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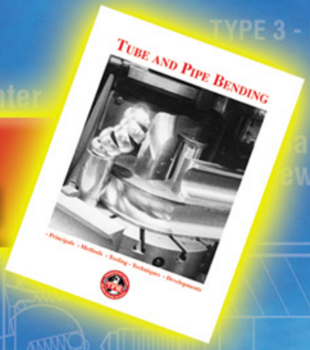
Capabilities Brochure

Tooling and Techniques Guide



Tube and Pipe Bending Manual

Wall Chart

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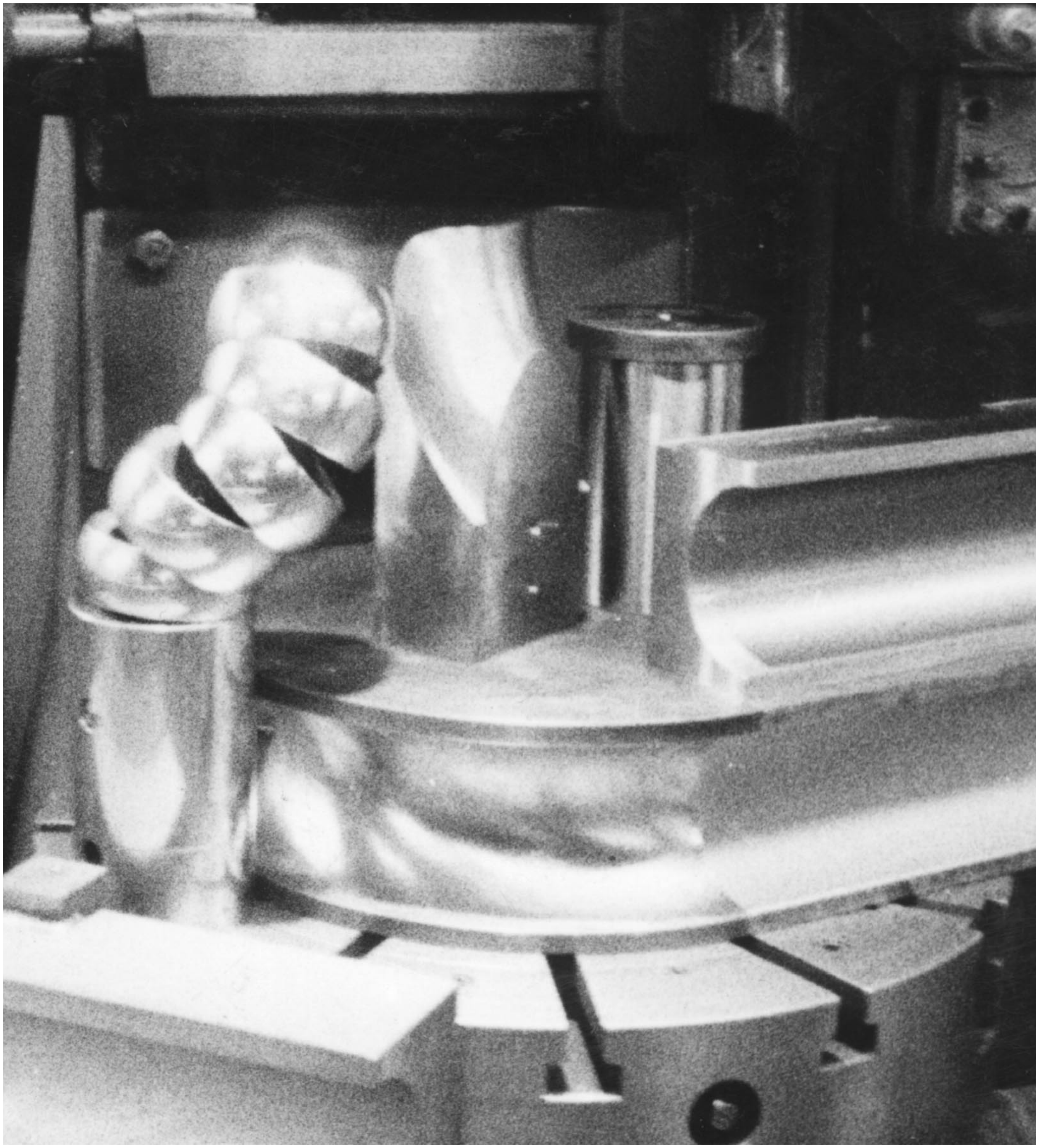
TUBE AND PIPE BENDING



- Principals - Methods - Tooling - Techniques - Developments

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Form No. 85163

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PRINCIPLES OF TUBE BENDING

There are several methods of bending tube, pipe, or extruded shapes. However, the economic productivity of a bending facility depends not only on the selection of the most effective method but also on the use of proper tooling and proven techniques. Of course, the operator is a factor, but the right equipment and tooling minimize the degree of craftsmanship and expertise required.

Two principles apply to all three primary methods - compression (Fig. 1), press (Fig. 2), and rotary bending (Fig. 3). First, the material on the inside of the bend must compress. Second, the material on the outside of the neutral axis must stretch (Fig. 4). A fourth method, crush bending, uses press bending to achieve bends.

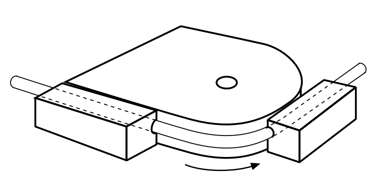


Figure 1 - Compression Bending

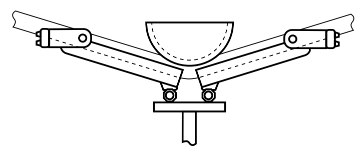


Figure 2 - Press Bending

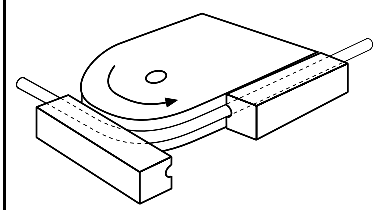


Figure 3 - Rotary Draw Bending

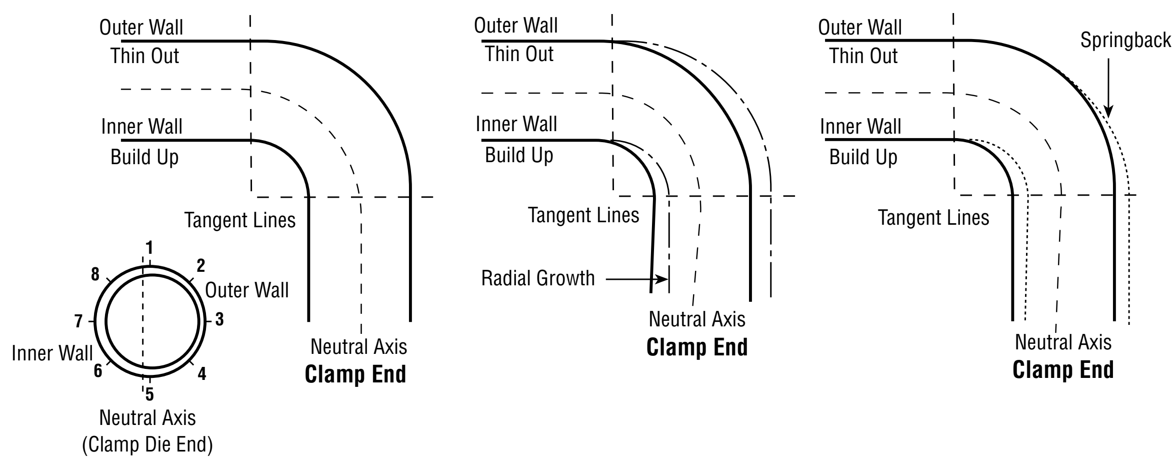
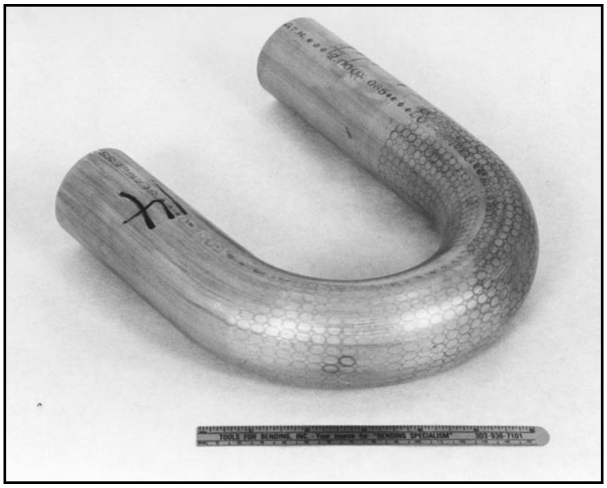


Figure 4 - These drawings illustrate the reaction of the tube to bending.

Little or no support is needed within the tube when the tube diameter is small and the wall is relatively thick. Tubes become weaker when the tube diameter increases or wall thickness decreases. In addition, when the bend radius decreases, the forces acting on the tube are effectively increased.



To visually determine the N̲eutral A̲xis, .250 diameter circles were etched on an aluminum tube (1.50 O.D.). It was bent on a 2 x D = C.L.R. (3.0") without a pressure die assist or collect boost. N̲.A̲. was @ 11:00 looking @ clamp die end. With a pressure die assist, N.A. was @ 2:00 and 12% less thinning. Please note elongated circles on the outside of bend and compressed circles on inside of bend.

Bend Die Functions

When the ratio of the tube diameter to wall thickness is small enough, the tube can be bent on a relatively small radius (CLR = 4 x tube O.D.) (Fig. 5) without excessive flattening or wrinkling of the bend. The outside of a bend tends to pull towards the center line flattening the tube. A conventionally grooved bend die supports the tube along the center line and the inherent strength of the round or square tube help prevent flattening.

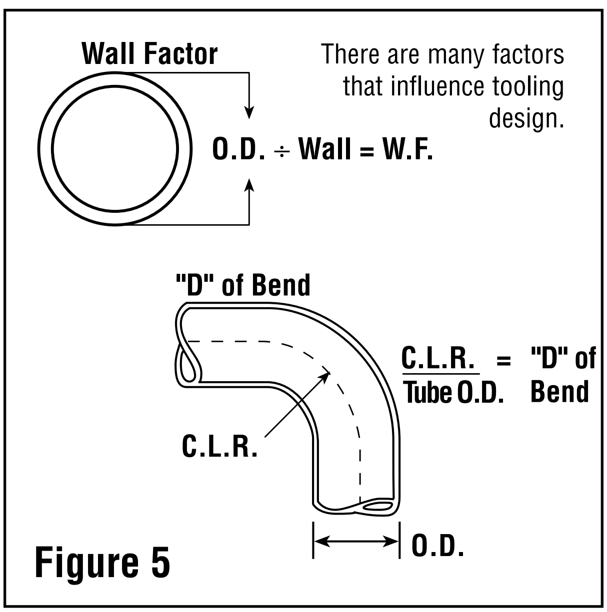


Figure 5

Compression Bending

There are three basic steps to compression bending:

(1) The work piece is clamped to a bend die (or radius block).

(2) The wipe shoe (or slide block) is brought into contact with the work piece.

(3) As the wipe shoe rotates around the static bend die, it bends the work piece to the radius of the bend die.

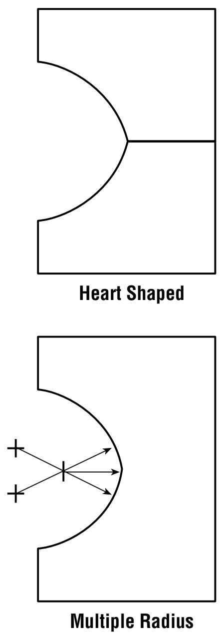
Depending on the tube and bend specifications, compression bending can range from a simple to complex procedure. It is relatively simple when the bend radius is generous (e.g. 4 x O.D.) and the wall-to-tube ratio is low. Compression bending is more complex and difficult when the radius of the bend is reduced to $1\frac{1}{2}$ or 2 x O.D. and the wall factor is as thin as 20 (Reference Tooling Selection Guide). In this situation, the tube groove of the bend die and/or the tube wipe shoe should be altered to enhance compression and stretching. Rather than a true radius in the tube groove, it may be heart shaped (Fig. 6) or multiple radius to help prevent tool marks and minimize collapse. In addition, the wipe shoe tool material should be hardened tool steel with a Kro-Lon® or hard aluminum bronze finish. Bend dies are generally made from tool steel and hardened through.

Press Bending (Fig. 2)

This method utilizes three steps:

(1) A ram die with the desired radius of bend is fitted to the press arm.
(2) The ram die forces the tubing down against the opposing two wing dies.
(3) The wing dies, with resisting pressure, pivot up, force the tubing to bend around the ram.

Figure 6 Contoured Tube Grooves



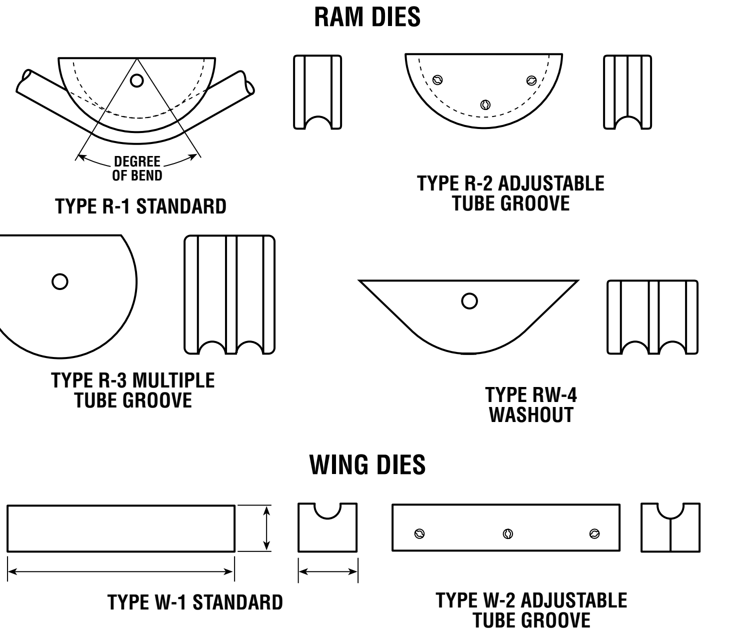


Figure 7 RAM AND WING DIES

The most common type of ram and wing die are the R-1 and W-1. The adjustable tube groove ram die (R-2) is fabricated from two plates. The plates are aligned on dowel pins and secured by cap screws. This die will accommodate variations in tube O.D. and can be adjusted for wear. The washout Ram Die (RW-4) helps eliminate inside humps but is used only for a specific degree of bend. Ram and Wing Dies are hardened 60-62 Rockwell C. Chromed tube grooves available on request. Adapters supplied when required.

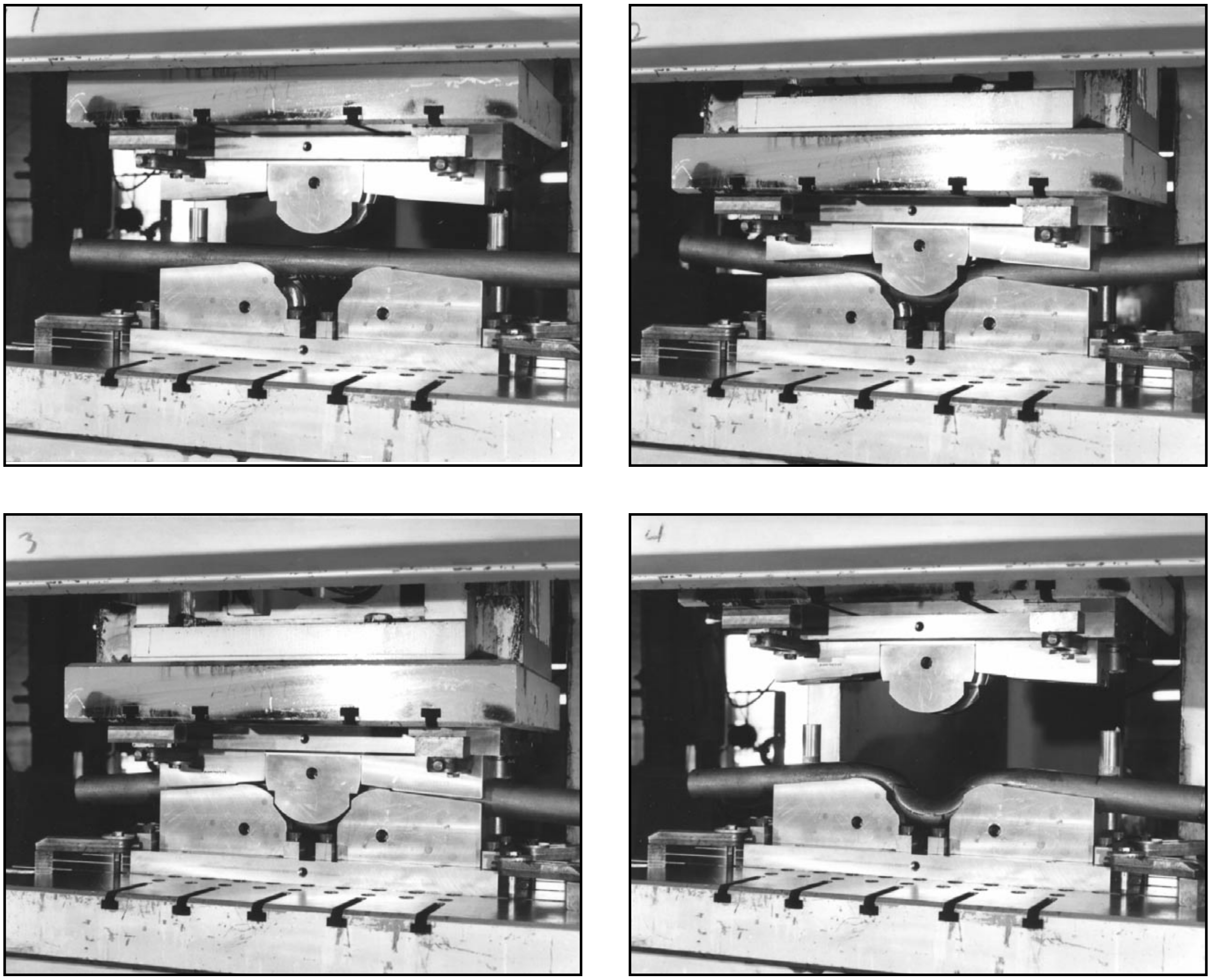
SPECIFY

1. Tube O.D. and Wall
2. Center Line Radius
3. Maximum Degree of Bend
4. Tube Material
5. Make and Size of Bender
6. Type of Die
7. Special Requirements

Tooling design is based on the desired production rate and part design (Fig. 7). When limited production is required, a half-round (R-1) ram with one case-hardened tube groove can be used. For high production rates of parts with bends in a single plane, multiple tube-groove tooling can be used (see type R-3). High-carbon, high-chrome, tool steel should be used for high production rates.

Because of its high rate of bending, press bending probably bends more miles of tubing than any other method. However, considerable distortion can occur since the tubing is not internally supported. For example, the tube may flatten on the outside of the bend and wrinkle or hump on the inside of the bend. A washout-type ram die (RW-4) helps eliminate humps on the inside of the bend at tangencies. Obviously, a washout-type ram die is designed for a specific degree of bend.

Split Ram and Wing dies (R2 and W2) can also be used to increase tool life and improve bend quality. The split construction varies “squeeze” pressure and permits adjustments for O.D. variations of the work pieces.



Ram and Wing dies for hydraulic press. One hit = 3 bends.

Washout Ram and Wing die set. Split construction to adjust for variations in tube O.D.

