Repair of Metal Bellows

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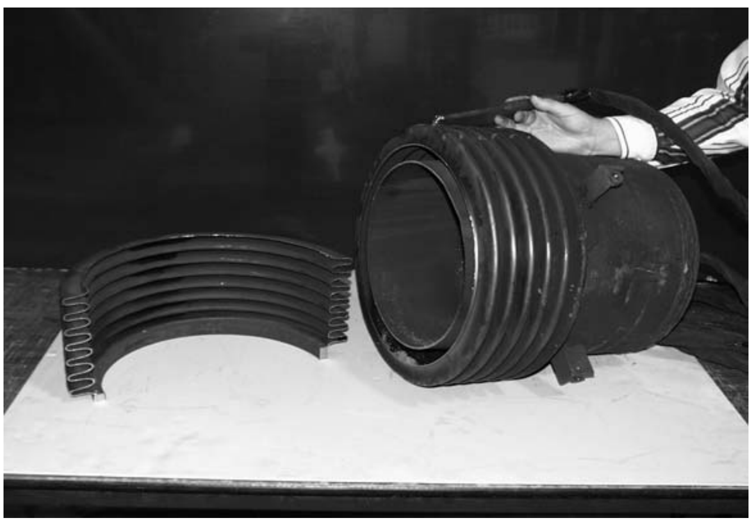

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Service Document, December 2000

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CITATIONS

This document was prepared by

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This document describes research sponsored by EPRI .

The publication is a corporate document that should be cited in the literature in the following manner:

Repair of Metal Bellows, EPRI, Charlotte, NC: 2000. 1001215.

REPORT SUMMARY

Background

Bellows expansion joints provide a flexible pressure retaining connection designed to absorb motion in a system caused by thermal expansion and low levels of vibration. In service, bellows can fail due to a variety of mechanisms such as fatigue cracking, corrosion, excessive vibration, or improper installation. The need to be flexible causes the bellows to be fabricated from thin material, which is difficult to repair successfully. As a result damaged bellows are commonly replaced in lieu of performing repairs. Emergency replacements of damaged bellows can result in significant down time and cost. The large cost associated with bellows replacements has generated an interest in developing in-situ repair techniques.

Objectives

To evaluate current repair technology, research applicable ASME code requirements, and identify design issues that could influence the ability to repair damaged bellows.

To develop and demonstrate temporary repair techniques that can be used to repair localized cracking and eliminate the need to perform costly emergency bellows replacements.

Approach

In response to the growing interest in bellows repair, the RRAC embarked on a two-year project to address the issue. The focus of the 2000 initiative was to research and evaluate current repair technology and to gain a clear understanding of the design sensitivities that might influence the repair of damaged bellows. The knowledge gained from the research and the expertise of the RRAC staff was then combined to develop in-situ weld repair techniques and procedures. The objective of 2001 efforts is to evaluate the effectiveness of the repair technique by performing fatigue tests. Results of these tests will be used to estimate the life of the repair and determine the relative performance of various filler materials and other variables associated with the repair technique.

Results

This interim report highlights the results of research and development efforts conducted by the RRAC in 2000. Included are discussions relating to bellows design, types, sensitivities, material types, manufacturing methods, service life, damage mechanisms, current repair options offered by manufacturers, previous repair development efforts by ASME, and new repair development activities conducted by RRAC. Development activities were aimed at developing optimum welding techniques, parameters and procedures. These development activities need to be followed up with fatigue testing in 2001 to evaluate the performance of the repairs under cyclic loading and to determine the overall effectiveness of the repair technique.

EPRI Perspective

As power plants age, potential equipment failure that can lead to unplanned outages and millions of dollars in lost revenue, is becoming an increasingly important utility issue. To address this need RRAC is continually searching for methods to eliminate and/or minimize unscheduled outages. Bellows expansion joints are a common source of problems in nuclear power plants, which often leads to unexpected outages. The RRAC has focused its resources on developing repair techniques that can be used to make temporary repairs on bellows with localized cracking and eliminate the need to perform some full-scale bellows replacements. The ability to perform such a repair can result in significant savings.

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Key Words

Maintenance

Repair

Bellows

EXECUTIVE SUMMARY

Bellows expansion joints are a common source of problems in nuclear power plants, which often lead to unexpected outages. Failures may occur without warning due to damage mechanisms such as fatigue cracking, corrosion, excessive vibration, and improper handling. In operation bellows are designed to absorb repeated deflection in piping systems due to thermal expansion, vibration and other sources of system motion. To absorb the motion bellows are designed to be flexible. The flexibility is achieved by forming relatively thin stock material into U-shape convolutions. Because the bellows are fabricated from such thin material it is difficult to perform structural repairs using conventional repair methods. As a result utilities are often faced with performing emergency bellows replacements, that lead to extended down time and large cost. Even though some bellows failures are catastrophic and unable to be repaired many others fail due to localized fatigue cracking or some other type of localized damaged, that could possibly be repaired if adequate techniques were available. To provide an alternative the RRAC has focused its resources on developing repair techniques that can be used to make temporary repairs on bellows with localized cracking in-lieu of performing some full-scale bellows replacements. The ability to perform such a repair could potentially save utilities a significant amount of money in lost revenue due to emergency replacements.

The first step in the development process was to perform a literature search to determine what had been done in the past with respect to bellows repair and to determine any design issues that could influence the ability to repair damaged bellows. This process turned up some previous test efforts published by ASME to determine effective repair methods and to evaluate those effects on the operation of bellows. The testing indicated that weld repair could be a viable temporary repair method under certain conditions. Unfortunately, no specific welding techniques or procedures were provided in the study. The results of these tests eventually lead to code case N-315, which outlines the conditions under which a weld repair can be performed. However, the code case is limiting in that it requires a full-scale mock-up of all repairs. In addition to researching the ASME testing efforts, bellows manufacturers were also contacted to gain their input. A summary of the manufacturer's recommendations and comments is provided in Appendix A.

Based on the knowledge gained through the ASME testing and discussions with manufacturers the RRAC set out to develop specific welding techniques and procedures. Testing and development activities were based on the careful consideration of several key factors such as welding process, repair accessibility, minimum repairable wall thickness, welding parameters, filler material, weld quality, welding technique and projected life of the repair. Repair welds were performed on a Type 304 stainless steel bellows removed from service due to cracking. GTAW was the welding process selected because it offered good controllability and accessibility when it was coupled with a micro TIG torch. Testing was focused on developing reliable welding techniques and procedures that could be used to repair crack like indications. Initially, problems were experienced with weld sugaring due to oxides and the absents of a back purge. This problem was solved by modifying the welding technique. The modified technique involved: grinding a 0.015-0.040" wide through wall slot along the entire length of a crack like indication, then applying a paste like fluxing agent, and finally welding where the slot had been inserted using a 0.040″ diameter filler material. The filler materials tested included Types 308L, 309L, stainless steel and Inconel 82 . Different filler materials were tested to evaluate their relative performance.

The welding technique produced a quality weld with good overall mechanical properties. Vickers Hardness measurements and tensile tests were performed to assess the mechanical properties of the test welds. Hardness profiles were performed on the Inconel 600 and the 308L test welds. Tensile tests were performed on repair welds made with the 308L SS, 309L SS and the Inconel 82 filler materials and on the original base metal. Results of the tensile testing were encouraging with respect to the original base material. All of the welds exceeded the design requirements specified for Type 304 stainless steel in Section II of ASME Boiler and Pressure Vessel Code with respect to yield and tensile strengths. Overall the welds executed with the 309L filler material perform best in terms of both strength and percent elongation.

In addition to the information summarized above this report also provides an overview of bellows types, materials, design considerations, and manufacturing methods.

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1 INTRODUCTION

Thermal expansion in piping systems is a major problem confronting designers. As metal temperatures in piping systems increase or decrease length varies due to thermal expansion or contraction. If the dimensional changes are not compensated for large forces will be transmitted through the system that could cause piping or other system failures to occur.

Thermal expansion and other dimensional changes in the piping system are generally controlled through the use of expansion joints. One of the most common types of expansion joints used in piping systems is the metal bellows expansion joint. These expansion joints are designed to accommodate axial, lateral, and/or angular motion and to serve as a primary pressure boundary. In carefully designed applications bellows will provide reliable performance. However, bellows are highly engineered components that are relatively fragile due to the need to be flexible. To obtain sufficient flexibility the bellows must be fabricated from thin material. Because of this bellows can be damaged easily and are difficult to repair. Determining how best to solve the problems associated with damaged expansion joints has become an area of growing concern. The current solution for solving expansion joint problems is replacement. The full-scale replacement of a bellows can be a time consuming process that could result in significant cost to the utilities. Consequently, plant personnel are becoming more interested in the possibility of repair.

In response to the growing interest in bellows repair, the RRAC embarked on a two-year project to address the issue. The focus of the 2000 initiative was to research and evaluate current repair technology and to gain a clear understanding of the design sensitivities that might influence the repair of damaged bellows. The knowledge gained from the research and the expertise of the RRAC staff was then combined to develop in-situ weld repair techniques and procedures. The objective of 2001 efforts is to evaluate the effectiveness of the repair technique by performing fatigue tests. Results of theses tests will be used to estimate the life of the repair and determine the relative performance of various filler materials and other variables associated with the repair technique.

2
BELLOWS DESIGN

2.1 General

The bellows element is designed to be strong enough to withstand the system pressure and flexible enough longitudinally to accept repeated deflections. Due to repeated deflections, bellows are subject to frequent bending stresses and these stresses must be kept to a minimum to prevent premature failure. To minimize the bending stresses in the bellows the convolutions are fabricated from thin stock material, which is flexible enough to accept repeated deflection. The bellows should be made as thin as possible but because it serves as a pressure boundary it must have sufficient thickness to withstand the induced stresses caused by the system pressure. This conflicting need for thickness for pressure and flexibility for deflection is a problem that requires careful design and compromise [1].

Bellows are not springs, in that most of their deflections produce bending stresses in excess of the materials yield strength. Because of this bellows are actually stretched each time they experience deflections in excess of the yield point and they do not return to their original shape. Because of this a bellows has a finite cycle life or number of deflections that it can withstand before it fails. The life is determined by the endurance limit of the material, which can be defined as the level of stress at which failure will occur at ten million cycles. Bellows are designed to withstand a required number of cycles. Most will fail as a result of circumferential cracking from cyclic fatigue. Occasionally, bellows will develop a fatigue crack prematurely after being subject to fewer cycles than the designed cycle life.

In carefully designed applications, bellows will provide reliable performance. However, problems arise when they are subjected to stresses that are outside of the design. Bellows are designed to withstand pure bending stress so the life of the bellows is determined by its ability to withstand a certain level of bending stress for a specified number of cycles. Bellows are very sensitive to torsion, vibration or any other dimensional changes that the bellows was not designed to withstand. These unwanted effects can, in some cases, affect the bending stress by the square or cube of their differences and cause the bellows to fail long before its designed cycle life. Bellows are also subject to premature failure due to defects or damage that cause excessive bending stress.

2.2 Terms and Definitions

The following section covers commonly used terminology that is associated with bellows expansion joints. This information was taken from the Fifth Edition of the EJMA standards [3].

Anchor Main. A main anchor is one, which must withstand the full bellows thrust due to pressure, flow, spring forces, etc.

Anchor, Directional. A directional or sliding anchor, is one which is designed to absorb loading in one direction while permitting motion in another. It may either be a main or intermediate anchor depending on the application involved. When designed for this purpose, a directional anchor may also function as a pipe alignment guide.

