

PRACTICAL GUIDE FOR FLAME BENDING OF PIPE

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U.S. DEPARTMENT OF TRANSPORTATION AND U.S. DEPARTMENT
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PROGRAM MANAGER'S FOREWORD

This manual satisfies the deliverables requirement for the task "Training Manual for Flame Bending of Pipe", sub-contracted by Ingalls' Shipbuilding Inc. to Puget Sound Naval Shipyard under Maritime Administration Contract MA-80-SAC-01041. It is the project report for the second SP-7 task performed by Puget Sound Naval Shipyard in the area of flame bending. In these two projects, the Welding Engineering group at Puget Sound, with leadership from Doug Coglier and Frank Gatto, have researched the technological basis and principles of thermal bending and straightening and applied that technology to marine piping systems. Considerable foundation material and quantitative data was developed and presented in the first project report, NSRP No. 0297, FLAME BENDING OF PIPE FOR ALIGNMENT CONTROL. That report included not only extensive descriptions of equipment and methods of acquiring process development data, but also laboratory evaluations which show no adverse effects of calibrated and controlled thermal bending processes on Carbon Steel, copper-nickel 90-10 and 70-30, and 300 series stainless steel pipes? both new and previously used in sea-water systems.

In this report, the Puget Sound group's primary effort has been to set forth the technology of flame bending of pipes in a format which will serve as a guide for shipyards to use in training personnel and in developing procedures specific to their own requirements. The information contained in this and the previous report should enable shipyard personnel to reach the state-of-the-art and to implement this technology with minimal cost and risk of error.

The reader may note that the legal notice on the inside cover touches some of the same points as the disclaimer provided by the authors. The first is the standard notice which accompanies all NSRP project reports. The disclaimer provided by the authors was not edited out because it is specific to the project and is especially relevant since this report is likely to become not only a future research reference but also a working document. Every effort was made by the authors to provide cautions regarding applications of the technology with regard to both technical considerations and to personnel health and safety. In that context the caution in Appendix A on use of "typical" procedures bears repeating: "these procedures or procedures similar to them

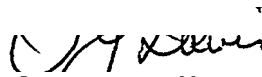
should not be implemented without proper operator training and without the procedure being properly qualified."

The intent of this task was to develop a practical guide for dissemination of flame bending technology developed at Puget Sound Naval Shipyard for application to piping systems in any shipyard. A study of this project report will show that objective to have been met with a high level of excellence.

* * *

The project which resulted in this report was submitted to and approved by the Executive Control Board of the Ship Production Committee of SNAME and received financial support from the Maritime Administration of the Department of Transportation and the U.S. Navy. The SP 7 panel Chairman was Lee Kvidahl and the Program Manager was O.J. Davis, both of Ingalls Shipbuilding, Inc. The project administrator for the Maritime Administration was Virgil Rinehart, Senior Advisor for Shipbuilding.

* *

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Program Manager, SP7

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PRACTICAL GUIDE
FOR
FLAME BENDING OF PIPE

This project was made possible by:

MARITIME ADMINISTRATION of
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U.S. DEPARTMENT OF THE NAVY

in cooperation with
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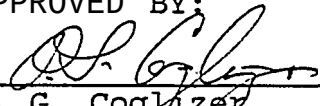
PRACTICAL GUIDE FOR
FLAME BENDING **OF** PIPE WITH ACCURACY CONTROL

PRESENTED TO THE
NATIONAL SHIPBUILDING REASEARCH PROGRAM
SHIP PRODUCTION PANEL #7

BY
PUGET SOUND NAVAL SHIPYARD
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The authors express their gratitude to those individuals who have reviewed and commented on this manual and those organizations who contributed support to its creation.

PROFESSOR HOLT

JAY DWIGHT

ALFONSO COLLIN

PUGET SOUND NAVAL SHIPYARD

SP-7 PANEL

DISCLAIMER

This manual represents the collective effort of many specialists and is intended to provide assistance in understanding and using the flame bending process. Care has been taken to collect and present accurate, reliable information. However, no representations or warranties, express or implied, are given in connection with the accuracy or completeness of this publication and no responsibility is taken for any claims that may arise. Nothing contained in this manual is to be construed as authorization for the use of any Process, procedure, method, technique or application contained in this manual by any person or persons, organization, agency or other legal entity, corporate or otherwise; nor as a defense against liability for the infringement of letters patent, registered trademark or other protected right.

INTRODUCTION

WHY IS PIPE ALIGNMENT CRITICAL?

Functional design failures can be the result of unanticipated service stresses coupled with piping system dimensional instability. For many purposes it is acceptable to assume that pipes retain their original shape and relative position after being placed in service. Unfortunately, a number of factors can invalidate this presumption commonly made by the inexperienced designer. Large external installation alignment loads coupled with other forming or manufacturing residual stresses can cause them to become dimensionally unstable in service.

SERVICE RELATED FAILURES

In most cases stresses and the strains associated with this slight metal movement due to elastic loads does not affect service. However in some cases this stress and unanticipated service loads are extremely critical. These conditions have caused piping and machinery failures. Many of which have been associated with turbines and pumps. This unanticipated loading has also resulted in premature failures of piping systems disabling ships at sea causing flooding of boiler rooms and when fuel systems are involved developing serious fire hazards.

Most of these failures are not due to internal residual stresses of individual fittings as stress relief of separate components or welds would resolve these failures. The majority of these failures are due to strains caused by the inability to properly aligned pipe and components to: turbines; valves; pumps; and other critical fittings for ships service. Frequently in the past if a pipe joint was misaligned it was common to force the materials into alignment and bolt or weld the joint together. These large external applied elastic loads to critical components have been responsible for hundreds of thousands of dollars of damage to marine vessels and their machinery components.

CORRECTING MISALIGNMENT

Piping system misalignment can be minimized by a number of different techniques. The material can be cold bent by plastic deformation to the desired shape; controlled distortion caused by welding can be used to align piping systems; weld joints can be cut and realigned; large sections of the pipe can be heated and hot stretched into shape and sometimes local area spot heats (called spot shrinking) is used to align pipe. All of these processes have limited success for critical applications. They can result in high residual stress causing unanticipated service loads and strains. Also these processes are too cumbersome to permit repeatable precise control.

Puget Sound Naval Shipyard has built upon what is called "Holt Method". The Holt method in particular has the advantage of speed, ease of use, and precise control that results in joints with low stress levels that are stable in service. The "Holt Method" is fast and with some training it is easy to accomplish.

Section 1
FLAME BENDING
WITH
ACCURACY CONTROL

APPLICATIONS

The techniques described here in are intended to produce accurate flame bending with minimal residual stress and minor, if any, resultant loss of base metal specification properties.

The primary purpose of these bending techniques are:

- to align piping systems to components
- to align piping" flanges so that their gasket surfaces are parallel
- to increase or decrease the clearance between fitting flanges
- to align bolt holes in mating system components
- to align weld joints for fit up

It is essential that the process of alignment result in minimal residual stress so that the joint connections do not create harmful in service strains. System operating loads due to vibrations or elevated temperature thermal expansion stresses can cause elastically loaded (unstable) joints to impose unanticipated service stresses on system components. The result of which can result in mechanical machinery failures or failed fluid boundaries.

ACCURACY

The processes described here in can achieve flange parallelism within five thousandths of an inch (0.005") per inch of flange face width. For example a flange with a 5" gasket seat can be made parallel with in 0.025". Higher accuracy than this is commonly achieved. Long stainless tubes with long sweeping bends of deviations greater than one inch can be straightened with 0.001" per foot of length. A fifty foot tube can be straightened within 0.030" total run out for its entire length. For many applications flame bending can frequently achieve desired results (straightness/parallelism) within five thousandths of an inch (0.0051") with proper planning.

LOW RESIDUAL STRESS

Properly made and placed VEE heats on pipe are expected to produce lower residual stress than any other bending technique except those that receive post bend stress relief. On structural shapes R. E. Holt has reported that "Properly placed heat patterns produce a residual stress pattern that is lower in magnitude and more uniform than as rolled material. Tests conducted by the US Army Corps of Engineers at Clear Alaska showed the flame straightened A36 beams were superior to the as rolled beams".¹

When very small movements are required, spot heats are sometimes necessary. Spot heats made as described in this text must be considered to be at yield point tension and some what unstable due to in-service thermal and/or mechanical fatigue. Whenever possible, brief run-in test trials should be performed to assure in-service stability.

There has been very little research or test and evaluation work accomplished to determine how low the residual stresses are but in service experience has demonstrated that proper flame bending of piping to machinery components such those involving main feed pump turbines are more stable in service than those aligned with other standard alignment techniques such as cold bending(stretching), hot bending (stretching), traditional flame bending techniques by local spot heats or by the use of weld shrinkage. Puget Sound Naval Shipyard has experienced no known machinery failures due to piping loads on machinery components since the Holt VEE heat technique has been used. Prior to using the VEE heating technique numerous machinery failures were attributed to elastic piping loads (cold spring) due to misalignment and or improper alignment techniques. Also numerous pipe leakage problems have been attributed to improper alignment of flange makeup joints to rotating machinery.

¹Holt, R. E., "Primary Concepts for Flame Bending," Welding Journal, June 1971.

Section 2

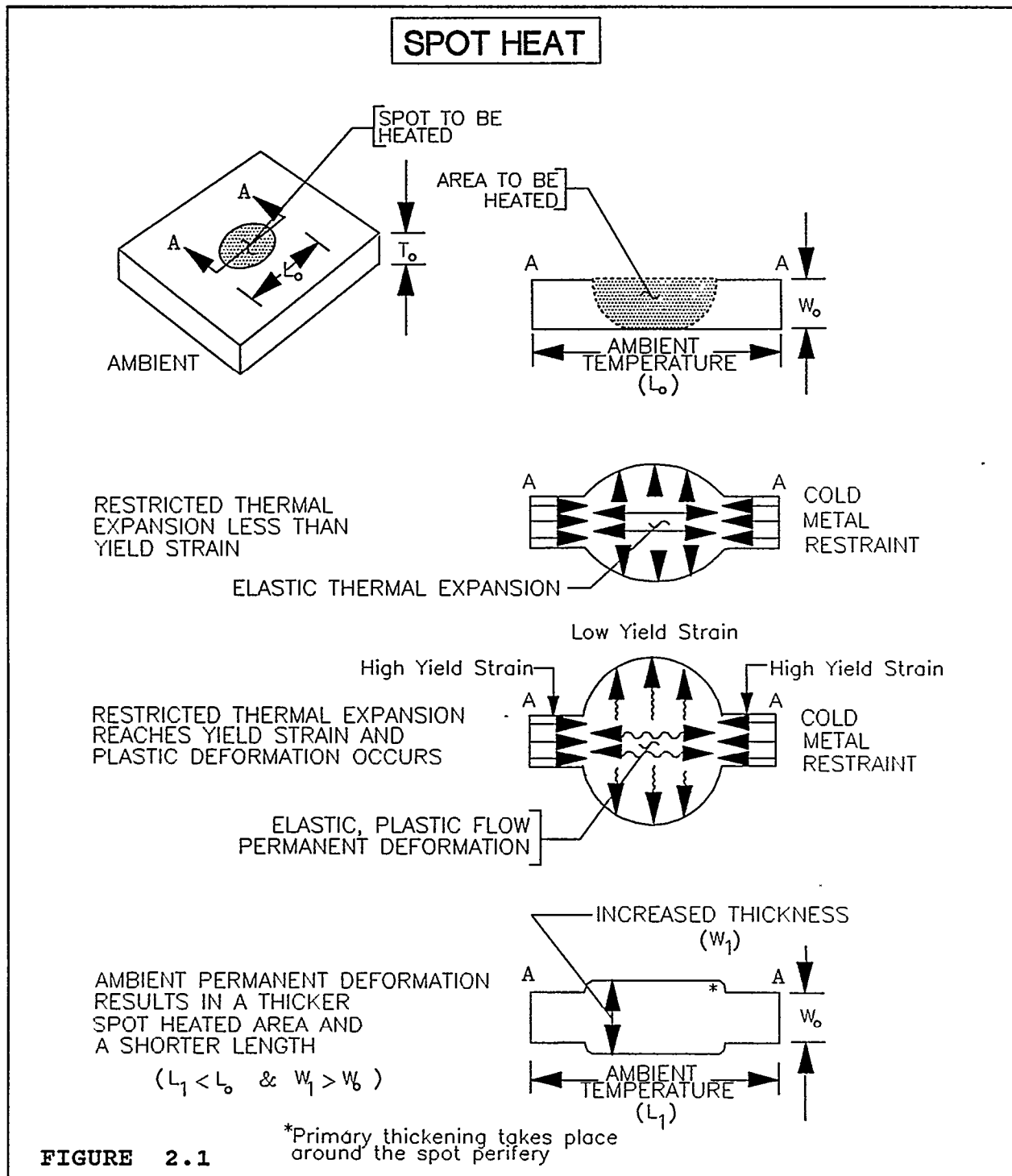
**BASIC CONCEPTS
OF
FLAME BENDING**

RESTRICTED EXPANSION AND FREEDOM TO CONTRACT

The primary mechanism by which flame bending operates is that the base metal is heated under restricted expansion (compression) and is only free to thermally expand and plastically deform in the through thickness dimension of the base metal. The end result is that the heated area is generally thicker than the adjacent base metal. Thus resulting in shorter dimensions in the plane of the base metal. It is extremely important that during all phases of production work that this concept be kept in mind and that "ALL FLAME BENDING WHEN ACCOMPLISHED PROPERLY RESULTS IN INCREASED THICKNESS AND SHORTER LENGTHS". This shorter length if not considered before flame bending is commenced may lead to unsuccessful flame bending finish dimensions and result in cutting and rewelding the pipe.

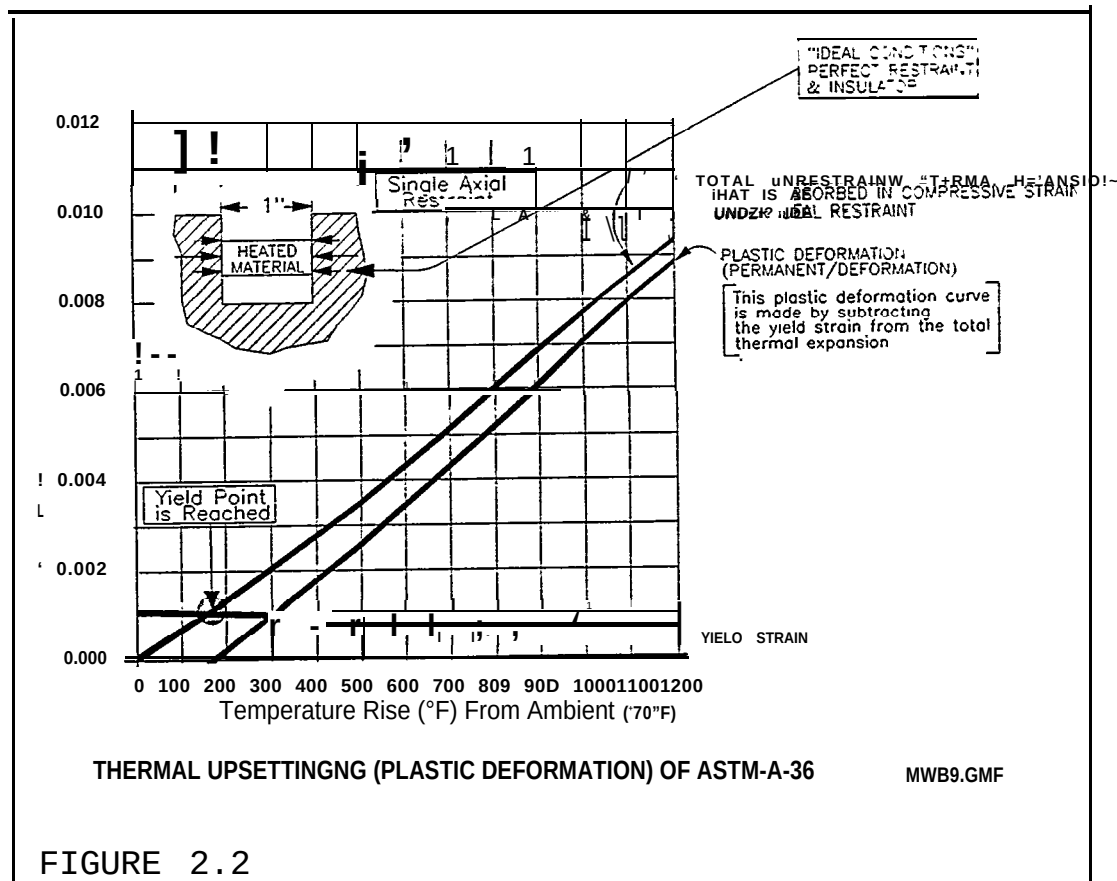
MECHANISM OF HEATING A SPOT

The following Figure 2.1 exhibits the primary mechanism involved in heating a spot. If a spot is to be heated in the center of a plate, the area being heated thermally expands as the temperature rises while the base metal adjacent to the spot being heated is relatively cold. This relatively cold base metal restrains this thermal expansion in the plane of the plate. This places the heated area under high compressive strain. The yield strain of the base metal being heated decreases with increasing temperature while the adjacent base metal remains relatively higher due to its lower temperature. As the spot is continued to be heated to higher temperatures and strains, it reaches yield point and the heated area yields or plastically flows perpendicular to the plate surfaces. As the heated spot cools off the area around the periphery of the spot that plastically deformed always is at a lower temperature than the center of the spot. This causes retained increased thickening or deformation in this peripheral area that was formed during the heating cycle. During the cooling cycle the periphery of the spot has a higher yield strength than the center of the spot due to its lower temperature. The average spot thickness at ambient temperature is thicker than it was prior to heating: The base metal is thicker in the area that was heated this can only be accommodated by shortening of dimensions in the plane of the base metal. Case History #1 demonstrates a practical example of using the primary concepts of spot heating to reduce the diameter of a die nut.

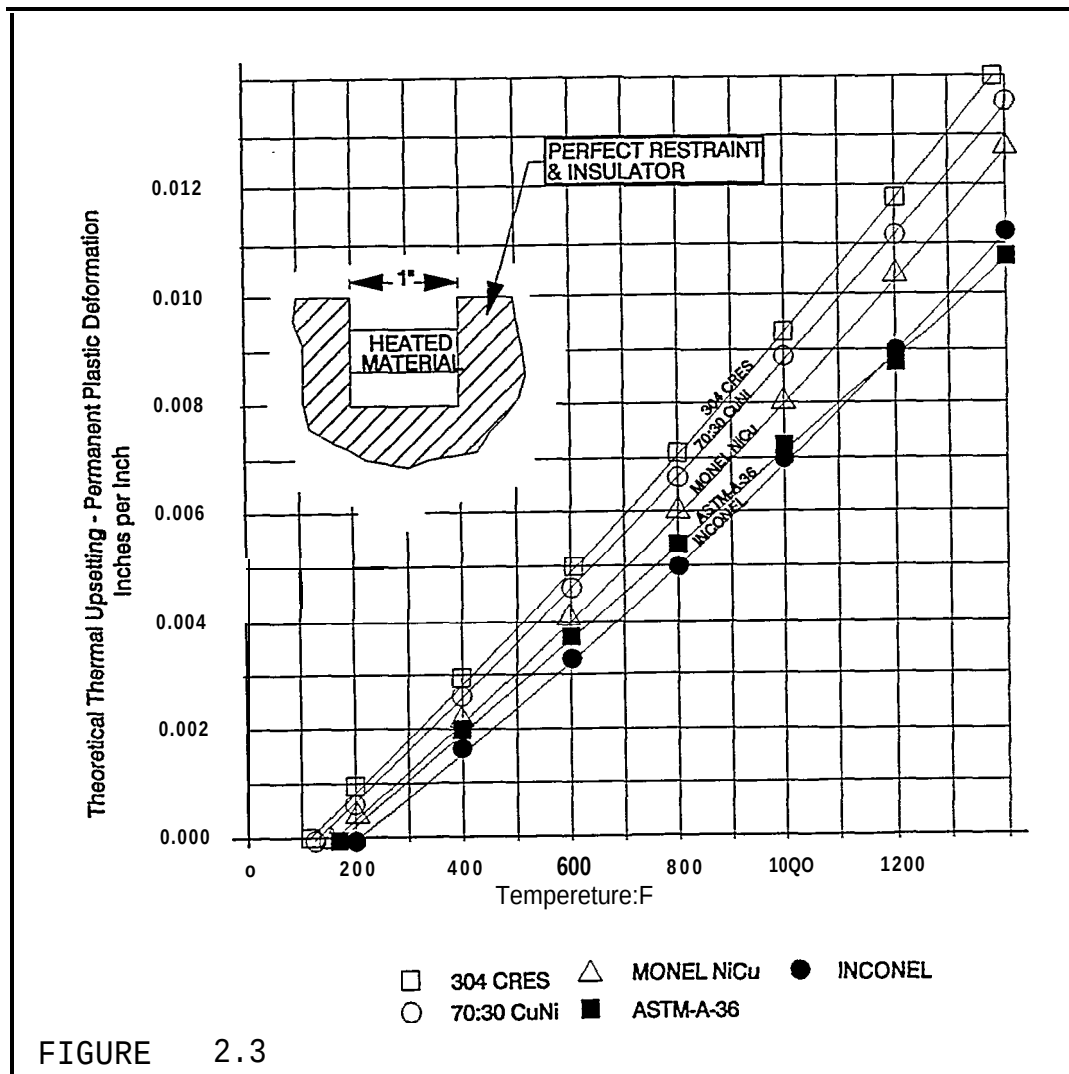


THEORETICAL SHORTENING UNDER IDEAL CONDITIONS

Figure 2.2 exhibits the theoretical shortening of one inch of base metal heated under ideal conditions of perfect restraint and no conductive thermal losses. The near horizontal curve represents the decreasing compressive yield strain of properties of mild steel with increasing temperature. It should be noted that as the temperature increases the strain to cause yielding (permanent deformation) decreases. As one inch of base metal is heated it must thermally expand (volumetrically) to accommodate this increased energy and since it can not thermally expand in its length because of restraint (ideal) the metal experiences compressive strains represented by the thermal expansion line of Figure 2.2. For additional information on the development of these curves and the affect of restraint, see AWS Welding Journal, June 1971, "Primary Concepts of Flame Bending", by R. E. Holt. At low temperatures these strains are elastic (no permanent deformation). As the temperature is increased the compressive stains become so high that they reach the compressive yield strain of "the base metal and any increased temperature results in plastic deformation. By subtracting the yield strain curve from the thermal expansion curve the resulting curve represents the permanent deformation (shortening) of the one inch length of base metal after it has been subjected to temperatures higher than 180°F.



By developing these curves for different base metals from published data and comparing them, increased information can be gained as to what temperatures are necessary to initiate deformation under ideal conditions with single axial restraint and what the comparative responses are to flame bending of different base metals. Plastic deformation occurs in the following order for different base metals and at the approximate rise in temperature (See FIGURE 2.3). It is not surprising that relative amounts of weld distortion for the same base metal follow the same order.

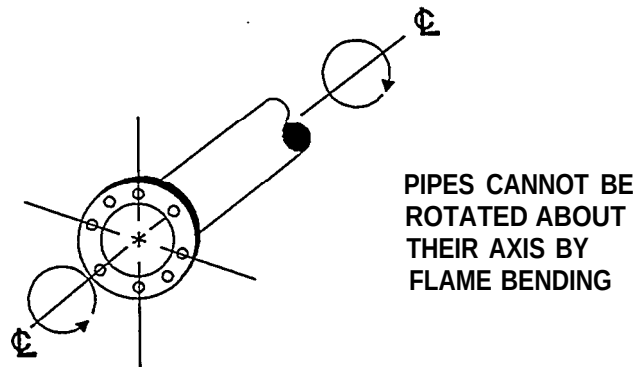


ORDER OF YIELDING FOR FLAME BENDING	BASE METAL TYPE	APPROXIMATE TEMPERATURE RISE TO CAUSE YIELDING °F
FIRST	300 SERIES STAINLESS STEEL	APPROX. 120°1
SECOND	COPPER-NICUCZL (70-COPPER 30-NICKEL)	APPROX. 130°F
THIRD	MONEL (70-NICKEL 30-COPPER)	APPROX. 150°F
FOURTH	CARBON STEEL (ASTM-A-36)	APPROX. 180°F
FIFTH	INCONEL (NICKEL-CHROME-IRON)	APPROX. 200°F
SIXTH	HY-100	APPROX. 480°F

BENDING TEMPERATURES

As can be seen on the preceding figure, under ideal conditions very small changes of temperature are required to reach base metal yield points and to cause plastic flow. In practice it is predominately found that flame benders heat the base metal to a red heat or a temperature that gives off light. It is recommended that in all circumstances that the base metal temperature be kept to a minimum. It should only barely give off light in a dark or dimly lit area or no light at all. When a heated spot is emitting light it should be no larger than 3/4" in diameter (Approximately the size of a nickel coin). One of the reasons operators heat the "base metal to the point of emitting light is it is nearly impossible to judge the base metal temperature when no light is given off. Travel speed can also be judged by the shape and size of the spot being heated.

