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July, 1993

Parker
FluidConnectors

Total Tubing System Concept

Section 1

Principles of Tube Line Fabrication

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Notes on Tube Line Fabrication

Most, if not all, hydraulic systems require some form of tube line fabrication in addition to fitting assembly. Proper fabrication and assembly will contribute to the overall efficiency, reliability and general appearance of the system.

This section will outline some general principles and techniques in Tube Bending, to help you achieve a good quality installation. Use good quality tools such as Parker's Fabrication Tools for a good quality job.

Parker
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Measuring and Marking Tubing

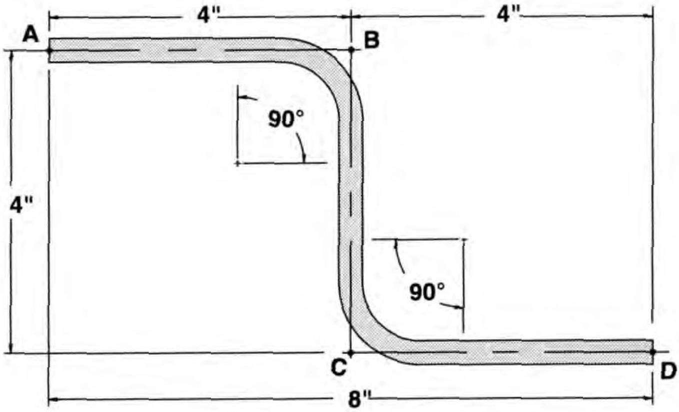

Figure 1 Accurate measurements coupled with exact angles must result in a tube line that will fit at A & D.

Measure Exactly - Bend Accurately
These are the two most important rules which must be observed when fabricating a tube line. (Figure 1)

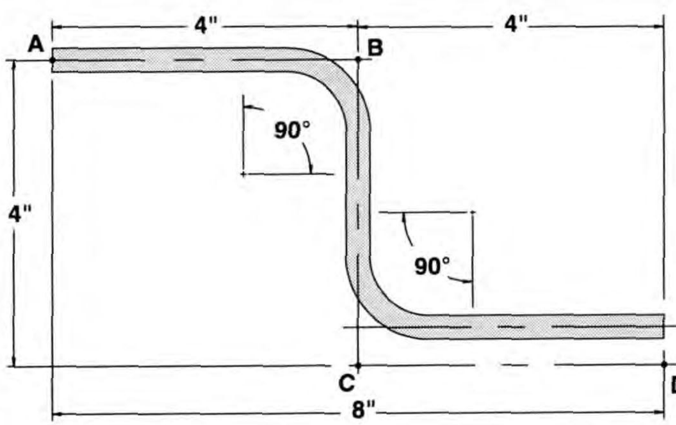

Figure 2 Measuring error on second leg B-C results in tube line that cannot fit at point D.

You Must Always Measure Exactly and Bend Accurately.
Exact Measurement is required to insure that you obtain the desired distance between bends. If you do not measure exactly, the tube line will not fit. (Figure 2)

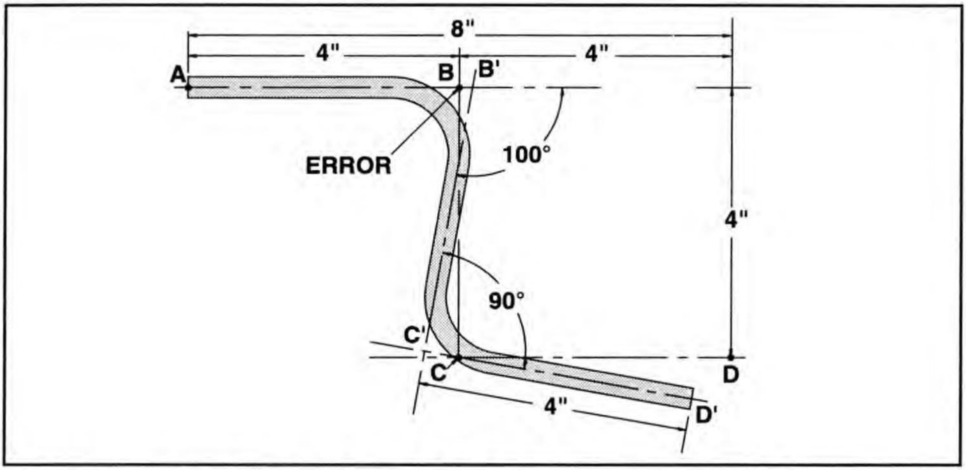

Figure 3 Bending error at angle B results in tube line that cannot fit at point D.

Accurate Bending

Accurate Bending is necessary to achieve the exact angles required for the tube line. If you do not bend accurately, the tube line will not fit. (Figure 3)

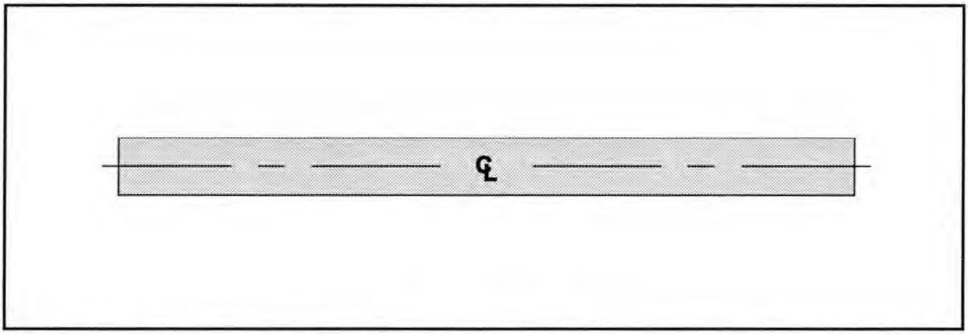

Figure 4 Use tube centerline as basis for measurements.

