TUBE FORM SOLUTIONS

Basics of Tube Bending

BENDING TUBE WITHOUT A MANDREL

Stretching and Compression Principles

When a tube is bent, two things happen to metal ***(Figure 1-a).*** The outside wall is reduced in thickness due to the stretching of the material and the inside wall becomes thicker due to the compressing of the material ***(Figure 1).*** The material actually is formed approximately about the centerline of the tube. The material that forms the outside of the bend has further to travel and therefore is stretched; the inside of the bend has less distance to travel and is compressed.

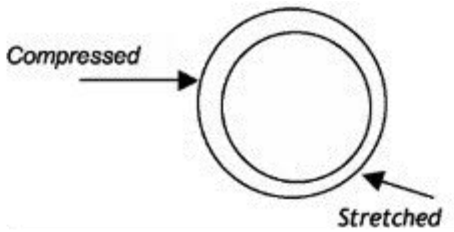


Figure 1-a

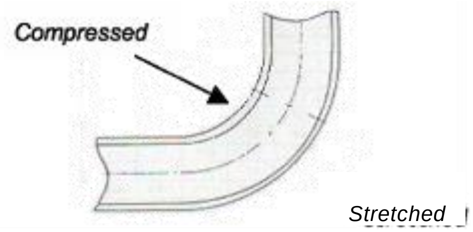


Figure 1

Function of Bend Die

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

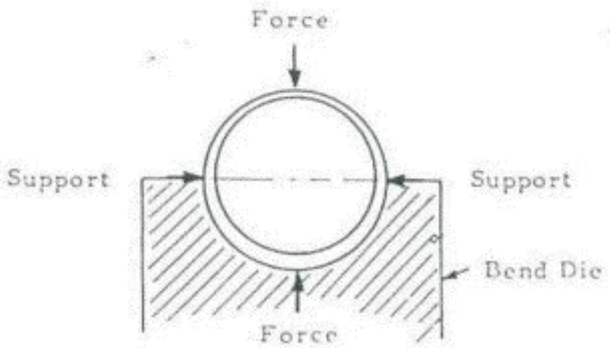


Figure 2

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 becomes greater as the radius of the bend becomes smaller.

Basic Primary Tooling

A bend die, clamp die, and pressure die are the minimum essentials for bending tube. ***(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.

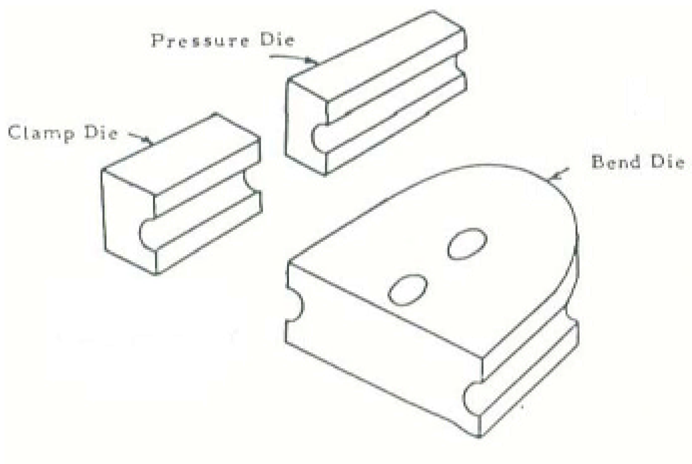


Figure 3

Control of Springback

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 that has been formed to return to its original shape. 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 radiuses of bend the smaller the springback.

Kinked or Buckled Bends

The tube may kink or buckle as shown in **Figure 4.** 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 centerline of the tube. This condition can be corrected (provided the tube is not too hard) by proper set up of the tooling. A plug mandrel **(Figure 5)** is indicated if the tube buckles and is still within the wall factor and the diameter of the bend.

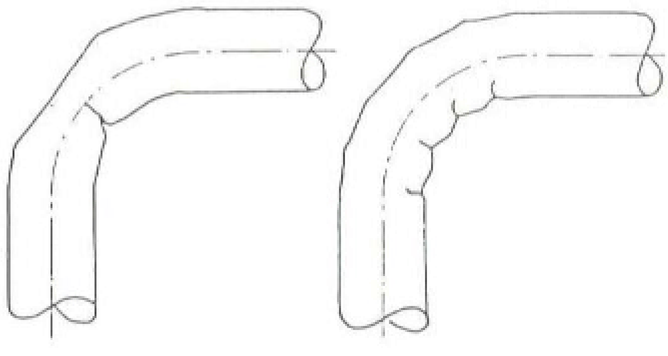


Figure 4

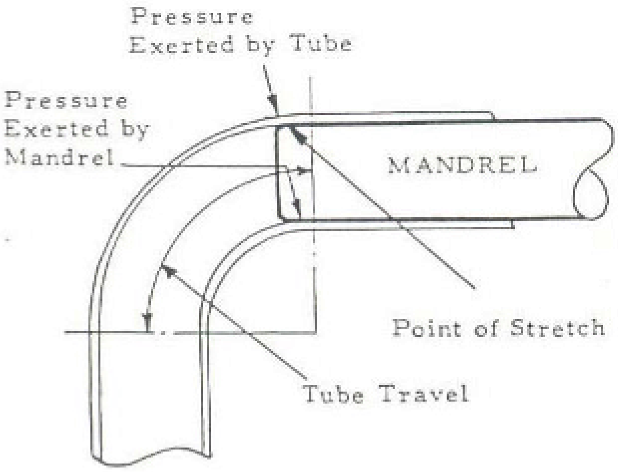


Figure 5

BENDING TUBE WITH A PLUG MANDREL

Balanced Pressures

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 the 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 **(Figure 5).** This force, acting on the mandrel tip, supports the inner radius of the bend, holding it firmly into the bend die groove.

A plug mandrel can be used to produce relatively good quality bends for tubing 3/8î diameter and smaller. Exceptions to this are thin wall tubing or a centerline radius that is less than 2 x tube O.D.. There also are certain limitations for tubes larger than 3/8î diameter.

Unbalanced Pressures

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 through 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 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. **Figure 6** is an overstated 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.

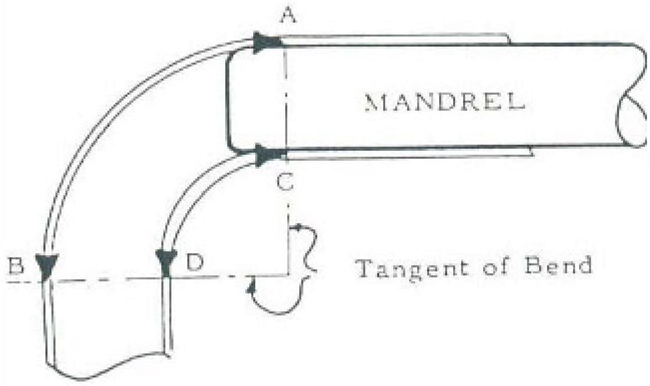


Figure 6

The mandrel in a position away from tangent will not stretch the material on the outside of the bend enough; consequently, there is not enough material to reach form A to B, putting a tension in the material. The forces at A and B are now the reverse of those shown in **Figure 6,** tending to open up the bend. Thus, mandrel location can cause excessive springback, which reduces the angel 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 clear; 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 rule out this likelihood. When the mandrel is set too far forward or the tube slips in the clamp die, breakage may occur also.** The problem of slippage will be discussed later.