Ideally flame bending temperatures should rarely exceed eleven hundred degrees (1100°F) however 1200°F is often witnessed in production. In practice, spot and line heats are found to be very effective at temperatures at well less than 1000°F (no light is emitted from the heated area). Holt's work indicates that temperatures as low as 700°F are all that are needed for spot heats to accomplish satisfactory flame bending of mild steel.



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FIGURE 2.4

PIPE OR FLANGES CAN NOT BE ROTATED BY FLAME BENDING

Frequently inexperienced flame bender will attempt to rotate pipe or pipe flanges around their centerline axis usually for bolt hole alignment. This can not be practically achieved by flame bending. Bolt hole alignment that requires rotation can sometimes be achieved by mechanical adjustment of component parts or by cutting and rewelding the system. It is not believed that pipe circumferential shear stress can be created by flame bending without very large external loads. Theoretically pipe can only be bent in planes intersecting the axis of the pipe. See Figure 2.4.

FLAME BENDING AND DAMAGE TO BASE METALS

When flame bending results in burning or melting of the base metal surface, flaking oxides or excessive buckling improper bending techniques have been used. If flame bending is accomplished by trained and knowledgeable flame bending operators in a conservative manner less damage to the base metal should be expected than that experienced by welding or brazing the same material. Flame bending occurs at a lower temperature than welding and most silver brazing processes and usually has considerably less heat input. In some cases flame bending can improve specific base metal properties.

FLAME BENDABILITY OF BASE METALS

Technically all base metals should be bendable, but in practice those metals that are wrought in the normalized or annealed condition having approximately 20 or more percent ductility are considered reliable candidates for flame bending. Those materials that are cast and are considered hot short such as many copper-tin, copper-zinc, or copper-silicon alloys are much less reliable candidates for flame bending. Hot short materials are those that have limited ductility at high temperatures. Materials that are high in tin, zinc, silicon, lead, sulfur, selenium may be hot short. In addition cast iron and copper are not good candidates for flame bending due to low ductility and high thermal conductivity respectively.

AFFECT OF FLAME BENDING ON BASE METAL PROPERTIES

Metals that obtain their strengthening through cold working; age hardening or quenching and tempering must have special consideration before flame bending. The high temperatures reached in this process can potentially cause drastic reductions in tensile and yield strength of the base metal properties. The National Shipbuilding Research Program (SP-7) has demonstrated that even when pipe materials such as 300 series stainless, carbon steel, 70:30 & 90:10 copper-nickel have been flame bent with maximum temperatures as high as 1500°F that there were no negative affects with most materials tested and only minimal negative metallurgical affects with 70:30 copper-nickel². Sensitization of properly flame bent 300 Series stainless steel is expected to always be less than that found in the heat affected zones of welds made on the same material.

²SP-7 Final Report, "FLAME BENDING FOR ALIGNMENT CONTROL", Dec. 15, 1989.

NUMBER OF HEATS IN THE SAME LOCATION

It is recommended the number of heats used in one location be limited to three heats where practical. Even though test work that has been accomplished indicates that some materials can be heated over and over again in the same location with similar flame bending response (SEE APPENDIX D), it is not recommended unless special circumstances exist. Metallurgical and physical property loss is not anticipated nor is it the limiting factor for multiple heats. The limiting factor is that when more than three heats are applied in the same location buckling of the pipe wall may result. This buckling can be the result of a number of factors such as too high of heat input, using an improper heating pattern, traveling too slow or using too large of a torch. Also, the diameter of the pipe and its' wall thickness may result in low buckling stability. Pipe with good buckling stability may be heated more than three times in the same location. Pipe with small diameters and heavy walls generally have good buckling stability.

spot heats result in yield point residual stress and no benefit will result from reheating these areas. Spot heats should be made only with one heat in each location.

BASE METAL THICKNESS AFFECTS ON FLAME BENDING

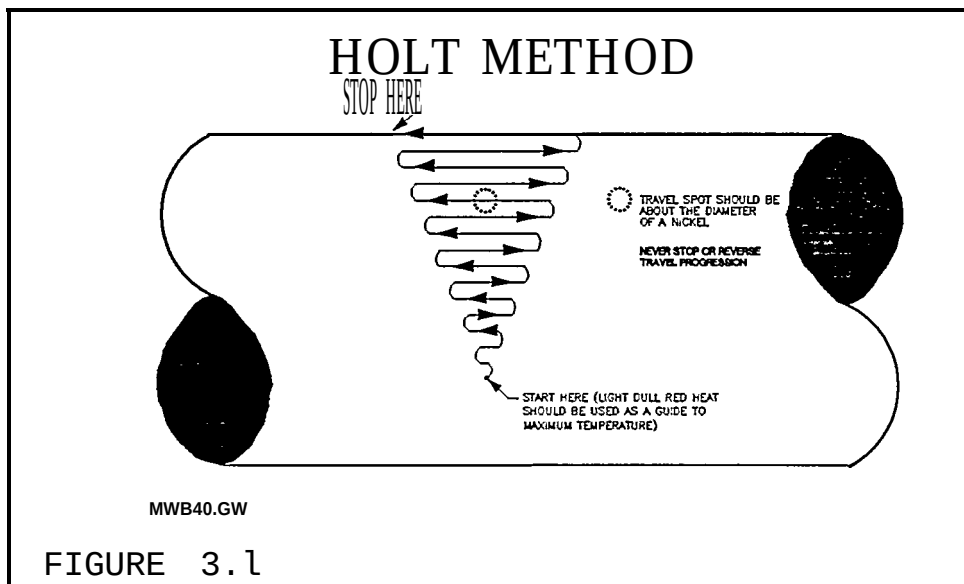
Base metal thickness can be a limiting factor on successful flame bending. For very thin materials the limiting factor may be finding a small enough torch tip and being able to travel fast enough to prevent over heating and buckling. Five eighths of one inch ($5/8"$) is generally considered to be the maximum thickness for readily flame bending of pipe with only outside diameter torch access. Thicker material can be bent with only outside diameter access but only with limited success. For material thicknesses greater than $5/8"$ it is recommended that two torches be used for each area being heated (See Case History #2). This means that both operators must work in unison as it is desirable that the torch inside and outside the pipe are heating the same spot at the same time and are traveling at the same rate. With this technique it is possible to achieve thorough thickness heating and yielding. In some cases this can be mechanized (See Case History #3).

Section 3

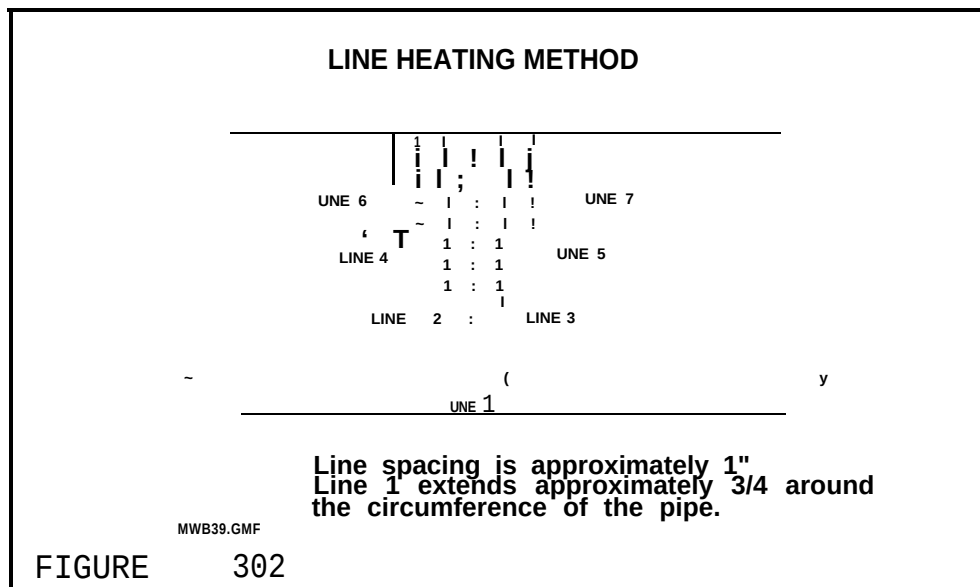
METHOD SELECTION FOR HEATING

METHOD DESCRIPTION

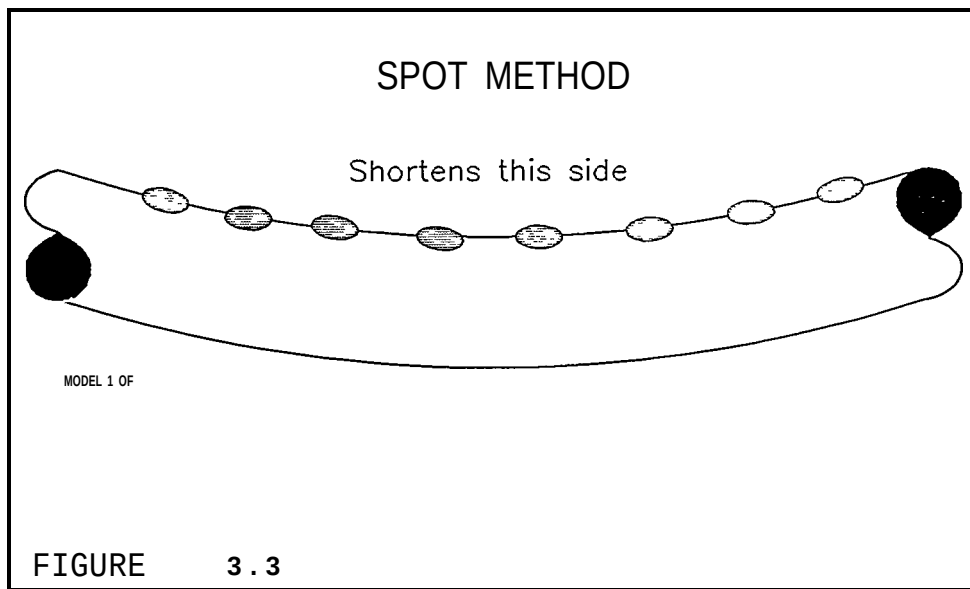
The three basic flame bending methods commonly used for distortion correction are the Holt, line heating, and spot heating methods. All three are similar in that a concentrated area is heated under the torch to a temperature at which the material is permanently made thicker. Each method is distinguished by the torch travel once the bending temperature (plastic deformation) is reached.



The Holt method (Figure 3.1) moves two torches in a snakelike path, one torch on each side of the pipe. Each torch is moved in an increasingly wider weave in a Vee-pattern. The torch travel speeds are synchronized to meet on the side of the pipe to receive the most shortening.



The line method (Figure 3.2) involves moving the torches in straight lines. It is used to minimize buckling, to minimize the heating affect on material properties, to make minor alignment corrections or to make large alignment corrections in small increments. The Vee-pattern outline is similar to that shown for the Holt method. The direction of torch travel is very different from the Holt method; in that, the torches start on the side to receive the most shortening and then travel directly away from each other around the circumference. The longest-line is heated first and the pipe is cooled. Then the next two longest lines are heated. Heating stops when all the lines are completed or the desired movement is achieved. Often minor alignment corrections can be completed with only one line heated. Low residual stress and dimensional stability can still be achieved with only one or two lines as long as the first line extends approximately 3/4 of the way around the circumference. If accessible, single heats can also be made longitudinally inside a pipe to correct an out-of-round condition. See Case Histories 5 & 6.



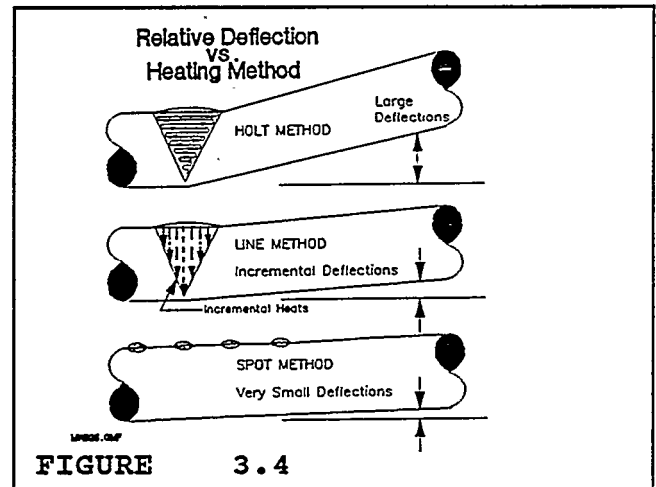
The spot method (Figure 3.3) moves the torch in a discontinuous travel from one spot to the next spot. This method is used when an extremely small amount of movement is needed, or when correcting for a small gradual bend. See Case History #4.

METHOD SELECTION

The following questions must be considered when selecting the correct heating-method:

1. How Much Movement is Required?

If a large deflection ($1/32''$ per foot or more) is required on pipe less than 14 inches in diameter, the Holt method is the preferred choice since the same vee can be heated quicker as compared to line heats. If small deflections are required or the pipe diameter is 14 inches or larger, the line method is preferred. Line heats are done in increments so that the heats can be stopped when the desired movement is reached. Occasionally, a very small amount of movement is needed and spot heats are necessary. See Figure 3.4.



2. What is the Buckling Stability of the Pipe?

In general, a pipe with a thick wall, small diameter or low thermal conductivity will have good buckling stability and the Holt method is preferred. If the pipe does not have good buckling stability, the line heating method should be used no matter what the pipe diameter is. Copper pipe has an extremely high thermal conductivity so it will only buckle or spread the heat so fast that it will not bend efficiently. Flame bending of copper is not recommended from a practicality standpoint. See Figure 3.5.

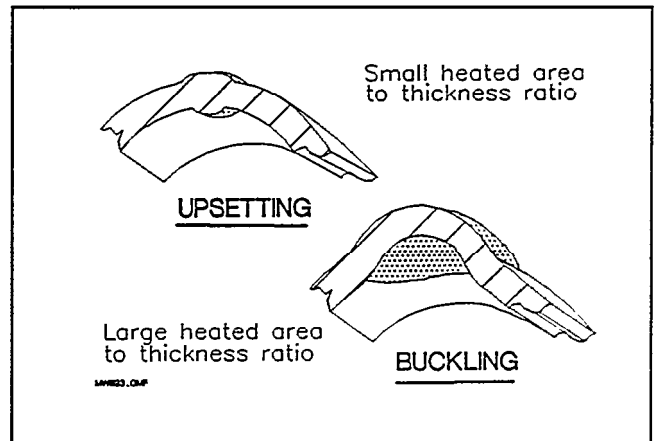
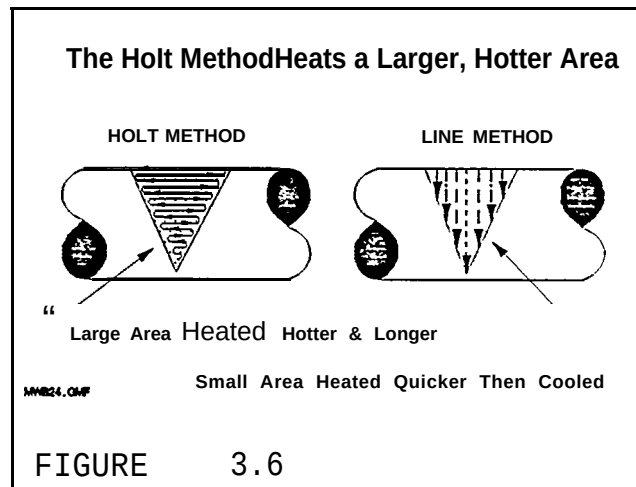


FIGURE 3.5

3. Is the Material Sensitive to Overheating?

If the material properties will degrade when held at elevated temperatures for long times then the line method or the spot method should be used with rapid cooling after each line or spot. For example, 304 stainless steel or NiAl Bronze may become sensitized to inter-granular corrosion using the Holt Method, although to a lesser degree than that for welding or brazing the same base metals. Other

materials which respond negatively to heating should not be flame bent without the design engineer's or metallurgists evaluation. Such materials include high strength low alloy steel pipe (heat treatable), age hardened pipe and cold worked pipe. Flame bending of brittle materials or materials subject to hot short cracking, such as cast iron and gun metal, is not recommended. See Figure 3.6.



Section 4

**SELECTING THE LOCATION
OF HEATS
AND PREDICTING MOVEMENT**

DEVELOP A PLAN BEFORE HEATING

Often, on complex piping systems, or machinery parts, many factors are involved in a successful flame bending solution. In these cases it may be necessary to carefully select the location and size of heats and predict the resulting movement. In order to do this, it is essential to understand the types of movement, both desirable and undesirable. The resultant direction and amount of movement may not be intuitively obvious, especially with complex piping systems. If proper planning is not done, unanticipated movement may not be recoverable. Selection and prediction can be done using graphical models, calculations, physical models, and mockups.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

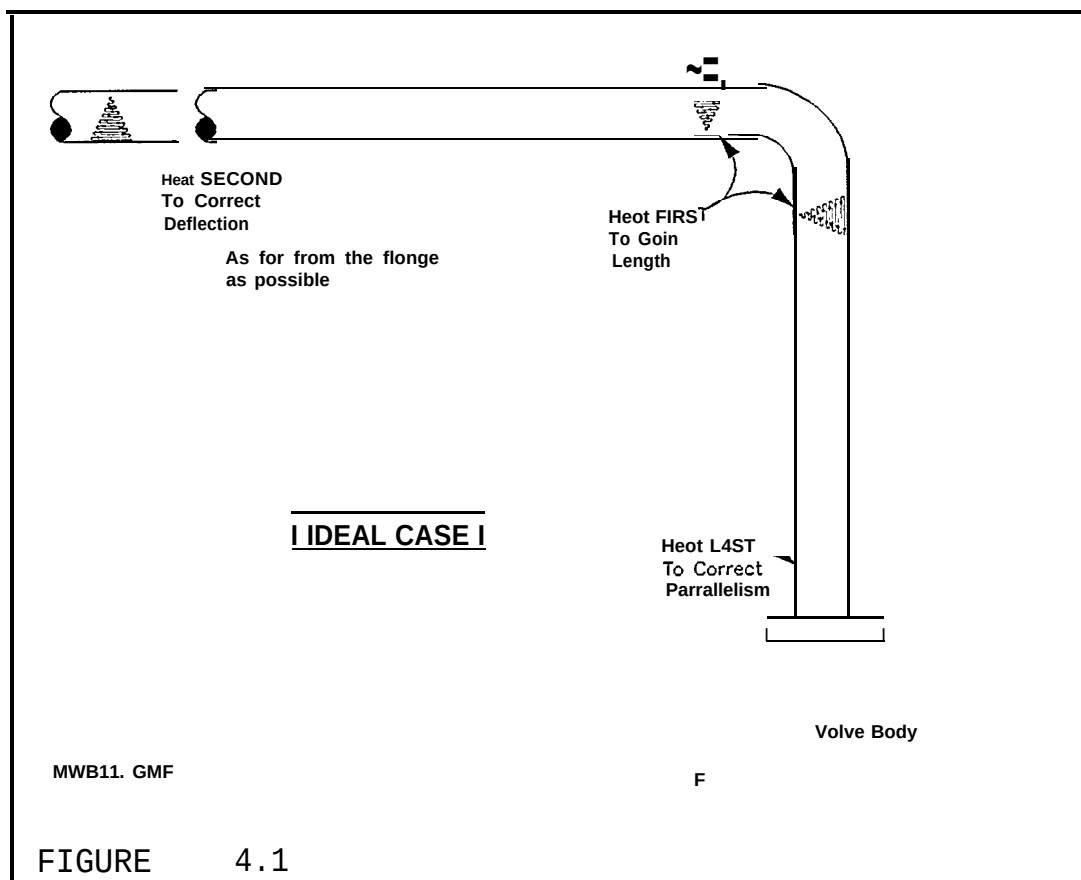
TYPES OF MOVEMENT

When selecting the location of heats, thought must be given to all three types of movements:

- a) heats to adjust deflection
- b) heats to increase pipe length
- c) heats to adjust flange parallelism

Often more than one type of heat will be necessary. Figure 4.1 gives an example of all three types.

In this example the flanges are parallel but the top flange is offset to the left. The top flange must be moved to the right without changing the parallelism.



4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

OPTIMUM LOCATION AND SEQUENCE OF HEATS

When selecting the location of heats, it is essential to carefully think out the bend locations in an effort to eliminate all unnecessary heats. This is important since each heat to bend the pipe will also shorten it. The most common mistakes in planning heats are made by planning more than a minimum number of heats and not predicting and allowing for subsequent pipe shortening. Often it is impossible to recover from unanticipated shortening. See Figure 4.1.

CAUTION: unanticipated shortening of the pipe is the most common cause of unsuccessful flame bending.

FIRST : Lengthen the Pipe Reach. The first set of heats are placed on each side of the elbow to straighten the elbow and effectively lengthen the pipe. After these heats are made, the top flange will be too high and out-of-parallel.

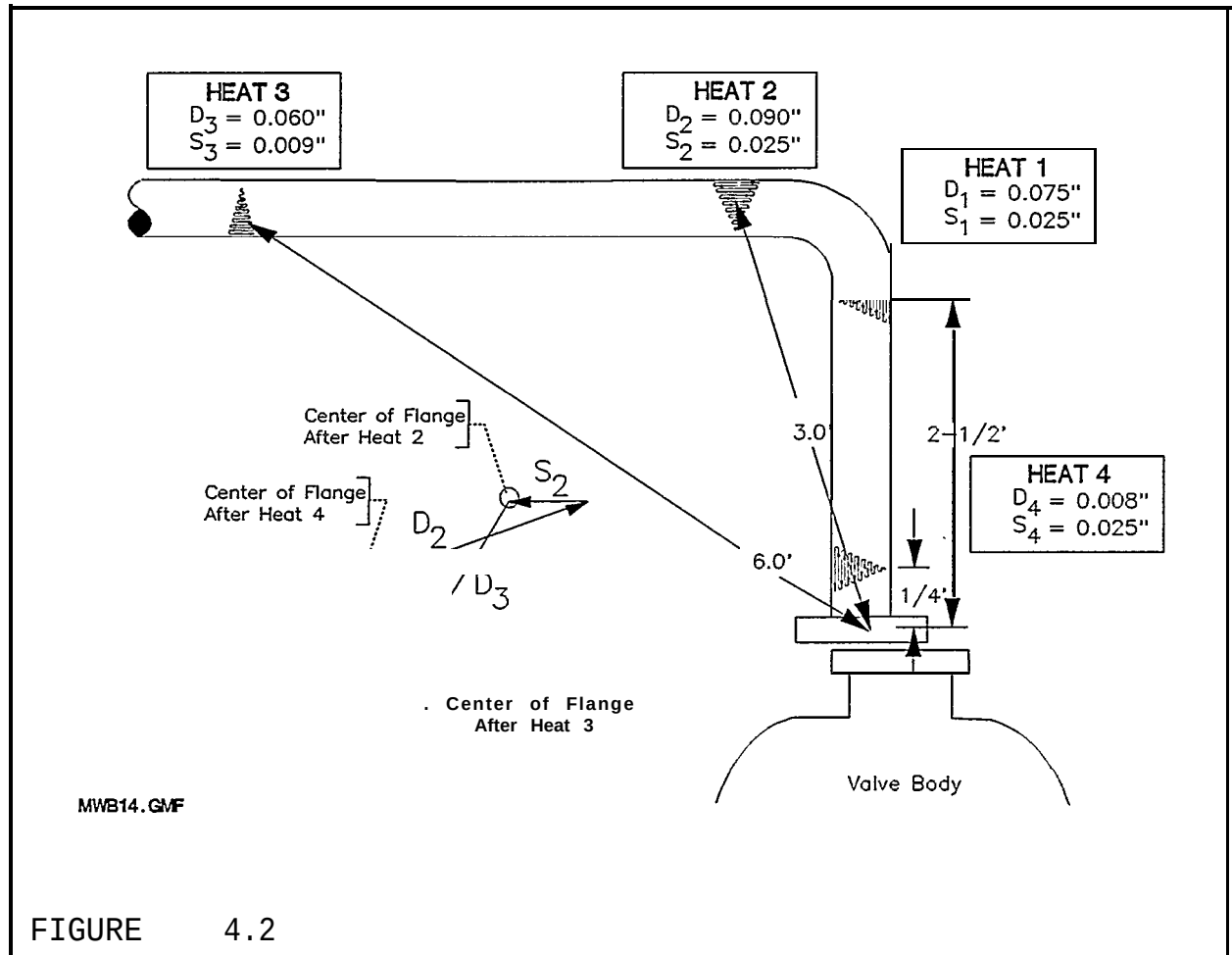
SECOND : Deflect the Pipe. To deflect the flange downward, the next heat should be placed as far from the flange as possible. The amount of deflection is proportional to the distance from the heat to the flange. The distance from the flange should be maximized so that even if the lengthening heats each have to be made twice, the deflection heat only has to be made once (or as few times as necessary). Making this distance as long as possible may also allow a smaller vee to be used or maybe only one line. Maximizing the distance from the flange will ~~maximize the deflection and minimize the shortening.~~

THIRD : Correct the Parallelism. The last step is to correct for flange parallelism. This is done as close to the flange as possible to avoid changing the deflection once the deflection has been corrected. Changes in parallelism are not increased by increasing the distance to the area heated. However undesirable deflection can result by increasing this distance. In this example, since two heats are made on one side of the pipe to gain length and one heat is made on the other side to correct deflection, then one heat should be sufficient to correct the parallelism, since two heats on each side will bring the parallelism back to the original value.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

USING GRAPHICS, VECTORS AND CALCULATIONS

Sketches such as shown in the previous example are excellent tools for planning the size, configuration, and location of heats. Vectors and calculations take the graphical model a step farther. (See Figure 4.2) . The vectors are especially useful for the novice



in that they help provide an understanding of the direction and amount of movement caused by each heat. This example shows how these techniques can be used to predict the amount of movement. Two vectors are shown for each heat. One vector for the deflection and one for the shrinkage.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

STEPS FOR DRAWING VECTORS

Step 1. Draw the Lever Arm. Draw a line between the center of the heat and the center of the flange. Measure this distance in feet using a scale.