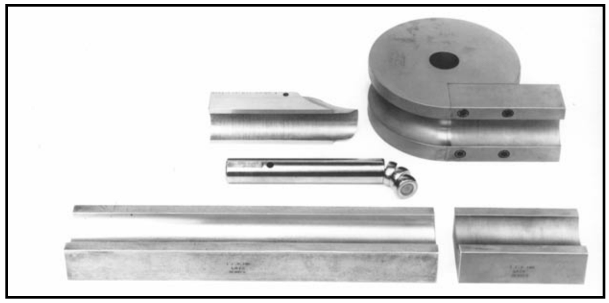
Crush Bending

In this method (as the name implies), the ram crushes the inner wall to bend the tubing or pipe. Wing dies can also be designed to produce what is referred to as a “double crush” on the outside of the bend. This can produce tighter bends but with weaker bend sections. Tooling must be designed to provide tubing material flow, minimal tool marks, acceptable bend cosmetics, and easy removal from the tooling.

Rotary Draw Bending (Fig. 8)

This is probably the most versatile and precise bending method. It consistently produces high-quality bends, even with tight radii and thin tube walls. Only three tools are required for bending heavy-walled tube to a generous radius:

(1) The work piece is locked to the bend die by the clamp die.
(2) As the bend rotates, the follower type pressure die advances with the tube.
(3) As the wall of the tube becomes thinner and/or the radius of bend is reduced, a mandrel and/or wiper are required* (Reference Tooling Selection Guide).



5 piece set rotary bending tools. Bend die, removable grit blasted clamping insert, clamp die, grit blasted surface, pressure die mirrored surface 180° of travel with 3 x O.D. mandrel chrome 3 balls "H" regular pitch wiper die square back 4130 with lube holes top and bottom.

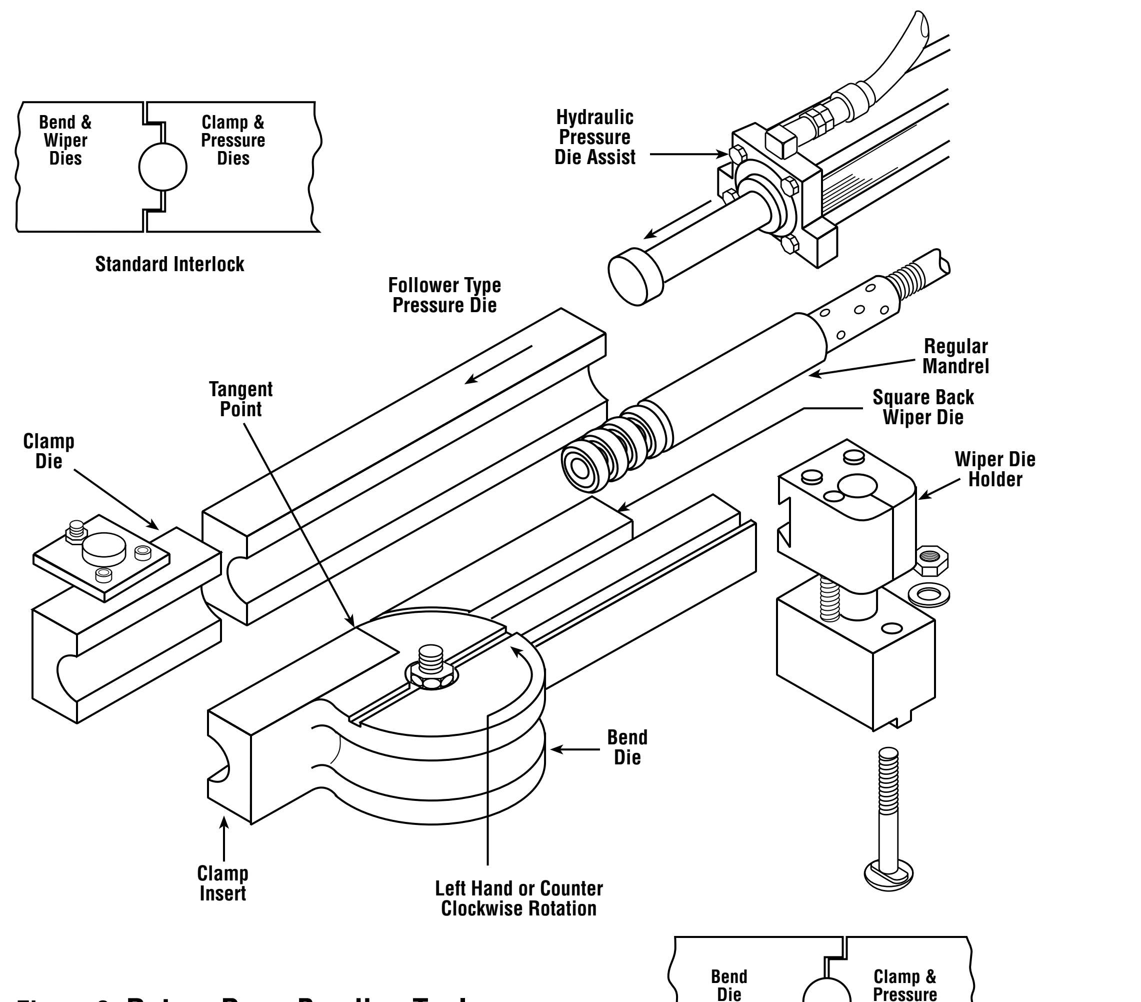


Figure 8 Rotary Draw Bending Tools

Springback Control

"Springback" describes the tendency of metal which has been formed to return to its original shape. There is excessive springback when a mandrel is not used, and this should be a consideration when selecting a bend die. Springback causes the tube to unbend from two to ten percent depending on the radius of bend, and this can increase the radius of the tube after bending. The smaller the radius of bend, the smaller the springback. Springback can be affected by the location and pressure of the pressure die (Fig. 9). This method can allow a range of radii from one bend die.

The design and manufacture of tools is influenced by several factors. Wall factor and "D" of bend (Fig. 5) are the two most critical considerations followed by desired production rate, tubing shape and material, and required quality of bends. The following example illustrates the reasons for various tool designs and bending techniques.

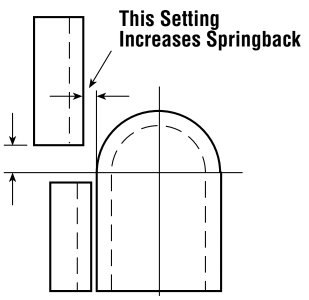


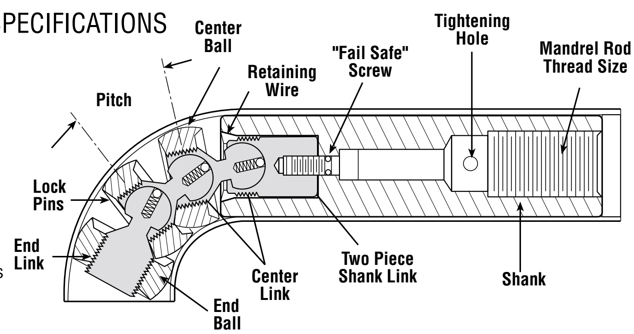
Figure 9

EXAMPLE #1

Application:

- 1.0" O.D. X .065" wall
- 1010 welded carbon tubing to be bent 90° on a 4 1/8" centerline radius of bend
- 5" legs each end
- Tooling to fit a "Wallace" bender 500 - 1 1/8"
- 120 total parts required - air vent tube.
- Wall factor 15 on 4 x D

Fig. 10-A SPECIFICATIONS



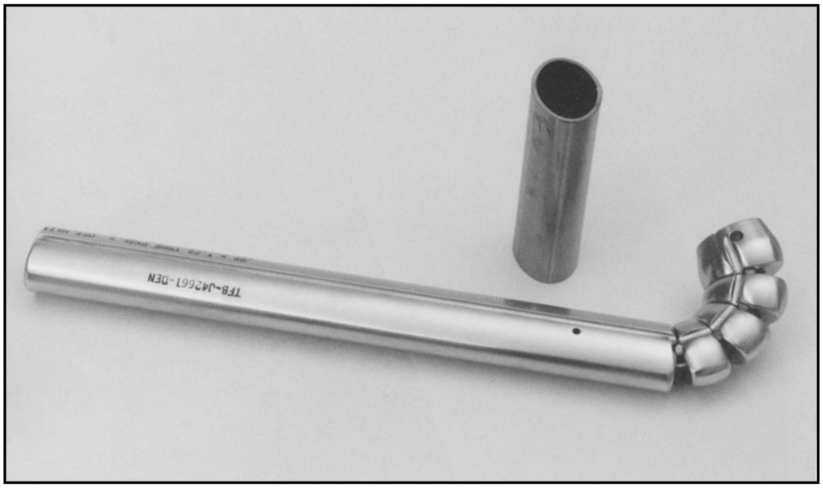
SPECIFY
- Chrome plated
- Plain tool steel
- Other
- No. of balls
- Tube O.D. size
- Wall thickness
- Tube material
- Weld flash
- Rod size
- Center line radius of bend
- Roberts Type
- H&H Type
- Brute Type

Pitch shown below is for Roberts regular mandrels. For close pitch mandrels use one size smaller. Mandrels available in tool steel with or without chrome, aluminum bronze, carbide, urethane and other special surfaces.

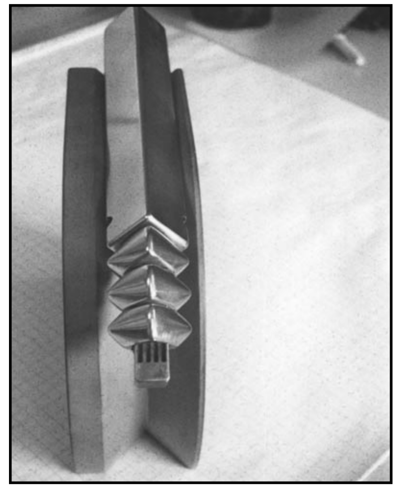
TUBE SIZE	LINK NO.	SHANK LENGTH	ROD THREAD SIZE	MIN CLR	MAX WALL	PITCH
.375	2	3"	10-24	2 x D	.028	.218
.500	3	4"	1/4"-20	1 1/2 X D	.038	.272
.625	4	4"	5/16"-18	1 1/2 X D	.042	.312
.750 thru .875	5	6"	3/8"-16	1 1/2 X D	.054	.411
1.000 thru 1.125	6	8"	5/8"-11	1 X D	.075	.460
1.250 thru 1.375	7	8"	5/8""-11	1 X D	.082	.590
1.500 thru 1.625	8	8"	1"-8	1 X D	.095	.750
1.750 thru 2.00	9	8'	1"-8	1 X D	.125	.920
2.125 thru 2.500	10	8"	1"-8	1 X D	.148	1.060
2.625 thru 3.250	11	10'	1 3/4"-10	1 X D	.172	1.400
3.375 thru 4.500	12	12"	1 3/4"-10	1 X D	.218	1.813
4.625 thru 5.250	13	12"	1 3/4"-10	1 X D	.250	2.508
5.375 thru 6.000	14	18"	1 3/4"-10	1 X D	.375	2.508

Recommendation:

- **Bend die -** Type 2, one-piece construction, 3 1/2" of clamping (3 1/2" X O.D.), 1020 material, (not case hardened because of low production and unusual radius).
- **Clamp die -** 3 1/2" long, heat-treated and nitrided alloy steel material, 50-56 R.C. Customer will use this with other bend dies.
- **Pressure die -** 3 1/2" long, static-type, heat-treated and nitrided alloy steel, 50-56 R.C. with Kro-Lon surface. Customer will use this with other bend dies. Hardening and a special surface of hard chrome and Teflon are recommended for increased tool life.
- **Tooling Set-Up -** Bend die is bolted in place. Sample tube is held in clamping area of bend die while clamp die is adjusted to proper pressure. Pressure die is located using minimum pressure. The tube should be painted with a tacky lube in the static pressure die area.
- **1st Bend:** No wrinkles, scratches or slip occurred. Clamping marks appeared, and centerline radius of bend is 4 1/2", not 4 1/8".
- **Correction -** Pressure decreased on clamp die and increased on pressure die to minimize springback.



4 ball chrome for true oval tubing. "E" plane - brute construction grooved 2 places for flash and with lube holes.



3 ball chrome, single-plane flexing. Square tube bent on "the corner".

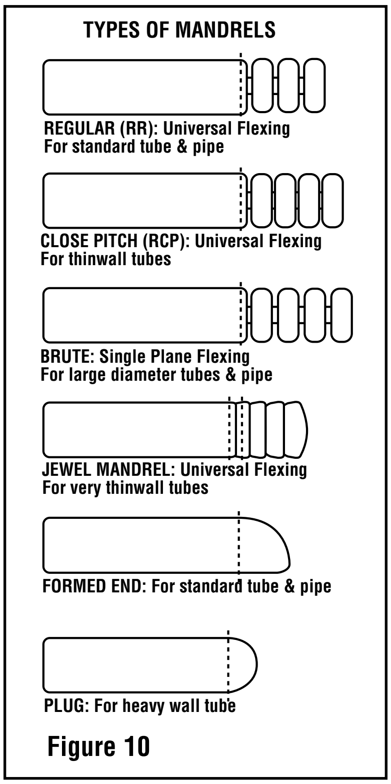


Figure 10

TYPES OF MANDRELS (Fig. 10)

Tube bending has progressed a long way from packing a tube with hard-packed wet sand. Back then, "high-tech" was a twenty-foot packing stand complete with sand-ram and water. Cable mandrels with flexing nested-saucer segments were used into the late 50's. Since then, the mandrel of choice has been the universal flexing steel-link mandrel in various forms including regular, close-pitch, ultra-close pitch. Single-plane, flexing, and brute mandrels are still being used.

Universal flexing mandrels rotate much like your wrist. Single plane-of-flex mandrels bend like your finger. It is obvious that if the ball assembly is not located and locked in-line with the bend die tube groove, expensive noises will be heard from both the machine and the supervisor.

The "Brute" mandrel is a single plane-of-flex. It is used when: ultimate mandrel strength is required, for square and rectangular tubing, and for large diameter tubing and pipe 3 inches and up.

As the wall factor increases and D-of-Bend decreases, closer ball support to the tube is improved by reducing the size and pitch of the link. For example, a regular size/pitch link will work with a 1.500" O.D. on a 1.500" CLR (1 X D Bend) x .065" wall. When the wall is reduced to .042", go to a close-pitch mandrel with links down one size from the regular size. With a .032" wall, there is another drop in link size and pitch to an ultra-close pitch mandrel.

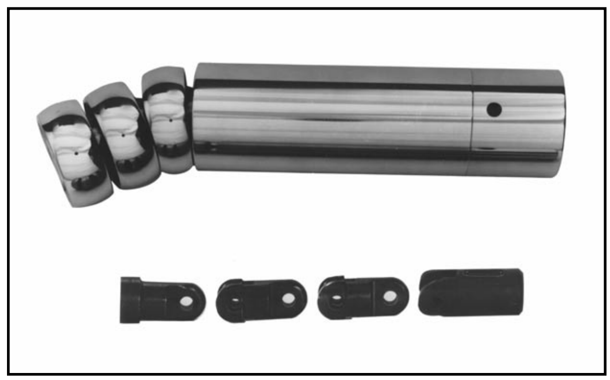
Single-plane flexing ball assemblies for mandrels 3.00" and larger are still in demand. Brute or single-plane flexing mandrel assemblies consistently stay in line with the shank for much easier tube loading. Because the balls are free rotating, wear is evenly distributed. Obviously, the link assembly will break if the ball assembly is not parallel to the tube groove.

Brute linkage or chain-link construction is ideal for non-round bending such as square, rectangular ("E" & "H" plane) extrusions, and rolled shapes. There are unique and special considerations for mandrels used in non-round bending applications - weld-flash height and consistent location, corner radius, material integrity and elongation, temper, dimensional consistency, distance between plane of bend changes and surface finish. To ensure proper tooling, users should provide their tooling source with a true representative sample of the work piece. It may

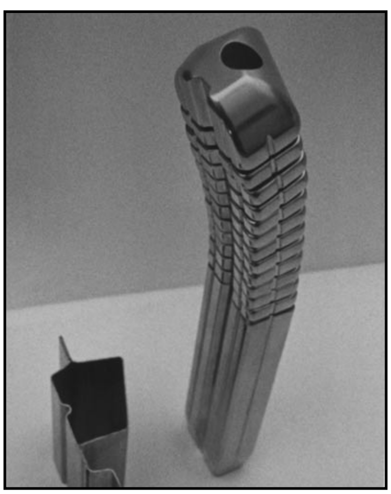
Every day "garden" variety of "H" universal flexing mandrels: Plug - 1 Ball - 3 Ball.

Ultra close pitch 10 ball universal flexing. 3.0 O.D. x .028 wall bent on 1 x D C.L.R. Ampco Bronze with through-the-mandrel lubrication.

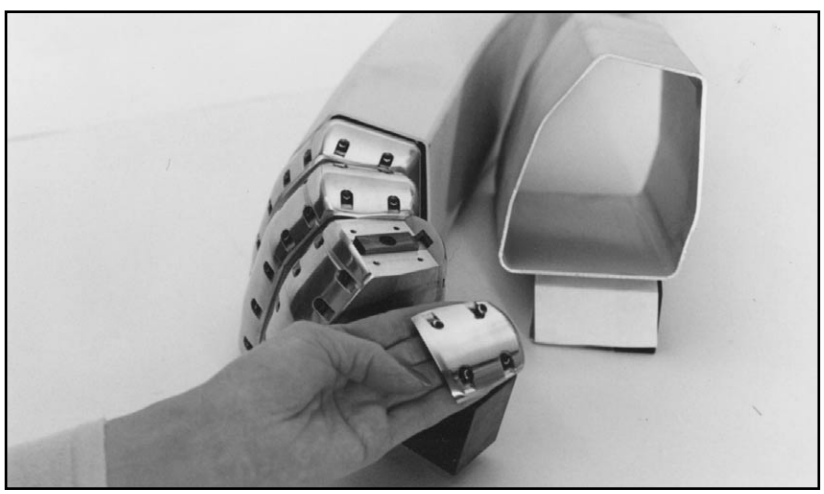
Large close pitch pipe size mandrels 5 ball chrome 12.750" O.D. x 156 wall (wall factor = 82) and a 10.750" O.D. x 134 (wall factor = 80).



"Brute" or single-plane flexing mandrel from left to right. End link - 2 center links - shank link.



Titanium Nitride coated 12 segment mandrel for fabricated shaped work piece.



4 ball chrome plated with replaceable working surfaces (4) to compensate for extrusion variation and wear.

also be cost effective to order test bending, especially for difficult bends. Even the most experienced bending operators can benefit from participating in this test bending.

Tooling has become very sophisticated and convoluted in general and particularly for mandrels used in wave-guide bending. As tube inside dimensions must be maintained, exterior tooling must be designed to allow the outer dimensions to expand.

The pressure die should be adjusted for a moderate pressure against the tube. The pressure die has three purposes. (1) It holds the tube against the bend die during bending. (2) It also keeps the mandrel from bending. (3) Finally, the pressure die maintains a straight tube behind starting tangent of bends (the portion of tubing still on the mandrel after bending).

The location of the mandrel relative to the point of bend or starting tangent affects the degree of springback. As one solution, the mandrel in a forward position (towards clamp) stretches the material on the outside of the bend more than necessary. This increases the length of material on the outside beyond what is required to make a bend. When the bent tube is removed from the bend die, it will conform to the bend die, and there will be less radial growth. Fig. 12 is an exaggerated example. The outside of the bend is actually in compression with forces acting at points A and B (Fig. 11). Counteracting forces occur at C and D. Forces A and B tend to close the bend while the forces C and D act to open the bend.