Anchor, Intermediate. An anchor that must withstand the bellows thrust due to flow, spring forces, etc. but not the trust due to pressure.

Bellows, Hydraulically Formed. Bellows made by applying hydraulic pressure internally to a tube, forming the convolutions within compressing dies.

Bellows, Mechanically Formed. Bellows formed on tubes by expanding and/or rotating tools for each consecutive convolution.

Bellows, Welded. A bellows made by alternately jointing the outer and inner edges of a series of flexible disk.

Bellows. The flexible element of an expansion joint consists of one or more convolutions and the end tangents, if any.

Control Rods. Devices, usually in the form of rods, attached to the expansion joint assembly whose primary function is to distribute movement. Control rods are not designed to restrain pressure thrust.

Convolution. The smallest flexible unit of a bellows. The total movement capacity of a bellows is proportional to the number of convolutions.

Cover. A device used to provide limited protection to the exterior surface of the bellows expansion joint from foreign objects or mechanical damage.

Cropped End. A flat circular surface similar to the side wall of a convolution, which has been trimmed at the crest.

Cycle Life. The estimated life of a bellows in terms of the number of movements it is capable of providing at a specific pressure and temperature at full stroke.

Double Expansion Joints. A double expansion joint consist two bellows jointed by a common connector, which is anchored to some rigid part on the installation by means of an anchor base. Each bellows act as a single expansion joint and absorbs the movement of the pipe section where it is installed independently of the other bellows.

Equalizing and Reinforcing Rings. Devices used on some expansion joints that fit snugly in the roots of the convolutions. The primary purpose of these devices is to reinforce the bellows against internal pressure. Equalizing rings are made from suitable alloys and are approximately “T” shaped in cross section.

Expansion Joints. Any device containing one or more bellows used to absorb dimensional changes such as those caused by thermal expansion or contraction of a pipeline, duct, or vessel.

Flanged Ends. The ends of an expansion joint equipped with flanges for the purpose of bolting the expansion joint to the matting flange of the adjacent equipment or piping.

Gimbal Expansion Joint. A gimbal expansion joint is designed to permit angular rotation in any plane by the use of two pairs of hinges fixed to a common floating gimbal ring. The Gimbal Ring, hinges and pins must be designed to restrain the trust of the expansion joint due to internal pressure and extraneous force, where applicable.

Hinged Expansion Joint. A hinged expansion joint contains one bellows and is designed to permit angular rotation in one plane only, by use of a pair of hinged pins attached to the expansion joint ends. Hinged expansion joints should be used in sets of two or three to function properly.

Internal Sleeves. A device which minimizes contact between the inner surface of the bellows and the fluid flowing through it. These devices have also been referred to as liners telescope sleeves, etc.

Internally Guided Expansion Joint. An internally guided expansion joint is designed to provide axial guiding within the expansion joint by incorporating a heavy internal guide sleeve, with or without the use of bearing rings. The use of such expansion joints will assure installation without initial lateral or angular misalignment and can be installed in pipelines where reverse flow will be encountered.

Limit Rods. Devices usually in the form of rods, attached to the expansion joint assembly whose primary function is to restrict the bellows movement range (axial, lateral, and angular) during normal operation. They are designed to prevent over extension or over compression of the bellows while restraining the full pressure loading and dynamic forces generated by a main anchor failure.

Multi-Ply Bellows. Multi-ply bellows are made by telescoping two or more close fitting tubes together before forming the convolutions. This permits a greater wall thickness while retaining a lower spring rate than a single wall tube. The result is a bellows with a higher pressure rating that maintains most of the flexibility of the thinner wall bellows.

Pantograph Linkages. A scissor like device. A special form of control rod attachment to the expansion joint assembly whose primary function is to positively distribute the movement equally between the two bellows of the universal expansion joint through its full range of motion.

Pipe Alignment Guide. A pipe alignment guide is a form of framework fastened to some rigid part of the installation, which permits the pipeline to move freely along the axis of the pipe. Pipe alignment guides are designed primarily for use in applications involving lateral deflection and angular rotation.

Pipe Section. A section is a portion of a pipeline between two anchors. All dimensional changes in a pipe section must be absorbed between these two anchors.

Pitch. The approximate free length per active convolution. Also the distance between the crest of two adjacent convolutions.

Planar Pipe Guide. A planar pipe guide is one, which permits transverse movement and/or bending of the pipeline in one plane. It is commonly used in applications involving lateral deflection or angular rotation resulting from “L” or “Z” piping configurations.

Pressure Balance Expansion Joints. A pressure balance expansion joint is designed to absorb axial movement and/or lateral deflection while restraining the pressure thrust by means of tie devices interconnecting the flow bellows with an opposed bellows also subject to line pressure. This type of expansion joint is normally used where no changes of direction occurs in a run of piping but can be designed as an inline device where no change of direction is necessary. The flow end of the pressure balanced expansion joint sometimes contains two bellows separated by a common connector, in which case it is called a universal pressure balance expansion joint.

Purge Connection. Purge connection, where required are usually installed at the sealed end of each sleeve of an expansion joint for the purpose of injecting a liquid or gas between the bellows and the internal sleeve to keep the area clear of corrosive and erosive media and/or solids that could pack the convolutions. Purging may be continuous, intermitting or just on start-up or shut down, as required.

Single Expansion Joints. The simplest form of expansion joint, of single bellows construction designed to absorb all the movement of the pipe section that it is installed.

Spring Rate. The spring rate of a bellows is equal to the spring rate per convolution divided by the number of active convolutions. Also the rate of deflection theoretically required to compress the bellows one-inch.

Squirm. A severe buckling or similar distortion of a bellows, produced by two much pressure inside a relatively long bellows.

Swinging Expansion Joint. A swinging expansion joint is designed to absorb lateral deflection and angular rotation in one plane. Pressure thrust and extraneous forces are restrained by the use of a pair of swinging bars, each of which is pinned to the expansion joint.

Tangents. The straight unconvoluted portions at the end of the bellows.

Tie Rods. Devices, usually in the form of rods or bars, attached to the expansion joint assembly whose primary function is to continuously restrain the full pressure thrust during normal operation while permitting only lateral deflection. Angular rotation can be accommodated only if two tie rods are used and located 90 degrees opposed to the direction of rotation.

Universal Expansion Joint. A universal expansion joint is one containing two bellows joined by a common connector for the purpose of absorbing any combination of three basic movements, i.e. axial movements, lateral deflections and angular rotation. Universal expansion joints are usually furnished with control rods to distribute the movement between the two bellows of the expansion joint and stabilize the common connector.

2.3 Design Considerations

Expansion joints are highly specialized products that are in some respects customized for each application based on service conditions. Because of this specialization there are a variety of design variables that must be considered in each application to determine their associated affect on the system and the operation of the bellows. If the influence of these factors are not properly assessed or communicated to the bellows manufacturer an improperly designed bellows will result, which could fail prematurely. The following design factors should be considered when selecting a bellows or determining the cause of a premature failure [3].

Size- The size of an expansion joint affects its ability to absorb certain types of movements, as well as its pressure-retaining capabilities.

Flowing Medium- The fluid that will come in contact with the expansion joint should be specified. In some cases due to excessive corrosion, erosion or fluid velocities special materials or accessories might be needed.

Pressure- Pressure is possibly the most important factor in determining expansion joint design. Minimum and maximum anticipated pressure should be accurately determined. If a pressure test is to be performed, this pressure should be specified as well. Care should also be taken not to apply unreasonable safety factors, which could result in a design that may not satisfy other performance characteristics.

Temperature- The operating temperature of the expansion joint will affect its pressure capacity, allowable stresses, cycle life, and material requirements. All possible temperature sources should be investigated when determining the minimum and maximum temperature requirements.

Motion- Movement due to temperature changes or mechanical motion that the expansion joint will be subjected to must be accurately determined and accounted for in the bellows design. Excessive movements outside of the range of the bellows will result in premature failure.

Spring Force- The spring force of a bellows is the force required to deflect the bellows joint one-inch. Spring force imparts a resisting force throughout the system. In order for an expansion joint to operate properly the spring force must be restrained by anchors. The magnitude of the spring force is determined by the expansion joints spring rate and by the amount of movement experienced by the bellows. The spring rate will also vary depending on the physical dimensions and material of the specific expansion joint.

Pressure Thrust Force- Pressure thrust force is a condition created by the installation of a flexible unit, such as an expansion joint, into a rigid piping system that is under pressure. Pressure thrust force is a function of the system pressure and mean diameter of the bellows. Mean diameter is determined by the height, or span of the bellows and can vary from unit to unit. Mean diameter is usually greater than the pipe diameter. In cases of internal or positive pressure, the convolutions are pushed apart causing the bellows to extend or increase in length while the opposite is observed in cases of external pressure or negative pressure. Larger pressure thrust forces can cause the expansion joint to over extent or compress and eventually fail. As a result pressure thrust forces must be properly restrained with anchors or accessories attached to the bellows to prevent premature failure. The magnitude of the pressure thrust can be determined using the following equations [3].

$$Fs = Pa$$

$$a = \frac{\pi (d_p)^2}{4}$$

Where: Fs = Pressure Thrust

P = Pressure

a = Effective area of bellows

d_p = Mean diameter

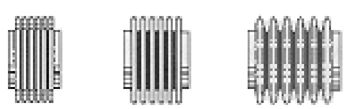
Vibration- Vibrations that cause repetitive deflections can cause premature failure of an expansion joint. Even though these deflections maybe small in magnitude they usually accumulate a significant number of cycles. Hints they are not suitable for vibration where the frequency is low and the amplitude is high, such as those resulting from reciprocating machines. Vibrations which are the result of pressure pulses can not be removed by the installation of an expansion joint, since the pressure pulses are transmitted through the fluid.

Squirm-Excessive internal pressure may cause a bellows to become unstable and squirm. Squirm can greatly reduce the fatigue life and pressure capacity of the bellows. The two most common forms of squirm are column squirm and in-plane squirm. Column squirm is defined as a gross lateral shift of the center section of the bellows and is analogous to a buckling column. In-plane squirm is a shift or rotation of the plane of one or more of the convolutions. It is characteristic by tilting or warping of one or more of the convolutions.

2.4 Types of Deflections

To understand the problems associated with expansion joints it is necessary to understand how they are designed to function and operate. The function of expansion joints that are most familiar to users is to accept the deflection that may result from thermal expansion or the movements and vibrations of equipment and structures. However, all expansion joints do not accept the same amount or type of deflection. It is necessary to determine what types of motions that the bellows will experience. Some of the more common types of movements are defined bellow [1].

2.4.1 Axial Deflection



Axial deflection refers to the compression or extension of the bellows in such a manner that the movement is parallel with the centerline of the expansion joint. Thermal expansion in a piping system usually causes the expansion joint to be compressed and piping systems operating at temperatures lower than ambient, will contract causing the expansion joint to stretch.

The axial movement per convolution resulting from an imposed axial movement can be expressed by the following equations for single and universal bellows elements [3].

$$e_x = \frac{x}{N} \quad \text{(For a Single Bellows)}$$

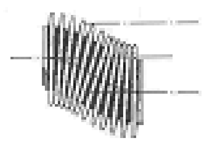
$$e_x = \frac{x}{2N} \quad \text{(For a Dual Bellows)}$$

Where: e_x = Axial movement per convolution.

x = Applied axial movement.

N = Number of convolutions in one bellows.

