BASIC TUBE BENDING GUIDE

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BASIC TUBE BENDING GUIDE

PART I

BENDING TUBING WITHOUT A MANDREL

When a tube is bent, two things happen to the metal which can be seen by sectioning the bent tube — the outside wall is reduced in thickness due to stretching of the material and the inside wall becomes thicker due to compressing of the material. (See Figure 1). The material actually is formed approximately about the center line of the tube. The distance along the center line is approximately the same as the original length of the tube. The material that forms the outside of the bend has further to travel and therefore is stretched; the material on the inside of the bend has less distance to travel and is compressed.

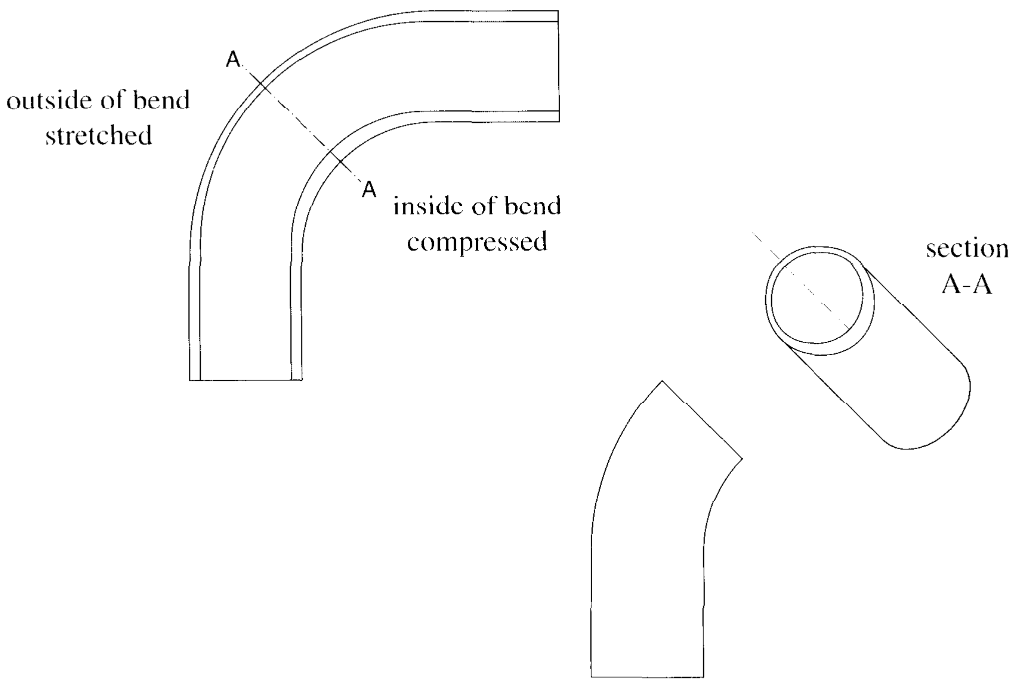

FIGURE NO. 1

STRETCHING AND COMPRESSION PRINCIPLES

When the ratio of tube diameter to wall thickness is small enough, the tube can be bent on a relatively small radius (CLR = 4 x TOD). Excessive flattening or wrinkling of the bend should not occur. The outside and the inside of the bend tend to pull towards the center line of the tube (flattening). Two factors which help prevent this from happening are, a grooved bending die which supports the tube along the center line, and the natural strength of the tube, round or square. (See Figure 2).

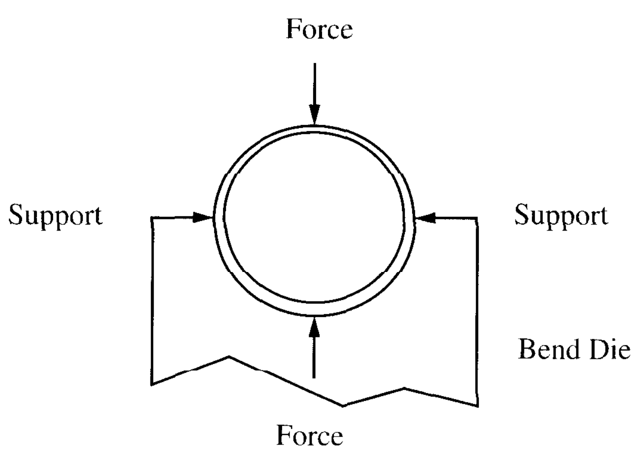

FIGURE NO. 2

FUNCTION OF BEND DIE

Little or no support is needed within the tube when the tube diameter is small and the wall is thick. As the size of the tube diameter is increased, the tube becomes weaker. If the wall thickness of the tube is decreased, it also becomes weaker. The forces acting on the tube also become greater as the radius of the bend becomes smaller.

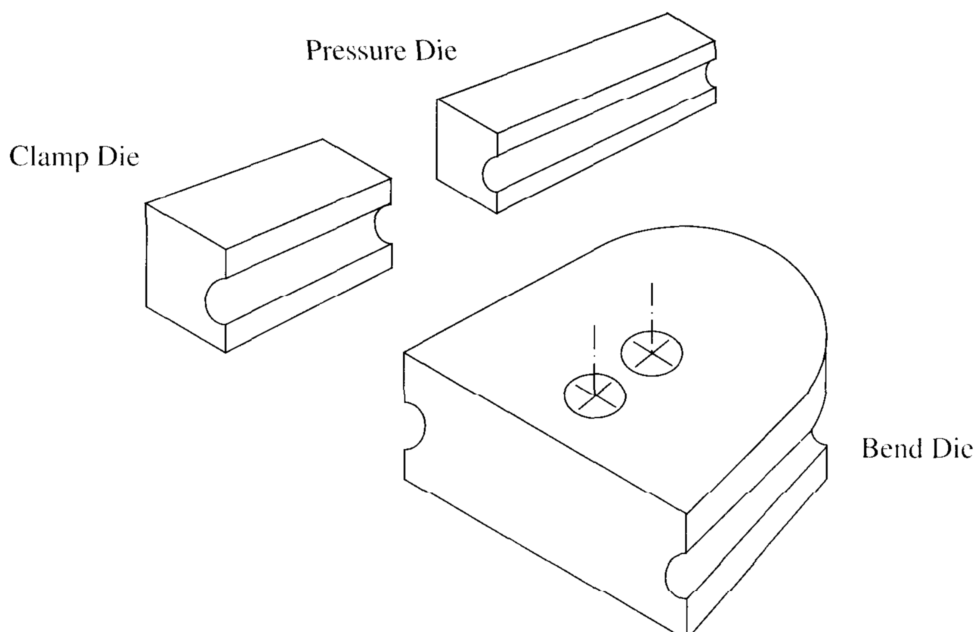

FIGURE NO. 3

BASIC PRIMARY TOOLING

A grooved bend die, clamp die and pressure die comprise the bare essentials necessary for bending tubing. (See Figure 3). The bend die helps to prevent the tube from flattening and forms a given radius of bend. The clamp die holds the tube in position while bending. The pressure die forces the tube into the bend die.

