

Repair of Metal Bellows

Fatigue Testing



WARNING:
Please read the License Agreement
on the back cover before removing
the Wrapping Material.

Effective December 6, 2006, this report has been made publicly available in accordance with Section 734.3(b)(3) and published in accordance with Section 734.7 of the U.S. Export Administration Regulations. As a result of this publication, this report is subject to only copyright protection and does not require any license agreement from EPRI. This notice supersedes the export control restrictions and any proprietary licensed material notices embedded in the document prior to publication.

Technical Report

Repair of Metal Bellows

Fatigue Testing

1003288

Final Report, December 2002

EPRI Project Manager
A. Peterson

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

EPRI

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520, (800) 313-3774, press 2 or internally x5379, (925) 609-9169, (925) 609-1310 (fax).

Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc. EPRI. ELECTRIFY THE WORLD is a service mark of the Electric Power Research Institute, Inc.

Copyright © 2002 Electric Power Research Institute, Inc. All rights reserved.

CITATIONS

This report was prepared by

EPRI Repair and Replacement Applications Center
1300 W. T. Harris Blvd.
Charlotte, NC 28262

Principal Investigators

A. Peterson

G. Hudgins

This report describes research sponsored by EPRI.

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

Repair of Metal Bellows: Fatigue Testing, EPRI, Palo Alto, CA: 2002. 1003288.

REPORT SUMMARY

Thermal expansion and other dimensional changes in a plant's piping system are generally controlled by the use of expansion joints. One of the most common types of expansion joints used in piping systems is the metal bellows expansion joint. Due to the thin material used to gain needed flexibility in these joints, damage to the joint can occur easily.

Background

Bellows expansion joints provide a flexible pressure retaining connection designed to absorb motion caused by thermal expansion and low levels of vibration in a system. In service, bellows can fail due to a variety of mechanisms such as fatigue cracking, corrosion, excessive vibration, and improper installation. The need for flexibility requires that the bellows 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 downtime and cost. The large cost associated with the replacement of bellows 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 replacements of bellows

Approach

In response to the growing interest in bellows repair, the EPRI Repair and Replacement Applications Center (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 RRAC staff was then combined to develop *in situ* weld repair techniques and procedures. The objective of future efforts is to evaluate the effectiveness of the repair techniques by performing fatigue tests. Results of these tests will be used to estimate the life of the repair, to determine the relative performance of various filler materials, and to determine any variables associated with the repair technique.

Results

This report highlights the results of research and development efforts conducted by RRAC in 2000. Included in this report are discussions relating to bellows design, types of bellows, 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 further fatigue testing 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, which 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, and problems with them often lead to unexpected outages. 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 for utilities.

Keywords

Maintenance

Repair

Bellows

EXECUTIVE SUMMARY

Bellows expansion joints are a common source of problems in nuclear power plants and these problems often lead to unexpected outages. Failures can occur without warning, due to damage mechanisms such as fatigue cracking, corrosion, excessive vibration, and improper handling. When 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 this motion, bellows are designed to be flexible. This flexibility is achieved by forming relatively thin stock material into U-shaped 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, which can lead to extended downtime and large cost. Although some bellows failures are catastrophic and unrepairable, many others fail because of localized fatigue cracking or some other type of localized damage that could possibly be repaired if adequate techniques were available. To provide an alternative, the EPRI Repair and Replacement Applications Center (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 for RRAC in the process of developing a bellows repair technique 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 revealed some previous test efforts published by ASME to determine effective repair methods and to evaluate the effects of repairs on the operation of the 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 led to Code Case N-315, which outlines the conditions under which a weld repair can be performed. The Code Case is limiting, however, in that it requires a full-scale mockup of all repairs. In addition to researching the ASME testing efforts, bellows manufacturers were also contacted to obtain their input. A summary of the manufacturers' recommendations and comments is provided in Appendix A.

Based on the knowledge gained through the ASME testing and discussions with manufacturers, 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. Gas tungsten arc welding (GTAW) was the welding process selected because it offered good controllability and

accessibility when it was coupled with a micro GTAW torch. Testing 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 absence of a back purge. This problem was solved by modifying the welding technique. The modified technique involved grinding a 0.015-in.–0.040-in. (0.038-cm–0.102-cm) wide through-wall slot along the entire length of the crack-like indication, applying a paste-like fluxing agent, and welding where the slot had been inserted using a 0.040-in. (0.102-cm) diameter filler material. The filler materials tested included Types 308L stainless steel (SS), 309L SS, 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, with respect to yield and tensile strengths, specified for Type 304 stainless steel in Section II of the ASME Boiler and Pressure Vessel Code. Overall, the welds executed with the 309L filler material performed best in terms of both strength and percent elongation.

In addition to summarizing this RRAC research and development effort, this report also provides an overview of bellows types, materials, design considerations, and manufacturing methods.

CONTENTS

1 INTRODUCTION	1-1
2 BELLOWS DESIGN	2-1
2.1 General	2-1
2.2 Terms and Definitions	2-1
2.3 Design Considerations.....	2-5
2.4 Types of Deflections	2-7
2.4.1 Axial Deflection	2-7
2.4.2 Lateral Deflection	2-8
2.4.3 Angular Deflection.....	2-9
2.4.4 Torsional Deflection	2-9
2.4.5 Combined Deflection.....	2-10
2.5 Bellows Types.....	2-10
2.5.1 Single Bellows.....	2-11
2.5.2 Hinged Bellows	2-11
2.5.3 Gimbal Expansion Joints.....	2-12
2.5.4 Universal Expansion Joints.....	2-12
2.5.5 Pressure Balanced Expansion Joints.....	2-12
2.5.6 In-Line Pressure Balanced Expansion Joints.....	2-13
2.5.7 Externally Pressurized Expansion Joints	2-14
2.5.8 Accessories.....	2-14
2.5.8.1 Internal Liner	2-14
2.5.8.2 Protective Covers.....	2-15
2.5.8.3 Purge Connectors	2-15
2.5.8.4 Limit Rods	2-15
2.6 Bellows Materials.....	2-15
2.7 Manufacturing Methods	2-16
2.7.1 Formed Bellows	2-16

2.7.2	Fabricated Bellows.....	2-17
2.8	Fatigue Life	2-17
3	BELLOWS REPAIR HISTORY	3-1
3.1	General	3-1
3.2	Typical Causes of Expansion Joint Failure	3-1
3.3	Repair History	3-3
3.3.1	Background	3-4
3.3.2	ASME Test 1	3-6
3.3.2.1	Description of Test	3-6
3.3.2.2	Results of Test	3-6
3.3.3	ASME Test 2	3-7
3.3.3.1	Description of Test	3-7
3.3.3.2	Results	3-7
3.3.4	ASME Test 3	3-8
3.3.4.1	Description of Test	3-8
3.3.4.2	Results	3-8
3.3.5	ASME Test 4	3-8
3.3.5.1	Description of Test	3-8
3.3.5.2	Results	3-9
3.3.6	Conclusions.....	3-9
3.4	Alternative Repairs	3-9
4	BELLOWS REPAIR DEVELOPMENT	4-1
4.1	General	4-1
4.2	Process Selection and Equipment	4-1
4.2.1	Process	4-1
4.2.2	Welding Torch	4-2
4.2.3	Power Supply	4-2
4.2.4	Grinding Equipment	4-3
4.2.5	Welder Skill	4-3
4.2.6	Welding Parameters.....	4-3
4.3	Repair Technique Development	4-4
4.3.1	Test Bellows.....	4-4
4.3.2	Testing Scope	4-6

4.3.3	Minimum Repairable Wall Thickness	4-6
4.3.4	Repair Accessibility	4-6
4.3.5	Filler Material Type and Size.....	4-7
4.3.6	Optimum Welding Technique.....	4-7
4.3.7	Mechanical Testing	4-10
4.3.8	Conclusions/Recommendations.....	4-13
4.4	Recommended Repair Procedures.....	4-14
5	FATIGUE TESTING.....	5-1
5.1	PTAW and GTAW Repair Coupons.....	5-1
5.1.1	Coupon Description.....	5-1
5.2	Weld Parameters	5-2
5.3	Testing Method	5-2
5.4	Fatigue Test Results	5-3
5.5	Conclusions	5-11
6	REFERENCES	6-1
A	MANUFACTURERS' RECOMMENDATIONS AND COMMENTS ON BELLOWS REPAIR	A-1
A.1	Weld Repairs	A-1
A.1.1	General Comments	A-1
A.1.2	Fatigue or Corrosion	A-1
A.1.3	Localized Defects.....	A-2
A.2	Conditions That Influence Weld Repairs.....	A-2
A.3	Alternative Repairs	A-2
B	CASES OF ASME BOILER AND PRESSURE VESSEL CODE	B-1

LIST OF FIGURES

Figure 2-1 Axial Deflection	2-7
Figure 2-2 Lateral Deflection	2-8
Figure 2-3 Angular Deflection	2-9
Figure 2-4 Torsional Deflection	2-9
Figure 2-5 Single Bellows	2-11
Figure 2-6 Hinged Bellows	2-11
Figure 2-7 Gimbal Expansion Joint	2-12
Figure 2-8 Universal Expansion Joints	2-12
Figure 2-9 Pressure Balanced Expansion Joint	2-13
Figure 2-10 In-Line Pressure Balanced Expansion Joint	2-13
Figure 2-11 Externally Pressurized Expansion Joint	2-14
Figure 2-12 Formed Bellows	2-16
Figure 2-13 Fabricated Bellows	2-17
Figure 4-1 Weldcraft MT-125 Water-Cooled Torch	4-2
Figure 4-2 Cross-Section of Test Bellows Convolution with Vickers Hardness	4-5
Figure 4-3 0.015–0.040-in. (0.038–0.102-cm) Wide Slot	4-7
Figure 4-4 Weld Sugaring	4-8
Figure 4-5 Weld Repair with Solar Flux B	4-9
Figure 4-6 Repair Weld with Inconel 82 Filler Material	4-9
Figure 4-7 Repair Weld with 308 Stainless Steel Filler Material	4-10
Figure 4-8 Hardness Profile	4-10
Figure 4-9 Typical Failure Location of Tensile Specimens	4-13
Figure 5-1 Testing Sample	5-2
Figure 5-2 The Welded Coupons	5-3
Figure 5-3 GTAW Weld	5-6
Figure 5-4 High Heat Input PTAW Weld	5-6
Figure 5-5 Medium Heat Input PTAW Weld	5-7
Figure 5-6 Low Heat Input PTAW Weld	5-7
Figure 5-7 Hardness Plot of Failed Samples	5-8
Figure 5-8 Typical Failure Location After Cycling	5-8
Figure 5-9 Number of Cycles (GTAW Weld)	5-9
Figure 5-10 Number of Cycles (High Heat Input PTAW Weld)	5-9

Figure 5-11 Number of Cycles (Medium Heat Input PTAW Weld).....	5-10
Figure 5-12 Number of Cycles (Low Heat Input PTAW Weld).....	5-10

LIST OF TABLES

Table 2-1 Common Bellows Materials	2-15
Table 3-1 Description of ASME Test Bellows	3-5
Table 4-1 Basic Welding Parameters for DC Straight Polarity Welding.....	4-4
Table 4-2 Specifications for Test Bellows	4-4
Table 4-3 Chemical Composition for Type 304 Stainless Steel Test Bellows.....	4-5
Table 4-4 Hardness Measurements.....	4-11
Table 4-5 Summary of Tensile Test Data	4-12
Table 5-1 Total Number of Cycles to Failure	5-4

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 compensation is not made for these dimensional changes, large forces will be transmitted through the system and 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 as a result of their 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 to best solve the problems that are associated with damaged expansion joints has become an area of growing concern. Although the current solution for solving expansion joint problems is replacement, plant personnel are becoming more interested in the possibility of repair. The full-scale replacement of a bellows can be a time-consuming process that can result in significant cost to the utility.