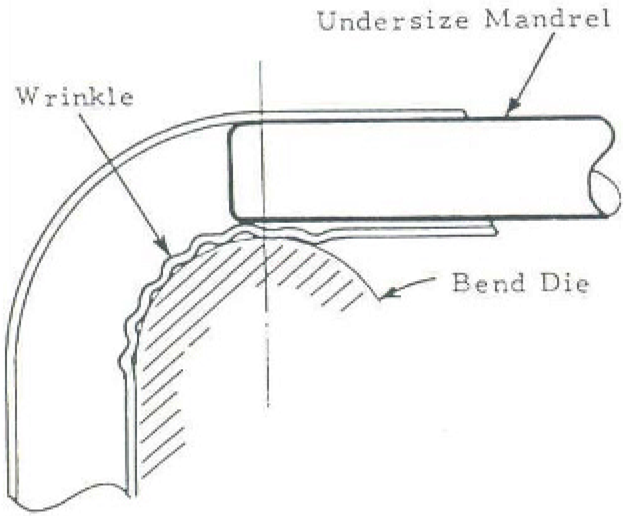


Figure 7

Mandrel Too Far Back

Advancing the mandrel slightly forward, the wrinkles may stop forming in front 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 **(Figure 8).** 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 9** shows what occurs when the mandrel is not full advanced.

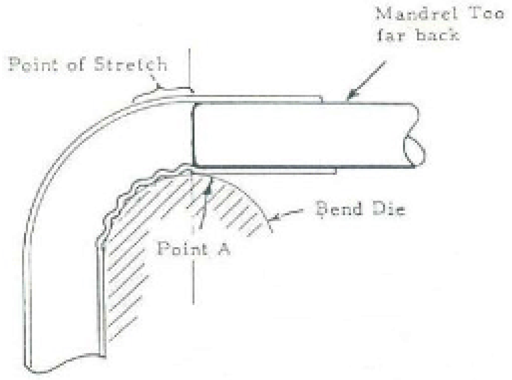


Figure 8

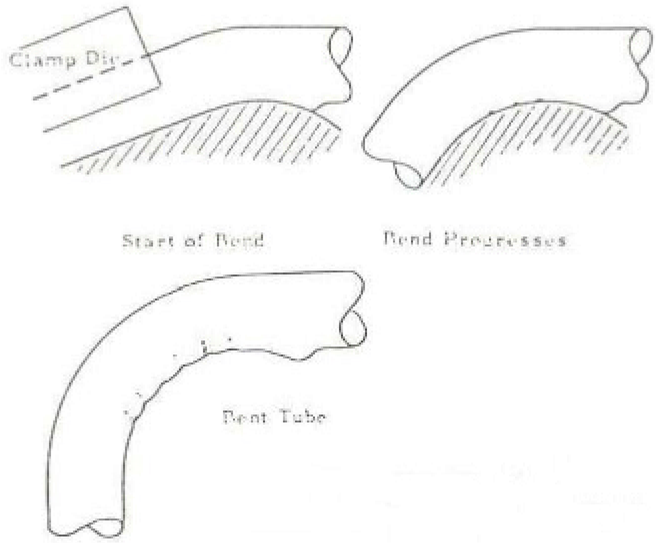


Figure 9

Mandrel T oo Far Forw ard

When the mandrel is too far forward **(Figure 10)** 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 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 end of the mandrel prying the tube away from the bend die forms the step.

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.

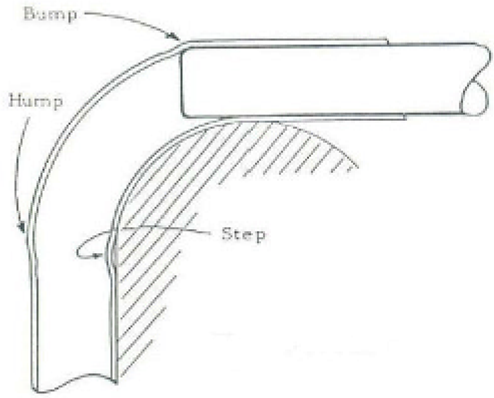


Figure 10

BENDING WITH BALL MANDREL AND WIPER DIE

When the radius of the bend is smaller and/or the wall is thinner, it becomes necessary to use a ball mandrel and wiper die. The wiper die is used to prevent wrinkles. The ball mandrel performs like a plug mandrel. The balls are used to keep the tube from collapsing after it leaves the mandrel shank.

Bending issues are enlarged when making tight bends or with thin wall tubing. It becomes more difficult to retain the material during compression. The pressure is so intense the material is squeezed back past tangent and buckles. **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.**

Bending Thin Wall Tubing

Requirements for the bending of thin wall tubing with tight radius bends of centerline radius equaling the tube outside diameter (1 x D) have become more common in recent years. To increase the problem, new alloys have been developed that are extremely difficult to bend. **The proper bending machine, good tooling, and a trained operator can make all the difference.**

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 acquired from one supplier, preferably even from the same lot or heat number.** Premium-priced close-tolerance tubing should be considered. It often saves many more times its added cost. **It may be necessary on occasion to size certain tubing before bending.**

There are many pipe bending machines but only a few are 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. The machine must be capable of retracting and advancing the mandrel with the clamp and pressure dies closed. A 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 boost counteracts the drag of the pressure die, mandrel and wiper die. It pushes the tube into the bending area, preventing excessive wall thin out.

Without a pressure die boost, the thinning that normally can be expected is about three-quarters of the elongation of the outer wall. Therefore, a two-inch tube bent to a three-inch centerline radius will thin by about 25% as seen in the cross section of **Figure 11.** 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 whatsoever, 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 12.**

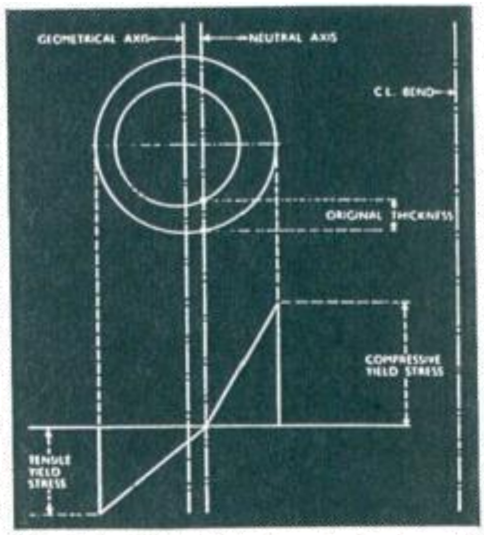


Figure 11

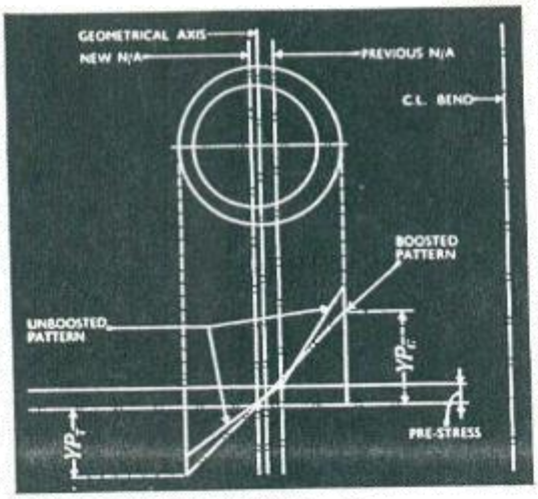


Figure 12

The pressure die boost 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 clamp 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 clamp 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.