To determine the minimum center line radius for bending without a mandrel, refer to Chart No. 1. This chart only considers tube diameter (TOD), wall thickness (WT) and center line bend radius (CLR), not the various types of metals.

Minimum Bending Radius (inches) without mandrel

Tube Diameter (inches)	Wall Thickness (inches)					
	.035	.049	.065	.083	.093	.120
3/16	5/16	1/4	3/16			
1/4	1/2	3/8	5/16			
5/16	7/8	3/4	5/8			
3/8	1-1/2	1-1/4	1-1/8	1		
1/2	2-1/4	2	1-3/4	1-1/2		
3/4	4	3	2-1/2	2		
1	8	6	4	3	2	2
1-1/2			12	10	8	6
2				24	20	16
2-1/2					24	20
3						25

CHART NO. 1

Springback is excessive when a mandrel is not used. This should be considered when selecting a bend die. "Springback" is the term used to describe the tendency of metal which has been formed to return to its original shape. The springback will cause the tube to unbend from two to ten degrees depending on the radius of bend and may increase the bend radius of the tube. The smaller the radius of bend, the smaller the springback. Springback can be affected by the location and pressure of the pressure die. (See Figure 4). This method allows variations in radii from one bend die.

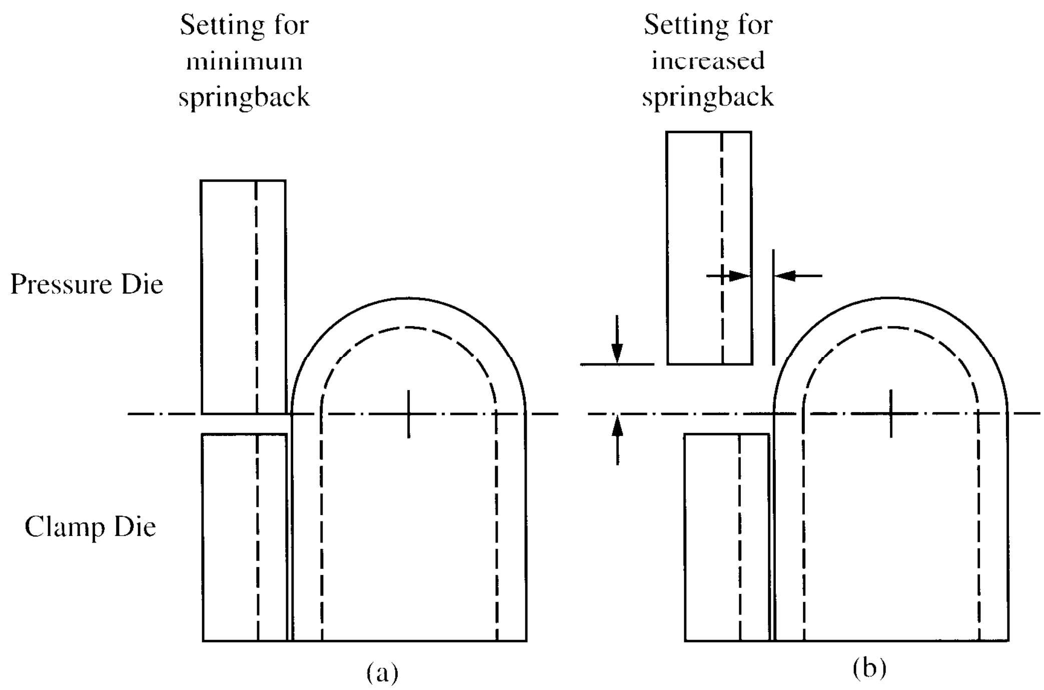

FIGURE NO. 4

CONTROL OF SPRINGBACK

The tube may kink or buckle as shown in Figure 5. This may be due to hard material which will not compress on the inside radius of the bend. The material, not being able to compress, pushes in toward the center line of the tube. This condition can be corrected (provided the tube is not too hard) by setting up tools as shown in Figure 4a. A plug mandrel (See Figure 6) is indicated if the tube buckles and is still within the limits of Chart 1.

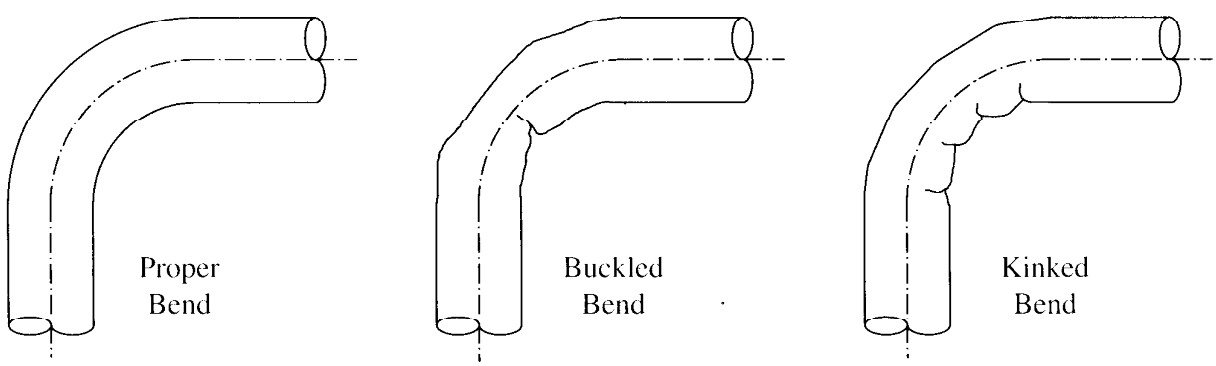

FIGURE NO. 5

KINKED OR BUCKLED BENDS

PART II

TUBE BENDING BY USE OF PLUG MANDREL

The purpose of a plug mandrel is to prevent the tube from flattening and to bend without wrinkles or kinks. The mandrel is held in a fixed position while the tube is pulled over it. The tube-stretching process is localized on the outer radius of bend and the material is work-hardened to retain its shape and not flatten. The material stretching is done on the forward tip of the mandrel. (See Figure 6). This force, acting on the mandrel tip, supports the inner radius of the bend, holding it firmly into the bend die groove.

