Justifying, Selecting and Implementing Tube Bending Methods

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I. Introduction

Companies considering the purchase of tube bending equipment are faced with an extensive set of alternatives. It is important that a potential purchaser research his needs and the various equipment available. The manufacturer who gives special attention to details will gain a significant edge over his competition.

In this discussion we will investigate some of the more popular options available for tube bending, their benefits, limitations, cost and applications.

A. REQUIRED BENDING DATA

Before an intelligent decision can be made, the potential purchaser must understand the basics of tube bending. Rather than delve into bending theory, we will look at the required physical information about the part.

The proposed machinery must have the physical and technical characteristics required to bend the part. The major factors influencing this are:

a: Outside diameter (OD)
b: Wall thickness
c: Bending radius (usually measured from tube center line)
d: Material
e: Part configuration
f: Bend quality required (ovality and wall thinning)

Of particular interest in the selection of a bending method are items a, b, and c. These factors correlate to each other and will directly influence the type and tooling configuration of a tube bending machine.

Modern design concepts generally develop a bent tube shape by cartesian coordinates. These points in space, X, Y, and Z dimensions mean nothing to a tube bending machine. Even the most advanced CNC machines will do nothing more with this information than convert XYZ coordinates to bending data.

Bending data can be defined as:

a: Degree of bend sometimes called "angle"
b: Distance between bends sometimes called "length", "feed", or "position"
c: Plane of bend, sometimes called "twist", "rotation", or "orientation"

It is imperative the potential purchaser understand what must be controlled in order to select the proper equipment.

B. BENDING METHODS

There are various categories of tube bending equipment available on the market today. It is important a potential purchaser of a machine pay particular attention to required bending data and apply that knowledge to what is commercially available. "Re-inventing the wheel" can be very time consuming and expensive. Tube bending solutions, when approached methodically, can be obvious and profitable.

1. Manual bending

The original method of manual bending began with human power. Although bending a tube by hand is very economical, it is not conducive to higher production rates, quality or repeatability.

To counter the adverse effects of bending strictly by hand, basic die sets with a mechanical method of producing leverage were developed. This increases the quality of the bend and the production rates attainable, as well as, decreasing the human power required. Although machines have been built with the leverage to handle 2" pipe, hand benders are generally suited for 1" or smaller tubing.

Operation of this style machine requires that the operator place the tube in the tooling area at the proper bend position, actuate the tooling into position, and physically "pull" the machine mechanism to produce a bend. Basic machines have a single dial, gage or adjustable stop which serve as a guideline to produce the desired degree of bend. When more than one bend per part is to be produced, the operator must index the part to the next bend point and repeat the process to the desired second bend angle.

Advanced hand bending machines have been developed which are capable of producing parts similar to those by much more complex equipment. Systems have been devised to enable very accurate part positioning and to duplicate the method and quality of rotary draw bending. Physical "hard stops" have been built by manufacturers or "rigged" by end users to accomplish this. These advanced machines are significantly more expensive and utilize custom made tooling. The fact remains that the power for indexing between the bends, rotating for plane of bend and producing the bend angle is provided by the operator.

The advantages of basic manual tube bending equipment are:

a: Low initial investment
b: Short lead times for machine and tooling
c: Simple to operate (if part configuration is unsophisticated)
d: Portable
e: Relatively safe to operate

The disadvantages of basic manual tube bending equipment are:

a: Maximum operator interface required
b: Limited capacity
c: Cannot be automated
d: Standard OD and CLR tooling is limited
e: Difficult to produce complex part configurations
f: Accuracy and repeatability in question

As a general rule of thumb, hand benders are best utilized for:

a: Lower volumes
b: Short runs
c: Small diameters
d: Basic part configurations
e: Low labor rates

Prototype areas, short run departments, job shops, remote location tube fabricating and situations where economical labor can be applied are all good applications for manual bending machines.

2. Semi-automatic bending

For this discussion, we will characterize semi-automatic tube benders as fundamental hydraulic or electric motor powered tube and pipe bending machines. This equipment is available in many sizes, shapes and features.

The most basic semi-automatic benders have degree of bend stop(s) connected to a control panel. "Stops" are either a physically set limit switch or electronic relay logic system. These machines can require manual positioning of the tooling or provide powered tool positioning via the control panel. The operator actuates the cycle via push-button and the machine bends the tube to the preset angle. After the bend is made, the operator physically indexes the part forward to the next bend position, actuates the return sequence and repeats the process.

Most machines come with several distance between bend stops. Distance between bend stops are usually adjustable physical "paddle" stops mounted on a rod running the length of the machine. The operator secures them to the desired distance between bend position. The trailing end of the tube contacts the stop and provides a way of repeating the distance between bend portion of the part configuration.

Basic machines require that the operator rotate the part to the plane of bend position. This is perhaps the most difficult operation in the process to achieve accuracy and repeatability. A "bubble gage" is the main method of achieving this orientation. Hard stops can then be "rigged" or built into the tooling to provide a method for repeating the position.

More advanced semi-automatic benders are almost like "NC" controlled machines. Bender manufacturers are now offering several options to alleviate the drawbacks of the basic machines. Features available are:

a: Digital input of part data and part number storage. Although actual machine control is limited to degree of bend sequencing and springback, this feature provides a method for storing valuable data about each individual part configuration.

b: Carriages/colleting arrangements which hold the trailing end of the tube. This system enables physical plane of bend stops and distance between bend stops. However, the operator provides the physical force required to position the part.

Significant advantages of this type equipment over manual machines are:

a: Increased capacity
b: Less physical operator interface
c: More available options
d: Suited for higher volumes
e: Standard machines are generally more accurate
f: Capable of more difficult applications

Disadvantages of semi-automatic bending are:

a: Labor input directly effects accuracies and production rates
b: Requires operator expertise
c: Accuracy and repeatability can sometimes be a problem
d: Limited part complexities
e: Difficult to automate

3. CNC bending

"Computer Numeric Controlled" (CNC) tube benders were developed to circumvent the problems associated with other methods. Modern computer technology linked with servo-mechanical control offers an excellent method for controlling the 3 bending axis'.

CNC bender mechanics operate very similar to the other methods. The difference is that servo drives control the distance between bend and plane of bend. A carriage/colleting system is standard equipment. Tooling movement and sequencing, part data storage, and other items to be discussed later are controlled by the computer automatically.