+ Step 2. Determine the Length of the Vectors. This is done using the predicted shortening (in inches) and deflection (in inches per foot of pipe length). Some of these predicted values are found in Appendix D and others are obtained from practical experience. The length of the deflection vector depends on the length of the lever arm whereas the length of the shrinkage vector is not dependent on the heat location. The following chart shows how the vector length is figured.

	Prediction from Section 1	Lever Arm	Vector Length
Heat 3" 1" 1 Vee Hinge	Deflection .030"/Ft	2.5'	$D_1 = .075"$
	Shortening .025"	--	$S_1 = .025"$
Heat 3" 1" 2 Vee Hinge	Deflection .030"/Ft	3'	$D_2 = .090"$
	Shortening .025"	--	$S_2 = .025"$
Heat 1" 1" 3 Vee Hinge	Deflection .010"/Ft	6'	$D_3 = .060"$
	Shortening .009"	--	$S_3 = .009"$
Heat 3" 1" 4 Vee Hinge	Deflection .030"/Ft	.25'	$D_4 = .008"$
	Shortening .025"	--	$S_4 = .025"$

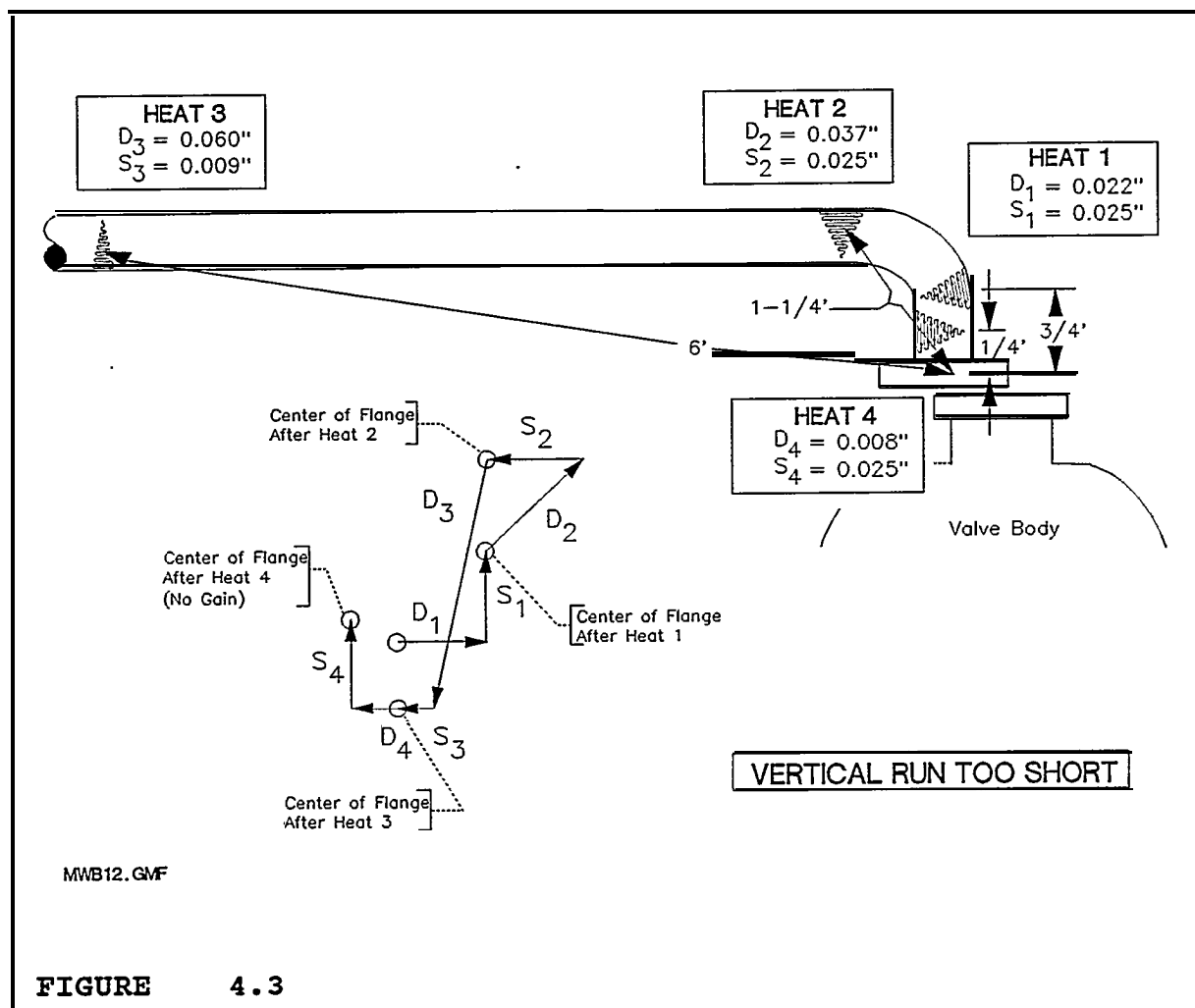
♦ Step 3. Determine the Direction of the Vectors. Deflection vectors are always drawn perpendicular to the lever arm and are pointed toward the heated side of the pipe. The direction of the shrinkage vector always points down the pipe bore away from free end.

♦ Step 4. Add the Vectors Together. The first vectors is drawn with the tail starting at the center of the flange. The tail of the next is placed at the point of the first and so on. It makes no difference in which order they are drawn.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

PREPLANNING FACTORS

Predict When Flame Bending Won't Work. The next example (Figure 4.3) shows a piping configuration which is similar to the previous example except the vertical run is much shorter. The lever arm of the two straightening heats are too short and have too little effect. In this case, the shrinkage vector from each heat significantly reduces the lengthening gained and the flange lineup improves very little.



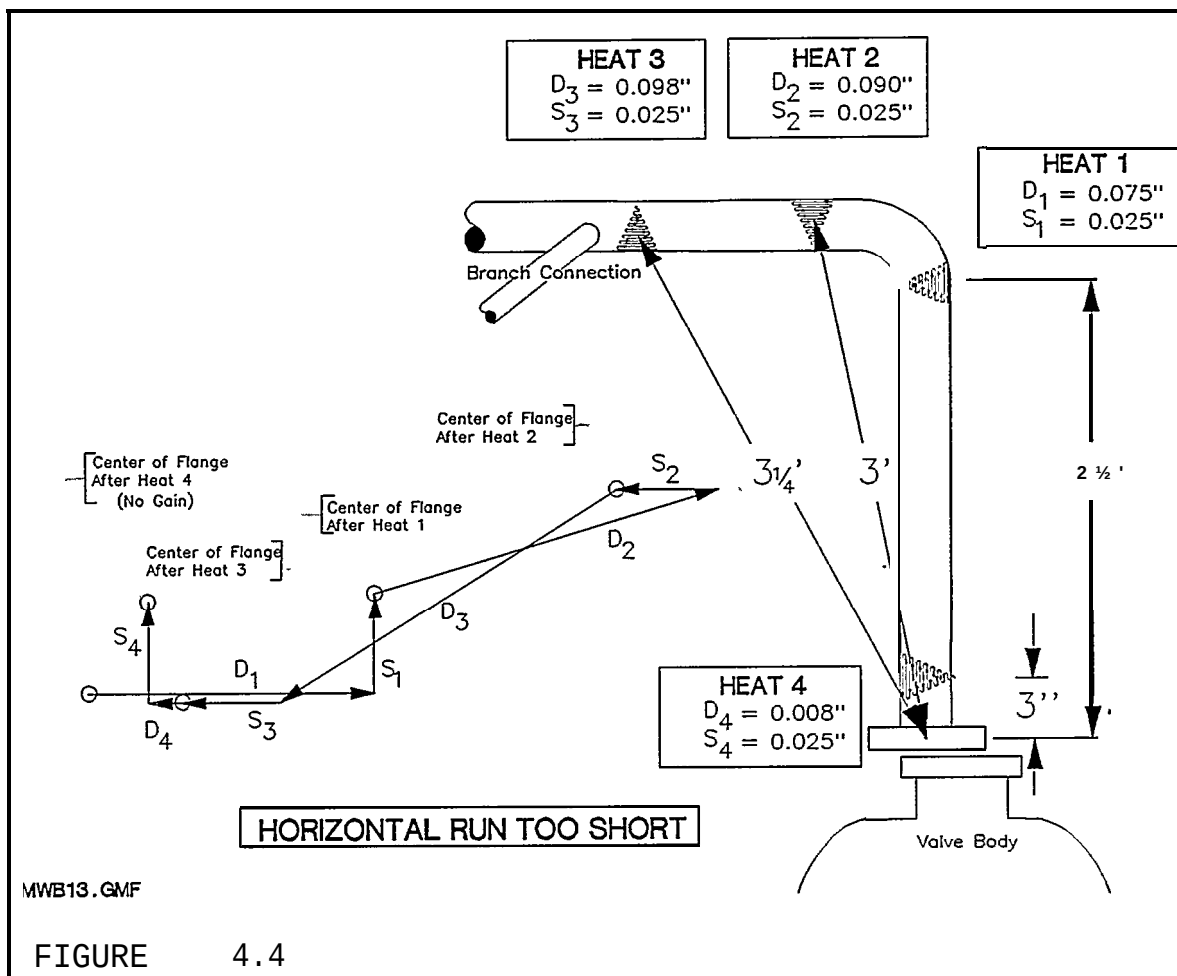
4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

MOVEMENT TABLE

(Values in following table relate to preceding FIGURE 4.3)

	Prediction from Section 1	Lever Arm	Vector Length
Heat 3" 1" 1 Vee Hinge	Deflection .03011/Ft	3/4'	$D_1 = .02211$
	Shortening .025"		$S_1 = .0251''$
Heat 3" 1" 2 Vee Hinge	Deflection .030"/Ft	1 1/4'	$D_2 = .037''$
	Shortening .0251"		$S_2 = .0251''$
Heat 1" 1" 3 Vee Hinge	Deflection .010"/Ft	6'	$D_3 = .060''$
	Shortening .009"	--	$S_3 = .009''$
Heat 3" 1" 4 Vee Hinge	Deflection .030"/Ft	1/4'	$D_4 = .008''$
	Shortening .025"	--	$S_4 = .025''$

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT



In another example, (See Figure 4.4) a branch connection in the horizontal run does not allow a heat to be made very far down the pipe. With a short lever arm, multiple attempts are made to correct the deflection causing more shortening and again the flanges are worse after each attempt.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

MOVEMENT TABLE

(Values in following table relate to preceding FIGURE 4.4)

	Prediction from Section 1	Lever Arm	Vector Length
Heat 3" 1" 1 Vee Hinge	Deflection .030"/Ft	2½'	D ₁ =.075"
	Shortening .025"	--	S ₁ =.025"
Heat 3" 1" 2 Vee Hinge	Deflection .030"/Ft	3'	D ₂ =.090"
	Shortening .025"	--	S ₂ =.025"
Heat 3" 1" 3 Vee Hincres	Deflection .030"/Ft	3¼'	D ₃ =.098"
	Shortening .025"	--	S ₃ =.025"
Heat 3" 1" 4 Vee Hinge	Deflection .030"/Ft	¼'	D ₄ =.008"
	Shortening .025"	--	S ₄ =.025"

OTHER PREPLANNING FACTORS

PHYSICAL RESTRICTIONS AND RESTRAINT

In complex piping systems, heats can rarely be laid out in the ideal location. The heat cannot be located in an area where physical restrictions will interfere with handling of the torch, and cannot be located in an area with restraint between the flanged end and the heating pattern layout. Examples are decks, bulkheads, piping branches, pipe hangers, and other physical restrictions and restraints. Always make a thorough hand over hand check of the pipe 360° around and along the entire length between the free end and the area to be heated to assure there are no physical restrictions which will affect movement. Often it will be desirable to remove or readjust pipe hangers prior to flame bending, for example, remove pipe hangers to allow a longer lever arm, or readjust the pipe hanger to correct alignment. Anytime the actual movement is very different from the predicted movement, stop and double check for physical restraints between the heat and the free end.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

EXPERIENCE

Experience is the most important ingredient in preplanning and prediction. Despite careful preplanning, there are sometimes factors which are unforeseen. For example, the pipe may contain residual stresses, wall thickness may be greater than expected or the system may have unidentified external loads or may have an additional weight or restriction which will cause the movement to differ from what is expected. In these cases, it is cumbersome to recalculate the predicted movement and locate heats. Adjustments are best made by experience. The unforeseen factors are a big reason why it is not good practice to try to gain all the required movement in one heat. A good rule of thumb is to attempt to gain only one third to $3/4$ of the movement in the first heat. Overshooting the mark causes a lot of rework time and sometimes is not recoverable. The amount of movement to shoot for in the first heat will depend on how precise the final tolerance is, and chance of recovery if the mark is overshoot. With experience flame bending success will come easy.

REHEATING VEE PATTERNS

Often it will be necessary and even desirable to heat the same area twice. As discussed earlier, it is desirable to plan out the best locations to minimize the number of heats required. But it is not desirable to make one large heat instead of two smaller heats. In fact it is best to make multiple smaller heats instead of one large heat for a number of reasons:

- 1) The movement can be made in increments so that the size, location, etc. can be adjusted based on the actual movement of the first heat.
- 2) Smaller heats are more efficient.
- 3) Smaller heats are less prone to buckling.
- 4) Smaller heats will affect the material properties to a lesser degree.
- 5) Smaller heats will cause less shortening.

In general, the same area should not be heated more than three times. If movement is still required after three heats, then a new heat should be laid out in another location such that the closest point is a minimum of 1 inch away from the adjacent heat.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

REHEATING SPOTS

Heat each spot only once. A spot heat will deflect a pipe but will not overcome the strongback effect of the unheated portion of the pipe diameter. Because of this, each spot will be at yield point tension and heating the spot the same amount the second time will not cause any more movement. Heating the same spot larger the second time will cause some additional movement and heating the same spot less the second time will lose some of the original movement. For maximum efficiency, it is recommended that each subsequent spot be separated by at least two diameters from the previous spots.

USE OF MODELS AND MOCKUPS

Mockups and models should be used whenever You are unfamiliar with the configuration or uncomfortable with predicting the amount or direction of movement and especially when the tolerances are extremely tight and recovery from mistakes is not possible. Applying a test heat on a similar size shape, configuration and material is the best way to achieve an indication of potential for a successful flame heat. The construction of wire models, especially in the case of complex piping systems containing many bends and supports, may also be beneficial in visualizing movements which may result from various flame heating applications.

ACHIEVE MINIMUM DESIGN REQUIREMENTS

Before starting the job, find out what the minimum design tolerances are for the joint. It may be obvious that the joint is not aligned correctly, but it is not obvious where the stopping point is. It is necessary to know the minimum acceptable fitup for several reasons. Sometimes flame bending can go on indefinitely, each time making finer and finer adjustments and working toward perfection. Perfection should not be the goal. Stop work as soon as the minimum requirements are met. It is not worth the risk of losing the alignment as a result of a mistake. It is also not worth the addition of more residual stresses, the potential for damage to the system and the added time and cost.

If you don't know where you are and where you're going you might end up somewhere else.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

RECORD THE STARTING MEASUREMENTS

Before effective preplanning can be done, it is essential to know what the initial conditions are. At the job site, use two workers to physically align the pipe, one for each direction of movement required without using mechanical assistance. If acceptable alignment is reached in this manner, flame bending is not necessary. If alignment is not achieved, then measure and record the movement still needed in each direction from the worker held position. For example: Flange 1/2" aft looking inboard, up 1", parallelism 3/16".

CALCULATE THE REQUIRED MOVEMENT

The movement needed is the total of the movement required for ideal alignment (as measured from the worker held position described above) minus the minimum design tolerance.

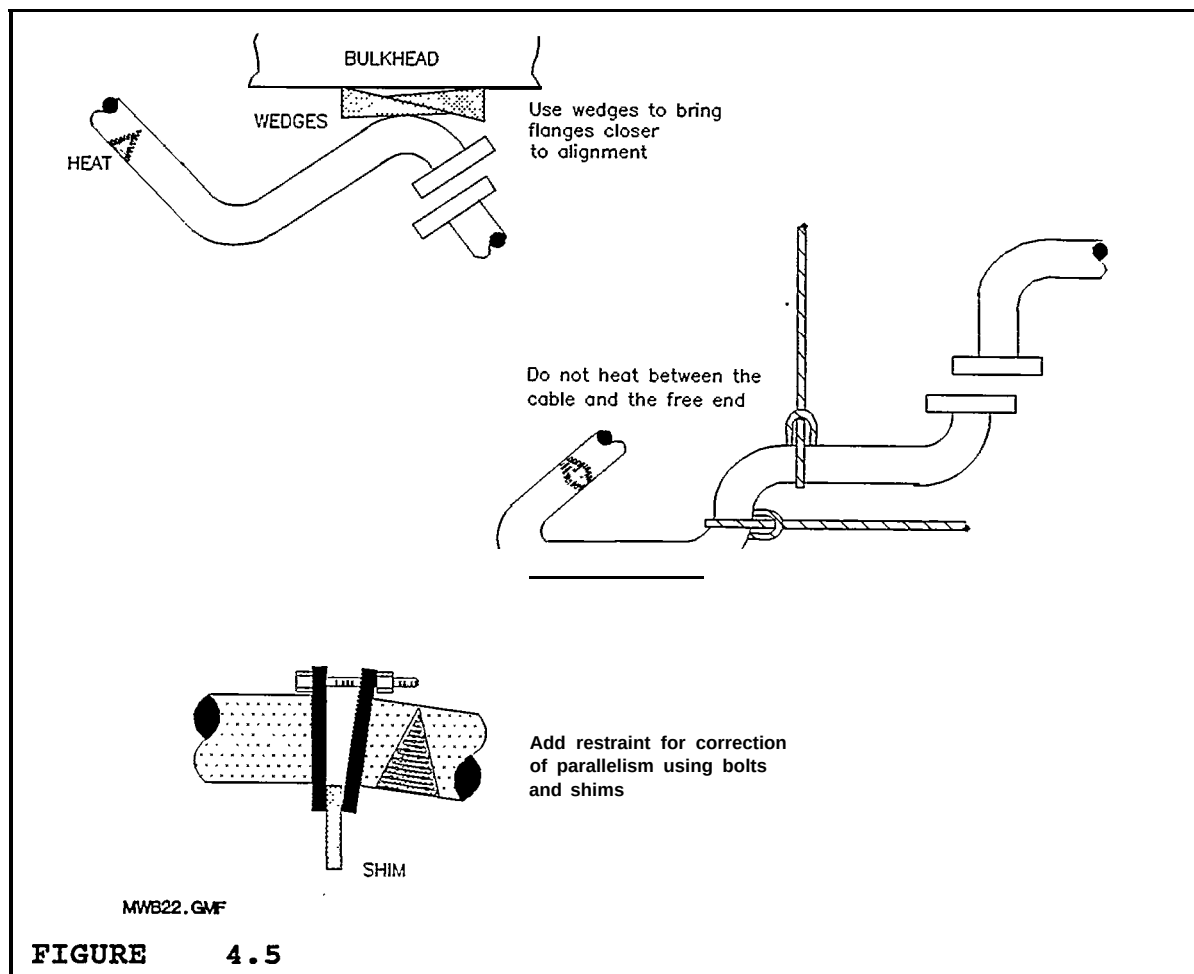
MONITOR AND RECORD THE MOVEMENT

For the purposes of making adjustments and assuring that the actual movement is not drastically different from what is expected, the movement from the alignment must be measured after each heat or cycle of heats. The areas heated and the adjacent areas must be within 100°F of ambient temperature before measurements are taken.

4. SELECTING THE LOCATION OF HEATS AND PREDICTING MOVEMENT

USING RESTRAINT

External force is very beneficial when used properly. The amount of force as determined by deflection should always be much less than the yield point; that is, the pipe must return to the original position when the force is relaxed. If the force causes the pipe to yield, the bending may be the result of thinning (stretching) the wall thickness buckling and thickening. The amount of deflection and the amount of force to cause deflection is dependent on the stiffness of the pipe, location of pipe hangers and bends. The pipe is commonly more rigid in one direction than another. The force can be applied by chainfalls, cables, shims, or by bolting the flange in place. Figure 4.5 gives examples of the various types of restraint and direction of restraint.



Section 5
**FUEL GAS, TORCH
AND
TIP SELECTION**

TYPES OF FUEL GASES

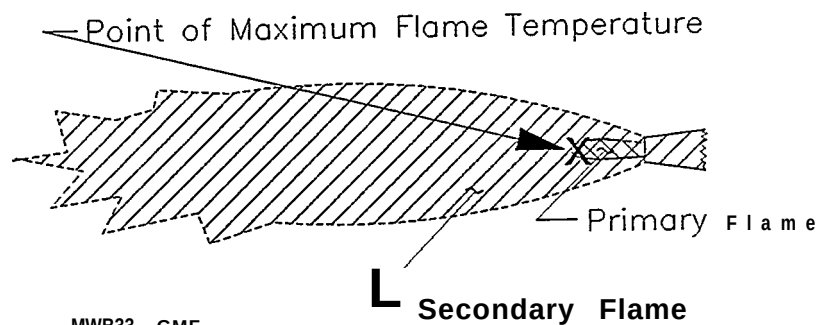
Flame bending can be accomplished with any type of heat source that will provide a sufficient localized difference in temperature to cause plastic deformation in the area being heated. Oxygen-fuel gas systems are by far the most common. Any fuel gas can be used for flame bending. However some fuel gases have specific advantages. The maximum flame temperature and the rate at which energy can be transferred to the base metal are important characteristics. There are a variety of fuel gases commercially available which meet the basic requirements to perform flame bending operations. The more commonly available fuel gases include ACETYLENE, MAPP GAS (MPS), PROPANE and NATURAL GAS.

The primary principle of flame bending is the degree or the extent of the difference in temperature (ΔT) between the heated area and its surrounding metal. This ΔT is directly dependent onto the speed in which the energy source can heat the metal to the desired temperature. It is well known not all fuel gases when mixed with oxygen will produce the same maximum temperature at the torch tip or the same rate of heat transfer to the base metal. All of the commercially available fuel gases listed in the following table, when combined with oxygen and the appropriate torch and tip size, will produce sufficient heat to achieve the desired flame bending results. Mapp and Acetylene fuel gases because of their rapid and higher heating potential at the primary flame tip are the recommended fuels. cost, availability and safety considerations may influence which fuel gas best suits a companies individual needs.

The specific flame output or the quantity of energy available for flame bending at the torch tip can be best measured by combustion intensity and its' ability to conduct heat into the base metal. These properties are related to the heating value of the oxy-fuel gas mixture, the conductive energy in the primary flame and the secondary flame, the velocity of the flame and the torch standoff distance from the base metal.