Tube Centerline Basis for Measurement

Use the centerline of the tube as the basis for all tube line measurements. (Figure 4) Always measure from the centerline except for the first bend which is measured from the end of the tube. On most benders the edge of the radius block is at the centerline of the tube.

You Control Accuracy

Remember, only you can control the accuracy of your work. Use good, careful workmanship at all times.

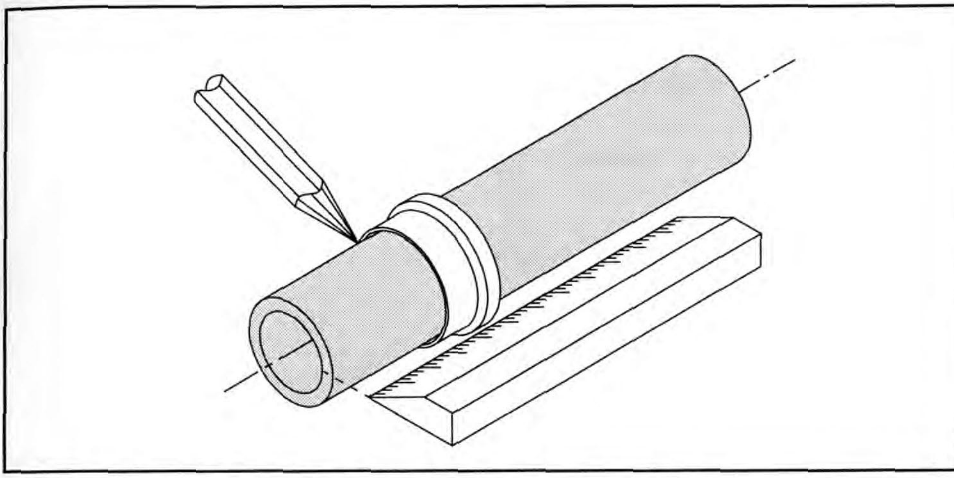

Figure 5 Use Ferrule or Sleeve as a guide for marking around the tube.

Marking the Tube

Whenever you make a mark on tubing, use a sharp pencil or fine felt tip marker. Use a ferrule or sleeve as a guide for completing measurement marks all the way around the tube so that the mark is always visible. (Figure 5) Don't use grease pencils or crayons as these make too wide a line which can easily affect accuracy.

Never use a sharp tool to scratch marks onto tubing. Scratches create points where corrosion or stress concentration can ruin or dangerously weaken the tube.

Best Way to Measure

For maximum accuracy, measure and bend exactly for each individual bend in the tubing line. We recommend the practice of Measure and Bend, Measure and Bend, etc.

Positioning Tube in Bender

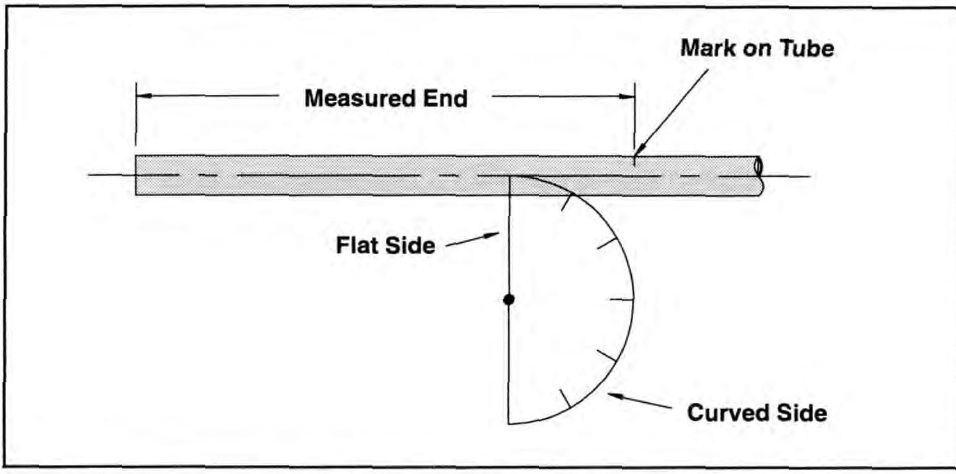

Figure 6 Position measured end of tube to flat side of radius block.

Rules for Positioning Tube in Bender

These rules will apply for almost any bender.

Consider the bender's radius block as a semi-circle and determine which side is *the flat vs. the curved side.* Always *make tube measurements or position the* measured end of the tube to the flat side of the radius block. (Figure 6)

A line which is tangent to the desired angle mark on the radius block and which intersects the measurement mark at the centerline of the tube is then used to control the distance between the end of the tube, or centerline of a previous bend, and the new bend.

Positioning Length Mark for Desired Angle of Bend

Regardless of the bend radius of the bender, (bend radius is the distance from the centerpoint to the edge of the radius block) the length mark should always be positioned tangent to the desired angle except for 180° bends. (For 180° bends, position the mark similar to 90° bends).

In figures 8, 9 and 10, origin indicates the point where straight line measurements were taken to and also where the straight centerline of the bent tube will appear to intersect. In the case of 180° bends (which are positioned similar to 90° bends) it's the desired turn around point that determines the position of the tube in the bender.