For the purpose of this discussion, a CNC bender will be defined as a self-sequencing tube bending machine. The operator hands the machine a part, actuates the start button, the machine bends the part, the operator removes it, actuates the return sequence and repeats the operation.

Advantages of CNC tube bending:

a: Maximum accuracy and repeatability
b: Low labor input for production sequences
c: High degree of control
d: Quick change-over
e: Versatility
f: Complex part capability

Disadvantages of CNC tube bending:

a: Capital expenditure
b: Requires operator computer familiarity
c: May necessitate water, air and additional electrical power
d: Maintenance department aptitude stress

4. Special application bending

Special application (sometimes called "dedicated" or "fixture") bending machines, are generally custom built machines created for specific parts or families of parts. Configurations range from manually powered, "pull the handle" fixtures to fully automated work cells. Control systems vary from hard stops and air logic to advanced programmable logic control (PLC) technology. Many different reasons motivate manufacturers to utilize this style equipment. "Necessity, the Mother of invention" was perhaps the original and most logical. When there is no alternative available, the best tube bending people will create a solution. This equipment is limited only by the imagination and bank account of the company buying it.

Some parts simply cannot be bent on conventional equipment due to size, shape, configuration, or any number of other physical factors. Previous operations to the part may make it impossible to bend by customary methods. In addition, standard commercially available equipment may not be capable of utilizing the necessary tooling and/or provide the force required to make the tooling work. Custom built equipment can solve even the most complex part designs and accommodate more complex tooling than was previously possible.

Another rationale for utilizing special application tube bending equipment relates to production requirements. Extremely high part volumes and a competitive economic environment can force a manufacturer to develop a faster and more efficient means of producing parts. In small diameters, equipment can be built using pneumatics. In conjunction with the fact that more than one bend can be taking place at the same time, makes dedicated benders faster than traditional machines. This is especially true for parts with numerous bends. This seems to hold true until hydraulics are necessary for bending power, then the cycle time difference can become borderline.

Other operations, such as trimming, hose crimping, end forming,"T" branching and many other secondary operations can be incorporated in this style equipment. Part transfer and orientation associated with holes, "T" branches, brackets, and fitting locations can become integral with the bending operation. These factors can favorably effect the economics and manpower requirements of producing parts in high volume.

Special application machines are generally either built "in-house" or by custom machine builders and engineering firms. It is important that a potential builder of this type equipment have tube fabricating expertise, as well as, the mechanical and design ability to make it a reality. These qualities are imitated often, but not found readily. Manufacturers of special machines are generally smaller companies and due to the "custom" nature of their work, can have difficulty meeting deadlines and economic constraints, especially if they are good at what they do. Beware of the custom builder with the amazing price and the extraordinary delivery.

This type equipment is not called "dedicated" without reason. If the part goes out of production, prior to the machine's payoff period, a manufacturer can be left with a very expensive "contraption". If this happens, all that can be done is to use it for spare parts and boat anchors. When looking at using this style equipment, consider the payoff period and the part's life cycle period carefully. If there is any chance of a design change, use caution! Alternative uses for the machine should be considered in the specification stage of purchasing.

Floor space requirements can be quite extensive for the manufacturer who bases the bulk of their production on this style equipment. Machines currently not being used take up space. They must still be maintained or repaired to bring into service after long periods of being idle. Part production contracts that require service periods after an initial large volume production run, make floor space a definite economic consideration.

Special application tube bending equipment is best suited for high volume complex parts, where design changes are not likely and production schedules remain constant. The automotive industry is perhaps the largest user of this style equipment due to sheer volume. Indeed, brake line manufacturers have created some of the most complex, expensive and productive dedicated benders ever produced. However, with the implementation of "just in time" flexible manufacturing techniques and the realization that floor space is expensive, manufacturers are beginning to give dedicated equipment more scrutiny.

Advantages of special application benders

a: Small diameter, pneumatic machines offer maximum speed
b: Can usually be automated when specified at build time
c: Secondary or other operations can be incorporated
d: Maximum part complexity capability
e: Minimum labor input with powered machines

f: Automatic orientation of hoses, "T" branches, hardware etc.
g: Purchaser can specify machine features and components

Disadvantages of special application benders

a: Capital expenditure can be high for complex machines
b: Minimum flexibility
c: Difficult to find qualified long term suppliers
d: Can be made obsolete by part design changes
e: Delivery time can be long and increases with machine complexity
f: Justification based on narrow range of parts
g: Floor space requirements can be extensive

C. JUSTIFICATION

The specifics of capital equipment justification procedures vary widely between companies. The spectrum ranges from the sole owner deciding "he's just going to buy one of those things" to corporate accountants pouring through computer generated justification programs. In either case, it is easy to neglect important factors that can make or break the process.

Justifying tube bending equipment is unique to each company and to each industry. The manufacturer of the equipment can provide relevant information about the machinery, but should not be expected to complete the justification procedure in it's entirety. Company personnel given responsibility for purchasing equipment must have the time and resources to properly research the project.

Operations personnel who are to "make it work and live with it every day" can provide an invaluable insight into which equipment will benefit production most, but may not have the accounting background required for modern "number crunching". Conversely, what may look good on paper may not always be true in the real world. It is rare that a company has one person capable of filling both an accounting function and the operational background to implement what he has purchased. Justification procedures should be approached as a "team effort" or at least within a broad spectrum of experience.

The basic factors involved in justifying tube bending equipment are:

1. Price

Tube bending machines range in cost between manufacturers depending on features and capacity. It is important that the purchaser be sure he is comparing "apples to apples" in this regard. The following pricing chart is meant strictly as a guideline. The machine variations are endless.

APPROXIMATE PRICING ($1000)

OD CAP.	**BASIC MANUAL**	**ADVANCED MANUAL**	**BASIC SEMI-AUTO**	**ADVANCED SEMI-AUTO**	**CNC**
.25"	.01-.1	N.A.	N.A.	N.A.	50-70
.5"	.05-.5	4-15	10-15	15-20	70-100
1"	.1-1	15-40	10-30	35-50	100-150
2"	3-8	N.A.	14-40	50-75	130-200
3"	N.A.	N.A.	20-75	60-90	180-260
4"	N.A.	N.A.	35-150	100-200	300-450

When we look at this chart, it is evident that the larger the machine, the greater the price variance. This is because the vast majority of tube benders built are for smaller OD capacities. Thus, due to economy of scale, bender manufacturers are able to keep pricing more in line with the market.