Table #1: Properties of common fuel gases (AWS HDBK VOL 2)

Properties	Acetylene (C_2H_2)	MPS (C_3H_4)	Propane (C_3H_8)	Natural Gas (CH_4)
Neutral flame temp., °F	5600	5200	4580	4600

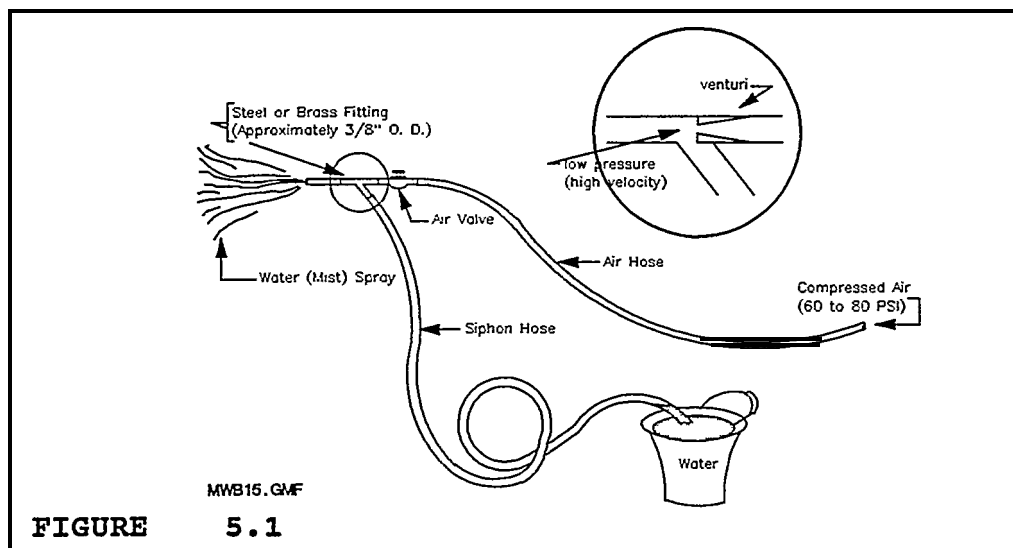


MWB33 . GMF

FLAME BENDING EQUIPMENT

The equipment and components needed to perform flame bending operations are grouped into three categories; (1) Oxy-Fuel Welding (OFW) equipment (2) temperature measurement and (3) cooling equipment. The primary function of OFW equipment is to supply the oxyfuel gas mixture to the welding tip at the appropriate rate of flow and mixture ratio. The gas flow rate and torch tip size affects the size of the spot heated; the pressure and velocity of the gases affect the rate of heating; and oxygen to fuel gas ratio regulates the flame temperature and flame chemical reactivity (atmosphere), which must be chemically suited to the metal being heated (i.e. neutral, oxidizing or carburizing). The balance of equipment is required to cool and measure the component line heated. The necessary components in an OXYFUEL Flame Bending system should include: (See Figure 5.1)

1. Fuel and Oxygen gas supply system (i.e. manifold, portable cylinders)
2. Gas flow and pressure regulation system
3. Hoses
4. Torches
5. Safety equipment (i.e. Flashback Arrester, Gloves, Safety Glasses, etc.)
6. Air hoses and air gun
7. Water bucket, rags and water spray gun (See Below)
8. Mist. equipment (i.e. Feeler gauge, marking pens, rulers, etc.)



REGULATORS

There are two basic types of gas regulators; single and two stage. There are a number of variations available from these two basic types of OXYFUEL gas regulators. Some are designed to drop high pressure cylinder pressure to the desired outlet pressure while others can only be used on low pressure cylinders or pipe manifold systems. It is important to understand that one should never use a pipe manifold regulator on a high pressure cylinder as it can blow apart the regulator.

It is recommended that two stage regulators be used for flame bending applications as they will maintain a relative constant output flow rate until the source pressure drops below the output pressure. Single stage regulators will need to be adjusted-as cylinder pressure changes.

Large flow volume requirements can sometimes cause problems by freezing up the regulator. Pipe line or manifold systems are desirable if this is a concern.

TORCHES

The torches used during flame bending operations are the most important single piece of equipment. It is through the torches that operating characteristics of the flame are established and maintained while also allowing manipulation of the flame on the surface of the workpiece. The size of the torch and tip will be dictated by the work which needs to be performed. Typically gas welding tips are used for flame bending. Rose bud multi-orifice torches may be used on very heavy section structural steel applications but very rarely on piping systems.

The torch inlet valves control fuel and oxygen gas pressure, velocity and flow. They also control the fuel to oxygen mixing ratio which directly relates to the heat and atmosphere at the tip. This control is extremely important when balancing torch tip heat for multiple torch pipe bending operations.

Three types of torches are available. They are; equal pressure also called positive or medium-pressure, injector and combination equal pressure and injector. All are suitable for flame bending operations depending on the type of fuel gas used. The combination equal pressure/injector type is capable of efficient operation with any type of fuel gas when matched with the proper tip.

TORCH TIPS

Torch manufacturers supply charts with recommended tip size in relation to the thickness of metal being welded. The type of fuel gas used must be known when referencing these charts to select the appropriate tip. These charts are suitable as a reference for selecting a tip used during flame bending operations. Typically oxy-fuel gas welding tips (not cutting tips) are used for flame bending. Typical flame bending tips used with methyl-acetylene-propadiene (MPS OR MAPP) gas are:

<u>TIP SIZE</u>	<u>MATERIAL THICKNESS</u>
#10	1/2" TO 5/8"
# 8	5/16" TO 1/2"
# 7	3/16 TO 5/16
# 0	LESS THAN 3/16"1

Section 6
TYPE OF FLAME
AND
CALIBRATION

FLAME TYPE (NEUTRAL, OXIDIZING AND REDUCING)

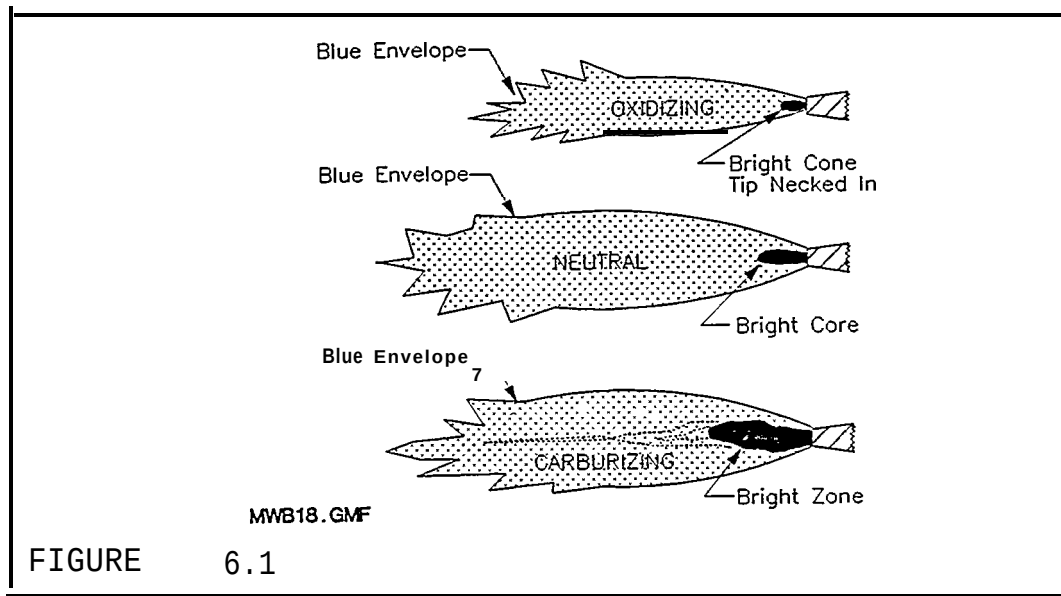
By varying the fuel to oxygen gas ratio at the torch tip a variety of atmospheres and temperatures can be produced. As a rule during flame bending operations a neutral flame (or slightly reducing) is most desired. (See Figure 6.1)

NEUTRAL FLAME

A neutral flame is the result of a 1 to 1 fuel to oxygen gas combustion ratio. A neutral flame is characteristically the clear, sharply defined blue inner cone at the end of the torch tip. Under brightly light conditions it is difficult to tell if you go beyond the neutral flame into an oxidizing flame condition.

REDUCING FLAME

An oxidizing atmosphere/flame is caused by having an excessive amount of oxygen present during combustion at the tip. It is not recommended for flame bending applications as it can produce detrimental base metal oxides on the outside diameter of the pipe surface.



Excessive oxygen and overheating is quite evident on some materials (e.g., 90:10 CuNi pipe) by large flaking oxide scales. In order to avoid an oxidizing flame condition, the use of a slightly reducing flame is recommended because of its ease of identification. A reducing flame contains a slightly higher fuel to oxygen gas ratio than a neutral flame and is identified by a small feather at the end of what would otherwise be a neutral flame. The feather length should not exceed approximately $1/4$ of the length of the inner cone. This flame configuration is not to be confused with a carburizing flame which can easily result from a slightly higher fuel to oxygen gas ratio. The flame becomes carburizing if the feather at the end of the inner cone exceeds $1/4$ its' length. This is not a desirable condition at the torch tip. Excess Carbon will be deposited onto the material surface and can actually be absorbed into the base material. This is detrimental when flame bending 300 series stainless steel and may produce undesirable affects when used on other ferrous alloys.

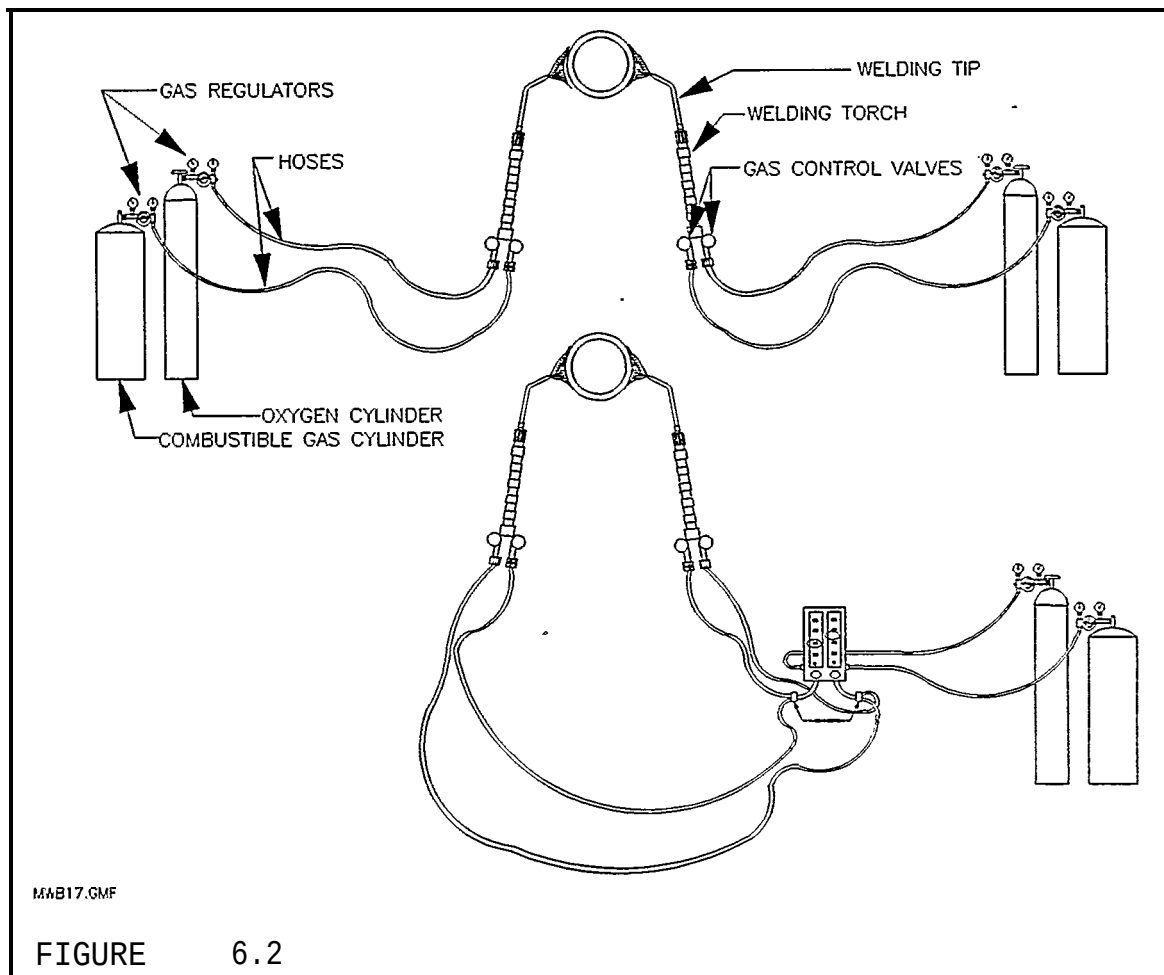
FLAME CALIBRATION (ADJUSTMENT)

During pipe flame bending operations two oxy-fuel torches are required. It is desirable to set up both torches as nearly as the same as is practical (i.e. regulators, torch tips and hose length). This is necessary so that the heat produced at the tip of both torches will match as closely as is practical when they are being used simultaneously to flame bend pipe. Unequal heat input with time to each side of the pipe during flame bending will create undesirable bending to one side. The first step in accomplishing uniform heat input to each side of the pipe is to assure that the torches have nearly the same heat output.

As stated earlier a neutral flame is desirable to minimize metallurgical reactions with the pipe. However, a slightly reducing flame is the easiest to identify during adjustment. It is better to lose the few degrees of heat and have matched flames than it is to have one torch with a neutral flame and the other with an oxidizing flame with different amounts of heat input. It is best to adjust the torches under dim light conditions. Under bright lighting conditions it is more difficult to tell when a neutral flame has been achieved.

There are basically three ways to synchronize the torches. The first method is to have one torch operator light and adjust the torch to the maximum heat and desired flame configuration and then light the second torch and adjust it to match the first operator's heat, velocity and flame configuration. The second method is light both torches and while they are placed in close proximity balance the torch heat, gas velocity and flame configuration. If both

torches are working from a single regulator, by use of a split, this method could prove somewhat difficult. See Figure 6.2.



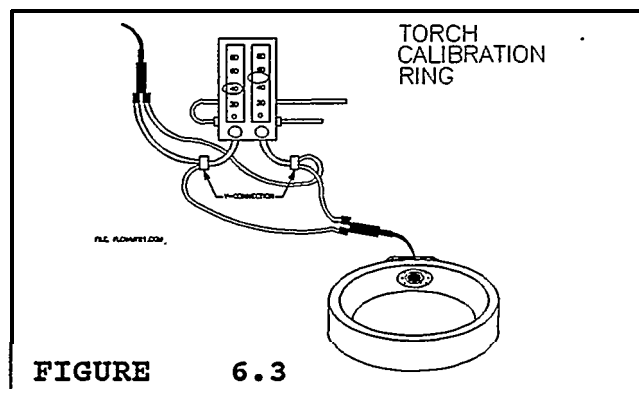
Each torch individually will feel the change in feed line pressure every time an inlet valve is adjusted. If you find yourself in this position adjust one torch as desired and try and maintain the torch setting while the second torch is being adjusted. Adjusting the torches properly takes experience in regard to the flames visual characteristics, the sound made by the gas velocity, and the number of turns of each torch control valves.

Various methods of torch adjustments already discussed can be used for torch calibration. However the following method is a little more complex but is more precise, direct and is very workable on the shop floor.

Flow rates can be set, monitored and controlled by precision flow meters with "Y" fittings on the output side of the meter.

Calibration of the torches involves setting the precision flow meter to preset values (i.e. 40 CFH oxygen and 35 CFH fuel gas) .

Both torches are ignited and the flames are held close to each other for comparison of color and length and sound velocity.



The final calibration is accomplished on a ring of pipe material or on similar thickness base metal as shown in the Figure 6.3. When precise control is needed, this method of calibration should be accomplished prior to each heat for each diameter and wall thickness of pipe. The pipe length should be six to eight inches wide.

The time to reach a specific temperature on the inside of the ring for both torches should be nearly the same if the torches are properly calibrated. Also checking the calibration to the original established requirements prior heating insures the operators they are operating with consistent conditions. This will help provide consistency in travel speed and the spot size being heated under the torch.

Section 7
MECHANICS
OF
FLAME BENDING

INTRODUCTION

When reviewing a job for the purposes of applying flame bending techniques, the following steps are recommended. These steps should be followed for each project prior to bending, during bending and after completion of the job. The steps detailed in the following sections should be applied whether the job is performed in the field or shop environment.

INITIAL ON-SITE JOB INSPECTION

During the initial on-site inspection, the decisions made will greatly affect the success o-r failure of the flame bending operation. The first items to consider are:

(1) WHAT MUST BE DONE?

Flange or Weld Joint Alignment
Parallelism
Bolt Hole Alignment

(2) WILL FLAME BENDING ACHIEVE DESIRED GOALS?

(3) WILL THE MATERIAL SUFFER ANY ADVERSE AFFECTS AS A RESULT OF FLAME BENDING?

Sensitization of Stainless Steel
Loss of Mechanical Properties

(4) WILL ACHIEVING YOUR INITIAL GOAL CAUSE OTHER PROBLEMS?

Shortening of the Pipe Beyond Fit-up Tolerance

Loosing Bolt Hole Alignment While Gaining Flange Parallelism

Gaining Alignment but Loosing Parallelism

- (5) WHAT TYPE OF HEATING TECHNIQUE SHOULD BE USED?
Holt Vee Heat
Line Vee Heat
spot Heat
- (6) CAN THE HEAT BE APPLIED IN THE PROPER LOCATION?
Flame bender access
- (7) WILL THE HEAT OF FLAME BENDING DAMAGE SURROUNDING COMPONENTS?
- (8) IS IT SAFE FOR THE PERSONNEL CONDUCTING FLAME BENDING?

Often it will be necessary to balance some or all of these factors to achieve the desired end result. When these questions have been addressed and it is determined they are controllable, it is time to proceed.

BASE METAL PREPARATION

Once the pipe has been determined to be a flame bending candidate, it must be cleaned in those areas where heat is to be applied. This usually involves more than one location. Once the locations to be heated have been identified, these areas on the external pipe surface must be cleaned to bright metal. The area cleaned must be of sufficient size to allow one or more heat patterns to be laid out. This cleaning is necessary: to inspect the area for defects prior to flame bending; to ensure uniform heat transfer from the torch to the surface of the base metal; and to minimized possible damage by base metal contamination as a result of the presence of hazardous elements at high temperatures.

Some piping systems may convey a fluid which promotes a buildup or accumulation of residue on the internal surface of the pipe. Some deposits if not removed could be detrimental to the piping material and absorbed into the material at flame bending temperatures. A general guide is if it is acceptable to weld or braze on the system, then it is usually acceptable to flame bend the system. Where possible the internal surface should be cleaned. Chemical conveyance or galvanized piping systems may even present personnel hazardous health considerations if heat is applied before cleaning.

BASE METAL INSPECTION

An external surface inspection should be performed prior to applying heat to the surface of a pipe where it has been cleaned. This surface inspection should be in the form of either a dye penetrant or magnetic particle inspection depending on the base material type. A visual inspection should be accomplished but can not be considered totally adequate for critical systems. These inspections can provide useful information such as to existing pipe surface indications. No defects (particularly linear indications) are acceptable which could propagate as a result of flame bending.

LAYOUT OF HEATING PATTERNS

Placement and orientation of the heat pattern is the next step after cleaning and inspecting the pipe in those areas to be heated. A careful evaluation must be made as to what direction the pipe or component must move. It is important as stated in Section 4 that it should not be attempted to gain all of the desired movement on the first heat. The reason being if you have miscalculated recovery could be time consuming and costly particularly in terms of shortening the pipe.

Simple tools are necessary to clean and layout the heat.

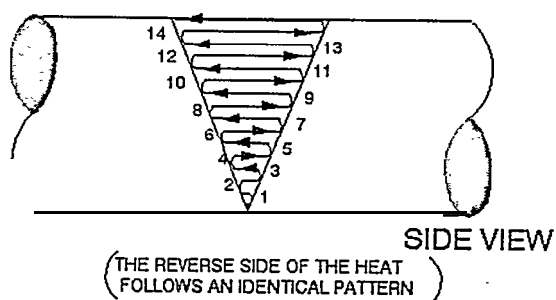
- a. Flexible measuring tape
- b. Soap stone or some other heat resistant marking device which contains no potentially hazardous constituents such as halogens, phosphorous or lead
- c. Strip emery cloth

While these are examples of simple layout tools, they are by no means the only ones which can be used. The layout method must not scar or leave a permanent indentation in the pipe or component surface as this could induce undesirable "Stress Risers" during and after the flame bending operation.

The first step to laying out the heat pattern is to measure the circumference of the pipe, then subtract the "Hinge" (shown in Appendix D - the unheated portion of the pipe circumference) from the total circumference and divide the number in half. This establishes the length of each side of the Holt Vee or Line Vee heat pattern. If the heat pattern is being laid out for a Vee heat, then the maximum width of the Vee pattern must be determined (See Section 4 regarding Vee heat patterns). The pipe will move in the same direction or side containing the widest area on the Vee

heat pattern after cooling. A line parallel to the pipe axis should be drawn across the widest area of the Vee. Mark the center of this line. With your flexible measuring tape, measure an equal distance from the center and perpendicular to the line around the pipe that distance which represents one half of the Vee heat pattern and mark that point on both sides. These points represent the torch starting position for the Holt technique on both sides of the pipe. Next from these points, trace the travel path of the torch during the heat and number or identify various points, identically on both sides of the Vee. When traveling this path the numbering system can be communicated to the flame benders to coordinate their travel speeds during the heat. See Figure 7.1.

**EXAMPLE OF NUMBERING PARALLEL RUNS
OF A "VEE" HEAT (HOLT METHOD SHOWN)**



By numbering both sides in the same way,
Two operators have a frame of reference which
allows them to coordinate their respective heats
to run simultaneously

LINE HEATING METHOD

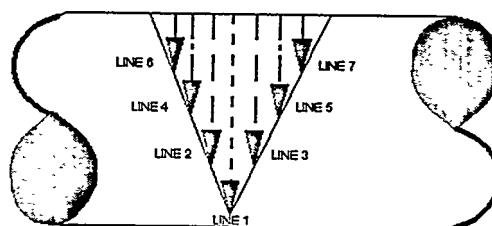


FIGURE 7.1

MMVB57.GMF

Line spacing is approximately 1" to 1-1/2"
Line 1 extends approximately 3/4 around
the circumference of the pipe.

When using the line heat method, follow the same procedure except numbering would be laid out along each straight line, equally spaced on both sides of the heat center line.

METHODS TO CONTROL HEAT INPUT

The methods to control heat input and the importance of operator skill level during field flame bending operations will be discussed here. During most pipe flame bending operations two torches are used simultaneously with coordinated movement. While some jobs may be accomplished using a single torch, depending on the job requirement (i.e. pipe end circularity) use of two torches is highly preferred in most cases.

A number of methods to control heat input during flame bending can be employed such as; operator(s) torch calibration (adjustment), torch tip size, torch travel speed, size of the heated area (traveling spot and Vee size), torch tip standoff distance, type of fuel gas used and most importantly the skill level of the torch operators.

Single torch flame bending operations will usually be confined to such jobs as, improving circularity of the diameter on the end of a pipe, (Line heat method) possibly for weld joint fit up, matching a mating surface or making minor adjustments in pipe deflection using the spot heat method.

During dual torch operation the flame benders can, with some experience, calibrate their torches by visually matching the flame configuration on both torches. It is usually best to set one torch to the desired heat (neutral flame) and then match the other to the first. Often times both torches will need minor readjustment during this process if both torches are connected to a "Y" connection from a single regulator. When Vee heat patterns are required, laying out the direction and course of torch travel is very beneficial. Numbering positions along the torch path help provide uniform travel speeds by the flame benders calling these numbers out to each other during the heating cycle. This operator communication technique is used when first establishing the heated spot at the starting point of the heat whether for a Line or a Vee heat. The flame benders announce to each other that they are at "Dull Red", "Red Hot" or "Beginning to Move". Communication between the flame benders during the heating cycle is crucial for matching the heat input on both sides of the pattern. If, for example, one flame bender is at the number 2 position and the other is almost at the 3 position then an adjustment must be made midway through the heating pattern without reversing the torch direction or stopping (holding torch in one position). The bender who is lagging behind may be running a colder torch or possibly heating that side of the pattern to a higher temperature. In either case the flame bender which is leading should make an adjustment by either slowing down, without reversing direction or by providing

more space between the torch tip and the work piece until the two torches are running together again. The flame benders should never try to adjust the heat of the flame, using the control valves, during a heat. The best results can be achieved during a flame bending heat when both torches arrive at the center of the heat at the same time.

HAZARDS DURING FLAME BENDING

During the initial on site job inspection an experienced flame bender will assess whether hazards may be present which could influence how the job is approached. While all of the potential hazards cannot be identified, some of the things one should be on alert to notice are contained in this manual. Fire hazards are by far the most important hazard to be avoided.