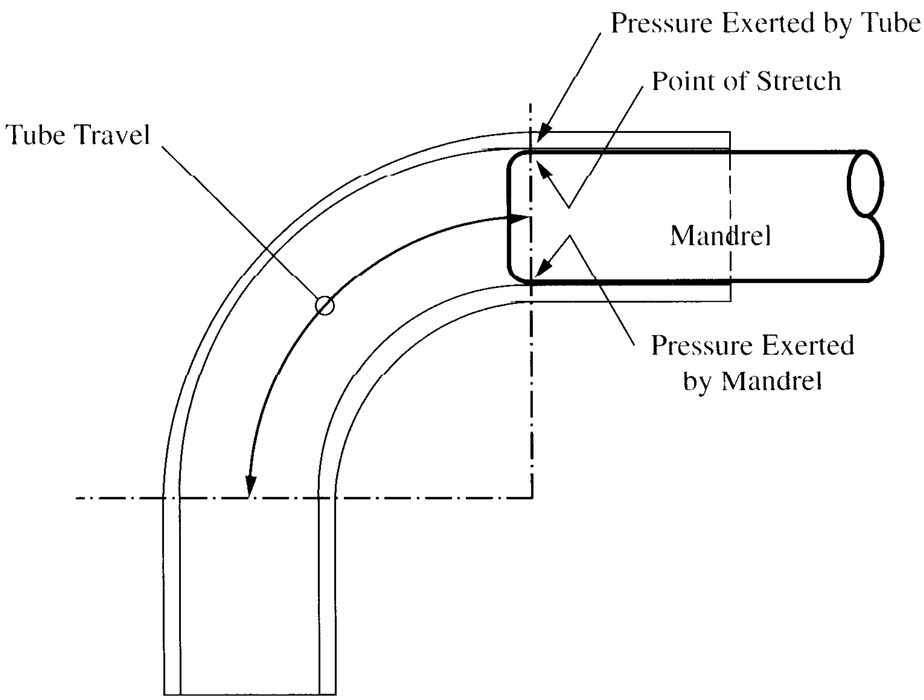

FIGURE NO. 6

BALANCED PRESSURES

A plug mandrel can be used to produce relatively good quality bends for commercial requirements involving tubing 3/8 inch diameter and smaller. Exceptions to this are thin wall tubing or a center line radius that is less than 2 x tube O.D. (See section on Thin Wall Bending, Part IV). There also are certain limitations for tubes larger than 3/8 inch diameter. (See Chart 2).

Minimum Bending Radius (inches) Plug Mandrel

Tube Diameter (inches)	Wall Thickness (inches) .035	.049	.065	.083	.093	.120
1/2	1	7/8	3/4	5/8	—	—
5/8	1-1/2	1-1/4	1-1/8	1	—	—
3/4	2-1/2	1-7/8	1-5/8	1-3/8	—	—
7/8	3-1/2	3	2-5/8	2-1/4	1-7/8	—
1	4-1/2	3-7/8	3-1/4	2-7/8	2-1/2	—
1-1/8	5-1/4	4-5/8	4	3-5/8	3-1/4	2-3/4
1-1/4	6-1/2	5-3/4	5-1/8	4-1/2	3-7/8	3-1/8
1-1/2	8	7	6-1/8	5-1/4	4-3/8	3-5/8
2	12	10-1/2	9	6	5	4
2-1/2	18	15	12	9	7-1/2	6
3	24	20	17	14	11	9

CHART NO. 2

The pressure die should be adjusted for a light pressure against the tube. The purpose of the pressure die is to keep the tube against the bend die throughout the duration of bending. The pressure die also keeps the mandrel from bending and maintains a straight tube between tangent points of bends (the portion of tubing left on the mandrel after bending). The location of the mandrel in respect to the point of bend or tangent affects the amount of springback. The mandrel in a forward position (toward tangent) will stretch the material on the outside of the bend more than is necessary. This increases the length of material on the outside beyond that which is required to make a bend. When the bent tube is removed from the bend die, it will conform to the die and there will be little or no springback. (See Figure 7). Figure 7 is an exaggerated example. The outside of the bend actually is in compression with forces acting at points A and B. Counteracting forces occur at C and D. Forces A and B tend to close the bend while forces C and D act to open the bend.

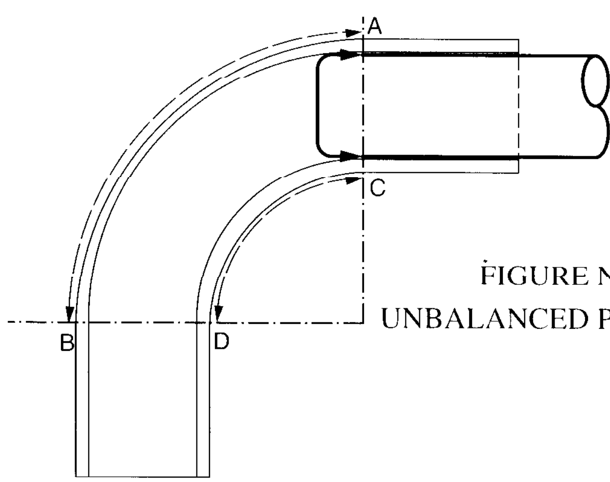

FIGURE NO. 7
UNBALANCED PRESSURES

The mandrel in a retarded position (away from tangent) will not stretch the material on the outside of the bend enough; consequently, there is not quite enough material to reach from A to B, putting a tension in the material. The forces at A and B are now the reverse of those shown in Figure 7, tending to open up the bend. Mandrel location, therefore, can cause excessive springback, which reduces the angle of bend and also may increase the radius. The mandrel should be brought forward (toward tangent) when the radius is increased. There is no given formula for correct mandrel setting. One thing is apparent: when the angle of springback is more than 3 degrees, the mandrel is too retarded and the tube's radius of bend will be larger than the bending die.

When the tube breaks repeatedly, it may indicate that the material is too hard. Hard material does not have the ability to stretch sufficiently. Working with recently fully-annealed material will preclude this possibility. When the mandrel is set too far forward or the tube slips minutely in the clamp die, breakage may occur also. The problem of slippage will be discussed later.

