SAE International

SURFACE VEHICLE RECOMMENDED PRACTICE

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

RATIONALE

The user community has expressed a need for additional documented knowledge associated with the design, expected performance and procurement of metallic fluid conductors. This revision to SAE J2551 reorganizes the document into three parts; design and fabrication, general specifications and performance requirements and procurement. The revisions include changes and additional information that are intended to bring this document up to date with current industry technology and provide the comprehensive application and procurement information requested by the user community. In addition, the document title has been revised to include steel tube materials that have been recently added to SAE standards.

FOREWORD

The May2010 edition of SAE J2551 was published as a single document covering the design and fabrication of carbon, alloy and high strength low allow 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 is intended as a guide to consider when designing and fabricating carbon, alloy and high strength low alloy steel 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 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 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 include 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.

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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.

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 supplier 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 fabricator should 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 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 724-776-4970 (outside USA), 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 J836 Automotive Metallurgical Joining

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 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 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 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 American National Standards Institute , 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, 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 9227 Corrosion tests in artificial atmospheres - Salt spray tests

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 American National Standards Institute , 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, 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

2.1.4 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 Standard Practice for Operating Salt Spray (Fog) Apparatus

ASTM D2247 Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity

2.1.5 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

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 724-776-4970 (outside USA), 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 American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, 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.

ASTM A 213/A 213MSeamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes

ASTM A 268/A 268MSeamless and Welded Ferritic and Martensitic Stainless Steel Tubing

ASTM 269-96 Seamless and Welded Austenitic Stainless Steel Tubing for General Service

ASTM 312A/A312MSeamless and Welded Austentic Stainless Steel Pipes

ASTM A 450/A 450M-96aGeneral 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 COMPOUND BEND

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

Refer to actual length requirement

3.14 "D" OF BEND

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

3.15 DEGREE OF BEND (DOB)

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

3.16 DESIGNER

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

3.17 DISTANCE BETWEEN BENDS (DBB)

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

3.18 DUCTILITY

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

3.19 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.

3.20 EXTRADOS

The outside arc of the bend.

3.21 FABRICATOR

An individual or company that makes parts and tube assemblies.

3.22 FLAT PLANE

See Out-of-plane.

3.23 FLASH

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

3.24 FLATTENING

See Ovality.

3.25 FLUID POWER

Energy transmitted and controlled using pressurized hydraulic fluids or gases.

3.26 FOLLOWER DIE

See Pressure die.

3.27 HUMP

A rounded protrusion or bulge on the outside radius.

3.28 HYDRAULIC PRESSURE SPIKE

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

3.29 ID

The inside diameter of the tube.

3.30 INNER RADIUS

See Intrados.

3.31 INTRADOS

The inside arc of the bend.

3.32 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.

3.33 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.

3.34 NEUTRAL AXIS

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

3.35 NOMINAL

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

3.36 NOMINAL OD

Usually refers to referenced pipe sizes, not actual OD.

3.37 NOMINAL WALL

The target measurement for the wall thickness.

3.38 OD

Outside diameter of the tube.

3.39 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.

3.40 OUTSIDE RADIUS

See Extrados.

3.41 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.

3.42 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.

3.43 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.

3.44 PRESS DIE

See Ram die.

3.45 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.

3.46 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.

3.47 USER

End user of the finished tube assembly

3.48 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.

3.49 RADIUS

See Centerline radius.

3.50 RAM DIE

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

3.51 ROUTING

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

3.52 SHOE

See Wiper die.

3.53 SPRING-BACK

The movement of the bent tube toward the original straight configuration after release of the bending moment. Also see over bend.

3.54 SUPPLIER

An individual or company that supplies goods and services. See vendor.

3.55 TANGENT

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

3.56 TANGENT POINT

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

3.57 TENSILE STRENGTH

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

3.58 TENSION

The force which thins the outside wall of the bend.

3.59 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”.

3.60 TUBE

The metallic fluid conductor.

3.61 TUBE ASSEMBLY

Tube with fittings and other components attached.

3.62 TUBE ASSEMBLY DRAWING

A visual representation of a tube assembly showing 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, reference to applicable specifications, and part weight.

3.63 TUBE FAILURE

Occurrence in which the tube stops meeting system requirements.

3.64 TUBE FITTING or FITTING

Connector which is attached to the tube.

3.65 TUBE SERVICE LIFE

Length of time tube meets system requirements without needing replacement.

3.66 VENDOR

An individual or company that sells goods and services. See supplier.

3.67 WALL FACTOR

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

3.68 WALL THICKNESS

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

3.69 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.

3.70 WING DIE

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

3.71 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.

3.72 WRINKLES

See Buckling.

3.73 YIELD POINT

The point at which material permanently deforms during bending.

3.74 YIELD STRENGTH

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

4. SAFETY CONSIDERATIONS

Metallic fluid conductors are typically pressurized during operation and are used in a wide variety of operating environments. Consider reasonable and feasible means, including those described in this document, to reduce the risk of injuries or property damage. Refer to the safety considerations listed in SAE J1273 for a list of potential conditions and situations that may lead to personal injury and/or property damage when using fluid conductors.

Training, including the information in this document, for assemblers, operators, maintenance personnel, and other individuals working with metallic fluid conductors under pressure is encouraged.

Coatings on metallic tube and fittings may volatilise when heating during brazing, welding and heat treatment. The resulting fumes may be dangerous and expose individuals in the work area to personal injury. Repeated exposure to these fumes may lead to illness and/or disease with prolonged latent periods. The complete removal of zinc, phosphate, paint and other coatings from all metallic tube and fittings prior to the application of thermal processes is recommended.

5. 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 conformance to ISO global standards.

5.1 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.

5.2 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.