Hazards can be present in many forms;

1. Paint on or near the component.
2. Insulation on or near the component.
3. Combustible material below the flame bending operation which could be ignited from falling sparks or material.
4. Flammable materials stored in the immediate area.
5. Piping systems or containers carrying combustible liquids which will receive deflected heat.
6. Small closed containers that will be pressurized by the heat of the torch.
7. Electrical, mechanical, or pressure control devices

These are a few of the types of fire and flame bending hazards which could be present. There are countless others, some may be specific to your company's work environment. When planning the job include the time and materials to protect against potential fire damage. Always provide for adequate safety for those who will be in the area and those performing the work.

There are other hazards which can be expected on some but not all flame bending operations. Success will depend on how well the flame bender can identify and protect against these unexpected hazards. Control of most industrial piping systems is accomplished by using a wide variety of machinery, electrical, pressure and temperature sensitive components (i.e. gauges, valves, motors, hydraulic equipment) many of which are extremely susceptible to damage by direct or indirect heat. The most common heat damaged items, however, are electrical cables. They are easily overlooked and damage is not always readily apparent due to the various types of shielding in which they are wrapped. Special precautions should

always be taken when performing flame bending operations around electrical cables.

Most fire hazards can be eliminated by either removing them from the work area or wrapping or covering them with a fire retardant/reflective material. It is further recommended that a designated fire watch be present during flame bending operations. If there is any question as to safety or fire hazards a safety engineer or environmental specialist should be consulted before accomplishing the heat.

TARGETS AND STRESS LOADED PIPE

Under certain conditions pipe sections can be removed from their installed piping system location and moved to a bench or slab to perform the flame bending operation. This may be necessary if you have poor accessibility or surrounding components could be heat damaged during the flame bending operation. This is not a major problem and in some cases it will be a beneficial. Having better accessibility to all areas on the pipe or component should increase success by allowing placement of heat patterns anywhere on the component where heat may be needed. A minimum of two targets, one for each end of the component will be required. The targets are necessary to establish the relative position of the both pipes ends in which the pipe segment must fit when properly installed. Once the ends are targeted the pipe segment must be bolted or secured to one end of the target to establish the pre-flame bending mismatch, etc.. If the pipe segment is hangered (supported) in the field, with a rigid type pipe hanger, it should be supported in the shop work bench target arrangement. Care must be taken not to load (force) the pipe segment when establishing target supports in the field or the workbench. Some piping systems incorporate spring or tension loaded type pipe support hangers, (i.e. Steam or shock protected systems). This type of pipe system is difficult to target for bench work. Never perform a heat on a pipe where a loaded hanger lays between the heat and the pipe end as this could drastically alter the predicted results of the heat. In general, hangers should be removed or disconnected when possible.

Compression loading a pipe in the area of the heating pattern to enhance the effects of a particular heat is usually beneficial if setup correctly. Methods to compression load pipe include wedges (wood or metal), chain falls and hydraulic jacking equipment, virtually anything which will restrict expansion during the heating cycle. The alignment of the loading to the desired direction of movement is critical. If excessive force is applied it could cause buckling of the pipe during application of the heat. This compressive loading technique should be used sparingly until

experience is gained on how to apply compression loads. Ideally a compressive load applied to a pipe, during flame bending, is to restrict thermal expansion during the heating cycle. Any applied load greater than that necessary to restrict pipe movement during the thermal expansion phase of the heating cycle is unnecessary and potentially hazardous to the pipe.

METHODS AND EFFECTS OF FORCED COOLING

Forced cooling primarily speeds up the flame bending process but has very little beneficial affect on the amount of shortening that takes place. It is always more efficient to flame bend a cold pipe than a hot pipe. As a result of the rapid cooling more heats can be performed in a shorter period of time and results after heats can be observed and measured much quicker with fast cooling. When working to very tight tolerances, it is recommended that final measurements not be taken for a minimum of 2 hours after completion of forced cooling. This allows the residual heat in the pipe or component to stabilize.

There are some specific precautions which must be considered if forced cooling techniques are to be used. With few exceptions, the forced cooling of a pipe or component by any means should not be attempted while visible signs (of light redness) appear on the surface of the heated area. This is of particular concern when flame bending ferrous alloys like carbon and chrome-moly steels where base metal mechanical properties could be altered by quenching. Mechanical and metallurgical properties of 300 series stainless steels; however, will benefit from immediate cooling after heat source removal. Most other non-ferrous alloys such as monel, copper-nickels or inconel piping will not be impacted adversely from immediate forced cooling. Always know the material type of the pipe to be heated and the affects of temperature on that material.

A relatively clean and effective method of removing heat from a pipe is with a combination of compressed air and water (mist) applied directly to the surface of the pipe. A good way to accomplish this is with an air nozzle which can syphon water from a reservoir through the nozzle where it is atomized as it leaves the air gun. Figure 5.1 is an example of a inexpensive effective system. Initial cooling pattern techniques should be just the reverse of the heating pattern. Cooling should proceed form the widest part of the Vee toward its apex. Another method of cooling is to wrap water soaked rags around the pipe and blowing compressed air either on or under the rags. Forced air or water soaked rags by themselves can be used for cooling but is much less effective."

The danger of steam burns to the person using water soaked rags is high. What ever the cooling sources used it should be ^{move all} around the heated area after the initial high temperatures are reduced to several hundred degrees. It is important to understand that the heat must be removed from the pipe before any further heats can be applied. The pipe or component should be at ambient temperature before the next heat is made for the most predictable results. No more than three heats in the same location is recommended.

FIRST HEAT EVALUATION

After completing all the sequential steps of: evaluation; inspection; setup; layout; and heating the pipe, determine if the desired results are being achieved. At the completion of the first heat take the time to evaluate the results to see if the pipe or component is reacting to the heat in the predicted manner. Check results against templates (targets) or if direct measurements are used take new readings and compare them against your original set. If bolt hole alignment was the objective then insert the proper installation bolt into all the holes. By taking the time to asses anticipated progress against actual progress valuable insight will be gained on how to proceed and the size and location of subsequent heats.

POST FLAME BEND INSPECTIONS

After the flame bending operation is complete, it is ^{time to sell} the fit-up to whomever has control or authority over the joint or component. It may at times, after inspection by the cognizant authority be necessary to perform an additional heat or heats to achieve design requirements. For critical applications, it is recommended that final inspection be performed several hours after the system has reach ambient temperature. If additional heats are necessary follow the same procedures as for the first heat.

After the joint has been dimensionally accepted, non-destructive tests should be performed on those areas where heat was applied to insure that no damage was done to the pipe or component.

Section 8
**PRECAUTIONS FOR
PIPING SYSTEM
LOADS**

INTRODUCTION

Forces acting on the piping system must be evaluated before bending. In some cases loading on the area being heated can be beneficial, depending on the amount of force and whether a compressive load is being applied. Loads on piping systems can be from a number of sources such as residual stress, self supporting loads (gravity) and external loads (applied loads from jacks, wedges and/or come-alongs). The affects of these loads can have drastic consequences on the flame bending results.

SELF-SUSTAINING LOADS

Heavy self-sustaining loads (the weight of the system) on vertical pipe can cause serious buckling of a pipe in the heated area. External support is of little benefit in reducing self-sustaining loads on vertical pipe and if vertical loads (free standing) are too large when an area is heated to excessive temperatures, it is possible to cause the complete collapse of the piping wall. It must always be kept in mind that increased temperatures reduce the ability of the pipe wall to carry loads without buckling. External support may be used to support horizontal runs of pipe. Heavy, long horizontal runs of pipe should be supported at their extremities in order to reduce excessive compressive stresses in the area to be heated. This will minimize potential buckling or pipe collapse. There are cases where the self-sustaining loads caused the area being heated to be placed in sufficient tension to counteract bending heats. This condition may be reduced or eliminated by the use of external support such as cables or jacks.

EXTERNAL APPLIED LOADS

External applied loads may be used to eliminate self-sustaining tensile loads or to reduce excessive compressive self-sustaining loads on areas to be flame bent. However, excessive external compressive loading on areas to be heated is probably one of the most common causes of unacceptable buckling of pipe wall. In most cases, external applied loads are very beneficial. However, these applied loads should be kept to a minimum and should be used basically to restrict thermal expansion during the heating cycle. This will cause additional compressive strains to be placed on the area being heated. If it is possible during the initial evaluation to determine where to apply heats and the number of areas to be heated, then no permanent fixed external loads such as foundations or hangers should be located in the system between the heats and the free end of the pipe. On complicated systems with multiple preloaded spring hangers, this may not always be possible.

RESIDUAL STRESS

Internal loads in the piping system as a result of its manufacturing can contribute to unexpected and potentially unacceptable results from flame bending. Residual tensile stresses due to cold bending, cold forming, uncontrolled heating and cooling of the pipe can occur in areas to be heated. High residual stress can result in little or no pipe deflection after the first heat. If small diameter pipe is being flame bent, reverse bending is actually possible as a result of pre-existing residual stress. If high residual stress is anticipated, it can be addressed using external loading to assure compressive loading in the area to be heated.

Section 9

HEALTH AND SAFETY

Flame bending requires the use of oxy-fuel gas equipment and is considered hazardous with the potential for fire, explosion, fumes, exhaust, and high temperatures. Accidents involving personnel and property damage may result if safety and equipment handling precautions are not practiced.

A thorough knowledge is required of the equipment's use and limitations.

Work areas must be free of combustibles when practical.

Work areas must incorporate adequate fire control measures such as proper fire extinguishers and, in many instances, a fire watch.

Paint, oil, and other coatings shall be removed from surface to be heated to minimize hazardous fumes and contamination.

Each flame bending application should be evaluated as a potentially closed area for relief of heat-expanded gas and noxious fumes.

Ventilation is necessary for work in confined areas.

Extra precautions should be taken in extremely confined work conditions where the operators exit may be restricted or torch hoses may inadvertently cross heated areas.

Personal protective equipment should be worn.

Proper precautions should be taken to avoid burns from heated material and steam that is created during the cooling cycle.

Equipment should be fitted with recommended gages, torch tips, and hoses for the work to be performed and the gases to be used.

Equipment should be in good working order and properly maintained.

Torches should be equipped with flashback arresters and quick disconnects when working in confined spaces.

Only mechanical friction lighters designed for oxy-fuel torches should be used for torch ignition.

Fuel/Oxygen sources should be protected from heat, checked regularly for leaks, and secured in an upright position.

Work area atmospheres should be monitored for explosive and oxygen deficient conditions.

Section 10
DOS AND DON'TS
OF
FLAME BENDING

1. Safety is a primary consideration for personnel and equipment.
2. Approach the job the same way each time (primary concept app). Consider the affects of flame bending on related systems.
3. Use only trained and qualified personnel.
4. Assure that the desired results can be achieved by flame bending.
5. Determine if shortening of material is acceptable before attempting to use a flame bending technique.
6. Determine if base metal can be flame bent without damage to the material.
7. Assure that the system/pipe is unrestrained during initial evaluation for suitability for flame bending.
8. Determine correct heating methods/patterns for pipe wall diameter, material and buckling stability.
9. Assure adequate equipment is available to perform the flame bending, cooling and pipe measurement.
10. Assure that consistently accurate measuring systems are used before and after heating.
11. Determine system acceptability requirements before bending.
12. Don't overheat pipe. (ie; large red areas, surface melting, scaling)
13. Don't reverse travel direction or stop during the heating cycle.
14. Don't apply cooling techniques until pipe is below 1000°F (No light is being emitted/redness).
15. Don't heat pipe with large self-sustaining loads without additional support.

16. Flame bend copper, cast iron or hot short materials is not recommended.
17. Special precautions are necessary for stainless, HSLA, HY 80/100, quenched and tempered, age hardened materials.
18. Don't heat with pipe hangers, branch connectors, foundations or other undesirable restraints between the heat location and the free end of the pipe.
19. Don't apply heat on unclean surfaces.
20. Don't "Vee" heat pipe in same location more than three times.
21. Pipe wall thicknesses should not exceed 5/8" when heated from one side.
22. Final determination for acceptance should not be until a minimum of hours after cool down.
23. Don't attempt all desired movement in one heat.
24. For critical systems (High pressure, High temperature, Steam, etc) post bend inspect by VT/PT/MT.
25. Correct for parallelism last where practical.
26. Ensure all possible hanger adjustment and component movement adjustments have been made prior to heating to correct an unacceptable condition.
27. Never apply flame bending to pipe that doesn't require it.
28. Use models and/or mock-ups where practical before heating pipe.
29. Do not attempt flange rotation for bolt hole alignment by flame bending.
30. Know the minimum design requirements for alignment.
31. Record in writing the starting measurements.
32. Monitor and record movements in process.
33. Stop when minimum alignment requirements have been met. Don't strive for perfection.

- 34. Never put flame bending operators in harm's way.
- 35. Never apply a spot heat in the same place twice.
- 36. Never heat a pressurized system.
- 37. Never heat a closed container without room to expand to avoid developing high pressures.
- 38. Never heat a container that contains or has possibly ever contained flammable, explosive or toxic substances.
- 39. Always accomplish a hand over hand check (inspection) of pipe system to the free end of the pipe to assure that it is free of branch connections, pipe hangers or other forms of restraint.
- 40. Remove hazardous material from around the flame bending operation.
- 40. Always layout heat location/pattern prior to commencing first heat.
- 41. Always use single orifice torch tips.

APPENDIX A TYPICAL FLAME BENDING PROCEDURES

The following procedures are typical of those which might be used for the production flame bending of pipe. Caution should be taken to insure that these procedures or procedures similar to them are not implemented without proper operator training conducted and the procedure being properly qualified. Also' special consideration must be given to the affects of shortening the lengths of pipe being heated. Preplanning is an important part of any flame bending operation.

1. THIS SPECIFICATION CANCELS AND SUPERSEDES WELDING PROCEDURE		WELDING PROCEDURE SPECIFICATION	
SPECIFICATION NO. REV.		2. DATE	3. No. 0001
4. SUBJECT Holt Technique for Flame Bending Alignment of 2"-12" Diameter Pipe.			
5. HEAT PROCESS Oxy-Fuel Heating	6. FLAME SETTING Most Base Metals - Neutral CRES - Slightly Oxidizing	7. PROGRESSION See attached Steps.	
8. BASE METAL (SPECIFICATION & THICKNESS) CFe, CMo, CuNi, CRES, CrMo Up to 12" diameter		9. FUEL GAS 1st choice - Acetylene 2nd choice - Mapp	
10. MIL-STD-278 "S" GROUPS S-1, S-3, S-4, S-5, S-8, S-34, S-42,		11. FUEL GAS FLOW RATE Same both torches.	
12. TORCH ADJUSTMENT Two flame bending operators are required. The same size gas welding tips shall be used by both operators. Gas flow rates and flame setting shall be adjusted to match. Torches may be adjusted using a calibration block.		13. RESTRAINT/FORCE Minimum restraint shall be used.	
16. BASE METAL HEAT TEMPERATURE (DULL RED) TYPICALLY 800°F MIN 1150°F MAX		14. TORCH Airco 800 or equiv.	
		15. TIP SIZE #7, 8 or 10 single orifice.	
		17. TRAVEL SPEED As required to produce a 1/2" dia. dull red heat.	
18. POST HEAT COOLING (CRES requires forced cooling) Air, water or water mist cooling is permitted below 1000°F.		19. OPERATOR QUAL. Note 1.	
20. CLEANLINESS: THE HEAT AREA PLUS 1" OF SURROUNDING BASE METAL SHALL BE FREE OF ANY FOREIGN MATERIAL; SUCH AS OIL, GREASE, MOISTURE, PAINT, LAY-OUT DYE, ETC. APPROVED CLEANERS, SUCH AS ALCOHOL, MAY BE USED TO REMOVE GREASE AND OIL. MECHANICAL CLEANING MAY ALSO BE USED.			
21. AUTHORITY FOR USE: This procedure can only be used when specifically authorized by cognizant authority for each case.		22. INTENDED USE: This procedure is intended for precise, low residual stress bending, where alignment, parallelism, and weld joint fit-up are required to be within tens of thousandths of an inch.	
23. INSPECTION			
A. PRIOR TO HEATING: VISUALLY INSPECT FIT-UP JOINT FOR CLEANLINESS AND JOINT DESIGN COMPLIANCE.			
B. DURING HEATING: VISUALLY INSPECT "V" HEAT AREA FOR CLEANLINESS. Clean to bright metal. Preform an informational PT inspection on critical systems.			
C. AFTER HEATING: VISUALLY INSPECT THE HEAT AREA. PT inspect heated areas on critical systems and PT inspect visually questionable areas on non-critical for cracks.			
D. VISUAL INSPECTION: No cracks or signs of melting are acceptable. Rejectable conditions should be evaluated as to end-use impact and repaired as practical.			
E. ADDITIONAL INSPECTION: SHALL BE AS REQUIRED BY AUTHORIZED INSTRUCTIONS.			
24. REMARKS AND/OR NOTES:			
1. The mechanic shall be a trained flame bender, who has demonstrated the capability of performing production work. All flame bending qualifications shall be performed on a test simulating a typical production joint for flange alignment and parallelism. Benders shall also receive a shop written test on the fundamentals of flame bending and to demonstrate their awareness of cognizant procedures. Any operator who has not flame bent pipe during any 6 month continuous time shall be required to requalify.			
PREPARED BY (Signature)	BRANCH HEAD REVIEW (Signature)	DISTRIBUTION	
APPROVED BY WELDING ENGINEERING DIVISION HEAD (Signature)			

1. THIS SPECIFICATION CANCELS AND SUPERSEDES WELDING PROCEDURE

WELDING PROCEDURE
SPECIFICATION

SPECIFICATION NO.

REV.

2. DATE

3. No.
0001

25. PROCEDURE FOR FLAME BENDING ALIGNMENT

Step 1 MEASUREMENT - The Lead Shop shall be responsible for measuring and recording mismatch dimensions of flanges between the pipe flange and target or matching flange. Make sure that the pipe section to be aligned is free to move, and not rigidly held by hangers or other restraint. Determine point of greatest mismatch of the flange with a target or mating surface, Figure 1. Mark the flange at this location as Point #1 and record this dimension. Flange parallelism is to be measured at 90° increments. The location of minimum and maximum gaps shall be marked on the flanges and the gaps shall be recorded (Figure #2). Mark and label each reference point to allow consistent data recording throughout the flame bending process.

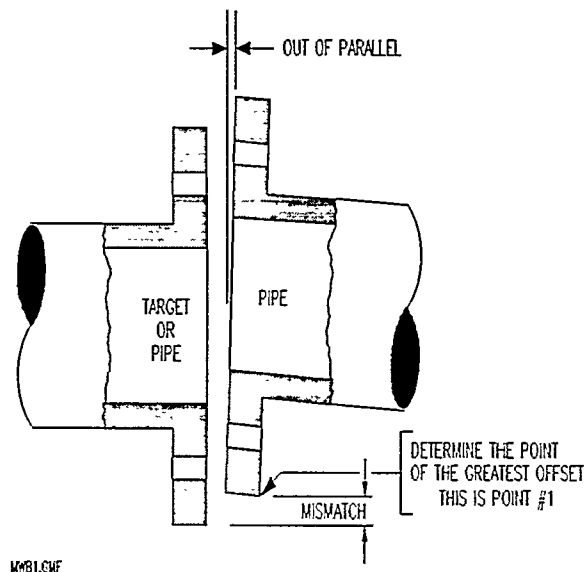


FIGURE 1

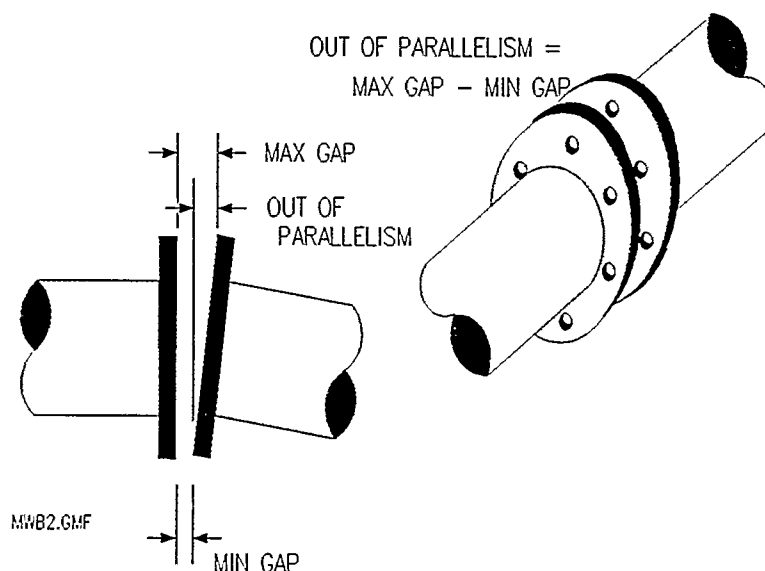
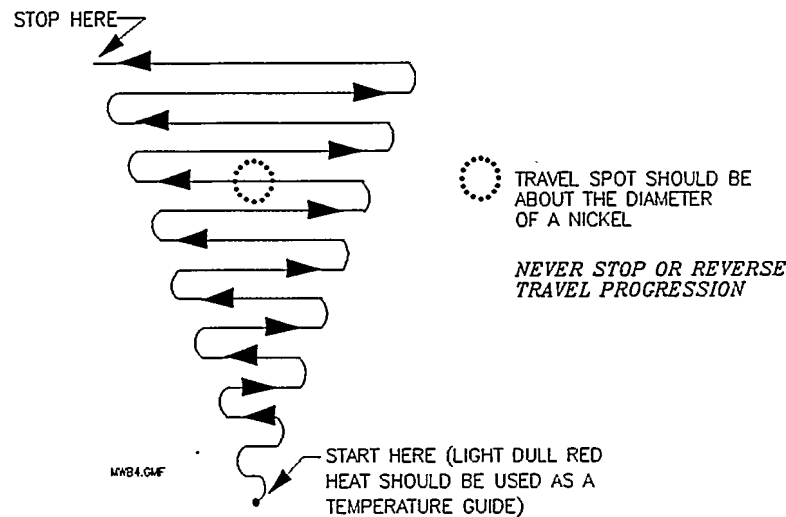


FIGURE 2

Step 2 REQUIRED ALIGNMENT - Determine at this time exactly what has to be aligned. If it is to make the boltholes line up, realize that flame bending cannot rotate the bolt pattern. Also it must be realized that flame bending always shortens the length of the pipe. This can cause permanent mismatch of flanges when bending pipe runs at 90° angles to flanges. Alignment target should be located to require the minimum movement to just meet the minimum governing fabrication document.

Step 3 HEAT LAYOUT - An experienced or trained flame bender will determine the location of the pivot hinge of the pipe. The area to be flame heated shall be clean of paint, oil, etc. If the inside of the pipe is accessible, the marine life should be scraped off and cleaned. The flame bender WILL then lay out a standard vee heat pattern (Figure 3 and 4). These lines should be fairly accurate and marked on the pipe with a permanent marks-a-lot black ink pen, chalk, soapstone, or other marker which endures flame temperatures.

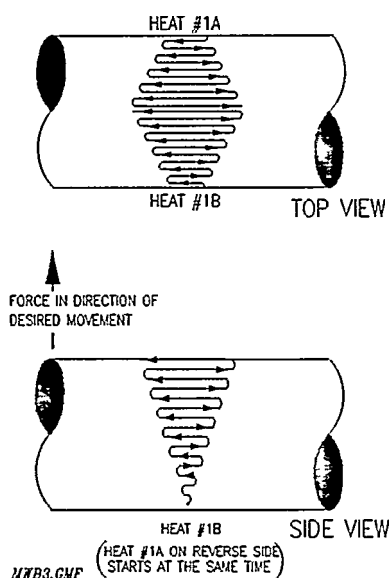
STANDARD "V" PATTERN - HOLT TECHNIQUE

VEE HEAT PATTERN
FIGURE 3

Step 4 PRESTRESSING- The lead shop using force (jack, port-a-power, etc.) shall push or pull the pipe flange towards its desired location (point #1) about 3/16"-1/2" depending on the ease of movement and the run of the pipe. The pipe shall not be moved past its desired final location. This load is put on the pipe to create higher compressive stresses in the heated area during the heating cycle and therefore provide more movement per heat. Check to see that the pipe can be moved prior to applying force (no hangers, dead weight, or bolts still in the flanges, etc.). This prestressing shall be accomplished prior to heating and no additional force shall be applied during heating.

NOTE: This procedure does not allow or infer use of oxy-fuel process to heat and bend a pipe by use of an external mechanical force.

Step 5 PRACTICE HEAT - Heats 1A and 1B are to be made at the same time by operators on opposite side of the pipe. (Figure 4).



