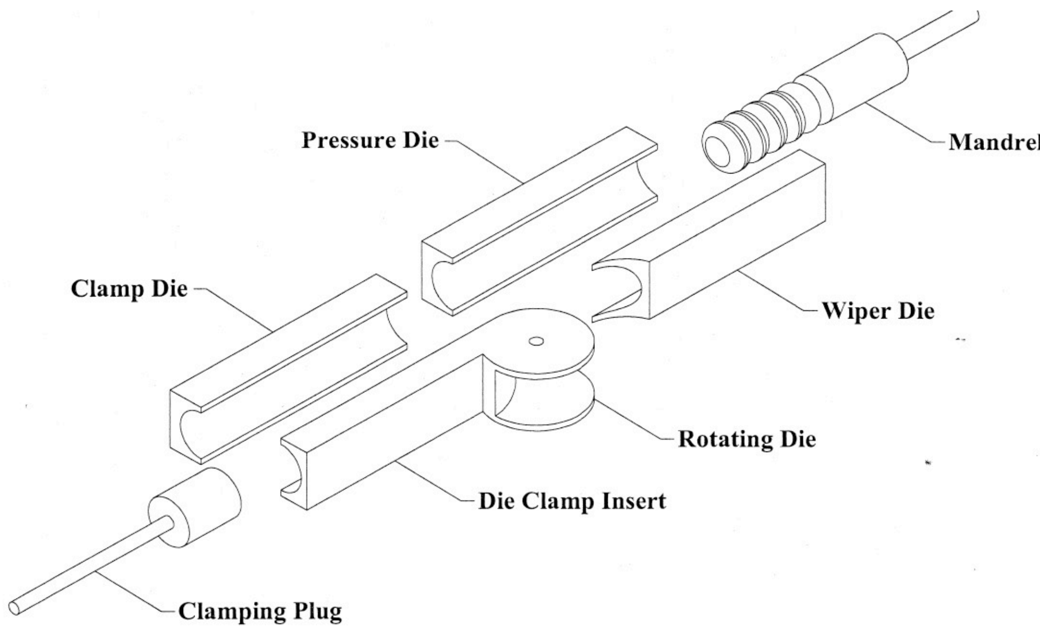
# Tube Forming Handbook




Use this handbook to design your exhaust tubing and we'll build it to your exact specifications.

- Specify tubing configuration
- Select size, type and grade of tubing
- Select plating or coating, if required
- Minimize the cost of your tubing components

Constant attention to detail and accuracy is an integral part of our manufacturing process. From the moment we receive raw material until your order leaves our door, we engage in step-by-step quality checks that insure critical tolerances have been met.

Our quality control is enhanced through the use of computerized plotting, memory storage, printout conformation, and data processing.  Inspections are automated for tighter control in critical areas including: bend angles, accurate straight surface positions, elongation, spring back, stresses factors and repetition.

PAUMAC TUBING, LLC is ISO 9001:2015 certified.

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# 1. INTRODUCTION

PAUMAC Tube Forming Handbook was designed to be a useful guide for the buyer, engineer or designer whose responsibilities include the specifications and procurement of metal tube assemblies. Sections on bending, end finishing, coating, and tube design provide previously hard-to-find information that will help to minimize the cost of your tube components.

The stock list included in the manual contains our most popular sizes, types, and grades of tubing which we currently work with. In addition, we have access to many other sizes, types, and grades of tubing which we can form to your exact dimensions. If necessary, tooling can be developed to fabricate non-standard or unique configurations.

Every effort has been made to ensure the accuracy of the information in this manual. Due to constant changes in technology, material availability, and your suggestions, contact PAUMAC sales for the most up-to-date information available in the tube forming industry.

# 1. TUBING STOCK LIST

**ALUMINUM**

Drawn Tubing:

Meets specifications of B210.
Alloy used in 6063, tempers 0, 4, and 6.

Extruded Tubing:

Meets specifications of ASTM B221/B241/B345.
Alloy used is 6061, tempers.

**CARBON STEEL**

HREW- Hot Rolled Electric Welded:

Meets specifications of ASTM A513, type 1.
Most common grade is MT 1010.

AKDQ- Aluminum Kilned Drawn Quality Tubing:

Meets specifications of ASTM A513, type 2.
Most common grade used is C- 1006/1008.

ALZD- Aluminum Coated AKDQ Tubing:

Meets specifications of ASTM A787, type 1, or A463.
Most common grade used is C- 1006/1008. Coating designations are T1-25 or T1-40.

Carbon Steel Seamless Mechanical Tubing:

Meets specifications of ASTM A519.

Carbon Steel Welded Hydraulic Tubing:

Meets specifications of SAE J525 and ASTM A214.

CDBW- Cold Drawn Butt Weld Tubing:

Meets specifications of ASTM A512 and AISI A214.

DOM- Drawn Over Mandrel Tubing:

Meets specifications of ASTM A513, type 5.
Grade designation of MT 1020.

**STAINLESS STEEL**

Stainless Steel Welded Tubing*:

Meets specifications of ASTM A249/A269/A554.
Grades used are 304L and 409.

***NOTE:** 1) Tubing may not be inventoried at the plant and may require a long lead time and must be purchased in mill quantities of 3000feet.

2) Due to the strength of stainless steel there are special requirements in tooling. Please check with your PAUMAC sales representative to ensure the tooling is required or if your tooling is needed to be purchased for your particular needs.

# 2. TECHNICAL DATA

## WALL TOLERANCE FOR ROUND TUBING

3.1.1 HREW (Hot Rolled Electric Weld)

| WALL THICKNESS | | OUTSIDE DIAMETER, INCHES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ¾ to 1, incl. | | Over 1 to 1-15/16, incl. | | Over 1-15/16 to 3-3/4, incl. | | Over 3-3/4 to 4- 1/2 , incl. | | Over 4-1/2, incl. | |
| INCHES | BWG | | | | | WALL THICKNESS TOLERANCES, INCHES | | | | | |
| | | Plus | Minus | Plus | Minus | Plus | Minus | Plus | Minus | Plus | Minus |
| .065 | 16 | .005 | .009 | .004 | .010 | .003 | .011 | .002 | .012 | .002 | .012 |
| .072 | 15 | .005 | .009 | .004 | .010 | .003 | .011 | .002 | .012 | .002 | .012 |
| .083 | 14 | .006 | .010 | .005 | .011 | .004 | .012 | .003 | .013 | .003 | .013 |
| .095 | 13 | .006 | .010 | .005 | .011 | .004 | .012 | .003 | .013 | .003 | .013 |
| .109 | 12 | .006 | .010 | .005 | .011 | .004 | .012 | .003 | .013 | .003 | .013 |
| .120 | 11 | .006 | .010 | .005 | .011 | .004 | .012 | .003 | .013 | .003 | .013 |
| .134 | 10 | .006 | .010 | .005 | .011 | .004 | .012 | .003 | .013 | .003 | .013 |
| .148 | 9 | | | .006 | .012 | .005 | .013 | .004 | .014 | .004 | .014 |
| .165 | 8 | | | .006 | .012 | .005 | .013 | .004 | .014 | .004 | .014 |
| .180 | 7 | | | .006 | .012 | .005 | .013 | .004 | .014 | .004 | .014 |
| .203 | 6 | | | | | .007 | .015 | .006 | .016 | .005 | .017 |
| .220 | 5 | | | | | .007 | .015 | .006 | .016 | .005 | .017 |
| .238 | 4 | | | | | .012 | .020 | .011 | .021 | .010 | .022 |
| .259 | 3 | | | | | .013 | .021 | .012 | .022 | .011 | .023 |
| .284 | 2 | | | | | .014 | .022 | .013 | .023 | .012 | .024 |
| .300 | 1 | | | | | .015 | .023 | .014 | .024 | .013 | .025 |
| .320 | | | | | | .016 | .024 | .015 | .025 | .014 | .026 |
| .344 | | | | | | .017 | .025 | .016 | .026 | .015 | .027 |
| .360 | | | | | | .017 | .025 | .016 | .026 | .015 | .027 |
| .375 | | | | | | | | .016 | .026 | .015 | .027 |
| .406 | | | | | | | | .017 | .027 | .016 | .028 |
| .438 | | | | | | | | .017 | .027 | .016 | .028 |
| .469 | | | | | | | | | | .016 | .028 |
| .500 | | | | | | | | | | .016 | .028 |

