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SURFACE VEHICLE RECOMMENDED PRACTICE

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Recommended Practices for Fluid Conductor Metallic Tubing Applications

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.

TABLE OF CONTENTS

1. Scope—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. These documents are primarily intended for mobile/stationary industrial equipment and automotive applications. Aircraft and Aerospace applications were not considered during the preparation of this document.

2. References

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

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J512—Automotive Tube Fittings
SAE J514—Hydraulic Tube Connections
SAE J518—Hydraulic Flanged Tube, Pipe, and Hose Connections. Four-Bolt Split Flange Type
SAE J533—Flares for Tubing
SAE J1065—Pressure Ratings for Hydraulic Tubing and Fittings
SAE J1231—Formed Tube Ends for Hose Connections and Hose Fittings
SAE J1453—Fitting—O-Ring Face Seal

2.1.2 ISO PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 6162—Four-screw split-flange connections
ISO 8434—Metallic tube connections for fluid power and general use
ISO 10763—Plain-end, seamless and welded steel tubes—Dimensions and nominal working pressures

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, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J246—Spherical and Flanged Sleeve (Compression) Tube Fittings
SAE J343—Tests and Test Procedures for SAE 100R Series Hydraulic Hose and Hose Assemblies
SAEJ356—Welded Flash-Controlled Low-Carbon Steel Tubing Normalized for Bending, Double Flaring, and Beading
SAEJ515—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 Low-Carbon Steel and Copper Nickel Tubing
SAE J1926-1—Connections for General Use and Fluid Power-Ports and Stud Ends with ISO 725 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 ISO 725 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 ISO 725 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
SAEJ2244-1—Connections for Fluid Power and General Use—Ports and Stud Ends with ISO 261 Threads and O-Ring Sealing—Part 1: Port with O-Ring Seal in Truncated Housing

SAEJ2244-2—Connections for Fluid Power and General Use—Ports and Stud Ends with ISO 261 Threads and O-Ring Sealing—Part 2: Heavy-Duty (S Series) Stud Ends—Dimensions, Design, test Methods, and Requirements
SAEJ2244-3—Connections for Fluid Power and General Use—Ports and Stud Ends with ISO 261 Threads and O-Ring Sealing—Part 3: Light-Duty (L Series) stud End—Dimensions, Design, Test Methods, and Requirements
SAEJ2244-4—Connections for Fluid Power and General Use—Ports and Stud Ends with ISO 261 Threads and O-Ring Sealing—Part 4: Heavy-Duty (S Series) External Hex Port Plugs—Dimensions, Design, Test Methods, and Requirements
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

2.2.2 ISO PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 272—Fasteners—Hexagon products—Widths across flats
ISO 273—Fasteners—Clearance holes for bolts and screws
ISO 2944—Fluid power systems and components—Nominal pressures
ISO 3304—Plain end seamless precision steel tubes—Technical conditions for delivery
ISO 3305—Plain end welded precision steel tubes—Technical conditions for delivery
ISO 3448—Industrial liquid lubricants—ISO viscosity classification
ISO 3457—Earth-moving machinery—Guards and shields—Definitions and specifications
ISO 3601—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
ISO6743-4—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, 100 Bar Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 268/A 268M—Seamless and Welded Ferritis and Martensitic Stainless Steel Tubing
ASTM 269-96—Seamless and Welded Austenitic Stainless Steel Tubing for General Service
ASTM 312A/A312M—Seamless and Welded Austentic Stainless Steel Pipes
ASTM 316—Stainless Steel Tubing
ASTMA450/A450M-96a—General Requirements for Carbon, Ferritic Alloy and Austenitic Alloy Steel 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 Extrados—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 Extrados.

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 Failure—Occurrence in which the tube stops meeting system requirements.

3.58 Tube Fitting or Fitting—Connector which is attached to the tube.

3.59 Tube Service Life—Length of time tube meets system requirements without needing replacement.

3.60 Wall Factor—The ratio of the tube outside diameter (OD) to its wall thickness.

3.61 Wall Thickness—The thickness of the material usually stated as a decimal or "Gauge".

3.62 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.

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

3.64 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.

3.65 Wrinkles—See Buckling.

3.66 Yield Point—The point at which material permanently deforms during bending.

3.67 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.