5.2.1 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.

5.2.2 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.

5.3 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.

5.3.1 Tube Selection

5.3.1.1 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	22%	* 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 is 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.

5.3.1.2 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)	690	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 is 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.

5.3.2 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	Braze[1]	Weld[1]	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) Caution: When brazing or welding is used as a tube end joining method, the structural integrity of the tube material can potentially be compromised due to the degradation of the areas affected by the thermal effect applied to the tubing; therefore, the ISO 10763 and SAE 1065 nominal working pressure may not be applicable. Cold forming the tube end configurations avoids this potential degradation by not compromising the structural integrity of the tube material.. Reference SAE J836 surface vehicle information report for information about different types of braze and weld methods. Welding operations should be performed by personnel certified per AWS D1.1/D1.1M, Structural Welding Code-Steel by the American Welding Society (AWS).

5.3.3 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

Typical connection types are shown in Figures 1 through 8. 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.

5.3.3.1 SAE J1453/ISO 8434 Part 3 - ORFS Connection

See Figure 1.

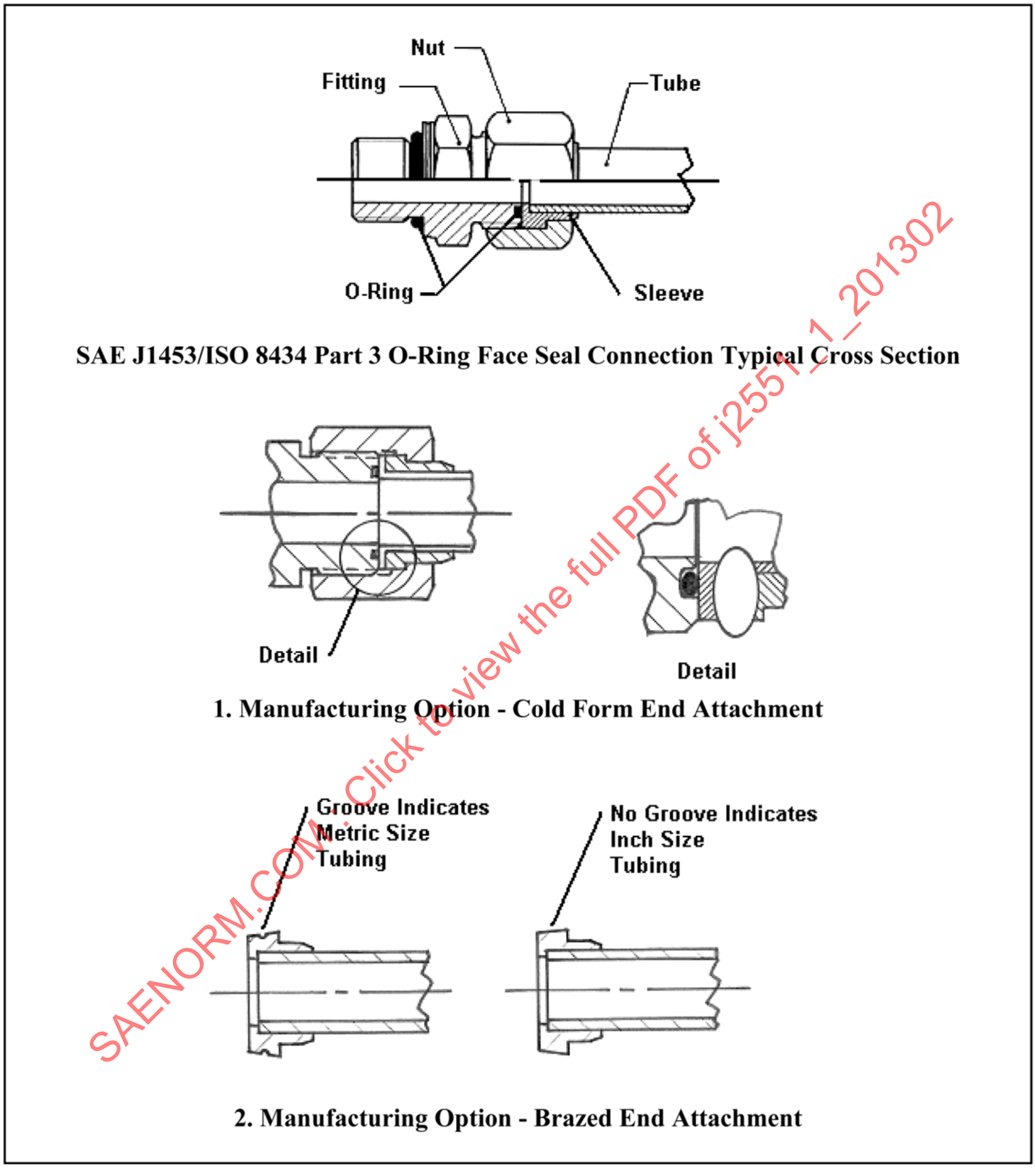
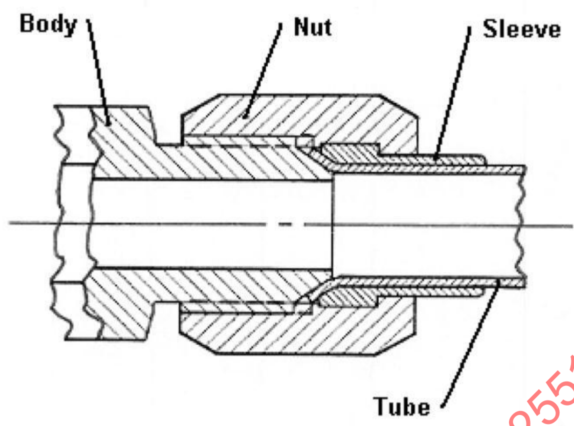