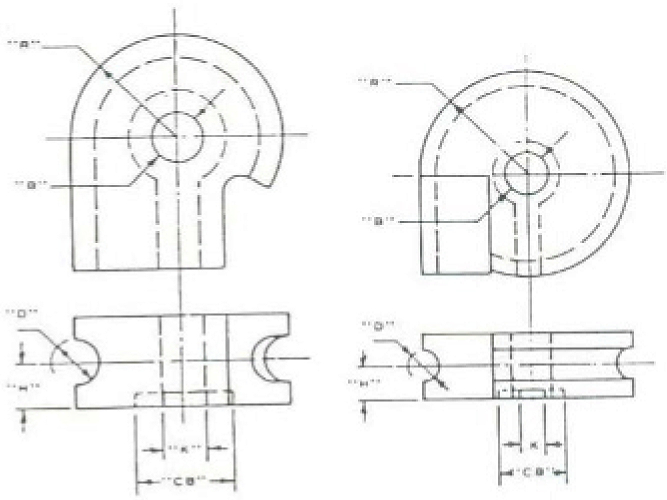
The quality and amount of lubricant used is extremely important. One lubricant will not work equally well on all materials. One lubricant for steel and another for aluminum is recommended. Considerable research and development was required to make special acceptable lubricants available. A generous amount 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 genius to compensate for near useless tooling. **Poor tooling results in longer set-up time, scrapping of expensive tubing, poorly bent tubes and fail to produce an acceptable bend.** Highly competitive custom tube bending companies 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 23 instances tested, 'set ups' averaged one-third the time allotted for conventional tooling. A 32% reduction of scrap was recorded over previous runs using conventional tooling.

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. To help prevent tooling marks on the top and bottom of the tube, the bend groove should be deeper than half the tube diameter. The bend groove should be dead round and the diameter should measure 10% time's 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 sandblasted 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. Centerline height must be maintained for both sides.

Bend dies are available in four basic styles A, B, C and D. **(Figure 14).** Each style is designed for different bending requirements: Type A for 1 x D radius and 180 degree of bend, Type B for 1 x D radius and 90 degree of bend, Type C for 1-1/2 x D radius and 180 degrees of bend, Type D for 2 x D radius and up and 180 degree of bend.



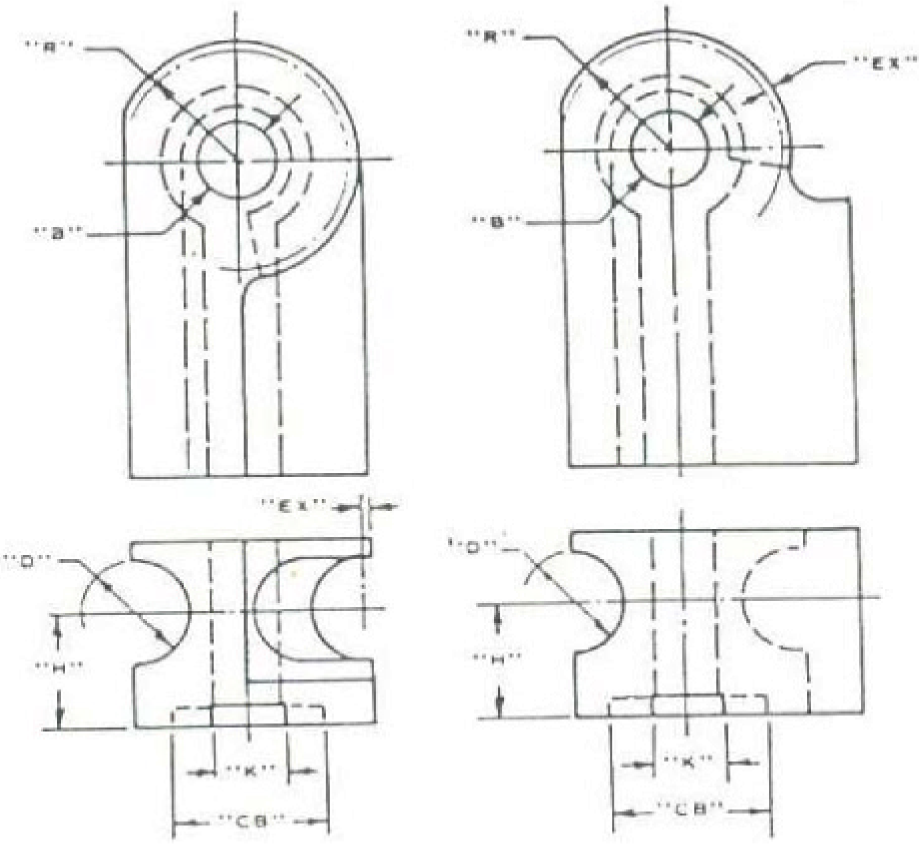


Figure 14

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. Variations 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. A solid bar to set the pressure die may be helpful. Loosen the holder until the adjustment screw turns freely, screw the pressure die holder in to meet the setup bar and retaining pressure is all that should be required. Excessive pressure on the pressure die increases thin out, marks the tube, and affects springback.

It is most important to have an accurate wiper die. The groove, which the tube slides through, must be slightly larger than the O.D. of the tube ñ 10% of wall thickness as being minimum. The groove must be of high polish lubricated with thin oil. Too much oil or too heavy 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 15-20 degrees back from tangency. When the bend die does not support the wiper die at this point, it will spring away from the mandrel and cause the tube to wrinkle **(Figure 15).**

A solid bar the exact diameter of the tubing to be bent would facilitate a proper wiper die fit. While the clamp die holds setup bar, the wiper die is soft mallet-tapped to the forward most 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. To check the amount of this rake or taper, 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 featheredge must be as close to tangent as possible. Wiper dies made with Ampco bronze material also helps minimize drag and prevent galling **(Figure 17).** Wiper dies made of 4130 have proven very successful and wear considerably less than mild steel or

Ampco Bronze. A minimum amount of high quality drawing lubricant is all that should be used. Excessive oil causes wrinkles.