In response to the growing interest in bellows repair, the EPRI Repair and Replacement Applications Center (RRAC) embarked on a two-year project to address the issue. In 2000, the project's 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 that research and the expertise of RRAC staff was then combined to develop *in situ* weld repair techniques and procedures. The objective of future efforts is to evaluate the effectiveness of the repair techniques by performing fatigue tests. Results of these tests will be used to estimate the life of the repair, to determine the relative performance of various filler materials, and to determine any other variables associated with the repair techniques.

2

BELLOWS DESIGN

2.1 General

The bellows element is designed to be strong enough to withstand system pressure and flexible enough longitudinally to accept repeated deflections. As the result of repeated deflections, bellows are subject to frequent bending stresses, which 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 that is flexible enough to accept repeated deflections. The bellows needs to be as thin as possible but, because it serves as a pressure boundary, it must also have sufficient thickness to withstand the induced stresses caused by 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 because most of their deflections produce bending stresses in excess of the material's 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. Consequently, 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, a bellows will develop a fatigue crack prematurely, after being subjected 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 occur and which they were 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 as a result of defects or other 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 Expansion Joint Manufacturers Association (EJMA) standards [2].

Bellows Design

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

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

Anchor, Main. A main anchor is one that must withstand the full bellows' thrust due to pressure, flow, spring forces, and so on.

Bellows, Hydraulically Formed. A hydraulically formed bellows is one that is made by applying hydraulic pressure internally to a tube, thus forming the convolutions within compressing dies.

Bellows, Mechanically Formed. A mechanically formed bellows is one that is formed on tubes by expanding and/or rotating tools for each consecutive convolution.

Bellows, Welded. A welded bellows is one that is made by alternately jointing the outer and inner edges of a series of flexible discs.

Bellows. A bellows is the flexible element of an expansion joint, which consists of one or more convolutions and end tangents, if applicable.

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

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

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

Cropped End. A cropped end is a flat circular surface, similar to the sidewall of a convolution, that has been trimmed at the crest.

Cycle Life. Cycle life is 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 consists of two bellows joined by a common connector, which is anchored to some rigid part on the installation by means of an anchor base. Each bellows acts 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. Equalizing and reinforcing rings are devices that are used on some expansion joints that fit snugly into 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. An expansion joint is any device that contains 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. Flanged ends are the ends of an expansion joint that is equipped with flanges. The flanged ends bolt the expansion joint to the mating 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 pair of hinges fixed to a common floating gimbal ring. The gimbal ring, hinges, and pins must be designed to restrain the thrust of the expansion joint, which occurs as a result of 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. An internal sleeve is a device that 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, and so on.

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 ensure installation without initial lateral or angular misalignment, and they can be installed in pipelines where reverse flow will be encountered.

Limit Rods. Limit rods are devices, usually in the form of rods, that are attached to the expansion joint assembly and 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 also 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 with a single wall tube. The result is a bellows with a higher pressure rating, which maintains most of the flexibility of the thinner-wall bellows.

Pantograph Linkages. Pantograph linkages form a scissor-like device, which is a special form of control rod attached to the expansion joint assembly. The primary function of the pantograph

Bellows Design

linkages is to positively distribute movement through full range of motion equally between the two bellows of the universal expansion joint.

Pipe Alignment Guide. A pipe alignment guide is a form of framework fastened to a 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. Pitch is the approximate free length per active convolution. This is also the distance between the crest of two adjacent convolutions.

Planar Pipe Guide. A planar pipe guide is one that 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 Balanced Expansion Joint. A pressure balanced expansion joint is designed to absorb axial movement and/or lateral deflection, while restraining pressure thrust by means of tie devices that connect the flow bellows to an opposed bellows, which is also subject to line pressure. This type of expansion joint is normally used where no changes of direction occur in a run of piping, but it can also 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 balanced expansion joint*.

Purge Connections. Purge connections, where required, are usually installed at the sealed end of each sleeve of an expansion joint. They are used to inject 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 can be continuous, intermittent, or just on startup or shutdown, as required.

Single Expansion Joints. The simplest form of expansion joint is a single expansion joint. It is a single bellows construction, designed to absorb all of the movement of the pipe section in which 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. It is also the rate of deflection that is theoretically required to compress a bellows one inch.

Squirm. Squirm is a severe buckling or similar distortion of a bellows, which is produced by too 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 tangents are straight unconvoluted portions at the end of the bellows.

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

Universal Expansion Joint. A universal expansion joint is one that contains two bellows joined by a common connector for the purpose of absorbing any combination of three basic movements (axial movements, lateral deflections, and angular rotation). Universal expansion joints are usually furnished with control rods that distribute 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 effect on the system and the operation of the bellows. If the influence of these factors is 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 [2].

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 be taken not to apply unreasonable safety factors, which could result in a design that might 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 that results from temperature changes or mechanical motion, and to which the expansion joint will be subjected, 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. 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 joint's 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. The opposite is observed in cases of external pressure or negative pressure. Larger pressure thrust forces can cause the expansion joint to over-extend 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 [2].

$$F_s = Pa$$

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

Where: F_s = 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 may be small in magnitude, they usually accumulate a significant number of cycles; hence, expansion joints are not suitable with vibration where the frequency is low and the amplitude is high, such as that resulting from reciprocating machines. Vibrations that result from pressure pulses cannot be removed by the installation of an expansion joint because the pressure pulses are transmitted through the fluid.

Squirm – Excessive internal pressure can 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 it 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 identifiable 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 most commonly known function of expansion joints is acceptance of the deflection that can 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 the types of motions that a bellows will experience. The following sections define some of the more common types of movements [1].

2.4.1 Axial Deflection

Axial deflection (Figure 2-1) 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. The piping systems, which operate at temperatures lower than ambient, will contract and cause the expansion joint to stretch.



Figure 2-1
Axial Deflection

The axial movement per convolution that results from an imposed axial movement can be expressed by the following equations for single and universal bellows elements [2].

$$e_x = \frac{x}{N} \quad (\text{for a single bellows})$$

$$e_x = \frac{x}{2N} \quad (\text{for a dual bellows})$$

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 (Figure 2-2) refers to motion perpendicular to the centerline of the expansion joint. It is also referred to as *parallel offset* and *transverse deflection*.



Figure 2-2
Lateral 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 occurring 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, and 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 [2].

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

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

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./cm) expansion joint

L_b = Bellows convoluted length (in./cm)

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./cm)

x = Applied axial movement

D_m = Mean diameter of a bellows convolution (in./cm)

N = Number of convolutions in one bellows

2.4.3 Angular Deflection

Angular deflection (Figure 2-3) is experienced when the expansion joint bends about its center, which is on the centerline and half way between the ends of the bellows.

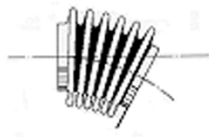


Figure 2-3
Angular Deflection

It can occur in any plane that passes through the centerline. If multiple deflections are experienced, selection of the expansion joint is based on the maximum angular deflection rather than on the resultant deflection, as is the case for lateral deflections. The axial movement per convolution resulting from pure angular rotation is represented by the following equation [2]:

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

Where: e_{θ} = Axial movement per convolution resulting from angular rotation

θ = Applied angular rotation per individual bellows (radians)

D_m = Mean diameter a bellows convolution (in.)

N = Number of convolutions in one bellows

2.4.4 Torsional Deflection

Torsional deflection (Figure 2-4) refers 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].

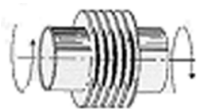


Figure 2-4
Torsional Deflection

2.4.5 Combined Deflection

In most cases, expansion joints experience a combination of the different deflections described. The deflections of each expansion joint should be analyzed and segregated into the various types of deflections to understand the associated effects of each one.

The effects of combined movements resulting from axial, lateral, and angular deflections can be calculated using the following equations [2].

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

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 manufacturer 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:

$$e_c(\text{calculated}) \leq e_c(\text{rated}) \leq e_c(\text{max})$$

$$e_e(\text{calculated}) \leq e_e(\text{rated}) \leq e_e(\text{max})$$

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

2.5 Bellows Types

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

2.5.1 Single Bellows

The single bellows expansion joint (Figure 2-5) 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 shows that the expansion joint must accept axial compression, then the piping must be guided and constrained so that only axial compression movement will occur. It is incapable of resisting the pressure thrust along its axis, which is the product of pressure multiplied by the cross-sectional area of the bellows. Even large diameter units operating at low pressure can create significant pressure thrust loads because of their large area. Pressure thrust forces will over-extend the bellows and cause failure.

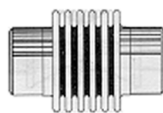


Figure 2-5
Single Bellows

2.5.2 Hinged Bellows

Hinged expansion joints (Figure 2-6) contain a single bellows and a hinge, which allow the expansion joint to bend in a single plane. The design of these units usually prevents them from moving axially by either extension or compression. These expansion joints are designed primarily to accept full pressure thrust. This type of expansion joint can also accept shear loads that result from the weight of adjacent piping, which relieves the pipe designer from having to provide additional piping supports and anchors.

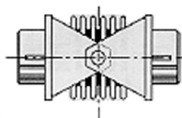


Figure 2-6
Hinged Bellows

2.5.3 Gimbal Expansion Joints

The gimbal expansion joint (Figure 2-7) is very similar to the hinge-type expansion joint, except that it can accept bending in any plane (instead of being limited to deflection in only one plane). It contains two sets of hinge pins or pivots, and the axis of each set of hinges is perpendicular to the other. The two sets of hinges are connected to each other with a central gimbal ring. Similar to hinged joints, the gimbal expansion joint is designed to accept pressure thrust and shear forces.

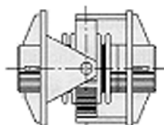


Figure 2-7
Gimbal Expansion Joint

2.5.4 Universal Expansion Joints

A universal expansion joint (Figure 2-8) 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 that it 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 this type of expansion joint to restrain unwanted movements, such as pressure thrust loads. When only two tie rods are used, 180° apart, the expansion joint is free to bend or deflect angularly and laterally. With three or more tie rods, movement is limited to lateral deflection only. Without tie rods, the universal expansion joint is free to accept all types of deflection. This would require additional anchors and pipe supports to control the movement of the piping and avoid damaging the bellows.