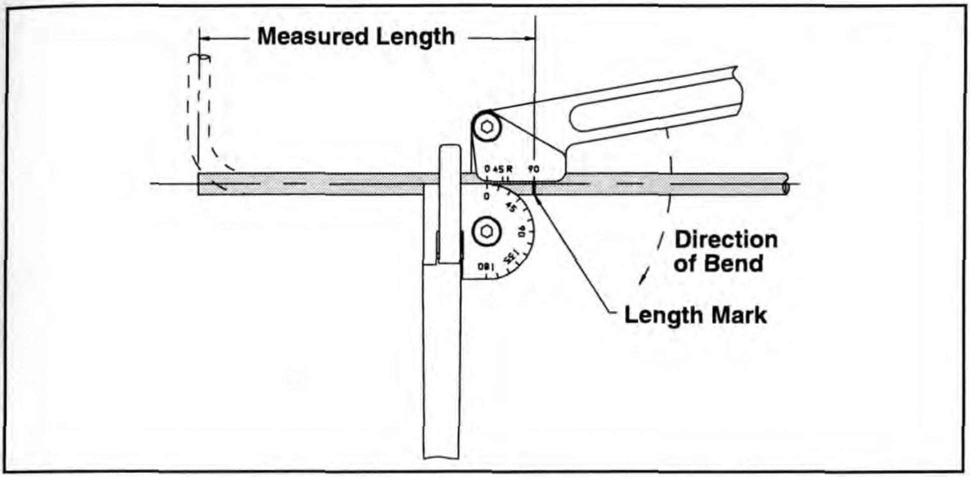

Figure 7 Tube positioned in hand bender for a 90° bend.

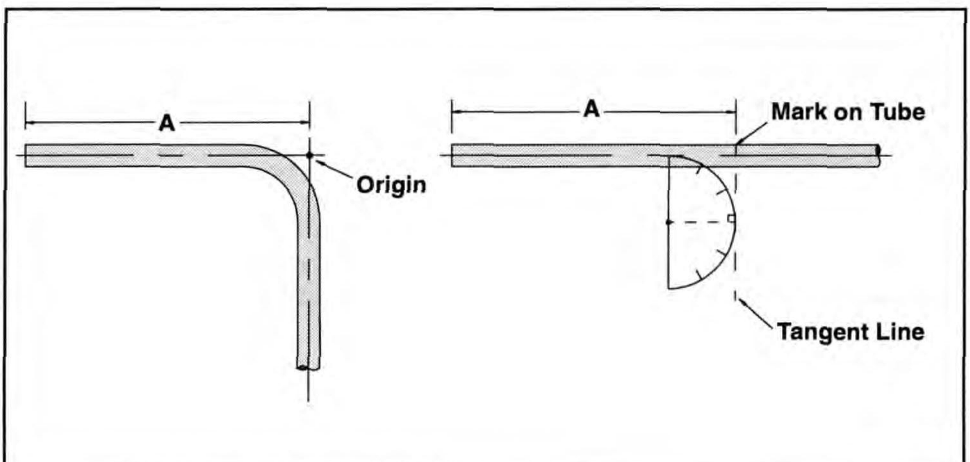

Figure 8 Positioning tube in bender for a 90° bend.

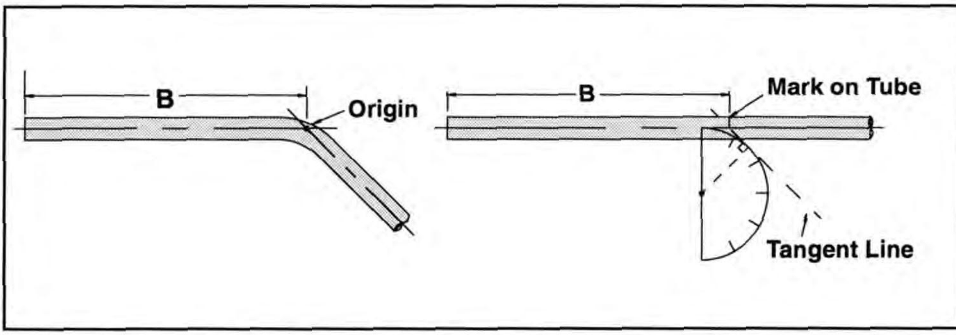

Figure 9 Positioning tube in bender for bend angles less than 90°

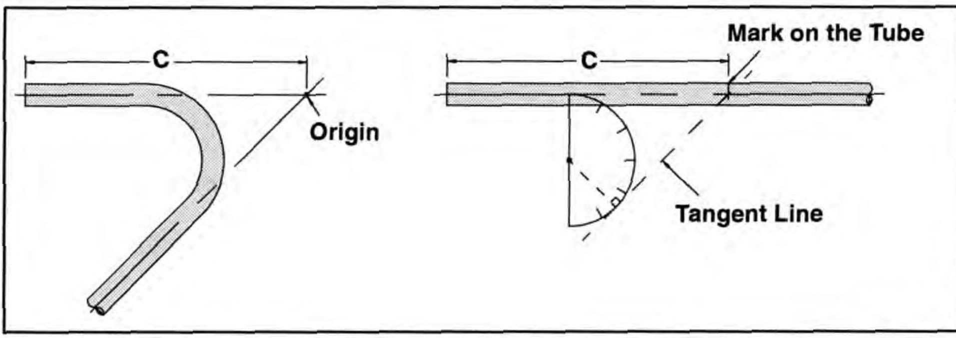

Figure 10 Positioning tube in bender for bend angles greater than 90°.