4.2.1 TUBE SELECTION—Refer to the Related Publications 2.2 for various types of tubing. Refer to SAE J1065 and ISO 10763 for common tube OD'S, wall thickness and applicable nominal reference working pressure ratings for carbon steel tubing.

4.2.2 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

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.

4.2.2.1 SAE J1453/ISO 8434 Part 3 - ORFS Connection—See Figure 1.

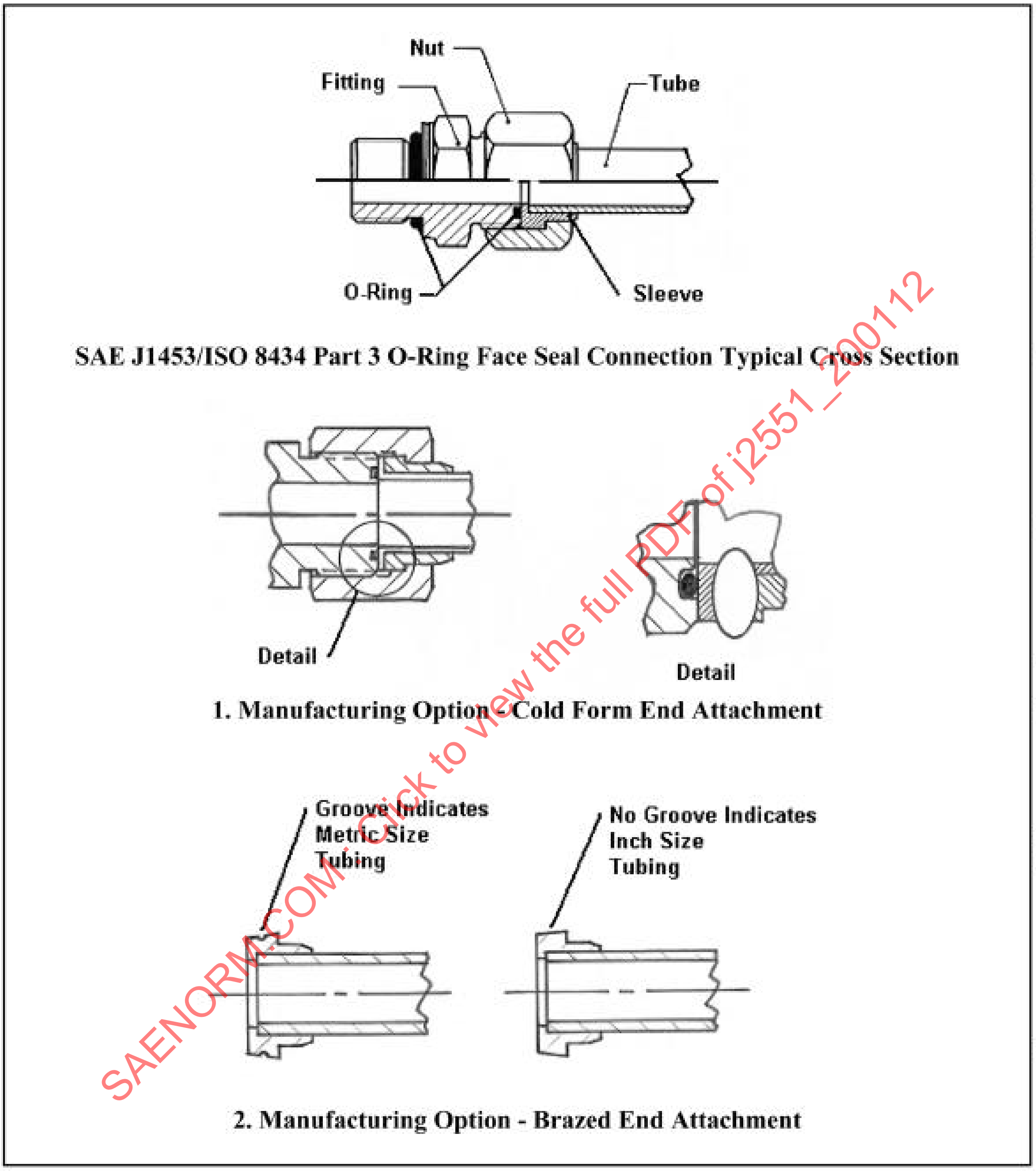
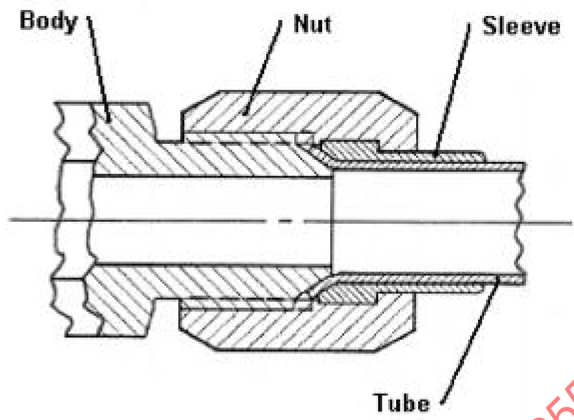
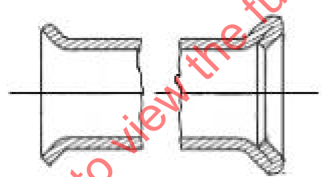


