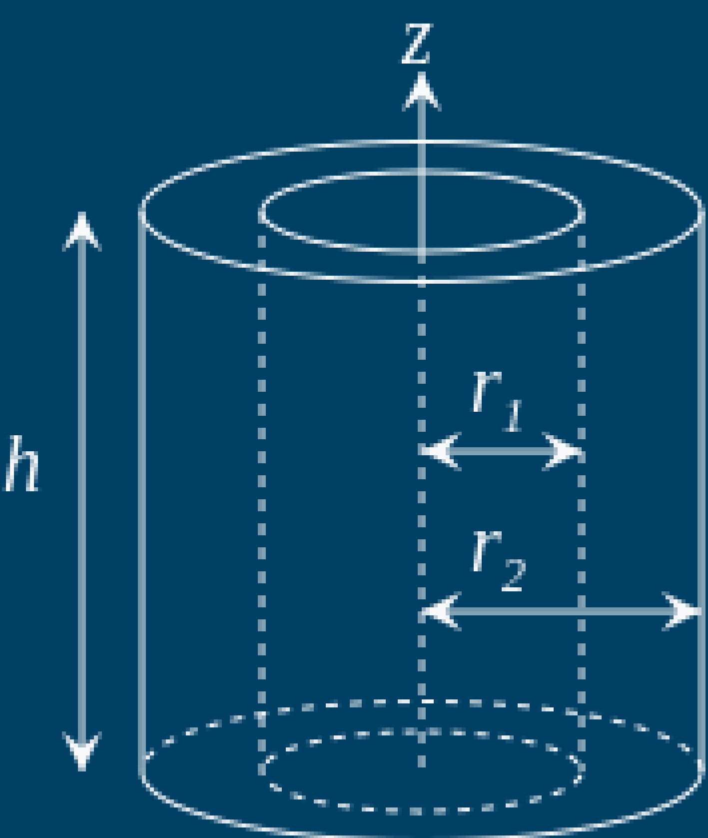
TUBE BENDING DESIGN GUIDE FOR DESIGN ENGINEERS



McHone Industries
Contract Metal Manufacturing
Established 1974

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Tube design can be messy, especially when you add bending to the mix. This guide provides essentials and tips for designing an optimal, affordable tubular metal product.

For your convenience, we've also included basics on:

- How to keep your design within budget
- Common terms
- Useful equations

If you get to the end and we haven't answered your questions, we can address them personally by email or phone.

McHone Industries has been in the tube production and fabrication business for over 40 years. We're happy to provide expert assistance for any tubing project.

Thank you for downloading this guide. If you find it helpful, please share it with your peers!

How to Keep Your Design Within Budget

Costs increase when you add bend quantities, specify complex bends, specify different radii within a single design, or design a part that requires other extra care during fabrication.

While some projects have unique requirements, many designs can be optimized for affordable manufacturing. Your specified manufacturer should provide **value engineering services*** to make this happen.

The lowest costs will always come from working with your manufacturer's pre-existing capabilities and services.

Beyond that, your tube bending specifications rely on two factors:

1. **End use function** - how your tube needs to fit into the space, how strong it needs to be after bending, whether it's structural or other tubing
2. **Aesthetic quality** - does the final product need to be attractive? This will affect tolerances and bend approach

*We provide a free 30-minute design consultation if you require assistance.

Common Terms

1. **Centerline Radius (CLR, neutral line)** - the line through the tube where no compression or stretching occurs during bending
2. **"D" of Bend** - CLR divided by tube outer diameter
3. **Outer Diameter (OD)** - length and width of the tube from the outside of the wall rather than the inside
4. **Wall Thickness (WT)** - the thickness of the tube's wall, commonly in inches or millimeters
5. **Ovality** - difference between max OD & min OD in a given section
6. **Gauge** - the thickness of the tube's wall, commonly a standard integer. (e.g. 0.049 inch wall thickness = 18 gauge)
7. **Inside Bend Radius (intrados)**
8. **Outside Bend Radius (extrados)**
9. **Bend Angle** - complementary angle of bend. If a tube is bent to 45°, it's 45° complementary, or 135° included bend angle.
10. **XYZ Method** - Common general tube shape defining method, based on three dimensional mathematical planes.
11. **Bend Data** - Common method of defining tube shapes when bending is involved. Complements XYZ measurements. Uses three elements to define shape: DBB, DOB, and POB
    a. **Distance Between Bends (DBB)** - distance between two *tangent points*, where a straight section begins to curve and the bend starts or finishes.
    b. **Degree of Bend (DOB)** - number of bend angle. Causes the most practical problems.
    c. **Plane of Bend (POB)** - Rotational relationship between one bend plane and the next. Also called "phase angle" or "twist." Defined in degrees.