HEAT APPLICATION FIGURE 4

- 1) Two "V" heats must be made concurrently, one on each side of the pipe by two operators traveling at the same speed.
- 2) Once heating is started don't stop, as over-heating will result and bending will not be uniform.
- 3) Do not travel backwards. Travel at a smooth and uniform rate that will just cause a dull red heat. (Feathering the torch back and forth is not permitted.)
- 4) Insure that all metal is heated to a dull red heat. This is accomplished by moving the heated spot in the pattern shown and not by heating the whole "V" to a red heat at one time.
- 5) A practice heat shall be made on a piece of scrap of the same type of base metal before performing production bending.

1. THIS SPECIFICATION CANCELS AND SUPERSEDES WELDING PROCEDURE		WELDING PROCEDURE SPECIFICATION	
SPECIFICATION NO.	REV.	2. DATE	3. No. 0001

- Step 6 FIRST HEAT/COOL CYCLE - Two experienced or trained flame benders start simultaneously at opposite sides at the apex ends of the "V" heats. The benders shall use oxy-fuel heating torches with a single orifice tip (#7, #8, or #10 depending on wall thickness and material reaction to heat, etc.). The travel speed and heat input is critical and should be established before starting on the actual job by practicing on scrap material. Traveling at the desired travel speed, the flame benders meet at the center at the wide end of the "V" heated patterns. The torches are extinguished. Using air, water or a water/air spray mist, the pipe is cooled to ambient temperature. The pipe (See CRES exception) shall be allowed to cool sufficiently so that the heated area is no longer red (i.e. below 1000°F), then force-cooled to ambient temperature using air, water or a water/air spray mist.
- CRES pipe shall be force-cooled immediately after the heat is completed.
- Step 7 REMEASUREMENT - After cooling release the force on the flange and measure point #1. The pipe must be at a near uniform ambient temperature before measuring. If movement is not in the direction anticipated or desired, evaluate movement and relocate heats to achieve requirements..
- Step 8 - If more movement is desired, re-apply force on point #1 and reheat the same "V" area until desired movement is obtained for proper flange alignment.
- Step 9 - Repeat steps as necessary to get required alignment. If at any time, the desired results are not obtained from the flame heating, stop and determine cause of unpredicted results.

1. THIS SPECIFICATION CANCELS AND SUPERSEDES WELDING PROCEDURE		WELDING PROCEDURE SPECIFICATION	
SPECIFICATION NO. REV.		2. DATE	3. No. 0002

4. SUBJECT

Line Heating for Flame Bending Alignment of Large Diameter Pipe.

5. HEAT PROCESS Oxy-Fuel Heating	6. FLAME SETTING Neutral	7. PROGRESSION See attached Steps.
8. BASE METAL (SPECIFICATION & THICKNESS) CuNi Approximately 1/2" wall and diameter greater than 12"		9. FUEL GAS 1st choice - Acetylene 2nd choice - Mapp
10. MIL-STD-278 "S" GROUPS S-34		11. FUEL GAS FLOW RATE Same both torches.
12. TORCH ADJUSTMENT Two flame bending operators are required. The same size gas welding tips shall be used by both operators. Gas flow rates and flame setting shall be adjusted to match. Torches may be adjusted using a calibration block.		13. RESTRAINT/FORCE Minimum restraint shall be used.
16. BASE METAL HEAT TEMPERATURE (DULL RED) TYPICALLY 800°F MIN 1150°F MAX		14. TORCH Airco 800 or equiv.
17. TRAVEL SPEED As required to produce a 1/2" dia. dull red heat. (1 1/2"-3"ipm)		15. TIP SIZE #8 or 10 single orifice.
18. POST HEAT COOLING Air, water or water mist cooling is permitted below 1000°F.		19. OPERATOR QUAL. Note 1.

20. CLEANLINESS: THE HEAT AREA PLUS 1" OF SURROUNDING BASE METAL SHALL BE FREE OF ANY FOREIGN MATERIAL; SUCH AS OIL, GREASE, MOISTURE, PAINT, LAY-OUT DYE, ETC. APPROVED CLEANERS, SUCH AS ALCOHOL, MAY BE USED TO REMOVE GREASE AND OIL. MECHANICAL CLEANING MAY ALSO BE USED.

21. AUTHORITY FOR USE: This procedure can only be used when specifically authorized by cognizant authority for each case.	22. INTENDED USE: This procedure is intended for precise, low residual stress bending, where alignment, parallelism, and weld joint fit-up are required to be within tens of thousandths of an inch.
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23. INSPECTION

A. PRIOR TO HEATING: VISUALLY INSPECT FIT-UP JOINT FOR CLEANLINESS AND JOINT DESIGN COMPLIANCE.

B. DURING HEATING: VISUALLY INSPECT "V" HEAT AREA FOR CLEANLINESS. Clean to bright metal. Perform an informational PT inspection on critical systems.

C. AFTER HEATING: VISUALLY INSPECT THE HEAT AREA. PT inspect heated areas on critical systems and PT inspect visually questionable areas on non-critical systems for cracks.

D. VISUAL INSPECTION: No cracks or signs of melting are acceptable. Rejectable conditions should be evaluated as to end-use impact and repaired as practical.

E. ADDITIONAL INSPECTION: SHALL BE AS REQUIRED BY AUTHORIZED INSTRUCTIONS.

24. REMARKS AND/OR NOTES:

1. The mechanic shall be a trained flame bender, who has demonstrated the capability of performing production work. All flame bending qualifications shall be performed on a test simulating a typical production joint for flange alignment and parallelism. Benders shall also receive a shop written test on the fundamentals of flame bending and to demonstrate their awareness of cognizant procedures. Any operator who has not flame bent pipe during any 6 month continuous time shall be required to requalify.

PREPARED BY (Signature)	BRANCH HEAD REVIEW (Signature)	DISTRIBUTION
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APPROVED BY WELDING ENGINEERING DIVISION HEAD (Signature)

SPECIFICATION NO.

REV.

2. DATE

3. No.
0002

PROCEDURE FOR FLAME BENDING ALIGNMENT OF MAIN SCOOP EXPANSION JOINTS

- p 1 MEASUREMENT - The Lead Shop shall be responsible for measuring and recording mismatch dimensions of flanges between the pipe flange and target or matching flange. Make sure that the pipe section to be aligned is free to move, and not rigidly held by hangers or other restraint. Determine point of greatest mismatch of the flange with a target or mating surface, Figure 1. Mark the flange at this location as Point #1 and record this dimension. Flange parallelism is to be measured at 90° increments. The location of minimum and maximum gaps shall be marked on the flanges and the gaps shall be recorded (Figure #2). Mark and label each reference point to allow consistent data recording throughout the flame bending process.

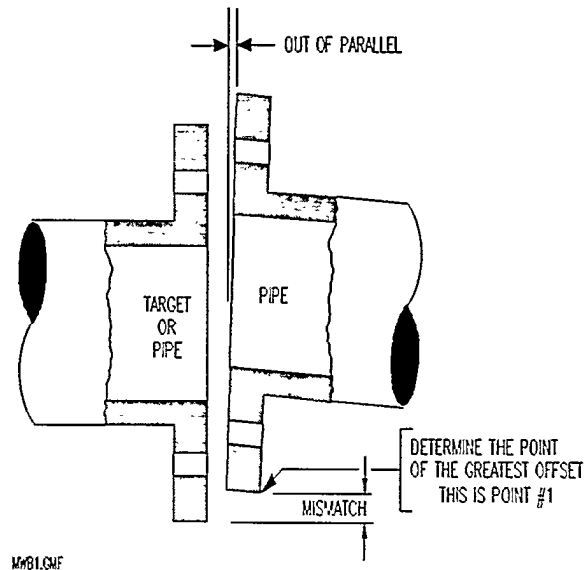


FIGURE 1

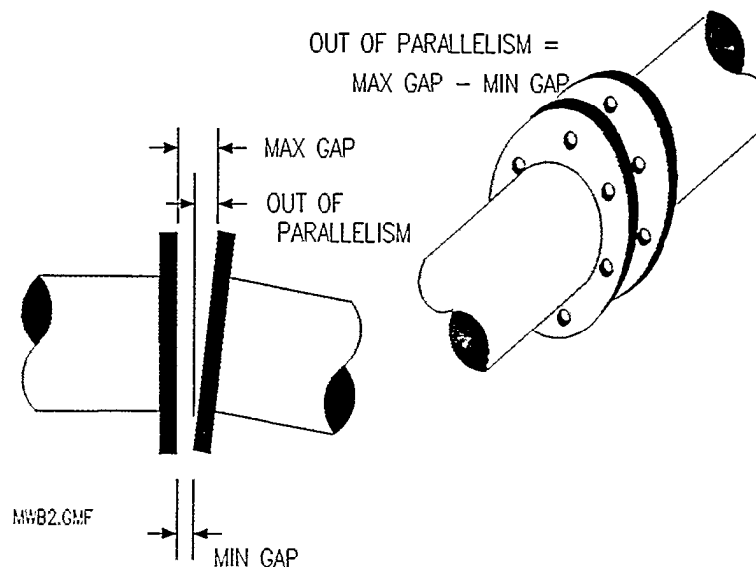


FIGURE 2

- p 2 REQUIRED ALIGNMENT - Determine at this time exactly what has to be aligned. If it is to make the boltholes line up, realize that flame bending cannot rotate the bolt pattern. Also it must be realized that flame bending always shortens the length of the pipe. This can cause permanent mismatch of flanges when bending pipe runs at 90° angles to flanges. Alignment target should be located to require the minimum movement to just meet the minimum governing fabrication document.

SPECIFICATION NO.

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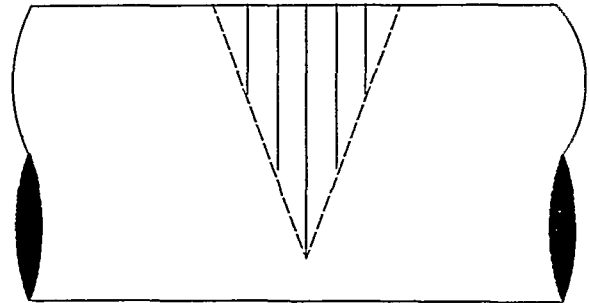
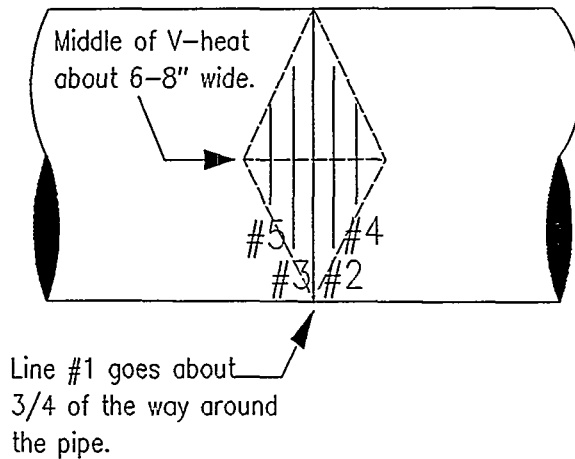
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Step 3 HEAT LAYOUT - An experienced or trained flame bender will determine the location of the pivot hinge of the pipe. The area to be flame heated shall be clean of paint, oil, etc. If the inside of the pipe is accessible, the marine life should be removed. The flame bender will then lay out a standard line heat pattern (Figure 3). The middle line (#1) will be $\frac{3}{4}$ of the pipe circumference long. The middle section of the line pattern shall be about 6-8" wide. Use 5 or 7 lines about 1-1 $\frac{1}{2}$ " apart and the proper length to establish a "Vee" pattern (Figure 3). These lines should be fairly accurate and marked on the pipe with a permanent marks-a-lot black ink pen, chalk, soapstone, or other marker which endures flame temperatures.

TOP VIEW

SIDE VIEW



Note: For clarity, the Vee-heat pattern shown on the pipe is not to scale.

TYPICAL LINE HEAT PATTERN FIGURE 3

Step 4 PRESTRESSING - Check to see that the pipe can be moved prior to applying force (no hangers, dead weight, or bolts still in the flanges, etc.). This prestressing shall be accomplished prior to heating and no additional force shall be applied during heating. Using force (jack, port-a-power, etc.) push or pull the pipe flange towards point #1 about $\frac{3}{16}$ "- $\frac{1}{2}$ " depending on the ease of movement. The pipe shall not be moved past its desired final location. This load is put on the pipe to create higher compressive stresses in the heated area during the heating cycle and therefore provide more movement per heat.

NOTE: This procedure does not allow or infer use of oxy-fuel process to heat and bend a pipe by use of an external mechanical force.

Step 5 FIRST HEAT/COOL CYCLE - Two experienced or trained flame benders start simultaneously at opposite ends of line 1 and heat toward the line center. As an alternative, line heating may also proceed from the widest area of the Vee toward the apex. The benders shall use oxy-fuel heating torches with a single orifice tip (#8, or #10 depending on wall thickness and material reaction to heat, etc.). The travel speed and heat input is critical and should be established before starting on the actual job by practicing on scrap material. Traveling at the desired travel speed, usually $\frac{1}{2}$ to 3 ipm, the flame benders meet at the center at the center of line #1. The torches are extinguished. The pipe shall be allowed to air cool sufficiently so that the heated area is no longer red (i.e. below 1000°F), then force-cooled to ambient temperature using air, water or a water/air spray mist.

Step 6 REMEASUREMENT - After cooling release the force on the flange and measure point #1. The pipe must be at a near uniform ambient temperature before measuring. If movement is not in the direction anticipated or desired, evaluate movement and relocate heats to achieve requirements..

Step 7 PRESTRESSING - Re-apply force on point #1 as in Step 4.

Step 8 SECOND HEAT/COOL CYCLE - Flame heat line #2, then without cooling, immediately heat line #3. Extinguish torches, cool pipe and release load stresses.

Step 9 REMEASUREMENT - Repeat Step 6.

Step 10 PRESTRESS, THIRD HEAT/COOL CYCLE - Re-apply force on point #1 as in Step 4. Flame heat lines #4 and #5, cool pipe and release load stresses as in Step 8.

Step 11 REMEASUREMENT - Repeat Step 6.

Step 12 - If there are additional heat lines, apply prestress as in Step 4 and perform heats then cool pipe.

Step 13 - Release all load on pipe. Repeat Step 1. Note direction of movement and repeat Step 2. If additional alignment is required the angle of force may have to be repositioned to get the desired line of movement.

Step 14 - Repeat Steps 3 through 13 as necessary to achieve required alignment. If at any time, the desired results are not obtained from the flame heating, STOP and determine cause of unpredicted results.

APPENDIX B OPERATOR TRAINING AND QUALIFICATION

CERTIFICATION TEST WRITTEN

The following is a recommended written examination with typical questions for certification of flame bending operators. The exam should have the name, personnel identification number and the date the exam was given. A passing score of 80 percent should be required and recorded on the test. Any questions missed should be thoroughly discussed with the flame bender.

FLAME BENDER FINAL EXAM WITH ANSWERS

DATE: _____

NAME: _____

IDENTIFICATION NUMBER: _____

SCORE: _____

1. Q. WHAT FIRST MUST BE ADDRESSED BEFORE STARTING FLAME BENDING?
 - A. CLEANLINESS, ACCURATE MEASUREMENTS, LOCATING AND LOADING OF PIPE HANGERS AND SPECIFICATION REQUIREMENTS.
2. Q. WHICH TECHNICAL CODE SHOULD BE PRESENT PRIOR TO AND TO WITNESS FLAME BENDING OF CRITICAL PIPING?
 - A. CODE 138 (WELDING ENGINEERING) OR THE COGNIZANT AUTHORITY.
3. Q. WHAT TYPICAL SIZE AND TYPE OF TORCH TIPS ARE RECOMMENDED FOR FLAME BENDING FERRITIC METALS 1/2" TO 5/8" THICK?
 - A. #7, #8, OR #10 SINGLE ORIFICE.
4. Q. WHAT BASE METAL TEMPERATURE IS RECOMMENDED FOR FLAME BENDING OF PIPE?
 - A. DULL RED OR 800°F MINIMUM TO 1150°F MAXIMUM (EXCEPT CRES). THE MAXIMUM Temperature RECOMMENDED FOR 300 SERIES STAINLESS STEEL IS 800°F.

FLAME BENDING FOR ACCURACY CONTROL

5. Q. BELOW WHAT TEMPERATURE MAY A WATER MIST BE USED FOR COOLING?
- A. LESS THAN 1000°F OR WHEN NO DULL RED COLOR IS PRESENT.
6. Q. WHAT DOES FLAME BENDING DO TO THE WALL THICKNESS AND LENGTH OF PIPING?
- A. INCREASE THICKNESS, SHORTENS LENGTH.
7. Q. WHAT ARE THE TWO PRIMARY APPROVED HEAT PATTERNS USED IN FLAME BENDING AND FOR WHAT SIZE PIPE?
8. A. HOLT "V" HEATS FOR 211 TO 12" DIAMETER PIPE; LINE HEATS ARE USED FOR 12" DIAMETER AND LARGER THIN WALL PIPE.
- Q. WHY ARE HOLT VII HEATS PREFERRED OVER LINE HEATS ON SMALLER DIAMETER PIPE?
9. A. V HEATS ARE MORE EFFICIENT AND PREDICTABLE ON SMALLER DIAMETER PIPE AND SMALL DIAMETER PIPE IS LESS SUSCEPTIBLE TO BUCKLING.
- Q. WHY ARE LINE HEATS USED ON LARGE DIAMETER PIPE?
10. A. LINE HEATS ARE MORE PREDICTABLE ON LARGE DIAMETER PIPE AND WITH THIN WALL PIPE SEVERE BUCKLING CAN RESULT FROM HOLT VII HEATS.
11. Q. CAN A PIPE FLANGE BE ROTATED USING THE TRADITIONAL FLAME BENDING TECHNIQUES?
- A. NO.
12. Q. WHAT THREE INSPECTIONS ARE TYPICALLY REQUIRED WHEN FLAME BENDING PIPING SYSTEMS?
- A. INFORMATIONAL PTS BEFORE FLAME BENDING AND REQUIRED PT AFTER FLAME BENDING. (VT - FOR CLEANLINESS PRIOR TO HEATING, PT - PRIOR TO HEATING, VT/PT - AFTER HEATING)
13. Q. WHY MUST YOU HAVE TWO FLAMEBENDERS TO DO FLAMEBENDING?
- A. CONTROLLED UNIFORM HEAT AND DIRECTION OF MOVEMENT.
14. Q. ONCE YOU START A FLAMEBENDING HEAT SHOULD YOU STOP OR GO BACKWARDS? WHY OR WHY NOT?
- A. **NO**, WILL CAUSE OVERHEATING AND BENDING MAY NOT OCCUR IN DESIRED DIRECTION OR THE DESIRED DEFLECTION WILL BE LESS THAN ANTICIPATED.

FLAME BENDING FOR ACCURACY CONTROL

15. Q. WHAT IS THE RECOMMENDED WIDTH FOR "V" HEAT?
- A. 4" MAXIMUM IS RECOMMENDED WITH APPROXIMATELY 30 DEGREE INCLUDED ANGLE FOR THE HOLT TECHNIQUE AND 5" TO 8" FOR LINE HEATS.
16. Q. WHAT MUST YOU DETERMINE BEFORE LAYOUT OF HEAT PATTERN?
- A. THE DIRECTION OF MOVEMENT AND PIVOT HINGE SIZE.
17. Q. MAY FORCE BE APPLIED WHEN YOU ARE DOING A HEAT PATTERN? EXPLAIN
- A. YES, BEFORE BENDING A SLIGHT LOAD CAN BE APPLIED, HOWEVER DURING HEATING NO ADDITIONAL LOAD MAY BE APPLIED. LOADING IS TO PROVIDED COMPRESSION FORCES IN THE AREA TO BE HEATED (I. E., INCREASES THICKENING). DO APPLY ADDITIONAL FORCE DURING THE HEATING CYCLE.
18. Q. HOW DO YOU DETERMINE LENGTH OR CENTER OF A "V" HEAT OR LINE HEAT?
- A. BY MEASURING THE OUTSIDE CIRCUMFERENCE AND USING 3/4 OF THE TOTAL LENGTH, 1/2 OF THE 3/4 TOTAL LENGTH WILL GIVE YOU THE CENTER.
19. Q. CAN YOU APPLY MORE THAN ONE HEAT TO THE SAME AREA? IF SO HOW MANY?
- A. YES BUT USUALLY NOT MORE THAN THREE HEATS IN ONE LOCATION ARE RECOMMENDED AS LOCALIZED BUCKING MAY OCCUR.
20. Q. FIAMEBENDING IS BASED ON RESTRICTED THERMAL EXPANSION DURING HEATING AND FREEDOM OF THE METAL TO CONTRACT AFTER HEATING DURING COOLING (TRUE OR FALSE?).
- A. TRUE
21. Q. WHO MUST BE NOTIFIED BEFORE FLAME BENDING PIPING ON SURFACE SHIPS?
- A. THE COGNIZANT FLAME BENDING TECHNICAL AUTHORITY.
22. Q. WHAT ARE THE INSPECTION REQUIREMENTS ON SURFACE SHIPS?
- A. VISUAL INSPECTION BEFORE AND AFTER. IF A DEFECT IS FOUND OR SUSPECTED, PT INSPECTION IS REQUIRED.
23. Q. CAN NEUTRAL FLAMES BE USED?
- A. YES, ON STAINLESS STEEL THEY ARE RECOMMENDED, OTHERWISE A SLIGHTLY REDUCING FLAME IS RECOMMENDED.

24. Q. WHAT IS THE SIGNIFICANCE OF TWO OPERATORS HAVING THEIR OXY/FUEL RATES SET THE SAME?
- A. UNIFORM TRAVEL SPEEDS AND HEAT APPLIED THEREFORE UNIFORM BENDING.
25. Q. WHY SHOULD NEUTRAL FLAMES BE USED?
- A. TO PREVENT OXIDATION (OXIDIZING FLAME) OR TO PREVENT CARBURIZATION (CARBURIZING FLAME).
26. Q. HOW DO YOU KNOW WHEN YOU HAVE A NEUTRAL FLAME?
- A. A NEUTRAL FLAME WILL HAVE A BLUE INNER CORE THAT COMES TO A SHARP POINT.
27. Q. CAN CALIBRATION BLOCKS BE USED TO ADJUST TORCHES? IF so, HOW?
- A. YES. BY HEATING ONE SIDE OF A GIVEN SIZE PLATE AND MEASURING THE TIME TO REACH A CERTAIN TEMPERATURE ON THE OPPOSITE SIDE.
28. Q. WHY IS WATER MIST COOLING PERMITTED?
- A. TO SPEED UP THE COOLING PROCESS SO MEASUREMENTS CAN BE TAKEN. IT DOES NOT APPRECIATIVELY AFFECT THE AMOUNT OF SHRINKAGE.
29. Q. HOW CLEAN MUST METAL BE PRIOR TO HEATING?
- A. TO BRIGHT METAL.
30. Q. WHEN MUST VISUAL INSPECTIONS BE ACCOMPLISHED?
- A. AFTER EACH HEAT. NO MELTING OR CRACKS ARE ACCEPTABLE.
31. Q. FLAME BENDING IS INTENDED TO SHAPE PIPE FOR MAJOR BENDING?
- A. NO. LARGE MOVEMENTS CAN BE OBTAINED BUT IT IS INTENDED FOR FINE ADJUSTMENT WHERE ACCURACY CONTROL IS NECESSARY.
32. Q. CAN BOLTING PATTERNS BE ROTATED BY FLAME BENDING?
- A. NO.
33. Q. IF THE INSIDE OF PIPE IS ACCESSIBLE, WHAT SHOULD BE DONE BEFORE BENDING?
- A. CLEANED IF POSSIBLE.