FIGURE 1—SAE J1453/ISO 8434 PART 3 O-RING FACE SEAL CONNECTION AND OPTIONAL MANUFACTURING METHODS. FOR USE IN SYSTEMS UP TO 63 MPA (9000 PSI), SEE ISO 8434 PART 3 FOR WORKING PRESSURES, O-RING SEAL INTERFACE HELPS PROVIDE LEAK FREE CONNECTIONS.

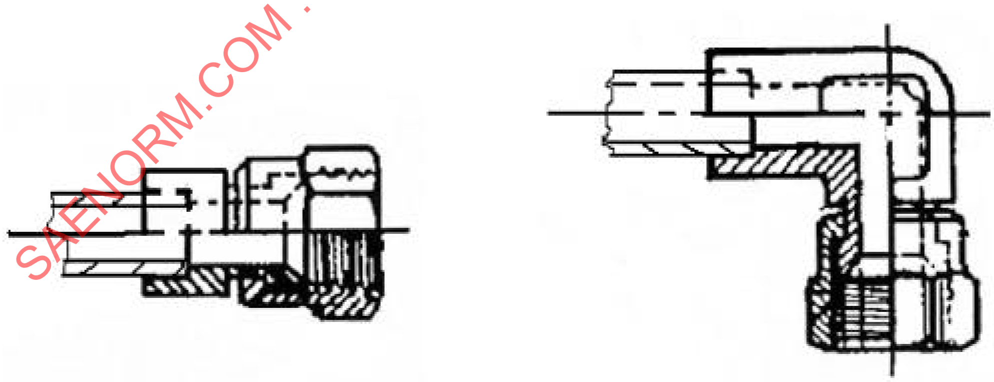
4.2.2.2 *SAE J514/ISO 8434 Part 2 - 37 degree Flared Connections*—See Figure 2.



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



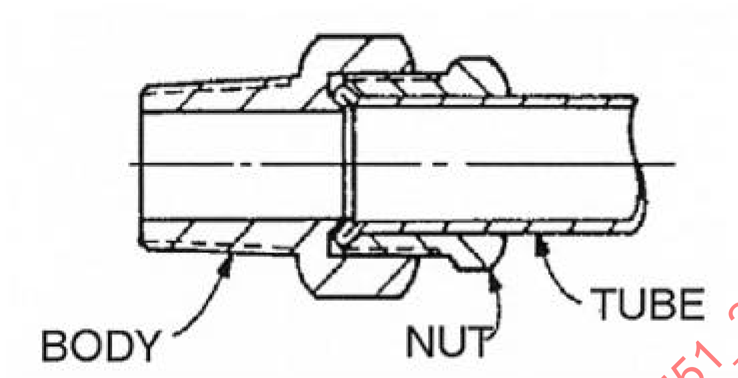
1. Manufacturing Option - SAE J 533 Flares for Tubing, Cold Forming