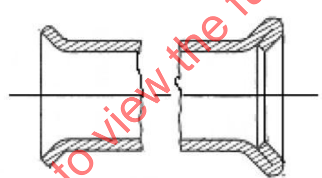
FIGURE 1 - SAE J1453/ISO 8434 PART 3 O-RING FACE SEAL CONNECTION AND OPTIONAL MANUFACTURING METHODS. FOR USE IN SYSTEMS UP TO 63 MPA (9000 PSI), SEE ISO 8434 PART 3 FOR WORKING PRESSURES, O-RING SEAL INTERFACE HELPS PROVIDE LEAK FREE CONNECTIONS

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

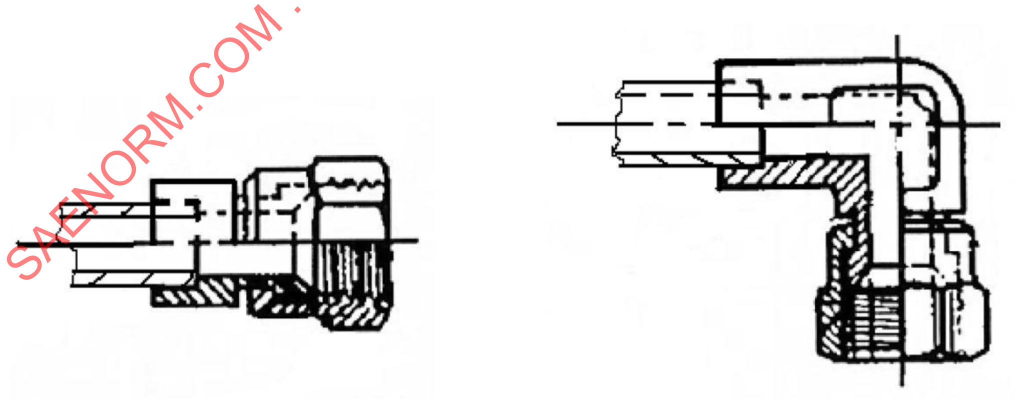
See Figure 2.



SAE J 514/ISO 8434 Part 2 - 37° Flared Connection Typical Cross Section



1. Manufacturing Option - SAE J 533 Flares for Tubing, Cold Forming

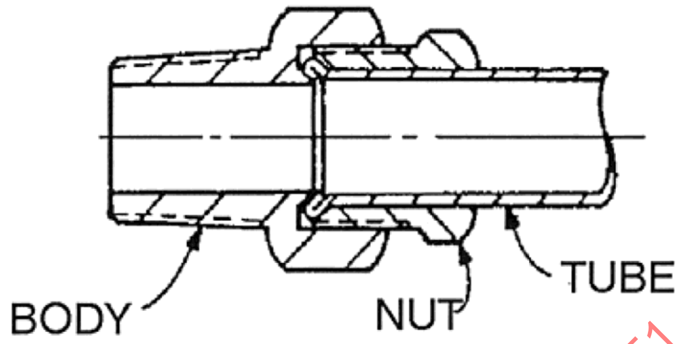


2. Manufacturing Option - Brazed End Attachment

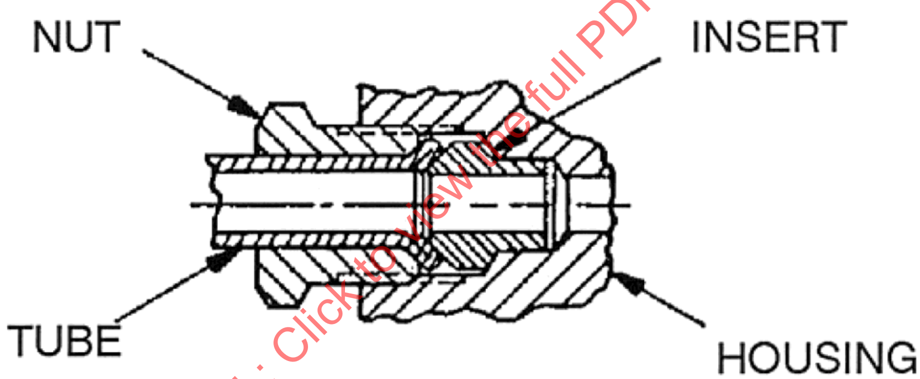
FIGURE 2 - SAE J514/ISO 8434 PART 2 - 37 DEGREE FLARED CONNECTION AND OPTIONAL MANUFACTURING METHODS. FOR USE IN SYSTEMS UP TO 35 MPA (5000 PSI), SEE ISO/SAE J514/8434 PART 2 FOR APPLICABLE WORKING PRESSURES FOR VARIOUS TUBE SIZES, METAL TO METAL SEALING INTERFACE

5.3.3.3 SAE J512 45 Degree Inverted Flare Connections

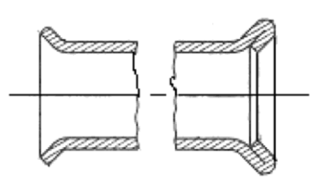
See Figure 3.



SAE J 512 45° Inverted Flare Connection



SAE J 512 45° Inverted Flare Connection with Inserted Seat



SAE J 533 Flares for Tubing, Cold Forming

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

5.3.3.4 SAE J1231 Formed Tube Ends for Hose Connections

See Figure 4.