2.4.2 Lateral Deflection



Lateral deflection refers to motion perpendicular to the centerline of the expansion joint. It is also referred to as parallel offset and transverse deflection. This type of movement occurs with both ends of the expansion joint remaining parallel to each other. It is not uncommon to find different lateral deflections that occur in more than one plane. Because the bellows is round it is commonly resolved into one single lateral deflection, which is referred to as the rated lateral deflection. The magnitude of the resultant lateral deflection is the root sum of the individual deflections [1].

Lateral deflection results in unequal movement distribution over the bellows, the amount of displacement increases with the distance from the center of the expansion joint. When considering lateral deflection in an expansion joint the only concern is the maximum displacement per convolution. The following equations yield maximum lateral deflection where axial movement is in extension and compression [3].

$$e_y = \frac{K_u D_m y}{2N(L_u - L_b + x/2)} \quad \text{(where axial movement is extension)}$$

$$e_y = \frac{K_u D_m y}{2N(L_u - L_b - x/2)} \text{ (where axial movement is compression)}$$

Where:

e_y = Axial movement per convolution resulting from imposed lateral deflections.

L_u = Distance between outermost ends of the convolutions in a universal (in.) expansion joint.

L_b = Bellows convoluted length (in.)

k_u = Factor establishing the relationship between the equivalent axial displacement per convolution due to lateral deflection and the ratio $L_u/(2L_b)$.

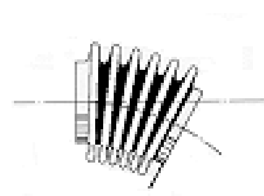
y = Applied lateral deflection (in.).

x = Applied axial movement.

D_m = Mean diameter of bellows convolution (in.).

N = Number of convolutions in one bellows.

2.4.3 Angular Deflection



Angular deflection is experienced when the expansion joint bends about it center, which is on the centerline and half way between the ends of the bellows. It can occur in any plane that passes through the centerline. If multiple deflections are experienced, the selection of the expansion joint is based on the maximum angular deflection rather than the resultant deflecting as is the case for lateral deflections. The axial movement per convolution resulting from pure angular rotation is represented by the following equation [3].

$$e_\theta = \frac{\theta D_m}{2N}$$

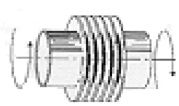
Where: $e_\theta =$ Axial movement per convolution resulting from angular rotation.

$\theta =$ Applied angular rotation per individual bellows (radians).

$D_m =$ Mean diameter of bellows convolution (in.).

$N =$ Number of convolutions in one bellows.

2.4.4 Torsional Deflection



Torsional deflections refer to the twisting of one end of the bellows with respect to the other end, about the centerline of the bellows. Expansion joints are not normally expected to accept torsional deflection because they are inflexible in this direction. Excess torsional deflection will severely damage the expansion joint [1].

2.4.5 Combined deflection

In most cases expansion joints experience, a combination of the different deflections described above. Each expansion joints should be analyzed and broken down into the various types of deflections to properly understand their associated effects.

The effects of combined movements resulting from lateral, angular and axial can be calculated using the following equations [3].

$$e_c = e_y + e_\theta + |e_x|$$

Where x is axial compression and y and θ occur in the same plane.

&

$$e_e = e_y + e_\theta - |e_x|$$

Where x is axial extension and y and θ occur in the same plane.

Note: when y and θ do not occur in the same plane, they must be added vectorially and combined with e_x to find the values of e_c and e_e .

All bellows are rated by the manufacture in terms of maximum allowable axial displacement per convolution, e_c and e_e . These values are established by the physical limitations of the bellows movement capability. The design of every expansion joint must be such that the total displacement per convolution from all sources does not exceed the rated values:

$$e_c(calculated) \le e_c(Rated) \le e_c(\max)$$

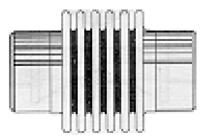
$$e_e(calculated) \le e_e(Rated) \le e_e(\max)$$

When bellows with equalizing rings are used, an additional calculation must be made to assure that there will be no interference between adjacent rings.

2.5 Bellows Types

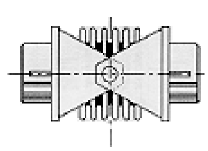
The primary function of bellows in a system is to provide flexibility. The flexibility can either be axial, lateral, or angular. In addition to being flexible, systems require that the bellows also be capable of withstanding the design temperatures, pressures, and media. There are a wide range of bellows designs to accommodate the various flexibility needs and other application specific requirements. In addition to the different designs there are also different features that are added to the expansion joints to limit the degrees of freedom, resistance to shear, tension or compression. These different features allow the bellows to be customized for the specific application. Some of the more common types of bellows expansion joints are discussed below [1].

2.5.1 Single Bellows



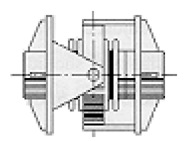
The single bellows expansion joint consists of a simple bellows with end connections. It will deflect in any direction or plane regardless of accessories, such as liners or covers. As a result pipe motion must be controlled. For example, if piping analysis showed that the expansion joint must accept axial compression then the piping must be guided and constrained so only that movement will occur. It is incapable of resisting the pressure thrust along its axis, which is the product of pressure times the cross sectional area of the bellows. Even large diameter units operating at low pressure can create significant pressure thrust loads due to their large area. Pressure thrust forces will over extent the bellows and cause failure.

2.5.2 Hinged Bellows



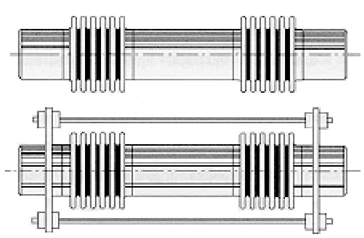
Hinged expansion joints contain a single bellows and a hinge, which allow the expansion joint to bend in a single plane. Normally these units are prevented from moving axial by their design either in extension or compression. These expansion joints are designed primarily to accept the full pressure thrust. Also, this type of expansion joint can accept, shear loads that result from the weight of adjacent piping, which would relieve the pipe designer from having to provide additional piping supports and anchors.

2.5.3 Gimbal Expansion Joints



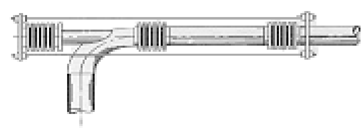
The gimbal expansion joint is very similar to the hinge type expansion joint, except that instead of being limited to deflection in only one plane, it can accept bending in any plane. It contains two sets of hinge pins or pivots and the axis of each set of hinges are perpendicular to the other. Each set of hinges is connected to each other with a central gimbal ring. The gimbal expansion joint is designed to accept pressure thrust and shear forces similar to hinged joints.

2.5.4 Universal Expansion Joints



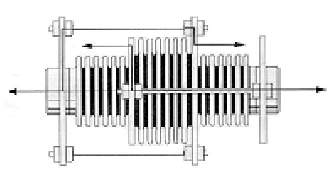
The universal expansion joint consists of two bellows separated by piping sections. The primary function of this configuration is to accept large amounts of lateral deflection. The amount of lateral deflection they can accept is a function of the amount of bending each bellows can absorb and the distance between the bellows. For a given bellows the amount of lateral deflection that can be absorbed can be increased or decreased by changing the length of the center pipe section between the bellows. Tie rods are used in these types of expansion joint to restrain unwanted movements such as pressure thrust loads. When only two tie rods are used 180 degrees apart the expansion joint is free to bend or deflect angularly, as well as laterally. With three or more tie rods the movement is limited to lateral deflections only. Without tie rods, the universal expansion joint is free to accept all types of deflections, which requires additional anchors and pipe supports to control the movement of the piping to avoid damaging the bellows.

2.5.5 Pressure Balanced Expansion Joints



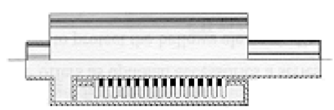
This type of expansion joint consists of a combination of simple bellows, which are tied together. The primary purpose of the pressure balance bellows is to retain or balance the pressure thrust so that the main anchoring of the pipe or adjacent equipment is not required. This type of expansion joint uses a balancing bellows and one of the other types of bellows discussed above, which is designed to accept the deflection experienced by the application. The most common configuration uses a universal bellows that is designed to accept lateral and axial movements in the system. In order to eliminate pipe supports or anchors there must be some means of balancing the pressure trust force. This is accomplished through the use of a balancing bellows. When used with a universal bellows the balancing bellows is tied to the pipe beyond the universal section with tie rods. The arrangement contains the pressure thrust force as tension in the tie rods. This allows the expansion joint in between the tie rods to move freely in the axial direction.

2.5.6 In-Line Pressure Balanced Expansion Joints



When axial deflections exist, and anchoring is impractical in-line pressure balanced expansion joints are commonly used. The function of this type of expansion joint is to balance the pressure thrust while allowing for axial deflections in the system that result from thermal expansion or other changes in the system. The axial pressure thrust is balanced by the pressure acting on a cross-sectional area equal to the area of the working or primary bellows. This is accomplishes using a primary and outer bellows. The primary bellows accepts the axial deflections and the outer bellows used to balance the internal pressure is placed around the outside of the primary bellows. Tie rods are also used in the unit to transfer and balance the pressure thrust created in the pipe on each end. The design of this unit eliminates unwanted forces and the remaining forces are only the result of the spring resistance of the bellows and main anchoring of the piping or vessel is eliminated.

2.5.7 Externally Pressurized Expansion Joints



Externally pressurized expansion joints are used when large amounts of axial deflection are experienced at relatively high pressures. Bellows that are internally pressurized are limited by the phenomenon referred to as squirm, which is caused by excessive deflections and high pressures. With this type of expansion joint the external surface is exposed to the media flowing through the pipe and as a result of this external pressurization problems with squirm are eliminated.

2.5.8 Accessories

The metallic bellows is by necessity very thin and is subject to being damaged easily. As a result manufacturers offer a variety of accessories designed to protect the bellows element. Some of the more common accessories are discussed below [1].

Internal liner

Internal liners are used to protect the convolutions from direct flow of the fluid, which can reduce the effects of erosion and flow-induced vibration. Bellows manufacturers recommend that internal liners be used when flow conditions exceed the following criteria.

- When flow velocities exceed the following values.

Air, Steam and other Gases

Up to 6-inch dia. – 4 ft/sec per inch of dia.

Over 6-inch dia. – 25 ft/sec .

Water and other liquids

Up to 6-inch dia. – 1-2/3 ft/sec per inch of dia.

Over 6-inch dia. – 10 ft/sec.

- When turbulent flow is generated within ten pipe diameters of the expansion joint.
- Where excessive erosion is experienced.
- For high temperature application to reduce the temperature of the bellows and help it retain its physical properties.

Internal liners are typically welded into the expansion joint and are made of the same material as the bellows.

Protective Covers

Protective covers are typically used to protect the bellows element from damage during installation and maintenance activities.

Purge Connector

A threaded purge connector is often used in systems where sediment can collect between the outside and inside of the internal liner and inside the bellows element. The connector allows gas to be injected periodically to blow out any sediment to prevent buildup.

Limit Rods

Limit rods are typically used to limit the unwanted motion in the bellows. They are also used to prevent the bellows from over extending in the event that an anchor should fail.

2.6 Bellows Materials

Bellows can be formed from a variety of ductile materials that can be welded by GTAW processes. Some of the more common bellows materials are included in Table 2-1.