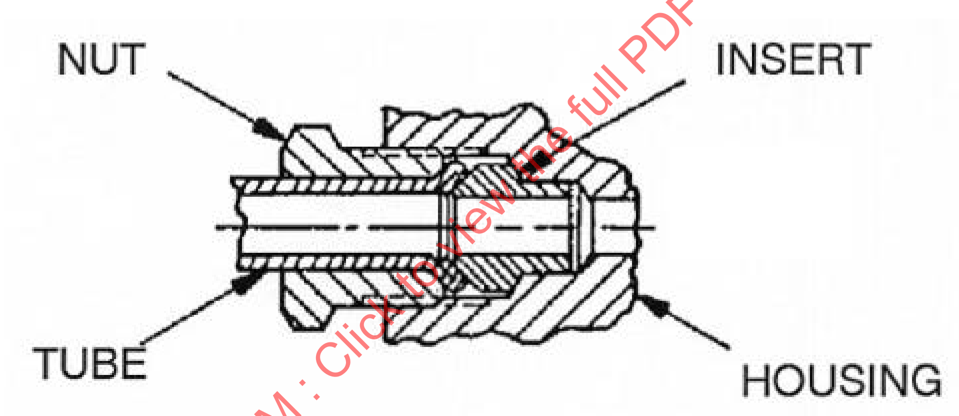
2. Manufacturing Option - Brazed End Attachment, ISO/SAE Specifications in Development

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.

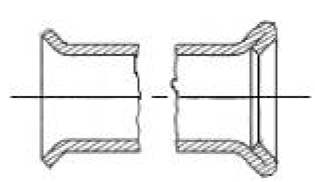
4.2.2.3 *SAE J512 45 degree Inverted Flare Connections*—See Figure 3.



SAE J 512 45° Inverted Flare Connection



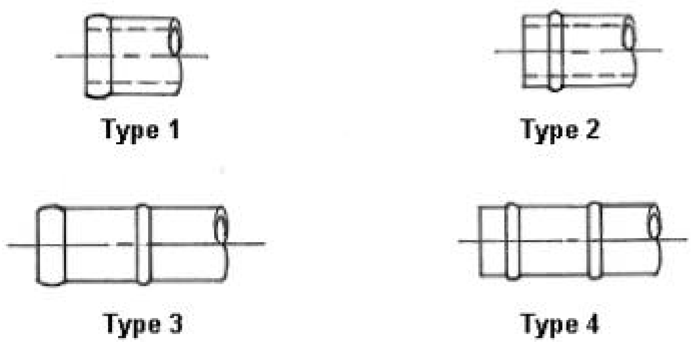
SAE J 512 45° Inverted Flare Connection with Inserted Seat



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.

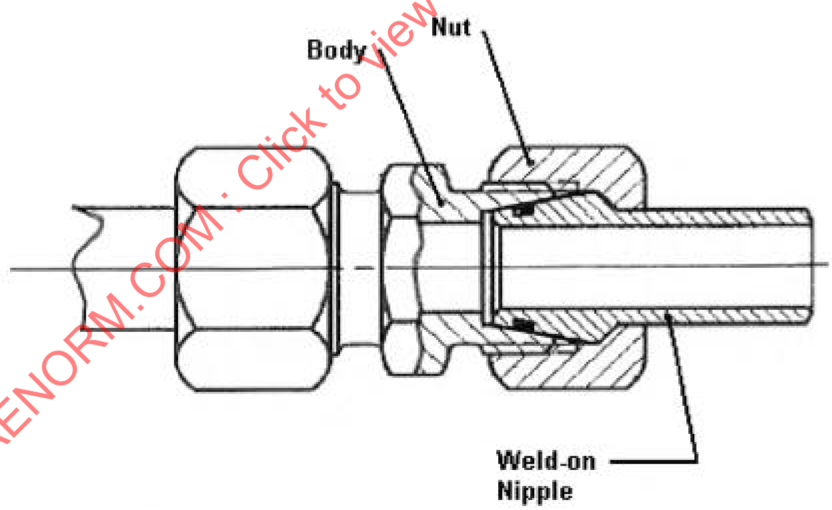
4.2.2.4 SAE J1231 Formed Tube Ends for Hose Connections—See Figure 4.