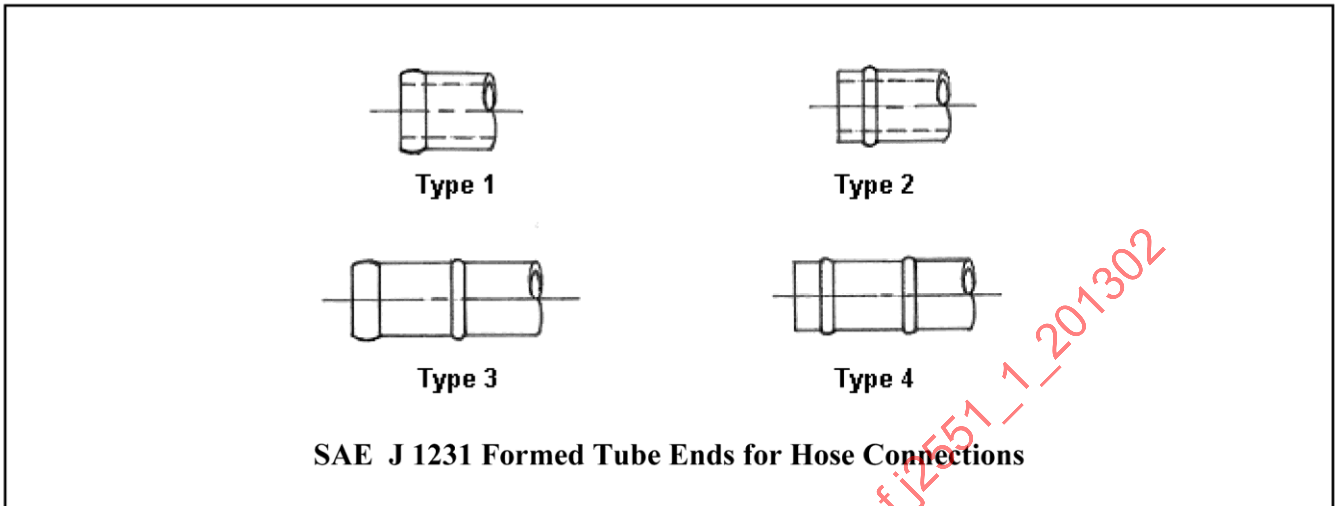


FIGURE 4 - SAE J1231 FORMED BEADED TUBE ENDS TYPICALLY USED FOR SUCTION LINES, CONTACT SUPPLIER FOR PERFORMANCE REQUIREMENTS

5.3.3.5 ISO 8434 Part 4 - 24 Degree Cone Welded Nipple Connections

See Figure 5.

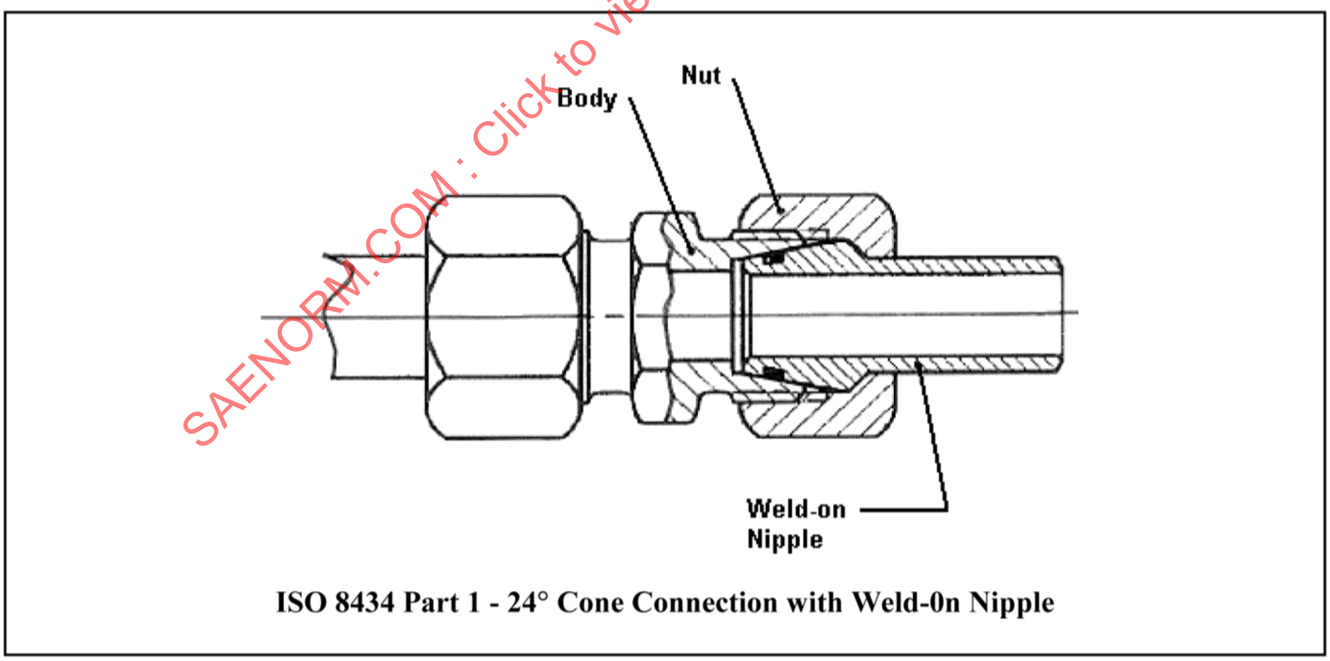
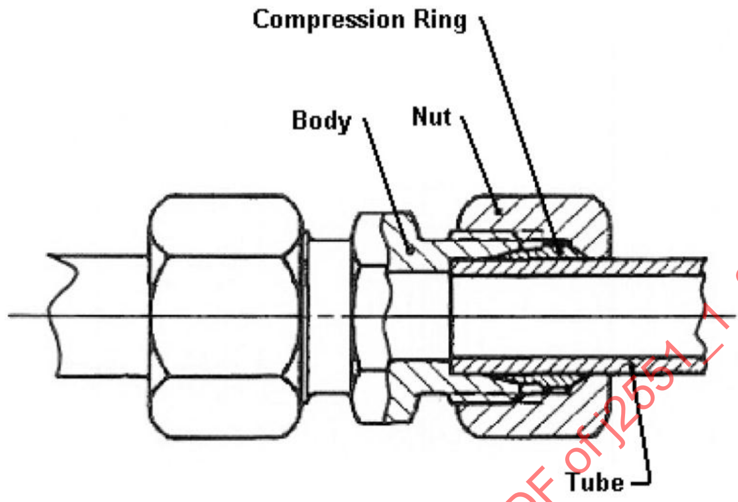