The larger CNC machines are basically "custom built" to fill a specific need. It is not unheard of to see a $1 million expenditure for a very large specialized machine. Very few CNC bender manufacturers offer machines over 4" as a standard catalog item.

2. Return on investment

This is a basic accounting procedure for determining if an outlay of money will yield the rate of return compared to other avenues. Each company has a set of options available that can be unique to their corporate philosophy and capabilities.

It is a very common argument among management as to what is a reasonable payback period for capital investment. Many companies look for a 1 year payback, others 3 years and some may set yet longer term goals. Many foreign "transplants" are set up for 5 to 10 year periods.

Setting a very short term payback invites either "fudging" the numbers or leads the project into an act of futility. In either case, time and/or money is thrown away. Most successful projects are based on a 3 to 5 year payback.

3. Production

Perhaps the most basic approach to justify a new machine is to look at how many more parts per hour can be produced. Many variables can effect this analysis. Tube shape, size, configuration, secondary operations, and operator proficiency, among others, have direct bearing on the actual production rate.

Before a potential purchaser looks at the new projected rates, he should be comfortable with the data he collects on current production methods. Make sure that the information is an accurate picture. More than one project has failed miserably because current methods were not properly assessed, leaving the payback period anemic. On the other hand, there is a strong tendency to over estimate the existing processes. "We set that operation up 20 years ago and there couldn't possibly be a better way". "We produce 1000 parts an hour with those hand benders and how many people"? The point is, measuring present methods is a variable that the manufacturer can find out for himself. Tubular components being purchased on the outside or produced in-house should be calculated and assigned an accurate value.

Analyzing bender catalogs and talking to machine sales people will provide the generalization that small diameter CNC tube bending machines will produce a bend every 2 to 3 seconds. At face value, a CNC bender should be able to produce a minimum of 1200 bends per hour. Right? **NOT SO!** When we add 5 seconds load and unload time, this figure drops to 450 assuming we are producing single bend parts. If you stand and watch an operator for 10 parts, this may be true, but the real world is not as perfect. Fatigue, other duties, break-time etc. must be accounted for to get an accurate picture.

The following chart illustrates a comparison between traditional semi-automatic bending to CNC. A semi-automatic tube bender will be defined as a hydraulic powered machine in which the operator must actuate the degree of bend by pressing a start button. The machine bends the tube, he actuates the return sequence, manually moves the part a distance between bends and rotates it to a position for the plane of bend or twist to be accomplished. The positions are attained by a series of hard mechanical stops which the part is moved to make contact with.

PART	#BENDS	VG DOB	SEMI-AUTO PARTS(BENDS)/HR	CNC PARTS (BENDS)/HR
A	1	65	401.3 (401.3)	401.6 (401.6)
B	3	63	120.7 (362.1)	168.9 (506.7)
C	6	63	39.89 (239.34)	89.6 (537.6)
D*	10	64	23 (230)	69.6 (696)

These are actual production figures for employees doing a variety of other functions including packing, installing end caps etc. The parts were 3/8" steel tubes being produced on a 1" capacity machine with an average production run of 500 pieces. Part D* was a part configuration with a tube, charge port, and another tube brazed together. The CNC bender was capable of bending the part pre-brazed in the straight. The semi-auto bender required bending both tubes separately, then secondary operations to braze them to the charge port. If you are familiar with brazing parts like this after they are bent, you know the problems that can occur, especially with orientation between the two tubes.

As you can see from this chart, if the parts are relatively simple, the differences are minimal; however, when the part difficulty increases, there is a significant variation.

Notice that the more bends a part has, the faster a CNC bender becomes in comparison with a semi-automatic machine. When an operator has to manually position a part, fatigue, care for accuracy and sheer movement time have great impact on the cycle.

The following table illustrates the labor savings between CNC and semi-auto bending. It is based on 1 years production, running 2 shifts 220 days/yr at a labor rate of $15/hr.

PART	#BENDS	SEMI-AUTO PARTS/YR	CNC PARTS/YR	LABOR SAVINGS
A	1	1,412,576	1,413,632	$39.47
B	3	424,864	594,528	$21,085
C	6	140,412	315,392	$65,798
D*	10	80,960	244,992	$106,977

4. Change-over time

There is yet, one more common productivity advantage to CNC benders, the change-over time. The next chart shows the change-over time for the same 4 parts using $15/hr labor rate. It has been assumed that the CNC bender has the program for the given part stored in memory.

PART	#BENDS	SEMI-AUTO CHANGE-OVER	CNC CHANGE	LABOR SAVINGS
A	1	.5 HR	.5 HR	$0
B	3	.8 HR	.5 HR	$4.50
C	6	1.1 HR	.5 HR	$9.00
E*	10	3.4 HR	.5 HR	$43.5

Shorter production runs require more change-over time. Thus, there can be significant savings for manufacturers who produce low volumes and/or concentrate on "just in time" inventories.

Note that the more bends a part has, the longer it takes to change-over a semi-auto bender. This is because the process of positioning the mechanical stops of a semi-auto bender is time consuming and may require several adjustments to qualify the part as acceptable for production.

5. Scrap rate

Although many tube bending operations don't really have an accurate way of measuring scrap, we will consider it as a tangible aspect in the justification procedure. The days of the "scrap barrel" in the corner of the shop are fast coming to an end. More and more managers are realizing the impact scrap rates can have on the overall profitability of their companies.

Measuring the amount of scrap produced is an area sometimes overlooked in the justification process. It is especially critical to the company that uses expensive or exotic materials. The aircraft industry is a perfect example. The automotive industry is constantly moving toward weight restrictions facilitating the increased use of aluminum. In addition, automotive engineers are designing stainless steel exhaust and fuel systems for durability.

Parts that have numerous components or operations performed to them prior to bending can be very expensive to throw away. Fittings or brackets that are brazed onto the tube before bending can be very expensive. End forming operations represent significant labor input that can also be miscalculated in scrap cost evaluation.

The effects of part complexity on bender performance has been documented in the previous sections. When looking at scrap rate the same holds true. A CNC tube bender can be changed over to produce an accurate 10 bend part in just a few attempts. In order to produce that same part on a semi-auto bender, it may take 10, 20 or more. The expertise of the operator has direct bearing on this. This is partial basis for the expression "the black art of tube bending".