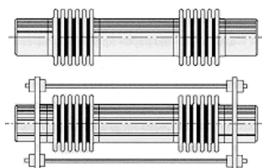


Figure 2-8
Universal Expansion Joints

2.5.5 Pressure Balanced Expansion Joints

The pressure balanced expansion joint (Figure 2-9) consists of a combination of simple bellows, which are tied together. The primary purpose of the pressure balanced bellows is to retain or balance the pressure thrust so that the main anchoring of the pipe or adjacent equipment is not

required. Designed to accept the deflection experienced by the application, this type of expansion joint uses a balancing bellows in combination with one of the other previously discussed types of bellows. The most common configuration uses a universal bellows that is designed to accept lateral and axial movements in the system.

To eliminate pipe supports or anchors, there must be some means of balancing the pressure thrust force and 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. This arrangement contains the pressure thrust force as tension in the tie rods. This allows the expansion joint between the tie rods to move freely in the axial direction.



Figure 2-9
Pressure Balanced Expansion Joint

2.5.6 In-Line Pressure Balanced Expansion Joints

When axial deflections exist and anchoring is impractical, in-line pressure balanced expansion joints (Figure 2-10) are commonly used. The function of this type of expansion joint is to balance the pressure thrust, while allowing for axial deflection that results 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 accomplished using a primary and an outer bellows. The primary bellows accepts the axial deflection, and the outer bellows (which is 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; the remaining forces are the result of the spring resistance of the bellows, and the main anchoring of the piping or vessel is eliminated.

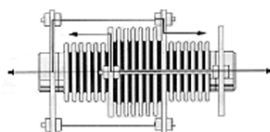


Figure 2-10
In-Line Pressure Balanced Expansion Joint

2.5.7 Externally Pressurized Expansion Joints

Externally pressurized expansion joints (Figure 2-11) 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 deflection and high pressure. With this type of expansion joint, the external surface is exposed to the media flowing through the pipe. As a result, external pressurization problems with squirm are eliminated.

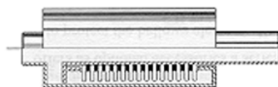


Figure 2-11
Externally Pressurized Expansion Joint

2.5.8 Accessories

The metallic bellows is, by necessity, very thin and subject to being damaged easily. Manufacturers offer a variety of accessories designed to protect the bellows element. Following is a description of some of the more common accessories [1].

2.5.8.1 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 meet or exceed the following criteria.

- When flow velocities exceed the following values:

Air, Steam, and Other Gases

Up to 6-in. (15.24-cm) diameter – 4 ft/sec per in. of diameter (1.22 m/sec per cm of diameter)
Over 6-in. (15.24-cm) diameter – 25 ft/sec (7.62 m/sec)

Water and Other Liquids

Up to 6-in. (15.24-cm) diameter – 1 2/3 ft/sec per in. of diameter (.51 m/sec per cm of diameter)
Over 6-in. (15.24-cm) diameter – 10 ft/sec (3.05 m/sec)

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

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

2.5.8.2 Protective Covers

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

2.5.8.3 Purge Connectors

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, which prevents buildup.

2.5.8.4 Limit Rods

Limit rods are typically used to limit 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 gas tungsten arc welding (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 subjected to a tensile stress and a corrosive medium. The variables that affect IGSCC are temperature, environment, material composition, stress level, and microstructure. The cracking can be either transgranular or intergranular, depending on 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 progresses very rapidly. One common method that is used to prevent IGSCC is to select bellows materials that have a high nickel alloy such as Inconel; however, caution should be exercised when selecting a nickel alloy because they are sometimes subject to caustic-induced stress corrosion. Final material selections should be based on the service conditions of the specific application.

2.7 Manufacturing Methods

There are several methods of manufacturing bellows. The two most common methods are forming and fabricating. Of these two methods, forming is by far the most used method. Formed bellows usually exhibit longer fatigue lives than fabricated bellows [3].

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 seam weld. The tube blank is made long enough to accommodate subsequent axial collapse resulting from convolutions forming, and a diameter that is 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 way, except that two tube blanks are fitted one inside the other. The spacing between the two plies is generally kept small to ensure uniformity. An illustration of the forming process can be seen in Figure 2-12.

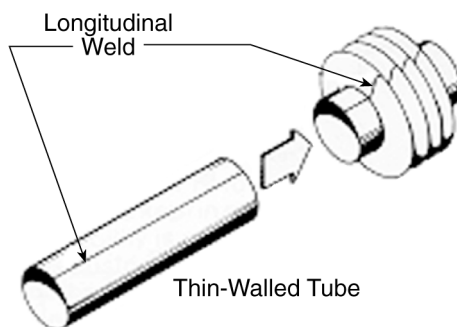


Figure 2-12
Formed Bellows [3]

It is important to note that the bellows experience a significant amount of cold work due to the forming process. The effect of cold work on the bellows is considered to be *beneficial* because it generally improves fatigue life. As a result, it is not normally considered beneficial to 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 these 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 fabricated 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 2-13.

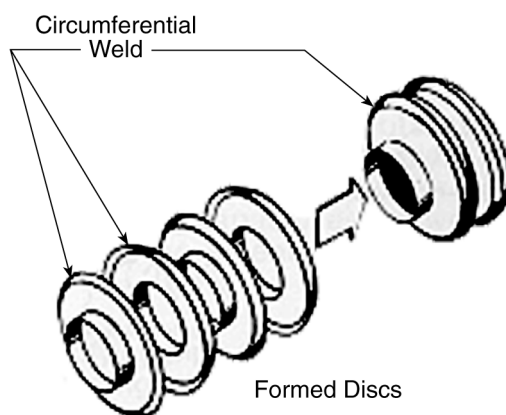


Figure 2-13
Fabricated Bellows [3]

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. The fatigue life expectancy of an expansion joint is affected by various factors such as operating pressure, material type, movement per convolution, thickness of the bellows, convolution pitch, 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 [2].

The EJMA defines fatigue life as the total number of complete cycles that 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

Bellows Design

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 the 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, but 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. When driven by an outside vibration, this specific resonance frequency 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 components, 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. Some bellows replacements have been documented to take 1200 work hours. Because of such 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, include *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 to the thin wall thickness and lack of accessibility that is characteristic of these types of expansion joints.

The following text provides a detailed discussion of the various failure mechanisms and repair methods 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 a 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. Following are some of the most common causes of expansion joint failure [1]:

Improper Handling – Bellows are frequently damaged as a result of improper handling (that is, from being struck by hard objects such as tools, chains, forklifts, and other adjacent structures). 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 have 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 manufacturer to another, but typical figures are ± 0.125 in. (0.318 cm) axial, ± 0.125 in. (0.318 cm) 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 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. These restraints allow movement only in directions intended by the designer. The design of pipe restraints must take into account the forces that result from the bellows' pressure thrust, hydraulic thrust, the bending of the pipe segment, and the spring rate of the bellows. Many designers often overlook 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, as in the 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 diameters of the first. Most expansion joint manufacturers provide spacing requirements.

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 follows:

- Stress corrosion, which is evident by cracking and 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
- 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 causes wall thinning, which eventually causes 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 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 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 bellows design must fall into to adequately satisfy both needs. Generally, 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 due, in large part, to wall thickness and accessibility problems. The common wall thickness of bellows ranges from 0.020 in. to 0.060 in. (0.051 cm to 0.152 cm). Because 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 sidewall 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 issue that must be considered is how the repair will affect 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. How much it will affect the cycle life 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 might provide adequate service life.

Bellows Repair History

In the past, there have 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 sections [4].

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 was 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. An overview of the tests performed is provided in Table 3-1.

Table 3-1
Description of ASME Test Bellows [4]

Test No.	Size	Plies		Material	Pressure			Type of Defect								Type of Repair				
		No. of Conv.	Thickness of Ply		Int. psi	Ext. psi	Medium	Holes		Gouge	Cracks		Dents		Scratch	Lap Patch	Plug	Groove	Blend	N/A
								Large (a)	Small (b)		Circ.	Long	Sharp	Smooth						
1	24 in.	4	0.050 in.	Type 304	10 (c)	---	Air		3	3	3	3				3			3	
2	42 in.	5	0.050 in.	Type 304	---	50 (c) (d)	Air	2 2								2	2			
3	25.75 in.	13	0.024 in.	Type 304	---	16 (c)	Water							4						4
4	24 in.	4	0.037 in.	Type 304	---	---	---						3	8	20					3 8 20

(a) Large hole is approximately 1 in. (25.4 mm) in diameter.

(b) Small hole is approximately 1/8 in. (3.2 mm) in diameter.

(c) 10 psi (68.9 kPa); 50 psi (344.8 kPa); 16 psi (110.3 kPa).

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

Notes:

Cracks were represented by slots 1/32-in. (0.8-mm) wide by 1/2-in. (12.7-mm) long through the outer ply only.

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

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

Test No. 2 was preceded by a hydrostatic test to 75-psig (518-kPa) external pressure.

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

Conversions: 1 in. is equivalent to 2.54 cm
 1 psi is equivalent to 6.89 kPa

3.3.2 ASME Test 1

3.3.2.1 Description of Test

The first test involved a two-ply, 24-in. (61-cm) 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 introduced into a bellows typical of those that might be encountered in installed bellows assemblies. The 24-in. (61-cm) diameter bellows used in the testing had four convolutions and a wall thickness of 0.050 in. (0.127 cm), which is typical of a bellows used in a containment vessel penetration. The defects that were introduced were repaired using one of the following three methods, depending on the severity of the defect:

- Welding patches of compatible material over the defect
- Filling the grooves with weld metal
- Contour grinding

The test assembly was then subjected 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. (2.438 cm), which was determined to be the 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 Two of the test consisted of 7000 additional cycles with a stroke of 2.156 in. (5.476 cm), 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.

3.3.2.2 Results of Test

The 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 One. It was determined that one 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. The results showed that the patch-type repairs had about 4% 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% 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.

Although the repairs had an average cycle life that was only 4% of a bellows without defects, 14 of the 15 defects exceeded the normal cycles experienced by a typical containment bellows because of over-design.

3.3.3 ASME Test 2

3.3.3.1 Description of Test

In Test 2, a one-ply, 0.050-in. (0.127-cm) thick, five-convolution, 42-in. (107-cm) diameter bellows was tested. In this test, burn holes were made in four places, 90° apart on the first convolution wall. The bellows was then mounted in a mockup 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 was repaired in the same position and with the same amount of access. Two of the holes were repaired with a lap-type patch and the other two holes were repaired with a 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 (517 kPa) was applied for ten minutes to be sure the defects were properly sealed. Then 50% of the water pressure was replaced by air to allow for cyclic movement. The pressure was maintained at 50 psig (345 kPa). The repaired bellows was then cycled. The bellows was cycled at 1000-cycle intervals, and then the test was halted with a pressure of 50 psig (345 kPa) and held for 15 minutes to check for leaks. This interval was later reduced to 500 cycles between checks.

3.3.3.2 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 a continuous loss of pressure was observed. 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 repairs over lap-type patch repairs.