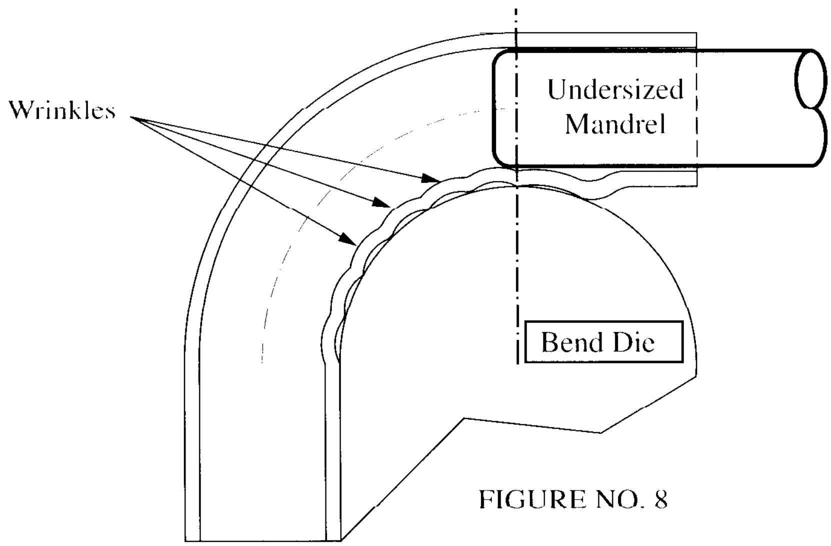

FIGURE NO. 8

UNDERSIZED MANDREL

Advancing the mandrel slightly forward, may stop wrinkles from forming in front of tangent and begin to form in back of tangent. The mandrel at this point is still not far enough forward to generate the necessary pressure on the inside of the bend and compress the material. The bend may start out smooth, but as it progresses past approximately 20 degrees, the material pushes back, forming a ripple or wave at point A (See Figure 9) This ripple is forming and being flattened continually between the mandrel and the bend die. The ripple, however, does not entirely disappear. When the bent tube is removed from the bend die, there is a large buckle at point A. It is necessary to continue to advance the mandrel until the material can't squeeze back between the bend die and mandrel. Figure 10 illustrates what occurs when the mandrel is not fully advanced.

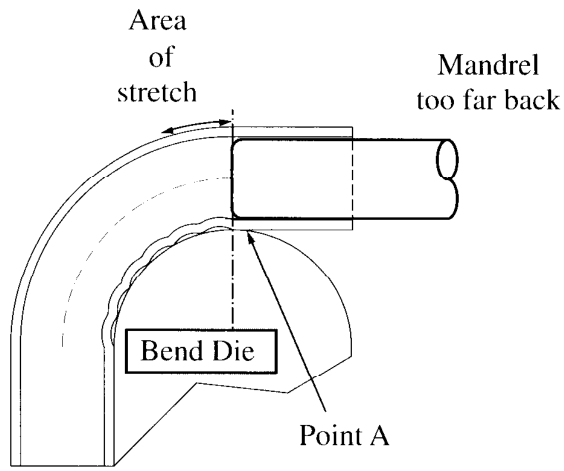

FIGURE NO. 9

MANDREL TOO FAR BACK

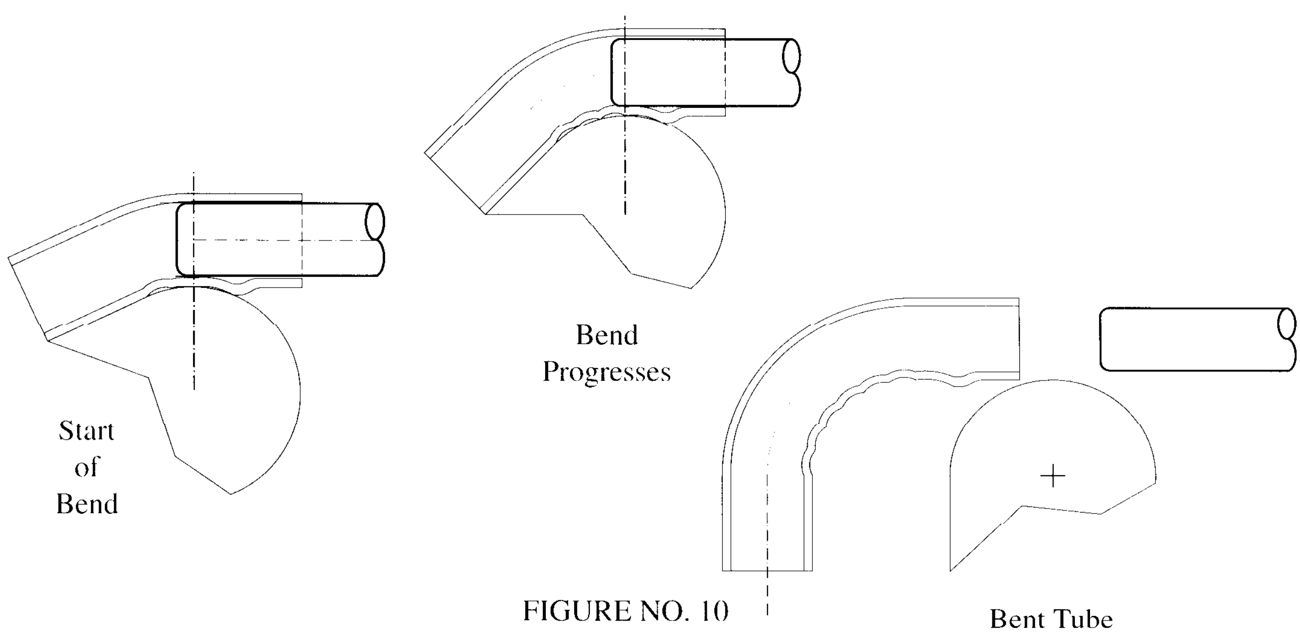

FIGURE NO. 10

MANDREL ADVANCED PARTIALLY

When the mandrel is too far forward, several things occur. Bumps appear on the outside of the bend at the terminal tangent and a step on the inside of the bend at the starting tangent. These malformations are shown on the same tube. They will not always appear at the same time, depending upon shape of the mandrel and bend radius. The bump, obviously, is caused by the mandrel. The step is formed by the end of the mandrel prying the tube away from the bend die.

Plug mandrels are inexpensive, easy to maintain and cause little drag. Ball-type mandrels, however, should be employed for small radius bends, thin wall tubes or where high quality is desired. The clamp die should have a minimum length of three times the tube diameter when using a plug mandrel.