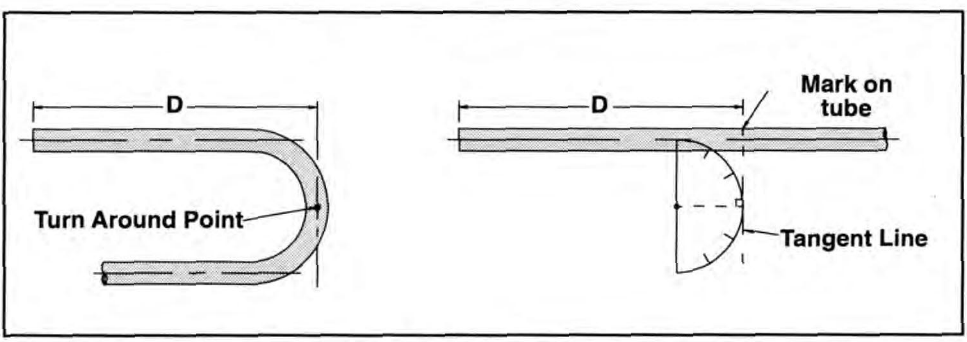

Figure 11 Positioning tube in bender for 180° bend.

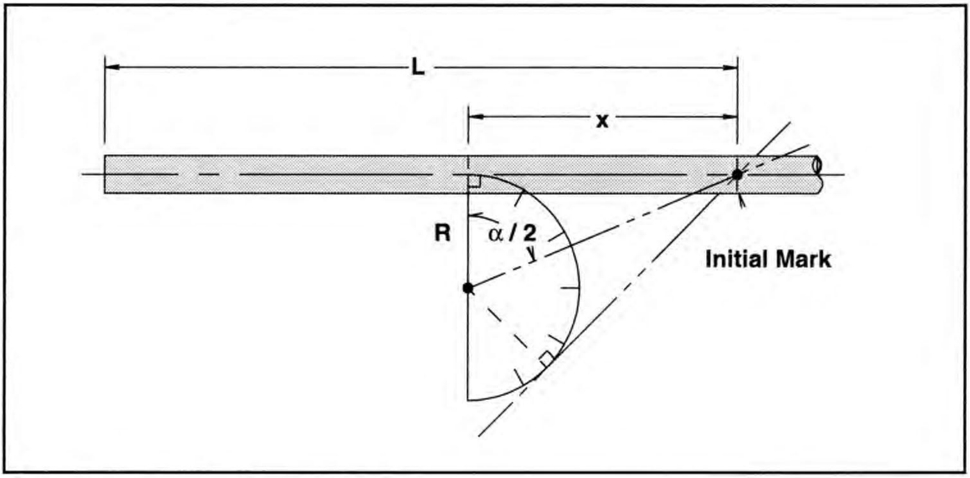

Figure 12 Alternate positioning method.

Alternate Positioning Method (from Calculations)
There may be instances when the radius block is not marked off in degree increments or some other method of positioning may be desirable. Positioning based on centerline measurements is possible after a trigonometric calculation.

First of all, mark the tube similarly to the previous method. (Figure 12) Secondly, calculate for x using the following formula:

$$x = R \tan \left(\frac{\alpha}{2}\right)$$

where R = bend radius of block (usually indicated or easily determined)

α = desired angle of bend

Mark off the distance x back from the initial mark and position this new mark at the zero mark of the radius block (zero mark is usually indicated or can be easily determined). Proceed now to make your bend to the desired angle and be assured that the center-lines will intersect at the origin.

Compensating for Springback

Test a piece of the material before you start fabricating a line to see how much it springs back. Different materials behave differently.

Overbend by the amount of springback. For example, if the material springs back 3° on a 90° bend, bend to 93° to secure a finished 90°.

Remember, it is always better to underbend slightly. You can always bend a little more if needed, but it's almost impossible to remove or straighten a bend, especially with large, heavy wall tubing.

Changing Plane of Bend

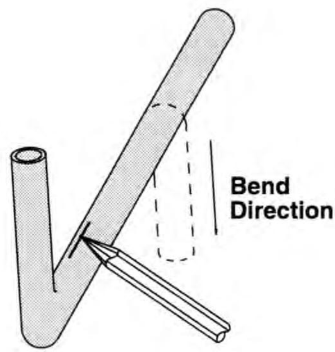

Figure 13 Keeping track of changes in plane.

Keep Track of Changes in Plane
Benders bend in only one direction. Changes in plane are accomplished by rotating the tubing in the bender. To insure that the tubing is correctly placed for the desired change in plane, a reference mark on the tube is very helpful.

One method for keeping track of changes in plane is to use a longitudinal or lengthwise bend direction mark. (Figure 13) Put the mark on the side opposite the direction in which you wish to bend. When you put the tube in the bender, center the mark face up in the groove of the radius block. This will insure that you bend in the correct direction. It also gives you a reference mark in case you must leave your work unfinished.

Determining Tube Gain

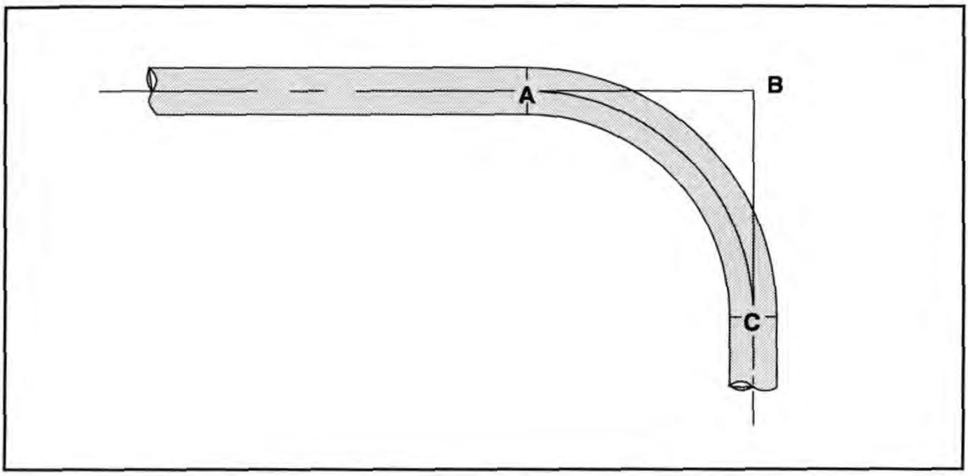

Figure 14 Apparent tube stretch occurs because AC is shorter than AB + BC.