Table 2-1
Common Bellows Materials [1]

Material Types	ASME Specification
304 SS	SA-240
304L SS	SA-240
316 SS	SA-240
316L SS	SA-240
321 SS	SA-240
Monel 400	SB-127
Inconel 600	SB-168
Inconel 625	SB-443
Incoloy 800/800H	SB-409
Incoloy 825	SB-409
Hastalloy C-276	SB-575

When selecting the bellows material consideration should be given to factors such as flowing medium, external environment and operating temperatures. Some of the more common environmental problems that affect material selection are erosion and corrosion. For example, 300 series stainless steels, which are the most common materials used in the fabrication of metal bellows, are subject to intergranular stress corrosion cracking (IGSCC). IGSCC of austenitic stainless steels can occur when the alloy is simultaneously subject to a tensile stress and a corrosive medium. The variables that effect IGSCC are temperature, environment, material composition, stress level, and microstructure. The cracking can either be transgranular or intergranular depending on the interaction of the variables. In most cases IGSCC is usually traceable to chloride ions in the internal or external environments of the stressed metal. Cracking due to this damage mechanism is usually unpredictable and progress very rapidly. One common method used to eliminate IGSCC is to select bellows materials that have a high nickel alloy such as inconel. Caution should also be exercised when selecting nickel alloy because they are sometimes subject to caustic induced stress corrosion. Final material selections should be based on the service conditions for the specific application.

2.7 Manufacturing Methods

There are several methods of manufacturing bellows, the two most common types are formed bellows and fabricated bellows. Of these two methods, forming is by far the most used method and formed bellows usually exhibit longer fatigue lives than fabricated bellows [4].

2.7.1 Formed Bellows

The process of forming a bellows begins with sheet metal that is rolled into a tube and jointed by a long autogenous seem weld. The tube blank is made long enough for subsequent axial collapse resulting from convolutions forming and a diameter approximately equal to that of a finished element. The tube blanks are then formed by expansion using hydrostatic pressure and/or mechanical force in local circumferential zones that will become the convolutes. Final forming of each convolute is accomplished by rolling the pre-formed tubes between rotating opposing dies whose spacing and degree of engagement can be varied until the desired convolute shape is achieved. Two-ply bellows are fabricated in the same shape fashion except that two tube blanks are fitted one inside the other. The spacing between the two plies is generally kept small to assure uniformity. An illustration of the forming process can be seen in Figure 2-1.

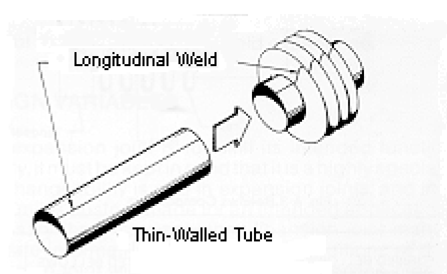


Figure 2-1
Formed Bellows [4]

It is important to note that the bellows experiences a significant amount of cold work due to the forming process. The effects of cold work on the bellows are considered to be ***beneficial*** in that it generally improves the fatigue life. As a result it is not normally considered beneficial to either stress relieve or anneal after forming. If special needs do arise that require heat treatment it is generally the responsibility of the purchaser to specify the requirements. Because of the benefits realized by cold forming the vast majority of bellows expansion joints are installed in the as formed state.

2.7.2 Fabricated Bellows

Fabricated bellows are made by welding together a series of thin gage diaphragms or discs. Generally, the bellows are made of heavier gage material than formed bellows and are therefore able to withstand higher pressures. However, they are less flexible and have a lower fatigue life. An illustration of this process can be seen in Figure 2-2.

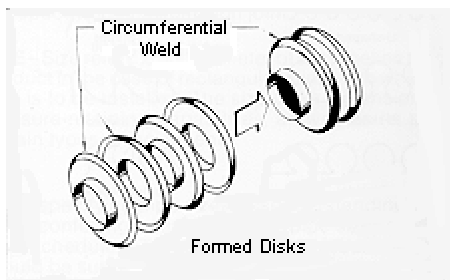


Figure 2-2
Fabricated Bellows [4]

2.8 Fatigue Life

Expansion joints experience numerous deflections during the life of the piping system. Most of the deflections occur as a result of changes in temperature, which occur each time the system is started and stopped and from predictable variations in the way the system is used. Repeated deflection also occurs as the result of mechanical movements and vibrations. Each deflection experienced by the expansion joint reduces its fatigue life. Fatigue life expectancy of an expansion joint is affected by various factors such as: operating pressure, material type, the movement per convolution, the thickness of the bellows, the convolution pitch, the depth and shape of the convolution and heat treatment. Any change in these factors will result in a change in the life of the expansion joint [3].

The Expansion Joint Manufacturers Association (EJMA), Inc. defines fatigue life as the total number of complete cycles, which can be expected from the expansion joint based on data tabulated from tests performed at room temperature under simulated operation. A cycle is defined as one complete movement from the initial position in the piping system to the operating position and back to the initial position. Fatigue life is dependent on the maximum stress range that is experienced by the bellows. The maximum stress amplitude is a far less significant factor. The equations for calculating the fatigue life of an expansion joint can be found in EJMA standards.

The major stresses in a bellows result from the effects of pressure and deflection. Normally, the deflection stresses are higher than the pressure stresses. The deflection stresses are generally above yield point of the bellows material and are meridional (longitudinal) in direction. Pressure produces circumferential (hoop) membrane stresses in the bellows. Bending stresses are also created by pressure to a lesser degree.

Variations in the system, which cause repetitive movements that were not accounted for in the original analysis can cause premature failure of expansion joints. Even if deflections are small in magnitude they usually accumulate a large number of cycles in a short period of time. Also, because the bellows are metallic components they have a specific resonance frequency and when driven by an outside vibration can magnify the incoming deflections until they exceed the yield strength of the bellows material, which can cause premature failures. Because of this any vibration by equipment such as fans, pumps or turbines should be accounted for in the design to ensure that the vibrations do not have the same resonant frequency.

3
BELLOWS REPAIR HISTORY

3.1 General

The replacement of critical bellows in confined areas can be extremely time consuming and costly to utilities. Some bellows replacements have been documented to take 1200 man hours to replace. Because of these lengthy replacement times many utilities are becoming interested in repair technology that would eliminate the need for complete bellows replacement.

The approaches taken in the past to repair damaged bellows, excluding complete replacement includes in-situ repair of the bellows element, installation of a new enveloping bellows, and partial replacement of the bellows element. Of these different repair techniques in-situ repair of the bellows element is the most desirable means of dealing with a damaged bellows. In-situ repair is more versatile and typically requires less down time than a complete replacement. Unfortunately, the process of repairing a bellows element in-situ is difficult at best due the thin wall thickness and lack of accessibility characteristic of these types of expansion joints.

The following text provides a detail discussion of the various failure mechanisms and repair method used in the past to address damaged bellows.

3.2 Typical Causes of Expansion Joint Failure

By necessity, the bellows is one of the thinnest and most fragile pressure-carrying components in the piping system. Because of this damage can result from improper handling, installation, or other careless practices. Bellows are also subject to deterioration from corrosion, erosion or a variety of other service related problems. Some of the most common causes of expansion joint failure are discussed below [1].

- *Improper Handling*- Bellows are frequently damaged from being struck by hard objects such as tools, chains, forklifts and other adjacent structures as a result of improper handling. Any denting or gouging of the bellows can severely affect the performance of the bellows and lead to premature failure. Weld splatter can also damage the thin bellows material.

- *Improper Installation*- A common error associated with bellows installation is moving the expansion joint to make up for misalignment. Any compression, extension, offset rotation and especially torsion, which has not been anticipated in the design, can substantially reduce the cycle life of the bellows. It should be emphasized that the piping should fit the bellows and not vice versa. Normally, a tolerance is provided, which indicates how much misalignment is permissible. Field installation tolerances vary somewhat from one manufacture to another but typical figures are ± 0.125 in. axial, ± 0.125 in. lateral and ± 1.0 degree angular. Another installation error that often occurs in bellows with internal liners is installing them in the wrong orientation with respect to the flow direction. If a bellows is installed in the wrong orientation then turbulent flow could result and cause unwanted vibrations or excessive erosion that could damage the bellows.

- *Improper Anchoring, Guiding, or Supporting*- Proper application of pipe restraints is essential to good bellows performance. Theses restraints allow movement only in directions intended by the designer. The design of pipe restraints must take into account the forces resulting from the bellows pressure thrust, any hydraulic thrust, the bending of the pipe segment and the spring rate of the bellows. Many designers often over look the effect of internal pressure and vacuum. A pipe under internal pressure or vacuum will have its wall subject to circumferential and longitudinal loading, which will transfer longitudinal pressure forces to the main anchor. If no main anchor is present, the bellows cannot withstand the pressure loading without ripping open or collapsing in case of a vacuum.

  If adequate main anchors cannot be provided to absorb the pressure thrust then the bellows should be equipped with tie rods. When a bellows is used primarily for axial movements a good rule of thumb is to locate the first guide no more than four pipe diameters away from the bellows and the second within thirteen diameter of the first. Most expansion joint manufacturers provide spacing requirement.

- *Anchor Failure*- If adjacent anchors do not function properly excessive pressure thrust forces will act on the bellows and cause it to fail.

- *Corrosion*- Corrosion is a problem that affects many aging bellows. It can affect the internal surface as well as the external surface of the bellows. The types of corrosion most frequently found in expansion joints are as followed: stress corrosion, which is evident by cracking, results because of stress and a corrosive environment;

intergranular cracking which is characterized by a preferential attack along the grain boundaries in metal; pitting which is a localized attack on metal; and general corrosion. Occurrences of all types of corrosion depend on the material type and service conditions. Bellows fabricated from 300 series stainless steels are particularly subject to stress corrosion cracking. High nickel alloys are also subject to stress corrosion cracking.

- *Erosion*- Erosion is a problem that affects bellows that are subjected to high flow velocities, fluid with abrasive media or turbulent flow. Over time the effect of erosion cause wall thinning, which eventually cause the bellows to fail. The effects of erosion can be reduced with the use of internal liners that protect the convolutions from direct flow of the fluid. Most bellows manufacturers recommend that internal liners be used when flow velocities exceed prescribed speeds. They also recommend them for high temperature applications.

- *Over Pressurization*- Expansion joint manufacturers rate their bellows in terms of maximum displacement per corrugation and maximum working pressure. These maximum pressure and deflection limits are critical in determining the bellows cycle life. Over pressurization in service or during a hydrotest will cause damage to the bellows that could result in a reduced cycle life or failure.

- *Excessive Bellows Deflection*- All bellows are designed to accept a specific amount of deflection. Any axial, lateral, or angular deflection that is in excess of the designed values will result in a reduced cycle life and premature failure. Extreme over deflection can cause catastrophic failure.

- *Vibration*- Excessive vibration in a system can lead to high cycle fatigue cracking and subsequent failure. Vibration is usually the result of system components or turbulent flow of the fluid. All system vibration should be monitored and minimized so that the bellows does not become damaged. In general very low amplitude vibration should not harm most expansion joints but high amplitude vibration will destroy a bellows.

- *Torsion*- Bellows are not designed to accept any amount of torsion. Twisting of the bellows must be prevented or the bellows will fail prematurely.

- *Fatigue*- Fatigue is one of the primary damage mechanisms that are responsible for expansion joint failure. Damage resulting from fatigue can be caused by excessive vibration, deflection or stress concentrations. The bellows susceptibility to fatigue is the main reason that they are designed with such a thin wall thickness. By nature bellows design is a compromise between the need to withstand pressure and the need to be flexible, which are two opposing needs. As a result there is a small thickness range that the bellows design must fall into to adequately satisfy both needs. Generally, the bellows designs have a larger safety factor with respect to pressure strength than they do with respect to flexibility because of safety precautions.