The scrap rate while in production will also be very different for the 2 methods. Outside of machine or tool failure, a CNC bender should not produce scrap while in production. With manual or semi-automatic equipment, operator fatigue can cause scrap or even worse, defective parts.

6. Accuracy and repeatability

Modern tube benders should be accurate and repeatable in their movements. A general guideline is as follows:

	Manual	**Manual+**	**Semi**	**Semi+**	**CNC**
Position +-:	?	.05"	.05"	.05"	.002"
Degree of rotation +-:	?	.5	.5	.5	.05
Degree of Bend +-:	?	.5	.5	.5	.05

While CNC bending offers unparalleled accuracy and repeatability of position, rotation and degree of bend, it does not guarantee the part will measure as such. It is important that the company realize the machine can only bend within the limitations of the material being used. Physical properties, such as wall thickness, hardness, tensile strength, and OD, if not held constant, can have direct impact on the part being produced.

Worn or inaccurate tooling can downgrade machine accuracies dramatically. If a company is going to spend six figures on a CNC bender, then skimp on the tooling, the part accuracy and repeatability will surely suffer. In fact, the entire machine performance may be severely diminished. The point to note: make allowances in the project budget for good tooling. It will pay off time after time.

7. Intangibles

The intangible aspects of tube bending can be the most overlooked aspect in a justification. Conversely, more than one machine has been purchased for reasons unrelated to the tube bending department.

If a company's finished product is something other than a fabricated tube or tube assembly, there may be additional benefits of controlling accuracy and repeatability of the tubular components. For example, an assembly operation with significant time spent "tweaking" the tubes so they will fit. This "tweeking" can also effect failure rates, especially in components for freon or other fluid transfer.

Product engineers, if they are made aware, may realize increased design capabilities which can give them more flexibility. A good example is a company that is striving to design a smaller product, but due to accuracy limitations must allow for a larger installation envelope than is desirable.

The advent and implementation of statistical process control and the increased emphasis on engineering design, have forced many companies out of contention for contract awards. Numerous purchasing decisions are contingent on factors the tube fabricator must meet before he is even permitted to quote. "Leading edge technology" can be an effective means of marketing your company's product and image.

D. SELECTION

Selecting a tube bender from the list of potential suppliers can be a long and involved process. Consistent with any good marketing effort, is projecting that one product is the absolute best for a given company. Expect machine sales personnel to reflect this. Unless a potential purchaser has extensive experience with tube bending, it can be very difficult to ascertain what is important and what is not. Selecting the wrong machine can have severe impact on careers, business relationships and the overall effectiveness of a company. Two broad categories can be looked at in the selection process: features and purchase intangibles.

1. Features

Machine features can offer a concrete method of comparing various tube bending machines. They can be divided into two areas: mechanical and control system.

a) Mechanical

Most all tube bending machines use the same basic mechanical principles. The differences occur in several areas that may or may not be patented. This area can be divided to encompass either machine characteristics or technical characteristics.

(1) Machine characteristics

Machine characteristics are features that effect the overall mechanical operation of a machine and it's ability to bend tubing. Basic similarities between manufacturers make this area more susceptible to "salesmanship" and/or personal preferences.

(a) Rotation

Standard bending machines can be built with the swing arm rotating either clockwise or counter-clockwise. The part configuration and machine interference zones will determine which is required. Give particular attention to the physical dimensions of a bender's interference zones. These zones will dictate the machine's ability to bend complex parts. If necessary, custom designed machines have been built to allow specific part configurations to be produced. However, the economic impact of a "special" machine could exceed its benefits.

(b) Speed

Published catalog positioning, rotating, and bending speeds do not necessarily translate into part cycle times. All manufacturers claim approximately the same axis speeds within a given capacity, but the actual rate may differ dramatically. The overall parts per time period matter more than machine axis' movement speeds. It may simply be impossible to bend a part at top speed because preceding bends would be deformed if the part is moved too fast. This is especially true in small diameters and soft materials. In practice, few manufacturers operate their machine axis' at top speed when part accuracy and repeatability are paramount.

The number of interference moves, non-axis movements, production controls, ease of load/unload and part configuration have more to do with actual cycle rates than does axis speed. The effects of these will be discussed throughout the following sections.

(c) Capacity

A potential buyer must be concerned with machine capacity. Bender capacities should be rated for a given wall thickness, OD, material and CLR. Yield points and other material strength indicators can be applied to the machine's mechanical leverage to determine this.

A manufacturer producing high volumes of 1" parts should not purchase a machine rated at a maximum of 1". The consequences can have direct impact on machine life, tool effectiveness and part accuracies. The point is, purchasing a machine utilized at maximum capacity today, can result in problems tomorrow.

(d) Hydraulic system

Most semi-automatic and CNC bending machines, especially the larger ones, utilize a hydraulic system. The effects of heat, cold, dirt etc. are documented and should be held in high regard. The most accurate machines should incorporate a heat exchanger to maintain hydraulic fluid temperature. The generally accepted practice is to provide fresh cold water. Optional water chillers and special hydraulic cooling systems are also available if water is not accessible. Hydraulic oil filtration systems are generally standard equipment. The quality of the filtration system however, is not the same between machines. It is advisable to research this.

(e) Servo drives

Servo motors for controlling machine movements are generally "AC" or "DC". Early CNC machines utilized DC servo drives and they were the standard for many years. AC drives offer better speeds and accuracies, are less expensive, more compact and are easily replaced. This is primarily due to the fact they run cooler at higher rpms and have a far superior acceleration and deceleration ramp. They are prevalent in most machinery today. Maintenance personnel can offer a preference based on their experience and judgment.

(f) Safety devices

Semi-automatic machines are generally supplied with a safety system to guard against being hit or pinched by the swing arm. Due to limited control capability and overall bending machine requirements, there are not many alternatives available except custom built safety systems or physical hard guarding.

CNC machines should be provided with a safety mat to guard the front of the machine while in operation. Dual palm buttons are fast replacing the foot pedal as standard equipment. Other safety measures can easily be added to the machine's control format. Light guards, additional mats, fences, etc. can all be added as long as they don't interfere with the tool area or the part being bent.