Apparent Tube Stretch or Pickup or Gain
When bent, tubing seems to stretch or pick up length. This is because it takes a curved shortcut across the inside of the angle. (Figure 14)

Rule of Thumb
A good "rule of thumb" for most standard tubing materials and radius blocks is that the tubing will stretch approximately one tube diameter for each 90° bend.

Always try to bend in the same direction - away from the original starting end. If you reverse the direction of bending (bending towards instead of away from the original starting end) you will "trap" the stretch. Thus, if you unknowingly make a reverse bend of 90°, you will trap approximately one tube O.D. and increase your length between bends by that amount.

If bend direction must be reversed, subtract one tube O.D. from the measured length for a 90° bend.

Calculation
The above rule of thumb is only an approximation. The amount of stretch or tube gain is related to the bend radius of the radius block being used and also the angle of bend being made.

Tube Gain for 90° Bends
Tube gain for 90° bends are shown in table 1 and also may be calculated from:
Gain = Leg AB + Leg BC - Arc AC

$$= R + R - \frac{2\pi R}{4} = 0.4292 \times R$$

where R = bend radius of bender.

Table 1 - Tubing Gain vs. Radius Block Size for 90° Bends

Tube O.D. (IN)	SAE Dash Size	Radius of Block (IN)	90° Tube Gain (IN)
1/8	2	3/8	.16
3/16	3	7/16	.188
3/16	3	9/16	.241
1/4	4	9/16	.241
1/4	4	3/4	.32
5/16	5	11/16	.29
5/16	5	15/16	.40
5/16	5	1	.43
3/8	6	15/16	.40
3/8	6	1-1/8	.48
3/8	6	1-1/4	.54
1/2	8	1-1/4	.54
1/2	8	1-1/2	.64
1/2	8	2	.86
5/8	10	1-1/2	.64
5/8	10	1-7/8	.80
5/8	10	2-1/2	1.07
5/8	10	3	1.29
3/4	12	1-3/4	.75
3/4	12	2-1/4	.96
3/4	12	3	1.29
3/4	12	3-3/4	1.61
7/8	14	2	.86
7/8	14	2-5/8	1.13
7/8	14	3-1/2	1.5
7/8	14	3-3/4	1.61
1	16	3	1.29
1	16	3-1/2	1.5
1	16	4	1.72
1-1/8	18	3-1/4	1.39
1-1/8	18	3-3/8	1.45
1-1/8	18	4	1.72
1-1/4	20	3-3/4	1.61
1-1/4	20	5	2.15
1-1/2	24	4-1/2	1.93
1-1/2	24	5	2.15
1-3/4	28	7	3.0
2	32	8	3.43

Tube gain for angles up to 90° may also be calculated by multiplying the appropriate gain factor from Table 2 by the bend radius. Ex. 55° bend angle with a 3" radius block would result in a gain of .0812 x 3 = 0.24"

Table 2 — Gain Factors for Angle up to 90°

	----	1°	2°	3°	4°	5°	6°	7°	8°	9°
0°	.0000	.0000	.0000	.0000	.0000	.0000	.0001	.0002	.0002	.0003
10°	.0005	.0006	.0008	.0010	.0013	.0015	.0018	.0022	.0026	.0031
20°	.0036	.0042	.0048	.0055	.0062	.0071	.0079	.0090	.0100	.0111
30°	.0126	.0136	.0150	.0165	.0181	.0197	.0215	.0234	.0254	.0276
40°	.0298	.0322	.0347	.0373	.0400	.0430	.0461	.0493	.0527	.0562
50°	.0600	.0637	.0679	.0721	.0766	.0812	.0860	.0911	.0963	.1018
60°	.1075	.1134	.1196	.1260	.1327	.1397	.1469	.1544	.1622	.1703
70°	.1787	.1874	.1964	.2058	.2156	.2257	.2361	.2470	.2582	.2699
80°	.2819	.2944	.3074	.3208	.3347	.3491	.3640	.3795	.3955	.4121
90°	.4292									

Tube Gain for Bends Between 0° and 180°
Tube gain for bends up to 180° may be calculated from the following:

$$\text{Gain} = 2R \text{ Tan } \left(\frac{\propto}{2}\right) - \frac{2 \pi R \propto}{360}$$

where: R = bend radius
∝ = angle of bend
π = 3.1416

Table 3 — Tangent For Half Angles up to 89°

----	1°	2°	3°	4°	5°	6°	7°	8°	9°	
0°	0	.017	.035	.052	.070	.087	.105	.123	.141	.158
10°	.176	.194	.213	.231	.249	.268	.287	.306	.325	.344
20°	.364	.384	.404	.424	.445	.466	.488	.509	.532	.554
30°	.577	.601	.625	.649	.675	.700	.727	.754	.781	.810
40°	.839	.869	.900	.933	.966	1.00	1.04	1.07	1.11	1.15
50°	1.19	1.23	1.28	1.33	1.38	1.43	1.48	1.54	1.60	1.66
60°	1.73	1.80	1.88	1.96	2.05	2.14	2.25	2.36	2.48	2.61
70°	2.75	2.90	3.08	3.27	3.49	3.73	4.01	4.33	4.70	5.14
80°	5.67	6.31	7.12	8.14	9.51	--	--	--	--	--

Applying Tube Gain

The values obtained from tube gain determination may be used for:

- Reverse bending
- Pre-measuring and marking
- More accurate pre-cutting

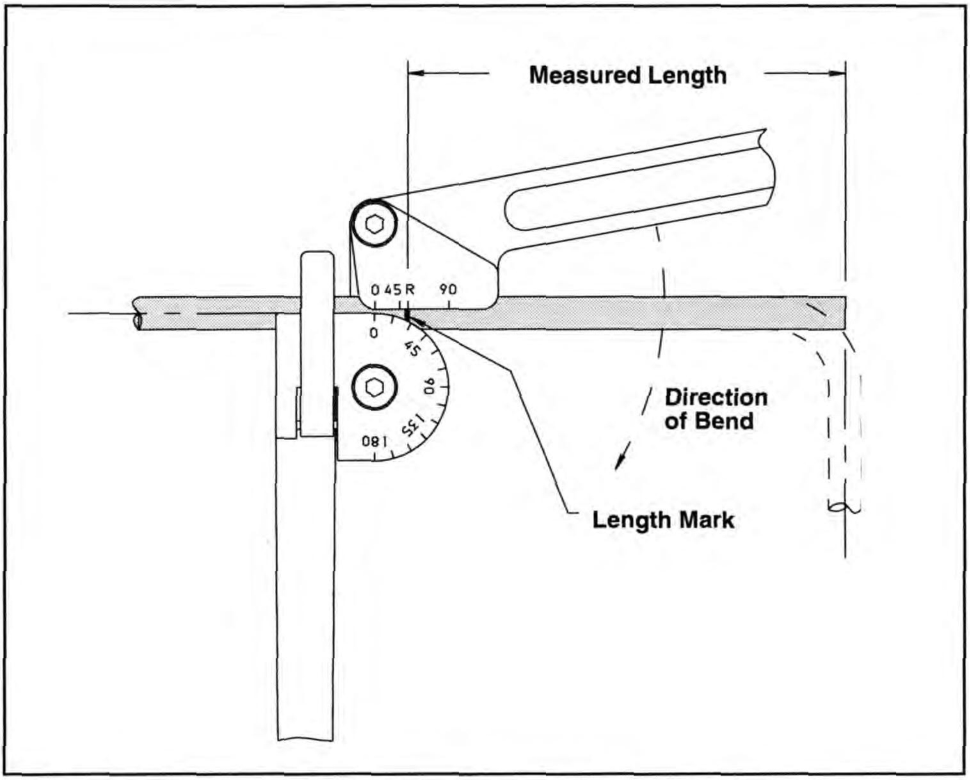

Figure 15 Compensating for tube gain (90° reverse bend).

Reverse Bending

There are instances when it is not possible to make all bends with the tube positioned from the same end, relative to the bender. It then becomes necessary to make a reverse or back bend. This is one instant when tube gain determination, or the "R" marking on some benders, come in handy. Subtract the tube gain from your original tube length mark and use that as the new position marker. On most lever type hand benders, the original length mark on the tube is aligned with the "R" mark on the bender to compensate for tube gain when making 90° reverse bends. (Figure 15)

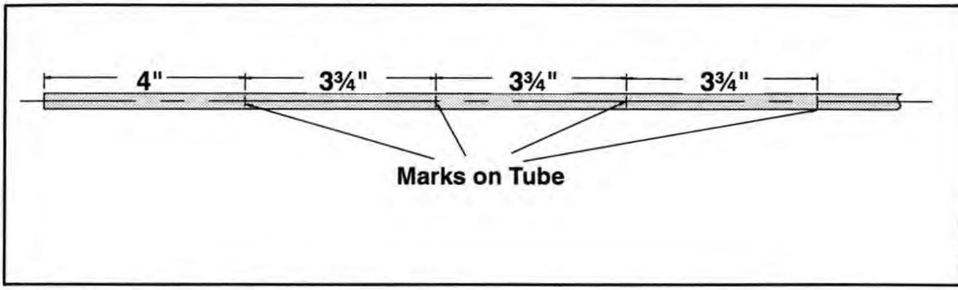

Figure 16 Pre-measuring and marking tube.

Pre-Measuring and Marking

Tube gain values are used when pre-measuring and pre-marking a tube for a series of bends. Measure for the centerline of the first bend exactly from the end of the tube, then compensate for other distances between bends by subtracting the tube gain from the true centerline distances.

Example

So as to make four 90° bends, 4" on center with a 1/4 "O.D. tube and 9/16" radius block, the tube would be marked as follows shown in figure 16.

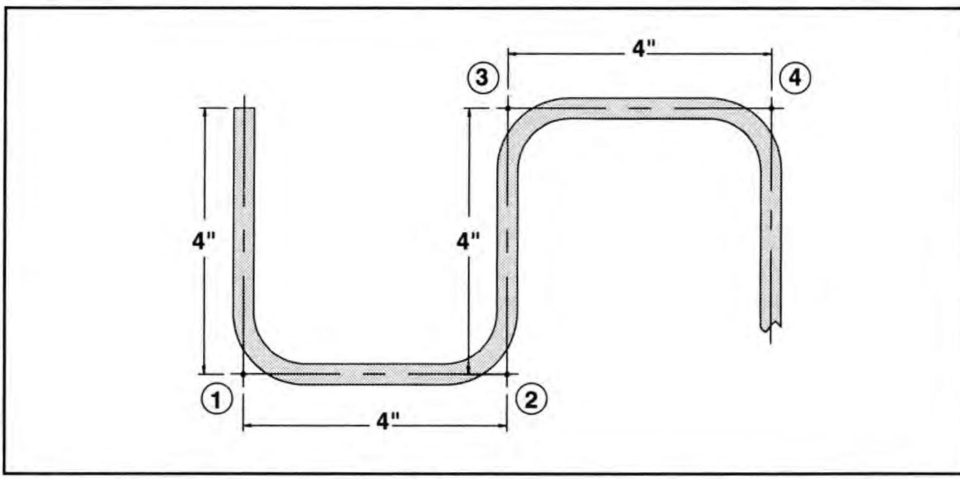

Figure 17 Compensating for tube gain in pre-measuring.