FIGURE 5 - ISO 8434 PART 4 - 24 DEGREE CONE CONNECTION WITH WELD-ON NIPPLE FOR USE IN SYSTEMS UP TO 63 MPA (9000 PSI), SEE ISO 8434 PART 4 - FOR APPLICABLE WORKING PRESSURES FOR VARIOUS TUBE SIZES, METAL TO METAL AND ELASTOMERIC SEALING INTERFACE HELP PROVIDE LEAK FREE CONNECTIONS

5.3.3.6 ISO 8434-1- 24 Degree Cone Compression Connections

See Figure 6.

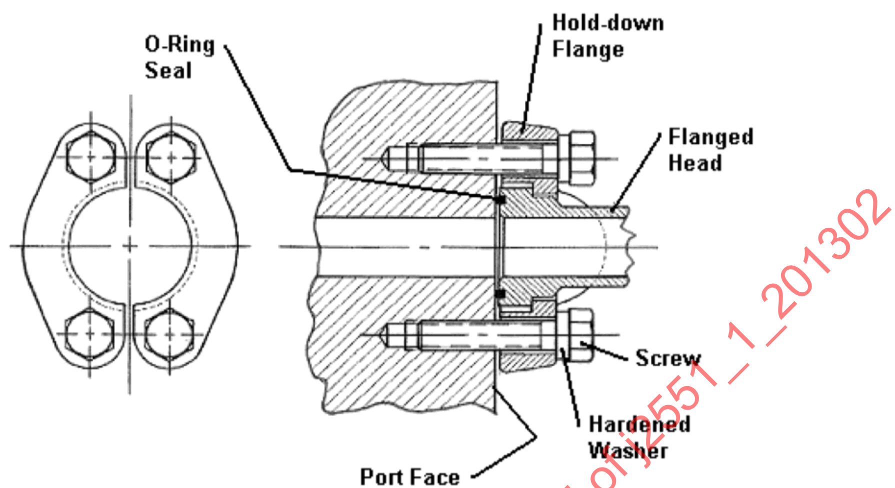


ISO 8434-1 (Metric) and SAE J514 (Inch) – 24° Cone Compression Connection

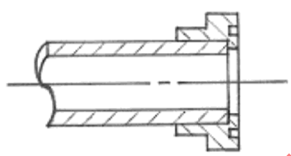
FIGURE 6 - ISO 8434-1 AND SAE J514 - 24 DEGREE CONE COMPRESSION CONNECTION - FOR USE IN SYSTEMS UP TO 63 MPA (9000 PSI), SEE ISO 8434-1 AND SAE J514 FOR APPLICABLE WORKING PRESSURES FOR VARIOUS TUBE SIZES, METAL TO METAL SEALING INTERFACE

5.3.3.7 SAE J518/ISO 6162 - 4-Bolt Flange Connections

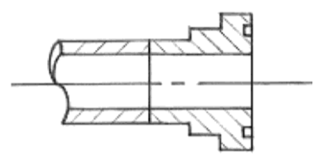
See Figure 7. (Replaced lock washers with flat washers)



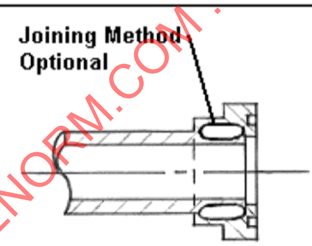
SAE J 518/ISO 6162 4-Bolt Flange Connection Typical Cross Section



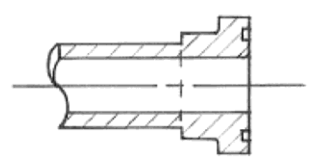
1. Manufacturing Option - Brazed End Attachment



2. Manufacturing Option - Welded End Attachment



3. Manufacturing Option - Mechanical Joint End Attachment



4. Manufacturing Option - Cold Formed End Attachment

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

5.3.3.8 SAE J2044 - Quick Connect Coupling

See Figure 8.

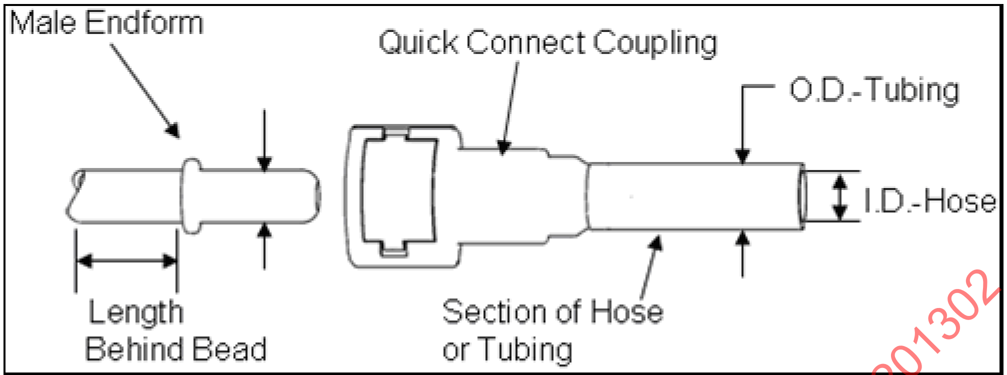


FIGURE 8 – SAE J2044 QUICK CONNECT COUPLING, FOR USE WITH SUPPLY, RETURN, AND VAPOR/EMISSION FUEL SYSTEM CONNECTIONS

5.4 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. Reference the corrosion protection and coatings sections in this document for typical coatings and warnings.