SAE J 1231 Formed Tube Ends for Hose Connections

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

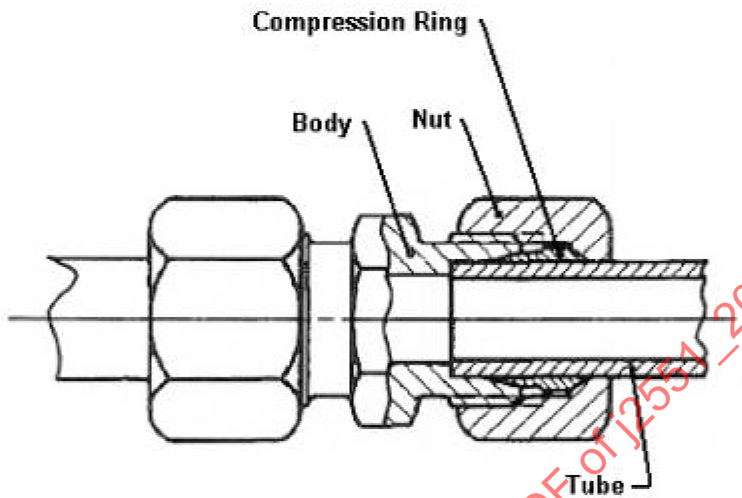
4.2.2.5 ISO 8434 Part 4 - 24 degree Cone Welded Nipple Connections—See Figure 5.



ISO 8434 Part 1 - 24° Cone Connection with Weld-0n Nipple

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.

4.2.2.6 *ISO 8434 Part 4 - 24 degree Cone Compression Connections*—See Figure 6.



ISO 8434 Part 1 (Metric) / SAE J 514 (Inch) - 24° Cone Compression Connection

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.