Start with the 4" length to the flat side of the radius block with the first mark tangent to the 90° mark. Bend to 90° then proceed with each mark consecutively. (Figure 17)

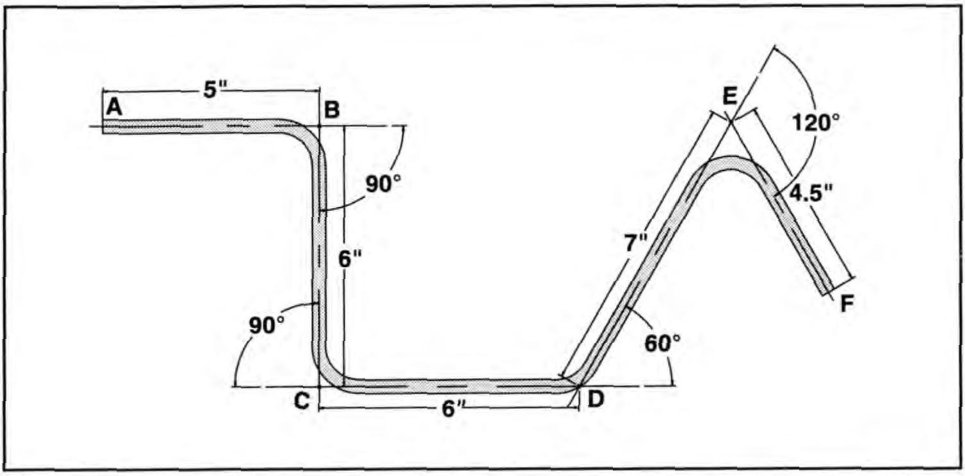

Figure 18 Using tube gain for more accurate pre-cutting.

Pre-cutting

In order to determine the length of tube required for making an assembly as shown in (Figure 18) above, the gain for each bend can be calculated and subtracted from the total of point to point dimensions.

Total point to point dimension
= AB + BC + CD + DE + EF
= 5 + 6 + 6 + 7 + 4.5
= 28.5

Assume 3" bend radius
Angle at B = 90°, C = 90°, D = 60°, E = 120°
Gain at B = 1.29, C = 1.29, D = .32, E = 4.10
Total gain = 7.0
Tube length required = 28.5 - 7.0 = 21.5

Making Offset Bends

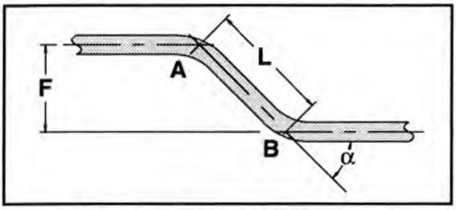

Figure 19 Making offset bends.

Offset Bends
To form a tube offset, it is usually necessary to make two bends. With Parker tube benders, it is easy to make double 30° or 45° offset bends.

To make an offset bend it is possible to use the "Offset Bend Allowance" chart herein to determine the proper distance between the two 30° or 45° bends. Here's the procedure:

Chart Method

Step 1 First, determine the total amount of offset required. (dimension "F" in the diagram, Figure 19)

Step 2 Next, determine the angle of offset - 30° or 45°.

Step 3 Figure the length of tube required to meet your offset requirements ("L" dimension in the diagram) from the table herein. For example: Say the amount of offset you require ("F" dimension, step 1) is 2-1/2". The figure next to this is the amount of tubing required for the offset bend you want ("L" dimension). In this case it's 3-17/32" for 45° angles.

Step 4 Determine where you want the offset bend of the tube to start, and make a reference mark (A). Now measure off the "L" dimension (determined in Step 2, example 3-17/32") starting from the reference mark and make a second mark (B). You are now ready to make the bends.

Step 5 Align mark (A) with reference mark 45° on bender shoe (measurement end to the left) and proceed with first bend. Then align (B) with 45° mark and make second bend in proper direction (measurement end to the left). Follow previous detailed instructions for making 45° bends in one plane.

Calculation Method
Offset dimensions may be calculated for any desired angles less than 90° by using the following formula:

$$L= \frac{F}{\text{Sin} \propto}$$

where L = distance between bends
F = distance between centerline (offset)
$\propto$ = angle of bends

Table 4 — Offset Bend Chart for 30° and 45° Bends

Angle of Offset 30°		**Angle of Offset 45°**	
Amount of Offset Dimension		**Amount of Offset** Dimension	
F	**L**	**F**	**L**
1	2	1	1-13/32
-1/8	2-1/4	-1/8	1-19/32
-1/4	2-1/2	-1/4	1-25/32
-3/8	2-3/4	-3/8	1-15/16
-1/2	3	-1/2	2-1/8
-5/8	3-1/4	-5/8	2-5/16
-3/4	3-1/2	-3/4	2-15/32
-7/8	3-3/4	-7/8	2-21/32
2	4	2	2-13/16
-1/8	4-1/4	-1/8	3
-1/4	4-1/2	-1/4	3-3/16
-3/8	4-3/4	-3/8	3-11/32
-1/2	5	-1/2	3-17/32
-5/8	5-1/4	-5/8	3-23/32
-3/4	5-1/2	-3/4	3-7/8
-7/8	5-3/4	-7/8	4-1/16
3	6	3	4-1/4
-1/8	6-1/4	-1/8	4-13/32
-1/4	6-1/2	-1/4	4-19/32
-3/8	6-3/4	-3/8	4-25/32
-1/2	7	-1/2	4-15/16
-5/8	7-1/4	-5/8	5-1/8
-3/4	7-1/2	-3/4	5-1/16
-7/8	7-3/4	-7/8	5-15/32
4	8	4	5-21/32
-1/8	8-1/4	-1/8	5-27/32
-1/4	8-1/2	-1/4	6
-3/8	8-3/4	-3/8	6-3/16
-1/2	9	-1/2	6-3/8
-5/8	9-1/4	-5/8	6-17/32
-3/4	9-1/2	-3/4	6-23/32
-7/8	9-3/4	-7/8	6-29/32
5	10	5	7-1/16
-1/8	10-1/4	-1/8	7-1/4
-1/4	10-1/2	-1/4	7-7/16
-3/8	10-3/4	-3/8	7-19/32
-1/2	11	-1/2	7-25/32
-5/8	11-1/4	-5/8	7-31/32
-3/4	11-1/2	-3/4	8-1/8
-7/8	11-3/4	-7/8	8-5/16
6	12	6	8-15/32