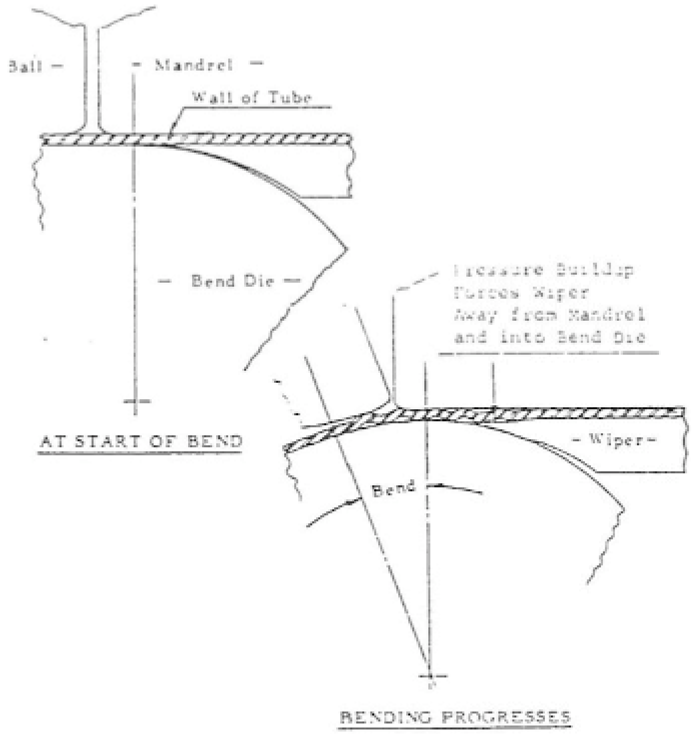


Figure 15

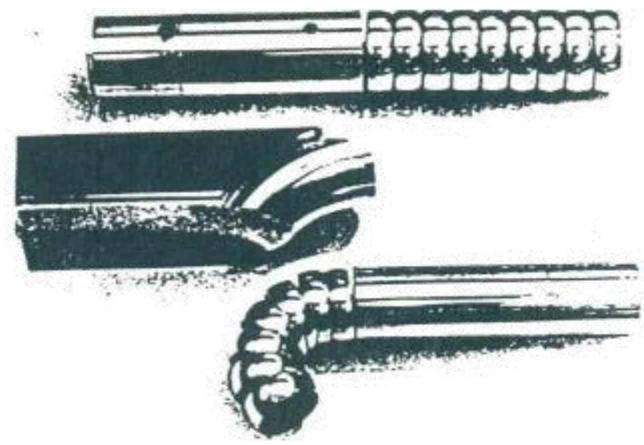


Figure 16

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. **(Figure 16) It will be necessary to have enough balls on the mandrel to support the tube around the entire bend. It is important that the spacing between balls (or pitch) be reduced. The close pitch universal flexing 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.

Ampco bronze frequently is preferred for stainless applications in order to reduce friction. Hardened steel with chrome is recommended on non-ferrous materials such as aluminum, copper, etc. Mandrel setting will be determined by the used and radius of bend. A template of the desired bend radius is helpful in determining the initial universal flexing mandrel location **(Figure 17).** To achieve full benefit from the mandrel it is necessary to project the mandrel shank past tangent.

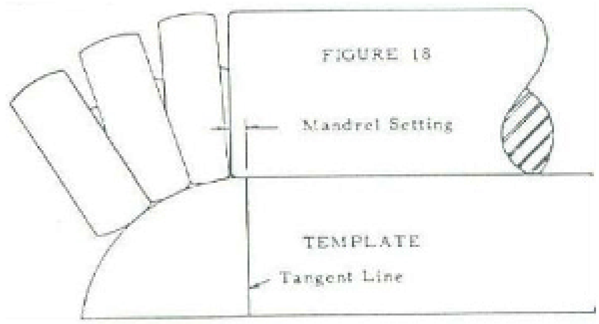
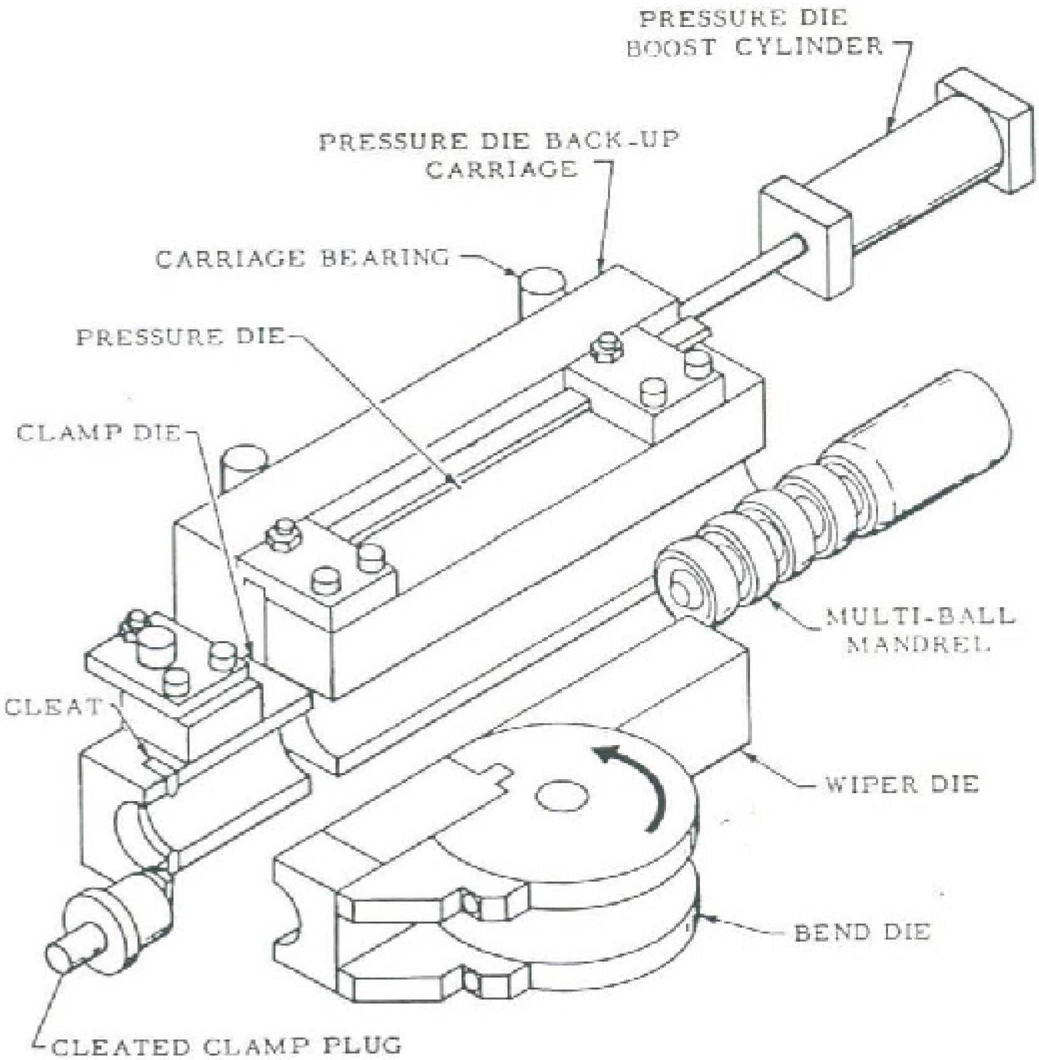