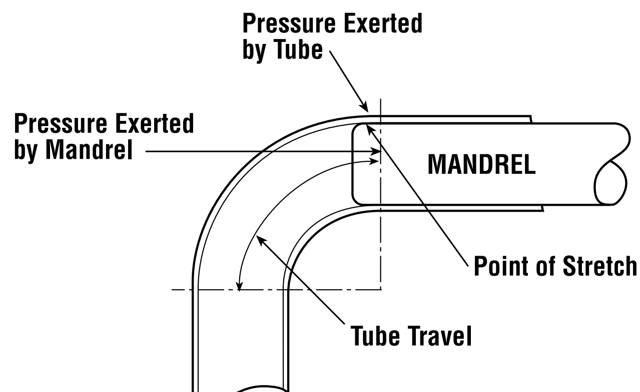


Figure 11

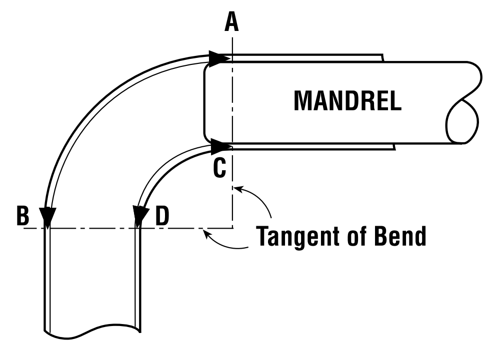


Figure 12

The mandrel in a retarded position (away from starting tangent) will not adequately stretch the material on the outside of the bend. Consequently, there is too little material to reach from A to B which puts tension on the material. Now, the forces at A and B are reversed from those shown in Fig. 12 and tend to open up the bend. This demonstrates how mandrel location can cause excessive springback reducing the bend angle and possibly increasing the radius. The mandrel must be brought forward (toward clamp) when the radius is increased. However, there is no simple formula for the exact mandrel setting so it should be determined with test bends.

When the tube breaks repeatedly, the material might be too hard for the application. Hard material lacks elongation properties and does not stretch sufficiently. Working with recently fully-annealed material can help preclude this possibility. Breakage can also occur when the mandrel is set too far forward or the tube slips minutely in the clamp die. Slippage problems are discussed later.

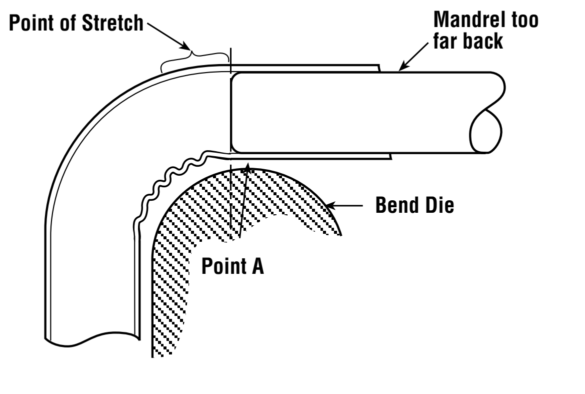


Figure 13

Problem: Mandrel Too Far Back From Tangent (Fig. 13)

When the mandrel is advanced forward in small increments, wrinkles may begin to form in back of tangent. At this point, the mandrel is not far enough forward to generate enough pressure on the inside of the bend to compress the material. Initially, the bend may be smooth, but as it progresses past approximately 20°, the material pushes back forming a wrinkle or wave at point A (Fig. 13). Continually formed and flattened between the mandrel and the bend die, the wrinkle never entirely disappears. When the bent tube is removed from the bend die and there is a large buckle or kink 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.

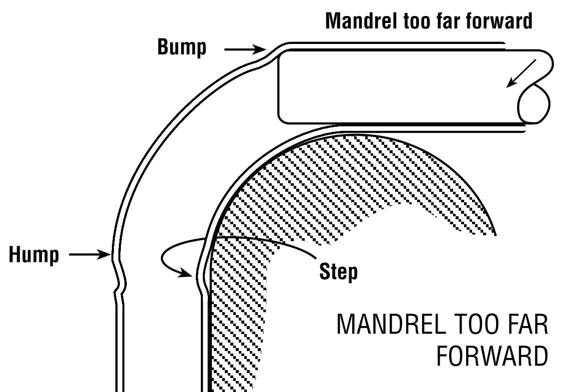


Figure 14

Problem: Mandrel Too Far Forward

Several problems occur when the mandrel is positioned too far forward. Bumps appear on the outside of the bend and are most evident at the end of bend. A step may begin to appear on the inside at the start of bend. Even though these malformations are shown on the same tube (Fig. 14), they will not always appear at the same time depending on tube material, shape of the mandrel, and bend radius. The bump is obviously caused by the mandrel shank, and the step is formed by the end of the mandrel prying the tube away from the bend die.

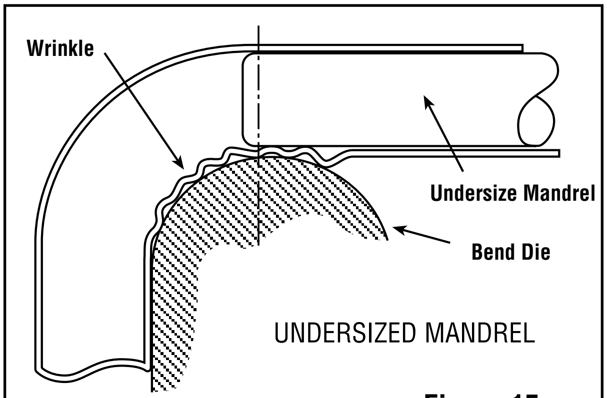
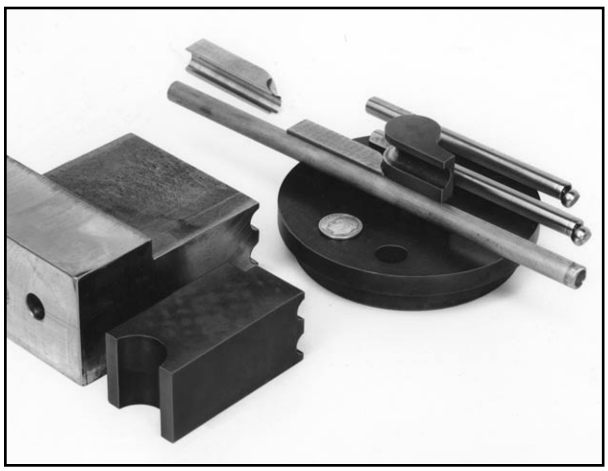
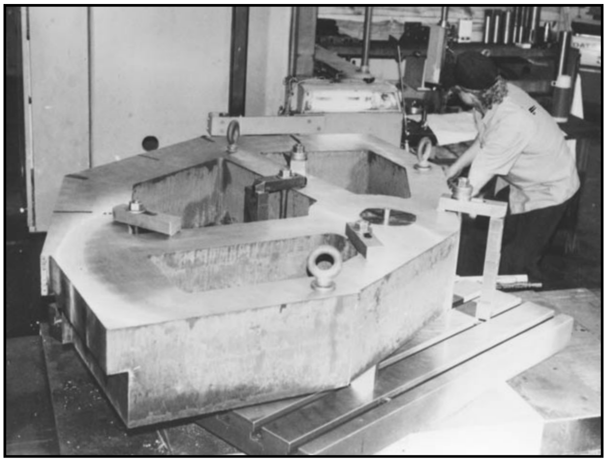


Figure 15

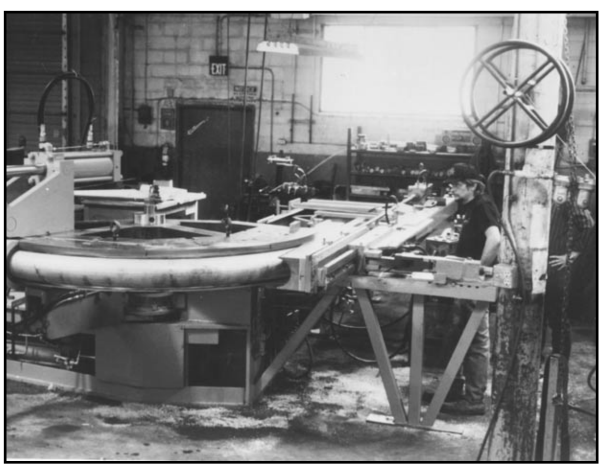


.500 x .028 on .625 C.L.R. bending 2 tubes at a time 180°. Steel wiper dies and chromed ball mandrels. A loading 2-prong fork was used to accurately locate the tubes to tangent, act as a clamping plug, and important to allow the operator to continue to play the piano.



Initial machining of a 6,500 lb. piece of steel for a 7.0 O.D. x 48.0 in. C.L.R. bend die.

Finnish machine but not hardened bend die. Test bending was done to confirm that our calculated compensation for spring-back was correct. Resulting 48" C.L.R. of bend 90° plus/minus .100 in.



Limited production bending to confirm "floor-to-floor" time and consistency of C.L.R., ovalty and minimal tool wear and marking. Note absence of swing arm by using integrally mounted over-head clamping.

TUBE BENDING USING BALL MANDRELS AND WIPER DIES

These two tools are reviewed together because, although they have different functions, they generally perform in conjunction with one another. Ball mandrels and wiper dies are used with the previously discussed tools (bend, clamp, and pressure dies) when the ratio of tube diameter-to-wall thickness exceeds a certain value and bent on a given radius. (See Tooling Selection Guide.) The wiper die is used to prevent wrinkles. The ball mandrel performs essentially like the plug mandrel with the balls keeping the tube from collapsing after it leaves the mandrel shank.

Wiper Dies

Wiper dies are available in the conventional square back configuration (Fig. 16). They allow for numerous re-cuttings of both the tube groove and center line radius. A quality wiper die tube groove is ground linearly in the direction of tube travel. While it is cheaper to radially machine this groove, this is not a good bending practice. The tube groove must be parallel to the mounting side and to the center line radius cut. It must also be parallel to the top and bottom sides, particularly when used with interlock tooling.

It is important to stress that the tip of the wiper die should be .005" to .010" thick depending on the size and material of the wiper die. The tip should never extend past tangent, but it should be set as close as possible. The CLR machined surfaces should be a given percentage larger than the root diameter of the bend die. This accommodates for rake and some adjustment for wear.

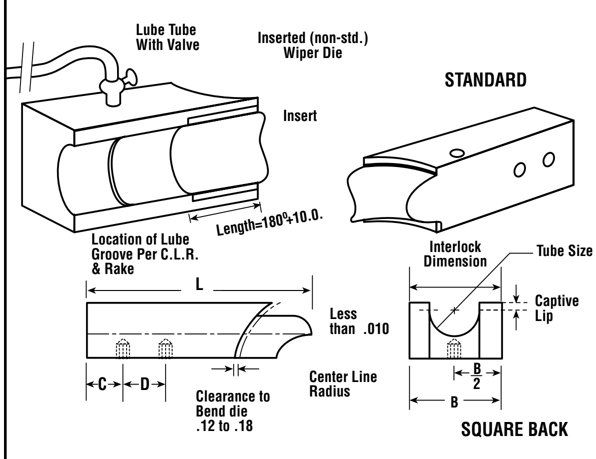


Figure 16 - Wiper Dies

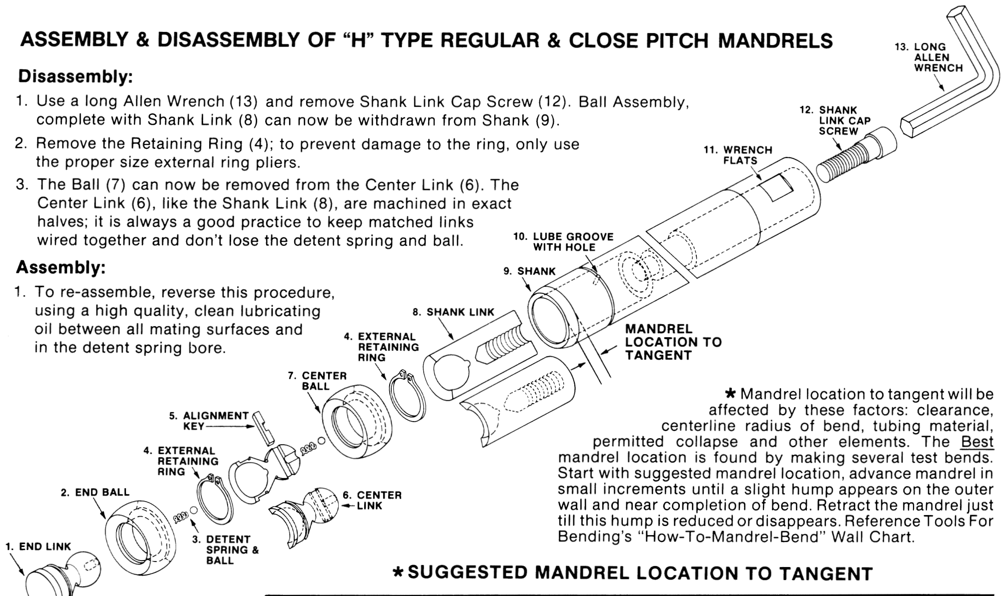
ASSEMBLY & DISASSEMBLY OF "H" TYPE REGULAR & CLOSE PITCH MANDRELS

Disassembly:

1. Use a long Allen Wrench (13) and remove Shank Link Cap Screw (12). Ball Assembly, complete with Shank Link (8) can now be withdrawn from Shank (9).
2. Remove the Retaining Ring (4); to prevent damage to the ring, only use the proper size external ring pliers.
3. The Ball (7) can now be removed from the Center Link (6). The Center Link (6), like the Shank Link (8), are machined in exact halves; it is always a good practice to keep matched links wired together and don't lose the detent spring and ball.

Assembly:

1. To re-assemble, reverse this procedure, using a high quality, clean lubricating oil between all mating surfaces and in the detent spring bore.



★ Mandrel location to tangent will be affected by these factors: clearance, centerline radius of bend, tubing material, permitted collapse and other elements. The Best mandrel location is found by making several test bends. Start with suggested mandrel location, advance mandrel in small increments until a slight hump appears on the outer wall and near completion of bend. Retract the mandrel just till this hump is reduced or disappears. Reference Tools For Bending's "How-To-Mandrel-Bend" Wall Chart.

TOOLS FOR BENDING, INC.
194 WEST DAKOTA AVE.
DENVER, CO 80223-2195

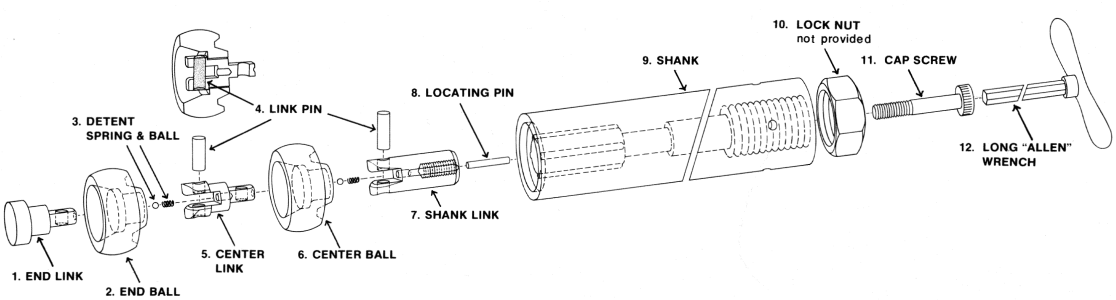
★SUGGESTED MANDREL LOCATION TO TANGENT

STANDARD PITCH MANDRELS	TUBE O.D.	¼ to 5/16	3/8 to 7/16	½ to 11/16	5/8 to 11/16	¾ to 7/8	1	1 1/8 to 1 3/8
	TANGENT	1/16	1/8	1/8	5/32	5/32	3/16	3/16
	TUBE O.D.	1 ½ to 1 5/8	1 ¾ to 2	2 1/8 to 2 ½	2 5/8 to 3 ¼	3 3/8 to 4 ½	4 5/8 to 5 ¼	5 3/8 to 6
	TANGENT	7/32	7/32	¼	5/16	11/32	3/8	7/16
CLOSE PITCH	TUBE O.D.	1 ¼	1 ½ to 1 5/8	1 ¾ to 2	2 1/8 to 2 ½	2 5/8 to 3 ¼	3 5/8 to 4 ½	4 5/8 to 5 ¼	5 3/8 to 6
	TANGENT	1/16	1/8	5/32	5/32	3/16	3/16	¼	¼

Form No. 85170

ASSEMBLY OF BRUTE MANDREL

First insert the detent springs then balls (3) in their appropriate bores. Assemble each ball and link, starting with the end link (1) and ball (2) by pressing the link pin (4) through each jointed position. After completing the ball and link assembly, the shank link (7) is then inserted into the shank (9). The cap screw (11) is then inserted and tightened. The shank can be rotated (plane of bend) to compensate for wear. When wear does occur on the shank, unscrew the cap screw (11) from shank link (7), slide shank link out of shank link bore. Notice which of the four pin locating grooves the locating pin (8) is situated in, rotate shank link groove to next groove in shank and replace locating pin. Insert shank link into shank and tighten cap screw (11). Caution: to prevent serious damage and/or costly repairs, prior to bending a tube always flex the ball assembly in and around the bend die groove and retighten lock nut (10).



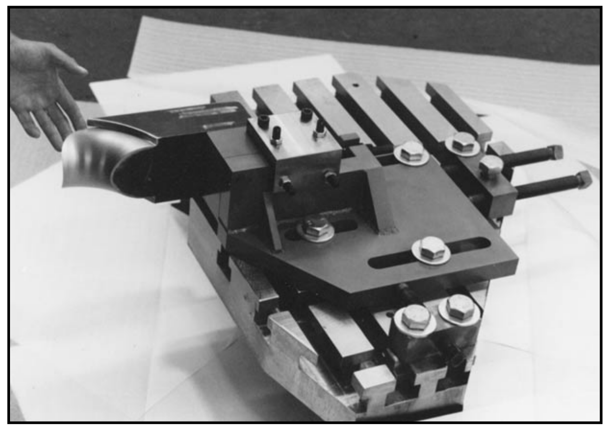
DISASSEMBLY OF BRUTE MANDREL

The ball and link assembly is separated from the shank by removing the cap screw from the mandrel rod end of the shank. Separation of each link from the ball is completed by removing the link pins from each jointed position, care should be taken not to lose the detent springs and balls.

The CLR, the surface supported by the bend die, must have a mirrored finish to avoid accelerated wear and chipping. The bend die should support the wiper die 30 to 40 percent back from the tip and should also be in radial contact slightly less than 180°. In the 1950s and 60s, round-back wiper dies were very popular, particularly for automotive applications, because they were easier and cheaper to make and to re-machine in-house. They are not as common today partly because of tighter radii, thin walls, harder tubing materials, and demand for higher quality bends.

In the early 1960s, wiper die tips or inserts made of aluminum bronze were used for bending large diameters of 4.00" and larger to gain material cost savings. The reduced time it takes to replace a tip is still a benefit. Conceptually, wiper die tips are tempting, but in reality there are problems. Many will not even fit the holder; frequently they are work-hardened and chip; and inferior materials wear out prematurely. As always with bending, this truism applies - cheap is costly and quality is cheap.

Large 5.0 O.D. and larger Ampco Bronze wiper dies for aircraft/aerospace bending. Note: double-ended wipers will be cut in half with substantial savings to customer



Steel (not cast iron) wiper die holder designed/manufactured for 6.0" O.D. bender. Easily adjusts for rake and location to tangent.

Bending Thin Wall Tubing

All of the problems outlined above are greatly magnified when making tight bends or bending thin wall tubing because containing the material during compression becomes increasingly difficult. The pressure is so intense the material is squeezed back past tangent where it is not supported by the bend die and wrinkles (Fig. 17). This area must be supported so the material will compress rather than wrinkle, and this is the primary purpose of the wiper die. Note wiper dies cannot flatten wrinkles after they are formed; they can only prevent wrinkles.