3.1.2 CREW (Cold Rolled Electric Weld)

| WALL THICKNESS | | OUTSIDE DIAMETER, INCHES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ¾ to 1, incl. | | Over 1 to 1-15/16, incl. | | Over 1-15/16 to 3-3/4, incl. | | Over 3-3/4 to 4-1/2, incl. | | Over 4-1/2, incl. | |
| INCHES | BWG | | | | | WALL THICKNESS TOLERANCE, INCHES | | | | | |
| | | Plus | Minus | Plus | Minus | Plus | Minus | Plus | Minus | Plus | Minus |
| .028 | 22 | .001 | .005 | .001 | .005 | | | | | | |
| .035 | 20 | .002 | .005 | .001 | .001 | .001 | .003 | | | | |
| .049 | 18 | .003 | .006 | .002 | .006 | .002 | .006 | | | | |
| .065 | 16 | .005 | .007 | .004 | .007 | .004 | .007 | .004 | .007 | .004 | .007 |
| .083 | 14 | .006 | .007 | .005 | .007 | .004 | .007 | .004 | .007 | .004 | .008 |
| .095 | 13 | .006 | .007 | .005 | .007 | .004 | .007 | .004 | .007 | .004 | .008 |
| .109 | 12 | | | .006 | .008 | .005 | .008 | .005 | .008 | .005 | .009 |
| .120 | 11 | | | .007 | .008 | .006 | .008 | .005 | .008 | .005 | .009 |
| .134 | 10 | | | .007 | .008 | .006 | .008 | .005 | .008 | .005 | .009 |

### **3.1.3** Wall Tolerances for Round Tubing

## COPPER AND BRASS ALLOY

| **WALL THICKNESS** | **OUTSIDE DIAMETER, INCHES** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1/32 to 1/8, incl.** | **Over 1/8 to 5/8, incl.** | **Over 5/8 to 1, incl.** | **Over 1 to 2, incl.** | **Over 2 to 4, incl.** | **Over 4 to 7, incl.** | **Over 7 to 10, incl.** |
| Up to .018 | .002 | .001 | .0015 | .002 | | | |
| Incl. .018 to .025 | .003 | .002 | .002 | .0025 | | | |
| Incl. .025 to .035 | .003 | .0025 | .0025 | .003 | .004 | | |
| Incl. .035 to .058 | .003 | .003 | .0035 | .0035 | .005 | .007 | |
| Incl. .058 to .083 | | .0035 | .004 | .004 | .006 | .008 | .010 |
| Incl. .083 to .120 | | .004 | .005 | .005 | .007 | .009 | .011 |
| Incl. .120 to .165 | | .005 | .006 | .006 | .008 | .010 | .012 |
| Incl. .165 to .220 | | .007 | .0075 | .008 | .010 | .012 | .014 |
| Incl. .220 to .284 | | | .009 | .010 | .012 | .014 | .016 |
| Incl. .284 to .380 | | | .011 | .012 | .014 | .0116 | .018 |
| Incl. .380 and over | | | | 5% | 5% | 6% | 6% |

## 3.2 DIAMETER TOLERANCE FOR ROUND TUBING

### 3.2.1 HREW (Hot Rolled Electric Weld)

| Outside Diameter Size Range in Inches | Wall Thickness | | Outside Diameter Tolerance, Inches | |
|---|---|---|---|---|
| | BWG | INCHES | Plus | Minus |
| ¾ to 1- 1/8, incl. | 16 to 10 | .065 to .134 | .0035 | .0035 |
| Over 1- 1/8 to 2, incl. | 16 to 7 | .065 to .180 | .005 | .005 |
| Over 1- 1/8 to 2, incl. | 16 to 3 | .203 to .259 | .005 | .005 |
| Over 2 to 2- ½, incl. | 16 to 3 | .065 to .259 | .006 | .006 |
| Over 2- 1/2 to 3, incl. | 16 to 3 | .065 to .259 | .008 | .008 |
| Over 2- ½ to 3, incl. | 2 to .320 | .284 to .320 | .010 | .010 |
| Over 3 to 3- ½, incl. | 16 to 3 | .065 to .259 | .009 | .009 |
| Over 3 to 3- ½, incl. | 2 to .360 | .284 to .360 | .012 | .012 |
| Over 3- ½ to 4, incl. | 16 to 3 | .065 to .259 | .010 | .010 |
| Over 3- ½ to 4, incl. | 2 to .500 | .284 to .500 | .015 | .015 |
| Over 4 to 5, incl. | 16 to 3 | .065 to .259 | .020 | .020 |
| Over 4 to 5, incl. | 2 to .500 | .284 to .500 | .020 | .020 |
| Over 5 to 6, incl. | 16 to 3 | .065 to .259 | .020 | .020 |
| Over 5 to 6, incl. | 2 to .500 | .284 to .500 | .020 | .020 |
| Over 6 to 8, incl. | 11 to 3 | .120 to .259 | .025 | .025 |
| Over 6 to 8, incl. | 2 to .500 | .284 to .500 | .025 | .025 |

3.2.2 CREW (Cold Rolled Electric Weld)

| Outside Diameter Size Range in Inches | Wall Thickness | | Outside Diameter Tolerance, Inches | |
|---|---|---|---|---|
| | BWG | Inches | Plus | Minus |
| ¼ to 3/8, incl. | 22 to 14 | .028 to .083 | .0025 | .0025 |
| Over 3/8 to 5/8, incl. | 22 to 16 | .028 to .065 | .003 | .003 |
| Over 3/8 to 5/8, incl. | 14 to 12 | .083 to .109 | .003 | .003 |
| Over 5/8 to 1- 1/8, incl. | 22 to 14 | .028 to .083 | .0035 | .0035 |
| Over 5/8 to 1-1/8, incl. | 13 to 11 | .095 to .120 | .0035 | .0035 |
| Over 1- 1/8 to 2, incl. | 22 to 14 | .028 to .083 | .005 | .005 |
| Over 1- 1/8 to 2, incl. | 13 to 9 | .095 to .148 | .005 | .005 |
| Over 3 to 3- 1/2, incl. | 20 to 14 | .035 to .083 | .006 | .006 |
| Over 2 to 2- ½, incl. | 13 to 9 | .095 to .148 | .006 | .006 |
| Over 2 to 2- ½, incl. | 20 to 18 | .035 to .049 | .008 | .008 |
| Over 2- ½ to 3, incl. | 16 to 9 | .065 to .148 | .008 | .008 |
| Over 3 to 3- ½, incl. | 20 to 9 | .035 to .148 | .009 | .009 |
| Over 3- ½ to 4, incl. | 20 to 8 | .035 to .165 | .010 | .010 |
| Over 4 to 5, incl. | 16 to 14 | .065 to .083 | .020 | .020 |
| Over 4 to 5, incl. | 13 to 8 | .095 to .165 | .015 | .015 |
| Over 5 to 6, incl. | 16 to 8 | .065 to .165 | .020 | .020 |

## 3.3 DIMENSION TOLERANCE

### Squares and Rectangles
### Electric Resistant Welded, (ERW), Tubing

| Largest Nominal Outside Dimension, in.(mm) | Wall Thickness, in. (mm) | Outside Tolerances All sides at Corners +/- in. (mm) |
|---|---|---|
| 3/16 (4.8 to 5/8 (15.9), incl. | 0.020 (0.51) to 0.083 (2.11), incl. | 0.004 (0.10) |
| Over 5/8 (15.9) to 1- 1/8 (28.6), incl. | 0.025 (0.64) to 0.156 (3.96), incl. | 0.005 (0.13) |
| Over 1- 1/8 (28.6) to 1- ½ (38.1), incl. | 0.025 (0.64) to 0.192 (4.88), incl. | 0.006 (0.15) |
| Over 1- ½ (38.1) to 2 (50.8), incl. | 0.032 (0.81) to 0.192 (4.88), incl. | 0.008 (0.20) |
| Over 2 (50.8) to 3 (76.2), incl. | 0.035 (0.89) to 0.259 (6.58), incl. | 0.010 (0.25) |
| Over 3 (76.2) to 4 (101.6), incl. | 0.049 (1.25) to 0.259 (6.58), incl. | 0.020 (0.51) |
| Over 4 (101.6) to 6 (152.4), incl. | 0.065 (1.65) to 0.259 (6.58), incl. | 0.020 (0.51) |
| Over 6 (152.4 to 8 (203.2), incl. | 0.185 (4.70) to 0.259 (6.58), incl. | 0.025 (0.64) |

### Convexity and Concavity

Tubes having two parallel sides are also measured in the center of the flat sides for convexity and concavity. This tolerance applies to the specific size determined at the corners, and is measured on the following basis:

| Largest Nominal Outside Dimension, in. (mm) | Tolerance Plus and Minus, in. (mm) |
|---|---|
| 2-1/2 (63.5) and under | 0.010 (0.25) |
| Over 2-1/2 (63.5) to 4 (101.6) | 0.015 (0.38) |
| Over 4 (101.6) to 8 (203.2), incl. | 0.025 (0.64) |

**Note:** The wall thickness tolerance for hot rolled and cold rolled squares and rectangles is ± 10% of the nominal wall thickness.