Premature fatigue damage can result from virtually any load or stress concentration outside of the allowable design values.

3.3 Repair History

Metal bellows expansion joints are very complex and fragile in their design, which make them difficult to repair. The difficulties involved with repairing bellows are in large part due to wall thickness and accessibility problems. The common wall thickness of bellows range from .020 to .060. Since most repairs require grinding and/or welding the thin wall thickness creates problems with burn-through and additional wall thinning. Because of burn through problems a highly skilled welder is needed to perform the repair. Accessibility problems occur when defects are located on the side wall of a corrugation or other areas on the bellows that do not have adequate space for a welding torch or grinder. Because of the various factors that influence a bellows repair, the ability to perform a successful repair is determined on a case by case basis. However, the ability to repair the element is only part of the solution. The next question that must be asked is how the repair will affects the operation and life of the bellows. Any weld deposit made on a bellows will create a stress riser that will adversely affect the life of the bellows but how much it will affect it is the factor that must be determined. Many of the bellows in operation have cycle lives that are significantly greater than the actual service life required by the application. Consequently, even though a repair reduces the cycle life of the bellows it still may provide adequate service life.

In the past there has been some efforts made by ASME to determine effective repair methods and to evaluate the effects of those repairs on the operation and function of bellows. A brief discussion of the testing performed by ASME is included in the following paragraphs [2].

3.3.1 Background

In 1983 ASME performed a series of four tests to determine the effectiveness of various weld repair techniques. The focus of these tests were to determine the feasibility of repairing bellows that were damaged by inadvertent mechanical abuse such as dents, gouges, arc strikes, holes, and localized cracking. The repair techniques that were explored included overlay patches, plugs, grooves, and contour grinding. The results of these tests eventually lead to code case N-315. A description of the tests and results are described below. An overview of the tests performed is provided in Table 3-1.

Table 3-1
Description of ASME Test Bellows [2]

Test No.	Size	Plies		Material	Pressure			Type of Defect								Type of Repair				
								Holes		Gouge	Cracks		Dents		Scratch					
		No. of Conv.	Thickness Of Ply		Int. Psi.	Ext. Psi.	Medium	Large (a)	Small (b)		Circ.	Long	Sharp	Smooth		Lap Patch	Plug	Groove	Blend	N/A
1	24 inch	4	.050 inch	Type 304	10 (e)	---	Air		3	3	3 3	3				3 3 3		3	3	
2	42 inch	5	.050 inch	Type 304	---	50 (e) (g)	Air	2 2								2	2			
3	25.75 inch	13	.024 inch	Type 304	---	16 (e)	Water							4						4
4	24 inch	4	.037 inch	Type 304	---	---	---						3	8	20					3 8 20

a) Approximately 1 inch (25.4 mm) in diameter.

b) Approximately 1/8- inch (3.2 mm) in diameter.

c) Cracks were represented by slots 1/32-inch (0.8 mm) wide by ½-inch (12.7 mm) long through the outer ply only.

d) Sharp dents had clearly defined, abrupt changes in direction of dent contour.

e) 10 PSI (68.9 kPa); 50 PSI (344.8 kPa); 16 PSI (110.3 kPa)

f) All patches were the same material and thickness as the bellows. Lap patches were fillet welded over defects.

g) Plug patches and groove welds were buffed flush with the outer surface.

h) Test No. 2 was preceded by hydrostatic test to 75 PSIG external pressure.

i) Blended repairs conformed to ASME Section III, Class MC rules. Depth of repair was .030-inch (0.08mm) maximum.

3.3.2 ASME Test 1

Description of Test

The first test involved a two-ply, 24 inch bellows with a wire mesh separator between the plies. There were twelve defects made through the outer-ply with repairs made by welded lay patches, groove welding, or blending. The testing conducted on the repaired areas was conducted in two phases.

In the first phase 12 defects were intentionally introduce into a bellows typical of those, which might be encountered in installed bellows assemblies. The 24-in. diameter bellows used in the testing had four convolutions, and a wall thickness of .050 in., which is typical of a bellows used in a containment vessel penetration. The defects that were introduced were repaired using one of the three methods listed bellow depending on the severity of the defect.

1. Welding patches of compatible material over the defect
2. By filling the grooves with weld metal
3. Contour grinding

The test assembly was then subject to a cyclic axial motion in two phases. All effects from torsional motion, misalignment or other types of unwanted conditions that commonly affect bellows were translated into axial motion. The first phase of the test subjected the repaired bellows to 7000 axial cycles with a stroke of .960 in., which was determined to be typical service requirements of a nuclear power plant containment bellows. The repaired defects evaluated in phase one consisted of those listed in Table 3-1.

Phase 2 of the test consisted of 7000 additional cycles with a stroke of 2.156 in., which was determined to be the normal maximum allowable movement for the bellows. In addition three other circumferential cracks were ground into the outer-ply of the bellows and were repaired by filling the grooves with weld metal prior to testing.

Results of Test

Results of phase one showed that 11 of the 12 defects exceeded the 7000 designed cycles for normal operation of a typical containment bellows. The one defect that did not reach the 7000 threshold failed at 6473 cycles.

Phase two of the test was designed to exceed normal service conditions and to compare the life of the repaired bellows to a similar undamaged bellows. The repaired bellows was subjected to more strenuous testing with significantly higher stresses than in phase 1. It was determined that 1 cycle in phase two was equal to 120 cycles in phase one. Each of the repairs was cycled until failure occurred and was compared to the average cycle life of an undamaged bellows. Results showed that the patch type repairs were expected to have about 4 percent of the cycle life of a bellows without defects. The groove repairs lasted about 10 times longer than the patch repairs and had about 40 percent of the cycle life of a bellows without defects. It was reported that the patch repairs failed in the welds used to attach the patch to the bellows and not in the original defect. As a result groove weld repairs were recommended over patch repairs when the defect size lends itself to this type of repair. It should also be noted that all of the gouges that were contour ground exceeded the cycle life of a normal bellows without defects.

Even though the repairs had an average cycle life that was only 4 percent of a bellows with out defects, 14 of the 15 defects exceeded the normal cycles experienced by a typical containment bellows because of over design.

3.3.2 ASME Test 2

Description of Test

In test 2, a one-ply, .050 inch thick, five-convolution, 42-in. diameter bellows was tested. In this test burn holes were made in four places 90 degrees apart on the first convolution wall. The bellows was then mounted in a mock-up repair fixture with the hole positioned in the actual position that would be experienced in the field. After the hole was repaired the fixture was rotated so that each of the holes were repaired in the same position and with same amount of access. Two of the holes were repaired with a lap type patch and the other two holes were repaired with plug type patch. Each hole was repaired using the GTAW process. The lap type patches were made from an identical bellows with the same thickness as the repaired bellows.

After the bellows was placed in the cyclic test fixture, an external hydrostatic pressure of 75 psig was applied for ten minutes to be sure the defects were properly sealed. Then 50 percent of the water pressure was replaced by air to allow for cyclic movement. The pressure was maintained at 50 psig. The repaired bellows was then cycled. The bellows was cycled at 1000-cycle intervals, the test was then halted with a pressure of 50 psig and was held for 15 minute to check for leaks. This interval was later reduced to 500-cycles between checks.

Results

Loss of pressure in the repaired bellows was first observed at 15,000 cycles when failure occurred in one of the lap type patches. Cycling was continued to 25,000 cycles while observing a continuous loss of pressure. There was no evidence of failure in the plug type patches. The calculated average fatigue life without damage was 17,180 cycles. The results of this test also indicated the superiority of plug type patch over lap type patch repairs.

3.3.4 ASME Test 3

Description of Test

In test three, a single-ply, .024 in. thick, thirteen convolution bellows fabricated with one longitudinal seam weld was tested. In the test actual damage that had occurred in the field was duplicated on the test bellows. The defects consisted of four dents in the end convolution side wall and one nick. The bellows was then tested as is without any type of repair. Testing consisted of two phases: the first for comparison with worst case plant condition displacements and number of cycles, and the second to simulate normal operational movement until failure occurred.

Phase one of the test consisted of 120 cycles of 4.147 inches of axial compression and 4.030 inches of axial extension, while the test bellows was subject to 16 psig external water pressure.

Phase two consisted of cycling the test bellows to failure at reduced axial movements of 2.47 inches of compression and 2.444 inches of extension.

Results

The test bellows failed at 4,975 cycles due to small cracks near the convolution crest at dent no. 4. The 4,975 cycles consist of the 2,272 cycles experienced during phase one at the longer movement and the 2,703 cycles experienced in phase two. Failure was determined by visual inspection.

3.3.5 ASME Test 4

Description of Test

Test four, was a single phase test conducted to failure. The test bellows, consisted of a single ply, 24-inch diameter bellows, made from 0.037-inch type 304 stainless steel. In this test a total of 31 defects consisting of dents, scratches, and gouges was inserted into the bellows to determine their affect on cycle life. The bellows was not pressurized during the cyclic test.

The bellows was then cycled at 0.75-inch compression and 0.125-inch extension. The axial movement for the bellows was arbitrary chosen and used approximately 70 percent of the rated compressive movement. Failure was determined by frequent dye-penetrant examination. The test bellows was subjected to 16,000 cycles.

Results

Of the 31 damaged areas three failed. Dent number 1 caused a pinhole leak after 9,170 and dents number 2 and three failed after 5,040 cycles. In comparison to an undamaged bellows, dent number one failed at 35 % and dents number two and three failed at 20.5 % of the average cycle life of an undamaged bellows. These results indicated that the prudent course of action taken after the discovery of damaged, is to evaluate the severity of damage, determined predicted average cycle life and to consider correcting the dented shape of the convolution. It is also important to note that 28 areas with less severe damage that did not fail. As a result it is important to assess the severity of the damage before any corrective action is taken to avoid creating more damage while trying to make unnecessary repairs.

3.3.6 Conclusions

The tests showed that weld repairs could be a viable option in some cases provided the damage is fairly localized. However, these test are fairly limiting in that they only addressed defects that are commonly associated with improper handling and not the more common service related problems. These tests also did not provide specific welding parameters that could be used to duplicate a weld repair. In addition, the N-315 code case that resulted from these tests requires a full-scale mockup of all repairs.

3.4 Alternative Repairs

Clamshell or enveloping bellows are one alternative to complete bellows replacement offer by several manufacturers. These bellows are designed to encase the damaged bellows and prevent it from leaking. Precaution must be exercised when using these bellows because they have a larger area than the original bellow, which will increase the pressure thrust. This increased load has the potential to create unsafe conditions if proper allowances have not been made in the adjacent anchors or supports. The oversize bellows is manufactured as one unit and cut in half longitudinally and the two halves are seam welded in the field. Typically, the clamshell bellows is mounted using standoff rings, which are welded to adjacent piping. The oversize clamshell bellows can be installed while the system is on-line, depending on operating conditions.

Some manufacturers also offer same size bellows, which are designed to replace the original bellows element. These types of bellows are installed in half sections like the oversize clamshell bellows. These bellows are attached to the same location as the old bellows and have the same area as the original bellows. As a result they do not create problems of increased pressure thrust. To install these bellows the unit must be shut down and the damage bellows element removed and the new same size bellows is installed in its place.

In some cases these oversized and same sized bellows offer an alternative to complete replacement or in-situ defect repair. They also have drawbacks as well and can not be used in many applications. The biggest problems that prevent enveloping bellows from being used is the lack of space. Because of their increased size they will not physically fit in to some areas. In addition these bellows require lengthy installation times and they will not last as long as a complete replacement due to the amount of field welding required to install them. They can not be used as a universal repair and do not eliminate the need for actual defect repair methods.