Bending thin wall tubing has become more prevalent in recent years, and 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, and the EPA has restricted the use of many good lubricants.

Tube-bending leaders are successfully meeting these challenges with innovative draw-bending techniques demonstrated in the examples that follow.

- 321 SS - 2 1/2" O.D. X .012" wall on 3" CL/R 90°
- AM 350 CRES Steel - 1 1/2" O.D. X .028" all on 1 1/2" CL/R - 180°
- Titanium A 40 - 4" O.D. X .035" all on 6" CL/R - 90°
- 400 SS - 1 1/2" O.D. X .028" wall on 1 1/2" CL/R - 180°
- Hastalloy - 3 1/2" O.D. X .028" wall on 3 1/2" CL/R - 45°
- Iconel X - 1 1/2" O.D. X .018" wall on 1 1/2" CL/R - 90°
- Aluminum 6061T6-0 - 2" O.D. X .028" wall on 1 3/4" CL/R - 90°
- 304 SS - 7" O.D. X .035" wall on 7" CL/R - 180°

Note: The most impossible bend imaginable can be achieved! However, the cost to produce it may quickly exclude it from any reasonable consideration.

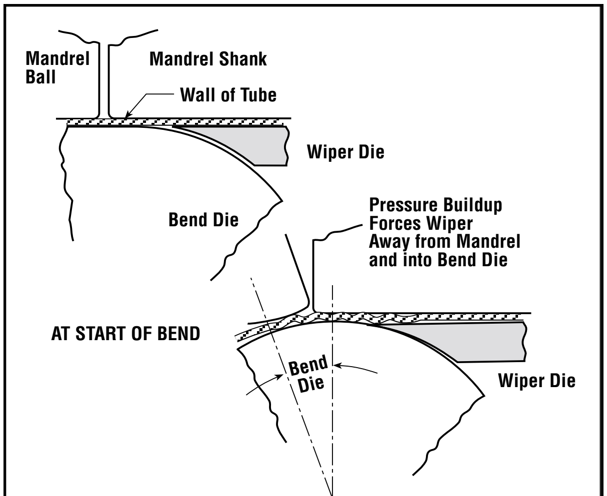
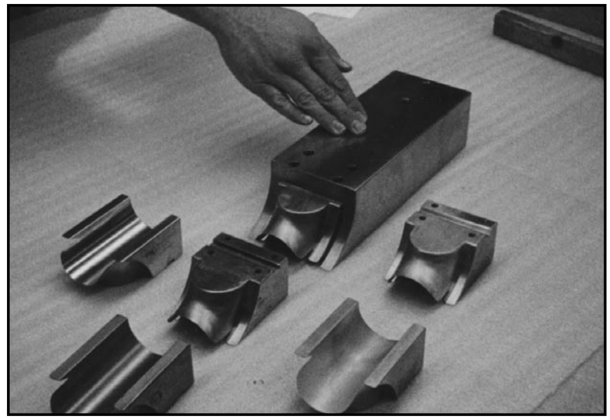
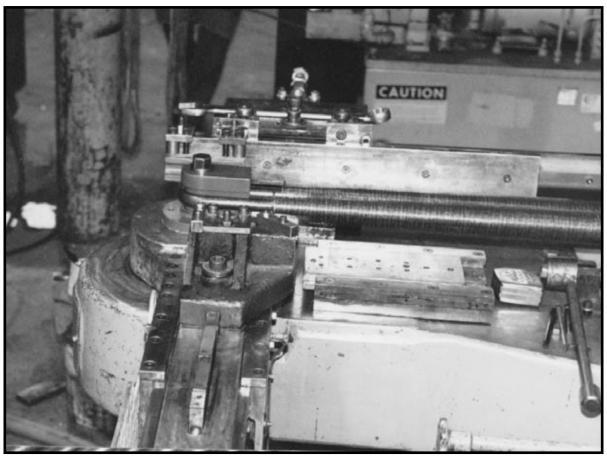
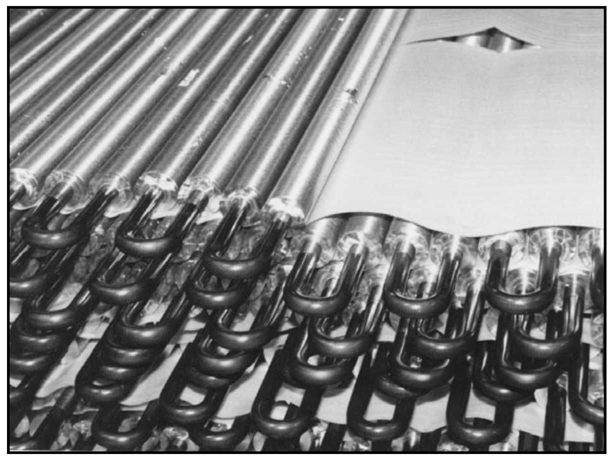


Figure 17

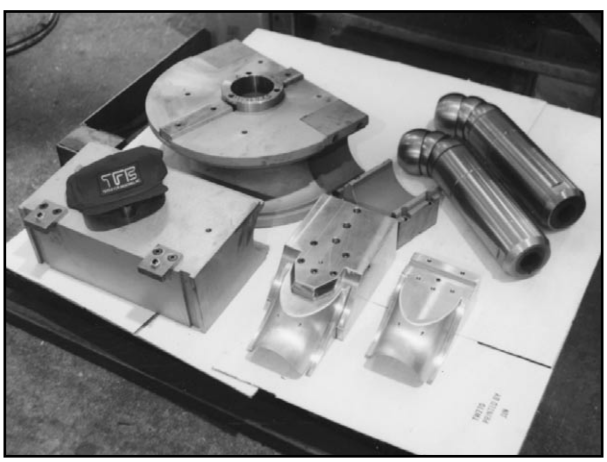


Replaceable wiper die inserts, 1.50 O.D. x 1.50 C.L.R., furnished here in Ampco Bronze - steel and Kro-Lon® for bending different tubing materials. These inserts provide superior support to the tube, wear much longer and can be quickly and accurately replaced.

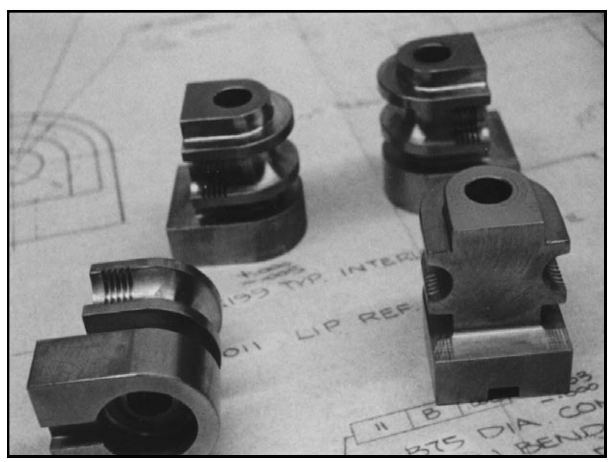




Radially-finned tubing bent to 180°. Fins were removed from bending area. Note: reverse interlock with Empty-Bending® tube grove on 1.5 x D = C.L.R.



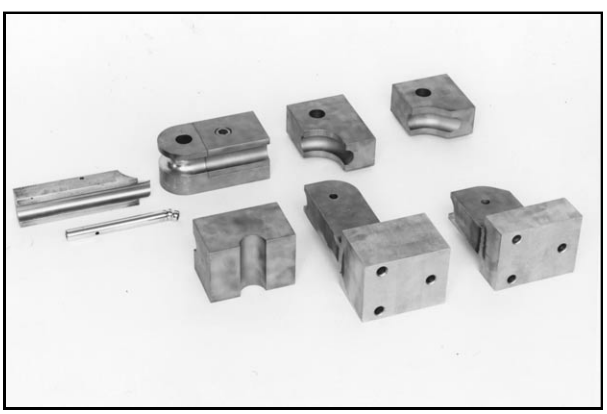
Tooling set for 5.0 O.D. x 10" C.L.R. reduced grip section using aggressive serrations. Note replaceable Ampco Bronze wiper die inserts with Kro-Lon mandrels. Both mandrels and wiper dies have lube holes.



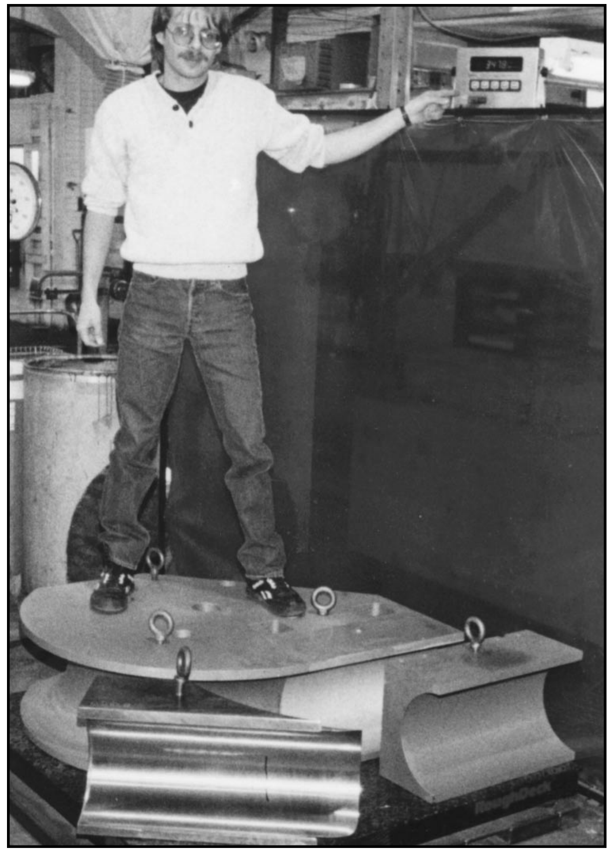
Multiple bend dies: double rotation, serrated grip section, full platform, captive lip.

5 piece tool set aerospace application. 5.0 O.D. x 1 x D (5.0 C.L.R.) captive lip, double rotation, close pitch Ampco bronze mandrels (3) and wiper die. 120° with wiper die clearance and horizontal location and lock of clamp die to clamp insert.

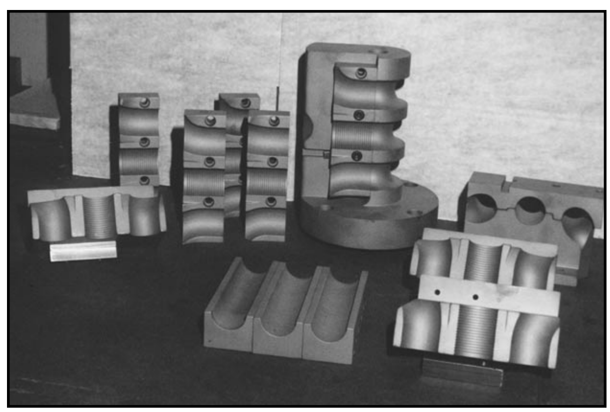
Sink-trap tooling 1.500 x 1.500 copper thin wall. Semi-platform bend die. Chromed wiper tube groove. Chromed mandrel with lube holes.



1.0 O.D. x 1.250 C.L.R. tool set with straight, 90° compound and 45° compound grip sections.

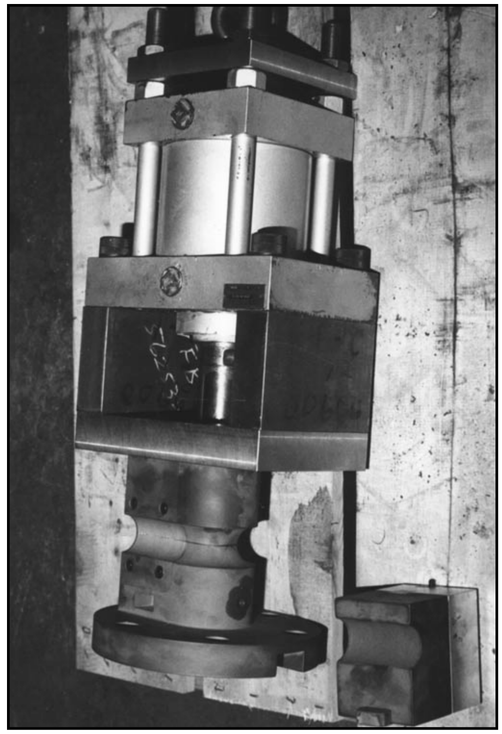


Bend die for 10" O.D. x 20" C.L.R. Ampco Bronze and steel wiper dies/mandrels for different tubing material. Only 12" grip length using serrated surface. Die set weighted 3,600 lbs.



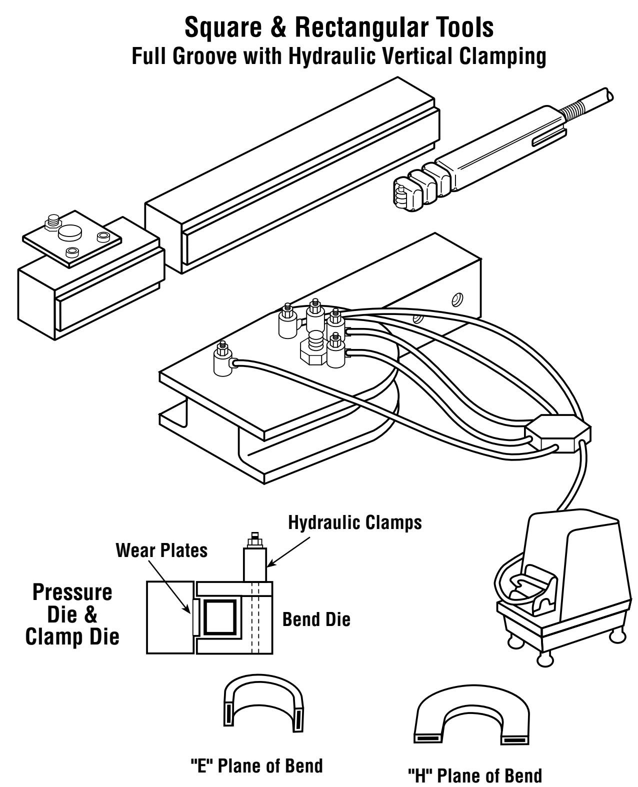
Triple stacked, C.N.C. Bender tool set. Multiple sets of double compound clamp inserts and clamp dies. Note aggressive serrated and short center clamp insert was 1st bend.

4 inch and 5 inch O.D. tooling with removable wiper die inserts, serrated grip section, reverse interlock and for pressure die assist of bender.



2.0" x 2.0 C.L.R. boiler tube 180° of bend with massive split die accuator to easily remove bent tube from die set.

In bending square or rectangular tubing, material builds up on the inside of bend and binds the tube in the bend die preventing easy removal. There are several ways to eliminate this. In leaf construction, the bend die captures one or both plates on the top and bottom of the pressure die; but this does not provide a high quality bend. A better approach is to capture three sides of the square tube in the bend die (Fig. 18). After the bend is completed, the top plate is lifted by a manual or hydraulic actuator.



Bending square, rectangular or extruded shapes are much more difficult than round tubing. Multiple ball mandrels and wiper dies are more frequently used. To help determine what tooling is required, we suggest 1.5 X Tooling Selection Guide recommendations. Bend dies are split horizontally to permit the top half to be raised and lowered. If a hydraulic split die actuator is not available, a manually operated cam lock can be furnished by T.F.B., Inc. or an independent hydraulic system.

SPECIFY
1. Tube Dimensions and C.L.R.
2. Make and Size of Bender
3. Degree of Bend
4. “E” or “H” Plane
5. Corner Radius of Tube
6. Weld Flash
7. Special Requirements

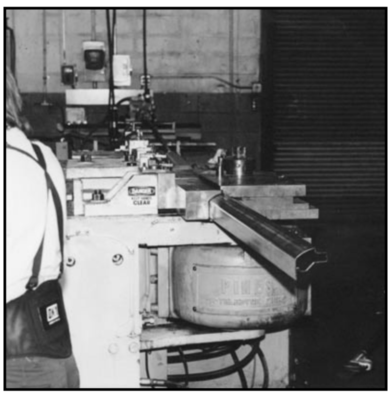
Figure 18

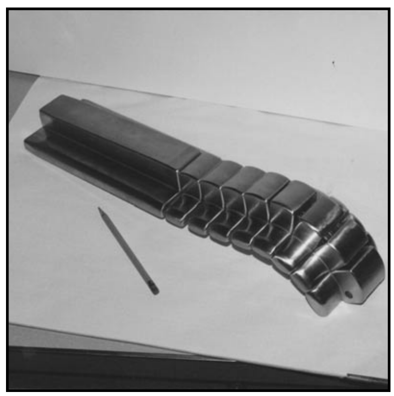
EXAMPLE #2

Application:

- 1.0" square x .035" wall - carbon steel welded and drawn.
- Two bends required, 90° each (same plane of bend), 7" inside distance between bends, 9" long legs each end, bent on a 3.0" inside radius.
- Tooling to fit a No. 1 “Pines” bender with split bend die actuator.
- Estimated production, 60 parts per hour. Long run usage is envisioned.
- Exposed part of furniture requires a good visual appearance.
- Factor (for square and rectangular tubes, used 1.5 x Tooling Selection Guide recommendations) 43 - 2 1/2" D.

Per our example, a split die actuator system is activated by small hydraulic clamps on the periphery of the bend die. This produces a bend with superior cosmetic appearance and can be adjusted to accommodate variations in tubing dimensions and tool wear.

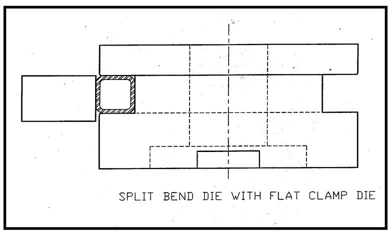


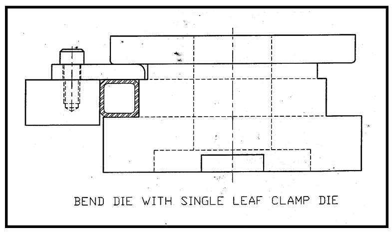


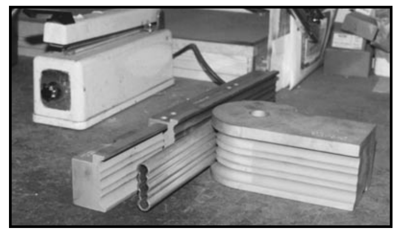
Rolled shape steel tubing. “H” plane leg in with multiple segmented mandrel.

Recommendation:

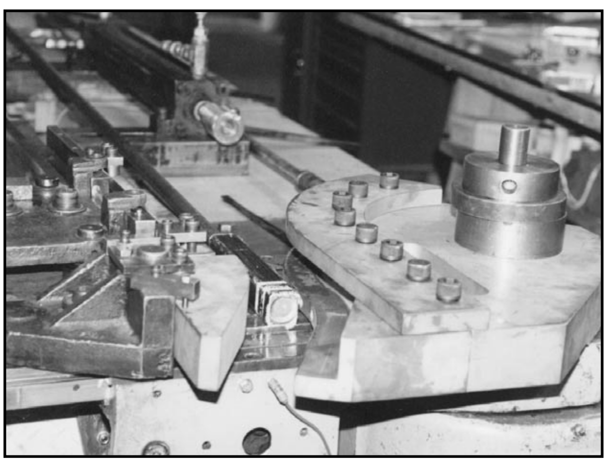
- **Bend die -** Split construction 58-62 R.C. hardness, clamping 4" long.
- **Clamp die -** Flat with hardened wear strip, 4" long.
- **Pressure die -** Follower type, flat with hardened wear strip.
- **Wiper Die -** 4000 Series alloy, 28-32 R.C. with Kro-Lon surface.
- **Mandrel -** 1 ball, single plane flexing, tool steel 58-62 R.C. with Kro-Lon surface.
- **Split-die actuator -** Complete with valve, pump and hydraulic clamps, or plumed and actuated into bender hydraulics and controls.
- **Tooling Set-up -** As in Example #1 plus adjusting split-die actuator on top plate of bend die. Location of mandrel is critical. A portion of the mandrel shank must project ahead of tangent. The amount of projection is determined by a "bend-and-try method". If a shank hump occurs on the outside of the bend at the termination of the bend, the mandrel should be retracted a small distance. A water soluble lube should be used. The tube should also be relatively clean and the weld flash facing up (neutral axis).
- **The wiper die** is the last tool to be located. A set-up bar, or a sample work piece is clamped into the bend die. With the pressure die in bending position the wiper is advanced as far forward as possible. A tacky water-soluble lubricant should be painted on that portion of the tube that will be sliding through the wiper die.
- **1st Bend -** Top and bottom of the tube bulged out .040". Wrinkling occurred on the inside of the bend.
- **Correction -** The split die actuator pressure increased. The wiper die was advanced towards tangency and pressure was added to the follower die.