3.3.4 ASME Test 3

3.3.4.1 Description of Test

In Test 3, a single-ply, 0.024-in. (0.06-cm) thick, 13-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 sidewall and one nick. The bellows was then tested as is without any type of repair. Testing consisted of two phases: the first phase was to compare worst-case plant condition displacements and number of cycles, and the second phase was to simulate normal operational movement until failure occurred.

Phase One of the test consisted of 120 cycles of 4.147 in. (10.53 cm) of axial compression and 4.030 in. (10.24 cm) of axial extension, while the test bellows was subjected to 16-psig (110 kPa) external water pressure.

Phase Two consisted of cycling the test bellows to failure at reduced axial movements of 2.47 in. (6.27 cm) of compression and 2.444 in. (6.21 cm) of extension.

3.3.4.2 Results

The test bellows failed at 4,975 cycles due to small cracks near the convolution crest at dent number 4. The 4,975 cycles consisted 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

3.3.5.1 Description of Test

Test 4, was a single-phase test conducted to failure. The test bellows consisted of a single-ply, 24-in. (60.96-cm) diameter bellows, made from 0.037-in. (0.094-cm) Type 304 stainless steel. In this test a total of 31 defects consisting of dents, scratches, and gouges were inserted into the bellows to determine their effect on cycle life. The bellows was not pressurized during the cyclic test.

The bellows was then cycled at 0.75-in. (1.91-cm) compression and 0.125-in. (0.318-cm) extension. The axial movement for the bellows was arbitrarily chosen and used approximately 70% of the rated compressive movement. Failure was determined by frequent dye-penetrant examination. The test bellows was subjected to 16,000 cycles.

3.3.5.2 Results

Of the 31 damaged areas, 3 failed. Dent number 1 caused a pinhole leak after 9,170 cycles and dents number 2 and number 3 failed after 5,040 cycles. Compared to an undamaged bellows, dent number 1 failed at 35% and dents number 2 and number 3 failed at 20.5% of the average cycle life of an undamaged bellows. These results indicated that the prudent course of action to take after discovery of damage is to evaluate the severity of the damage, determine predicted average cycle life, and consider correcting the dented shape of the convolution. It is also important to note that 28 areas with less severe damage 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 ASME tests showed that weld repairs could be a viable option in some cases, provided that the damage is fairly localized. However, these tests were fairly limited because 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, Code Case N-315, which resulted from these tests, requires a full-scale mockup of all repairs.

3.4 Alternative Repairs

Using clamshell or enveloping bellows is one alternative to complete bellows replacement. These bellows are offered by several manufacturers and 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 oversized bellows is manufactured as one unit and is cut in half longitudinally; 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 oversized clamshell bellows can be installed while the system is on-line, depending on operating conditions.

Some manufacturers also offer bellows of the same size, which are designed to replace the original bellows element. These types of bellows are installed in half sections like the oversized 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. The damaged bellows element is removed and the new, same-sized 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 too have drawbacks, however, and cannot be used in many applications. The biggest problem that prevents enveloping bellows from being used is the lack of space. Because of their increased size, they will not physically fit in some areas. In addition, these bellows require lengthy installation times and will not last as long as a complete replacement due to the amount of field welding required to install them. They cannot 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 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 3.3.1, showed some success with weld repairs and was used as a starting point for development activities. The complexities associated with bellows design cause a bellows to be very susceptible to failure from the stress concentrations created by welding. Consequently, all weld repairs will reduce the fatigue life of a 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), the project team decided that 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 factors in determining which welding process would be used. The most important factors were accessibility and control. The welder had to be able to perform a detailed low profile weld in the root of a convolution. To accomplish this, the welding torch had to 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 plasma transfer arc welding (PTAW) processes provided the necessary control needed to weld the thin material, however, none of the commercially available PTAW torches were small enough to 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. Thus, 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. It is the smallest commercially available torch. 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 sidewalls of convolutions on bellows with a clearance as small as 0.560 in. (1.42 cm) between adjacent convolutions. The MT-125 torch offers 90°, 45°, and 180° nozzle and head arrangements, which allow for adequate maneuverability, access to out-of-position welds, and access in areas of transition. The torch body of the MT-125 is 0.312 in. (0.792 cm) in diameter and nozzle sizes for the 90°, 45°, and 180° arrangements are 0.430 in. (1.092 cm), 0.703 in. (1.786 cm), and 0.430 in. (1.092 cm), respectively. The torch also features clear glass or quartz nozzles, which increase visibility of the weld area. Each of the three different head arrangements were used 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:

Miller Aerowave 300

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 in. (1.016 cm) and a thickness of 0.025 in. (0.064 cm). Any small rotary tool with a similar grinding disc 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

	Thickness (in./cm)	Amps
Amperage Range	0.015/0.038	8–12
	0.020/0.051	10–13
	0.030/0.076	12–18
	0.040/0.102	16–22
	0.050/0.127	18–24
Voltage Range	8–15 volts	
Travel Speed	3–4 in./min (7.62–10.16 cm/min).	
Tungsten Size	0.040 in. (0.102 cm)	
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 provided in Table 4-3.

Table 4-2
Specifications for Test Bellows

Nominal Diameter	14 in. (35.56 cm)
Design Pressure	75 psig (518 kPa)
Design Temperature	390°F (199°C)
Material	Type 304 SS
Thickness of Ply	0.055 in. (0.140 cm)
Convolution Pitch (peak to peak)	1.00 in. (2.54 cm)
Convolution Height	1.300 in. (3.302 cm)
Clearance Between Convolutions*	0.560 in. (1.422 cm)

*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

Microhardness measurements were also taken on a section of the test bellows to determine if significant variations were present in different regions of the convolutions as a result of forming. This also established a basis that could be used for comparison of the 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.

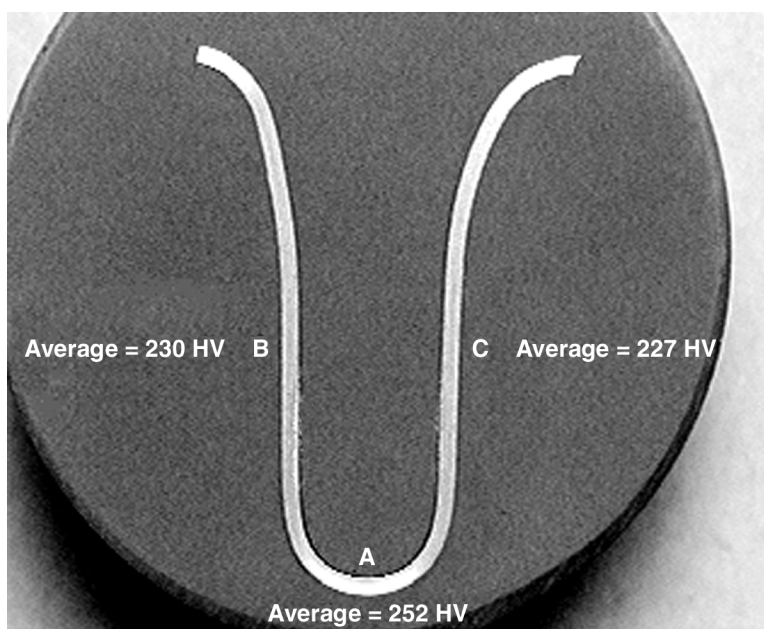


Figure 4-2
Cross-Section of Test Bellows Convolution with Vickers Hardness

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 a 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 and 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 thicknesses that ranged from 0.015–0.050 in. (0.038–0.127 cm) thick. The welding parameters defined in Section 4.2.6 were used as a starting 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 in. (0.064 cm) required significant welder skill to prevent burn-through. Welds on materials 0.030-in. (0.076-cm) thick and greater could be welded consistently without 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. Limited accessibility makes the cracks difficult to repair. 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 in. (1.321 cm) 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 that is required to perform an actual weld repair, two sections of the test bellows were sectioned along the axial direction, butted together, and seam-welded. The repair started on the crest of a convolution, progressed down the sidewall, then up the adjacent sidewall, and concluded at the crest of the adjacent convolution. It was determined that the 0.056 in. (0.142 cm) convolution clearance was the minimum clearance that would allow weld repairs at the root of the convolution, and particularly up the sidewall 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 sidewall. Some minor modifications were also needed on the 90°-nozzle configuration to improve clearance. The modifications consisted of grinding approximately 1/8 in. (0.318 cm) off the face of the 90°-glass nozzle. Additional test repairs were performed in the root, on the sidewall, and on the crest of the convolutions. No accessibility problems were experienced with the modified torch.

4.3.5 Filler Material Type and 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-in. (0.101-cm) diameter wire yielded the best results. The 0.040-in. (0.102-cm) wire produced a small uniform weld with a smooth even contour. The larger sized 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, which were approximately 0.015–0.040-in. (0.038–0.102-cm) wide, into bellows convolutions as seen in Figure 4-3.

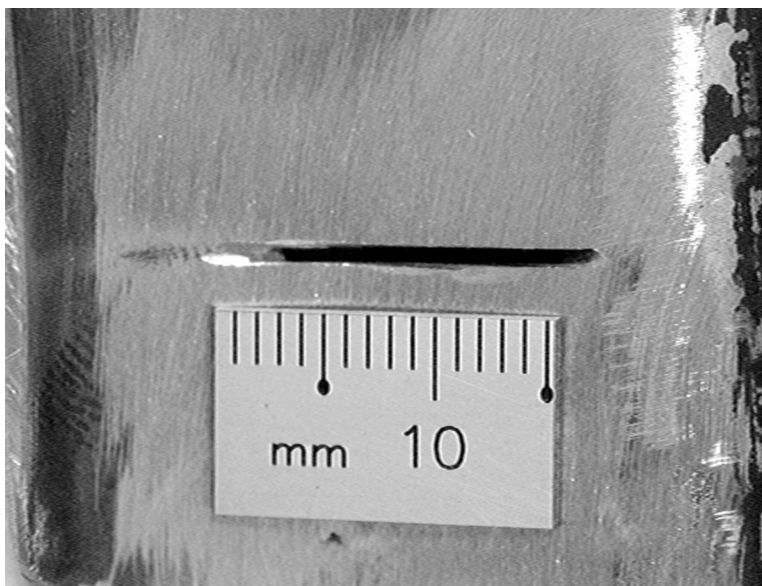


Figure 4-3
0.015–0.040-in. (0.038–0.102-cm) Wide Slot

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 was performed 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 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.