4
BELLOWS REPAIR DEVELOPMENT

4.1 General

The task of developing weld repair techniques to address damaged bellows presented many interesting challenges. Welding was targeted as the method of repair because it was felt that it provided the best means of making an effective structural repair that could withstand cyclic motion and pressure forces. Previous ASME testing, which is discussed in Section 3.3, showed some success with weld repairs and was used as a starting point for development activities. The complexities associated with bellows design cause them to be very susceptible to failure due to stress concentrations created by welding. Consequently, all weld repairs will reduce the fatigue life of the bellows. The degree of life reduction will vary widely depending on the quality and location of the weld repair.

The focus of this project was to develop temporary repair techniques that could be used to repair localized fatigue cracking or damage. Due to the requirements of Code Case N-315 Repair of Bellows, which requires a full-scale facsimile of a weld repair, it was felt that the RRAC should initially target non-code related bellows. The results of this work could then be extrapolated to code components with successful test results and code revisions. Development activities were based on careful consideration of several key factors such as: welding process, repair accessibility, material thickness, filler material, welding parameters, weld quality, and projected life of the repair.

4.2 Process Selection and Equipment

4.2.1 Process

Several key factors were used to determine, which welding process would be most suitable for this application. Accessibility, control, cost, the availability of trained personnel and equipment were all important in determining which welding process would be used. The most important factors were accessibility and control. The welder must be able to perform a detailed low profile weld in the root of a convolution. To accomplish this the welding torch must fit between the convolutions of a bellows and allow sufficient maneuverability to execute the weld. This requirement alone eliminated most welding processes. Both the GTAW and the PTAW processes provided the necessary control needed to weld the thin material, however none of the commercially available PTAW torches were small enough to physically fit between the closely spaced convolutions of the most commonly used bellows. Fortunately, this was not a problem with the commercially available GTAW torches. The torch used for the GTAW process is relatively inexpensive and readily available. GTAW was selected as the most feasible process for this application.

4.2.2 Welding Torch

The welding torch selected was the MT-125 water-cooled torch manufactured by Weldcraft and is the smallest commercially available torch presently available. A picture of the MT-125 can be seen in Figure 4-1. The torch enabled the welder to execute welds in the roots and on the side walls of convolutions on bellows with clearance as small as 0.560″ between adjacent convolutions. The MT-125 torch offers a 90°, 45°, and 180° nozzle and head arrangements, which allows for adequate maneuverability and access for out of position welds and in areas of transition. The torch body of the MT-125 is 0.312″ in diameter and nozzle sizes for the 90°, 45° and 180° arrangements are 0.430″, 0.703″, and 0.430″ respectively. The torch also features a clear glass or quartz nozzles, which increases visibility of the weld area. Each of the three different head arrangements were utilized during testing, depending on which area of the convolution was being repaired.

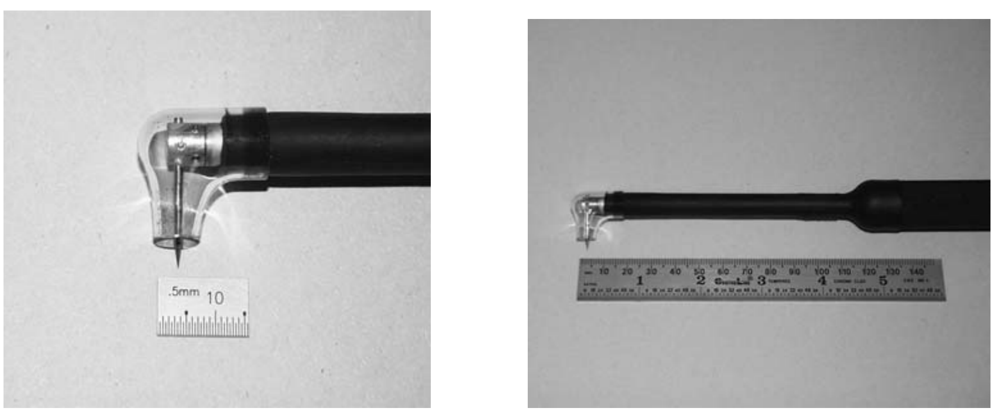


Figure 4-1
Weldcraft MT-125 Water-Cooled Torch

4.2.3 Power Supply

The power supply used in the development work was a Miller Aerowave 300. The capabilities of the power supply include the following:

<u>*Miller Aerowave 300*</u>

Volts: 30

Duty Cycle: 60%

Welding Amperage Range (DC): 1-375

Any GTAW power supply with the ability to weld in the 1-30 amperage range is sufficient for this application. The machine used in the testing exhibited pulsing capabilities, but this feature is not considered necessary for bellows repair. Repairs were performed with and without pulsing with no visible differences in the weld quality.

4.2.4 Grinding Equipment

Grinding equipment that will fit between the convolutions of the bellows is needed to clean and prepare the damaged area for welding. Development work was performed using a Dremel Tool with a small cut off grinding disc with a diameter of approximately 0.400″ and a thickness of 0.025″. Any small rotary tool with similar grinding disk would be sufficient.

4.2.5 Welder Skill

A welder must exhibit a good understanding of the welding equipment being used and have the ability to perform small intricate welds. It is recommended that the welder perform several practice welds on thin stock material of the same type and thickness as the bellows prior to performing the actual weld repair. Shim stock and thin walled tubing are excellent materials to use for equipment setup and practice welds.

4.2.6 Welding Parameters

The first step in developing an acceptable weld repair technique is to establish basic welding parameters. This was accomplished by performing a series of test welds on Type 304 stainless steel and Inconel 600 tubing, which are two commonly used types of bellows materials. Welds were performed on various thicknesses of tubing and shim stock equivalent to common bellows thicknesses. The parameters that were developed are listed in Table 4-1.

Table 4-1
Basic Welding Parameters for DC Straight Polarity Welding

Amperage Range:	Thickness	Amps
	0.015	8-12
	0.020	10-13
	0.030	12-18
	0.040	16-22
	0.050	18-24
Voltage Range:	8-15 volts	
Travel Speed:	3-4 in/min	
Tungsten Size:	0.040 in	
Argon Gas Flow:	8-10 scfh	
% Background current:	35 %	
Pulse per Second or Frequency:	80 Hz	
% On time Peak:	65 %	

4.3 Repair Technique Development

4.3.1 Test Bellows

Test welds were performed on a bellows that had been removed from service due to a crack in one of the convolutions. The specifications for the test bellows are provided in Table 4-2 and the chemical composition of the material is provide in Table 4-3.

Table 4-2
Specifications for Test Bellows

Nominal Diameter:	14 in
Design Pressure:	75 psig
Design Temperature:	390°F
Material:	Type 304 SS
Thickness of ply:	0.055 in
Convolution pitch (peak to peak):	1.00 in
Convolution Height:	1.300 in
Clearance Between Convolutions:*	0.560 in

*Note: This is the limiting dimension that determines the accessibility of the repair.

Table 4-3:
Chemical Composition for Type 304 Stainless Steel Test Bellows

Content	WT%
Carbon	0.073
Manganese	1.39
Phosphorus	0.026
Sulfur	0.022
Silicon	0.66
Nickel	8.65
Chromium	18.46
Molybdenum	0.20
Copper	0.30

Microharness measurements were also taken on a section of the test bellows to determine if significant variations were present in different regions of the convolutions due to forming and to establish a bases, which could be used to compare a weld repair. A cross section showing the average Vickers hardness measurements can be seen in Figure 4-2. These measurements indicated that the hardness through the convolution was consistent.

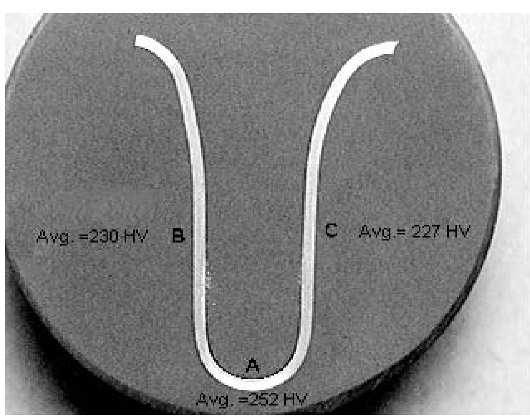


Figure 4-2
Cross section of Test Bellows convolution with Vickers Hardness

4.3.2 Testing Scope

The goal of the testing was to develop a reliable welding technique and procedure that could be used to repair cracks or other localized damage on the bellows. The factors that were considered in the development of the repair process include the following:

- Minimum repairable wall thickness
- Repair accessibility
- Filler material type & size
- Optimum welding technique

4.3.3 Minimum Repairable Wall Thickness

The first objective was to determine the limitations of the equipment by establishing the minimum repairable wall thickness. Test welds were performed on stainless steel and Inconel tubing and shim stock with thickness that ranged from 0.015-0.050″ thick. The welding parameters established in section 4.2.6 were used as a staring point and were adjusted as needed. The amperage range required for the various material thicknesses is provided in Table 4-1. Successful welds were completed on all material thicknesses without experiencing burn through. Material thicknesses below 0.025″ required significant welder skill to prevent burn through. Welds on materials 0.030 ″ thick and greater could be welded consistently with out burn through.

4.3.4 Repair Accessibility

The next factor evaluated was repair accessibility. This is important because much of the cracking that is experienced in bellows occurs in the roots of the convolutions, which make the cracks difficult to repair due to limited accessibility. Accessibility is dictated by the physical size of the torch. The total width of the MT-125 torch head used in the testing was approximately 0.520″ when allowing for tungsten stick-out. Slightly more room was required for the insertion of filler material and maneuverability. To determine the maximum amount of clearance required to perform an actual weld repair, two sections of the test bellows were section along the axial direction and then butted together and seam welded. The repair started on the crest of a convolution, progressed down the side wall, then up the adjacent side wall and concluded at the crest of the adjacent convolution. It was determined that the 0.056″convolution clearance was the minimum clearance that would allow weld repairs at the root of the convolution and particularly up the side wall of the convolution.

To perform the seam weld the straight or 180° torch head was used in the root area and the 90° torch head was used to weld up the side wall. Some minor modifications were also needed on the 90° nozzle configuration to improve clearance. The modifications consisted of grinding approximately 1/8″ off the face of the 90° glass nozzle. Additional test repairs were performed in the root, on the side wall and on the crest of convolutions. No accessibility problems were experienced with the modified torch.

4.3.5 Filler Material Type & Size

Welds were performed using several different sizes of Types 308L and 309L stainless steel, and Inconel 82 filler materials. It was quickly found that filler material size had a significant impact on the size and profile of the weld repair. Several tests confirmed that 0.040″ diameter wire yielded the best results. The 0.040″ wire produced a small uniform weld with a smooth even contour, while the larger size wires resulted in a large non-uniform weld. No visible difference in weld quality was observed between the stainless steel and Inconel filler materials. However, their relative performance should be determined based on the cycle life of the repaired area.

4.3.6 Optimum Welding Technique

After the physical limitations and requirements were established focus shifted to performing test repairs on simulated flaws. Two approaches were examined. The first assumed that the crack would be removed via grinding. This was simulated by inserting various length slots that were approximately 0.015-0.040″ wide into bellows convolutions as seen in Figure 4-3. The second repair scenario assumed that the welder would weld directly over the existing cracks. This was accomplished by butting two sections of the stainless steel test bellows together and welding along the joint. Improved weld quality was realized when welding where a slot had been inserted.