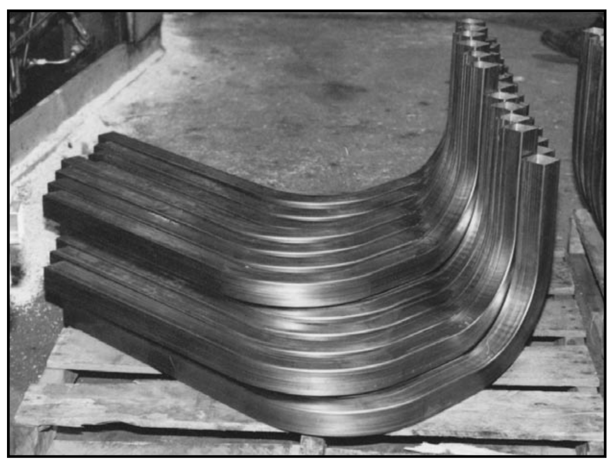






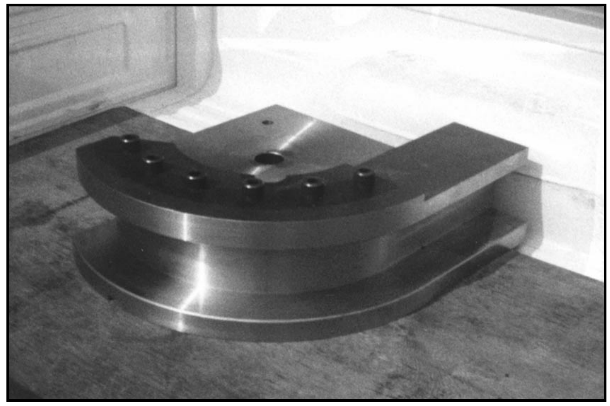
Hollow aluminum extrusion "E" plane 3" x .750 x 3" inside radius 180° of bend.





1.50" square steel tubing tool set with straight and compound grip section. In-house test bending to confirm quality of bend, distance between bends and floor-to-floor production rates.

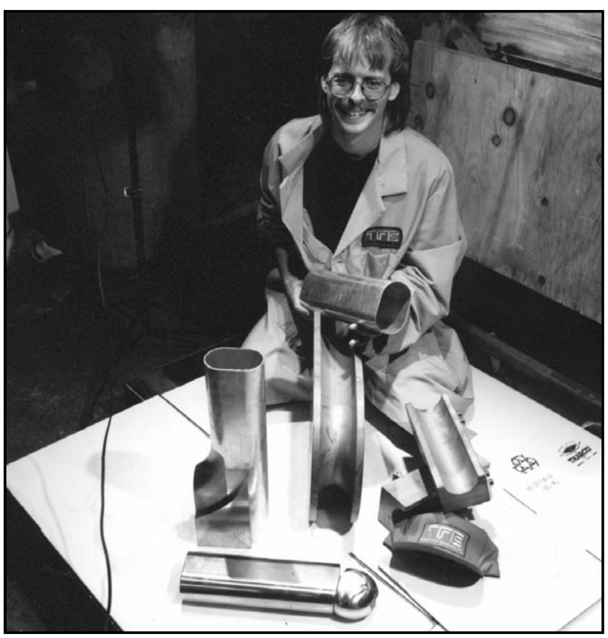
Wave guide tooling with 180° plus degree of bend capabilities. 3 ball chrome mandrel and wiper die. Note wave guide bends can accept outside dimensional growth but not inside dimensions.



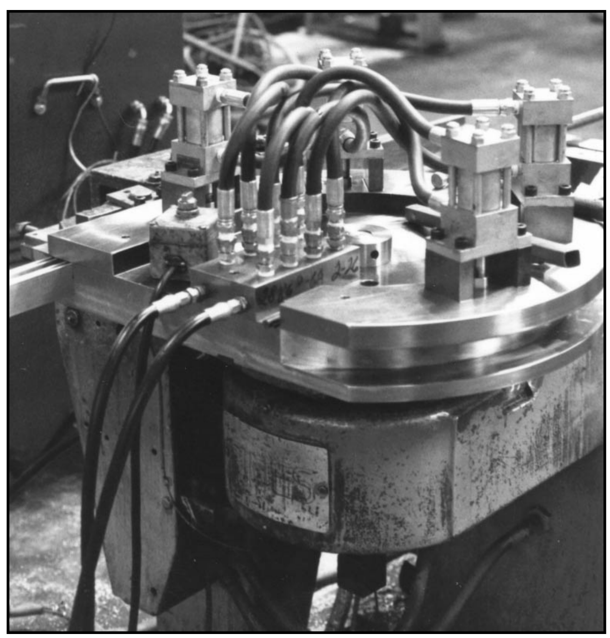
Bend die of a complete set of tools for 7 inch square with .500 wall.

Aluminum extrusion set of tools. Split bend die with hydraulic accuator, chromed wiper die and 4 segmented mandrel bent in the "H" plane.

8.50" x 1.50" open aluminum extrusion x 3.0 inside radius "E" plane used a split bend die material support.



2" x 4" flat-oval tooling set "H" plane and one segmented and chromed mandrel and wiper die.



2" x 4" rectangular tubing bent "H" plane 180° using hydraulic accuated split die construction.

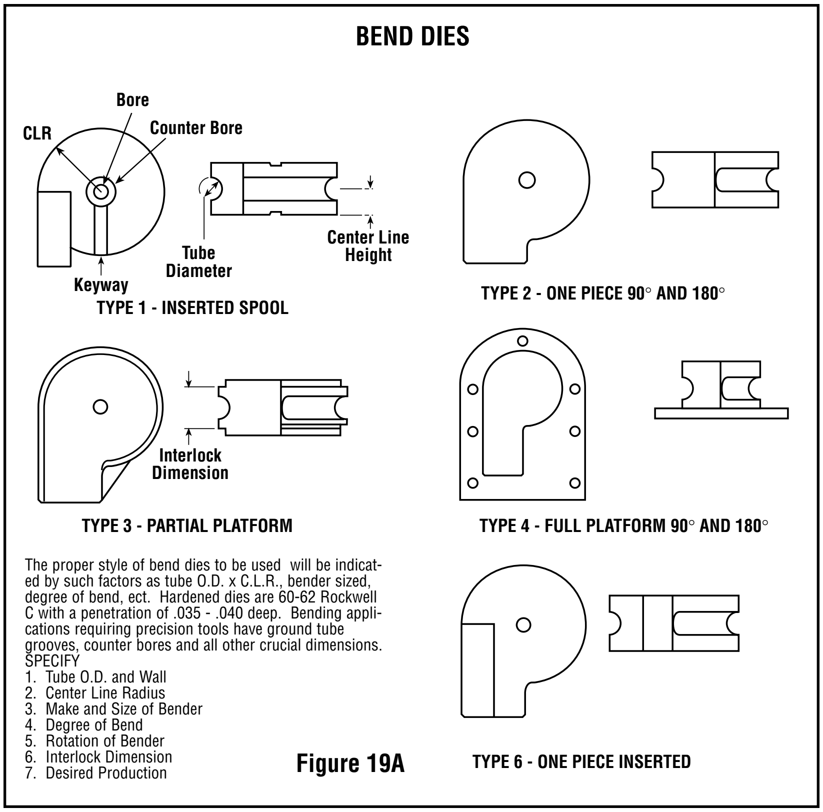


Figure 19A

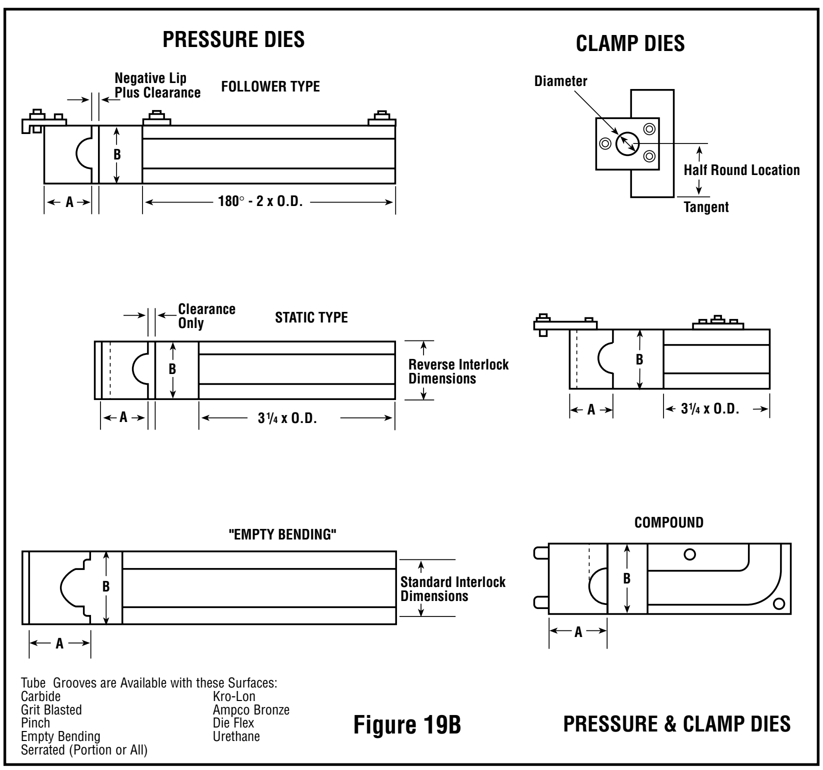


Figure 19B

EXAMPLE #3

Application:

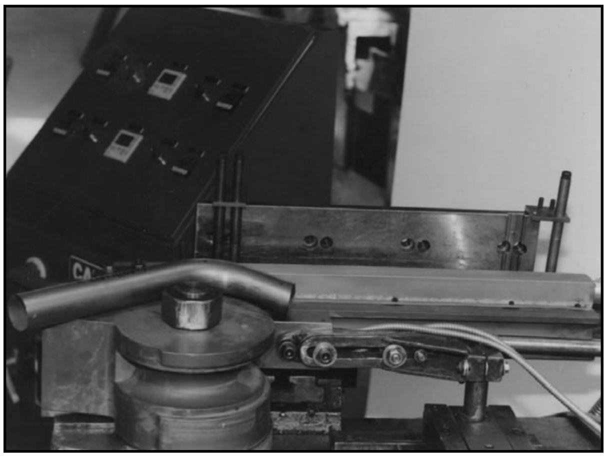
- 2.0" O.D. X .035" wall on a 2" centerline radius bend.
- Tubing material is 6061-T4 aluminum, one bend 90°, 4" long legs.
- Tooling to fit “Conrac” No. 72 with pressure die advance system.
- Total parts 2,000 pieces. Aircraft Quality.
- Factor: 60 - 1 X D

Recommendation:

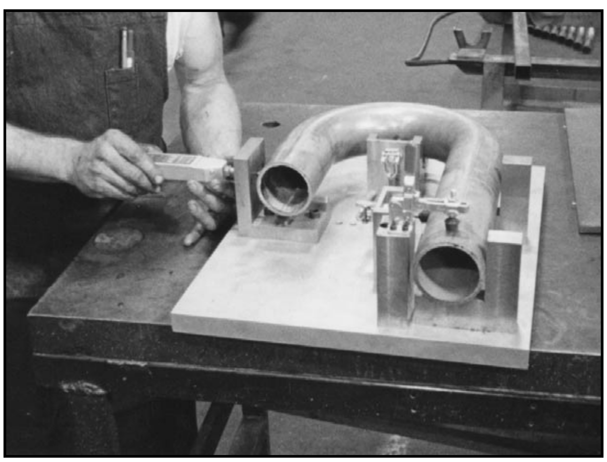
- **Bend Die -** Type 3 (Fig. 19), one piece construction with a partial platform for rigidity. Reverse interlocking for ease of set-up and quality bend. Hardened 58-60 R.C., 6" long clamp. Radius portion to have .060 lip or 1.060 deep tube groove to minimize possible tool marks.
- **Clamp die -** Light grit blast in tube groove for improved grip. Interlocked to bend die for ease of set-up and minimize clamp marks.
- **Pressure die -** Interlocked to bend die for ease of set-up. Negative lip - preventing pressure die from hitting the bend die. Tube groove with light grit blast to enhance benefit of pressure die advance.
- **Wiper die -** 4130 alloy material pre-heat treated 28-32 R.C. Interlocked to pressure die.
- **Mandrel -** close pitch series to prevent wrinkles. Four balls for additional support. Hardened tool steel with hard chrome surface to minimize drag. (Kro-Lon surface is not used for soft or non-ferrous tubing.)
- **Tooling Set-Up -** Basically the same as Example 2. However, much more attention is required to properly position the wiper die and

mandrel. The bender is fitted with a pressure die advance to increase pressure applied through the tube against the wiper and bend die without the normal drag which can stretch the wall to rupture. To conserve material and expedite production the work piece will be bent 90° on each end, clamping twice in the center, when parted making two parts.

- **1st Bend -** Excessive collapse of over 5% of O.D. occurred. Wrinkles of .040 high appeared only in wiper die area.
- **Correction -** Mandrel advanced .070. The blunt end of the wiper die located closer to the tube reducing rake. Obviously, to achieve a successful bend for this application, several more adjustments would have been made. It is prudent to make only one adjustment at a time.



Heated tool set for thin wall titanium aerospace application. In-house test bending included pressure die assist. High-temp lube complete with control cabinet and enough electrical input to dim the lights of Denver.



Checking fixture to confirm 180° of bend, parallel legs, and flatness after making 2nd 180° bend.

Thin Wall Bending Applications

Typically, aerospace and aircraft tube bending is characterized by a number of factors: (1) tight radius bends some less than 1 X D (C.L.R. ÷ tube O.D.); (2) high wall factors of 100 plus (tube O.D. ÷ wall); (3) often, too little or no straight between bends; (4) minimal permitted wall thinning (12-18 percent) and collapse (3-6 percent); (5) wide range of tubing material, many with very poor elongation (12-18 percent); (6) low production with many frequent tool changes.

Aircraft/aerospace bending 7.0 O.D. x 7" C.L.R. x .032 wall. Note full platform, reverse interlocking, removable grip section. Ampco bronze wiper die and close pitch 8 ball mandrel (not shown).

For THIN WALL tube bending, there are special considerations regarding the material to be bent. To ensure consistent tubing dimensions and characteristics, all material required for a job should be procured from one supplier, preferably from the same lot or heat number. Premium-priced close-tolerance tubing should be considered because it will often save many times the added cost. It is often cost effective to size batches of tubing that best fit several mandrels for the same O.D. and wall before bending. When the inside finish of a tube is a critical factor, the I.D. of the tube can be electro-polished before bending, and extreme care should be taken to protect the finish during bending.

Guidelines for Thin Wall Bending

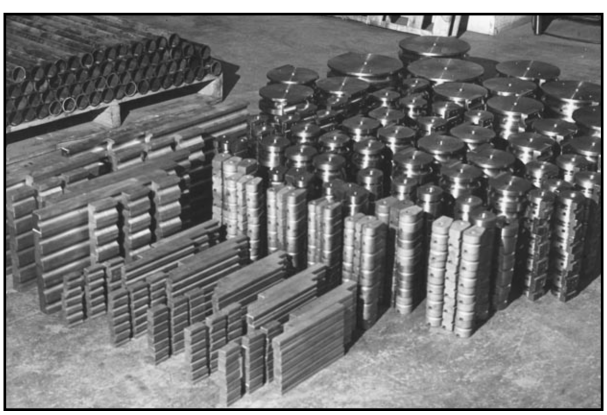
The tubing should be a firm slip fit on the mandrel and clearance should not exceed 10% to 15% of wall thickness. This same clearance also applies to the four pieces of outside tools. The tube material specifications and characteristics found in tubing catalogs are very helpful. For example, the rated ductility and elongation of a material may indicate the need for special bending methods such as heated tools, positive “Boost” bender, and even mandrel oscillation.

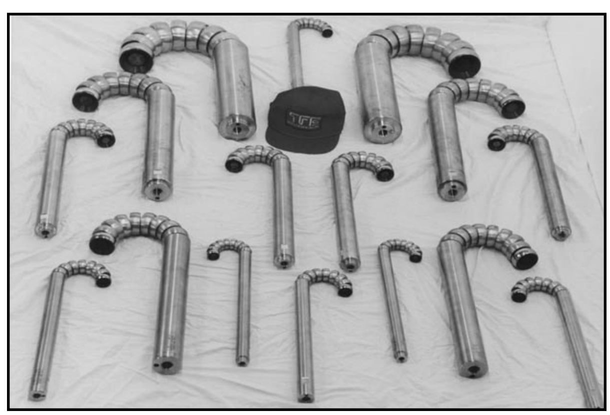
Few tube machines are capable of bending thin wall, 1 X D tubing. Even machines designed for this special bending must be in excellent condition and be large enough to assure tooling rigidity. Any sources of appreciable loss of rigidity of tooling members should be eliminated. The machine spindle should have less than .0005 inch total indicated run-out. The mandrel rod should be as large as possible to eliminate its stretching. Wiper dies and their holders must be solid. Clamp and pressure die slides and tool holders must be tight.

A full complement of controls is essential for bending thin wall tubing. The machine must be capable of retracting and advancing the mandrel with the clamp and pressure dies closed. A direct acting hydraulically-actuated pressure die is desirable because it provides consistent pressure on the tube regardless of wall variation.

A pressure die advance should also be available. This counteracts the drag of the pressure die, mandrel, and wiper die, and pushes the tube into the bending area which prevents excessive wall thin-out.

Without a pressure die advance, the normally-expected thinning is about three-quarters of the elongation of the outer wall. Therefore, a two-inch tube bent to a three-inch center line radius will thin about 25 percent, and the cross section of this bend is shown in Fig. 20. As the comprehensive yield stress is generally higher than the tensile value, the neutral axis (that portion of the tube that is not stretched or thinned out) will be inside the geometric axis of the tube. Since distortion is proportional to the distance from the neutral axis, thinning of the outside of the bend may be greater than thickening of the inside.





Certainly TFB, Inc. solves the high-degree of difficult bending applications. We also manufacture tons of standard tooling.