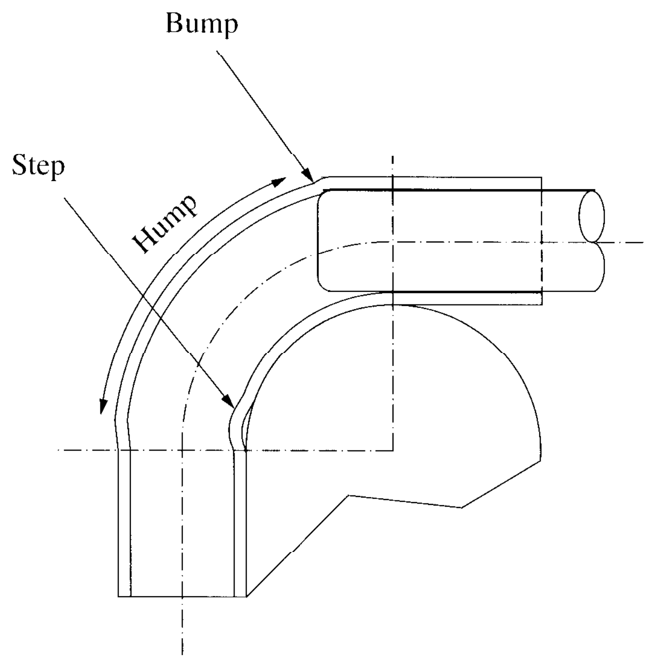

FIGURE NO. 11

MANDREL TOO FAR FORWARD

PART III

TUBE BENDING BY USE OF BALL MANDREL AND WIPER DIE

Both of these tools should be discussed at the same time. Although their functions are different, they are used in conjunction with one another. It is necessary to use these tools with the basic tools when the ratio of tube diameter to wall thickness exceeds a certain figure bent on a given radius. (See Chart 3). The wiper die is used to prevent wrinkles. The ball mandrel performs essentially like the plug mandrel. The balls are used primarily to keep the tube from collapsing after it leaves the mandrel shank.

The problems that have been discussed are greatly magnified when making tight bends or with thin wall tubing. It becomes increasingly difficult to retain the material during compression. The pressure is so intense the material is squeezed back past tangent, the area not supported by the bend die, and buckles. (See Figure 10). This area must be supported so that the material will compress rather than buckle; this is the prime purpose of the wiper die. Note, the wiper die cannot flatten wrinkles after they are formed; it can only prevent them.

When the radius of the bend is smaller and/or the walls thinner than shown on Chart 2, it becomes necessary to use a ball mandrel and wiper die. Table 3 indicates when a single ball mandrel should be used. When the bend radius is smaller than shown on this chart, two, three or more balls should be used.

Minimum Bending Radius (inches) Plug Mandrel

Tube Diameter (inches)	Wall Thickness (inches) .035	.049	.065	.083	.093	.120
1/2	*1/2	*1/2	—	—	—	—
5/8	*5/8	*5/8	—	—	—	—
3/4	3/4	*3/4	*3/4	—	—	—
7/8	1-1/4	1-1/8	*1	—	—	—
1	1-3/4	1-1/2	1-1/4	*1-1/8	—	—
1-1/8	2-1/2	2	1-3/4	1-1/2	—	—
1-1/4	3-7/8	3-1/2	3	2-1/2	2	—
1-1/2	5	4-1/4	3-3/4	3-1/4	2-3/4	2-1/4
2	9	8	7	6	5	3-1/2
2-1/2	12	10-1/2	9-1/4	8	6-1/2	5
3	15	13	11	10	9	8

CHART NO. 3 * Wiper Die Required

PART IV

BENDING THIN WALL TUBING

Requirements for the bending of ultra thin wall tubing have become more prevalent in recent years. Tight radius bends of center line radius equaling the tube outside diameter (1 x D) have accompanied thin wall bending. To compound the problem, new alloys have been developed that are extremely difficult to bend.

To facilitate this type of tube bending, the material to be bent should receive special consideration. To help maintain the consistency of the tubing dimensions and characteristics, the entire material required for a given job should be purchased from one supplier, preferably even from the same lot or heat number. Premium priced close tolerance tubing should be considered. It often will save many more times its added cost. It may be necessary on occasion to size certain tubing before bending. When the inside finish of a tube is a prominent factor, it may be wise to electro-polish the I.D. of the tube before bending. Extreme care should be given when bending to protect the finish.

The tubing should be a firm slip fit on the mandrel and clearance should not exceed 10% to 15% of wall thickness. This same clearance also should apply to the four pieces of outside tools. The tube material specifications and characteristics found in tubing catalogs can be of great assistance. The rated ductility and elongation of a material, for example, may indicate the need of special bending methods.

There are many pipe bending machines but only two or possibly three machines capable of thin wall, 1 x D bending. Even those machines best suited for this special bending must be in excellent condition and of a size large enough to assure rigidity. Any appreciable give or spring of its members during the bending cycle should be eliminated. The machine spindle should have less than .0005 inch total run-out. The mandrel rod should be as large as possible to reduce its stretching.

A full complement of controls is essential. The machine must be capable of retracting and advancing the mandrel with the clamp and pressure dies closed. An hydraulically actuated pressure die is desirable. One feature of this system is that it provides identical pressure on the tube regardless of wall variation.

A pressure die booster also is available. It counteracts the drag of the pressure die, mandrel and wiper die by pushing the tube into the bending area, and reduces wall thinning.

Without a pressure die booster, the thinning which normally can be expected is about three-quarters of the elongation of the outer wall. Therefore, a two-inch diameter tube bent on a three-inch center line radius, will thin by about 25% and the cross section of such a bend would be as in Figure 12. As the compressive yield stress generally is higher than the tensile value, the neutral axis will be inside the geometric axis of the tube and, the thinning of the outside of the bend will be greater than the thickening of the inside.

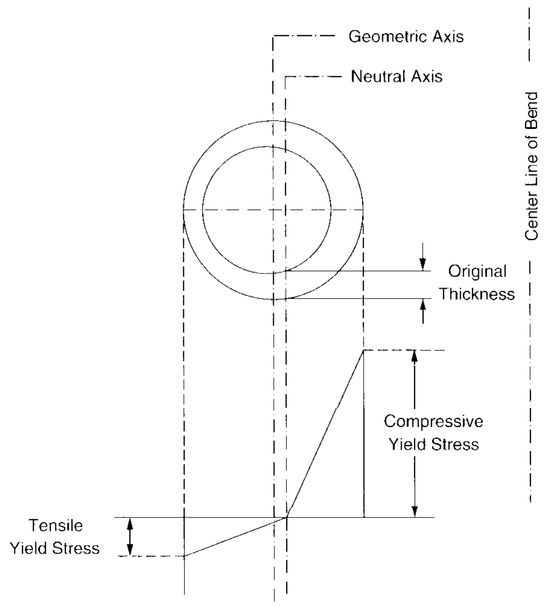

FIGURE NO. 12

TUBE CROSS SECTIONS

To reduce the thinning, it is necessary to move the neutral axis to the outside of the bend. If the neutral axis coincides with the outer wall, there will be no thinning whatever, but heavy thickening of the inside. One method of achieving this is to put the tube into compression before bending commences; this will modify the stress distribution in the section as shown in Figure 13.