4.2.2.7 SAE J518/ISO 6162 - 4-Bolt Flange Connections—See Figure 7. (Replaced lock washers with flat washers)

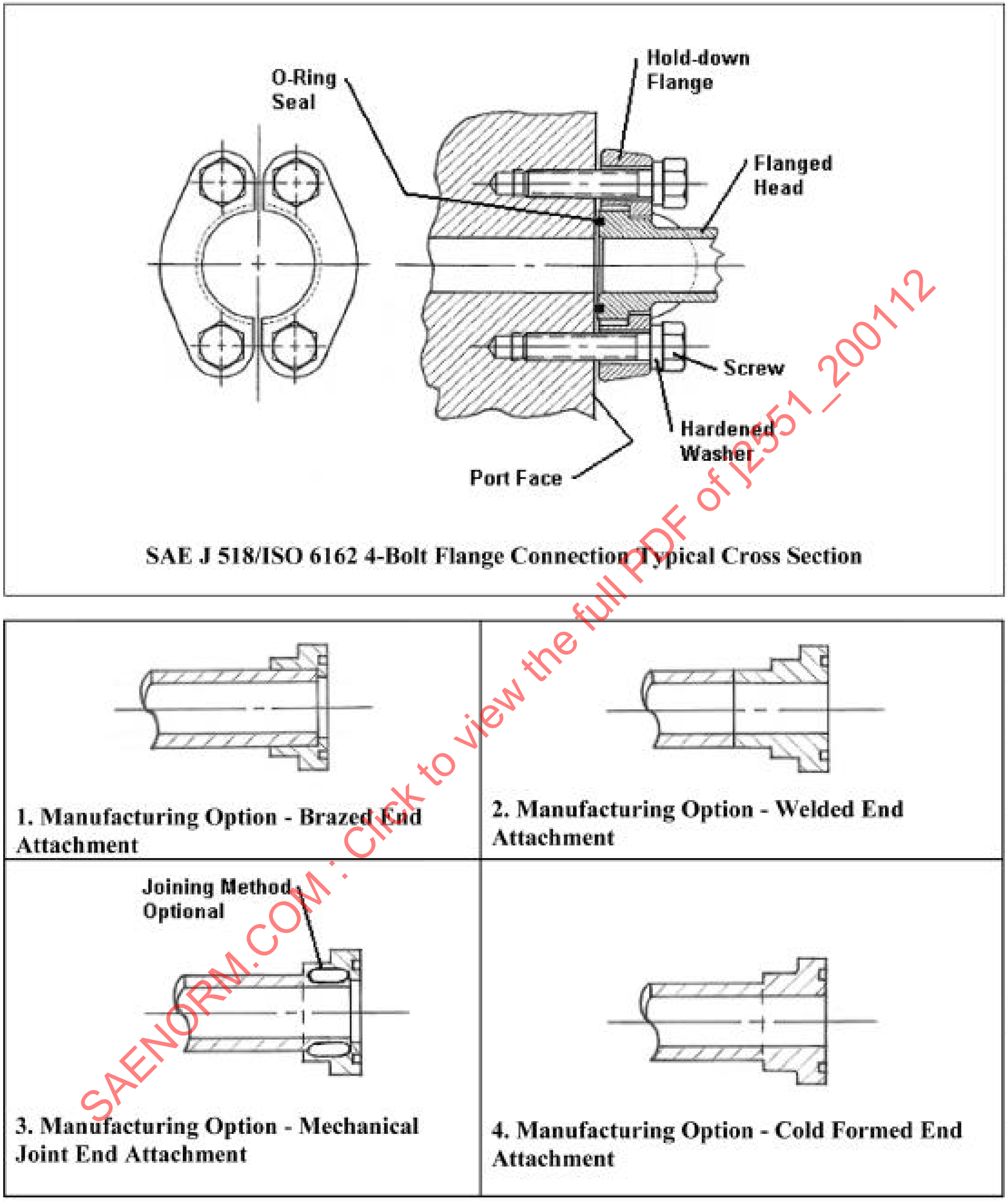


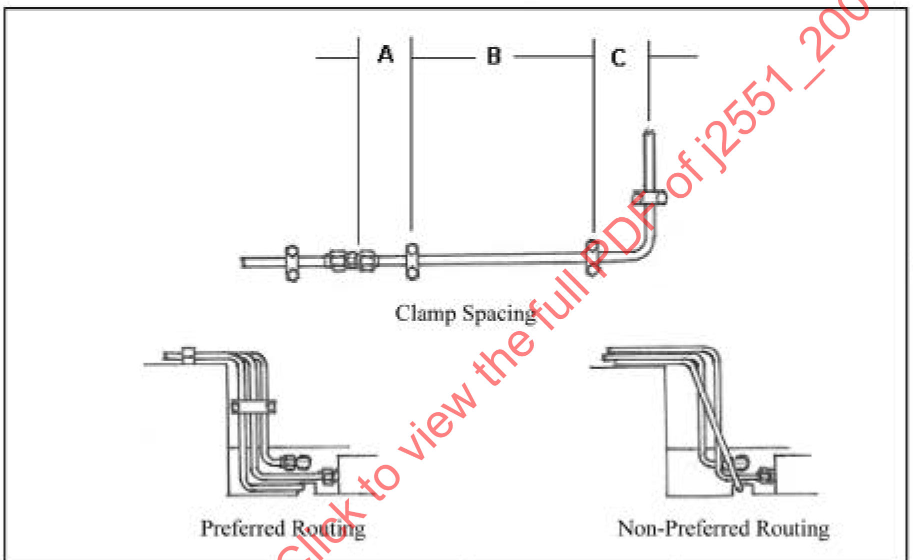
FIGURE 7—SAE J518/ISO 6162 4 -BOLT FLANGE CONNECTION, FOR USE WITH SPLIT OR CAPTIVE 4-BOLT FLANGES IN SYSTEMS UP TO 41.4 MPA (6000 PSI), SEE ISO 6162/SAE J518 FOR WORKING PRESSURES FOR VARIOUS TUBE SIZES. ELASTOMERIC SEAL INTERFACE HELPS PROVIDE LEAK FREE CONNECTIONS.

4.3 Environment—Carbon steel tube in itself offers little or no corrosion resistance. Appropriate coatings for the usage environment to 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.



Tube OD	A mm	B mm	C mm
6.35 7.94 9.52	50	600	100
12.70 15.88 19.05 22.22 25.50	100	900	200
31.75 38.10 50.80	150	1200	300

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 AREAS OF DYNAMIC MOVEMENT—Tube assemblies should be isolated from vibration stresses as much as possible. Flexible hose and dampening clamps should be used to isolate the tube assembly from vibratory stresses.

4.4.5 EXPANSION LOOPS—Expansion loops should be installed to prevent tension stresses and allow for temperature expansions. The use of "U" shapes instead of straight line runs between connections will increase the assemblies tolerance to expansion and contraction due to temperature changes and allow for motion under load, see Figure 9. Even some rigid systems do move when placed under a heavy load.