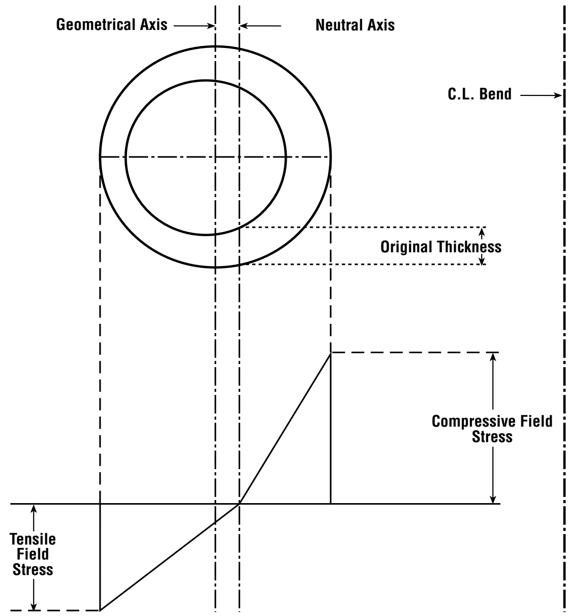


Figure 20 **Tubing Cross Sections without pressure die assist**

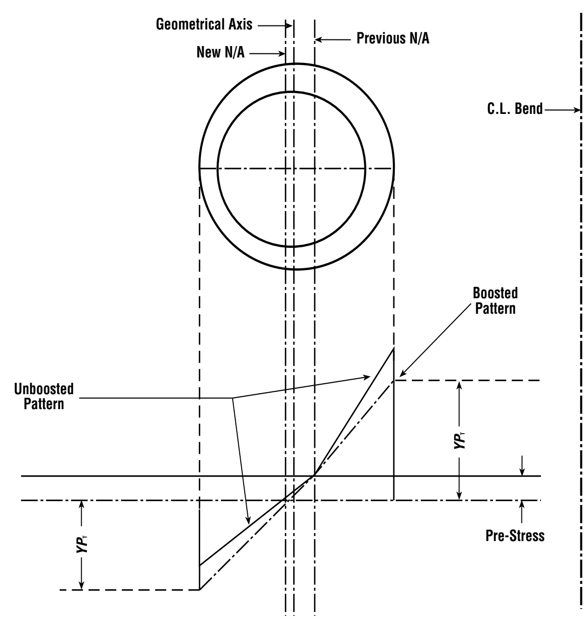


Figure 21 **Tubing Cross Sections with pressure die assist**

Reduced wall thinning using heated work piece and/or tooling

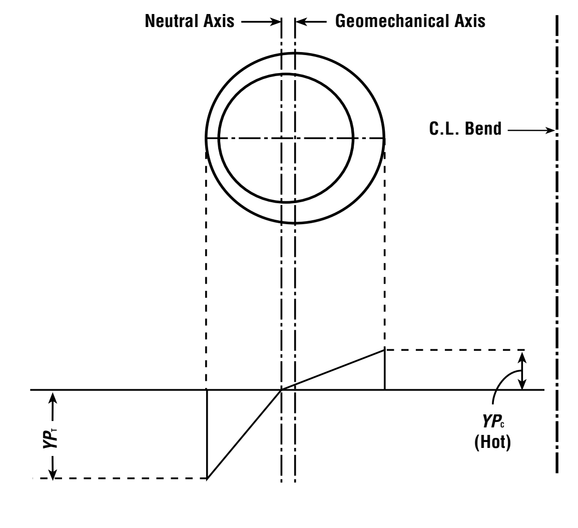


Figure 22 **Tubing Cross Sections with heated tube and/or tools**

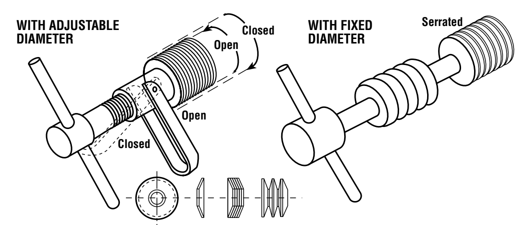


Figure 23 **INTERNAL CLAMP PLUGS**

Moving the neutral axis towards the outside of the bend will reduce thinning. Theoretically, when the neutral axis coincides with the outer wall, thinning is eliminated but heavy thickening occurs on the inside. There are two methods of moving the neutral axis. First, put the tube into compression before bending commences which modifies the stress distribution in the section as shown in Fig. 21. A second method is to reduce the compressive-yield stress of the material. This is accomplished by heating the part of the tube that will form the inside of the bend which yields a stress pattern as shown in Fig. 22.

Thinning can be substantially reduced when both methods are employed simultaneously. It is not necessary to reduce wall thinning much more than 10% so the extra advantage can be gained in terms of closer bend radii or lighter-walled tubing. The pressure-die assist should push the pressure die and tube separately or simultaneously.

A clamping plug (Fig. 23) should be used when the wall is so thin it is distorted by the clamp die or collapses under the clamp-die pressure. It also helps eliminate slippage with very short clamp dies and with less clamping pressure. A clamping plug should be a press fit. It is placed in the clamping area prior to closing the clamp die and removed before the pressure die is opened. Expanding clamping plugs are also available to make insertion and removal easier. They are designed to accommodate wall variations, as well as different walls for tubing with the same O.D.

Lubrication

Both the quality and quantity of lubricant used are extremely important. One lubricant will not work equally well on all materials. For example, ferrous and non-ferrous materials may require different lubricants. The EPA does not permit the use of some of the best-performing lubricants because of their high chlorine and sulfur content and their effect on the I.D. of the tubing. Considerable research and development resulted in special biodegradable and acceptable lubricants which are now available. The Kro-Lon® finish was developed and patented by Tools For Bending, Inc. in part to compensate for decreased lubricity and tacky agents in water-soluble lubricants. This hard chrome surface .002" thick contains Teflon (Du Pont registered trade name) mechanically trapped in microscopic fractures (Fig. 24).

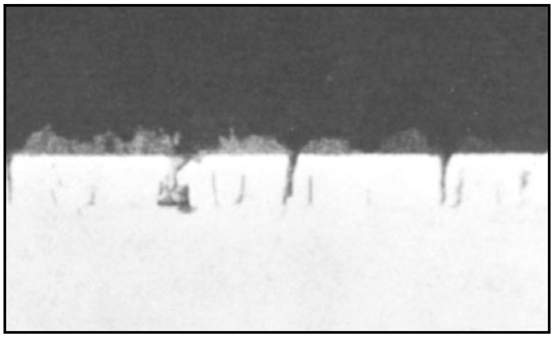


Fig. 24A
The Kro-Lon process starts with the tool first being heat - treated, ground and polished. It is then very precisely plated with a special hard chrome to a substantial thickness of .002. Controlled cavitation of the chrome plating produces thousands of microscopic openings and fissures. These openings, called micropores, penetrate the entire thickness of the plating.
The Teflon is applied by a capillary thermal-mechanical method. The micropores are all literally packed with Teflon (10 microns or less). A clear surface of physically bonded Teflon and chrome is achieved. The initial surface ratio of 60% chrome: 40% Teflon remains through the life of the plating.

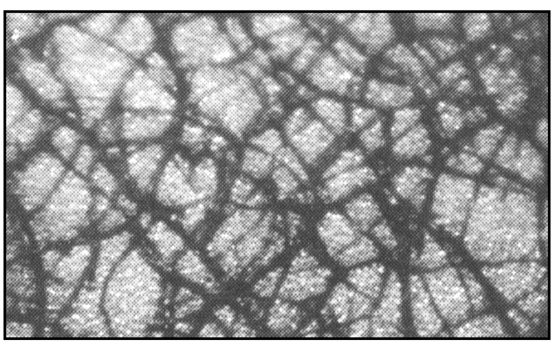


Fig. 24B
"Test Sample No. HL-57-80-2 prepared by the Kro-Lon method for Teflon impregnation of hard chrome not only had initial advantage over all other test surfaces but maintained this advantage (friction coefficient) over the entire test span."
Hauser Laboratory
Dr. T.D. Ziebarth

A controlled amount of lubricant can be applied to the mandrel and inside the tube. The lubricant must cover the entire inside of the tube. Wiper dies, and especially mandrels, can be machined to permit auto-lubrication.

Reverse interlock tooling may represent the ultimate in tube bending tooling. Complete interlock tooling originally developed for CNC benders has also proven advantageous for conventional machines. Each tool of the matching set is vertically locked in alignment. The clamp die is locked to the bend die. The wiper die located and locked to the bend die. Finally, the pressure die is locked in alignment to the bend die for a completely interlocked tool set.

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 while it provides vastly improved gripping properties. Bend die and pressure die marks on the top and bottom of the tube are reduced or completely eliminated.

With interlock tooling, the five pieces of tooling (bend die, pressure die, wiper die, mandrel and clamp die) must all be machined to close-tolerances. The bend die should have a maximum run-out at the bottom of the bend groove of not more than .005 total indicated run-out. To help prevent tooling marks at the top and bottom of the tube, the bend groove should be approximately 6 percent deeper than half the tube diameter (captive lip). The bend groove should be dead round, and the diameter should measure +.003/-.000. The clamping area should be three times tube diameter unless knurled or with other provisions such as flaring, beading, serrating, carbide spray, etc. 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 are often machined on both sides of the bend die. Center line height (C.L.H.) must be maintained for both sides.

Bend dies are available in many styles. The most common are illustrated (Fig. 19). Each style is designed for different bending requirements.

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. A variation in the thickness of the pressure die may cause a pinching or relieving effect as it feeds forward. Properly-fitted quality tooling should only require the application of containing pressure. A set-up bar or thick-walled tube may be helpful with a difficult bending set up using a five-piece family of tools. Loosen the tool holder until the vertical adjustment screw turns freely. Advance the pressure die holder in to grip the set-up bar retaining pressure. Then tighten the vertical adjustment screws. Excessive pressure on the pressure die increases thin-out, marks the tube, and affects springback.

A precision wiper die is very important. The groove through which the tube slides must be slightly larger than the O.D. of the tube, and this groove must have a high polish lubricated with a thin oil. Excessive or overly heavy oil in this area can cause wrinkles. The wiper die must fit radially to the bend with 85 percent contact from 12:00 to 6:00 and for at least 15 to 20 degrees back from tangency. If the wiper die is not supported by the bend die at this point, it will spring away from the mandrel and cause the tube to wrinkle (Fig. 17). In addition, the tube groove and centerline radius must be parallel by .002.

The proper fit of wiper die to bend die is facilitated by a solid bar or thick walled tube the exact diameter of tubing to be bent. While the set-up bar is held by the clamp die and pressure die, the wiper die is advanced to the most forward position and secured to the wiper die holder. To minimize drag, the flat end of the wiper can be brought back from the pressure die or “rake”. The amount of rake or taper is checked by placing a straight edge in the core of the clamp groove so it extends to the rear of the wiper. Then the amount of rake is readily visible.

The softer the tubing material, the less rake, and the harder the tubing material, the more rake. The feather edge must be as close to tangent as possible, obviously never past tangent. Wiper dies made of AMPCO Bronze material also help minimize drag and prevent galling (see Fig. 17). Wiper dies made of 4130 have proven to be very effective with considerably less wear than mild steel or AMPCO Bronze. Use no more than a minimum amount of high quality drawing lubricant as excessive oil can cause wrinkles. Wipers can be furnished with auto lubers. Whenever the wiper is not on the bender, it should be protected with a section of tube taped into the tube groove. Tape this tube to the wiper when returning for re-machining.

When using a universal flexing ball mandrel, it should have a clearance of approximately 10% of the wall thickness of the tube to be bent. There should be enough balls on the mandrel to support the tube around 40% of the bend.

AMPCO Bronze is often preferred for stainless applications to reduce friction and prevent marking. Hardened steel with chrome or Kro-Lon finish is recommended for commercial bending of carbon steel. Mandrels with a high polish hard chrome surface are used with non-ferrous materials such as aluminum, copper, etc. Mandrel settings are partially determined by the tubing materials and radius of bend. A template of the desired inside radius helps determine the initial mandrel location (Fig. 25). Project the mandrel shank past tangent to achieve the full benefit of the shank and protect the ball assembly from breaking.

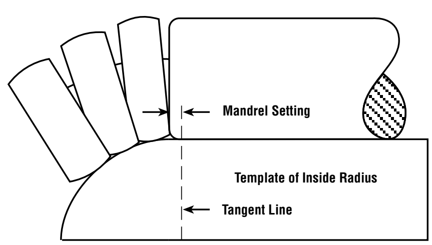


Figure 25

Let’s assume we have now located all the required tooling. We are not using either the mandrel oscillator or internal clamp plug.   We will certainly use the pressure die assist.

Push a tube back and forth over the mandrel to distribute lube and check for fit. As the clamp die and pressure die come up against the tube, make sure the bend die is not deflected by this force. Scribe, with a red marking pen, three (3) rings, each about .125" apart on the tube projecting out of the clamp die to indicate the amount of creep or slippage.

Before pressing the bend button, quickly check the tool set-up again (the mandrel is in the advanced or start position), the swing arm has been set to a very slow R.P.M. to allow checking, that the pressure die is not over running the tube, that the clamp die and pressure die do not touch the bend die, that there is no clamp slippage, that the rake in the wiper die is maintained. After completing the 90° bend, feel the tube.

If it's warm, OK; if it's hot you have too much drag and the pressure die assist can be increased or more friction or grab is required between pressure die groove and tube. Extract the mandrel from the bend area only with the pressure die and clamp die in clamped position. Remove the tube and inspect the bend die and wiper die with swing arm still at a 90° bend. Look for "lube wrinkles" in the tube groove of the bend die, wiper die chips, tube marks in wiper die which can confirm rake. Now examine the bent tube with the same scrutiny and logic. The bent tube is your best primary source for information.

Measure for collapse and wall build-up, as well as for wall thin-out. Inspect the tube I.D. for galling or other tool marks. Make the corrections to the tool set-up (only one at a time) with logic and common sense, (and don't swear too much). The page entitled Corrections for Poorly Bent Tubes is also available as a wall chart. It illustrates some of the more obvious errors and corrections to set-ups. If you need this free wall chart, please ask. A close examination of the bent tubing, inside and out, often reveals where your problem lies.

A cost effective, precision bending facility is achieved only with a little extra work, a lot more thinking, but not much more money. You get more bends for bucks ($).

EMPTY-BENDING®

After years of research, TFB has developed and patented a system of bending tube/pipe that is compatible with the material flow. The outer wall of the tube wants to stretch or thin out (Fig. 26). When it does, it also tends to collapse.

An Empty-Bending pressure die compensates for this by having a proprietary-designed, multiple-radius and a round tube groove (Fig. 27). It does not have a tube groove that is a true radius or heart shaped for the length of the die. The multiple radius tube groove forces the tube/pipe to bend, but only touches that portion of the tube that has the least tendency to collapse. The very outer wall of the tube is NOT in contact with the die and receives the least bending pressure. The surface of the tube groove is conditioned to provide maximum grip or traction to the tube. This allows much more pressure die assist force to be used, which minimizes wall thinning and collapse.

To bend a tube/pipe, the inner wall must compress. Like the pressure die, TFB's Empty-Bending bend die also has a true radius and a multiple radius groove (Fig. 27). The multiple radius groove forces the tube to assume a configuration that induces material compression and can also eliminate wrinkles. In bending heavy-walled pipe, this proprietary design also provides a space that allows the material to thicken.

Testing and field reports have demonstrated that Empty-Bending does minimize wall thinning, reduces tooling set-up time, reduces required clamping lengths and eliminates mandrel and wiper die humps and scratches. Empty-Bending can also bend a "lower" elongation tubing than with conventional dies.

Obviously, a bending lubricant is not used, a big savings from applying the lube and de-greasing operations.

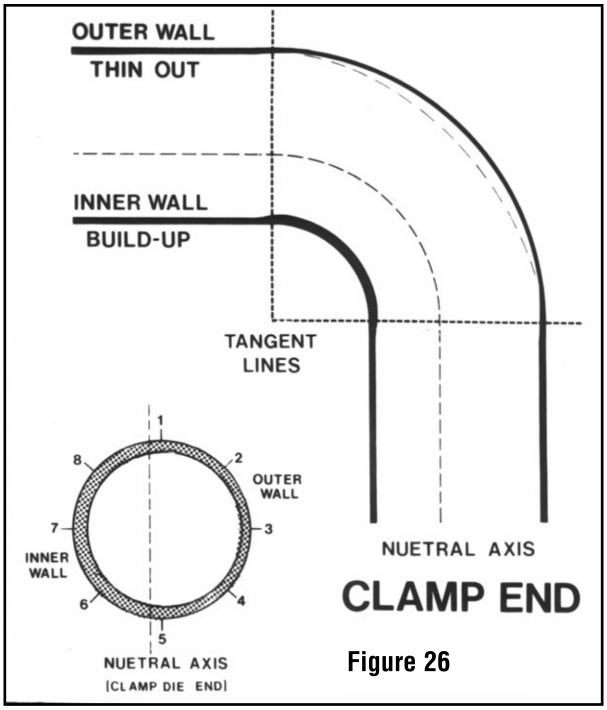


Figure 26

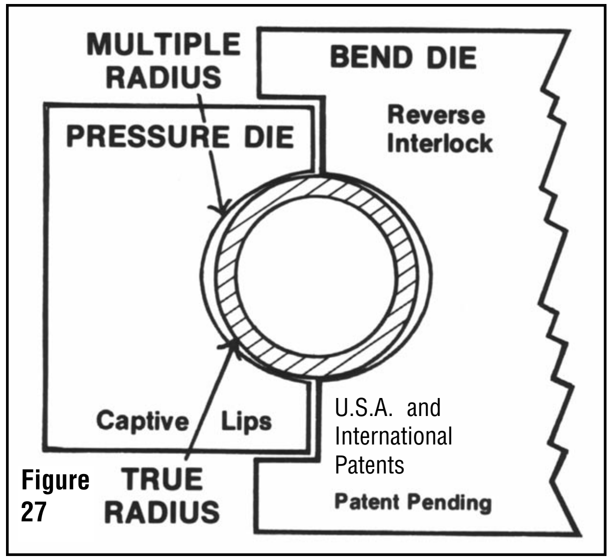
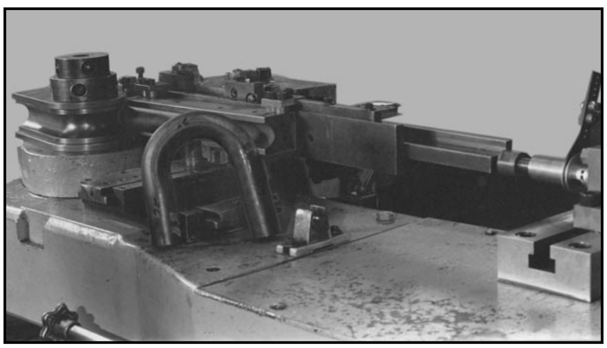
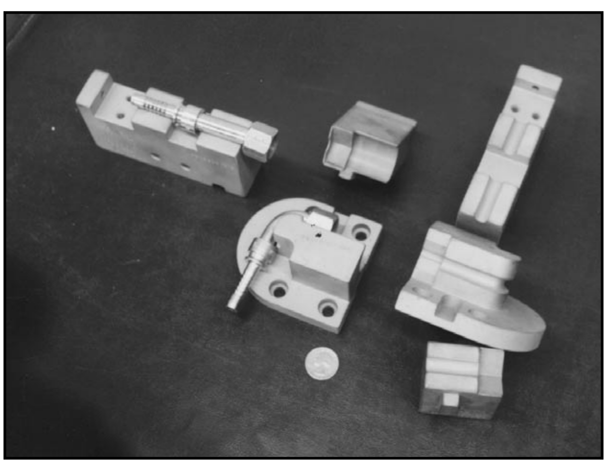


Figure 27

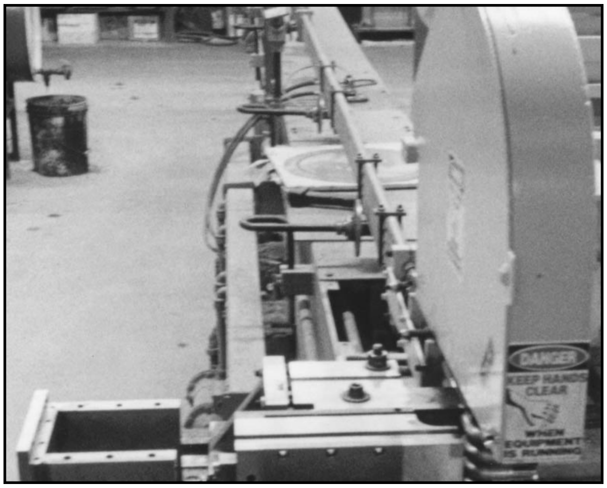


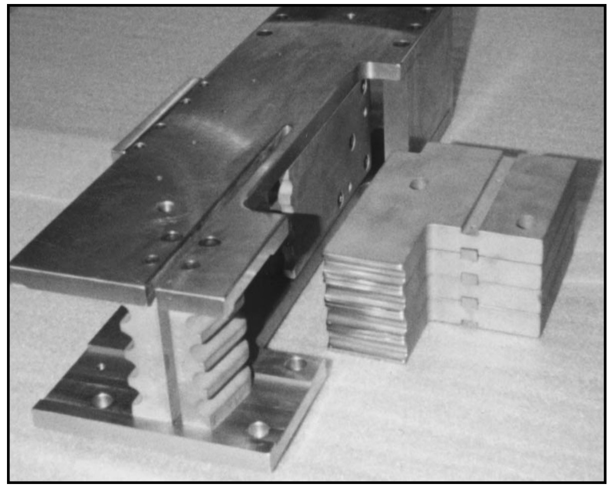
Empty-Bending for boiler tube 2.125 O.D. x .180 wall on 2.250 C.L.R. Note in-line pressure die advance cylinder reverse interlock.