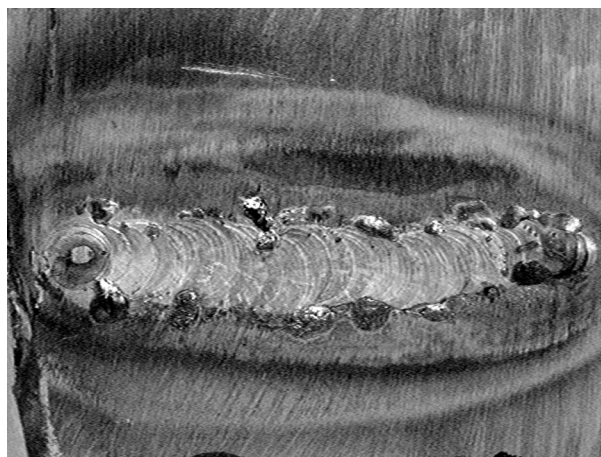
Back purging was not performed on any of the repair welds, assuming that it would not be possible in field applications. The welds that were produced during the testing appeared very uniform on the surface of the weld; however, heavy sugaring was experienced on the opposing side of the weld on virtually 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 in the same manner as other solid wire would be applied.

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-in. (0.038–0.102-cm) wide slot ground completely through the damaged area. It was not as effective, however, 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 use of flux cored wire also eliminated the problems experienced with sugaring; however the flux cored wire being used was too large and resulted in a non-uniform weld, which creates a significant stress riser. Several vendors were contacted in an effort to find 0.040-in. (0.102-cm) diameter flux cored wire but none of them offered the product in a diameter that small.

The cross-sections of welds made using the Solar Flux, the Inconel 82, and the 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 was 0.009 in. (0.023 cm) and 0.008 in. (0.020 cm), respectively. In addition, each of the repair welds produced a very small heat-affected zone (HAZ). 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.

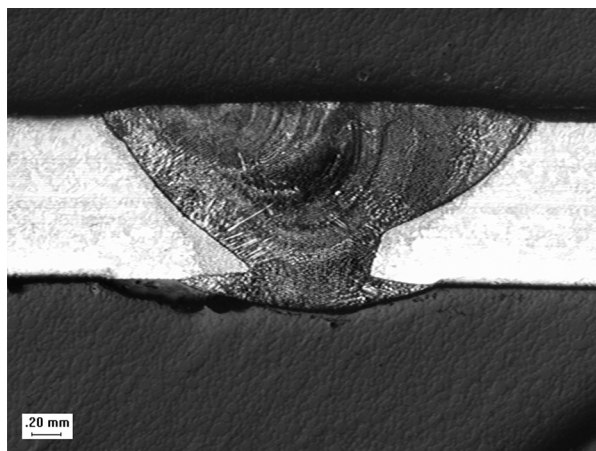
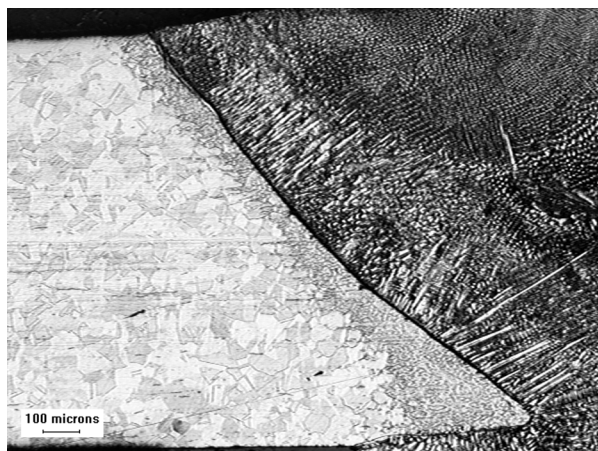


Figure 4-6
Repair Weld with Inconel 82 Filler Material

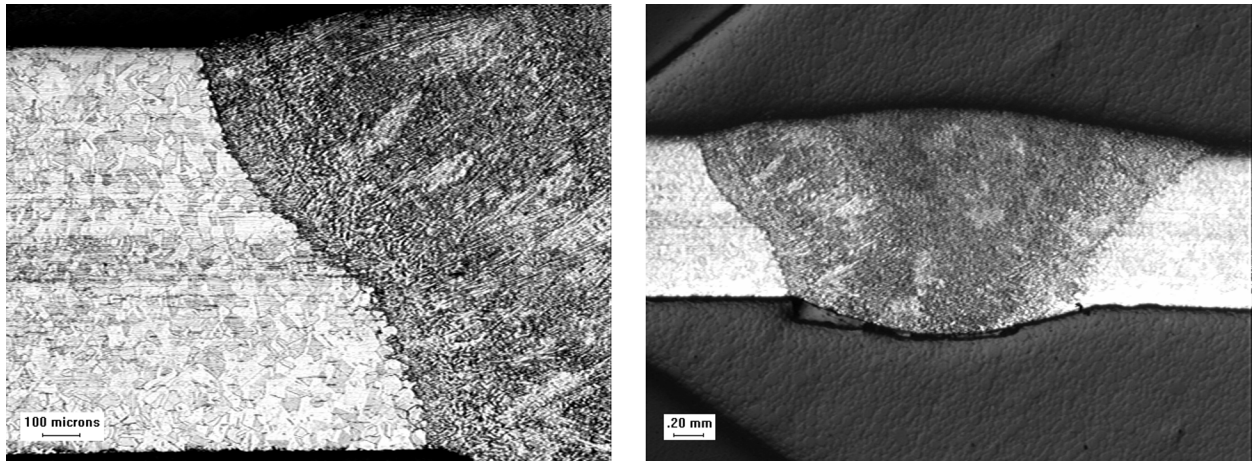


Figure 4-7
Repair Weld with 308 Stainless Steel Filler Material

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.

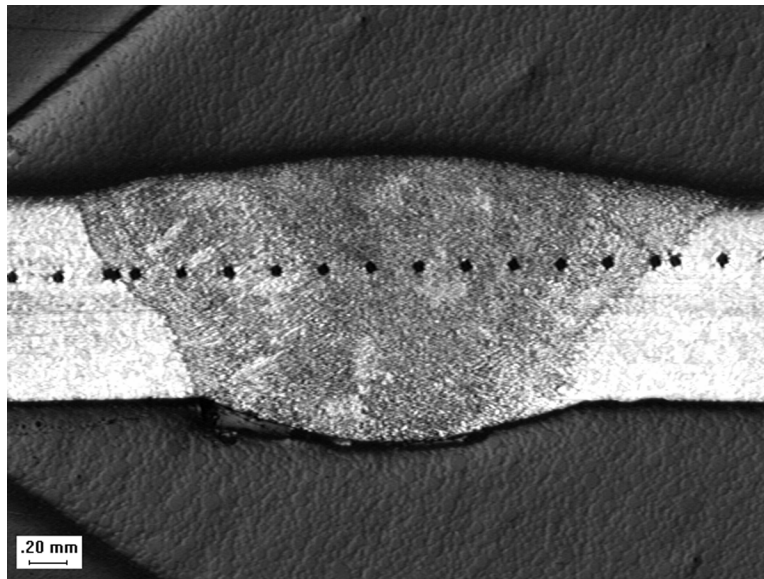


Figure 4-8
Hardness Profile

Table 4-4
Hardness Measurements

Inconel 82 Weld		308L Stainless Steel 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 possible to take only one hardness measurement in that region.

The average Vickers hardness in the Inconel and stainless steel welds was 154 HV and 171 HV, respectively. 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

Bellows Repair Development

to determine if it had any significant effect on the ductility or tensile strength of the weld and the HAZ. In total, ten tensile tests were performed, two for each filler material and two base metal tests. The results 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 in. (5.08 cm)	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.

** Note: 1 psi is equal to 6.89 kPa.

Results of the tensile testing were encouraging with respect to the original base material. With respect to yield and tensile strengths, all of the welds exceeded the design requirements specified for Type 304 stainless steel in Section II of the ASME Boiler and Pressure Vessel Code. Each of the test welds failed in the HAZ of the weld, as seen in Figure 4-9, but not in the weld. Overall, the welds executed with the 309L filler material performed the best in terms of 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 suggests a loss in ductility. The effect of this loss in ductility cannot 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.

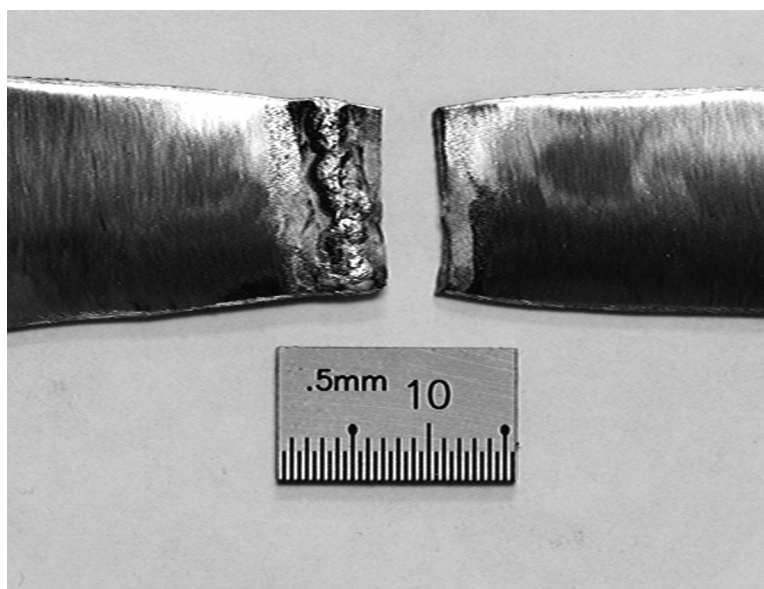


Figure 4-9
Typical Failure Location of Tensile Specimens

4.3.8 Conclusions/Recommendations

In 2000, RRAC focused on developing a reliable weld repair technique that would provide utilities with an alternative to performing some full-scale bellows replacements. The development effort was 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.

Bellows Repair Development

- The amperage range that is 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 in. (0.076 cm).
- The minimum clearance needed between the bellows convolutions for adequate accessibility is 0.560 (1.422 cm).
- 0.040 in. (0.102 cm) is the optimum sized 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 might lead to sensitization of stainless steels.
- Solar Flux B prevents the occurrence of sugaring.
- Welds 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-in. (0.038–0.102-cm) wide throughwall 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 is to evaluate its effectiveness. To accomplish this, test repairs will be subjected 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 might 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 contaminants 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-in. (0.038–0.102-cm) 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 the defects in such a manner that it completely fills the crevice or slot previously ground into 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-in. (0.102-cm) 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 as the damaged material to obtain a proper feel for the welding conditions, and to optimize weld settings. Execute the 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

FATIGUE TESTING

This section documents Phase Two of the preceding work. When this task began, the primary focus was to investigate possible repair options for bellows that were not limited by current Code rules.

Successful repair welds have been made with good mechanical properties. Fatigue testing was suggested as a method for validating those repair techniques.

5.1 PTAW and GTAW Repair Coupons

Additional weld repairs were evaluated using the PTAW method. Several bellows pieces had grooved flaws placed on the outer edge of the convolute and were welded using Alloy 625 powder.

To offer a comparison of welding processes, GTAW repairs were made on flawed samples for fatigue testing in conjunction with the PTAW samples. GTAW samples used Alloy 82 as the filler material.

5.1.1 Coupon Description

A single convolute of a large radius bellows was provided to RRAC for repair analysis. This portion of the bellows came from a utility that had replaced a defective/failed bellows. This piece had seen extensive service and was used for weld repairs because of its larger surface (ease of access) as well as providing a realistic scenario for repair due to its service life.