Mandrel Bending

A mandrel is usually necessary to prevent wrinkling or flattening in a tube bend when the tube wall thickness is relatively thin. As a general "Rule of Thumb", a mandrel is required if the tube wall ratio to tube outside diameter is less than 7% with the bend radius between three and four times the tube outside diameter. (See graph for more specific application of mandrels, because the need for a mandrel is also dependent on the bend radius).

If tube flattening and/or wrinkling in the arc of a tube bend are not eliminated or reduced, then the following may occur:

- Flow path restricted
- Uneven stresses develop, resulting in premature tube failure due to fatigue
- Poor quality appearance

Flatness in the area of a tube bend is usually defined in terms of percentage flatness and may be calculated from the following:

$$\% \text{ Flatness} = \frac{\text{Max OD - Min OD}}{\text{Nominal OD}} \times \frac{100}{1}$$

Acceptable values are usually in the range of 0-5% and 0-10% depending on the tube material and pressure application. Wrinkles are usually measured for their maximum height and defined as a percentage of the tube outside diameter. Permissible wrinkles are usually 0, 1 or 2%; depending also on tube material and pressure application. Higher pressure applications have tighter restrictions.

Parker's bench mount type benders, such as the 412, 420, 424, and 632 can be equipped for mandrel bending. The most common type of mandrel used is the plug type which is inserted inside the tube to prevent tube wall collapse during bending. The mandrel is accurately positioned, relative to the bend radius, and during the bending process the tube is drawn over the mandrel which supports the tube wall from the inside to keep the tube fully open for a smooth bend. After the bend is formed, the mandrel is removed.

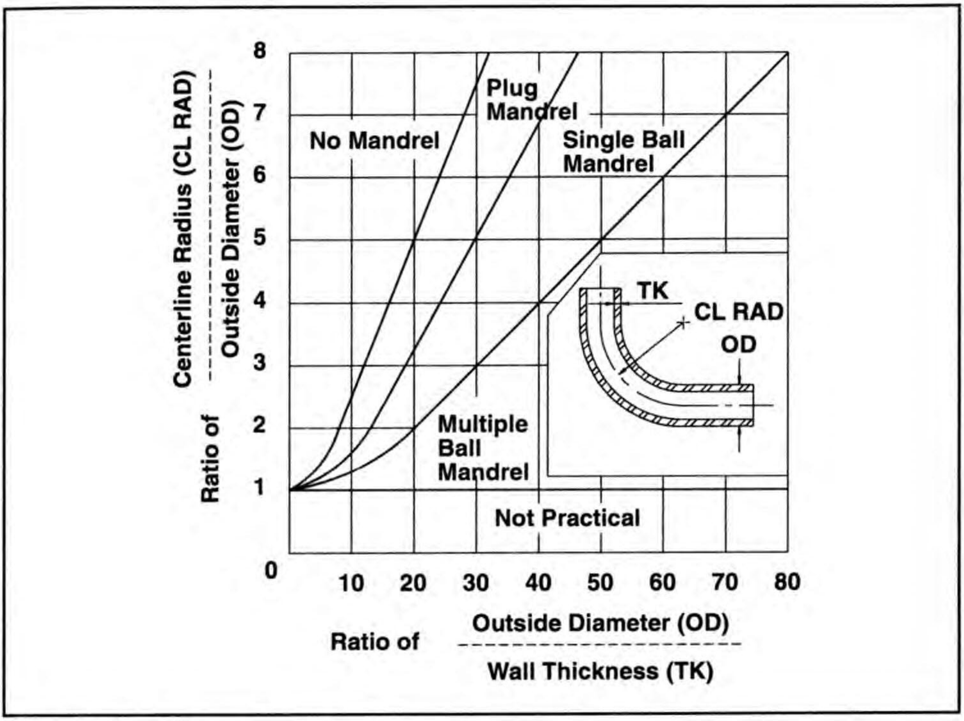

Figure 20 Mandrel bending chart.

When to Use Mandrel (Figure 20)

Example: Determine if it's necessary to use a mandrel for bending 3/4 x .049 steel tube through a 3" bend radius without excessive flattening.

Solution: $\frac{\text{Centerline Radius}}{\text{Outside Diameter}} = \frac{3}{.75} = 4$

$$\frac{\text{Outside Diameter}}{\text{Wall Thickness}} = \frac{.75}{.049} = 15.3$$

Intersection of these two ratios on the graph falls within the area indicating that no mandrel is required. Note however, for the same tube at a smaller bend radius, a mandrel would be required for preventing excessive flattening.

If the tube wall is very thin then a plug mandrel alone may not be adequate to prevent wrinkling. In such cases, special ball type mandrels and wiper shoes may be necessary.