(g) Serviceability

The machine's serviceable parts should be easy to find and identify. Valves and cylinders should have identification tags relating function and electronics. Chain drives and wear plates should be easily adjustable and replaceable. Grease fittings should be clearly marked and positioned to enable easy access. Grease service of 20 to 30 fittings is generally called for once a month. An optional automatic lubrication system may be prudent for many companies. This will take the margin of error out and facilitate much faster maintenance. Modern bending machines do not require a great deal of maintenance, just consistency.

(2) Technical characteristics

Technical characteristics are features that effect the specific functions of a machine. Manufacturers can vary widely in this area and the differences can directly effect machine performance. The potential purchaser should give discriminating attention to the details of what his needs are and what they will be.

(a) Power transfer

An important mechanical aspect in machines is the method of power transfer to the bending head for degree of bend control. The bending head receives the most stress of any movement the machine makes. The purchaser should pay particular attention to rigidity, maintenance, flexibility and design.

The most widely accepted and time proven method is to use a gear, sprocket and chain link to supply force to the swing arm. Systems have been designed to allow independent swing arm and tool movement, shaft power transfer, belt drives, and rotary actuators, among others. Potential purchasers should be aware that the size of the bend head can directly effect the ability of the machine to produce their parts.

(b) Multiple radius capabilities

Many design engineers today are specifying more than one bend radius. A feature which most all CNC bender manufacturers offer is the ability to bend a part on more than one center line radius. This is accomplished by stacking the tooling. The part is then transferred between the bend dies. Another use for this feature is to transfer the part between compound bend dies or other special tooling. This can permit a part to be bent in one set-up that otherwise may have to be 2 or more operations. (i.e. part E of previous section)

The first way of transferring tubes between dies is moving the bend head. The head can move up, down, and side to side. This, in effect, moves the tooling to the part. The problem with this approach is that the heaviest part of the machine must be accurately moved and repositioned. The bend head is one area of the machine that requires absolute rigidity to ensure tool effectiveness and thus, part accuracy. The wear associated with the additional moving parts can effect the overall accuracy and maintenance requirements of the machine.

A second approach moves the bend head and the part. The tool area can move side to side and the part, through positioning with the carriage, moves up and down. Conversely, some machines move the part side to side and the tooling up and down. Special tooling and/or part configurations can arise where this may be the necessary method. Either system still requires pivoting the heaviest and most critical area of the machine.

A third method moves only the part. The tool area remains fixed while the carriage holding the part moves up, down, left and right. The rigidity of the tool area is not compromised, there are less moving parts to service and there is greater flexibility of tooling design.

No matter how a tube is transferred for multiple radius bending, attention should be directed to accommodate the tube that is not straight. A bow in the tube can create problems. Most CNC benders use a pipe support and/or guide to ensure the tube's position in the tooling. Although not necessarily standard equipment, this is critical to guarantee multiple radius bending success.

(c) Pressure die assist

Pressure die assist should be a considered option for any machine over 3/4" capacity. The pressure die assist offers significant bend quality improvement and the definite likelihood that efforts to eliminate mandrels and/or wiper dies will be successful. There is no increase in cycle time, the cost is minimal compared to upgrading later, and the benefits are tangible.

(d) Drop away clamp

The drop away clamp is an attribute that is standard on most CNC machines. Angular movement of the clamp die assembly, retracting it partially into the swing arm, notably improves the interference zone of the machine. This permits a more complex part to be formed with less chance of machine interference.

(e) Colleting

All machines have some means of colleting or grasping the tube. Most have a way to control how far the collet opens. This enables tooling to be made to grasp over a fitting or end form. It is important to note that some designs achieve this better than others. Care should be taken to insure that the ID of the carriage spindle is large enough to accept present and future designs. The most widely used collet in small machines incorporate 3 "jaws". 4 jaw systems are available for square or rectangular tube shapes. Larger machines can utilize rubber collets or an internal collet. The decision of which method to use depends on part configuration.

(f) Mandrel extractor and lubrication

Mandrel extractors and automatic mandrel lube systems may or may not be standard on smaller machines. Larger machines should definitely have at least a mandrel extractor. Automatic mandrel lube can increase tool life and improve bend quality by taking the margin for error out of the operator's hands.

b) Computer

Computer technology today offers unequaled control of many different machine and programming functions. Our discussion of computer functions will be mainly applicable to CNC machines. The control system and software have a direct relationship to machine performance. Computer technology varies between CNC bender manufacturers, therefore, it is important that a potential purchaser get "hands on" experience with as many controllers as possible. Predisposed attitudes about those "damn computers" should be rejected and replaced by a more pragmatic approach.

(1) Control system

Most all powered tube bending machines use components such as relays, power supplies and switches common to many other electrically controlled devices. There should be a series of sensors and encoders throughout the machine to provide feedback to the computer of machine position. Anywhere from 1 to 25 command circuit boards may be used to control machine functions. It is important that the purchaser resist the "whistles and bells" and concentrate on the functional aspects of a machine's control system.

(a) Dust and heat controlled electronics

The effects of heat and dirt to sophisticated electrical components can create down time and machine inaccuracies. However, modern electrical systems are very reliable in harsh environments. The computer systems utilized in automobiles are a good example of the improvements made over the years for this type application. CNC control systems should be protected from the environment by design, components, and reliability data.

(b) Data entry

Data is usually entered though a keyboard and viewed on a CRT screen. Entering data is generally accomplished by either traditional buttons, incorporated on the CRT as a "touch screen", or membrane pad.

The traditional button approach due to dust and dirt can get sticky, as anyone who ever spilled coffee on a keyboard should know. There are plastic protectors available that can minimize the effects of dirt in keyboards.

The "touch screen" offers the "flash" of modern technology but is highly susceptible to grease and dirt on the operator's hands. Software for these type systems generally does not allow random access of program functions. Additionally, they can be a source of frustration and slowed input because it can be unclear as to which area has been touched, and how many times. This is especially evident when entering number sequences.

Offering the best approach, is the membrane pad. It is not affected by dust, can be easily wiped off and provides a definite contact position.

Items such as color CRTs, graphics, and larger screens should be approached with caution. Simplicity and functional design should be the rule.

(c) Data storage

Long term storage of data in the electronic memory of the CNC controller should be avoided because it does not provide "hard" copy of the program. In the event of controller failure the data could be lost. Permanent data storage is performed by either a tape, floppy disc, data cartridge, or hard wire transferred to a secondary computer.