# 4. TUBE FORMING TECHNIQUES & ENGINEERING SUGGESTIONS

## 4.1. Electronic Data Interchange and Bar Coding for Shipping and Part Identification

PAUMAC tubing utilizes state-of –the-art technologies and systems to ensure full EDI capabilities.

Shipping container and part identification makes use of industry standard Bar Coding.

We are able to exchange information and prints via a modem, FAX or e-mail with our customers. This will help shorten the time period required for part design.

The following two pages contain a list of the capabilities of our system and the hardware and software in use. If you have any questions about possible applications, please contact your PAUMAC sales representative for more information.

## 4.2. Computer Aided Design / Computer Aided Manufacturing (CAD/CAM)

Our plant utilizes Computer Aided Design/ Computer Aided Manufacturing systems. These CAD/CAM systems have direct and indirect communication with many different CAD/CAM systems, such as DXF, IGES, DWG, and STEP.

<u>The XYZ Coordinate System:</u> Dimensions expressed by the display of XYZ coordinates are convenient when establishing a bend shape. Dimensions are absolute distances from a datum on centerline to the intersection point in question. Three dimensions are needed to describe each point of the system. The intersection of lines created by the description of XYZ coordinates establishes the line lengths.

The CAM system uses the ―Right Handed Rule‖ system to maintain its vector direction; therefore, we must input data in the same manner, or the ―mirror image‖ part will be created.

To determine the correct direction to establish as the datum for XYZ dimensions, think of your right hand, with thumb, index, and middle fingers at right angles to one another. Figure 1 shows the Right Hand Rule for determining positive direction of vectors form the Cartesian Coordinate System.

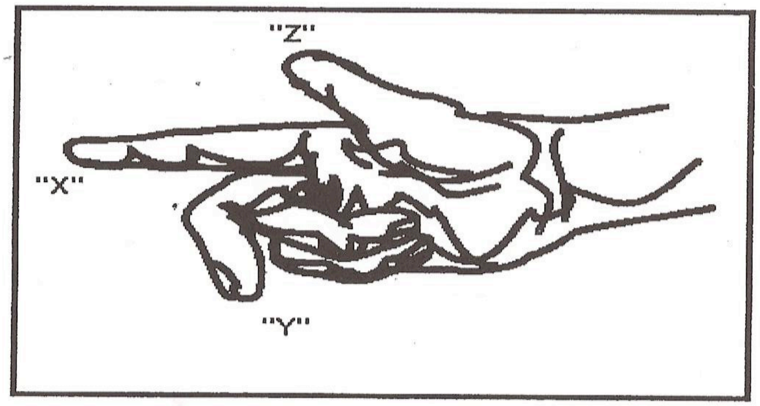



**Figure 1—The Right**
**Hand Rule**

When viewing a blueprint, establish the XYZ directions as though the thumb of your hand points in the +Z direction, your index finger points in the +X direction, and the middle finger points in the +Y direction. Select a datum which is easy to work with, and chart the dimensions, preferably completing all the entries of a single axis before continuing to the next axis.

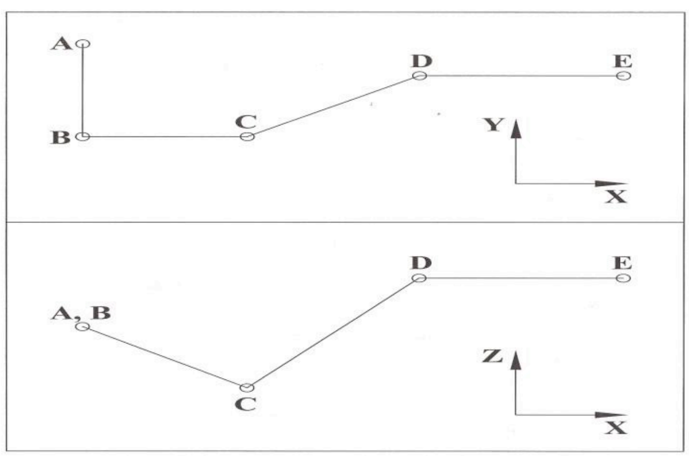



**Figure 2—XYZ Data Form**

Note the same shape can be described by a unlimited number of sets of XYZ coordinate dimensions, merely by moving the datum.

Actual tube dimensions are created mathematically from the XYZ coordinates, and are unique; that is, it completely describes the tube shape in reference to itself.

## 4.3. TUBE BENDING BASICS

### 4.3.1. Key Elements of Tube Bending

The figure below details all the key elements of a bent tube and the critical areas affected by the tube bending action.

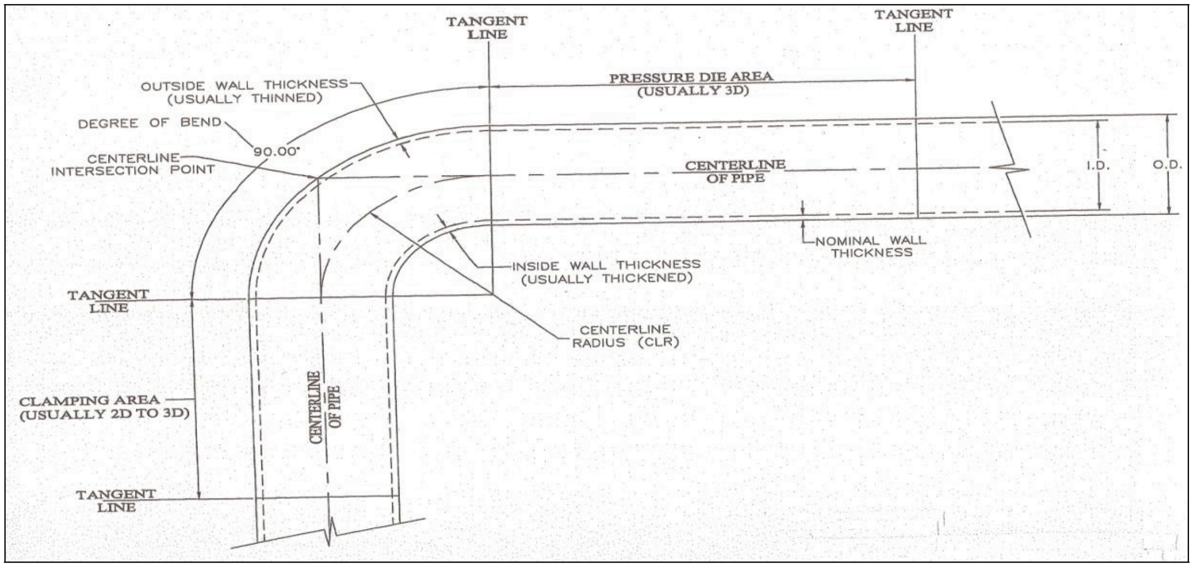



**Figure 3—Key Elements of Tube Bending**

### 4.3.2. Rotary Bending

This method of bending is detailed on the following pages. PAUMAC primarily incorporates the rotary or draw method.