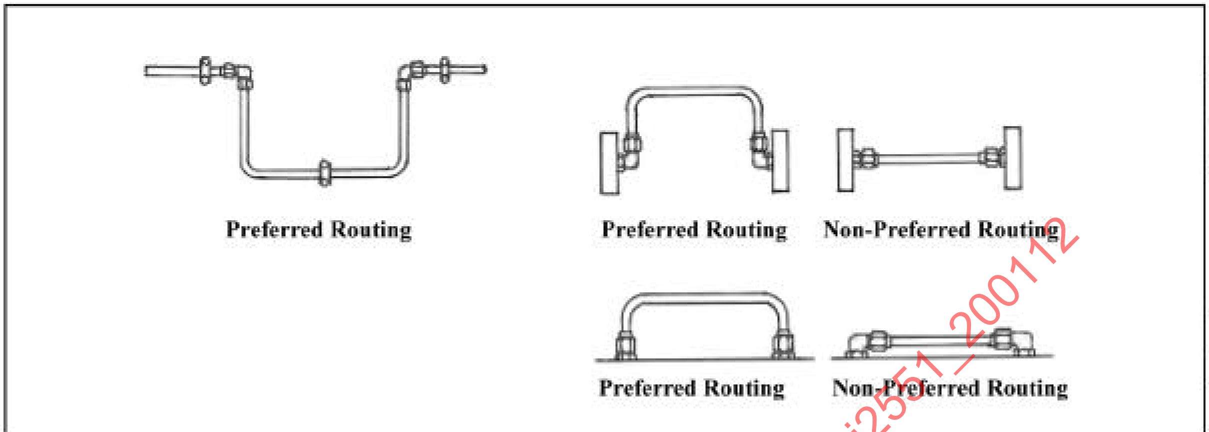


FIGURE 9—EXPANSION LOOPS

4.4.6 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 is 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 can not be provided.

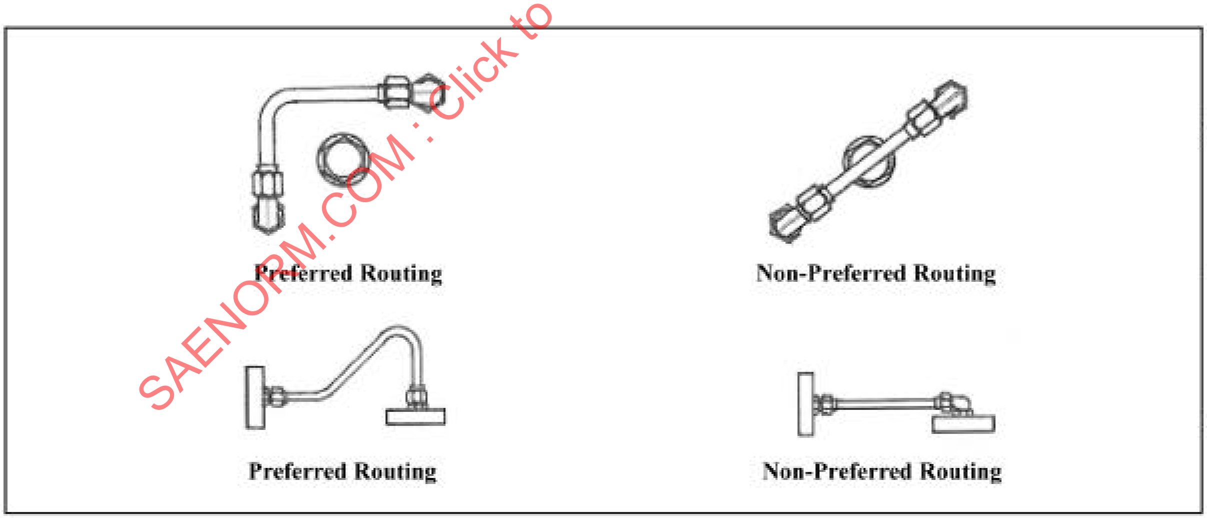


FIGURE 10—ROUTING BETWEEN FIXED POINTS

4.4.7 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.

4.4.8 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.

4.4.9 TIGHTENING SEQUENCE CONSIDERATIONS—To ensure proper alignment of the sealing interfaces, close attention should be paid to provide a design that allows correct tightening sequence when installing all fluid carriers. When the clamps are tightened first, the tube becomes fixed in space and the sealing interfaces at the tube assembly ends may become improperly aligned as shown in Figure 11, and will eventually leak. The joint interface will not leak when properly closed, as shown in Figure 12.