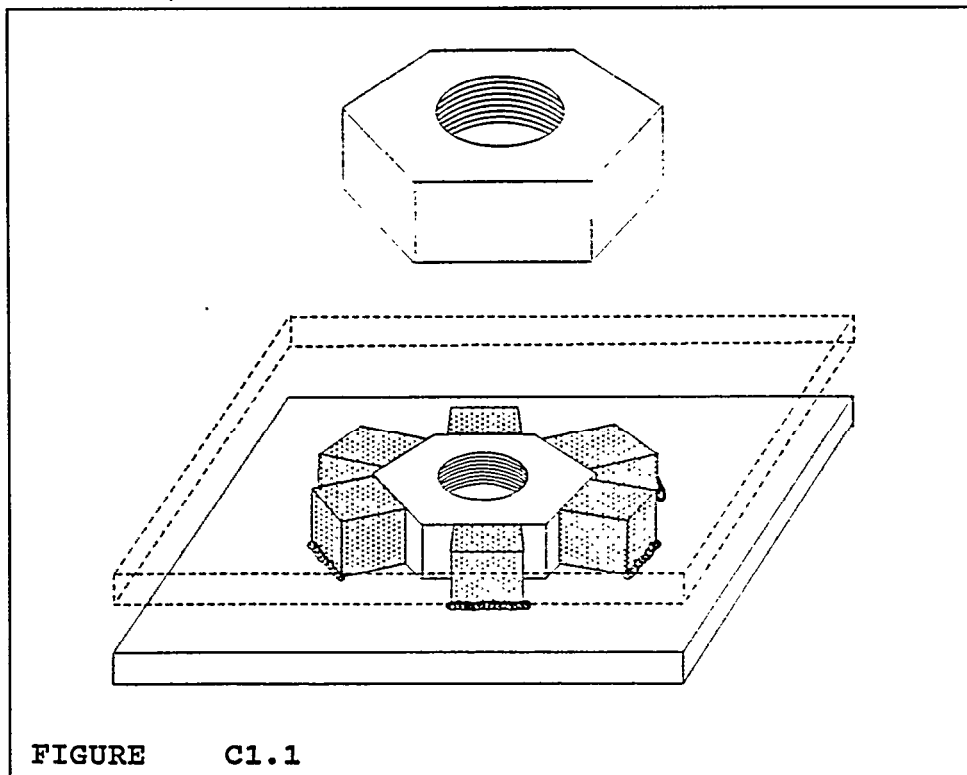
FLAME BENDING FOR ACCURACY CONTROL

34. Q. SHOULD HEATING PATTERNS ALWAYS BE LAID OUT PRIOR TO HEATING? (EXPLAIN)
- A. YES. THIS IS TO PROVIDE UNIFORM HEATING PATTERNS AND TECHNIQUES WHEN TWO OPERATORS ARE USED. THIS HELPS PROVIDE UNIFORM BENDING.
35. Q. EXPLAIN THE USE AND PURPOSE OF JACKS, COME-A-LONGS (I.E., SLIGHT FORCE)
- A. TO PROVIDE A SLIGHT COMPRESSIVE FORCE IN THE AREA BEING HEATED TO CREATE THE MAXIMUM RESTRAINT ON HEATED METAL, THEREFORE MAXIMIZING THE AMOUNT OF BEND OR SHORTENING PER HEAT
36. Q. HOW SIGNIFICANT IS THE TEMPERATURE OF THE MEMBER AFTER FLAME BENDING TO ASSURE ACCURATE MEASUREMENTS?
- A. THE TEMPERATURE IS VERY SIGNIFICANT FOR CRITICAL APPLICATIONS. THE TEMPERATURE SHOULD BE UNIFORM TO THE HAND TOUCH AND VERY CLOSE TO AMBIENT TEMPERATURE.
37. Q. DO MULTI BEND SYSTEMS (I.E., EXPANSION LOOPS) REQUIRE EXTRA CONSIDERATION?
- A. YES.
38. Q. FOR HELP WITH COMPLICATED SYSTEMS WHO SHOULD BE CONTACTED?
- A. THE COGNIZANT FLAME BENDING ENGINEERING CODE.
39. Q. IN WHAT CONDITION SHOULD PIPING SPRING HANGERS BE IN BEFORE FLAME BENDING IS COMMENCED?
- A. ALL SPRING HANGERS MUST BE PROPERLY INSTALLED AND ON HOT SETTINGS.

CASE HISTORY 1: Reducing The Diameter Of A Die Nut

BACKGROUND: This case history involves the reduction in size of the cutting diameter of a large diameter die nut used to cut threads. The die nut being quite large and having close tolerances on the thread diameter was found after machining to be .004 inches too large in diameter and unacceptable for use. Because of the cost and the time to manufacture a new die nut it was decided to reduce the diameter by flame shaping.

TECHNIQUE: Figure C1.1 exhibits the die nut before flame heating and also shows a thermal expansion restraining fixture which was used to reduce the diameter of the nut. The restraining fixture was made entirely of flame cut mild steel base metal and no pieces were machined.



An approximation of the minimum temperature necessary to reduce the diameter of the nut by 0.004 inches can be estimated by solving the following equation by estimating the plastic yield strain temperature to be 475°F, the coefficient of thermal expansion to be 0.000008 in/in/°F and the ambient temperature to be 60°F.

$$0.00411 = \text{thermal expansion} - \text{yield strain}$$

$$0.004 = .000008(T_i - 60) - .000008(475)$$

$$0.004 = (\text{coef. of thermal expansion}) \times (\text{Ideal temperature} - \text{the compressive thermal expansion yield temperature} - \text{ambient temperature})$$

$$\text{Ideal temperature} = 0.00411 / \text{coef. of thermal expansion} + \text{compressive thermal expansion yield temperature } ^\circ\text{F} + 60^\circ\text{F}$$

$$= 0.004 / 0.000008 + 475^\circ\text{F} + 60^\circ\text{F}$$

$$= 500^\circ\text{F} + 475^\circ\text{F} + 60^\circ\text{F}$$

$$= 1035^\circ\text{F}$$

The die nut was then placed in the restraining fixture and heated uniformly to approximately to a red heat 1200°F to 1300°F while taking care to minimizing heating of the restraining fixture. Since during heating the die nut was not allowed to expand diametrically outward it was required to plastically flow throughout its thickness. The end result is a thicker die nut that is a smaller diameter die nut at room temperature. The nut inside diameter was reduced by 0.007 inches which provided enough metal for a light clean-up cut and it was saved for use.

This is a classic example of restricted thermal expansion of a metal resulting in permanent plastic deformation (yielding) and after deforming having freedom to contract on cooling.

CASE HISTORY 2: FLAME BENDING OF LARGE CAST STEEL PIPE FITTINGS

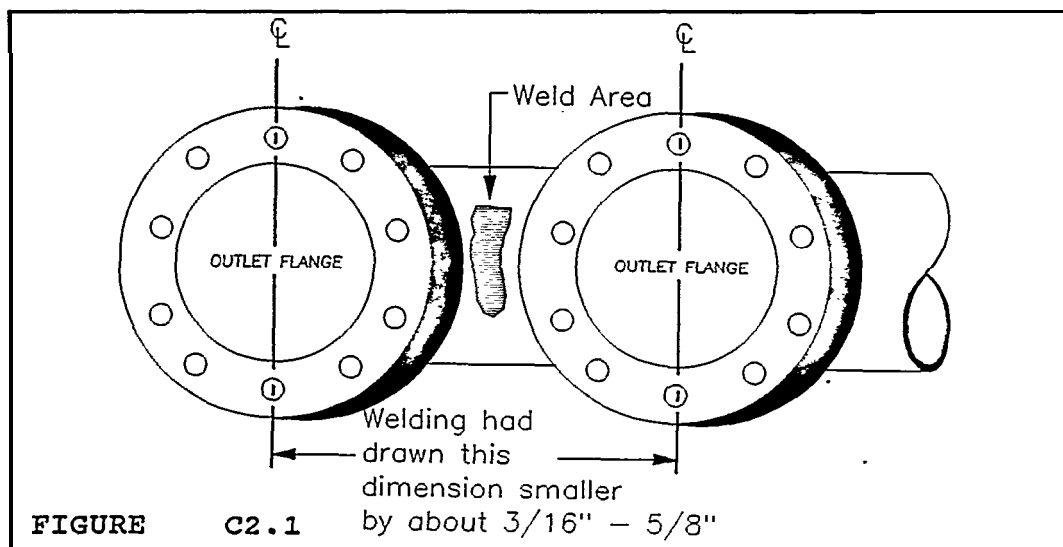
SCOPE: This case history covers the realignment of weld distorted exhaust manifolds using the flame bending technique. The cast mild steel manifolds were clad welded in areas to compensate for loss wall thickness due to corrosion. The alternative to flame bending was to cut an existing pipe butt weld, realigning the manifold and reweld. The rewelded pipe weld joint would have required a Radiographic Inspection (RT). The manifolds were successfully realigned by flame bending.

BACKGROUND: The exhaust manifolds were cast mild steel (MIL-S-15083, Grade B). The manifolds had corroded away approximately 1/4 inch of its wall thickness. The lagging covering the manifolds was occasionally soaked with sea water which increase normally expected corrosion rate.

The four manifolds were taken from the ship to shop where they were fitted to heavy steel plate fixtures (targeted). The outside of the manifolds were laid out in a grid pattern and Ultrasonically Tested (UT) for wall thickness. Those areas below design wall thickness limits were clad welded using the Gas Metal Arc Welding (GMAW) process. The manifolds were removed from the targets for this welding.

Subsequent fitting of the manifolds back into the targets showed that three of the manifolds did not fit their targets due to weld distortion and shrinkage.

The production shops decided that most of the misalignment could be made up with additional clad welding of the flange surfaces. The one area that presented a major problem was the distance between centers of the two outlet holes (See Figure C2.1).



FLAME BENDING FOR ACCURACY CONTROL

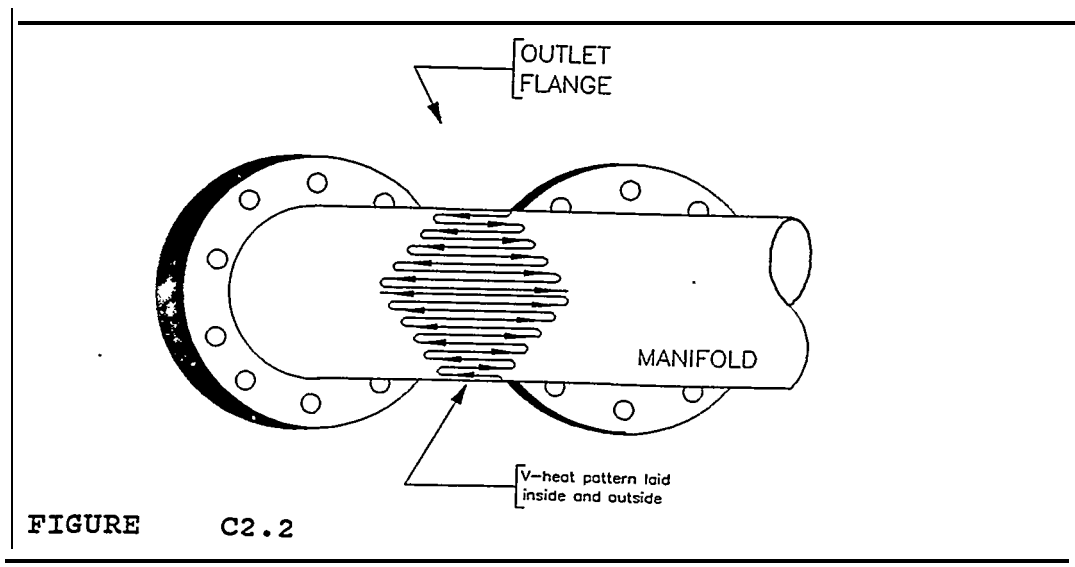
This distance had pulled together from 3/16 inch to 5/8 inch on three of the four manifolds.

Since any cutting and rewelding for alignment would require RT examination, it was decided to try flame bending the manifolds.

Four flame benders began practicing on a mock-up to become familiar with the equipment, the travel speed and working together. The equipment each bender used was a Model 800 Oxy-mapp torch with a #12 single orifice tip.

The area to be heated was Magnetic Particle (MT) Inspected prior to any heating and after the final heat. The MT inspections were all satisfactory.

A Holt V-heat pattern was laid out inside and outside (See Figure C2.2). The maximum width of the V-heat pattern was approximately four inches. The V-heat patterns extended around 90% of circumference of the manifolds. The V-heat patterns were also laid out in a grid work of numbered squares with the inside pattern and numbers corresponding with the outside pattern.



FLAME BENDING FOR ACCURACY CONTROL

With two torches inside and two outside, the four torch operators move together simultaneously, shouting their grid locations, traversing the V-heat pattern, ending at the wide area of the "V". After the heat was allowed to cool from approximately 1000-1200 F to about 600-700 F, an air hose with a water spray attachment was used to cool the manifold to room temperature. Prior to heating, a wedge was driven into the gap between the two flanges to provide compressive strain on the V-heated area. The wedge was also tightened up during the heating cycle.

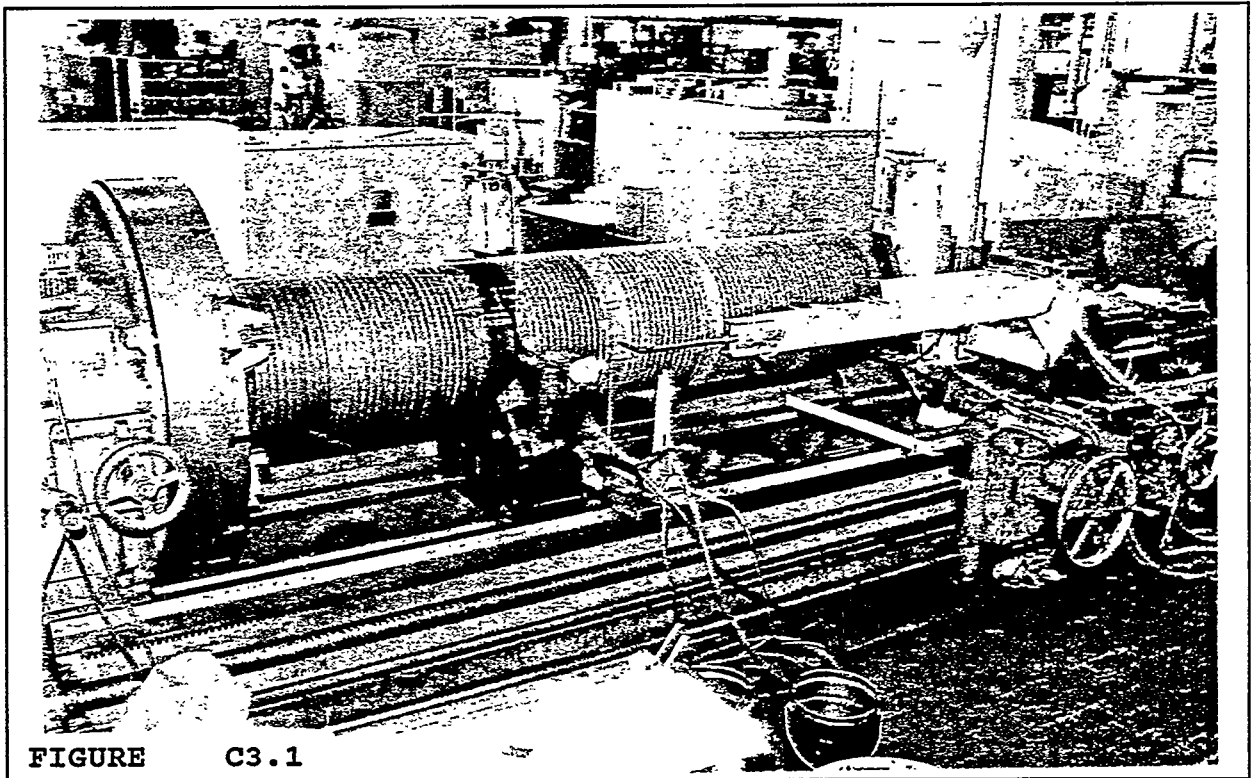
Some heats seem to give no measurable movement, while others were over 1/16 inch movement. Usually eight to 10 heats would move the flanges apart 1/4 inch.

After flame bending, the manifolds fit the targets.

CONCLUSIONS: This flame bending job went well because of the coordinated effort put forth by the four torch operators.

CASE HISTORY #3: Reducing the Diameter of a Main Propulsion Shaft Sleeve

A centrifugally cast Monel sleeve about 100" long by 20" in diameter and 1" thick was machined on the inside diameter (ID) to provide a precise interference fit over the seal area of a main propulsion shaft. See Figure C3.1. After machining, the ID was found to be oversized by about 0.030" beyond allowable tolerance. It was decided that since the sleeve was scrap in its present condition, an attempt should be made to shrink the shaft using the concepts of flame bending (i.e.: use torch heating to thicken the material, shorten the circumference and thereby reducing the ID).



The unusual challenges presented by this case were:

- a. The sleeve ID must be made uniformly smaller. In other words, the heat must be carefully controlled to heat evenly around the diameter and down the length. Uneven heating would cause an out-of-round condition or a bend of the sleeve.
- b. The 100" length of the sleeve presented a problem with getting a torch on the inside to reach at least half way down the length and stay perfectly in synch with the outside torch.

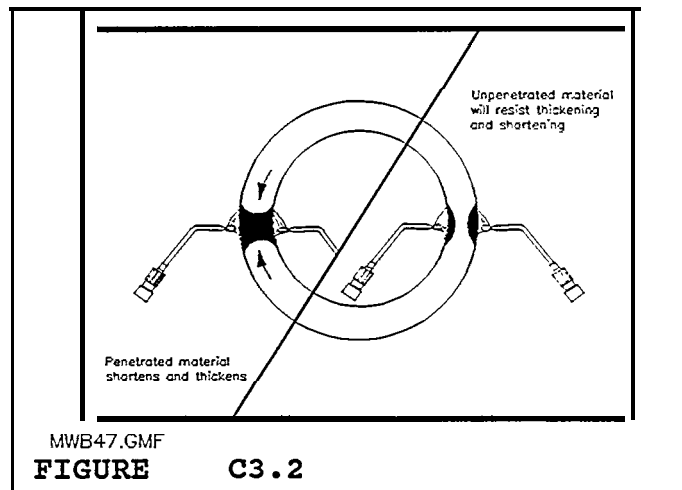
c. The heat absorbed by the sleeve presented a potential safety problem. Since the entire surface would need to be heated without stopping to cool, the heat accumulation, especially on the inside could potentially turn the sleeve into an oven and melt the oxy-fuel gas lines and cause a fire or explosion.

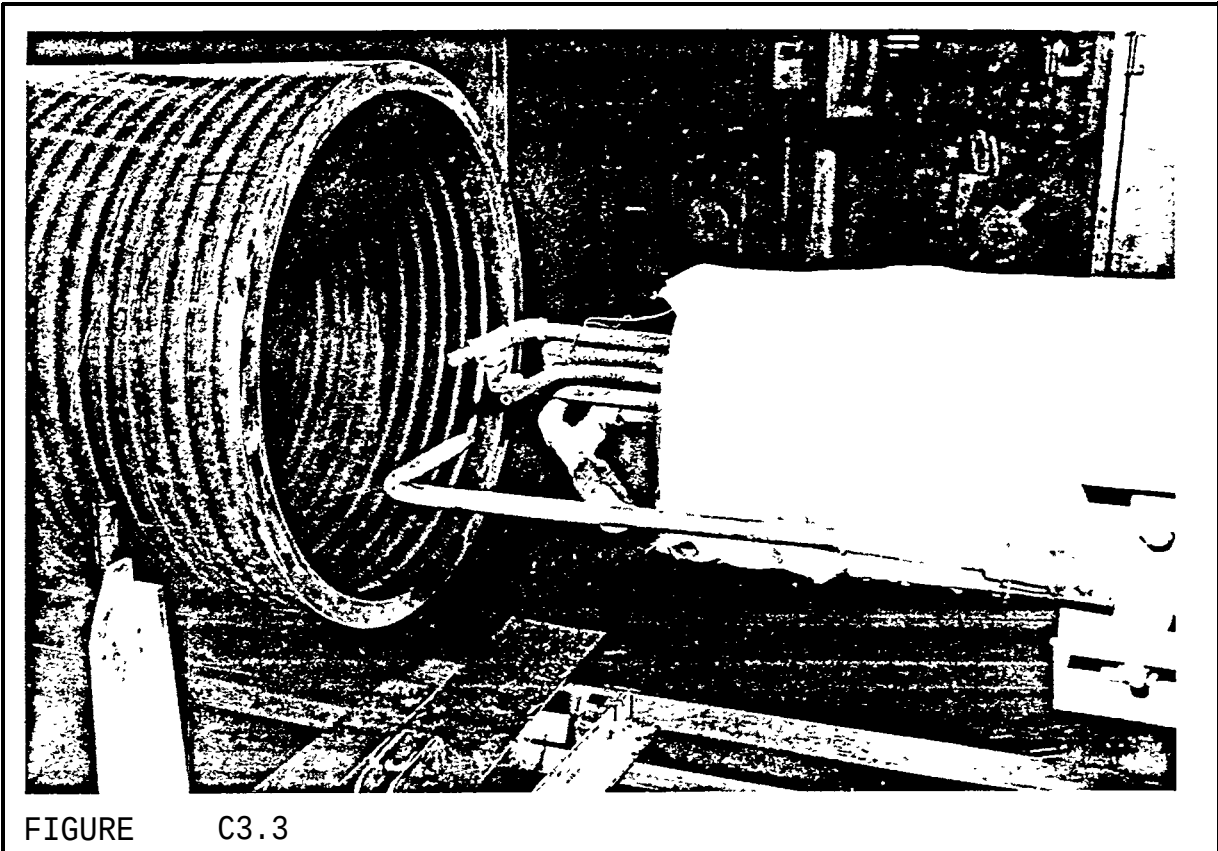
d. The 11" thickness of the sleeve posed a problem with being able to heat completely through the thickness. Without heating and plastically flowing the material completely through the thickness, the circumference would resist shortening.

Even heating was the most crucial part of making this job a success. To assure the sleeve was heated evenly, it was set up in a lathe with the torches mounted on the tool carriage. With this setup, a line heat travels in a continuous spiral around and down the length of the sleeve. The lathe allowed precise control of the rotational speed of the sleeve (torch travel speed) and amount of torch traverse per revolution (line spacing). The result was uniform heating around the circumference and down the length of the sleeve.

To reach down the length of the sleeve, the torches were placed on the end of two channel beams one on the inside and one on the outside. The beams were long enough to extend a little over half way into the sleeve. The torches were adjusted to be exactly opposite each other and have the hottest part of the flame impinge the surface of the sleeve.

For the heat to penetrate the entire thickness, two torches were used to heat the same spot from both sides. Heating from both sides is commonly done when the material is over 5/8" thick. Since the sleeve was 1" thick, two torches with very large tips (#13) were needed. If the heat does not penetrate the thickness, the unheated material will resist thickening of the wall, shortening of the circumference and shrinking of the ID. See Figure C3.2.





- To shield the torches and hoses from the heat, the beams were covered with a heat resistant cloth. Air/water sprayers were also used to minimize the heat accumulation as well as increase the temperature gradient across the heated area. Four sprayers were used, one forward and one behind each torch. See Figure C3.3.

Procedure

Torch Size: # 13

Travel Speed: 16 inches per minute (4.4 minutes per revolution)

Line SPacing: 1" set tool carriage for 1" traverse per revolution

FLAME BENDING FOR ACCURACY CONTROL

Set Torch Settings: Set the torch fuel gas and oxygen for a slightly carburizing flame. Use a plate of same material and thickness to set flame and torch to work distance. Once the flame is set, turn the torch off using cutout valves located at the base of the tool carriage. Do not lose the throttle valve settings at the torch.

Starting Technique: To avoid melting the edge, start the torches 5/8" in from the edge while rotating and traversing. Use the cutout valves to start the torch and quickly open them wide to the preadjusted settings of the throttle valves.

Safety Precautions: Use flashback arresters, and place quick disconnect fittings in easily accessible locations.

Results.

Dist From End	Outside Diameter			Inside Diameter			Wall Thickness		
	Before	After	Change	Before	After	Change	Before	After	Change
1/2"	22.169	22.166	.003	20.021	20.003	.018	1.075	1.081	.006
4"	22.176	22.162	.014	20.022	20.000	.022	1.077	1.081	.004
8"	22.171	22.146	.025	20.017	19.985	.032	1.077	1.081	.004
12"	22.170	22.137	.033	20.017	19.976	.041	1.076	1.081	.005
17"	22.170	22.136	.034	20.016	19.971	.045	1.076	1.082	.006
20"	22.169	22.137	.032	20.014	19.974	.040	1.077	1.082	.005
23"	22.170	22.143	.027	20.015	19.974	.041	1.077	1.084	.007
26"	22.169	22.142	.027	20.014	19.974	.040	1.078	1.084	.006
29"	22.170	22.140	.030	20.015	19.974	.041	1.078	1.083	.005

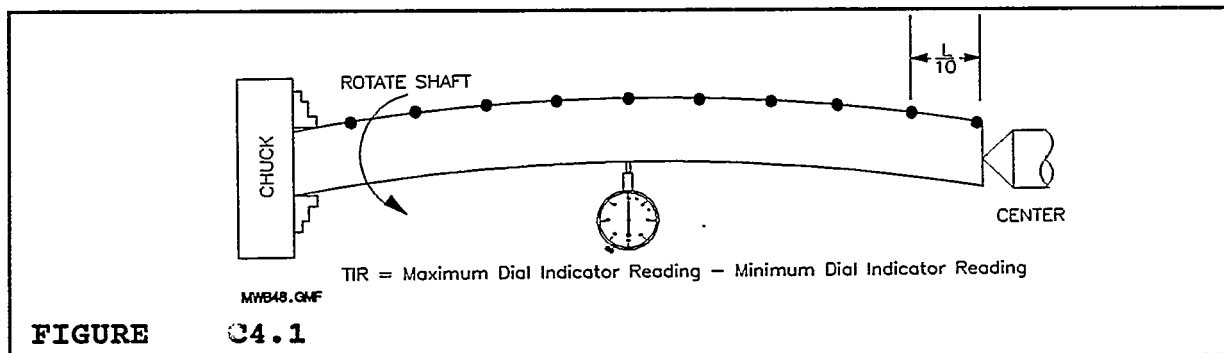
Length Before Heating: 102 3/16"

Length After Heating: $\frac{-101 \frac{13}{16}"}{3/8}"$

Note that the end is flared. Near the sleeve end, the area under the torch is free to shorten lengthwise but the diameter is restrained by the surrounding material. Because of this restraint, the wall thickening is accommodated more by shortening of the sleeve length than shortening of the circumference.