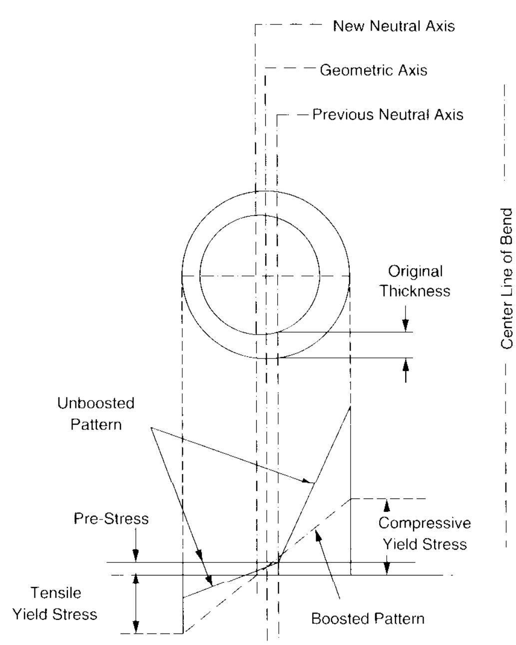

FIGURE NO. 13

TUBE CROSS SECTIONS

Another way of moving the neutral axis is to reduce the compressive yield stress of the material. This can be done by heating the part of the tube that will form the inside of the bend and will give a stress pattern as shown in Figure 14.

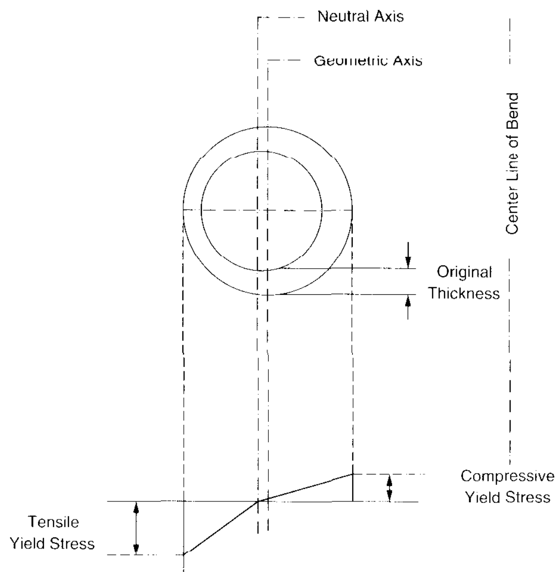

FIGURE NO. 14

TUBE CROSS SECTIONS

If both these means are employed at the same time a great reduction of thinning can be achieved. Since it is not necessary to reduce thinning much below 12%, the advantage gained can be taken in terms of closer bend radii. The pressure die booster should be capable of pushing the pressure die and tube separately or simultaneously.

A few tube bending machines have similar devices, but they generally are designed to assist the machine in bending thick wall tubing. They do not have the required precise control or hydraulic independence to assist appreciably in thin wall tube bending.

A clamping plug should be used when the wall is so thin that it is being distorted by the clamp die or collapsing under the clamp die pressure. It also helps eliminate slippage with less clamping pressure. A clamping plug should be a press fit. It is located in the clamping area prior to closing the clamp die and removed before the pressure die is opened. Expanding clamping plugs also are available. Their advantage is the ease of insertion and removal. They are designed to accommodate wall variation as well as different walls for the same O. D. size of tubing.

The quality and amount of lubricant used is extremely important. One lubricant will not work equally well on all materials. One lubricant for steel and another for aluminum is recommended. A generous amount of lubricant can be applied to the mandrel and inside the tube. The lubricant must cover the entire inside of the tube.

The three principal requirements in tube bending are simply: machine, operator and tooling. All three factors must be especially good to work with thin wall tubing on tight radii. Too many facilities still depend on the operator's knowledge to compensate for worn or inferior tooling. Poor tooling results in longer set-up time, scrapping of expensive tubing, poorly bent tubes and failure to produce an acceptable bend. Highly competitive custom tube bending firms realize cheap and inferior tooling is the most expensive they can buy. Interlock tooling represents the ultimate in tube bending tooling. Complete interlock tooling, although developed and successful for numerical-control benders, has proven advantageous for conventional machines. Each tool of the matching set is laterally locked in alignment. The clamp die is keyed and locked to the bend die, the wiper die located and locked to the pressure die and the pressure die in turn is locked in alignment to the bend die.

Field reports have confirmed several advantages of interlock tooling. The clamp die, with all the hydraulic pressure available to it, will not crush or even mark the tube, thereby providing vastly improved gripping properties. Bend die and pressure die marks on the top and bottom of the tube are completely eliminated. In tests, set-ups averaged one-third the time allotted for conventional tooling with similar results found in scrap reduction.

The five pieces of tooling (bend die, pressure die, wiper die, mandrel and clamp die) must all be close-tolerance excellent tooling. The bend die should have a maximum run-out at the bottom of the bend groove of not more than .001 total indicated run-out (TIR). To help prevent tooling marks on the top and bottom of the tube, the bend groove should be dead round and the diameter should measure 10% times wall thickness over tube diameter. The clamping area, unless cleated or with other provision such as flaring, beading, etc., should be three to six times tube diameter with a sand-blasted or rough finish. The diameter of a clamp area should not be undersize more than 10% of wall thickness. Grip or pinch clearance should be held to a minimum. To permit the bend die to be used on right and left hand machines, the counter bore and keyway often are machined on both sides of the die. Center line height must be maintained for both sides.

Bend dies are available in four basic styles, A, B, C and D. Each style is designed for different bending requirements: Type A for 1 x D radius and 180° bend, Type B for 1 x D radius and 90° bend, Type C for 1 1/2 x D radius and 180° bend, Type D for 2 x D radius and up with 180° bend.