Many of the welds performed on the tight crack like joints experienced a lack of fusion on the opposing side of the weld. As a result, it was determined that it would be beneficial with respect to weld quality to remove the damaged material by grinding a slot along the full length of the crack rather than welding directly over the crack.

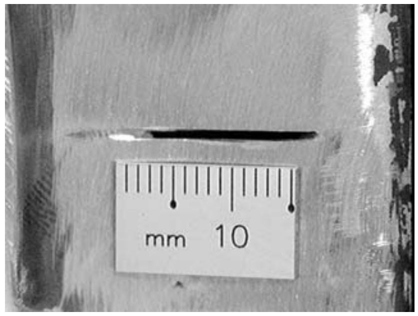


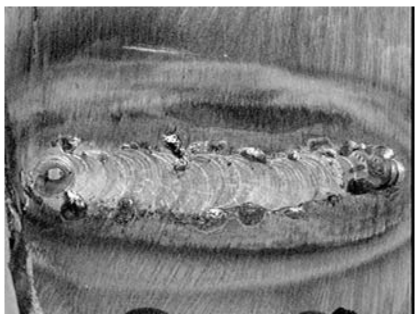
Figure 4-3
0.015-0.040″ Wide Slot

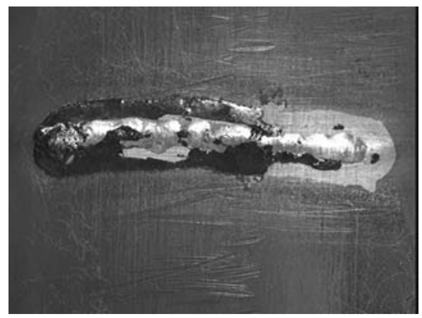
Back purging was not performed on any of the repair welds assuming that it would not be possible in field applications. The welds that were produced during the testing appeared very uniform on the surface of the weld; heavy sugaring was experienced on the opposing side of the weld on virtually every repair performed. Sugaring typically occurs when there is a lack of an inert atmosphere and a build up of oxides on the opposing side of the weld. An example of the sugaring experienced can be seen in Figure 4-4.

Figure 4-4
Weld Sugaring

To reduce the level of sugaring experimental welds were performed with two forms of fluxing agents. The two forms included flux cored wire and Solar Flux B (which is a powder that is mixed with alcohol and applied to the surface being welded). During the welding process the Solar Flux is consumed creating a chemical reaction that causes deoxidization to occur and provides an off gas that helps purge the weld. Solar Flux B material was applied to the outside surface of the defects in such a manner that it completely filled the open slot of the simulated defect. The flux cored wire was applied similar to other solid wire.

The Solar Flux B eliminated the problems experienced with sugaring on the opposing side of the weld as seen in Figure 4-5, when applied to simulated defects with a 0.015-0.040″ wide slot ground completely through the damaged area. However, it was not as effective, when it was applied directly over defects that exhibited a tight crack-like joint rather than the open slot. The flux was unable to penetrate the opposing side of the weld on defects with tight joints but it was able to penetrate on areas that had an open slot.





Weld Surface **Opposing side of Weld**

Figure 4-5
Weld Repair with Solar Flux B

The flux cored wire utilized also eliminated the problems experienced with sugaring, however the flux core wire being used was too large and resulted in a non-uniform weld, which will create a significant stress riser. Several vendors were contact in a effort to find some 0.040″ diameter flux core wire but none of them offered the product in a diameter that small.

The cross sections of welds made using the Solar Flux and the Inconel 82 and Type 308L stainless steel filler materials can be seen in Figures 4-6 and 4-7. Both of the filler materials produced very consistent microstructures that exhibited good penetration. The depth of penetration for the stainless steel and Inconel welds were 0.009″ and 0.008″ respectively. In addition each of the repair welds produced a very small heat affected zone. The width of the HAZ in the Inconel weld ranged from 50-200 microns and the HAZ of the stainless steel weld was almost undetectable.

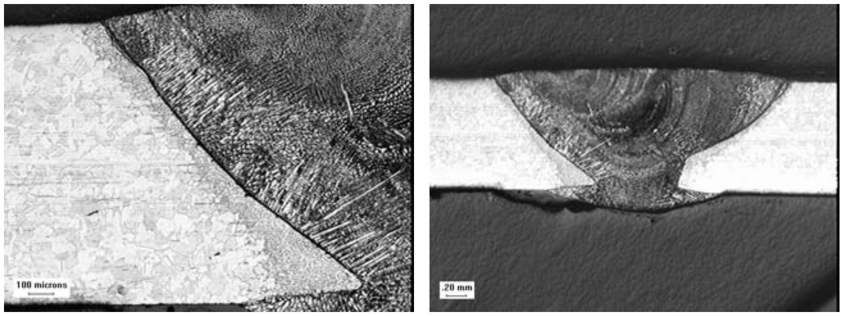


Figure 4-6
Repair Weld with Inco. 82 Filler Material

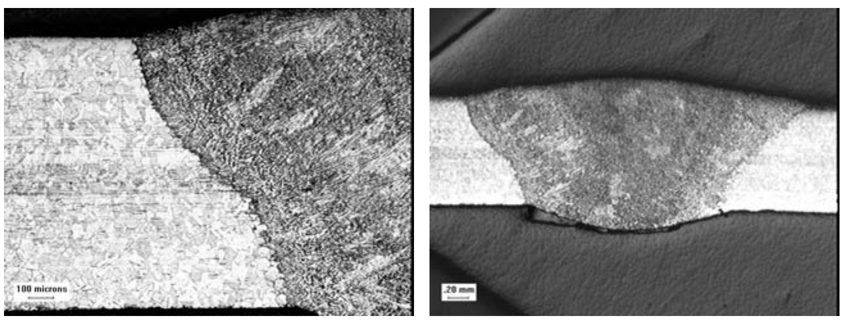


Figure 4-7
Repair Weld with 308 Stainless Steel Filler Material

4.3.7 Mechanical Testing

Vickers Hardness measurements and tensile tests were performed to assess the mechanical properties of the test welds. Hardness profiles were performed on the Inconel 600 and the 308L test welds. The profiles began in the base material and progressed through the HAZ and into the weld as seen in Figure 4-8. A summary of the hardness measurements is provided in Table 4-4.

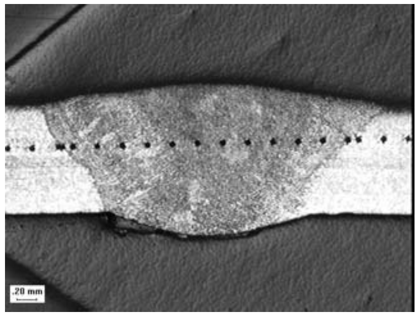


Figure 4-8
Hardness Profile

Table 4-4
Hardness Measurements

Inconel 82 Weld		308L Weld	
Vickers Hardness	**Location**	**Vickers Hardness**	**Location**
174	Base Metal	165	Base Metal
169	Base Metal	174	Base Metal
161	Base Metal	169	Base Metal
175	HAZ*	174	HAZ*
145	Weld Metal	179	Weld Metal
145	Weld Metal	161	Weld Metal
156	Weld Metal	165	Weld Metal
145	Weld Metal	179	Weld Metal
145	Weld Metal	174	Weld Metal
145	Weld Metal	165	Weld Metal
189	Weld Metal	174	Weld Metal
156	Weld Metal	169	Weld Metal
165	Weld Metal	165	Weld Metal
149	Weld Metal	174	Weld Metal
165	HAZ*	174	HAZ*
165	Base Metal	169	Base Metal
165	Base Metal	174	Base Metal
165	Base Metal	174	Base Metal

* Note: Each of the welds had a small HAZ region and it was only possible to take one hardness measurement in that region.

The average Vickers Hardness in the Inconel and stainless steel welds were 154 HV and 171 HV respectively and hardness measurements in the HAZ were 170 HV and 174 HV respectively. No hardness data was taken on the welds completed with the 309L filler material.

Tensile tests were performed on repair welds made with the 308L SS, 309L SS and the Inconel 82 filler materials and on the original base metal. Each of the weld repairs was executed using the welding technique discussed in the previous section. Two additional samples welded with the 309L filler material were heat treated and tested. The heat treatment was accomplished by heating each weld until it glowed orange in color using a hand held torch. The heat was removed immediately after the repaired area began to glow orange. This annealing process was performed to determine if it had any significant affects on the ductility or tensile strength of the weld and HAZ. In total ten tensile tests were performed, two for each filler material and two base metal tests. The result of these tests can be seen in Table 4-5.

Table 4-5
Summary of Tensile Test Data

Sample*	Yield Strength (PSI)	Tensile Strength (PSI)	% Elongation in 2”	Location Of Fracture
Base Material	78800	107100	30	Base Metal
Base Material	77300	110500	27	Base Metal
Base Material Average	**78050**	**108800**	**28.5**	
308L Weld Metal	46800	95300	17	HAZ
308L Weld Metal	61300	95800	18	HAZ
308L Weld Metal Average	**54050**	**95550**	**17.5**	
309L Weld Metal	58800	100800	17	HAZ
309L Weld Metal	69300	101700	19	HAZ
309L Weld Metal Average	**64090**	**101250**	**18**	
309L Weld Metal/ with heat treat	65200	104000	18	HAZ
309L Weld Metal/ with heat treat	58600	97000	15	HAZ
309L Weld Metal/ with heat treat Average	**61900**	**100500**	**16.5**	
Inconel 82 Weld Metal	52900	95500	15	HAZ
Inconel 82 Weld Metal	53100	90900	10	HAZ
Inconel 82 Weld Metal Average	**53000**	**93200**	**12.5**	

*Note: Two samples were tested for each filler material.

Results of the tensile testing were encouraging with respect to the original base material. All of the welds exceeded the design requirements specified for Type 304 stainless steel in Section II of ASME Boiler and Pressure Vessel Code with respect to yield and tensile strengths. Each of the test welds failed in the heat-affected zone of the weld as seen in Figure 4-9 and not in the weld. Overall the welds executed with the 309L filler material perform best in terms of both strength and percent elongation. Yield and tensile strengths of the 309L weld without heat treatment were within 82% and 93% of the base metal. The localized heat treatment performed on the 309L welds did not seem to provide any additional benefit. The percent elongation of the test welds ranged from 10-19% compared to the 30% elongation of the base material, which suggest a loss in ductility. The effects of this loss in ductility can not be accurately assessed until cyclic fatigue testing is performed. Testing did not indicate any significant problems that would suggest a modification of the repair technique.

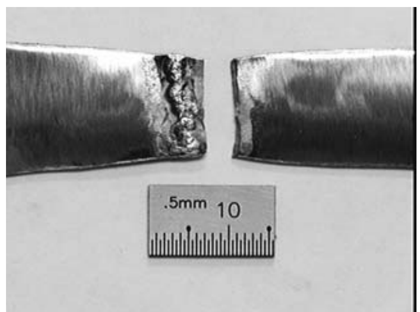


Figure 4-9
Typical Failure Location of Tensile Specimens

4.3.8 Conclusions/Recommendations

In 2000 the RRAC has focused on developing a reliable weld repair technique that will provide utilities with an alternative to performing some full-scale bellows replacements. The development effort has been successful in producing a practical repair technique that will consistently produce good quality welds with acceptable mechanical properties. The main issues considered in the development process included: welding process and equipment, welding parameters, repair accessibility, minimum repairable wall thickness, filler material and weld quality. The evaluation of these factors lead to the following conclusions:

- The GTAW process coupled with the MT-125 torch provides the necessary control and accessibility to perform critical welds between bellows convolutions.
- The amperage range required to perform successful welds on thin bellows materials will range between 8-24 amps depending on thickness.