Figure 17



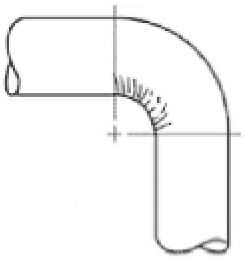
TROUBLESHOOTING

Tube Breakage

Tube breakage may be caused by:

1. Material lacking proper ductility and elongation
2. Tube slipping in clamp die
3. Pressure die too tight causing excess drag
4. Material wrinkling and becoming locked between mandrel balls
5. Clamp die pressing on mandrel balls
6. Improper or insufficient lubrication
7. Mandrel too far forward

Tube Wrinkling

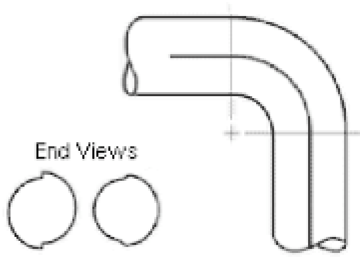


Tube wrinkling may be caused by:

1. Tube slipping in clamp die
2. Mandrel not far enough forward
3. Wiper die not seated properly in bend die
4. Wiper die worn or of improper fit
5. Too much clearance between mandrel and tube
6. Not enough pressure on pressure die
7. Improper or excessive amount of lubrication
8. If mandrel & wiper die are in proper locations, check inboard pressure on pressure die. You may need to apply more pressure on pressure die to hold tube into die. Adjust in slowly until you have no wrinkles. Lastly, check mandrel fit.

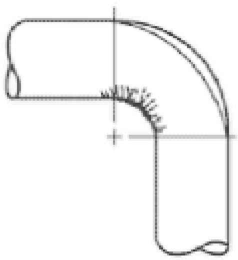
Note: Materials offering less resistance to flow will have fewer tendencies to wrinkle. For instance, 3/8" OD x .020 wall Type 304 can be bent on as small as 2 x diameter radius without a wiper die. On the other hand, AM 350 CRES stainless will require a wiper die on any radius up to 3 x diameter. The wiper die must fit the bend die and the tip 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 is usually where the trouble occurs.

Scratches/Marking on Tube Centerline



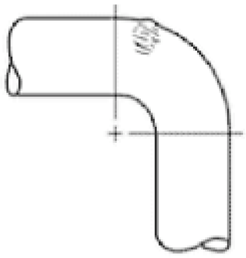
1. Check alignment of all dies.
2. Ensure all tools are free of dirt and scale. If not, clean tools.
3. Check tube is clean and free of oil and grease.
4. Use interlock style tooling.
5. Check forces on clamp and pressure dies.
6. If deep scratches in bend and in wiper die areas try to check wiper angle and increase a little. Also, back end of wiper should not touch the tube; it must have a gap. Lastly, make sure tube is getting plenty of lube along with lubrication on wiper die in bend area.

Tube Collapses Either With or Without Wrinkling Through Bend

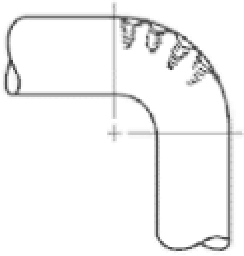


1. Check for clamp slip.
2. Check for sufficient push-assist.
3. Check mandrel positioning in relation to tangent.
4. Check that number of mandrel balls is sufficient for application.
5. Check for drag.

Hump at the End of a Bend and Mandrel Ball Humps



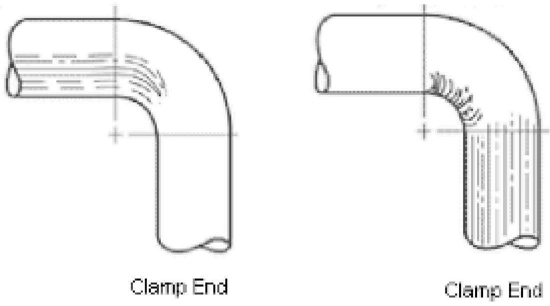
At end of Bend



Due to Mandrel Balls

1. Check mandrel positioning. Try to move mandrel back from tangent until hump goes away.
2. Check free movement of pressure die.
3. Check force on pressure die, pressure die assist.
4. Check mandrel ball sizing.
5. Ensure material is suitable for application.

Tool Marks/Scratches



Without Wrinkling *With Wrinkling*

1. Check for alignment of clamp.
2. Check location and pressure of all dies.
3. Check clamp is clean and free of oil and grease.
4. If clamp force is excessive, check for proper surface texture on bend die insert.
5. Increase rake of wiper die.
6. Check condition of wiper die. If worn, pitted or scored, re-cut or replace.
7. Ensure sufficient lubrication. 8. With wrinkles in bend area only and scratches in bend area make sure clamp die is not slipping and recheck pressure die pressure. Clamp die may need serrations to hold tube or it may also be worn out.

Excessive Springback

1. Check that pressure die is not holding the tube back during bending.
2. Check ductile strength of tube and program over bend to compensate.

Possible reasons for link failure

1. Insufficient tool-to-tool clearance
2. Insufficient tool to part clearance
3. Geometry of bend
4. Mandrel positioning
5. Sub-standard tooling

Final Tips

1. Use complete sets of tooling, purchased together. Mixing and matching tools may not match perfectly, causing inconsistent and often poor quality bends.

2. Lubrication is a key factor in making good bends. Type of lubrication is dependent upon the material of the tube to be bent. A generous amount should be applied to the mandrel and interior of the tube.

GLOSSARY OF TERMS

Ampco-18 ñ A trade name for the softer grade of aluminum-bronze in general use. This is the preferred grade for aluminum-bronze wiper tooling because it lacks the brittleness of harder grades that cause the feathered edge to break and chip instead of wear out.

Ampco-21 ñ A trade name for the harder grade of aluminum-bronze in general use. This is the preferred grade for aluminum-bronze mandrel tooling because it is harder and therefore wears longer than Ampco-18.

Assist, assist pressure ñ A pressure function common to modern rotary-draw tube-bending machines in which a pressure or speed setting drives the pressure (or follower) die forward. The importance of assist pressure is that it relieves the drag caused by the tooling on the tubing at the point of bend, which helps to reduce wall thinning and deformation.

Back tangent ñ The straight section of the tube behind the line of tangency.

Ball ñ A part of the mandrel assembly that supports the arc of the bend from flattening along the outside radius *after* the tube has passed through the point of bend.

Ball sub-assembly ñ The flexing portion of the mandrel assembly that consists of a series of balls linked together.

Barrel ñ That part of a link that is nested inside of the bore of a ball when assembled.