- Tube is clamped to a rotating bend die.
- As the bend rotates, the pressure advances forcing the tube to conform to the radius of the bend die.
- Tools for heavy wall tubing:
  - Rotating bend die
  - Sliding pressure die
  - Clamping block
- Tools for thin wall tubing:
  - Same as above
  - Wiper die
  - Mandrel
- Advantages:
  - Most versatile
  - Most precise
  - Highest quality with tight radii
  - Highest quality with thin wall tubes
  - Least distortion to tubing

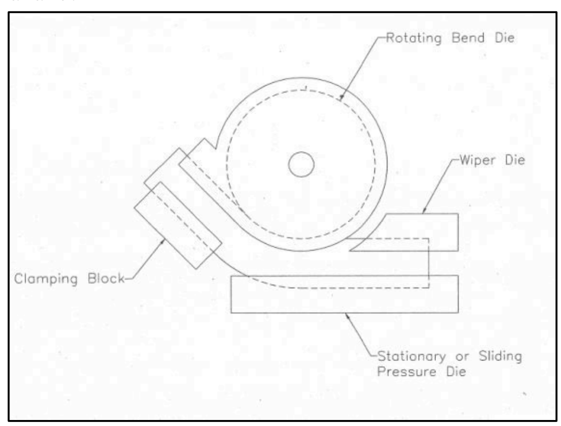



**Figure 4-- Rotary or Draw Bending**

### 4.3.3. Wall Thinning

To determine the percentage of wall thinning expected for a particular bend, use the formula below. The outside wall of the bend is stretched and thins out when a pipe is bent and the inside wall is compressed and thickens, but the neutral axis or centerline remains virtually unchanged. If we take the outside radius of the bend, subtract the centerline radius, and divide the difference by the outside radius, we will get the percentage of thinning:

$$\frac{OR-CLR}{OR}$$

Where: OR = Outside Radius
CLR = Centerline Radius

For example: 5‖ tubing on a 5.50‖ radius bend would show something like this:

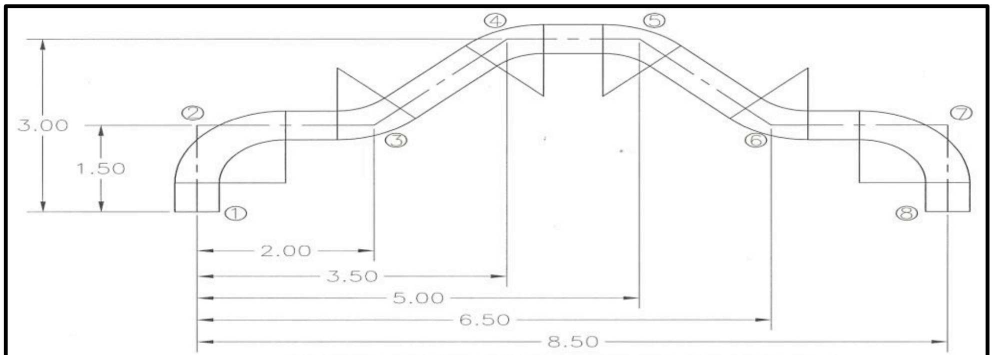
1) OR = CLR + Tube Diameter = 5.50 + 5/2 = 8.0‖

2) $\frac{8.0-5.5}{8.0} = \frac{2.5}{8.0} =$ .3125 or 31% wall thinning

This example does not consider other factors, such as movement of a neutral axis from the geometric axis, pressure die assist or pressure die boost, tool drag, and lubrication, all of which can and will effect the actual amount of wall thinning achieved. In most cases, however, benders can closely predict how much thinning to expect on a particular machine.

## 4.4. COST EFFECTIVE DESIGN OF TUBULAR COMPONENTS

- Use absolute coordinate dimensions. The common name for this dimensioning system is X-Y-Z coordinates (refer to Figure 5-XYZ Coordinates). Always dimension from a datum reference point or origin.
- Dimension to the intersection of tube centerlines and tube end points. Use tangent point dimensions for reference only.
- Use separate tolerances for the accuracy of the end point and for the intermediate sections.
- Provide tolerances for long parts in proportion to length.
- All radii should be specified to the centerline of the tube and not to the outside or inside of the bend.
- Always try to design a nominal bend radius that is an approximate multiple of the outside diameter of the tube.
  For example, for a 2.5 OD tube:
  1D bend = 2.5 centerline
  2D bend = 5.0 centerline
- <u>Design tubes which have a minimum of different bend radii.</u> Tubes with all bends of the same radius are desirable from a cost saving standpoint.
- Absolute minimum bend radii are approximately equal to the outside diameter of the tube. Such bends are difficult and expensive however. Always try to design bends which are greater than the diameter of the tube.
- <u>Expense can be minimized by selecting bend radii for tooling that we already have.</u> Consult the bend radius tables found in section 4.5 or contact your sales representative for further details.




| Point | --X-- | --Y-- | --Z-- |
|---|---|---|---|
| 1 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 1.50 | 0.00 |
| 3 | 2.00 | 1.50 | 0.00 |
| 4 | 3.50 | 3.00 | 0.00 |
| 5 | 5.00 | 3.00 | 0.00 |
| 6 | 6.50 | 1.50 | 0.00 |
| 7 | 8.50 | 1.50 | 0.00 |
| 8 | 8.50 | 0.00 | 0.00 |

**Figure 5—XYZ Coordinates**

- The distance between the bend tangent and the end of the tube must be equal to or more than the outside diameter in order to maintain the nominal tube diameter at the ends and to avoid excess scrap.
- Adequate straight sections should be allowed between bends that are long enough for clamping the tube firmly during bending operations. A general rule is to keep a distance between bend tangents which is at least twice the outside diameter of the tube. Special tooling or cut and weld construction is required when bends are too closely spaced to allow the minimum clamp grip length needed.
- Avoid bends greater than 90 degrees where possible because it is increasingly more expensive to bend beyond 90 degrees. If such bends are unavoidable, keep them to a minimum.