The coupons were cut 4-in. (10.16-cm) long and had a convolute width of 1 in. (2.54 cm). The depth of the convolute was 2 1/2 in. (6.35 cm). The nominal wall thickness of the bellows was 0.045 in. (0.114 cm).

Two holes were drilled through the web of the coupon 1 in. (2.54 cm) from each end (2 in. [5.08 cm] on center), and approximately midway from the edge of the sample to the wall of the convolute (see Figure 5-1). This provided a mechanism to join the sample to the testing fixture.

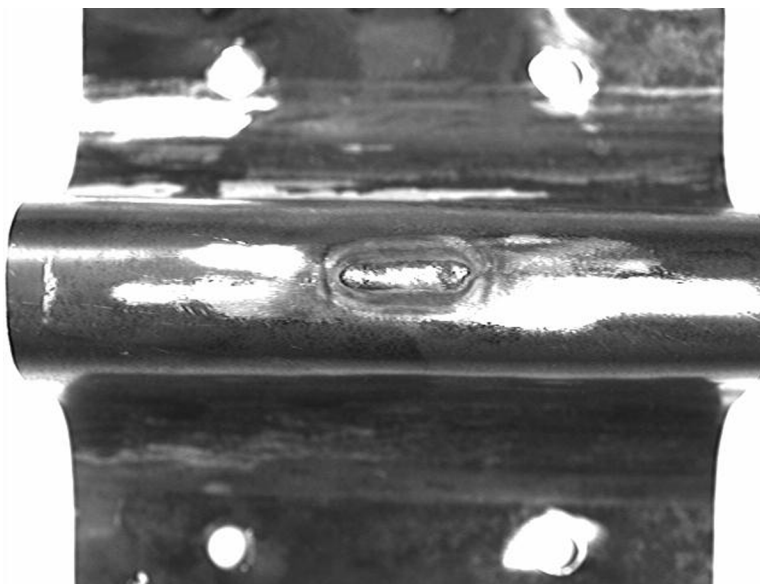


Figure 5-1
Testing Sample

5.2 Weld Parameters

PTAW welding was done with a Stellite Microstar hardfacing system. This system provides the ability to set parameters for low current/voltage welding conditions. The power supply used in the GTAW development work was a Miller Aerowave 300.

Parameter development was done on one of the bellows sections. Sufficient current and voltage are required to create good wetting of the molten powder.

Initial PTAW welds were made at 15 amps and 19 volts, with a powder flow setting at 3/4. The deposited powder did not seem to wet properly. This was indicated by the uneven buildup on the outside surface, as well as the lack of fill in the crack when viewed from the underside.

The current was increased to 21 amps with some improvement in penetration through the depth of the flaw. The third set of PTAW samples were welded at 24 amps. This provided the best penetration to fill in the void. Anything greater than 24 amps initiated key holing.

5.3 Testing Method

The fatigue testing of bellows sections serves two purposes:

- To verify the integrity of the repair weld
- To provide a supporting basis for a revised Code Case outlining the lack of necessity to perform testing on a full-scale mockup

As illustrated in Figure 5-2, the welded coupons were bolted to two 1/2-in. (1.27-cm) thick plates with steel roundstock welded to the plates, forming a T-shaped fixture. These plates allowed the universal tensile testing machine a mechanism to clamp to the coupons without sacrificing the integrity of the bellows.

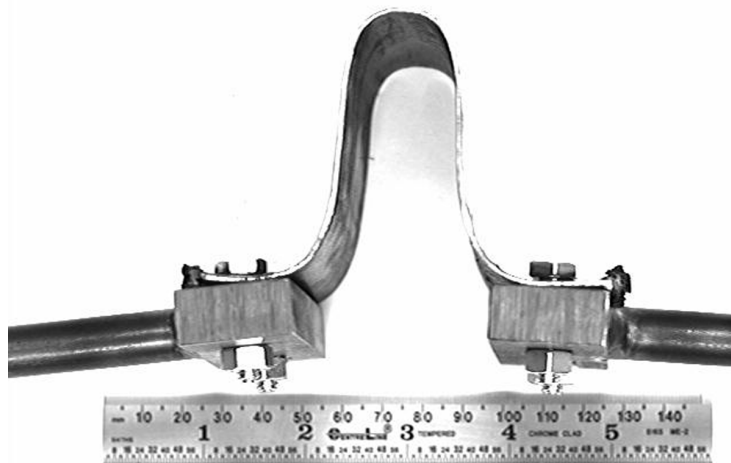


Figure 5-2
The Welded Coupons

Testing was done by repetitive cycling of the bellows section in a uniaxial direction. Torsion and lateral displacement were not evaluated. Initial displacements were targeted for 1/4 inch (0.64 cm) and were gradually increased until the load sensor displayed sufficient force. The coupons were cycled, based on displacement rather than load. The intent of fatigue testing is to determine the number of cycles required to induce failure. Failure was determined by visual inspection. Upon detection of cracking, the coupon was deemed to have failed. Cycling of the bellows sections continued until the load induced on the piece was reduced by 10%.

5.4 Fatigue Test Results

The repaired coupons failed as expected. On average, the higher the heat input the greater the integrity of the weld. Higher heat input induces greater filler penetration, thereby providing a better quality weld. Displacements varied from 0.25 in. (0.64 cm) (0.5-in. [1.27-cm] full stroke) to 0.625 in. (1.59 cm) (1.25-in. [3.18-cm] full stroke). For a bellows with a 1-in. (2.54-cm) convolute width, this provided a significant range of testing. The total number of cycles to failure also varied depending on displacement. Cycles ranged from 1357 to in excess of 32000 (see Table 5-1). In several cases, the displacement of a sample was not sufficient to induce failure and the test was either stopped or the displacement increased.

The resultant data (see Figures 5-3 through 5-6) indicate that the samples with the GTAW repairs performed the best (Fig 1, Fig 2, and Fig 3). The best performing PTAW repairs were those with the highest heat input (H1, H2, and H3), followed by the medium heat input (M1, M2, and M3) repairs, and finally the low heat input repairs (L1 and L2).

Fatigue Testing

Table 5-1
Total Number of Cycles to Failure

Sample	Displacement	Load	90% of Load	Cycles for Exam	Total Cycles	Failure? Y/N
Test	0.25	70	63	400	400	N
	0.375	100	90	1000	1400	N
	0.5	117	105.3	1372	2772	Y
L1	0.375	87	78.3	400	400	Y
	0.375				4200	Y
	0.375				8504	Y
	0.5	107	96.3		11191	Y
No weld	0.5	91	81.9		2723	Y
M1	0.5	109	98.1	400	400	Y
	0.5				1929	
H1	0.5	94	84.6	400	400	N
				1000	1400	Y
					3041	
Tig1	0.5	112	100.8	400	400	N
				1023	1423	Y
					5004	
No flaw or weld #1	0.5	113	101.7	400	400	N
					1422	N
No flaw or weld #2	0.5	111	99.9	400	400	N
					5270	Y

Table 5-1 (cont.)
Total Number of Cycles to Failure

Sample	Displacement	Load	90% of Load	Cycles for Exam	Total Cycles	Failure? Y/N
L2	0.25	53	47.7	400	400	N
				1000	1400	N
				1000	2400	N
					32940	N
M2	0.625	96	86.4		1357	
H2	0.625	99	89.1		1593	
Tig2	0.625	122	109.8		1637	
M3	0.375	66	59.4		10000	
	0.425	76	68.4		12559	
Tig3	0.425	77	69.3		23676	
H3	0.425	103	92.7		3712	