FIGURE 11—IMPROPER JOINT CLOSURE

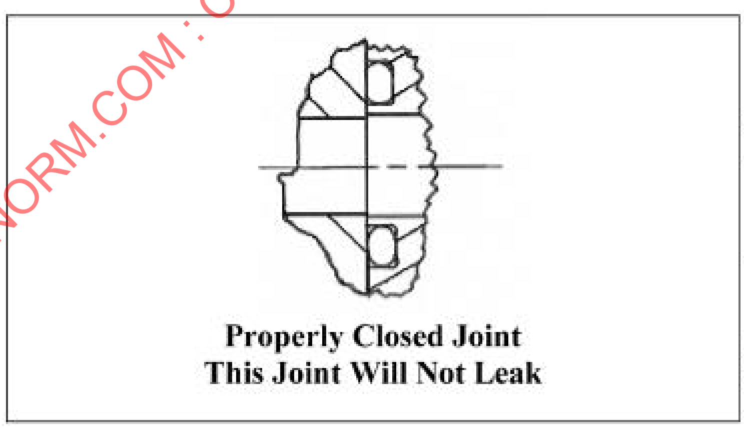


FIGURE 12—PROPER JOINT CLOSURE

4.4.10 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.

4.4.11 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 1. "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.

TABLE 1—BENT TUBE SUGGESTED END POINT TOTAL ZONE TOLERANCES LISTED BY METRIC BLANK LENGTHS

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										
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⇒	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
Total True Position ⇒ Tolerance	6	8	8	10	10	12	12	14	14	16	16	18	18	20	20	22

5.5 Types of Inspection Methods—There are several types of accepted inspection methods for tube assemblies. Each has it's unique advantages and disadvantages. The greatest challenge is finding the specified vertex points. These points are the dimensioned points where the centerline of the straight lengths intersect. On most assemblies, you will find these points "off the part," or hanging in mid air. A full size layout, check fixture, a vector inspection table or co-ordinate measuring machine utilizing appropriate software designed for this purpose should be used. Just as important is to determine, during the design process, the specific inspection method to be used between the designer and the manufacturer.

5.5.1 HAND LAYOUT—The hand lay out of a tube assembly is normally only utilized during the sampling or prototyping of a new design. Hand layout of an assembly is accomplished with gauge blocks, and usually, a full size Mylar or paper template. Precise measurements are difficult, time consuming, and susceptible to errors due to "eyeballing" measurement points.

5.5.2 VECTOR INSPECTION—Vector inspection tables usually consist of a measurement probe attached to an articulated arm to measure points on the assembly. The measurement data supplied by the operator is interpreted by a computer and compared to the print dimensions. Vector inspection tables are used to check for the tube contour and end point locations, although some newer machines have the ability to perform CMM measurements of attached components on the assembly. Checks on this type of machine can be made in 2 to 3 minutes and the machine may be electronically interfaced with the CNC bending machine. This interface allows for the automatic downloading of print characteristics and for machine adjustments after the part is checked.

5.5.3 HARD POINT AND BEST FIT INSPECTION

5.5.3.1 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.

5.5.3.2 Best Fit Inspection—The tube is supported on a holding device and the features are verified with an electronic detection system to fit inside of a mathematically calculated envelope established by the computer. This system allows the tube to float along the X, Y and Z axis and about the A, B and C roll axis to minimize or uniformly distribute the errors. Often, such as with the system "Supravision," the ends may be selected to have the ends of the tube held to a relatively closer fit than the intermediate portions. Tube assemblies that may be verified with this method of inspection are recommended. The vast majority of tube assemblies in the earth moving industry are of this type.

5.5.4 ADVANTAGES OF BEST FIT INSPECTION

5.5.4.1 Ideal Simulation—Ideally simulates the final installation conditions whereby errors are distributed and accommodated at many points.

5.5.4.2 Neutral Evolution—Allows neutral evolution from the hard gauge.

5.5.4.3 Non-Zero/Zero Accuracy—Does not require any one portion of the tube assembly to be "zero-zero" accurate.

5.5.5 CHECKING FIXTURES—Check fixtures are used to perform attribute checks on the assembly. These fixtures may be used to check the tube contour, location of components, tube end points, and other attachments to the assembly. A check fixture may only check for a specific dimension or may be constructed to check the entire assembly. Check fixtures are good for random checking of parts by a process operator to ensure compliance to print dimensions and are especially effective during large-scale production runs of the same part. Check fixtures are recommended to inspect "hard point" designed tube assemblies.