## 4.5. PAUMAC TUBE BENDING CAPABILITIES

### 4.5.1. Rotary/Draw Tooling: Port Huron, Michigan

| Tube Diameter (OD) | Centerline Radius | Inside Clamp Die Length | Outside Clamp Die Length | Wall Thickness |
|---|---|---|---|---|
| 0.63 | 1.25 | **.75** | **.375, .5, .75, 1.25** | .049, .065 |
| **0.75** | **1.25** | **1.00** | 1.00, 1.25, 1.675, 2 | **.065** |
| 0.75 | 1.50 | 1.00 | 1.00, 1.25, 1.675, 2 | .065 |
| 0.75 | 1.75 | 1.00 | 1.00, 1.25, 1.675, 2 | .065 |
| 0.75 | 2.50 | 2.50 | 1.00, 1.25, 1.675, 2 | .065 |
| 1.00 | 1.00 | .750 | 1.75, 2.75 | .065 |
| **1.00** | **1.25** | | | .065 |
| 1.00 | 1.50 | 1.00, 1.50 | 1.00, 1.50 | .065 |
| **1.00** | **2.00** | | | .065 |
| 1.00 | 3.00 | 3.00 | 2.00, 3.00, 4.00 | .065 |
| 1.00 | 4.00 | 1.00 | 2.00, 3.00, 4.00 | .065 |
| 1.00 | 5.00 | 1.00 | 2.00, 3.00, 4.00 | .065 |
| **1.13** | **3.00** | 1.50, 2.50 | 1.50, 3.50, 4.00 | .065 |
| 1.25 | 1.25 | | | .065 |
| 1.25 | 2.00 | 2.00, 3.00, 4.00 | 2.00, 3.00, 4.00 | .065 |
| **1.25** | **3.00** | **2.50, 3.00** | 1.00, 2.00, 3.00, 4.00 | .065 |
| **1.25** | **5.00** | **2.50, 3.00** | 1.00, 2.00, 3.00, 4.00 | .065 |
| 1.50 | 2.00 | 2.25 | 2.00 | .065 |
| **1.75** | **2.00** | 1.00, 2.00 | 2.00, 3.00 | .065 |
| 2.00 | 2.25 | 2.00, 3.00, 4.00, 5, 6 | 4.00, 5.00, 6.00 | .065 |
| **2.00** | **3.00** | **3.00** | 5.00, 6.00 | .065 |
| 2.00 | 5.00 | 4.00 | 5.00, 6.00 | .065 |
| 2.25 | 2.50 | 3.00, 5.00 | 5.00 | .065 |
| **2.38** | 9.75 | 7.00 | | .065 |
| **2.38** | 6.00 | 7.00 | | .065 |
| **2.38** | 3.00 | 5.00 | 5.00 | .065 |
| 2.50 | 2.50 | 3.00, 4.00, 6.00 | 3.00, 4.00, 6.00 | .065 |
| 2.50 | 3.00 | 1.50, 2.50, 3.00, 4.00 | 2.50, 3.00, 4.00, 5.00 | .065 |
| **2.50** | **3.75** | 5.00 | 5.00 | .065 |
| 2.50 | 5.00 | 1.50, 2.00, 4.00, 5.00 | 1.50, 2.00, 4.00, 5.00 | .065 |
| 2.88 | 5.00 (X2) | | | **.25** |
| **3.00** | **3.00** | 3.50, 4.00, 5.00, 6.00 | 3.00, 4.00, 5.00, 6.00 | .065 |
| **3.00** | **4.00** | 6.00 | | .065 |
| 3.00 | 4.50 | 5.00 | | .065 |
| **3.00** | **5.00** | 6.00 | 6.00 | .065 |
| 3.50 | 4.00 | 6.00 | | .065 |
| **3.50** | **5.00** | 4.0, 5.0, 5.50, 6.0, 8 | 4.0, 5.0, 6.0, 8 | .065 |
| 4.00 | 4.00 | 5.0, 6.0, 8.0, 10.0 | 5.0, 6.0, 8.0, 10.0 | .065 |
| 4.00 | 4.50 | 8.50 | | .065 |
| **4.00** | **5.00** | 5.0, 6.0, 8.0 | 5.0, 6.0, 8.0 | .065 |
| **4.00** | **6.00** | 5.0, 6.0, 8.0, 10.0 | 5.0, 6.0, 8.0, 10.0 | .065 |
| **4.00** | **7.00** | 20.0 | 20.0 | .065 |
| **4.50** | **5.00** | 3.5, 4.5, 6.5, 8.5 | 5.0, 6.0, 8.0, 10.0 | .065 |
| **4.50** | **6.00** | 3.5, 4.5, 6.5, 8.5 | 5.0, 6.0, 8.0, 10.0 | .065 |
| **5.00** | **5.50** | 6.0, 8.0, 12.0 | 6.0, 8.0, 12.0 | .065 |

| | | | | |
|---|---|---|---|---|
| 5.00 | 6.00 | 5.0, 6.0, 8.0, 10.0 | 5.0, 6.0, 8.0, 10.0 | .065 |
| 5.00 | 6.50 | 5.0, 6.0, 8.0, 10.0 | 5.0, 6.0, 8.0, 10.0 | .065 |
| 5.00 | 7.50 | 20.0 | 20.0 | .065 |
| **5.00** | **8.00** | 20.0, 24.0 | 12.0 | .065 |
| 6.00 | 7.00 | 6.5, 12.0, 16.0, 20.0 | 6.5, 12.0, 16.0, 20.0 | .065 |
| **6.00** | **10.0** | 16.0 | 16.0 | **.065** |
| | | | | |

Note:
1. All BENDING CAPABILITIES shown are in inches.
2. **Values shown in bold are preferred for lowest cost and quicker shipping cycles**

ENDFORMING

## 4.6. Single (37º & 45º) Flare (SAE J533)

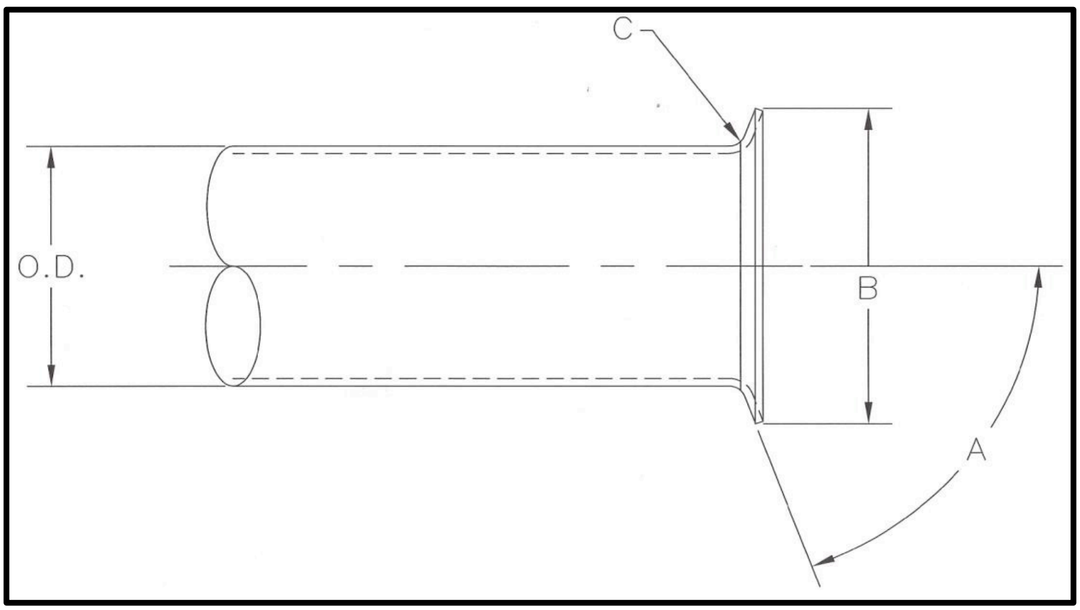



**Figure 6—Single 37 and 45 Degree Flare**

| Nominal Tubing OD | A Degree Flare | B Flare Diameter | | C Radius | |
|---|---|---|---|---|---|
| | | MAX | MIN | MAX | MIN |
| 1.00 | 37 | 1.187 | 1.172 | 0.103 | 0.083 |
| 1.500 | 37 | 1.730 | 1.700 | 0.110 | 0.120 |
| 1.50* | 45 | 1.725 | 1.695 | 0.110 | 0.120 |
| 1.750 | 45 | | | 0.110 | 0.120 |
| 2.50 | 45 | | | | |
| 4.00* | 45 | 5.000 | 4.970 | 0.110 | 0.120 |

**NOTE:**
1. All values shown are in inches
2. Asterisk items (*) are not included in SAE J533.

## 4.7. TURBO FLARES (20º)

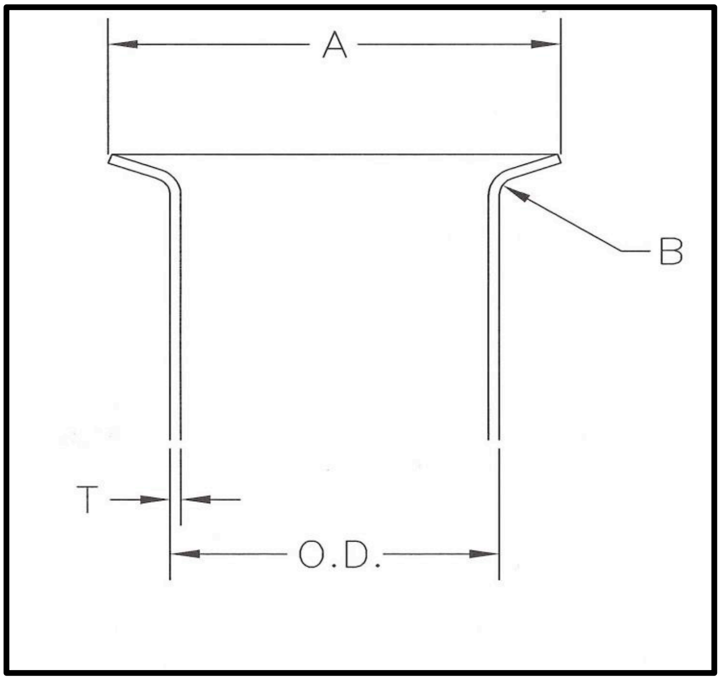



**Figure 8—Turbo Flares (20º)**

| Tube Diameter | A Flare Diameter | B Centerline Radius | Clamp Die Length | (T) Wall Thickness |
|---|---|---|---|---|
| 2.500 | | 0.220 | | .065, .083 |
| 3.000 | | 0.220 | | .065, .083 |
| 4.000 | 4.600 | 0.220 | 1.500 | .065, .083 |
| 5.000 | 5.680 | 0.220 | 1.500 | 0.065 |