B-axis ñ On CNC rotary-draw bending machine this is the rotary motion about the Y-axis, which is used to set (or orient) the tubing material in the plane of bend.

Bend data ñ A programming term for CNC tube-bending machines referring to the basic elements of motion that must be programmed into the machineís controller to bend a tube.

Bend die ñ The primary tool on a rotary-draw tube-bending machine; the form against which the tube is clamped and then drawn around to produce a bend; less commonly known as the bend form or the radius die. The essential specifications of a bend die are the outside diameter and the bend radius of the tube to be bent.

Bend radius ñ The radius of the arc of the bend. This is a general term that does not precisely specify the radius, therefore it can mean inside radius, centerline radius, or any other arbitrary reference point. The preferred reference point is the centerline radius for round tubing and the inside radius for square and rectangular tubing.

Bend specifications ñ The basic elements of machine, material, and bend that define a tube bend application; typically: make and model of the machine; shape, outside dimensions, wall thickness, and material of the tubing; radius and depth of the bend. Other elements may also be significant, such as a large weld seam or an extremely short tangent between bends. For most circumstances, three basic specifications are sufficient to define the applications: *Tube outside diameter (OD)* ñ Usually specified in inches or millimeters. Note that certain nominal "pipe" diameters vary considerably from their true diameters; therefore, the pipe system (e.g., IPS, EMT, K-type) must also be specified. *Wall thickness (WT)* ñ Specified in inches, millimeters, or wire gauge unless the material belongs in one of the pipe systems. In that case, the schedule number or other wall thickness designator of the system should be specified. If the wall thickness varies by 5% or more, it is advisable to specify the thickest wall dimension. *Centerline radius (CLR)* ñ Specified in inches, millimeters, or "D" of bend. "D" is the ratio of the centerline radius to the *nominal,* not the true, outside diameter of the material: *"D" = CLR / nominal OD.*

Boost, boost pressure ñ A pressure function found on some tube-bending machines which is similar to the common assist-pressure function but is distinguished from it by applying pressure to both sides of the tube behind the line of tangency. Assist pressure is applied only to the outside half of the tube at the line of tangency. Boost pressure pushes the tubing material through the point of bend as it is drawn forward around the bend die. This increased flow is necessary when wall thinning must be kept to an extreme minimum.

Carbide impregnation ñ A process of electrically embedding carbon onto a steel surface in order to increase its roughness. Sometimes used on the cavities of clamp dies and clamp inserts to improve their grip on the tube without leaving the marks serrations or knurling do. "Surfalloy" and "Rocklinizing" are trade names for this process.

Carbon steel ñ A common tubing material.

Casehardening ñ A heat treatment process which cases a steel component with a very hard skin, usually with carbon. Carburizing, nitriding, and flame hardening are good examples of casehardening. Casehardening is a good process for hardening bend dies, clamp dies, and pressure dies because it combines a hard wear surface with toughness ñ i.e., resistance to chipping and breakage.

Cavity ñ The part of the bend die, clamp die, pressure die and wiper that contains the tubing material during the bending process. Generally the cavity is machined to the true shape and size of the tubing material with a small allowance to ensure that the tube moves smoothly through the cavity.

C-axis ñ The rotary motion about the Z-axis of a rotary-draw tube-bending machine; the rotary axis of the bend die.

Center link ñ The component that joins two balls or the first ball of multi-ball mandrel assembly to the mandrel shank.

Centerline height ñ The distance between the mounting surfaces of the bend head to the plane of bend. This value is determines the location of the cavity in a die block.

Centerline radius ñ The most common specification for the arc of a tube bend. Physically, it is the location of the crown of bend; geometrically, it is the continuation of the vertical centerline of the tube into the arc.

Clamp die ñ The tool that clamps the tubing material against the bend die as it rotates to form the bend. There are two specifications of primary importance in a clamp die: Length and cavity texture, which are related to each other. The shorter the clamp, the rougher the cavity surface must be to maintain the force of the grip on the tube. Serrations, knurling, and carbide impregnation roughen the cavity surface; therefore improve the clamp die's grip upon the tube.

Clamp insert ñ The detachable grip or clamp section of the bend die. The same design considerations for the clamp die apply to the clamp insert.

Close pitch ñ Type of ball string that uses one size smaller link size (shorter pitch) in order to have more balls in the same amount of space. When the tubing material requires more than normal support after the point of bend because it is thin-wall, soft, or some combination of factors, a close-pitch mandrel assembly is usually the solution.

CLR ñ Abbreviation for *centerline radius.*

CNC V.S. NC ñ CNC: Computer Numeric Control of the tube in all axis of movement. (X, Y, Z,). NC: Numeric control of only the degree of bend.

Cold drawing ñ The normal method of rotary-draw tube-bending; bending without heating the tubing material.

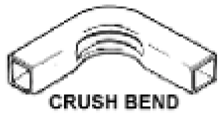
Cold rolled steel tube ñ A common tubing material.

Compound clamp ñ 1. A clamp die or clamp insert with a cavity shaped to grip on a bend rather than a tangent. This type of clamp is used when a mid-tangent (i.e., a tangent between bends) is too short for a conventional straight-cavity clamp.

Compression bending ñ 1. As commonly used today: Bending with heart-shaped tooling. 2. An older method of bending in which the tube is clamped against a stationary bend die and the pressure die sweeps the tube around the bend die to form the bend. This differs importantly from rotary-draw bending in that the point of bend is the point of contact between the pressure die and bend die. Therefore the point of bend moves through space, which makes the use of a mandrel impossible.

COMPRESSION BEND

Crush bending ñ A non-mandrel method of bending in which the compression of the intrados is controlled by stretching it over a "crush knob" seated in the cavity of the bend die. This eliminates the wrinkling or buckling that might occur if the tube were bend without a mandrel. Commonly used on non-round tube bends.



"D" of Bend: CLR / OD = "D" of bend. For example, the centerline radius of a 3-"D" bend of a 2" IPS pipe (which is 2.375" true diameter) is 6 inches instead of 7.125 inches.

DBB: Distance Between Bends is the straight section of the tube from tangent to tangent

Degree of bend ñ The depth of bend; the sweep of the arc. The minimum degree of bend is about five degrees; the maximum degree of bend in rotary-draw bending is 180 degrees.

Direct Acting Pressure Die - Clamping method using a hydraulic cylinder without the use of any toggle linkage.

DOB ñ Abbreviation for *degree of bend.*

Double-wall tubing ñ Also called laminated tubing, this type of tubing consists of two strips of coiled steel, one tube inside another. Because the material cannot flow from one wall to the other as it becomes plastic at the point of bend, the thickness of the interior wall should determine the number of balls, nose and ball diameters, and the nose placement of the mandrel assembly. The inside wall should be treated as a thin-walled tube.

Easy way ñ (or E-Plane) A term of art in tube-bending for the orientation of a non-round tube shape relative to the plane of bend; in an "easy way" bend the major axis of the tube shape is perpendicular to the plane of bend. Occasionally called an "E-way" bend.