5.5 Routings

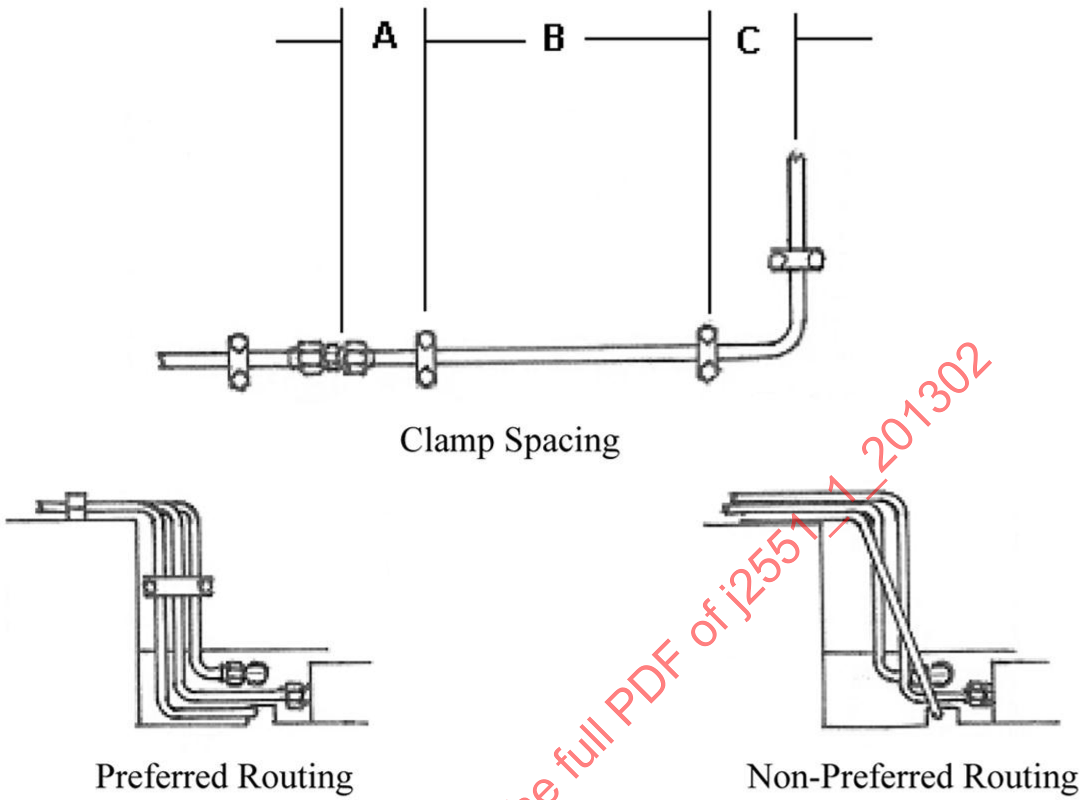
Proper fluid carrier routings are essential for ease of assembly, overall efficiency, leak-free performance and general system appearance. After sizing the tube lines and selecting the style of fittings, consider the following in the design of the system.

5.5.1 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.

5.5.2 Adequate Tube Supports

Tube supports are mainly for dampening vibrations, see Figure 9 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.



Tube OD	A mm	B mm	C mm
UP TO 10 mm	50	600	100
> 10 mm TO 28 mm	100	900	200
> 28 mm	150	1200	300

FIGURE 9 - ADEQUATE TUBE SUPPORTS AND CLAMP SPACING GUIDELINES TESTS SHOULD BE CONDUCTED TO EVALUATE THE OVERALL SYSTEM VIBRATION TO PREDICT ADEQUATE SERVICE LIFE

5.5.3 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

5.5.4 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 can lead to 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.

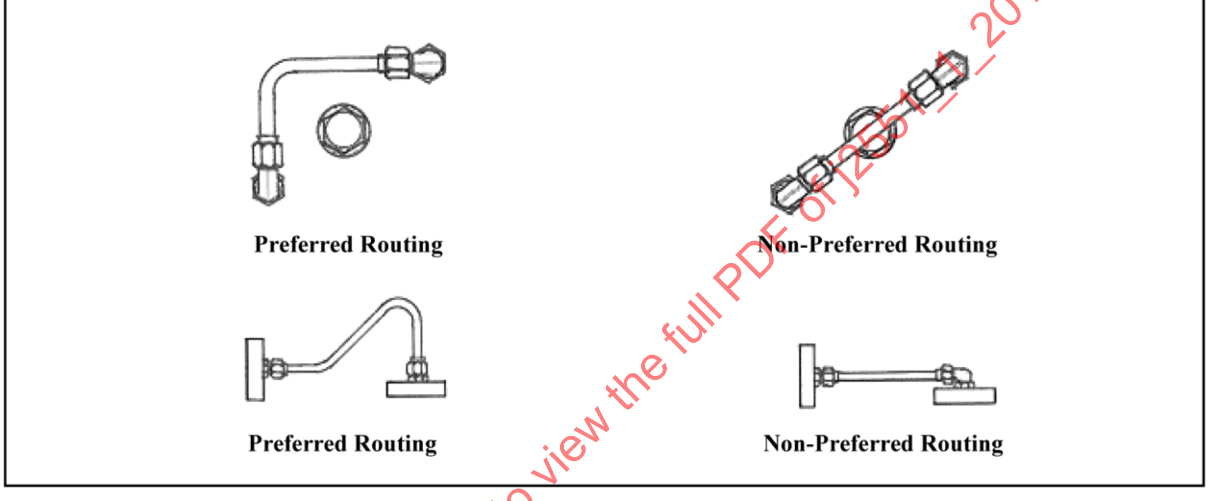


FIGURE 10 - ROUTING BETWEEN FIXED POINTS

5.5.5 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.