Useful Equations

1. **"D" of Bend:**
   a. CLR / OD

2. **Inside Diameter:**
   a. OD - (WT x 2)

3. **Inside Radius:**
   a. CLR - (OD / 2)

4. **Outside Radius:**
   a. CLR + (OD / 2)

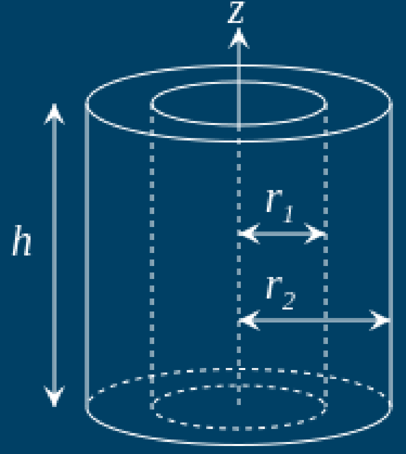
5. **Wall Factor:**
   a. OD / WT

6. **Extrados Wall Thinning %** (after bending):
   a. (Outside Radius - CLR) / Outside Radius

7. **Percentage Elongation at Arc of Bend** (rule of thumb):
   a. (Outside Radius / CLR) - 1

8. **Ovality**
   a. Max OD - min OD

Designing for Tube Bending



Design Must-Haves

1. **Material identifier** - with OD and wall thickness
2. **Radius of bend** - decided by the space the part fits in, dies available
3. **Bend location**
4. **Bend angle** - number of degrees; greatly affects raw material calculations
5. **Length of bend** - equation for length of arc, based on bending radius through centerline
    a. **L = 0.01745ur**
        i. L = length of bend, in.
        ii. u = angle of bend, degrees
        iii. r = radius of bend, in
        iv. The constant is a conversion from radians to degrees
6. **Raw material length** - after determining location of bends, radii, angle; straight stock
7. **Assign final part dimensions** with appropriate tolerances - tighter tolerances mean higher costs, longer lead times, more scrap

Design Tips

1. Keep bend CLR less than 6”, and at least 2 x OD
2. If your bend is less than 2 x OD, specify mandrel bending to prevent collapse
3. Keep at least 2 x OD between bends to allow room for the clamp
4. Avoid crossing the tube over itself
5. Avoid bends greater than 90° where possible
6. Dimension to the intersection of tube CLRs and end points
7. Use separate tolerances for accuracy of the end point and intermediate sections
8. ABSOLUTE MINIMUM radii are approximately the OD of the tube (but minimum radii are expensive to bend)
9. Thicker tube walls allow for tighter bend radii
10. Use a larger bend radius where possible

Materials

Some materials handle bending better than others.

Stainless steel handles bending well versus mild steel. It has a higher percentage of elongation, making it easier to bend on tight radii.

However, stainless steel costs more than mild or galvanized steels. While stainless steel, copper, or aluminum may have better properties overall, your application may not require material quality beyond mild steel.

ASTM types of steels:

- Iron, Nickel Alloy/Heat Resistant Nickel Alloys and High Silicon Steel
- Structural and Constructional Steels
- Stainless Steels
- Castings
- Coated Steels
- Ferro Alloys, Others

Best Types of Aluminum for Bending:

- 3003
- 5052
- 6061

Types of Other Metals:

- Type K Copper
- Type L Copper
- Type M Copper
- DWV Copper
- ACR Copper
- OXY/MED Copper
- 272 Brass
- 330 Brass
- 443 Brass

Sizing

Standard tube sizes offer a number of benefits:

- Easier to bend
- Material readily available
- No minimum batch order charges
- Tooling available - custom tooling starts around $2,000
- Faster response
- Quick prototyping
- Shorter lead times

Most standard tubing ranges from ⅛" OD to 3" OD. Here is a full guide to standard tube sizing.

Fabrications

- Beading
- Flaring
- Expanding
- Flattening
- Reducing
- Welding
- Brazing
- Roll Bending
- Heat Treating
- Sizing

Tube Shapes

Modern manufacturing makes any tube shape possible (if you're willing to pay for it). Here are some of the most common standard and nonstandard shapes.

- **Round**
- **Square**
- **Oval**
- **Triangle**
- **Rectangle**
- **Rounded Rectangle**
- Hexagonal
- Octagonal
- Square Inverted Corner
- Rectangle Inverted Corner
- Rectangle Inverted Corner with Radius
- D-Shape Oval/Semi-Rectangle/Half Round
- Single/Double Round
- Double "D" Shape
- Tear Drop
- Peanut Shape
- Grooved Round Shape

Similar to tube sizing, standard tube shapes are more affordable, readily available, and provide shorter lead times.

Bend Shapes

Bend shape is only limited by what your manufacturer can (or will) accommodate. However, the most common and affordable bends are:

- "L" bend
- "U" bend
- "S" bend
- Coil bend
  - Helical, double helical
  - Box-type, box-type return
  - Flat spiral, flat spiral return, conical
  - Flat return, flat return collapsed
- Compound bend
  - No straight between tangents
  - Tangents overlap on bends
  - Endless design possibilities
- Compound multi-plane bend
  - Tube shaped using all three dimensions (X, Y, Z)

Quantities of Bends

More bends = higher costs and lead times.

The same goes for multiple angles and radii.