Tape storage is probably the oldest method to date. Without proper care, the tape can be damaged and the unit susceptible to dirt. Use with secondary computers require a tape reader to translate data.

Floppy disc storage offers an advantage over other methods. They can be used on a secondary computer for additional manipulation of the data. The units are also less prone to failure due to dust and dirt. In addition, file management techniques are simplified.

Data cartridges are unique to given brands of equipment and are generally very reliable. The cartridges are much more expensive and will require additional hardware to use on secondary computers.

Linking a bender to a secondary computer is an option available if a fabricator wishes to store or manipulate the data in another area of the plant. The secondary computer must have the necessary software to analyze the data being transferred. Limitations on distance from the bender and interference of high voltage equipment should be held in regard.

(d) Data output

A printer in the control system permits output of information on the part, what is in storage, and the diagnostic functions of the machine. This is valuable information which can be used to confirm data, help storage management and increase diagnostic effectiveness.

(e) Control pedestals

The set-up of machine tooling requires easy access to the manual mode functions on the controller. Controllers are usually placed on a movable pedestal or on an adjustable column attached to the machine.

Movable secondary pedestals provide start, stop, and emergency stop functions while the machine is in operation. This decreases the time and effort it takes to load and unload the machine.

(f) Production controls

There are certain control functions that are not common to all CNC machines. Intermediate pressure die positions, plane of bend delay, and swing arm return delay can greatly enhance machine performance.

Intermediate pressure die positions allow the open position of the pressure die assembly to be selected during automatic cycling. This decreases machine movement, thus improving cycle time. Half-out position can also be indispensable when attempting to cycle tubes that are bowed or not straight. Basically, it acts as a guide to insure that the tube stays in the bend die tube groove.

Plane of bend and swing arm return delay controls act as an alternative to programming avoidance or wedging movements. These delay controls provide a method of adjusting the machine movement timing sequence. Many times, this eliminates the need for a separate line of data in the program. This improves programming time and the machine cycle time.

(g) Serviceability

The machine control system is an area, unlike machine mechanics, that maintenance personnel are ordinarily unfamiliar with. 9 out of 10 machine problems not solved by in-house maintenance personnel are due to control system malfunction. Command control boards should be identified and easy to replace. Relays, switches and related components should be accessible and available for purchase. Sensors and encoders should be dirt resistant and positioned to avoid excessive wear and tear. Finally, an accurate maintenance manual and/or video tape should be mandatory.

(2) Software

The software of a CNC tube bender should parallel and augment the control system. "User friendly" software should not be taken for granted. Again, the only way to be sure is to get first hand experience with the machines being considered. The following sections will outline the major operational and control characteristics of CNC bender software.

(a) Operational software

Software that directs the operation of the bender will be considered as operational. Although it is closely tied to the control system, operational software is the vehicle to tell the machine what it is supposed to do. Outside of controlling the sequencing of machine movements through "closed loop feedback" this software provides critical data input and format channels.

i) Simultaneous programming

The ability to program the next part without interrupting production is a valuable feature. It is possible to line up several parts in advance, eliminating necessity of secondary programming computers. The advantages translate directly to decreased change-over times and the bottom line: parts per time period.

ii) Sequenced production

This is the ability to produce several different parts in succession. It can be very useful for producing multiple part tube assemblies.

iii) PRB input

Usually in chart form, the traditional PRB (position, rotation and bend) data can be input to create a bending machine program. The machine accepts the information similar to the following charts.

PART NUMBER	1123B
OD	1"
MATERIAL	STEEL
WALL	.065
BEND RADIUS 1	2"
BEND RADIUS 2	2.5"

Although the categories of material, OD and wall mean nothing to the machine, it is useful to have this information stored with each part number. This will insure proper material selection when it is retrieved from storage.

PART NUMBER	1123B
LOADING POSITION	104
OFFSET POSITION	88
PRESSURE DIE COLLISION POINT	8
BEND DIE COLLISION POINT	3
BOOSTER MODE	-5

The loading position is where the carriage will be when the operator gives it the part. Offset position is where it moves to for the first bend. Pressure and bend die collision points are positions where the carriage will contact the tooling. Collision points are to protect the machine and tooling and are used as a benchmark for other machine movements. The booster mode determines a stop point for the pressure die assist unit. The settings in this screen may be set numerically or by physically moving the carriage to the desired point and pushing the "insert position" key. It is important to note that not all bending machines are the same here. The difficulty of inputting these numbers ranges from a keystroke to scrap paper calculations.

PROCESS #	R	FEED	SP	PLANE	SP	BEND	SP
1-0	1	0	4	0	3	90	5

2-0	2	5	4	90	3	45	3
3-0	2	3	4	30	3	10	3

This is where the specific bending data is entered. The point number is entered automatically. The radius (R), distance between bends (FEED), plane of bend (PLANE), degree of bend (BEND) and the axis speed for each (SP) can be entered in succession or random order.

iv) Bending and wedging processes

Most CNC benders allow input of 25 to 30 bends and 10 to 20 wedging movements per bend. Although this may seem excessive, there are many manufacturers that have requested optional increased capability to over 60 bends per part.

v) Electronic memory storage

Manipulating and storing part data in the electronic memory allows the operator faster access than relying on tape, floppy, cartridge etc. This is particularly useful for the more popular parts being produced with greater frequency. It can also be used as temporary storage before a part design is completed.

vi) Single movement control

The process of "de-bugging" a new part program is much easier if the initial try can be broken down into individual machine movements. In this way interference points, tooling modifications, speed changes etc. can be noted and corrected.

It is important to note that every individual machine movement can be separated in the program to create customized bending sequences. The more complicated a part is, the greater likelihood that this will be required.

(b) Control software

Control software calculates, measures, and records data for manipulating the operational programming or for output to the operator. It can prove valuable and is not always offered as standard equipment by CNC bender manufacturers. The following sections will outline the major features available.

i) XYZ calculations

XYZ coordinates directly from drawings or CAD designs can be input in the same manner as PRB data. The coordinates are then processed and converted to traditional bend data. Cut length, extended length, and offset position are additionally calculated and displayed. This feature can be an excellent time saver if the engineering department is frequently backlogged.

ii) Inverse bending calculations

Many times the bend sequence makes it impossible to bend the part as entered. However, if it were started from the other end, it would cycle fine. Inverse bending calculations automatically "flip" the tube over and start the bends from the other end. This feature can cut programming time and basically eliminate a great deal of frustration associated with complicated parts.

iii) Diagnostics

Three areas of diagnostic functions should be standard equipment on CNC bending machines with output on the CRT and the printer.