**Note:** All values shown are in inches.

## 4.8. BEADING

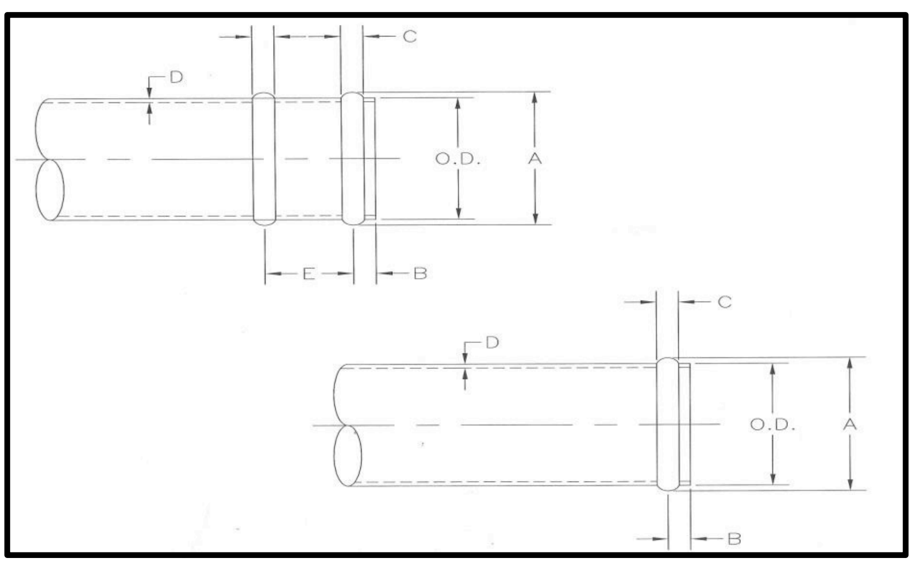
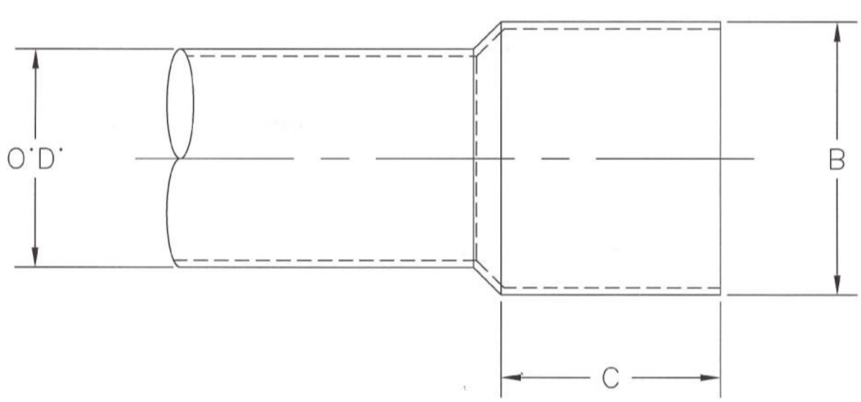


**Figure 9—Single and Double Bead**

| Bead Type | OD | A | B | C | E | D |
|---|---|---|---|---|---|---|
| Standard | .500 | .620 | .250 | .250 | | .065 |
| Standard | .625 | .745 | .250 | .250 | | .035, .049, .065 |
| Standard | .750 | .870 | .250 | .250 | | .035, .049, .065 |
| Standard | .875 | .995 | .250 | .250 | | .065 |
| Inverted | 1.000 | 1.120 | .250 | .250 | | .049 |
| Standard | 1.000 | 1.120 | .250 | .250 | | .065, .083 |
| Double Bead | 1.000 | 1.120 | .250 | .250 | .970 | .049 |
| Standard | 1.125 | 1.245 | .250 | .250 | | .049, .065 |
| Standard | 1.250 | 1.370 | .250 | .250 | | .065 |
| Standard | 1.375 | 1.495 | .250 | .250 | | .049, .065 |
| Standard | 1.500 | 1.620 | .250 | .250 | | .065, .120 |
| Standard | 1.625 | 1.745 | .250 | .250 | | .065 |
| Standard | 1.750 | 1.870 | .250 | .250 | | .065 |
| Standard | 2.000 | 2.120 | .250 | .250 | | .065, .120 |
| Double Bead | 2.000 | 2.120 | .250 | .250 | 1.400 | .065 |
| Standard | 2.125 | 2.245 | .250 | .250 | | .065 |
| Standard | 2.250 | 2.370 | .250 | .250 | | .065 |
| Double Bead | 2.250 | 2.370 | .250 | .250 | .325 | .065 |
| Standard | 2.375 | 2.495 | .250 | .250 | | .065 |
| Standard | 2.500 | 2.620 | .250 | .250 | 1.500 | |
| Double Bead | 2.500 | 2.620 | .250 | .250 | | |
| Standard | 2.750 | 2.870 | .250 | .250 | | .065 |
| Standard | 3.000 | 3.120 | .250 | .250 | | |
| Standard | 3.500 | 3.620 | .250 | .250 | | .065 |
| Double Bead | 3.500 | 3.620 | .250 | .250 | | |
| Standard | 4.000 | 4.120 | .250 | .250 | | |
| Standard | 5.000 | 5.120 | .250 | .250 | | |
| Standard | 6.000 | 6.120 | .250 | .250 | | |

## 5.3.1 EXPANDING DATA



## Figure 10—Expanded Tube

| | MAXIMUM | | SINGLE OPERATION MAXIMUM | |
|---|---|---|---|---|
| **Tube Outside Diameter** | **B Inside or Outside Diameter of Expansion** | | **C Length of Expansion** | **Wall Thickness** |
| 0.750 | 0.750 | ID | | 0.049 |
| 0.750 | 0.930 | ID | 3.00 | 0.049 |
| 0.750 | 1.000 | ID | 1.750 | |
| 1.000 Flex Tube | 0.930 | ID | | |
| 1.000 | 1.000 | ID | 2.250 | .035, .049, .065 |
| 1.000 | 1.125 | OD | 2.250 | 0.065 |
| 1.000 | 1.250 | OD | 1.375 | 0.083 |
| 1.000 | 1.750 | OD | | |
| 1.0625 | 1.000 | ID | | 0.049 |
| 1.125 | 1.124 | ID | | 0.049 |
| 1.125 | 1.300 | ID | | 0.049 |
| 1.125 | 1.160 | ID | | 0.049 |
| 1.250 | 1.500 | OD | | .049, .065 |
| 1.250 | 1.625 | OD | | |
| 1.250 | 1.375 | ID | | |
| 1.250 | 1.750 | OD | | 0.049 |

**Note:**

1. All values shown are in inches.
2. Actual maximum and minimum diameters may vary according to the type of material and bend configuration. These figures are approximate and are intended to be used as general guidelines only. Contact your PAUMAC sales representative for specific information.