BENT EASY WAY

End link ñ The component that joins the end ball to the rest of the mandrel assembly. The end link is distinguished from the center link by having a solid base instead of a socket.

Hanger bracket ñ A small plate or tab fastened to pressure die (and for some machine models, the clamp die) in order to fixture the die to the machine by means of hanging it from the follower bar (or clamp slide block).

Hard chrome ñ A plating commonly used on steel bending tools to extend tool life and prevent galling.

Hard way ñ (or H-way) The orientation of a non-round tube shape relative to the plane of bend; in a "hard way" bend the major axis of the tube shape lies in the plane of bend.

BENT HARD WAY

H-type link ñ The most common style of mandrel linkage, which reduces pitch and permits universal flexure of the mandrel balls. H-type links come in two major varieties, poppet and split.

ID ñ Abbreviation for *inside diameter.*

Insert link ñ The link that attaches the ball sub-assembly to the mandrel shank. Functionally the insert link is the same as a "mandrel link" or "shank link" but applies specifically to inserted mandrel assemblies.

Inserted bend die ñ The most common type of bend die consisting of a radius block and a detachable clamp insert section.

Inserted mandrel assembly ñ A mandrel assembly in which the shank consists of a steel body and a replaceable nose insert.

Inserted wiper die ñ A wiper die in which consists of a steel wiper holder and a replaceable tip insert.

Inside diameter ñ The outside diameter of a tube or pipe less twice the wall thickness.

Inside radius ñ A specification for the arc of bend with non-round tubing. (The centerline radius [CLR] is used to specify the bend of a round tube.)

Interlock (bend die) ñ A common feature of bend dies; a pair of tabs extending circumferentially from the top and bottom surface of the die which interlock with mating shoulders on the clamp and pressure dies. The purpose of interlock is to help hold the clamp and pressure dies in the plane of bend.

Interlock (wiper) ñ A common feature of inserted wiper tooling; the tip insert is keyed to the wiper holder. The purpose of the interlock is to help the insert resist being dragged while under direct pressure.

IPS ñ A pipe specification system that associates certain nominal pipe diameters with standardized wall thickness called "schedules". The same schedule number will have a different fixed decimal inch value for each nominal diameter. For example the wall thickness for 1" Schedule 40 pipe is .133", but for 2" Schedule 40 pipe is .154". It is also important to note that the nominal diameter in this system vary considerable from the true diameter. For example, 1" pipe has a true diameter of 1.31 5" and 2" pipe has a true diameter of 2.375". Furthermore, the bend radiuses of pipes in the IPS system are often expressed in terms of "D" of bend. For example, the centerline radius of a 2 "D" bend of a 1" pipe is 2.0" inches, not 2.63" inches.

ISR ñ Abbreviation of inside radius

Key ñ 1. The horizontal raised steel block on the bend head of a rotary-draw bending machine which mates with the keyway on the bottom side of the bend die to drive the die in the direction of the bend head's rotation.

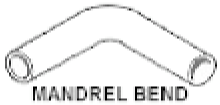
Keyway ñ The mating channel in a bend die or pressure die for the drive key.

Knurling ñ A pattern of small diamond-shaped points cut into the surface of a clamp die or a clamp insert to increase its grip; the knurled points bite into the tubing material, thereby improving the clamps hold upon the tube. Functionally this is the same as serrations and carbide impregnation, however not as preferable. The points wear quickly in comparison cutting the surface of the tube.

Link ñ A joint-like component of a mandrel assembly, which attaches balls to each other and to the nose of the mandrel shank. The H-style link remains the predominant style today with the only major improvement being the development of the single-piece poppet variety.

Mandrel ñ Short for mandrel assembly, this tool is a part of the rotary-draw tube-bending process to maintain the shape of tube as it sets into the arc of the bend. If the tube wall is thick enough relative to the overall size of the tube or if the specifications are not too severe (e.g., shallow depth of bend or a large "D" bend radius), then a mandrel may not be necessary.

The mandrel is the tooling component that provides support to the inside of the tube. Its primary function is to prevent the tube from buckling and necking. Many different variations of mandrels exist. The required style and material depends on the outside diameter (OD) and wall thickness (WT) of the tube being bent. The simplest design style is the plug mandrel and the most complex design style is the ball mandrel. The ball mandrel is designed to internally support the tube beyond tangent and depending on the number of ball segments, throughout the entire bend.



Mandrel assembly ñ Consists of (1) a mandrel body (2) a mandrel nose insert (3) a mandrel link or insert link (4) mandrel screw (5) if needed, a ball subassembly.

Mandrel body ñ The section of the mandrel assembly that connects the mandrel subassembly to the mandrel rod of a tube-bending machine. In an inserted mandrel assembly, the mandrel body does not include a nose, which is a separate detachable component held to the body by an insert link and a mandrel screw. Therefore, the mandrel body in this case has a relatively long service life and needs to be replaced only after extreme wear.

The mandrel body of a non-inserted mandrel assembly has an integrated nose that controls the flow of material at the point of bend. Thus, such a mandrel body wears out when the nose does and has a relatively short service life compared to that of an inserted assembly. A mandrel body is not a plug. A plug is a complete fully functioning mandrel assembly, whereas a mandrel body is a component of a mandrel assembly. In the case of a non-inserted plug, the mandrel body is the only component of the assembly.

Mandrel nose insert - The replaceable nose section of an inserted mandrel body. It is designed as a relatively inexpensive component of a mandrel assembly to be detached from the mandrel body and disposed when it is worn out. Another feature is that a mandrel nose insert of one material can be swapped with one of another material so that the same mandrel body can be used for different tubing materials.

Mandrel sub-assembly - A ball subassembly plus a mandrel nose insert. A one-ball mandrel subassembly includes the following components: (1) mandrel nose insert, (2) insert link, (3) mandrel ball, and (4) end link. Multiple-ball mandrel subassemblies include a mandrel and a center link for each additional ball of the assembly.

Mandrel thread - All mandrel bodies have internal threads at the opposite end of the nose to attach the mandrel assembly to the mandrel rod. The mandrel thread specification typically varies with tube diameter. Although there is no official standard, some common relationships have developed over time for non-metric tube bending machines. Some tube diameters and their typical corresponding mandrel thread specification are: For approximately 1-inch-diameter tube: 1/2-13 UNC thread; from about 1.25-to 1.375-in.-dia. Tube: 5/8-11 UNC thread; 1.5- to 3-in.- dia. Tube: 1-8 UNC thread.

Multi-Stack: Refers to a machines ability to have more than one bend die stacked on it.

No-lip- A common type of cavity design for tube bending dies that is true to the size and shape of the tube to be bend (with minor allowances) and a bend die lip extending over the centerline of the tube.

Non-mandrel bending- A method of rotary drawtube bending that does not require a mandrel assembly. Instead, it uses bending dies with heart shaped cavities. Non-mandrel bending is not a substitute method for applications that use conventional dies but do not require mandrels. Such applications, which include heavy-wall tube or large-radius bends, do not need mandrels in the first place. Non-mandrel bending compromises bend quality for the benefit of eliminating mandrel and wiper tooling costs. Quality suffers most in terms of the critical attributes of bend reduction and wrinkling, which account for the significant decline in the use of non-mandrel bending over the past several years.