The first area identifies the present condition of normal functions, such as, "emergency stop activated", "automatic mode", "illegal data", "manual mode" etc. This is used routinely by the operator and is the first logical step in finding a machine problem.

Second, the machine operation indication should provide a systematic review of every major mechanical system on the machine. All cylinders and servo motors should be monitored by position and identified if they are not reaching the target location. This identifies cylinder or motor malfunction and the possibility that position sensors are not operating properly.

Third, I/O monitoring should provide data on the input ports, output ports and encoders. Readouts of the binary code on these systems indicate which command circuit board or encoder is malfunctioning. It is normal practice to FAX the printout of this display to central service facilities. Trained technicians can analyze it much faster than most in-house maintenance personnel. Unless the facility is within driving distance, the technician will overnight mail replacement parts. This approach is fast and economical.

iv) Springback and elongation

Springback is measured manually then automatically applied on a straight line basis to the bending program's compensation values for degree of bend. Thus, a 90 degree bend measuring a 2 degree springback would be applied to a bending program for a 45 degree bend as 1 degree.

Elongation is measured automatically or manually and applied to the bending program. This is accomplished by closed loop feedback between the carriage and bend head. For example, if the machine is making a bend, the trailing end of the tube should move forward a given distance factoring in the bend radius. Due to the stretch or elongation of the material, it does not. The machine measures this difference and applies it to the bending program's compensation values for distance between bends.

v) Counter and work reports

The counter provides the operator with a method of accurately determining how many parts are desired and have been produced. It can eliminate over and under counting of a production run.

Work reports can display and print out a daily tact time and count for a series of production runs. This feature will measure actual cycling time, number of parts produced and the time the machine was in automatic operation. This can provide estimating or industrial engineering departments with concrete data on cycle rates. It can also be used to justify automatic loading systems based on actual manual load and unload times over a production run.

2. Purchase intangibles

Purchase intangibles can be defined as factors separate from the immediate physical properties of the machine being considered. They should be held in high regard but should not dictate the selection process if possible.

a) Delivery

An area of concern in our fast paced world is always delivery. Bender manufacturers often stock more popular models of machines. If a machine is ordered from stock, it can usually be delivered anywhere in the U.S. in 1 or 2 weeks. Ordering a specific machine from the factory can take from 4 to 6 months.

b) Manufacturer characteristics

The characteristics of the company being considered should hold much consideration. The reputation and solvency that a manufacturer of tube benders has should be held in high regard. The best way to find out about a manufacturer is to talk to people. Find out who uses their machines and look at what business they are in. If you are not strictly in the tube fabricating business call people who are. A little research before committing to significant capital outlay can prevent disaster.

c) Factory location

Selecting a machine based on where it is made discounts the entire selection process. Capital equipment should stand on it's own merit. Personal preferences should be rejected in favor of doing what is right for the company. Protectionism does no service to American competitiveness abroad nor is it consistent with capitalist ideals. Conversely, it is not right to purchase based on the idea that because if it is from a given place, "it must be the best".

d) Service organization

The service organization can greatly effect the overall success of a project before and after the purchase. Service calls by technicians can cost between $50 and $100 per hour plus expenses. The availability and qualifications of service personnel directly influence the cost of a service call. The ability to modify IC chip programs, provide RS232 or other interface methods and a record of doing so, can indicate the competency of a service organization. It may not be necessary for a purchaser now, but future modification, servicing, expansion and automation of the bender will require this expertise. If possible, it is prudent to visit the service facilities of a manufacturer to determine the extent of spare parts inventory and the quality of the service technicians.

E. IMPLEMENTATION

Implementing a tube bending machine into the production process can be the most important phase of a tube bending project. While it is important that a tube bending operation research its needs and the various equipment available, the inevitable end must be to produce parts. The justification procedure, production criteria and time tables associated with capital equipment purchases sometimes overshadow the importance of seeing the project to completion.

Proper implementation of a tube bending machine into a company's manufacturing processes is critical for project success. Special attention to details can drastically decrease the time it takes for a machine to be fully integrated in plant operations. Just getting a machine and turning on the power will not assure future benefits. This article will outline several areas that will speed the implementation of a machine.

1. Before the machine arrives

a) Choose a machine location

It is important that the machine be located in a way that is logical and advantageous for production. Many times, companies do extensive research into production flow, cellular and production concepts, and plant floor design layouts. Even life-size models have been constructed and put into place prior to the actual equipment delivery. Assuring that the desired footprint and the maximum operators= productivity are achieved will go a long way in making the payoff schedule of the new equipment become a reality.

b) Arrange for utilities

The new machine will most likely require air and power. Some machine hydraulic systems may require that water supplies and drains be available. Researching what is necessary and thinking far enough ahead to have these items in position will greatly improve the chances of a flawless installation.

Arranging for the utilities to be put in place *before* the machine arrives will diminish frustration and the time required to get a machine operational. Too often expensive and hard to schedule technical personnel can be left ineffective when they are waiting for a new machine to receive the required utilities.

c) Determine the personnel to be trained

Ascertaining who, their schedules and how much time needed for training is very important. The project coordinator should plan out exactly whom, what, and when training will occur. Personnel directly responsible or involved with the machine should be trained. The project coordinator should have reasonable confidence that operators trained in tube bending will continue in that function. It is not in a company=s best interest to be forced to repeat the training process later due to personnel changes.

Individual situations and experience levels vary widely between companies.   Adding a duplicate machine on the plant floor is quite different from a company implementing an entirely new process. Many companies adding another identical machine to many do not schedule a formal training session. Alternatively, a company that has never been involved in tube bending will want significant training on bending theory and tooling functions. Discussing this with the supplier in advance can make the training process much more effective.

It is also important if second and third shift personnel are to be trained that arrangements are made to assure their availability. It can be counterproductive for a company to train one shift completely and ignore others expected to operate the same machine. This can be one reason a lot of operational problems and down time occur on second and third shifts.

d) Select parts

Most machines are justified and purchased on its ability to produce a given part or parts. In order to prove out the process, these parts should be run while the service technician is in the plant. Before the machine arrives make sure that part data and drawings are selected and available.