VARIOUS BEND DIES

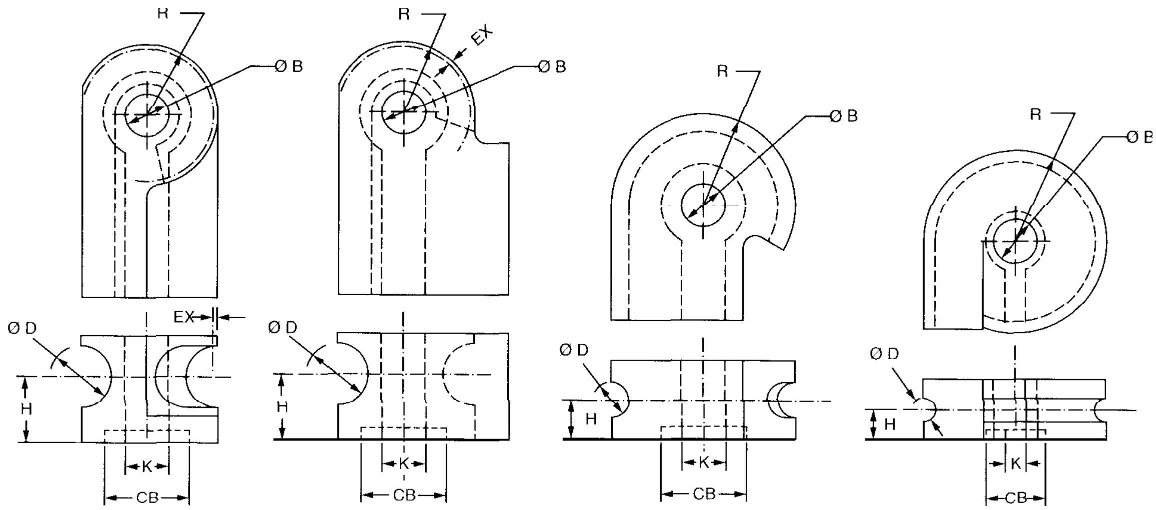

FIGURE 15A FIGURE 15B FIGURE 15C FIGURE 15D

FIGURE 15

The pressure die should have a groove diameter slightly larger than the O. D. of the tube to be bent. It should not vary in thickness from one end to the other by more than .0005. Variation in thickness will cause a pinching or relieving effect as it feeds forward. With good tooling properly fitted, it should only be necessary for very light pressure to be applied. Excessive pressure on the pressure die increases thinning, marks the tube and affects Springback.

It is most important to have an accurate wiper die. The groove the tube slides through must be slightly larger than the OD of the tube — 10% of wall thickness is optimum. The groove must be of high polish and lubricated with a thin oil. Too much oil or too heavy an oil in this area will cause wrinkles. Wiper die fit to bend die groove must be 85% contact from 12:00 o'clock to 6:00 o'clock and for at least 15° to 20° back from point of tangency. When wiper die is not supported by the bend die, it will spring away from the mandrel and cause the tube to wrinkle (See Figure 16).

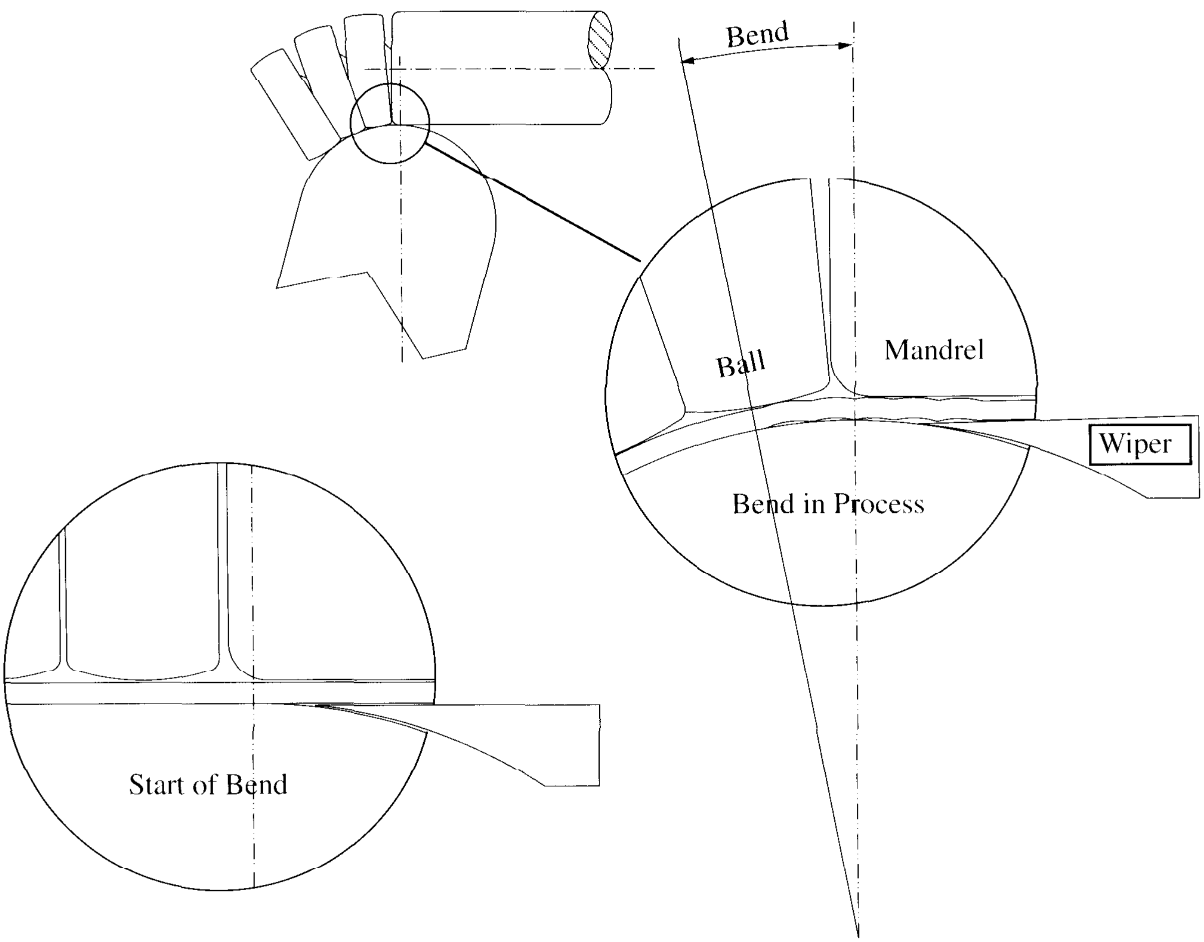

FIGURE NO. 16

A solid bar the exact diameter of the tubing to be bent would facilitate a proper wiper die fit. While the set-up bar is held by the clamp die, the wiper die is tapped to the forward most position and then secured to the wiper die holder. To minimize drag, the flat end of the wiper can be brought back from the pressure die. To check the amount of this rake or "taper", a straight edge is placed in the core of the clamp groove, extending to the rear of the wiper. The amount of rake is then readily visible. The feather edge of the wiper must be as close to tangent as possible. Wiper dies made of Aluminum Bronze material also help minimize drag and prevent galling. Wiper dies made of 4130 alloy steel have proven successful with less wear than mild steel or Aluminum Bronze. A minimum amount of high quality drawing lubricant is all that should be used. Excessive oil causes wrinkles.