5.5.6 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.

5.5.7 Tightening Sequence Considerations

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

5.5.8 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.

5.5.9 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 or 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.

6. TUBE DESIGN, DIMENSIONING, TOLERANCES, AND INSPECTION

6.1 Tube Design

The design of a tube assembly and the required tolerances will have a significant effect 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.

6.2 Developed Length and Maximum Recommended Tube Length

The developed length of a tube assembly is the dimension that defines the required length of the tube blank. This length takes into consideration many factors, including material displacement for fitting counterbores, tube end forms and the elasticity of the tube material. Developed length tolerance requirements can vary depending upon the tube diameter, tube wall size, number of bends in the final assembly, and tube end form material displacements. A typical length tolerance for a tube blank is ± 1.5 mm. To facilitate manufacturing and shipping/handling purposes, the maximum recommended tube length blank before bending is 3000 mm.

6.3 Tube Dimensioning

Tube assemblies should be designed using the X, Y, Z, Cartesian right hand coordinate system and dimensions for the straight length intersection points. Every feature on the tube assembly (e.g., straight lengths, bend radius, end surfaces, bolt holes) should have both a dimension and a tolerance. Use of this system makes the dimensioning compatible with most CNC tube bending and inspection equipment and allows electronic interfacing, fabrication, and inspection of the assembly. The tolerance values should ensure that a functional part can be manufactured repeatedly, without excessive inspection and handling. Tight tolerances should only be applied in specific applications where all other alternatives have been exhausted and higher costs can be justified. Geometric Dimensioning and Tolerancing (GD&T) is the recommended drawing format because it provides a clear definition of the tolerance zones and is the only standard tolerancing format that is recognized around the world.

Tube assemblies are typically toleranced by providing a tolerance zone around each end surface, and a defined envelope of routing contour. It is important that the tolerance values reflect the functional requirements of final application. The tolerance values specified on the drawing should lie within reasonable manufacturing capabilities to avoid unnecessary costs. The inspection methodology will be determined by the dimensioning/tolerancing scheme on the drawing. It is critical that clear tolerance zones are defined. A “Least Squares Best Fit” methodology is recommended because it closely simulates the actual manufacturing, inspection, and assembly practices for most tube assemblies. “Hard Point” methodologies are not recommended because they tend to require relatively large tolerance values and generally do not reflect the tube assembly’s design intent. Hard Point methodologies can significantly increase tube assembly costs due to increased set-up time, inspection frequency, and scrap rates. Refer to table 4 for straight length position tolerances. Contact the tube supplier for recommended end point tolerances.

TABLE 4 - BENT TUBE SUGGESTED STRAIGHT LENGTH POSITION TOLERANCE ZONES
LISTED BY METRIC BLANK LENGTHS (mm)

TUBE OD																
4.76	0- 924	0- 924	925- 1188	925- 1188	1189- 1452	1189- 1452	1453- 1716	1453- 1716	1717- 1980	1717- 1980	1981- 2244	1981- 2244	2245- 2508	2245- 2508	2509- 2772	2509- 2772
6.35	0- 885	0- 885	886- 1138	886- 1138	1139- 1391	1139- 1391	1392- 1644	1392- 1644	1645- 1897	1645- 1897	1898- 2450	1898- 2450	2151- 2403	2151- 2403	2404- 2656	2404- 2656
7.94	0- 906	0- 906	907- 1165	907- 1165	1166- 1424	1166- 1424	1425- 1683	1425- 1683	1684- 1942	1684- 1942	1943- 2201	1943- 2201	2202- 2460	2202- 2460	2461- 2719	2461- 2719
9.52	0-955	0-955	956- 1228	956- 1228	1229- 1501	1229- 1501	1502- 1774	1502- 1774	1775- 2047	1775- 2047	2048- 2320	2048- 2320	2321- 2593	2321- 2593	2594- 3000	2594- 3000
12.70	0- 1099	0- 1099	1100- 1413	1100- 1413	1414- 1727	1414- 1727	1728- 2041	1728- 2041	2042- 2355	2042- 2355	2356- 2669	2356- 2669	2670- 3000	2670- 3000		
15.88	0- 1274	0- 1274	1275- 1638	1275- 1638	1639- 2002	1639- 2002	2003- 2366	2003- 2366	2376- 2730	2376- 2730	2731- 3000	2731- 3000				
19.05	0- 1463	0- 1463	1464- 1881	1464- 1881	1882- 2299	1882- 2299	2300- 2717	2300- 2717	2718- 3000	2718- 3000						
22.22	0- 1659	0- 1659	1660- 2133	1660- 2133	2134- 2607	2134- 2607	2698- 3000	2698- 3000								
25.40	0- 1862	0- 1862	1863- 2394	1863- 2394	2395- 2926	2395- 2926										

TUBE OD																
28.58	0- 2068	0- 2068	2069- 2659	2069- 2659	2660- 3000	2660- 3000										
31.75	0- 2278	0- 2278	2279- 2929	2279- 2929												
38.10	0- 2698	0- 2698	2699- 3000	2699- 3000												
44.44	0- 2848	0- 2848	2849- 3000	2849- 3000												
50.80	0- 3000	0- 3000														
NO. OF BENDS⇒ TOTAL	1 - 5	6-10	1 - 5	6-10	1 - 5	6-10	1 - 5	6-10	1 - 5	6-10	1 - 5	6-10	1 - 5	6-10	1 - 5	6-10
TRUE POSITION ⇒ TOLERANCE	6	8	8	10	10	12	12	14	14	16	16	18	18	20	20	22

6.4 Hard Point Tolerancing and Inspection (not recommended)

The tube is constrained with datum features in a manner that locks all six degrees of freedom to obtain dimensions for all of the other tube features in order to calculate the errors. The tube features used to create the datums are assumed to have zero error with their mating components and errors are magnified as the distance to the datum features is increased. Although it is common for drawings to use a sealing surface as a primary datum to locate the tube assembly, this is not a recommended practice.