Educated or controlled wrinkle set of tooling with Empty-Bending tube groove serrated grip section and reverse interlocking in Empty-Bending section.

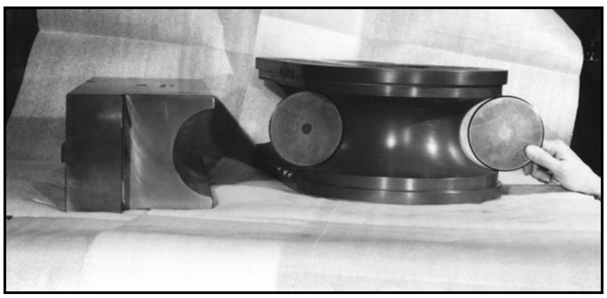


Empty-Bending tool sets for one-piece fittings on conventional bender.





Empty-Bending tube grooves in 4 tubes at a time tool set fitted to Hines bender with auto cut off.



Empty-Bending tool set for 4.5 O.D. x 6" C.L.R. plastic-lined pipe. Note radius gauge on left shows true radius tube groove; on right it shows multiple radius tube groove.

CAUTION

GENERIC TOOL HOUSES AND GARAGES HAVE ATTEMPTED TO FURNISH LOOK-ALIKE EMPTY-BENDING TOOLS... WITH DISASTROUS RESULTS. ALWAYS DEMAND TRUE EMPTY-BENDING TOOLING MADE BY THE PATENT-HOLDER, TOOLS FOR BENDING, INC.

CAUTION

Empty-Bending® Applications

NOTE:
(O.D.÷ Wall = Wall Factor) ÷ (Center Line Radius ÷ Tube O.D.) = Empty-Bending Factor

INDUSTRY	O.D.	x Wall	x CLR	Material	E-B Factor	Collapse Percent	Thin-out Percent
AIRCRAFT	.250	.020	.750	321-S.S. 3AL-2.5 Ti.	4.2	.8 to 1.5%	6%
	.250	.028	.750	6061-T6	3.0	2.5%	6%
	.375	.019	1.125	3AL-2.5 Ti. 321-S.S.	6.6	1.5%	8%
	.375	.020	1.125	21-6-9 S.S.	6.3	2.5%	8%
	.500	.028	1.50	321-S.S.	6.0	3.0%	8%
	.500	.035	1.50	6061-T6	4.8	2.5%	8%
	.625	.032	1.875	321-S.S.	6.5	2.7%	8%
	.625	.035	1.875	6061-T6	6.0	1.5%	8%
AIR CONDITIONING & REFRIGERATION	.375	.034	.750	COPPER	5.5	2.5%	7%
	.500	.028	.750	COPPER	11.9	3.0%	10%
	.500	.045	.750	COPPER	7.4	2.5%	10%
	.625	.035	1.125	COPPER	9.7	4.0%	10%
AUTOMOTIVE	.312	.028	.472	MILD STEEL	7.4	3.0%	9%
	.375	.028	.551	MILD STEEL	8.9	3.8%	10%
	.500	.035	.750	MILD STEEL	9.5	4.2%	11%
	.750	.049	1.500	MILD STEEL	10.0	4.1%	12%
BOILER TUBE	2.00	.227	2.0	321-S.S.	8.8	7.0%	13.5%
	2.00	.160	2.5	STEEL	12.0	7.0%	12.0%
	2.00	.110	3.0	STEEL	12.0	8.0%	11.0%
	2.125	.180	2.25	STEEL	10.7	11.5%	13.3%

SPEEDSHIFT TOOL SETS®

Speedshift Tool Sets® provides Just In Time manufacturing for rotary tube bending machines. In just five (5) minutes or less, a five piece rotary bending tool set can be changed. As an example: from the last good bend produced from a 2.00" O.D. tool set to the first good bend from a 3.00" O.D. tool set, it should take only five minutes. Without Speedshift Tooling each of the 5 dies are mounted to the bender separately.

Many tooling set ups can take hours, particularly the mandrel and wiper die. With Speedshift Tooling all tools are locked in their exact bending relationship, lifted off as an assembly and removed from the bender. The next set of tools are immediately lowered and secured on the bender.

The wiper die is attached to the wiper die arm, which is integral to the bend die. The multiple ball mandrel has a quick connect that also positions it for optimum bend quality. Load sending cells can be fitted that will assure quick and accurate adjustments for clamp and pressure die forces. Die serving carts or fork lift attachments are matched to the size and capacity of the benders (Fig. 35).

Speedshift Tool Sets® are our most recent development (patent applied July, 1996) and first shown at September's I.M.T.S., 96. Reactions were very enthusiastic. It was necessary, however, during this exposure and worthy of reiterating now, that portions of the Speedshift Tool Set concept can be used separately. Obviously the quick-disconnect mandrel attachment can be used by itself. The bend die, having a wiper die arm with the wiper die securely located, can also be used separately. It should also be noted that the Speedshift Tool Set design, in some instances, can be retrofitted to existing tools.

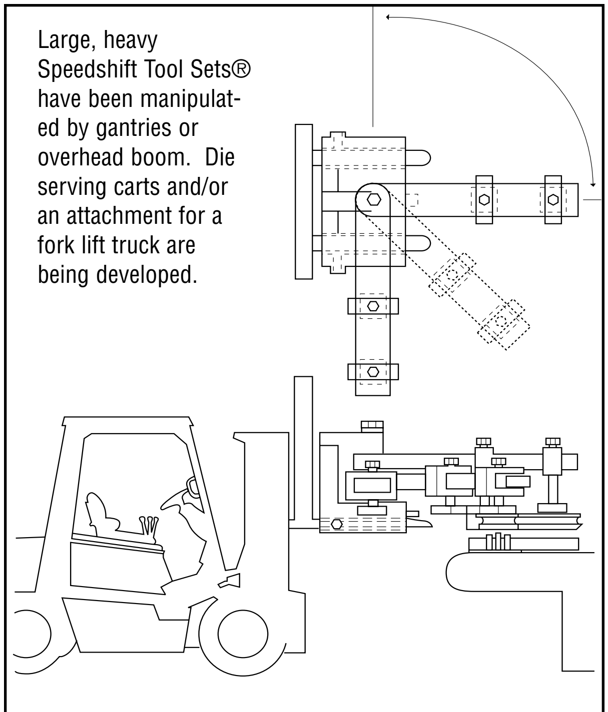
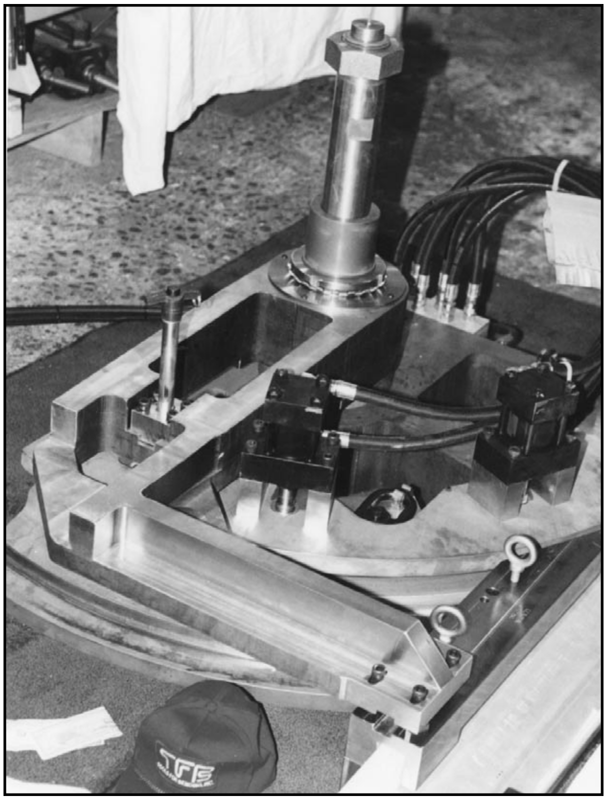


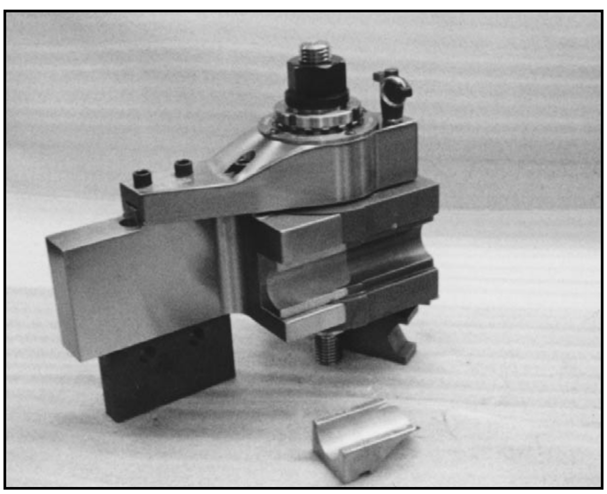
Figure 35


Speedshift Tool Set. Double-stacked tooling each 5 piece set of tools. Aluminum hollow extrusion "E" plane 1.500 x 3.0. Note "T" handle locking the bend die from rotating and flex lube tubes for the wiper dies.

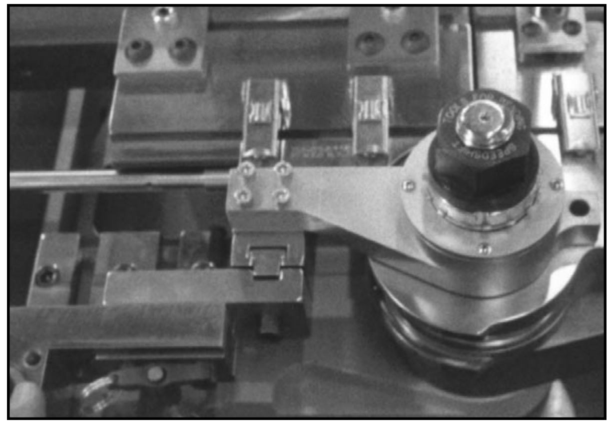

Complete 5 piece tool change from .625 O.D. to .750 O.D. in 3.5 minutes.



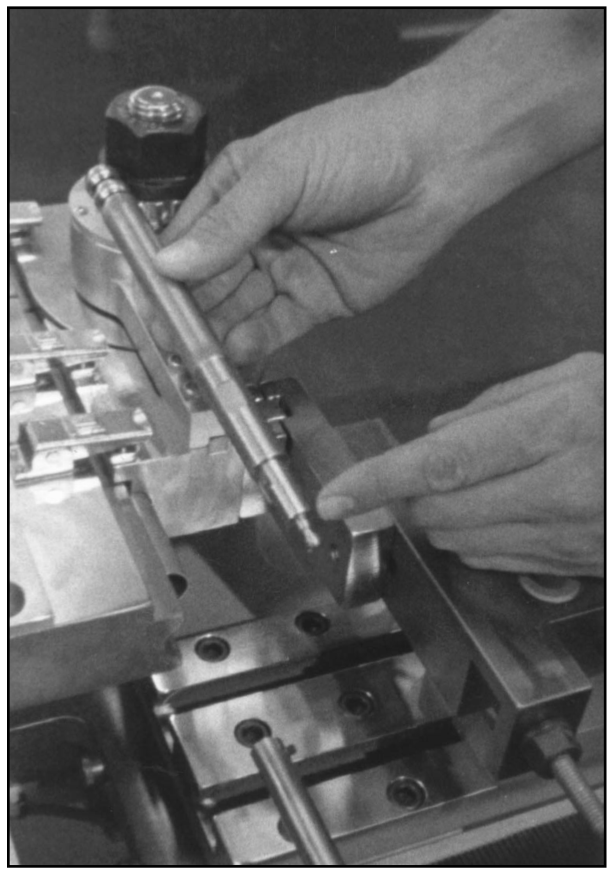
Speedshift Tool Set for large hollow aluminum extrusion. Note hydraulic manifold for split die actuation and the massive wiper die arm supporting/locating the wiper die. 5 piece tool set-up time 37 to 46 minutes.



Speedshift Tool Sets® 1 1/2 O.D. x 2.0 C.L.R.. Note replaceable wiper die Ampco bronze insert.



Last bend has been made. A tube is located in the clamp and pressure die groves. Clamp and pressure dies are brought forward. Cam-lock latches are secured. The tool set is lifted off the bender as assembly. Each tool remains in the best bending position.



Mandrel quick-disconnect locates mandrel in relation to tangent as well as an instant release. It also permits thorough mandrel lubrication.

TOOLING SELECTION GUIDE

$$\text{“D” of Bend} = \frac{\text{centerline radius}}{\text{tube outside diameter}}$$

(2.0 C.L.R. ÷ 1.0" O.D. = 2 x D)

$$\text{Wall Factor} = \frac{\text{tube outside diameter}}{\text{wall of tube}}$$

(2.0" O.D. ÷ .032 = 62.5 W. F.)

“D” of bend		1 x D		1.50 x D		2 x D		2.50 x D		3 x D		3.5 x D	
Degree of bend		**90°**	**180°**	**90°**	**180°**	**90°**	**180°**	**90°**	**180°**	**90°**	**180°**	**90°**	**180°**
10	Ferrous	P	P	P	P								
	Non-Ferrous	P	P	P	P	P	P						
* 20	Ferrous	RP-1	RP-1	RP-1	RP-1	RP-1	RP-1	P	P				
	Non-Ferrous	RP-1	RP-2	RP-2	RP-2	RP-2	RP-2	RP-1	RP-1	P	P		
30	Ferrous	RP-2	RP-2	RP-2	RP-2	RP-2	RP-2	RP-1	RP-1	P	P		
	Non-Ferrous	RP-3	RP-3	RP-3	RP-3	RP-3	RP-3	RP-2	RP-2	RP-1	RP-1	P	P
40	Ferrous	RP-3	RP-3	RP-3	RP-3	RP-2	RP-2	RP-2	RP-2	RP-1	RP-1	P	P
	Non-Ferrous	CP-4	CP-4	CP-4	CP-4	RP-3	RP-3	RP-3	RP-3	RP-3	RP-3	RP-2	RP-2
50	Ferrous	CP-4	CP-4	CP-3	CP-3	RP-3	RP-3	RP-2	RP-2	RP-2	RP-2	P	P
	Non-Ferrous	CP-4	CP-4	CP-4	CP-4	CP-4	CP-4	RP-3	RP-3	RP-3	RP-3	RP-2	RP-2
60	Ferrous	CP-4	CP-4	CP-4	CP-4	CP-4	CP-4	RP-3	RP-3	RP-3	RP-3	RP-1	RP-1
	Non-Ferrous	CP-5	CP-5	CP-4	CP-4	CP-4	CP-4	CP-4	CP-4	RP-3	RP-3	RP-1	RP-1
70	Ferrous	CP-5	CP-6	CP-5	CP-6	CP-4	CP-5	CP-4	CP-4	RP-3	RP-4	RP-1	RP-1
	Non-Ferrous	UCP-6	UCP-6	UCP-6	UCP-6	CP-4	CP-4	CP-4	CP-4	CP-4	CP-4	RP-2	RP-2
80	Ferrous	CP-5	CP-5	CP-5	CP-6	CP-4	CP-4	CP-4	CP-4	RP-3	RP-3	RP-1	RP-1
	Non-Ferrous	UCP-6	UCP-8	UCP-6	UCP-8	UCP-5	UCP-6	CP-4	CP-5	CP-4	CP-4	RP-3	RP-3
90	Ferrous	UCP-6	UCP-8	UCP-5	UCP-5	CP-4	CP-4	CP-4	CP-4	CP-4	CP-4	RP-3	RP-3
	Non-Ferrous	UCP-8	UCP-10	UCP-8	UCP-10	UCP-6	UCP-6	UCP-6	UCP-6	CP-4	CP-4	RP-3	RP-3
100	Ferrous	UCP-6	UCP-8	UCP-6	UCP-6	UCP-5	UCP-5	UCP-5	UCP-5	UCP-5	UCP-5	CP-4	CP-4
	Non-Ferrous	UCP-8	UCP-8	UCP-8	UCP-8	UCP-8	UCP-8	UCP-6	UCP-6	UCP-5	UCP-5	CP-5	CP-5
125	Ferrous			UCP-6	UCP-6	UCP-6	UCP-6	UCP-5	UCP-5	UCP-5	UCP-5	CP-4	CP-4
	Non-Ferrous					UCP-6	UCP-6	UCP-6	UCP-6	UCP-6	UCP-6	CP-4	CP-4
150	Ferrous		**CAUTION:**			UCP-8	UCP-8	UCP-6	UCP-6	UCP-6	UCP-6	CP-5	CP-5
	Non-Ferrous							UCP-8	UCP-8	UCP-6	UCP-6	UCP-6	UCP-6
175	Ferrous			**BETTER CALL:**				UCP-6	UCP-6	UCP-6	UCP-6	CP-6	CP-6
	Non-Ferrous									UCP-8	UCP-8	UCP-8	UCP-8
200	Ferrous					**TOOLS FOR BENDING, INC.**				UCP-6	UCP-6	CP-6	CP-6
	Non-Ferrous												

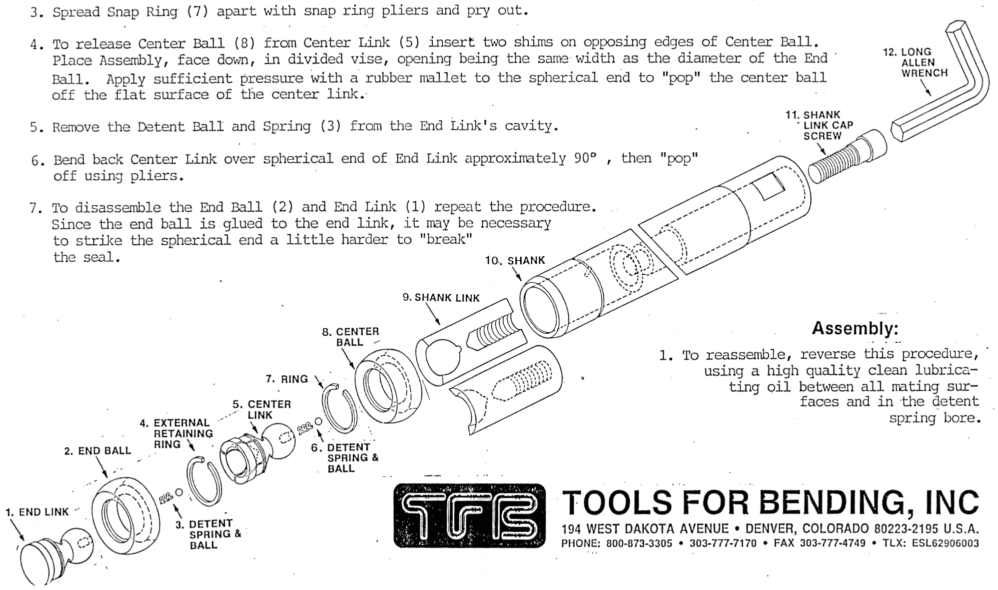
KEY
- P-Plug or Empty-Bending
- RP-Regular Pitch
- CP-Close Pitch
- UCP-Ultra Close Pitch
- No. indicates suggested number of balls

NOTE
1. The Empty-Bending system (without a mandrel or wiper die) is recommended for applications above the dotted line.
2. A wiper die is recommended for applications below the dotted line.
3. “H” style, brute, chain link mandrel in regular pitch, close pitch, and ultra-close pitch.
4. All mandrels are available with lube holes and grooves and finished in chrome, Kro-Lon, AMPCO bronze.