Fatigue Testing

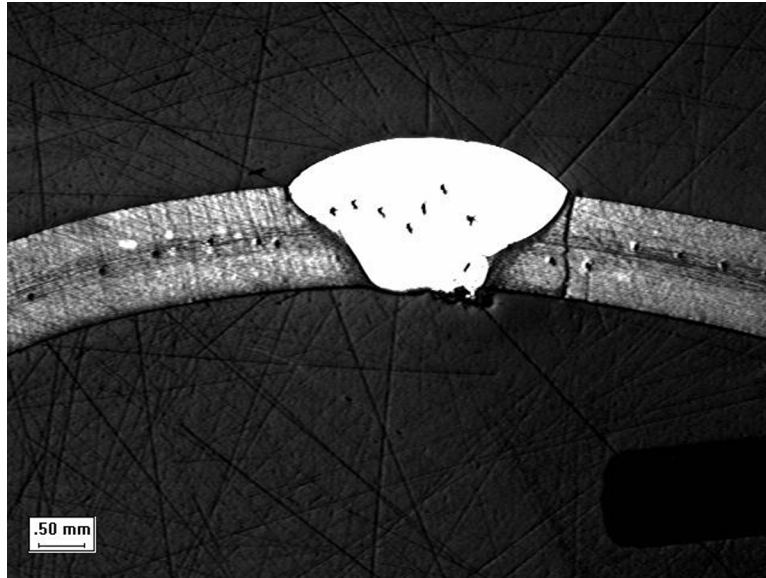


Figure 5-3
GTAW Weld

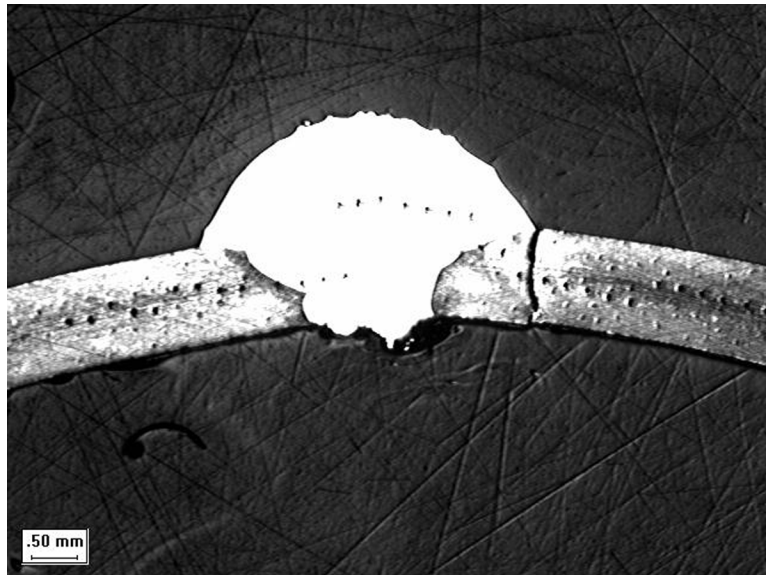


Figure 5-4
High Heat Input PTAW Weld

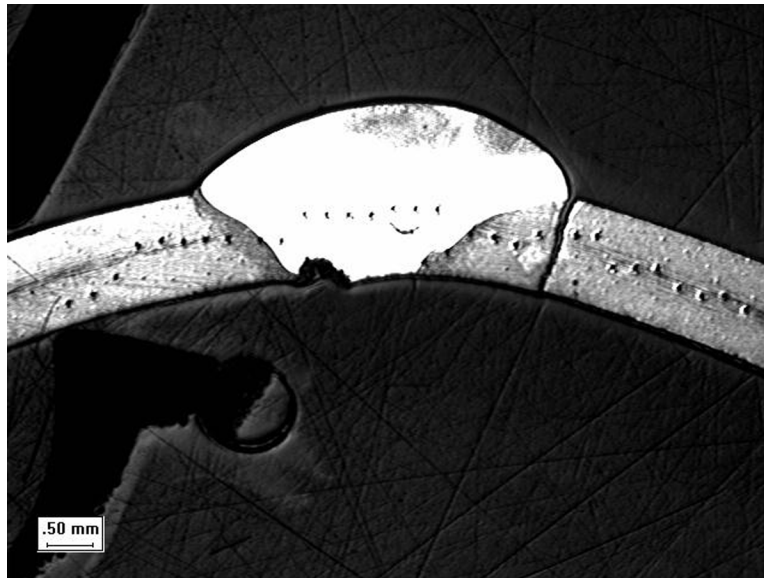


Figure 5-5
Medium Heat Input PTAW Weld

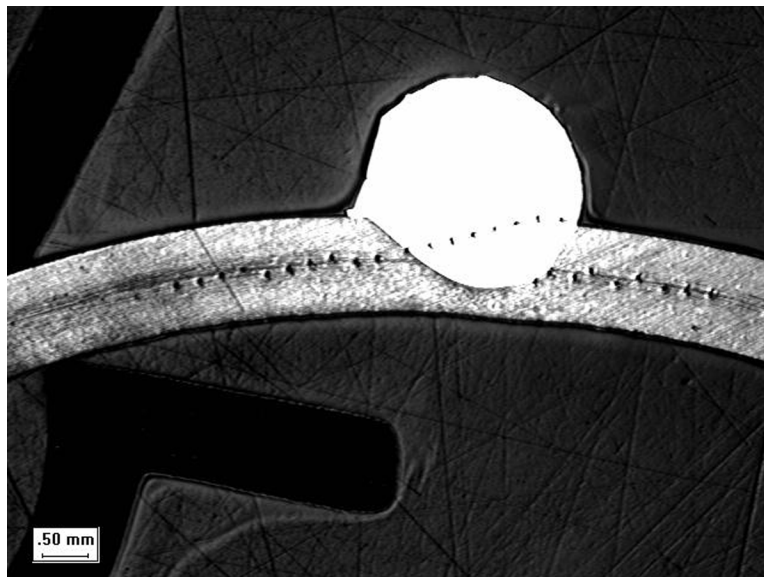


Figure 5-6
Low Heat Input PTAW Weld

Hardness testing of the failed samples illustrates the significance of work hardening on the bellows material as a result of cycling (see Figures 5-7 through 5-12). Sample L2 never failed. Its test was stopped after more than 32,000 cycles. Viewing the hardness plot, it is apparent that the coupon did not fully work harden prior to halting the test. Samples M2, H2, and T3 are 30 to 50 points harder in the HAZ and base metal.

Fatigue Testing

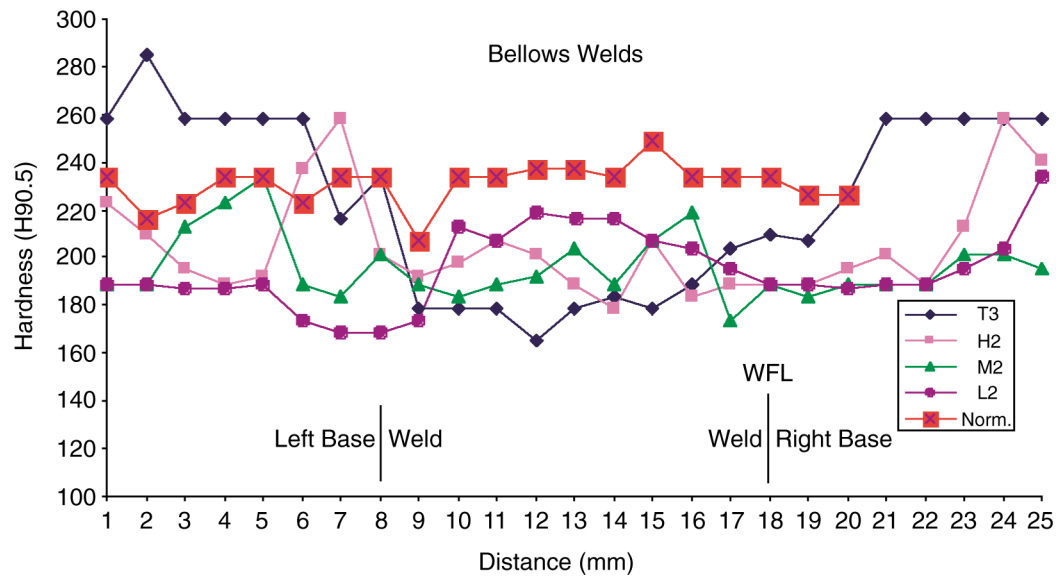


Figure 5-7
Hardness Plot of Failed Samples



Figure 5-8
Typical Failure Location After Cycling

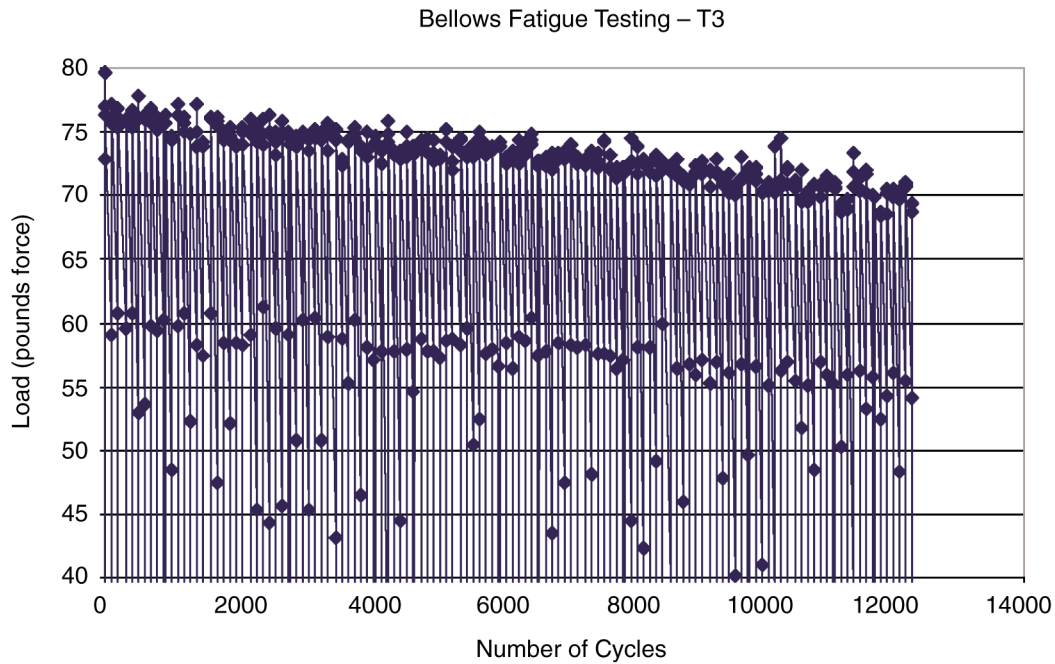


Figure 5-9
Number of Cycles (GTAW Weld)

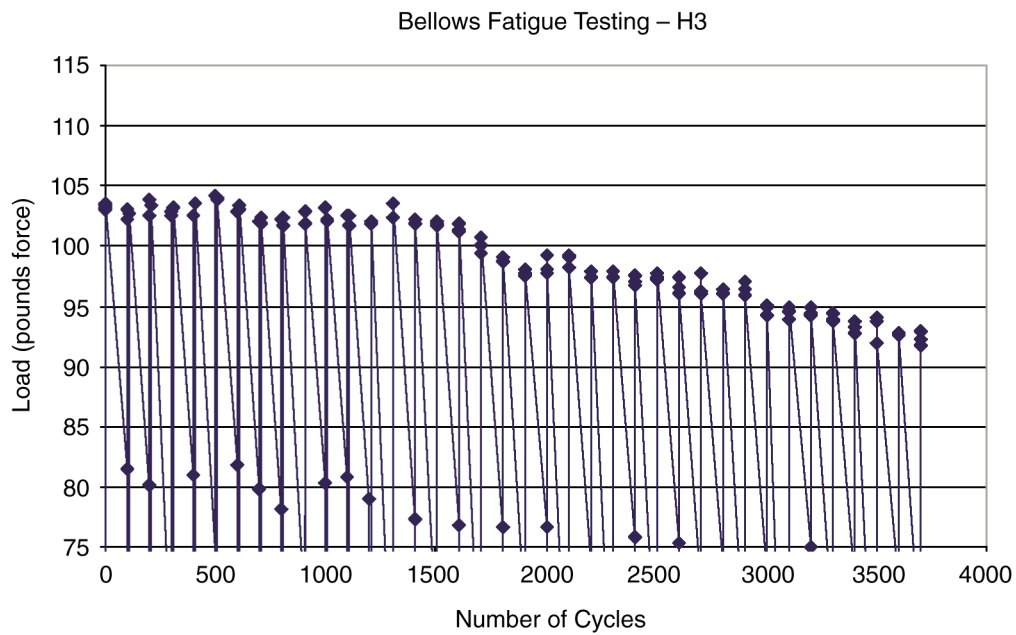


Figure 5-10
Number of Cycles (High Heat Input PTAW Weld)

Fatigue Testing

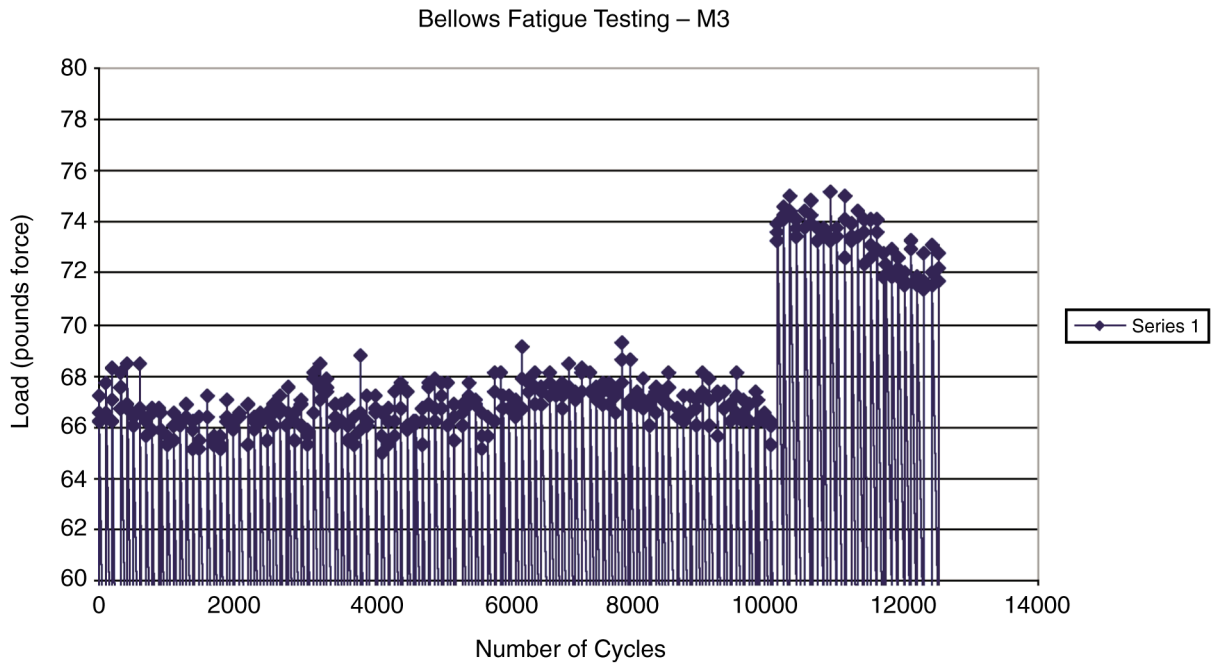


Figure 5-11
Number of Cycles (Medium Heat Input PTAW Weld)