In some new tube bending machine projects, such as a job shop environment, a specific part or family of parts are not originally specified for the machine to produce. In these cases, a cross-section of the parts should be determined. The maximum and minimum size, as well as, maximum and minimum part complexity should be represented in a new machine=s production mix.

e) Arrange for part inspection

A method or process should be in place to qualify if the new machine is producing acceptable parts. Checking gages, fixtures or coordinate measuring systems can be used to qualify that the parts produced from the new machine are adequate. It is also entirely feasible to have complete statistical process control (SPC) analysis, but it should be specified prior to ordering the machine.

f) Order straight, cut to length tubes

The purpose here is to guarantee that valuable time is not wasted waiting for parts. In order to insure that parts are ready to be bent during the training process, it is prudent to make sure that production schedules are arranged. Blank, unbent parts need to be available to personnel involved in the installation and training process.

g) Make sure tooling for the new machine is on schedule

A machine installation is not effective if the tools are not available. Many times, tool delivery is longer than that of the machine. Some manufacturers of tube bending equipment will provide tooling with the machine. Although not a requirement, specifying a runoff at the machine supplier=s facility, prior to shipment, assures part, machine and tooling compatibility.

2. When the machine arrives

a) Confirm shipment

It goes without saying that it is important to confirm that everything expected is received. However, with extensive and complicated tooling and machine orders, it is easy to miss important items. Each item should be confirmed against the original order. This can prevent lost time waiting for critical or essential items that could have been damaged in shipment or not shipped at all.

b) Position the machine

Competent personnel need to be charged with moving and positioning the machine in the planned location. The manufacturer=s specifications on machine rigging and anchoring should be followed in the best way possible.

3. Begin the training process

In most tube bending machine purchases, factory technicians or representatives are available for operator training. It is strongly advisable to coordinate the amount and type of training required. Experienced machine sales and service personnel can be invaluable in this regard. A little time and extra money can make a big difference when it comes to speedy installations.

Repetition is perhaps the best way to become more proficient at a skill. Most tube bending training is based around setting up the machine and tools, then producing an acceptable part, then doing it all over again. While the service technician is there, it is important that his or her time be spent teaching the machine and process, not waiting for utilities, tooling, material, prints, gages, etc.
Prior to beginning training it is desirable to have several blueprints, cut tubes and checking gages readily available. When beginning to bend parts, it is best to start with simple configurations and work up to the more complex. It is preferable to have 20-30 cut tubes for each part drawing. In this way, machine programming, tool set up and simulated production runs can be practiced. Hand tools and bender tooling should be in good condition and ready to use.

The standard in-house operator training provided with a machine purchase varies between manufacturers. It may range from nothing for simple tube benders, to approximately three days for a computer numerical control (CNC) machine. The actual time required may vary according to a company=s level of expertise. Time for in-house training should be specified and agreed upon prior to purchase.

Also of importance to operator training is that the instructor is qualified and interacts well with plant personnel. The instructor does not need to be an electrical engineering technician, but should have ample experience with the machine and tube bending. Barring damage in transit, well designed and built equipment should basically be mechanically and electrically operational when received on the plant floor. If this is not the case, more study should have been given in the selection process and the trouble is just beginning.

The following chart is a general idea of time required for a CNC bender installation.

Day 1
1 hour - utilities connection and technical check
2 hours- tube bending and tooling technique overviews
1 hour - explain and demonstrate of computer functions
1 hour - explain and demonstrate program sequence/method and safety
3 hours- begin hands-on programming

Day 2
2 hours- demonstrate tooling setup and safety
4 hours- begin hands-on tooling setups
2 hours- hands-on setup, bending parts, tear down

Day 3
6 hours- hands-on tear-down and setup of all operations
2 hours- maintenance department training

This chart is only a guideline. It is entirely possible that bending can actually take place on the first day if operators are already familiar with bending or if qualifying production runs and training were completed at the machine supplier=s facility prior to shipment.

It is important that only a few people be trained at one time and the instructor has their full attention. The confusion of people coming and going for other duties disrupts the training process and greatly reduces the retention level of personnel involved. The first days of a machine should not be treated as a "dog and pony show" for management or customers until the training is complete. A more effective and productive show can be made when the machine is making money for the company.

4. Maintenance training

Many companies want the operator to do daily maintenance of the machine. This instills a sense of responsibility for the bender in those that use it. There is not a great deal of time required for maintenance personnel. The basics are:

1) machine components and operation
2) grease fitting locations
3) fuse and relay locations
4) hydraulic system oil and filters
5) miscellaneous components and adjustments
6) command circuit board location and replacement
7) diagnostic program analysis and printout
8) cleaning and care
9) Preventive maintenance programs and spare part lists can be recommended by the manufacturer or

developed in-house.

5. Other departments

It can be beneficial to instruct other departments on the basic operation of the machine. The extent and selection should be determined in advance and may greatly enhance the implementation of the new machine.

Industrial engineering or estimating departments may wish to utilize the data produced by the control system. Many of the more advanced CNC machines can develop and record much information about production, tact time, etc.

Product engineering may benefit from learning what is feasible with the new machine. If design personnel have first hand experience with tube bending techniques and applications, they will be better equipped to design parts more conducive to production.

Marketing departments may benefit from information on the new machine capabilities. The realization that new capability exists and a thorough understanding of plant operations can greatly increase sales effectiveness. This can therefore, increase the amount and type of business a tube bending operation is favored with.

6. Follow-up

The best way to complete the training process is to "turn them loose" with the machine. Expecting personnel with little or any prior tube bending experience to be 100% proficient at the end of three days training, is not realistic. The true learning curve comes when no one is there to look over their shoulders. A well-written operation manual will be essential to operators at this stage of the training process.

It is important that the tube bender supplier have technicians available for questions and analysis. Many suppliers can work out problems in their facility and pass the solutions on via fax, phone or even program data discs. This is especially true for suppliers who have machines in stock or for demonstration purposes.

If a tube bending operation has a large number of complex parts, it may be beneficial to schedule a follow-up training session. In a few weeks, operators have specific questions and obstacles related to individual parts. Budgeting additional funds for a follow-up training session could speed the implementation of the machine by leaps and bounds.

II. Conclusion

It should now be apparent the factors influencing a tube bending project are extensive. Criteria for evaluation should be indicative of individual company philosophies and requirements. A well thought out, consistent and pragmatic approach will yield far better results than reactionary decision making.