ASSEMBLY & DISASSEMBLY OF "H" 5&6 TYPE REGULAR MANDRELS

Disassembly:

1. Use a long Allen Wrench (12) and remove Shank Link Cap Screw (11). Ball assembly, complete with Shank Link (9) can now be withdrawn from Shank (10).
2. Detent Spring & Ball (6) will release from Center Link's cavity, be careful not to lose them.
3. Spread Snap Ring (7) apart with snap ring pliers and pry out.
4. To release Center Ball (8) from Center Link (5) insert two shims on opposing edges of Center Ball. Place Assembly, face down, in divided vise, opening being the same width as the diameter of the End Ball. Apply sufficient pressure with a rubber mallet to the spherical end to "pop" the center ball off the flat surface of the center link.
5. Remove the Detent Ball and Spring (3) from the End Link's cavity.
6. Bend back Center Link over spherical end of End Link approximately 90° , then "pop" off using pliers.
7. To disassemble the End Ball (2) and End Link (1) repeat the procedure. Since the end ball is glued to the end link, it may be necessary to strike the spherical end a little harder to "break" the seal.



Assembly:

1. To reassemble, reverse this procedure, using a high quality clean lubricating oil between all mating surfaces and in the detent spring bore.

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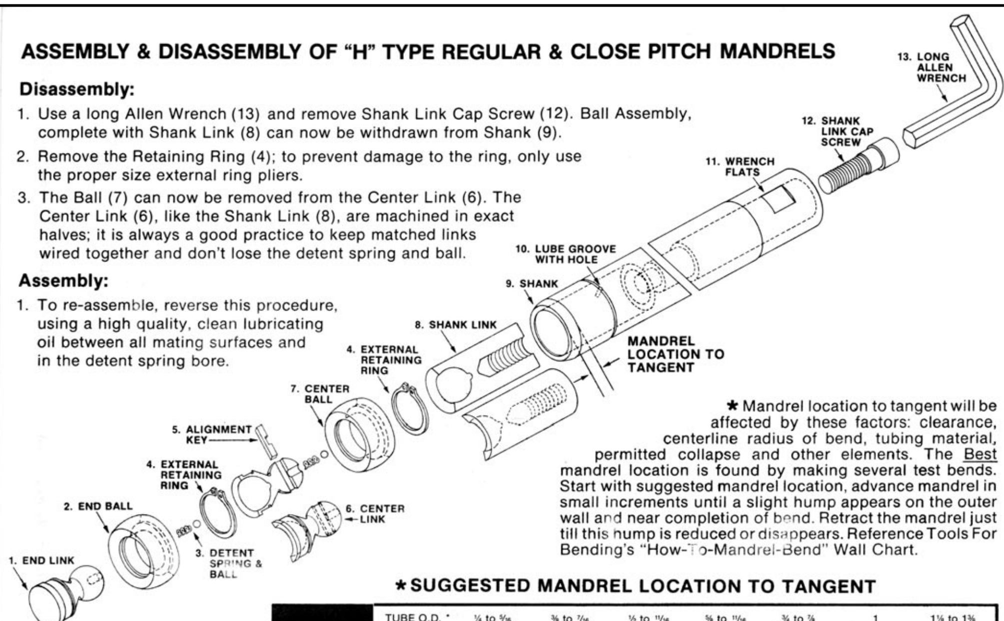
ASSEMBLY & DISASSEMBLY OF "H" TYPE REGULAR & CLOSE PITCH MANDRELS

Disassembly:

1. Use a long Allen Wrench (13) and remove Shank Link Cap Screw (12). Ball Assembly, complete with Shank Link (8) can now be withdrawn from Shank (9).
2. Remove the Retaining Ring (4); to prevent damage to the ring, only use the proper size external ring pliers.
3. The Ball (7) can now be removed from the Center Link (6). The Center Link (6), like the Shank Link (8), are machined in exact halves; it is always a good practice to keep matched links wired together and don't lose the detent spring and ball.

Assembly:

1. To re-assemble, reverse this procedure, using a high quality, clean lubricating oil between all mating surfaces and in the detent spring bore.



★ Mandrel location to tangent will be affected by these factors: clearance, centerline radius of bend, tubing material, permitted collapse and other elements. The Best mandrel location is found by making several test bends. Start with suggested mandrel location, advance mandrel in small increments until a slight hump appears on the outer wall and near completion of bend. Retract the mandrel just till this hump is reduced or disappears. Reference Tools For Bending's "How-To-Mandrel-Bend" Wall Chart.

★SUGGESTED MANDREL LOCATION TO TANGENT

STANDARD PITCH MANDRELS							
TUBE O.D. *	1/4 to 5/16	3/8 to 7/16	1/2 to 11/16	5/8 to 11/16	3/4 to 7/8	1	1 1/8 to 1 3/8
TANGENT	1/16	1/8	1/8	5/32	5/32	3/16	3/16
TUBE O.D.	1 1/2 to 1 5/8	1 3/4 to 2	2 1/8 to 2 1/2	2 5/8 to 3 1/4	3 3/8 to 4 1/2	4 5/8 to 5 1/4	5 3/8 to 6
TANGENT	7/32	7/32	1/4	5/16	11/32	3/8	7/16

CLOSE PITCH								
TUBE O.D.	1 1/4	1 1/2 to 1 5/8	1 3/4 to 2	2 1/8 to 2 1/2	2 5/8 to 3 1/4	3 3/8 to 4 1/2	4 5/8 to 5 1/4	5 3/8 to 6
TANGENT	1/16	1/8	5/32	5/32	3/16	3/16	1/4	1/4

Form No. 85170

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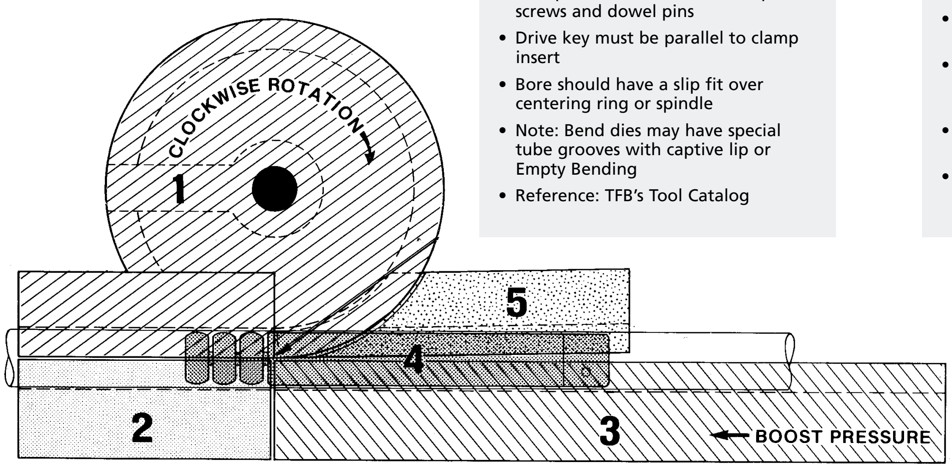
DENVER, CO 80223-2195

Rotary Draw Bending

The Design and Set Up of Tooling

Typical Example:
2.0" O.D. x .065 Wall on 4" Centerline
Wall Factor 30 - 2 x "D" of Bend



1. Bend Die

- Hardened tool steel or alloy steel, heat-treated and nitrided
- Clamp insert is secured with cap screws and dowel pins
- Drive key must be parallel to clamp insert
- Bore should have a slip fit over centering ring or spindle
- Note: Bend dies may have special tube grooves with captive lip or Empty Bending
- Reference: TFB's Tool Catalog

2. Clamp Die

- Hardened tool steel or alloy steel, heat-treated and nitrided
- Preferable length is 3½ x tube O.D.
- Tube groove is grit blasted or may be serrated if less than preferred length
- With tube held in bend die, advance clamp die and adjust for vertical alignment
- Adjust for parallel contact with entire length of clamp
- Adjust for pressure

3. Pressure Die

- Alloy steel and nitrided
- Tube groove must be parallel to back of die
- If follower type pressure die is used, length equals 180° + 2 O.D.
- If a boosted system is used, groove should be grit blasted
- With tube clamped to bend die, advance pressure die and adjust for vertical alignment
- Start with minimum pressure and increase as required in small increments

4. Mandrel

For tight radius and/or thin wall bending

- Type of mandrel and number of balls indicated by Tooling Selection Guide which is on back of this wall chart.
- Aluminum/bronze, chrome, or Kro-Lon™ mandrels for ferrous tubing. Only chrome mandrels for non-ferrous
- Gain best results with most mandrels when shank projects a small amount past tangent (bend & try)
- Lube I.D. of each tube

5. Wiper Die

For tight radius and/or thin wall bending

- The Tooling Selection Guide (on back of this wall chart) indicates when a wiper may be required
- Push tube over properly located mandrel and bring clamp and pressure dies up to bending position
- Slide wiper along tube as far as possible into bend die then secure to holder
- Unclamp pressure and clamp dies, tip of wiper should be "very close" to tangent
- Adjust for rake and vertical alignment
- Lube each tube and the wiper

Rotary Draw Bending

Corrections For Poorly Bent Tubes

After the initial tooling set-up has been made, study the bent part to determine what tools to adjust to make a better bend. Keep in mind the basic bending principle of stretching the material on the outside radius of bend and compressing the material on the inside of bend. Make only one adjustment for each trial bend unless the second adjustment is very obviously needed. Avoid the tendency to first increase pressure die force rather than adjust the wiper die or mandrel location. Start with a clean, deburred and lubed tube with the elongation properties sufficient to produce the bend.

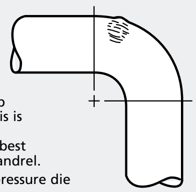
Note: There are certainly other corrections that could be made for the following problems. These illustrations are a few examples of how to "read" a bend and improve the tooling set-up.

1. Problem

Hump at end of bend.

Correction

1) Adjust mandrel slightly back from tangent until hump is barely visible. This is also a good system to find the best location for the mandrel.
2) Increase force on pressure die assist.



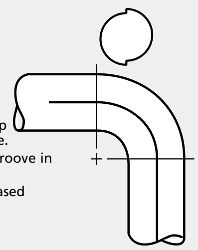
Clamp End

2. Problem

Tool marks on centerline of bend.

Correction

1) Re-adjust vertical alignment of clamp and/or pressure die.
2) Undersized tube groove in bend die.
3) Tooling not purchased from TFB.



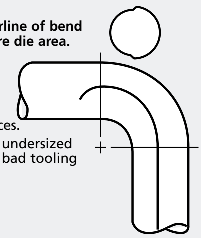
Clamp End

3. Problem

Tool marks on centerline of bend in clamp and pressure die area.

Correction

1) Reduce pressure and clamp die forces.
2) Oversized tube or undersized tube groove from bad tooling source.



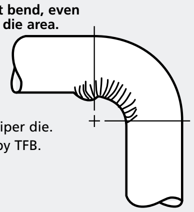
Clamp End

4. Problem

Wrinkling throughout bend, even extending into wiper die area.

Correction

1) Advance wiper die closer to tangent.
2) Decrease rake of wiper die.
3) Recut worn wiper by TFB.



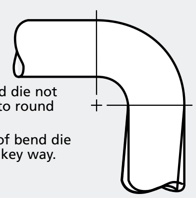
Clamp End

5. Problem

Bad mark at start of bend and over bend for 90°.

Correction

1) Removable clamping portion of bend die not matched properly to round part of bend die.
2) Clamping portion of bend die not parallel to the key way.



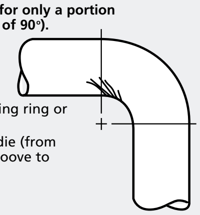
Clamp End

6. Problem

Wrinkling occurring for only a portion of the bend (45° out of 90°).

Correction

1) Bend die out of round. Bad centering ring or counter bore.
2) Taper in pressure die (from bottom of tube groove to back of die).



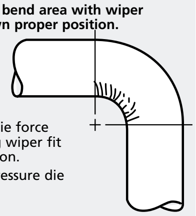
Clamp End

7. Problem

Wrinkles throughout bend area with wiper and mandrel in known proper position.

Correction

1) Check for undersized mandrel.
2) Increase pressure die force only after checking wiper fit and mandrel location.
3) Reduce force on pressure die advance.



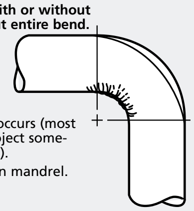
Clamp End

8. Problem

Excessive collapse with or without wrinkling throughout entire bend.

Correction

1) Advance mandrel toward tangency until slight hump occurs (most mandrels must project somewhat past tangent).
2) Need more balls on mandrel.



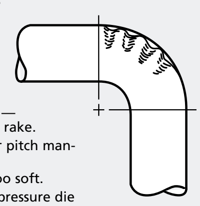
Clamp End

9. Problem

Mandrel ball humps.

Correction

1) Too much drag on tube; back off pressure die force — increase wiper die rake.
2) May require closer pitch mandrel ball assembly.
3) Tubing material too soft.
4) Increase force on pressure die assist.



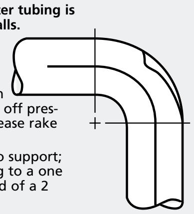
Clamp End

10. Problem

Excessive collapse after tubing is pulled off mandrel balls.

Correction

1) Check for too much drag on tube; back off pressure die force; increase rake on wiper die, etc.
2) Increase mandrel to support; change from a plug to a one ball; a 3 ball instead of a 2 ball mandrel, etc.



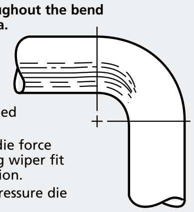
Clamp End

11. Problem

Deep scratches throughout the bend and in wiper die area.

Correction

1) Increase rake.
2) Check for undersized mandrel.
3) Increase pressure die force only after checking wiper fit and mandrel location.
4) Reduce force on pressure die advance.
5) Use more and/or a better lube.
6) Recut tube groove at TFB.



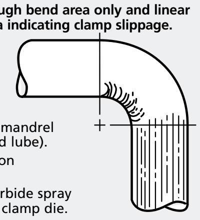
Clamp End

12. Problem

Heavy wrinkles through bend area only and linear scratches in grip area indicating clamp slippage.

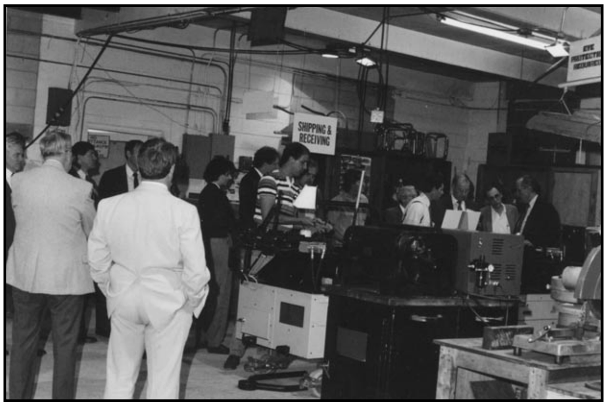
Correction

1) Reduce pressure die force.
2) Check location of mandrel and wiper die (and lube).
3) Increase pressure on clamp die.
4) Use serrated or carbide spray in tube groove of clamp die.



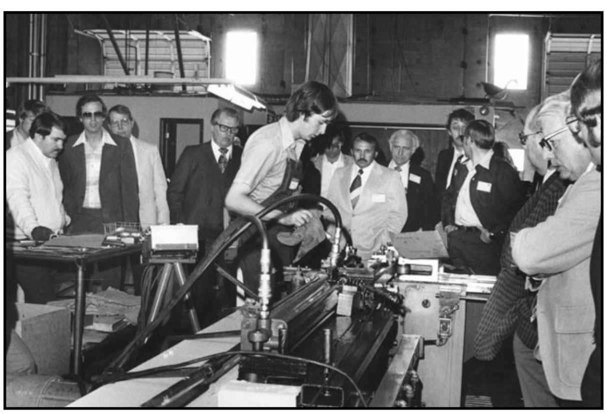
Clamp End

Continuing Education



Society of Automotive Engineers. G-3 committee tour and advanced bending tutorial. This in-plant session included hands-on-bending with specific presentations directed to their areas of responsibility and concerns within the aircraft/aerospace industry.

At TFB's Machine Division, customers tooling of our benders are encouraged not just to witness the buy-off. We prefer to take the time to instruct and assist so when the tooling and/or bender is received in their facility, it's there ready to make good bends.



Society of Manufacturers Engineers. 3 day in-plant seminar included formal tooling/bending presentations. Most important, it included the latest innovations for automotive type bending. Note retrofit pressure die assist had incremental advance capabilities.

Facts, Misconceptions, and Exceptions

This paper attempts to separate facts and modern good practices from misconceptions and antiquated methods. Admittedly, there are and will continue to be isolated instances where deviations from these recommendations will be required. New techniques and extensions of systems that have been discussed here will continue to be developed.

A 5.0 inch O.D. thin wall coil bent on a rotary bender with mandrel, wiper die, and "wizard" operator.

Ronald R. Stange
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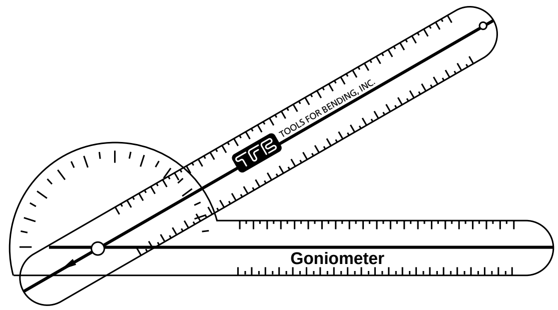

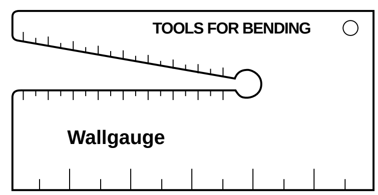

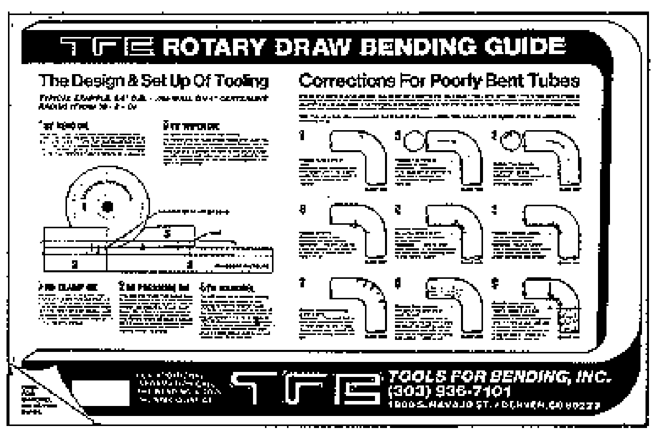

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