OD- Abbreviation for outside diameter.

Orientation- The bend specification for whether a non-round tube is bent the easy way or hard way; more generally, the position of a tube's cross section relative to the plane of bend. This specification is commonly relevant for rectangular and oval tubing because it is necessary to identify whether the major (long) axis of the tube's shape is perpendicular to the plane of bend (the easy way) or lies in it (the hard way).

OSR- Abbreviation for outside radius.

Outside diameter- Tube outside diameter; the standard way to specify the size of a tube or pipe as measured at its outside surface; the bore diameter plus twice the wall thickness of a tube.

Plane of Bend (POB) - In the rotary draw process; the machine's X and Y-axes determine the plane of bend. Because the plane of bend is fixed in space at the bend die's centerline height in the rotary draw process, the plane of bend is not important in single-bend applications after all of the tools are properly fixtured relative to it. In multiple-bend applications, the tube acquires an orientation in terms of plane of bend upon completion of the first bend. All subsequent bends must be made relative to that orientation. This means rotating the tubing material a certain number of degrees relative to the plane of the previous bend. On CNC bending machines, the collet grips the tubing material and rotates it as needed. On manual machines, stops must be set at the correct orientation relative to the plane of the next bend for the bent section of the tube to rest against.

Point of Bend - The point of bend refers to a part of the tube, whereas the line of tangency defines a fixed plane in space through which the tube passes as it is bent. It is important to understand the point of bend as a region rather than a geometric element, because good bend quality requires fixturing the mandrel and the wiper die properly to control the flow of material in that point of bend region.

Poppet link- One of two varieties of H- type links in which the body of the link is solid instead of split into pieces. This means that poppet links require a press for assembly; unlike split links that usually can be assembled by hand. The single-piece poppet design makes them more durable than the split variety and less expensive.

Post -Part of the bend die mounting system of a rotary draw machine. The post is a large, threaded stud that is screwed into the center of the bend head, around which the die is mounted and to which the bend die is secured by a large nut.

Post Hole-The large clearance hole drilled through the center of a bend die to accommodate the mounting post.

Press Bending - Press bending is less expensive and faster than rotary draw bending. Its primary disadvantage is reduced bend quality. Because the lines of tangency in press bending move through space, as opposed to the single line of tangency in rotary draw bending which is fixed in space, it is not possible to fixture mandrel tooling inside the tube or wiper tooling outside of it to control the flow of material. Press bending is suitable only applications with relatively heavy tube walls and large centerline radiuses.

Pressure Die - The tool that holds the tube against the bend die under constant pressure at tangent and follows the tube through the bend. The follower type of pressure travels forward during the bending process and almost all modern rotary draw bending machines are equipped with this type of pressure. On most bending machines, two settings control the operation of the pressure die: direct pressure and assist pressure. To reduce drag on the point of bend, direct pressure must be kept to the minimum necessary to hold the tube without it separating from the bend die cavity.

Retaining Ring- A component of an H-type center or end link that holds the mandrel ball in place over the barrel of the link. Also called a snap ring.

Roll Bending - A method of bending in which material is fed through a triangular arrangement of rollers. The positioning determines the radius of the bend. It is a quick and effective method of forming extremely thick walls and large radiuses that exceed the capacity of rotary draw benders.

Rotary Draw Bending (or Radial) - A principal method of tube bending. In this process, drawing the material around a rotating bend form or die forms the bend. Specifically, the forward tangent of the tube is clamped to the bend die and is drawn around the die as it rotates while the back tangent is held in place against the rotating bend die by a pressure die. Thus, the mandrel and wiper tooling can be fixtured at the point of bend to control the flow of material fully.

Schedule-A wall thickness designator used in certain pipe specification systems, such as IPS, in which a schedule number for a given nominal pipe diameter designates a wall thickness in decimal inches. A single schedule number designates different wall thickness for different nominal pipe diameters. Fore example, 1.5- in. Schedule 40 IPS pipe has a wall thickness of 0.145 in., while 2.5-in. Schedule 40 IPS pipe has a wall thickness of 0.203 in. In the IPS system, Schedule 40 sometimes is referred to as standard pipe and Schedule 80 as XS, or extra-strong.

Seam -The joint along the axis of tube at which the two edges of the original coiled stack are welded together to create the tube. Usually the seam is not a matter of concern in tube bending, unless it has a weld bead that protrudes excessively into the ID of the tube and causes interference with the mandrel. Besides replacing the tubing material, an excessive seam can be handled in two ways; (1) Machine a groove into the mandrel that is sufficiently deep and wide to clear the seam (2) reduce the diameter of the mandrel to minimize interference with the seam. Once the mandrel's design is compromised to accommodate a weld seam, bend quality is reduced.

Serpentine Bend - A long tubular part, especially as a component of a heat exchanger, that is characterized by a pattern of 180- degree bends alternating in two planes of bend that are 180 degrees apart in orientation. While the bends of a serpentine application typically are not intrinsically difficult to form, the D of bend usually is generous they often must be formed without a mandrel, because the great length of the tube needed for the finished part exceeds the length of the bed of the bending machine. Setting the wiper at zero rake and increasing the assist pressure can compensate for the absence of a mandrel if the bend specifications are not other wise extreme.

Serration - The threading of clamp die and clamp insert cavities to improve the grip of these tools on the tube. The drawback of serrations is that they can mark, and even cut into, the OD of the tube. Fine serrations mark the tube less, but provide lesser grip than coarser pitched serrations. Serrations are an effective solution for applications demanding clamps as short as 1x OD.

Shank- The body of a mandrel assembly. In the case of an inserted mandrel assembly, the shank is the subassembly of the mandrel body and the mandrel nose insert.

Shank link- Another term for mandrel link and, less commonly, for insert link.

Socket-The spherical bore of H-type center links and mandrel links into which the head of another link is inserted to chain mandrel balls together in a mandrel assembly.

Springback- A bent tube's response to having the stress removed after the bending process. The increase in degree of bend can be offset by over bending the tube that is, exceeding the specified degree of bend by 3 to 8 percent so that the tube will open up to the desired degree of bend after the stress is released. Material rigidity, D of bend, and wall factor are the key factors in springback. However, other factors such as machine setup also can influence springback. No comprehensive guide can describe how all of the other factors, taken as a whole, influence springback. Therefore, with each new application, trial and error remains the quickest way to determine the amount of springback.

Stackable Tooling- Die sets that can be stacked for use on head or collet- shifting rotary draw bending machines.

Tangent - The beginning and ending of an arc or bend

Ultra Close Pitch - Type of ball string that uses two sizes smaller link size (shorter pitch) in order to have more balls in the same amount of space.

Wiper die (or Shoes) - The primary function of the wiper die is to prevent the tube from wrinkling during bending. A wiper die is required when the tube's resistance to compression is high.