EXPANDING DATA (continued)

| | MAXIMUM | | SINGLE OPERATION MAXIMUM | |
|---|---|---|---|---|
| **Tube Outside Diameter** | **B Inside or Outside Diameter of Expansion** | | **C Length of Expansion** | **Wall Thickness** |
| 1.375 | 1.380 | ID | | |
| 1.375 | 1.500 | ID | | |
| 1.500 | 1.500 | ID | | 0.083 |
| 1.500 | 1.520 | ID | 2.000 | |
| 1.500 | 1.750 | OD | 2.000 | 0.065 |
| 1.500 | 2.000 | ID | 3.000 | 0.065 |
| 1.750 | 1.750 | ID | 2.000 | |
| 1.750 | 2.000 | OD | | |
| 1.750 | 2.250 | OD | 2.500 | |
| 1.750 | 2.500 | OD | | |
| 2.000 | 2.125 | OD | 2.250 | |
| 2.000 | 2.250 | OD | 1.500 | |
| 2.000 | 2.500 | OD | | 0.065 |
| 2.000 | 2.530 | ID | | |
| 2.250 | 2.250 | ID | | 0.065 |
| 2.250 | 2.500 | ID | 4.250 | |
| 2.250 | 2.750 | OD | 2.750 | |
| 2.250 | 3.000 | OD | | |
| 2.500 | 2.500 | ID | 3.250 | |
| 2.500 | 2.550 | ID | 2.500 | |
| 2.500 | 2.750 | OD | 3.000 | |
| 2.500 | 3.000 | OD | 4.000 | |
| 2.750 | 2.750 | ID | | 0.083 |
| 2.750 | 3.000 | OD | 3.000 | |
| 3.000 | 3.000 | ID | 2.750 | .065, .083 |
| 3.000 | 3.500 | OD | 3.750 | |
| 3.000 | 4.000 | OD | 4.500 | |
| 3.500 | 3.500 | ID | 3.500 | |
| 3.500 | 4.000 | OD | 4.250 | |
| 3.500 | 4.000 | ID | 3.250 | 0.083 |
| 4.000 | 4.000 | ID | 3.000 | |

**Note:**

1. All values shown are in inches.
2. Actual maximum and minimum diameters may vary according to the type of material and bend configuration. These figures are approximate and are intended to be used as general guidelines only. Contact your PAUMAC sales representative for specific information.

5.3.2 REDUCING DATA

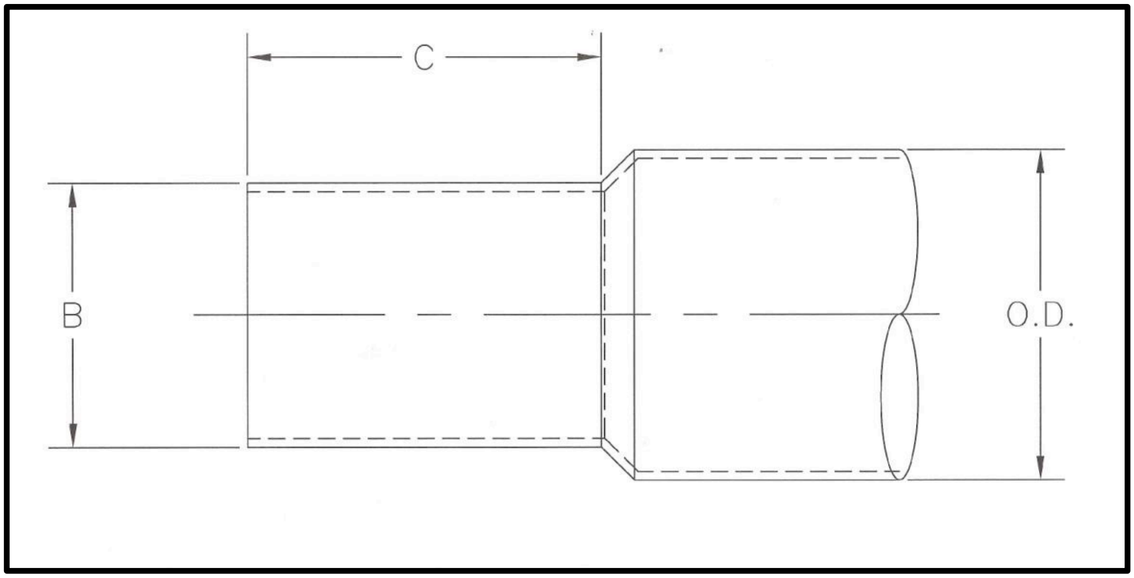



**Figure 11—Reducing or Swaged Tube**

| Tube Outside Diameter | MAXIMUM B Inside or Outside Diameter of Expansion | | SINGLE OPERATION MAXIMUM C Length of Expansion | Wall Thickness |
|---|---|---|---|---|
| 0.750 | 0.625 | OD | | |
| 1.125 | 1.000 | OD | 2.500 | |
| 1.250 | 1.000 | OD | 2.250 | |
| 1.500 | 1.250 | OD | | |
| 1.500 | 1.375 | OD | 2.500 | |
| 1.750 | 1.500 | OD | 3.250 | |
| 2.500 | 2.125 | | | |
| 3.000 | 2.750 | OD | | 0.065 |

**Note:**
1. All values shown are in inches.
2. Actual maximum and minimum diameters may vary according to the type of material and bend configuration. These figures are approximate and are intended to be used as general guidelines only. Contact your PAUMAC sales representative for specific information.

## 5.4 SPECIALTY ENDFORMING

PAUMAC has extensive capabilities producing a wide range of special endforms. Contact our Engineering staff to discuss any special endform requirements.

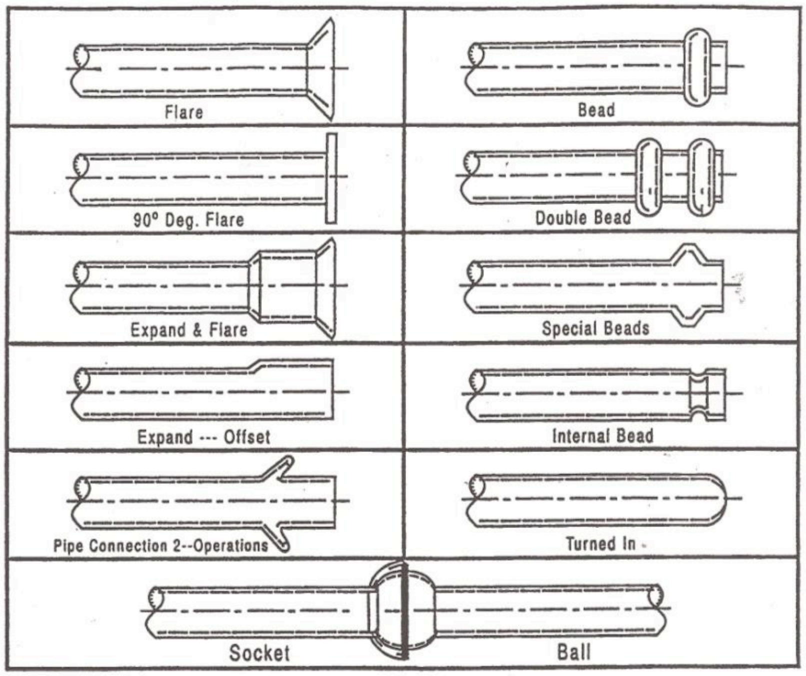



**Figure 12—Specialty Endforms**

# 5. COATINGS

A wide range of corrosion resistant coated tubes can be provided depending upon your particular application. Descriptions of coating which are commonly used for formed tubes are as follows:

## 5.1. Zinc Plating

Zinc Plating has been used on tubing for many years. There are a variety of different plate thickness, colors, and supplementary treatments which are available. In addition, other types of electroplating are possible. Contact your PAUMAC sales representative for further information.

## 5.2. High Temperature Painting

Though painting is a technique that continues to be a widely used method of coating tubing, it is being increasingly replaced by more modern techniques. The enactment of environmental protection laws and the increase in the cost of petroleum products has caused the coating industry to reformulate its products and change its application technology. The newer techniques, such as powder coating, are both cost competitive and superior in quality to painting. A salt spray resistance of 100 hours is normal for painted tubes.

### 5.3. Powder Coating

Powder Coating is a recently developed technique which works very well on formed tubes. It is replacing black enamel as a cosmetic coating due to its superiority in durability, uniformity, and corrosion resistance. Powder is really paint in solid rather than liquid form. The powder is applied to the part by electrostatic spray. The tube is given a negative charge and the powder particles are given a positive charge; the result is that the tube attracts the powder, just like two magnets. The part is then heated, often in an ultraviolet oven, and the powder is converted to a continuous and uniform film. Powder coated tubes have successfully passed salt spray tests in the 200 hour range.

### 5.4. Chrome Plating

Chrome plating of cold rolled steel parts is frequently used on exposed exhaust tubing. The chrome plating provides a bright mirror finish and enhances vehicle appearance. High quality forming and installation are required to avoid surface irregularities which can lead to external rust. Corrosion from the inside of the product can still occur. Where corrosion is a concern, stainless steel tubing may be selected to provide exceptional corrosion resistance.