Some bends may be unnecessary for your product. Your manufacturer may be able to tweak your design to decrease bend quantities and save you time and money.

If you require multiple bends, follow these guidelines:

- Keep enough distance between bends to allow for clamp
- Specify compression bending if your bends are symmetrical

Tolerances

In general, tighter tolerances mean a more expensive project.

Envelope Tolerance - the zone around the tube that the tube should not intrude upon; a theoretical casing of allowable error. Generally = diameter of the max material condition of the tube plus 2 x allowed tolerance.

Linear Tolerance - allowable deviation at either end of the tube

Deformations

- Hump - maximum height of hump
- Kink - maximum depth of kink
- Wrinkle - average depth, crest to valley

Ovality

Wall Thinning

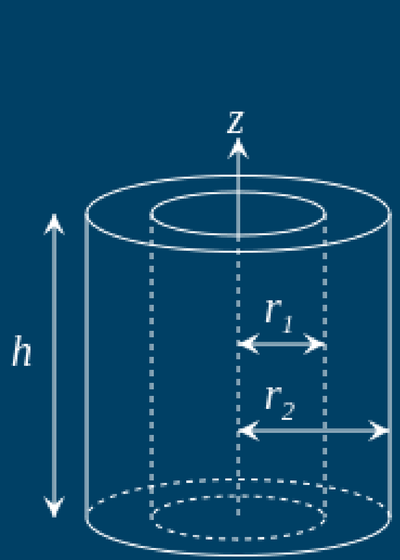
Radii

The size of your radii will determine the type of bending.

Guidelines:

1. **Standard draw bend radius = 3 x tube diameter.** This will avoid rupturing or tearing your material - tighter radii are more likely to cause structural issues.
2. Avoid bends greater than 180°
3. Keep radii consistent throughout your assembly if possible - multiple radii quickly inflate costs

Types of Tube Bending



Types of Bending

1. Ram/Press Bending

Similar to a vertical press.

- Common for square tubing
- Least expensive
- Least amount of control over bend quality
- Not good for aesthetic or precise bending

2. Roll Bending/Interpolation Bending

Large radii = push or roll bending (7 x diameter)

- Common for large components
- Large radii
- Can produce continuous bends

3. Compression Bending

- Common for symmetrical bend projects
- Good for larger radii

4. Rotary Draw Bending

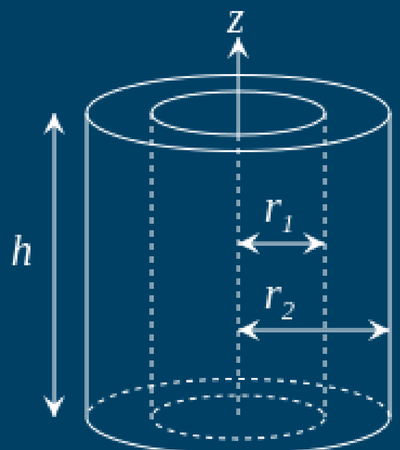
Small or large radii. Use mandrel for full radius, no mandrel for collapse

- Good for tight radii
- Complex parts
- Cannot create continuous bends

5. Hand Bending

- Most appropriate option for complex multi-bend projects
- Small diameter tubing

Potential Design Issues



Springback Compensation

Springback is the tendency of a metal to return to its original shape after forming. It's more common with hard metals and smaller centerline radii.

Some metals accept bending nicely. Others need some design leeway to account for springback.

304 Stainless Steel: **2 - 3 degrees**

Mild Aluminum: **1.5 - 2 degrees**

Cold-Rolled Steel: **0.75 - 1 degrees**

Hot-Rolled Steel: **0.5 - 1 degrees**

Copper: **0.00 - 0.5 degrees**

Brass: **0.00 - 0.5 degrees**

Weld Seam

You will most likely use welded tubing for your project - it's affordable and just as strong as seamless tubing.

The **weld seam** must be taken into consideration for your design.

- Most commonly, the weld seam is located on the CLR in round tubing.
- If appearance is your biggest concern, the weld seam should be specified on the "back" of the bend.
- If you choose a tubing shape with corners, the seam should not be in a corner. There are rare exceptions to this guideline. (e.g. one tube telescoping inside another)

Tube Elongation

Tube elongation is thinning of the tube's outside radius, which stretches during bending. As the metal resists the bend, the outside radius caves in and distorts. This produces *ovality*, and you lose the original round shape of the tube.

Elongation as a material property refers to how far the metal can stretch before it fractures.

The smaller your "D" of bend (tighter bend radius), the more the metal's elongation is tested. Specifying larger radii can reduce this effect.

Is your tube design optimized for bending?

Or, are you struggling with a design aspect? Can't seem to meet your purchaser's budget requirements?

We might be able to help. Schedule a free 30-minute design consultation to get your project in motion.

McHone Industries strives to provide value, creative engineering solutions, and high-quality all-in-one manufacturing every day.

Give us a call to find out more.

McHone Industries
Contract Metal Manufacturing
Established 1974