Case History # 4: Spot Heat to Straighten Stainless Steel Tubes

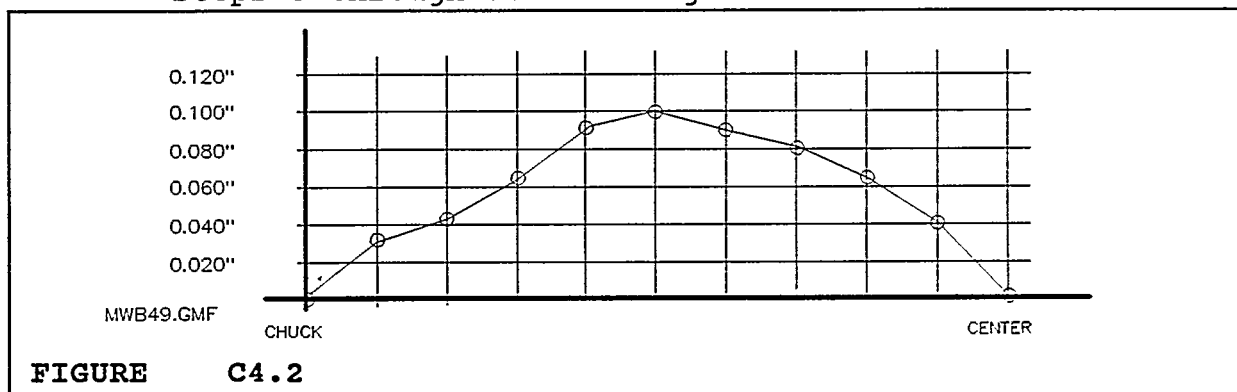
Flame bending can be used very successfully for precision straightening of tubing. The method used should match the amount of straightening required. Several examples are given for tubes of various lengths, diameters and wall thicknesses. See Figure C4.1.



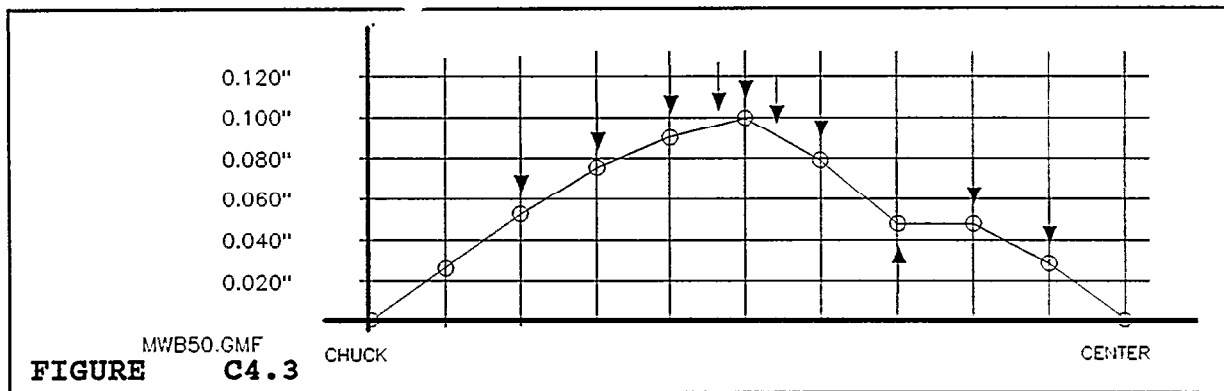
General Procedure.

Step 1. Measure the Bend. The first step (as with all flame bending) is to find out how far the part is out of tolerance. To do this, the tube must be supported at both ends and must be unsupported in the middle. In this way, the tube can be rotated and a dial indicator can be used to measure the bend at various points along the length. Before taking measurements, adjust both ends so that the total indicator runout (TIR) at the ends is as close to zero as practical. After the ends are zeroed, take TIR readings every foot or $L/10$ whichever is more measurements.

Step 2. Plot the TIR readings versus distance from one end. If the TIR readings are not within tolerance continue with steps 3 through 7. See Figure 4.2.



Step 3. Determine the Location and Size of Heats. Using a straight edge and the latest plot made in step 2, compare the curvature of each increment of the sleeve. The size of the heat should be based on the severity of the bend, and whether the bend is gradual or concentrated in one area of the tube. For example, if a tube has a maximum runout of .100" and the plot shows a kink in one area, then a line heat predicted to give .080" correction should be used. If the tube had .100" maximum runout but in a gradual bend, then 8 spot heats giving an average of .010" correction per spot should be dispersed to match the bend of each increment. Straight increments indicated on the plot should not be heated at all. The heats should be located on the bowed out side of the tube, (the side with the maximum indicator reading). Sometimes increments with a bend in the reverse direction will show up on the plot. As shown below, these increments should be heated on the opposite side. See Figure C4.3.



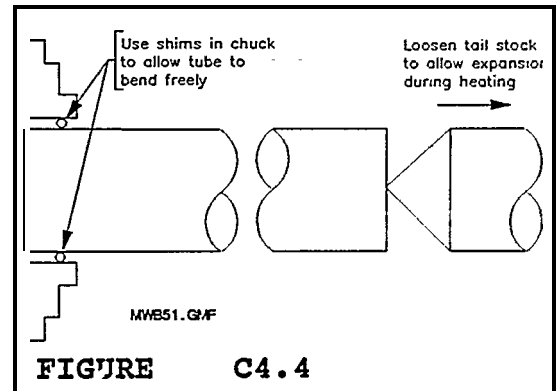
Heat size in order of increasing movement:

spot heated for a short time,
 spot heated longer time,
 short line less than 1/2 the tube circumference,
 longer line less than 1/2 the tube circumference,
 NOTE longer line more than 1/2 the tube circumference,
 NOTE shorter line more than 1/2 the tube circumference,
 narrow vee using Holt method
 wider vee using Holt method

It is best to compare the configuration and required movement with known movement achieved by a prior job. If no comparisons are available, it is recommended to use the method which will give the most conservative results and adjust later or simulate the job using a test piece prior to attempting the production job.

Step 4. Mark the areas to be heated. Mark the heat locations on the plot. The mark should indicate the size of the heat and the side heated. Mark the locations to be heated on the tube. Remember always heat the bowed out side.

Step 5. Check for Freedom of Movement. The part should be free to grow in length and bend while heated. Restriction will interfere with predicted movement. If the tube is in a lathe the tailstock should be loosened enough to allow for expansion and contraction of length during heating and cooling. Never use a chuck and a center on the same end since this will resist bending. It is best to use round stock as shims between the chuck jaws and the tube to allow the tube to pivot freely on the shims when bending. See Figure C4.4.



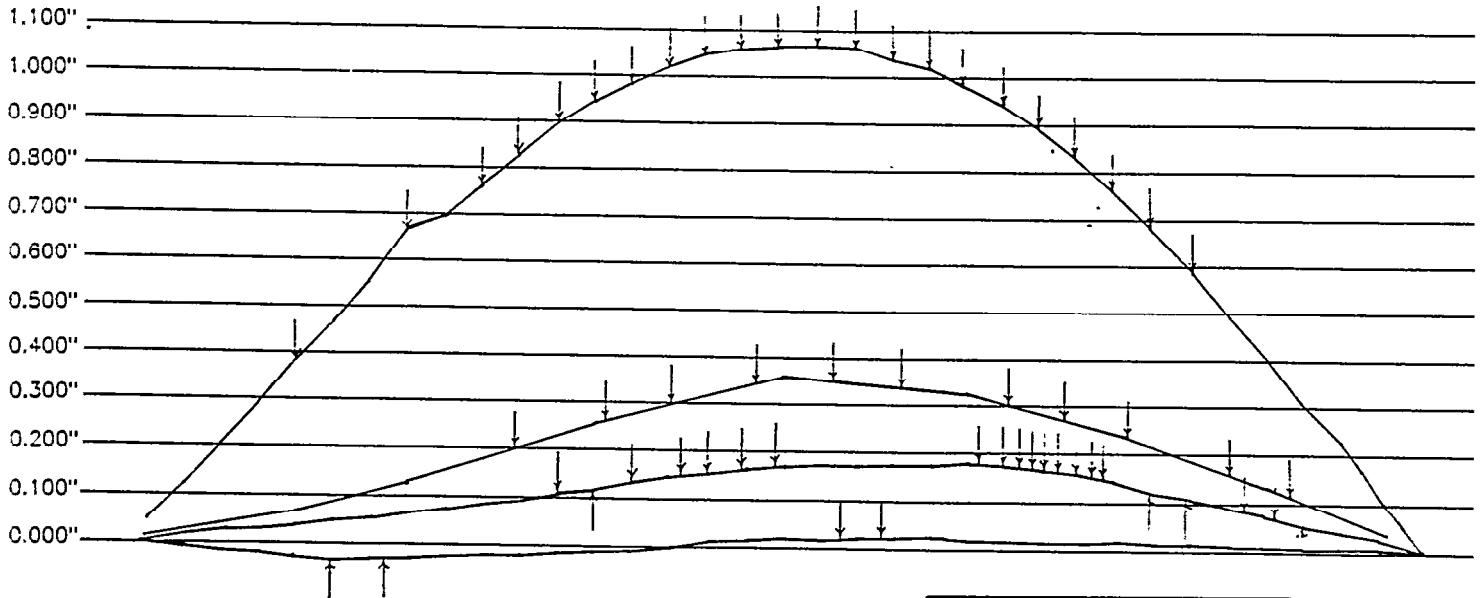
Step 6. Calibrate the flame. Using a test block of similar material type and thickness as the tube, adjust the flame as necessary to heat the block to a predetermined temperature in a predetermined amount of time. For example 200°F in 10 seconds. Apply the hottest point of the flame to one side and measure the temperature on the other side directly opposite the flame. If the temperature is reached too slowly or too fast, adjust the flame. Cool the test block to ambient temperature between torch adjustments. Calibrating the flame is important since an accurate prediction of the movement is possible only if each heat is consistent.

Step 7. Heat each Location. Heat each location using a flame calibrated in step 6. For spot heats, each heat should be timed as predetermined in step 3. Spot heats should never be less than two spot diameters from a previously heated spot, see section 4. After heating, continue again with step 1 and 2.

FLAME BENDING FOR ACCURACY CONTROL

Results.

Here are four examples of tubes of various sizes and bows showing how they were heated and how they responded.



Example 1.

Stainless Steel Tube

Length: 40 feet

Diameter: 6 inches

Wall Thickness: 1/2"

Total Indicator Runnout: 1.062"

Heating Method: Spot heats

Flame Calibration: 200°F in 10 seconds

Heating Time per Spot: 20 seconds for first two sets, 10 seconds for the third heat, 7 seconds for the fourth heat

HEAT No.	FLAME SETTING Time and Temp. as measured on back side of 1/2" thick 300 series stainless plate	TIME SPOT (sec)
1	700°F at 25 sec.	20
2	700°F at 25 sec.	20
3	200°F at 10 sec.	10
4	200°F at 10 sec.	7

Example 2.

Stainless Steel Tube
Length: 20 feet
Diameter: 9 inches
Wall Thickness: 3/4"
Total Indicator Runnout: 0.062"
Heating Method: Spot heats
Flame Calibration: 200°F in 15 seconds

Example 3.

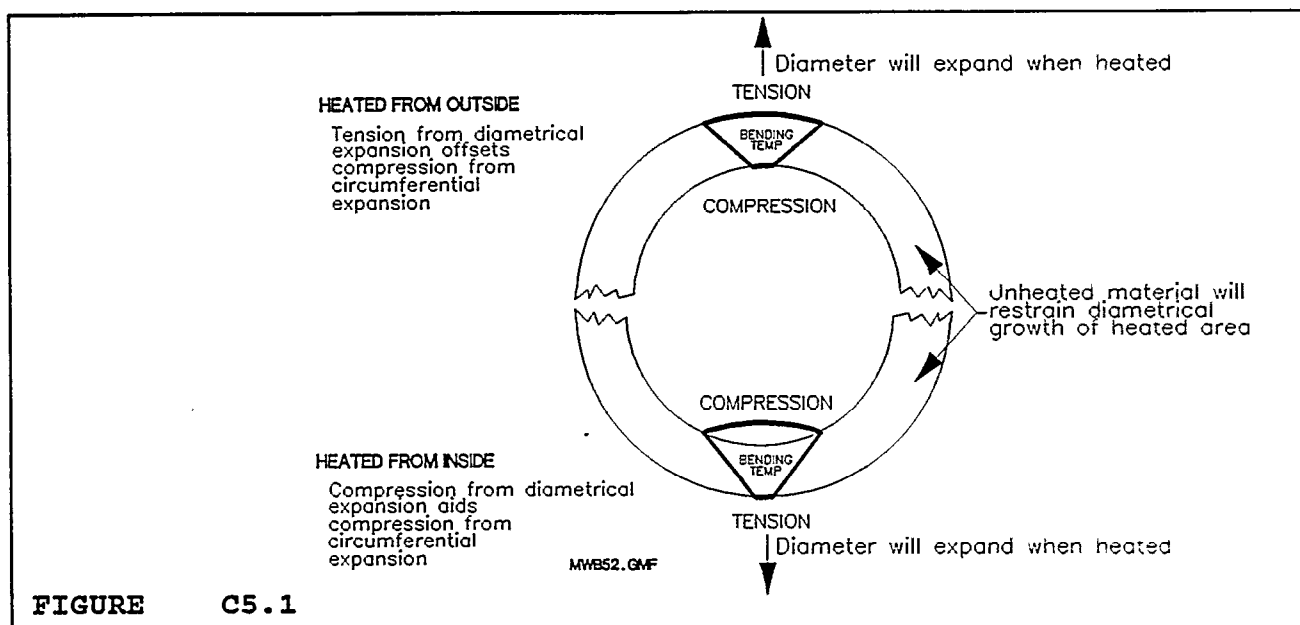
Stainless Steel Tube.
Length: 14 feet
Diameter: 4 inches
Wall Thickness: 1/4"
Total Indicator Runnout: 0.062"
Heating Method: Spot heats
Flame Calibration: 600°F in 10 seconds

Example 4.

Stainless Steel Screw Press Bearing Journal
Length: 18 feet
Diameter: 6 inches
Wall Thickness: 1/2"
Total Indicator Runnout: 0.062"
Heating Method: Line heats then spot heats

Case History # 5: Line Heats to True-Up Out-of-Round Stainless Tubes

Flame bending has also been very successful for correcting an out-of-round condition. This condition can only be corrected by heating from the inside. When heated from either side, the pipe wall will expand outward in the area heated but will be restrained by the surrounding unheated pipe which wants to remain at the original size. See Figure C5.1.



Because of this restraint during heating, the inside surface is in compression and the outside surface is in tension regardless of whether heated from the inside or from the outside. Since the upsetting (plastic flow) occurs when the heated area is compressed against the surrounding material, a heat from the inside will work to increase compression loading; whereas, a heat from the outside will work against the desired compression loading and tend to increase tension loading on the tube inside diameter.

An example of this is a tube which was counterbored four inches into the tube on one end so a vee-packing seal would fit. Since the counterbore was out-of-round, the vee-packing wouldn't seal. The heat size needed to correct the condition was determined by completing tests on a pipe of similar size. It was determined that the proper amount of correction could be obtained using line heats, a #6 tip and traveling as fast as possible while melting a 500°F temperature crayon mark on the outside surface.

FLAME BENDING FOR ACCURACY CONTROL

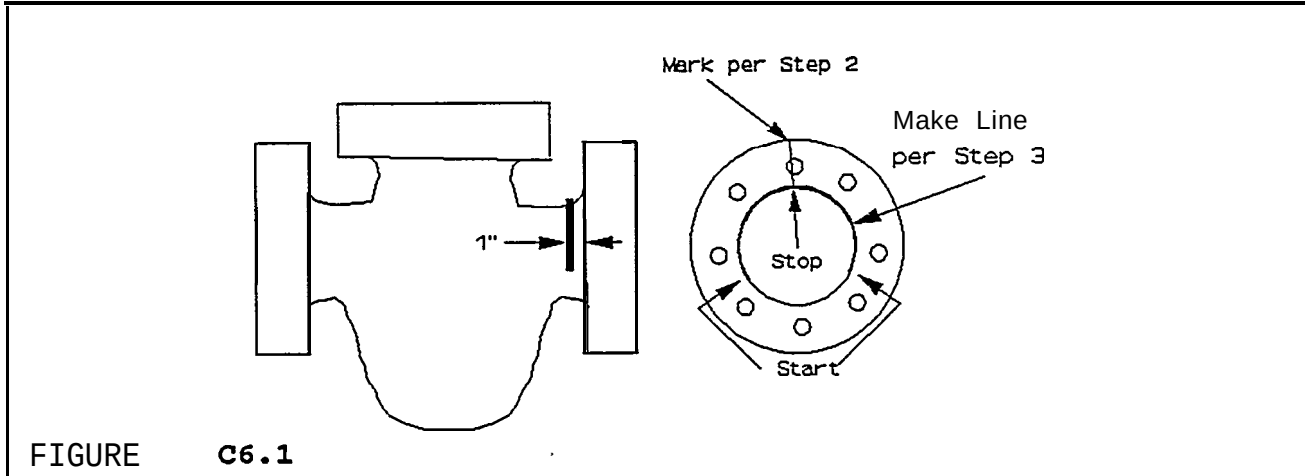
	Measurements at Tube End			Measurements 4" into Tube		
	Before Heating	After 1st Heat	After 2nd Heat	Before Heating	After 1st Heat	After 2nd Heat
0°	13.947	13.972	13.978	13.966	14.006	14.012
15°	13.969	13.995		13.974	14.012	
30°	13.993	14.003		14.002	14.015	14.015
45°	14.009	14.005	14.002	14.014	14.0095	14.008
90°	14.018	14.003		14.020	14.001	13.999
Out-Of-Round	0.071	0.033	0.024	0.054	0.014	0.016

After the first heat, the tube was well within tolerance 4" into the tube but was still out of tolerance at the tube end. (This is similar to the flare seen on the shaft sleeve of Case History #3). The second line heat extended only 2" into the tube. This short line concentrated the movement on the end and had very little affect on the dimensions 4" into the tube. The dimensions were within tolerance after the second heat.

In hindsight, the second line probably should have been done 180° from the first heat to avoid bulging only one side; however, it was thought that the grease fitting on the OD would interfere with the heating. Welding of the grease fitting may have been what caused the out-of-round condition in the first place. In which case, the first heat may best have been placed on the grease fitting side not 180° from it. There are often several ways to fix a part but only experience (a lot of trial and error) can prepare an operator to achieve the best results.

Case History # 6: Line Heats to Adjust Control Valve Flange Parallelism

Repair welding of the external surface of a low carbon steel control valve body caused the connecting flanges to distort out of parallel. To correct this condition, line heats were done on the flange neck. Location of the line heats were as shown in the following sketch. The wall thickness was about 5/8" in the area heated.



Procedure:

- Step 1. Measure the distance between flanges to determine the amount of out-of-parallel distortion and determine the exact location of minimum and maximum values. Record these starting values for reference.
- Step 2. Mark the side which needs to be pulled closer, (the side with the maximum value). If a line heat has already been made, make the mark on the flange neck opposite to the previous line heat. Subsequent marks might be rotated slightly or may be 180 degrees from the previous marks. See Figure C6.1.
- Step 3. Make a Line on the flange neck using a soapstone approximately 1" from the flange. The line length shall be approximately 2/3 of the flange neck circumference, and shall be centered on the mark made in step 2.
- Step 4. Heat using an oxy-fuel torch with a # 8 single orifice tip and a neutral flame. Start heating on one end of the line. After the spot under the flame becomes slightly red and grows to approximately the size of a nickel, begin moving the spot along the line at a rate which will maintain the spot width. Weaving is not allowed. Progress to the mark which indicates the center of the line and stop. Using the same technique, immediately heat the second half of the line starting at the second end and again stopping at the line center mark. After the part is below 600°F, cool to room temperature using forced air or wet rags.

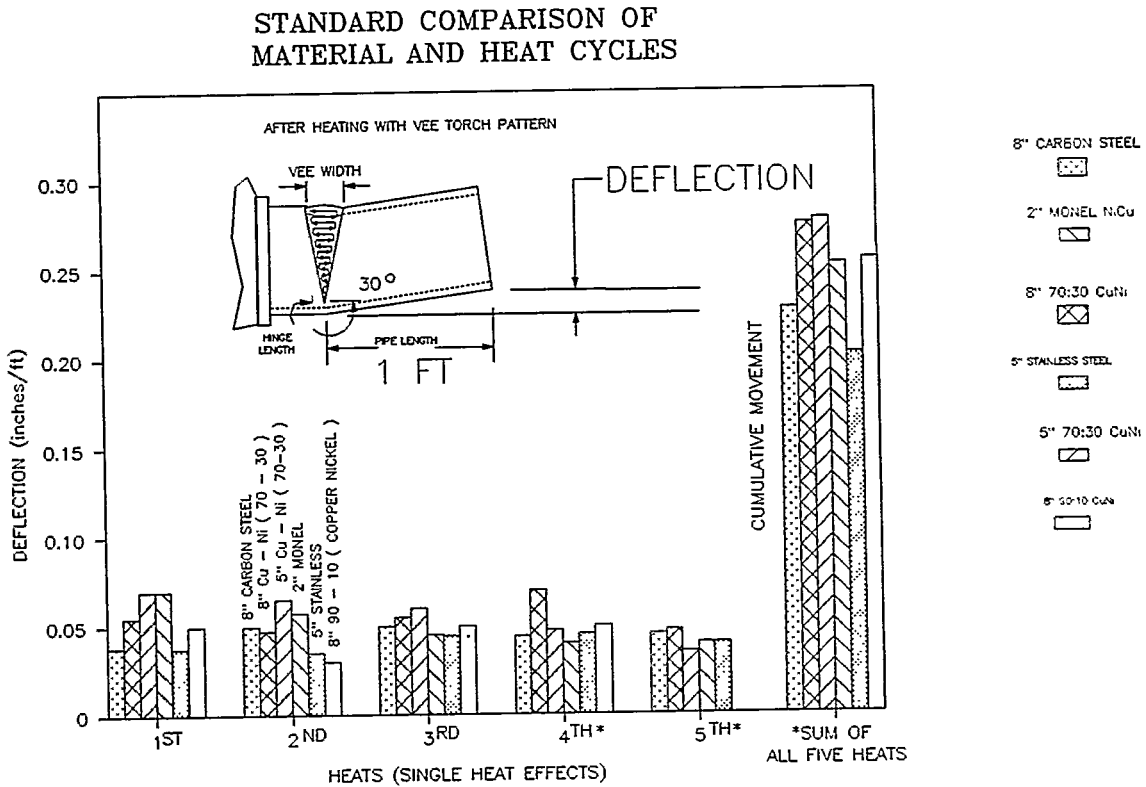
FLAME BENDING FOR ACCURACY CONTROL

- Step 5. Remeasure the distance between flanges to determine the change of parallelism. Record the minimum and maximum measurements with the corresponding number of line heats previous to the measurements. If the distortion is within allowable tolerances, then stop here. If the flanges are not within tolerance, continue with step
- Step 6. Adjust the line length After the first line heat, the length of the line may be shortened to one half the circumference minimum if less correction is needed. Continue with step 2 on the opposite flange from the one previously heated.

Results.

Clock Position of Measurement (see Sketch)	Distance Between Flanges	
	Before Heating	After Line Heat
12 o'clock	13.959"	13.946"
3 o'clock	13.949"	13.941"
6 o'clock	13.940"	13.946"
9 o'clock	13.951"	13.941"
Parallelism	0.019"	0.005"

APPENDIX D LABORATORY TEST RESULTS OF HEATS



DEFLECTION EFFECTS OF HEATING
THE SAME AREA FIVE (5) TIMES

* Heating one area more than
three (3) times is not
recommended due to buckling.

FILE: COMPARE6

LINE HEATS DOWN (TOWARD APEX)

90:10 CuNi

8" DIAMETER