Because Hard Point methodologies require that specific features have zero tolerance, tolerance stackup calculations for other features (e.g., straight lengths, bend angles, rotations, etc.) can become extremely complex. Large errors can be expected when a tube assembly is constrained by datum features which are significantly smaller than the overall size of the tube, see Figure 11, hard point views. If a Hard Point methodology is required by the application, the mating components must allow for enough adjustment to accommodate the large tolerance values.

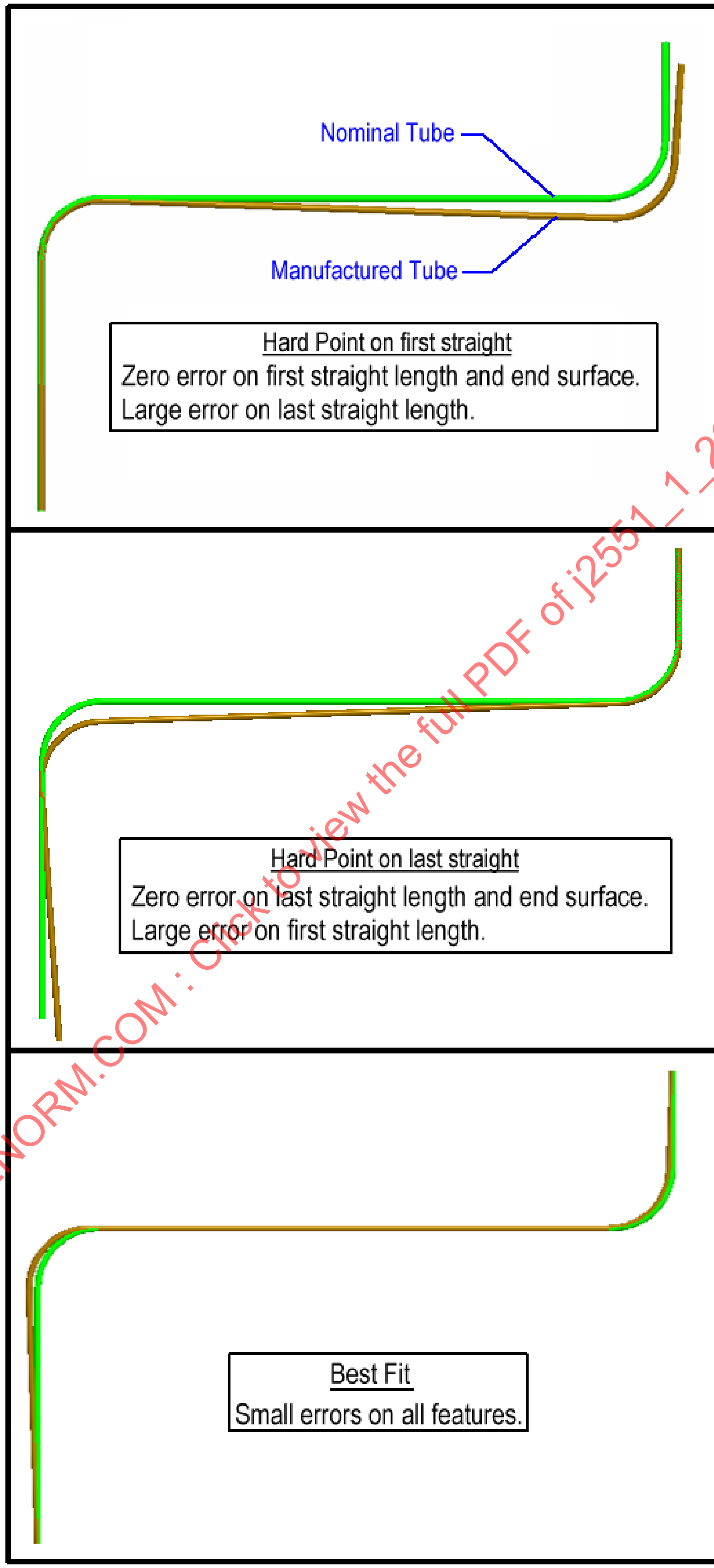


FIGURE 11 - HARD POINT AND BEST FIT VIEWS

6.5 Least Squares Best Fit Tolerancing and Inspection (recommended)

Best Fit methodologies closely simulate actual fit-up conditions in designs where the location of both ends of the tube assembly are equally important, see Figure 11, best fit view. Best Fit is also the methodology inherently used with many functional check gages. Because this method distributes the errors about the entire tube assembly, lower cost tubes can be produced due to reduced set-up time, inspection frequency, and scrap rates.

Every feature on the tube assembly is given a tolerance zone and the tube is allowed to float within the confines of these zones. Because no individual feature is locked down to a zero error condition, measured errors are uniformly distributed. With appropriate geometric tolerances, the ends of the tube assembly can be held to a relatively closer fit than the middle portions. Refer to Figure 12 as an example of a tube assembly which uses a Best Fit Geometric Tolerance format.