency, leak-free performance and general system appearance. After sizing the tube lines and selecting the style of fittings, consider the following in the design of the system.

##### 4.4.1 Accessibility of Joints for Assembly

All joints in the system should be designed with adequate wrench clearance to provide the use of the proper torque wrench to apply the correct torque.

##### 4.4.2 Adequate Tube Supports

Tube supports are mainly for dampening vibrations, see Figure 8 for clamp spacing guidelines. They reduce the noise and the potential for fatigue failure due to mechanical vibration. Tube line supports should only support the weight of the tubing. They should not support the weight of the valves, filters, regulators, etc. Valves should be mounted separately to prevent rotation of the valve body. When dynamic hoses are attached to tube assemblies, the tube should be clamped securely as near to the joint connection as possible to provide adequate support.

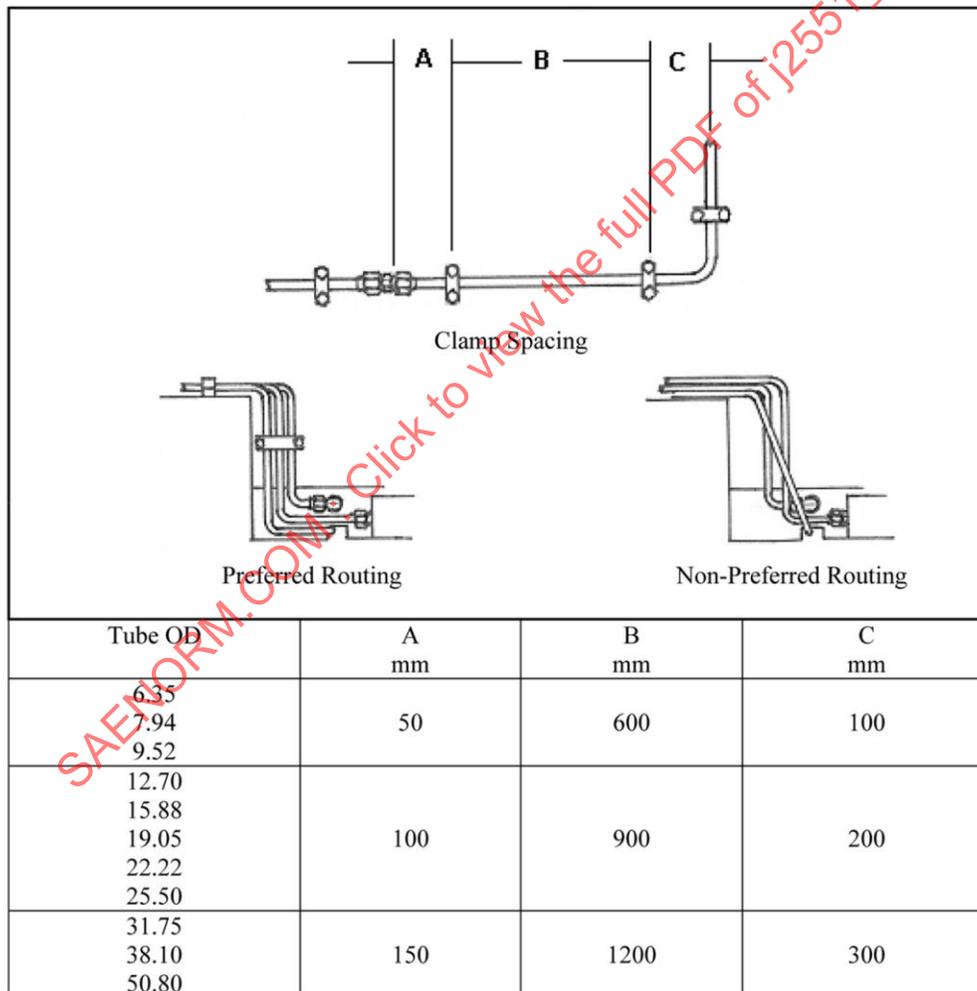


FIGURE 8 - ADEQUATE TUBE SUPPORTS AND CLAMP SPACING GUIDELINES TESTS SHOULD BE CONDUCTED TO EVALUATE THE OVERALL SYSTEM VIBRATION TO PREDICT ADEQUATE SERVICE LIFE

#### 4.4.3 Maintenance and Access Constraints

Tube routings should not interfere with access doors, attaching bolts and other equipment that must have access for regular maintenance. In addition, the fluid carriers should remain clear of controls and not prohibit the operator's access to the controls

#### 4.4.4 Routings Between Fixed Points

Tolerance build up should be considered when designing tube assemblies, see Figure 10. Adjustable brackets to allow the mating components to be properly located for correct joint interface alignment are recommended. Very often the ability to adjust the location of the mating components is very difficult, and the resultant is induced loads into the tube assembly after final assembly, which leads to early hour failure. Tube assembly design of this type should be avoided if adjustment cannot be provided; **therefore, the addition of a hose to allow for large tolerance float may be necessary.**