## 6. TUBING TERMINOLOGY

| | |
|---|---|
| Annealing: | Also see Heat Treatment. A thermal treatment to soften metal by removal of stress resulting from cold working or by coalescing precipitates from solid solution. Performed on all aluminum alloys at approximately 650 degrees Fahrenheit soaking temperature. |
| Carbon Drawing: | A steel consisting of essentially iron, carbon, manganese, and silicon. Carbon steel has no minimum content required for aluminum, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium or other element added to obtain alloying effect. Small quantities of certain residual elements are considered incidental. |
| Corrosion: | Chemical or electrochemical deterioration of a metal or alloy.<br><br>Galvanic Corrosion: Corrosion associated with the presence of two dissimilar metals in solution (electrolyte). In principle, it is similar to bath-type plating in the sense that the anode surface has lost metal (corroded).<br><br>Inter-granular Corrosion: Occurs preferentially along the grain boundaries of the alloy.<br><br>Pitting Corrosion: Non-uniform corrosion usually forming small cavities in the metal surface. |

Corrosion Resistance: The ability to resist attack by corrosion.

Cut Length: Refers to tubing ordered to a specified length and permitting a tolerance of a standardized fraction of an inch over but nothing under the specified length.

DBB: Distance Between Bends.

Dimension: OD- Outside diameter. Specified in inches and fractions of an inch, or inches and decimals of an inch.

ID- Inside diameter. Specified in the same units as the OD.

Mean diameter- The average of two measurements of the diameter taken at right angles to each other.

Wall- Wall thickness of gage. Specified in either fractions or decimals of an inch or by a ―wire gage‖ number. In the United States, the most common gage used for tubing is the ―Birmingham‖ wire gage, designated ―BWG‖.

Nominal- The stated value of the OD, ID, or wall dimension as specified by the customer.

DOB: Degree of bend.

Electric Resistance Welded Steel Tube (HREW, CREW): Tubing made from strip, sheet or bands by electric resistance heating and pressure, the strip being part of the electrical circuit. The electric circuit, which may be introduced into the strip through electrodes or by induction, generates the welding heat through the electrical resistance of the strip.

As Welded Hot Rolled- ERW tubing exhibiting the pickled or shot blasted surface of hot rolled strip (HREW).

As Welded Cold Rolled- ERW tubing exhibiting the surface of cold rolled strip. (CREW)

As Drawn- Tubing is un-heat-treated, cold drawn tubing and has a scale free cold drawn surface.

Flash-in Tubing- Is welded from the ID flash formed during the welded operation. It can be furnished in either the as-welded, sunk or heat-treated condition.

Flash-removed- Welded tubing from the ID flash formed during the welding operation has been removed by some mechanical method. It can be furnished in either the as-welded, sunk or heat-treated condition.

Elongation: The amount of permanent stretch, usually referring to a measurement of a specimen after fracture in a tensile test. It is expressed as a percentage of the original gage length.

Expansion: A mechanical enlarging of the cross sectional area of a metal, performed hot or cold by forging, pressing, or hammering.

Flash removed: See Electric Resistance Welded Tubing.

Gage, Gauged: A measurement of thickness. There are various standard gages such as United States Standard Gage (USS), Galvanized Sheet Gage (GSG), or Birmingham Wire Gage (BWG).

Grain Size: A measurement of the size of individual metallic crystals usually expressed as an average. Grain size is reported as a number in accordance with procedures described in ASTM grain size specifications.

Hardness: A measure of the degree of a material's resistance to indentation. It is usually determined by measuring resistance to penetration, by such tests as Brinell, Rockwell, and Vickers.

Heat Treatment of Steel: A combination of heating and cooling operations applied to a metal or alloy in the solid state to obtain desired conditions or properties. Heating for the sole purpose of hot working is excluded from the meaning of this definition. See the various types below:

Age Hardening- An aging process that increases hardness and strength. Ordinarily, ductility decreases. Age hardening usually follows rapid cooling or cold working. Hardening is a result of a precipitation process, often sub-microscopic, which occurs when a supersaturated solid solution is naturally aged at atmospheric temperature or artificially aged in some specific range of elevated temperature. Aging occurs more rapidly at higher temperatures. (Synonymous with precipitation hardening)

Air Hardening- Heating a suitable grade of steel with high harden ability above the critical temperature range and then cooling in air for the purpose of hardening.

Anneal- The annealing process is a combination of a heating cycle, a holding period and a controlled cooling cycle. Annealing is used to obtain a variety of results, among which are: to soften or alter the grain structure of steel, to develop formability, machinability, and required mechanical properties, or to relieve residual stresses. The temperatures and cooling rates used depends on which results are desired. It is generally desirable to use more specific terms in describing the annealing.

Bright Anneal- Carried out in a controlled furnace atmosphere, so that surface oxidation is reduced to a minimum and the tube surface remains relatively bright.

Dead Soft Anneal- A heat treatment applied to achieve maximum softness and ductility.

Soft Anneal- When maximum softness and ductility are required are required without charge in grain structure, tubing should be ordered soft annealed. This process consists of heating to a temperature slightly below the critical temperature and cooling in still air. Usually performed in 1250 degrees/ 1350 degrees Fahrenheit range for carbon steel.

Heat Treatment of Aluminum: Aluminum alloys are divided into two distinct groups based upon their reaction to thermal treatment. Heat-treatable tubing alloys (2000, 6000 and 7000 series) can be strengthened by thermal treatment and subjected to repeated heat treatment cycles without harmful effects. Non-heat-treatable tubing alloys (1000, 3000, and 5000 series) can be strengthened only be cold working. Applicable terms are listed below:

Annealing- A thermal treatment to soften metal by removal of stress resulting from cold working of by coalescing precipitates from solid solution. Performed on all aluminum alloys at approximately 650 degrees Fahrenheit soaking temperature.

Kilned Steel: Steel deoxidized with an agent such as silicon or aluminum to reduce the free oxygen content so that no harmful reaction occurs between carbon and oxygen during solidification.

Mandrel:

1. A device used to retain the cavity in hollow metal products during working.
2. A metal bar around which other metal may be cast, bent, formed, or shaped.

Mechanical Properties: Those properties of a material that reveal the elastic and in-elastic reaction when force is applied, or that involve the relationship between stress and strain—for example, the modulus of elasticity, hardness, tensile strength and fatigue limit. These properties have often been referred to as ―physical properties‖, but the term ―mechanical properties‖ is correct.

Mechanical Tubing: Used for a variety of mechanical and structural purposes, as opposed to pressure tubing, which is used to contain or conduct fluids or gases under pressure. It may be hot finished or cold drawn. It is commonly manufactured to consumer specifications covering chemical analysis and mechanical properties.

Ovality: The difference between the maximum and minimum outside diameters of any on cross section of a tube. It is a measure of deviation from roundness.

Physical Properties: Those properties not specifically related to reaction to external forces. These include such properties as density, electrical resistance, co-efficient of thermal conductivity.

POB: Position of Bend (also rotation).

Pressure Tubing: Tubing produced for the purpose of containing or conduction of fluids or gases under pressure.

| | |
|---|---|
| Rockwell Hardness: | See Hardness. |
| Scale: | An oxide of iron which forms on the surface of a wrought metal product. |
| Soft Anneal: | See Heat Treatment. |
| Specification | A document defining the measurements, tests, and performance requirements to which a product must conform—typically covering chemistry, mechanical properties, tolerances, finish, reports, marking and packaging. |
| Strip: | A flat-rolled steel product which serves as the raw material for welded tubing. |
| Swaged: | A mechanical reduction of the cross sectional area of a metal, performed hot or cold by forging, pressing, or hammering. |
| Tempering: | Re-heating quenched or normalized steel to a temperature below the transformation range (lower critical) followed by any desired rate of cooling. Tempering reduces brittleness and develops the desired harness, structure, and properties. |
| Tensile Strength: | The maximum load per square inch of original cross- sectional area carried during a tension test to failure of the specimen. This term is preferred over the formerly-used ultimate strength. |
| Tolerance: | Permissible variation. |
| XYZ: | Cartesian Coordinate System. |
| Yield Strength: | The stress at which a material exhibits a specified deviation from proportionality of stress and strain. An offset of 0.2% is most frequently used. |