- The minimum wall thickness that can be repaired comfortably with this process is approximately 0.030″.
- The minimum clearance needed between the bellows convolutions for adequate accessibility is 0.560″.
- 0.040″ is the optimum size filler material
- Welds performed with the 309L filler material produced better overall strength and ductility.
- Localized heat treatment of repair welds is not beneficial and may lead to sensitization of stainless steels.
- Solar Flux B prevents the occurrence of sugaring.
- Weld performed directly over tight crack like indications experience lack of fusion.
- Complete fusion and better overall weld quality is realized when a 0.015-0.040″ wide through wall slot is inserted along the full length of the crack or damaged area.

The conclusions outlined above only represent the development of the initial repair technique. The overall success of the technique will depend on the reliability and life of the repair. Phase two of the project and the task for 2001 is to evaluate its effectiveness. To accomplish this test repairs should be subject to a series of cyclic fatigue tests. These tests will provide an estimate of the expected life of a repair. If the results of these tests are favorable, Code modifications to address the limiting requirements of code case N-315 may also be warranted.

4.4 Recommended Repair Procedures

The following procedures should be used to perform weld repairs.

1. Assess the damaged area to determine its full extent. This can be done by performing a liquid penetrant examination.

2. Thoroughly clean the surface of the bellows around the damaged area making sure to remove all oxides and any other contaminates that might be present. This can be done with a small grinding tool that can fit between the convolutions.

3. Remove the damaged material in the cracked area. This should be done by grinding a small slot approximately 0.015-0.040″ wide completely through the full thickness of the bellows material along the full length of the crack.

4. Apply Solar Flux B to the outside surface of defects in such a manner that it completely fills the crevice or slot previously inserted in the material. The Solar Flux

B, which is initially in powder form, should be mixed with methyl alcohol to form a thin paste that can be spread with a small brush or swab. Do not mix the Solar flux with the alcohol until it is ready to be used it will dry quickly after mixing.

5. Allow the flux to dry completely. This will take approximately 5-8 minutes depending on the consistency of the paste.

6. Remove excess flux from the surface of the area to be welded with a clean dry cloth. This is done to increase the visibility of the slot. Care should be taken not to remove the flux in the slot. If any of the flux is removed or if it does not completely fill the slot it should be reapplied.

7. Obtain 0.040″ diameter filler material. The specific type of filler material to be used will depend on the results of the proposed fatigue testing.

8. Set the proper welding parameters, which are specified in Tables 4-1 and 4-4.

9. Perform several practice welds on thin stock material of the same type and thickness to obtain a proper feel for the welding conditions and to optimize weld settings. Execute repair weld when ready.

10. Once the repair is complete the weld should be ground smooth on the outside surface of the bellows if possible. This will reduce stress concentrations created by welding.

5
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2. Bressler, Merrick, O'Toole, and Reimus. Alternatives to Replacement of Damaged Expansion Joints. Pressure Vessel and Piping Technology, 1985.

3. Standards of the Expansion Joint Manufacturers Association, Inc. Seventh Edition 1998.

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APPENDIX A:

Manufacturers Recommendations and Comments on Bellows Repair

As part of the bellows repair project various bellows manufacturers were solicited to determine the various repair techniques that are available and their feasibility. Specific questions were asked about the feasibility of welding damaged bellows. The recommendations and comments of those companies contacted are summarized below.

Weld Repairs

General Comments

Due to the design and complexity of the bellows it is very difficult to perform a successful weld repair. The quality of the weld repair is directly related to the life of the bellows. Due to the conditions that are encountered during in-situ weld repair it is impossible to restore the bellows to it original integrity and any weld repair will act as a stress riser and reduce the cycle life of the bellows. The degree of life reduction will depend on the quality of the weld and the service conditions experienced by the bellows. As a result the overall quality and life of the repair will depend on the type and amount of damage experienced by the bellows. Because of these different factors the feasibility of a weld repair must be determined on a case by case bases.

Fatigue or Corrosion

It was recommend by the manufacturers that weld repairs should not be attempted on bellows that are damaged by corrosion or severe fatigue cracking. Generally, when a bellows starts to show signs of corrosion or fatigue damage in one area, the entire bellows is usually infected. As a result the repair of one isolated section of the bellows only serves as a temporary patch and will not in most cases provide a long-term solution to the problem. However, if fatigue damage is known to be isolated to one area it may be beneficial in some cases to perform a weld repair if the conditions are conducive to repair. Due to wall thinning it was discouraged by the manufacturers to attempt any type of weld repair on bellows damaged by corrosion. However, the overwhelming consensus of the manufactures was that weld repairs should not be attempted to repair fatigue or corrosion related problems.

Localized Defects

Localized cracks, scratches, dents, or holes can in some cases be successfully repaired through welding. The weld repair will not restore the original designed cycle life of the bellows but it can be view as a viable solution in some cases, which will extend the service life of the bellows and time before a complete replacement in necessary. However, manufacturers suggested that weld repairs only be attempted on non-critical, low-pressure applications.

Conditions that Influence Weld Repairs.

ASME code case N-315 provides rules for repair welding bellows. The factors outlined by the manufacturers that influence the success of a weld repair include the following:

Accessibility- There must be access to the back of the crack so that the area can be purged prior to welding. Due to the lack of access it is sometimes difficult to obtain an adequate purge on multi-ply bellows prior to welding. Another concern is access for the welding torch. For example, cracking in the root of a convolution of a bellows would be difficult to weld due to the limited amount of space between the convolutions. As a result this confined space could limit the welders ability to produce a sound weld.

Wall thickness- The need for flexibility requires the wall thickness of the bellows to be relatively thin, which complicates the welding process. The common wall thickness of bellows range from .020 to .060. However, the minimum wall thickness, recommended by the manufactures, that can be successfully welded is about .040. It may be possible for a highly skilled welder to weld on a thickness as thin as .030 but anything thinner would be very difficult to weld with out burn through. Another concern that applies to multi-ply bellows is the possibility of welding the different ply together, which will prevent the bellows from functioning properly.

Service conditions- Any weld metal applied to a bellows will introduce stress risers. The impact of the stress riser on the life of the bellows depends on the amount of vibration and movement that the bellows experiences during operation. As a result, a weld repair will last much longer on a bellows that only experience movement during start-up and shut down than it would in a system that experiences significant vibration or frequent movements.

Alternative Repairs

One alternative technique used to repair damaged bellows is to install *Clamshell* bellows. There are two basic types of clamshell bellows available. The first type is an oversize bellows, which is designed to fit over the existing bellows. This type of bellows is manufactured from a thicker walled material than standard bellows, which is cut in 180° sections to facilitate installation. The two halves of the bellows are then fitted around the existing bellows and seam welded together. The bellows are attached to the existing system using standoff rings. If conditions permit this type of bellows can be installed while the system is online.

The other type of clamshell bellows used is the same size bellows. This type of clamshell requires that the existing bellows be removed by grinding off the attachment welds. The factory made same size bellows is then installed in 180° sections and fitted to the attachment surface on the existing pipe. This type of bellows eliminates the need to cut the existing piping, which is required when replacing the entire expansion joint assembly. This type of clamshell bellows can not be installed while the system is online.

Clamshell bellows provide an alternative to replacing the entire expansion joint, however they only have approximately half the life of a standard bellows. This reduction in cycle life is due to the wall thickness of the bellows and the quality of the seam weld used to install the clamshell. Obviously, the in-situ seam welds will not be of the same quality as the bellows welded by machine in the factory. The seam welds cause stresses which reduce the life of the bellows. Also, to facilitate welding and prevent burn through the clamshell bellows are usually thicker than standard bellows, which causes the bellows to be stiff. As a result of this stiffness the clamshell will not perform as well in application that are subject to frequent movements or large amounts of vibration. Because of these characteristics of clamshell bellows they are more suitable for non-critical and low-pressure applications.

If expansion joints are low-pressure (less than 5 psig) breeching joints there are non-metallic expansion joints that are available, which clamp over the existing metal joint. This type of joint like the oversize clamshell bellows could be installed while the system is on-line.

The notes provide were obtain from discussion from the following manufacturers.

Company	**Contact**	**Phone #**
Pathway Senior Flexonics Inc.	Robert K. Broyles	1-800-882-6755
Expansion Joint Systems	Dick Miller	(619) 562-6083
American BOA.	Eric (?)	1-800-856-4580
Wahlco Engineering	Andrew Frohlich	(207) 784-2338 x 211

APPENDIX B

CASE

N-315

CASES OF ASME BOILER AND PRESSURE VESSEL CODE

Approval Date: February 14, 1983

See Numeric Index of expiration
and any reaffirmation dates.

Case N-315

Repair of Bellows

Section III, Division 1

Inquiry: Under what rules may repairs by welding be made on bellows elements for Section III, Division 1, Class 2, 3, and MC construction?

Reply: It is the opinion of the Committee that, for Section III, Division 1, class 2, 3, and MC construction, repairs by welding may be made on bellows elements by an N-Certified Holder, provided that:

(1) The size of the repair shall be limited to 4 sq in. for each repair.

(2) Prior to performing the repair to the bellows element, the repair shall be qualified on a full scale facsimile bellows by depositing weld metal as described below to simulate the production repair, particularly in terms of the actual welding parameters, the accessibility that will be seen in the production weld, and the material to be welded. The facsimile bellows weld repair shall be examined in accordance with (5), and shall be pneumatically or hydrostatically tested in accordance with the applicable requirements of NC/ND/NE-6000 in the presence of the ANI.

(3) The N-Certificate Holder shall prepare, or cause to be prepared, a revision to the Design Report listing tests and calculations that ensure that the repaired bellows meets the requirements of the Design Specifications. The effect of the repair on the design of the bellows (NC/ND-3649.4 and NE-3366.2) shall be evaluated by testing a facsimile bellows, or portion thereof, that has been repaired in accordance with this Case to the requirements of NE-3365.2(e)(2) or NC/ND-3649.4(e)(2), as appropriate, except that only one facsimile bellows is required to be tested. In determining Ks, the number of replicated tests shall be taken as 0. The revised Design Report shall be certified by the N-Certificate Holder and reviewed by the Owner, as required by NCA-3000.

(4) Following fatigue testing, prooftesting shall be demonstrated by a hydrostatic test of the facsimile bellows in accordance with the applicable requirements of NC/ND/NE-6000, in lieu of the rupture test required by NE-3365.2(e)(2) or NC/ND-3649.4(e)(2).

(5) Following completion of the fatigue and hydrostatic tests, the repaired areas shall be examined by the liquid penetrant or magnetic particle method, in accordance with NC/ND/NE-5000.

(6) Welders and welding procedures shall be qualified for groove welding, in

accordance with Section III, Division 1, and Section XI. Welding shall be performed using the GTAW process.

(7) Prior to making the repair on actual bellows the welder shall demonstrate on a prototype test assembly, under the conditions (including accessibility and position) that will be seen when making the production repair weld, the capability to make a weld repair acceptable to the ANI.

(8) Repairs shall be made by deposition of weld metal or by butt welding repair that does not alter the original design configuration.

(9) The root pass and final pass of the weld repair shall be examined by liquid penetrant or magnetic particle method, in accordance with the requirements of NC/ND/NE-5000.

(10) The completed repair shall be subjected to a hydrostatic or pneumatic test, in accordance with NC/ND/NE-6000.

(11) This Case number shall be identified in the Data Report for the component or system.

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