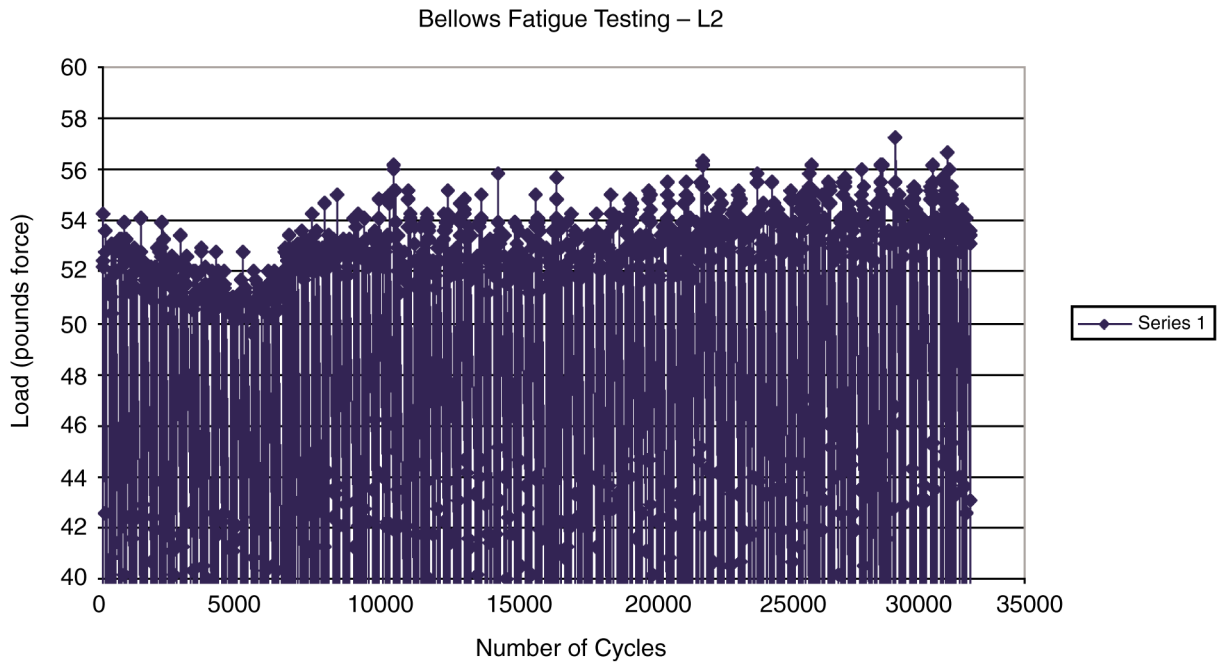


Figure 5-12
Number of Cycles (Low Heat Input PTAW Weld)

5.5 Conclusions

The testing proved to be very successful. This data should provide a solid basis for allowing an organization the means to defend their ability to make circumferential weld repairs on a bellows in lieu of the restriction of Code Case N-315. Other conclusions are as follows:

- Penetration of the weld filler is key. With a notched flaw, the samples that had filler material that reached all the way to the inside surface provided better results.
- All of the samples initiated failure on the inside surface first.
- Work hardening is very prevalent on a load-versus-cycles plot. This is a prelude to failure.
- Some samples exceeded the number of cycles to failure compared to testing done by ASME.
- In general the GTAW repairs performed best.

6

REFERENCES

1. Expansion Joint Catalog, Piping Technology & Products Inc. Copyrighted 1997.
2. Standards of the Expansion Joint Manufacturers Association, Inc. Fifth Edition 1998.
3. A Practical Guide to Expansion Joints. Expansion Joints Manufacturers Association, Inc. 1985.
4. Bressler, Merrick, O'Toole, and Reimus. Alternatives to Replacement of Damaged Expansion Joints. Pressure Vessel and Piping Technology, 1985.
5. ASME Boiler and Pressure Vessel Code, Section XI. American Society of Mechanical Engineers, New York.

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.

A.1 Weld Repairs

A.1.1 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 its original integrity. Any weld repair will act as a stress riser and will 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 basis.

A.1.2 Fatigue or Corrosion

It was recommended 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 affected. 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 might 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. The overwhelming consensus of the manufacturers was that weld repairs should not be attempted to repair fatigue- or corrosion-related problems.

A.1.3 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 viewed as a viable solution in some cases (which will extend the service life of the bellows and the time before a complete replacement is necessary). Manufacturers suggested that weld repairs only be attempted on non-critical, low-pressure applications.

A.2 Conditions That Influence Weld Repairs

ASME Code Case N-315 provides rules for the repair welding of bellows. As outlined by the manufacturers, the factors 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 a 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. This confined space could limit the welder's ability to produce a sound weld.

Wall Thickness – The need for flexibility requires that the wall thickness of a bellows be relatively thin, which complicates the welding process. The common wall thickness of a bellows ranges from 0.020 in. to 0.060 in. (0.051 cm to 0.152 cm). However, the minimum wall thickness recommended by manufacturers, to be successfully welded is about 0.040 in. (0.102 cm). It might be possible for a highly skilled welder to weld on a thickness as thin as 0.030 in. (0.076 cm), but anything thinner would be very difficult to weld without burn-through. Another concern that applies to multi-ply bellows is the possibility of welding the different ply together, which would 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 experiences movement during startup and shutdown than it would in a system that experiences significant vibration or frequent movement.

A.3 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 oversized 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 on-line.

The other type of clamshell bellows used is the same size as the installed bellows. This type of clamshell requires that the existing bellows be removed by grinding off the attachment welds. The factory-made, same-sized 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 cannot be installed while the system is on-line.

Clamshell bellows provide an alternative to replacing the entire expansion joint; however, they only have approximately half of 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 that 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 applications that are subject to frequent movements or large amounts of vibration. Because of these characteristics, clamshell bellows are best suited to non-critical and low-pressure applications.

If expansion joints are low-pressure (less than 5 psig [35 kPa]) breeching joints, there are non-metallic expansion joints that are available, which clamp over the existing metal joint. This type of joint, like the oversized clamshell bellows, could be installed while the system is on-line.

These recommendations and comments were obtained from discussions with the following manufacturers:

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

B

CASES OF ASME BOILER AND PRESSURE VESSEL CODE

**CASE
N-315 [5]**

Approval Date: February 14, 1983

See Numeric Index of expiration
and any reaffirmation dates.

*Cases of ASME Boiler and Pressure Vessel Code***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, proof testing 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.

Target:
Nuclear Power

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

SINGLE USER LICENSE AGREEMENT

THIS IS A LEGALLY BINDING AGREEMENT BETWEEN YOU AND THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). PLEASE READ IT CAREFULLY BEFORE REMOVING THE WRAPPING MATERIAL.

BY OPENING THIS SEALED PACKAGE YOU ARE AGREEING TO THE TERMS OF THIS AGREEMENT. IF YOU DO NOT AGREE TO THE TERMS OF THIS AGREEMENT, PROMPTLY RETURN THE UNOPENED PACKAGE TO EPRI AND THE PURCHASE PRICE WILL BE REFUNDED.

1. GRANT OF LICENSE

EPRI grants you the nonexclusive and nontransferable right during the term of this agreement to use this package only for your own benefit and the benefit of your organization. This means that the following may use this package: (I) your company (at any site owned or operated by your company); (II) its subsidiaries or other related entities; and (III) a consultant to your company or related entities, if the consultant has entered into a contract agreeing not to disclose the package outside of its organization or to use the package for its own benefit or the benefit of any party other than your company.

This shrink-wrap license agreement is subordinate to the terms of the Master Utility License Agreement between most U.S. EPRI member utilities and EPRI. Any EPRI member utility that does not have a Master Utility License Agreement may get one on request.

2. COPYRIGHT

This package, including the information contained in it, is either licensed to EPRI or owned by EPRI and is protected by United States and international copyright laws. You may not, without the prior written permission of EPRI, reproduce, translate or modify this package, in any form, in whole or in part, or prepare any derivative work based on this package.

3. RESTRICTIONS

You may not rent, lease, license, disclose or give this package to any person or organization, or use the information contained in this package, for the benefit of any third party or for any purpose other than as specified above unless such use is with the prior written permission of EPRI. You agree to take all reasonable steps to prevent unauthorized disclosure or use of this package. Except as specified above, this agreement does not grant you any right to patents, copyrights, trade secrets, trade names, trademarks or any other intellectual property, rights or licenses in respect of this package.

4. TERM AND TERMINATION

This license and this agreement are effective until terminated. You may terminate them at any time by destroying this package. EPRI has the right to terminate the license and this agreement immediately if you fail to comply with any term or condition of this agreement. Upon any termination you may destroy this package, but all obligations of nondisclosure will remain in effect.

5. DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, NOR ANY PERSON OR ORGANIZATION ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS OR SIMILAR ITEM DISCLOSED IN THIS PACKAGE, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS PACKAGE IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS PACKAGE OR ANY INFORMATION, APPARATUS, METHOD, PROCESS OR SIMILAR ITEM DISCLOSED IN THIS PACKAGE.

6. EXPORT

The laws and regulations of the United States restrict the export and re-export of any portion of this package, and you agree not to export or re-export this package or any related technical data in any form without the appropriate United States and foreign government approvals.

7. CHOICE OF LAW

This agreement will be governed by the laws of the State of California as applied to transactions taking place entirely in California between California residents.

8. INTEGRATION

You have read and understand this agreement, and acknowledge that it is the final, complete and exclusive agreement between you and EPRI concerning its subject matter, superseding any prior related understanding or agreement. No waiver, variation or different terms of this agreement will be enforceable against EPRI unless EPRI gives its prior written consent, signed by an officer of EPRI.

© 2002 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc. EPRI. ELECTRIFY THE WORLD is a service mark of the Electric Power Research Institute, Inc.

 Printed on recycled paper in the United States of America

1003288