A universal flexing ball mandrel must be employed having a clearance no greater than 10% of the wall thickness of the tube to be bent. It will be necessary to have enough balls on the mandrel to support the tube around the entire bend. It is essential that the spacing between balls (pitch) be reduced. The UNI-FLEX "thin wall" (TW) mandrel is recommended over the standard. The ball spacing (pitch) is closer and the first ball off the mandrel shank gives very close support both to the outside as well as the inside of the bend. When possible mandrel balls should be undersized sufficiently to eliminate the possibility of clamping interference.

Aluminum Bronze frequently is preferred for stainless steel applications to reduce friction. Tool Steel or Alloy Steel, both chromed, is recommended on non-ferrous materials like aluminum, copper, etc.. Mandrel setting will be determined by the mandrel used and the radius of bend. A template of the desired bend radius is helpful in determining the initial UNI-FLEX mandrel location (See Figure 18). To achieve full benefit from the mandrel it is necessary to project the mandrel shank past tangent.

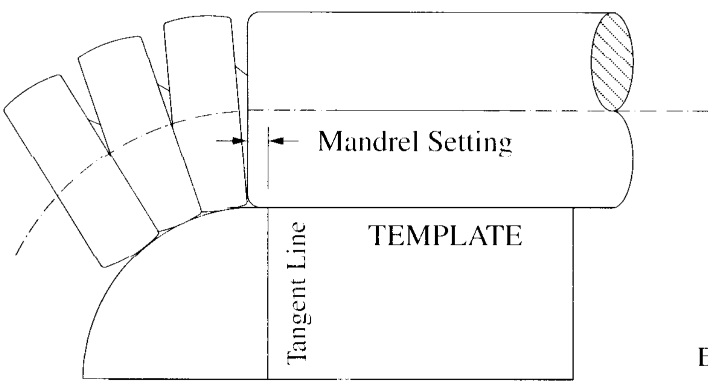

FIGURE NO. 18

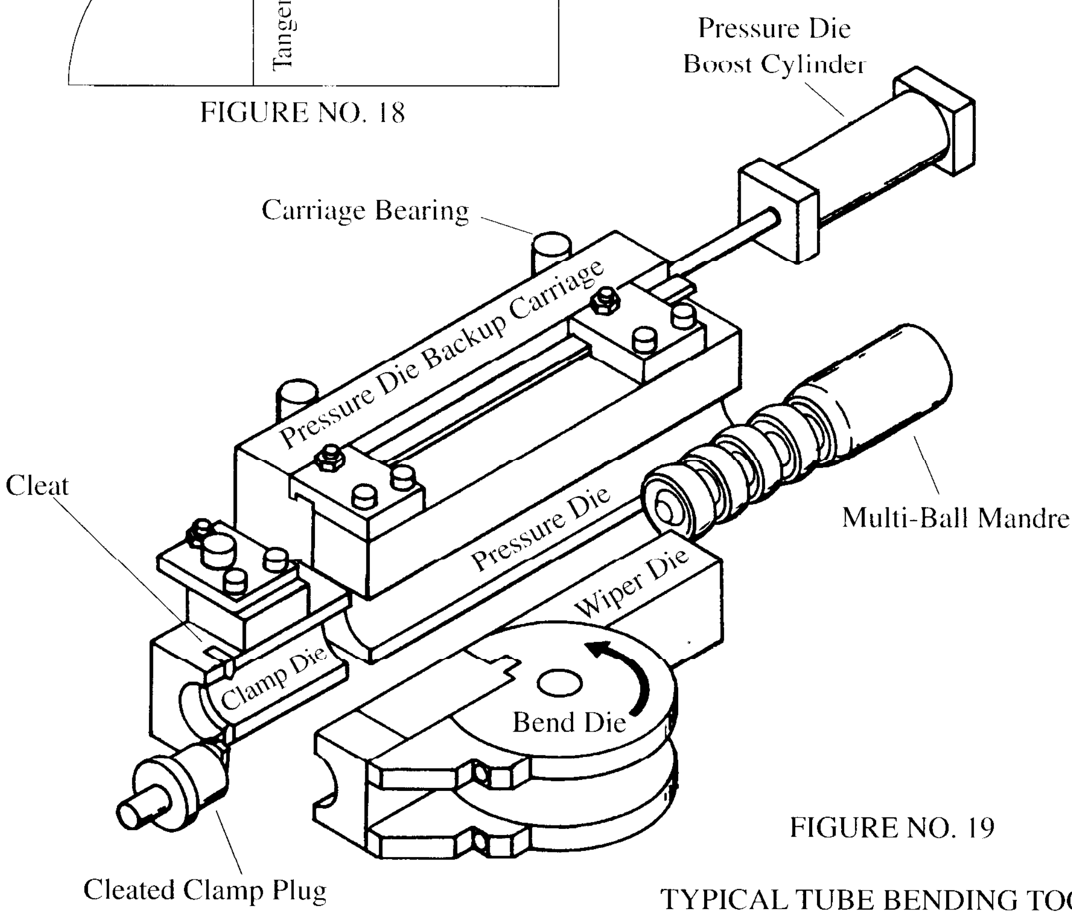

FIGURE NO. 19

TYPICAL TUBE BENDING TOOLS

APPENDIX

TROUBLE SHOOTING

Tube breakage may be caused by:

a. Material lacking proper ductility and elongation.
b. Tube slipping in clamp die.
c. Pressure die too tight, causing excess drag.
d. Material wrinkling and becoming locked between mandrel balls.
e. Clamp die pressing on mandrel balls.
f. Improper or insufficient lubrication.
g. Mandrel too far forward.

Tube wrinkling may be caused by:

a. Tube slipping in clamp die.
b. Mandrel not far enough forward.
c. Wiper die not seated properly in bend die.
d. Wiper die worn or not properly seated in bend die.
e. Too much clearance between mandrel and tube.
f. Not enough pressure on pressure die.
g. Improper or excessive amount of lubrication.

NOTE:

Materials offering less resistance to flow will have less tendency to wrinkle. For instance, 3/8 OD x .020 wall type 304 can be bent on as small as 2 x D radius without a wiper die. On the other hand, AM 350 CRES stainless steel will require a wiper die on any radius up to 3 x diameter. The wiper die must fit the bend die and the tip be as close to tangent as possible. The biggest problem in bending tubing on tight radii is making the material compress without buckling. A worn or improperly fitted wiper die is usually where the problem occurs.