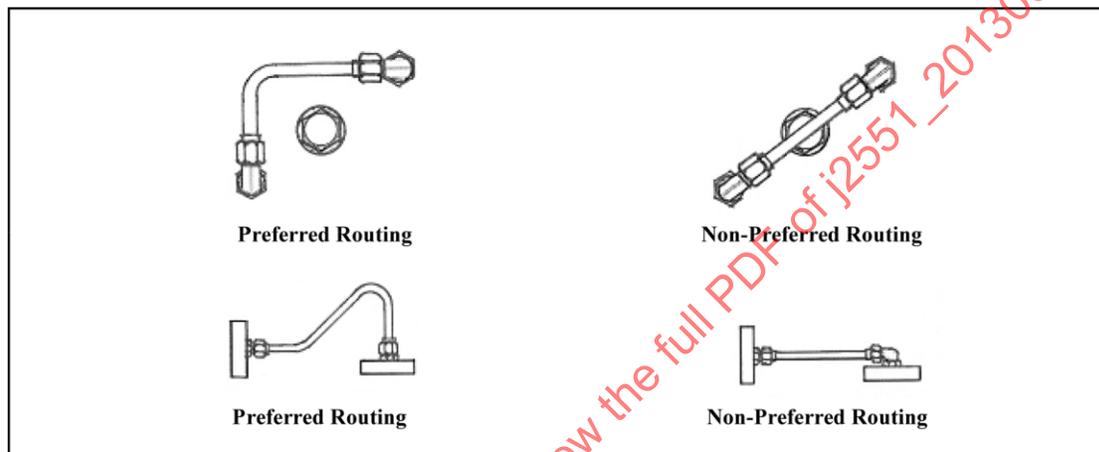


FIGURE 10 - ROUTING BETWEEN FIXED POINTS

#### 4.4.5 Contact after Assembly

Fluid carriers that are allowed to rub sharp edges, criss-cross each other and rub other components often fail prematurely, which leads to reduced reliability, increased warranty and dissatisfied customers. Fluid carriers should follow the most direct and workable route. They should run parallel to each other for best appearance and function.

#### 4.4.6 Clips and Clamps

Clips and clamps that have adequate structural integrity should be used to support and fasten the fluid carriers to the machine to a rigid support location. Clamps that are brazed or welded to the tube assembly are not recommended because these introduce stress risers in the tube assembly that may reduce fatigue life. Also these brazed or welded clamps introduce manufacturing difficulties that may be otherwise avoided.

#### 4.4.7 Tightening Sequence Considerations

See SAE J2593 Information Report for the Installation of Fluid Conductors and Connectors.

#### 4.4.8 External Physical Abuse

Fluid carriers should be guarded and located so they are not subject to damage from rocks/debris, or used as a step, platform or load holding device when removing or installing adjacent components.

#### 4.4.9 Heavy-Duty Applications

A heavy wall and larger OD tube may be required if the assembly may be regularly subjected to contact by foreign objects, such as, rocks, gravel. Stand off from uncoated surfaces should be at least 12 mm. Tube assemblies should be kept away from uncoated surfaces that may exhibit rust and corrosion over the life of the system.

### 5. TUBE DESIGN, DIMENSIONING, TOLERANCES, AND INSPECTION

#### 5.1 Tube Design

The design of a tube assembly and the required tolerances may have a drastic affect on its end use, manufacturability and cost. Assemblies designed outside of the recommendations of this document may drive excessive tooling costs, manufacturing costs, packaging/shipping/delivery problems, assembly problems, reliability problems, and quality issues.

#### 5.2 Tube Dimensioning

Tube assemblies should be designed using the X, Y, Z, Cartesian coordinate system. Use of this system makes the dimensioning 100% compatible with most CNC tube bending and inspection equipment, allowing electronic interfacing of the print, fabrication, and inspection of the assembly. When designing a fabricated tube assembly it is very important to ensure that all dimensioning allows sufficient clearance during assembly of the finished part inside of the defined tolerance.

#### 5.3 Maximum Recommended Tube Length

To facilitate manufacturing and shipping/handling purposes, the maximum recommended tube length blank before bending is 3000 mm.

#### 5.4 Tube Dimensional Tolerance

Tube assemblies are typically toleranced by the location of the end points and a defined envelope of routing contour. End point tolerances are usually figured per assembly based on a formula that accounts for the outside diameter, wall thickness, number of bends, and developed length of the assembly, see Table 4. "Best Fit" method of inspection is recommended because it closely simulates results obtained with a standard inspection gage. "End Fit," "A End Fit," and "Hard Point" dimensioning are not recommended, due to added cost of manufacturing and inspection. As with all manufacturing processes, tolerance specifications can drive unnecessary costs. The specified tolerance should ensure a functional part that can be manufactured repeatedly, without excessive inspection and handling. Tight tolerance dimensioning should only be applied in specific applications where all other alternatives have been exhausted and the higher cost per assembly can be justified.

##### 5.4.1 Hard Point versus Best Fit Inspection

###### 5.4.1.1 Hard Point Inspection

The tube is supported at three defined points to obtain all of the tube dimensions relative to these points for the purpose of calculating the errors. The first two set up points should always be on or near one end of the tube. The third point should be as far possible from a straight line which connects the first two points. Otherwise, large errors can be expected when a tube is referenced to a support system which is significantly smaller than the overall size of the tube. Tube assemblies that require "hard point" inspection are not recommended.