EPRI

Expansion Joint Maintenance Guide

Revision 1, Replaces 1003189

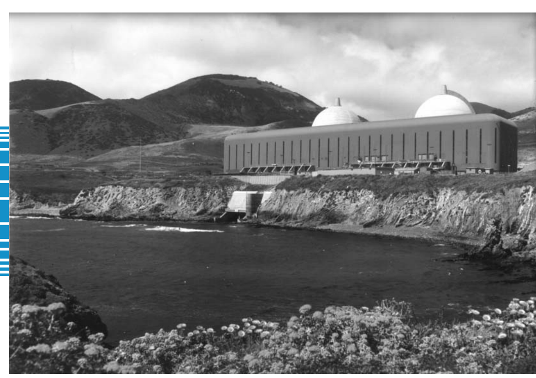
Effective December 6, 2006, this report has been made publicly available in accordance with Section 734.3(b)(3) and published in accordance with Section 734.7 of the U.S. Export Administration Regulations. As a result of this publication, this report is subject to only copyright protection and does not 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

Plant Maintenance Support

Reduced Cost

Equipment Reliability



NMAC

Expansion Joint Maintenance Guide

Revision 1

1008035

Final Report, May 2003

EPRI Project Manager
A. Grunsky

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION 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).

CITATIONS

This report was prepared by

EPRI Nuclear Maintenance Applications Center (NMAC)
1300 W.T. Harris Boulevard
Charlotte, NC 28262

This report describes research sponsored by EPRI.

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

Expansion Joint Maintenance Guide, Revision 1, EPRI, Palo Alto, CA: 2003. 1008035.

REPORT SUMMARY

Background

As the age of nuclear units approaches 25 years, the maintenance costs required for continued operation begins increasing. The condition of expansion joints in power plants is important for continued reliability of the equipment. The life of the expansion joints varies with the design, storage conditions, installation practices, application, and service of the joints. Appropriately timed inspections, repairs, and/or replacement of critical joints will ensure the reliable operation of the associated equipment.

Because of the many recent failures of expansion joints in nuclear stations and the survey responses from the EPRI Nuclear Maintenance Applications Center (NMAC) Site Coordinators in August 2000, a need to develop a guide on expansion joints was identified. During the February 2001 NMAC Steering Committee meeting, the attendees voted unanimously to approve the expansion joint guide project, which resulted in the original edition of this technical report—a comprehensive guide for metal and rubber/fabric expansion joints.

NMAC revised and amended the report subsequent to conducting related research during 2002–2003 after the original report was published. This revision now includes the results of the research and additional guidance for determining the degree of aging and remaining life of certain types of rubber/fabric expansion joints.

Objective

- To develop a comprehensive guide for metal, rubber, and fabric expansion joints that includes descriptive information, design considerations, industry failure data, inspection criteria, maintenance tasks, and replacement issues

Approach

To accomplish the objectives of the project, a search was made for industry information relating to expansion joint practices. The technical information presented in this report was compiled from both utility personnel and manufacturers of expansion joints. Information regarding the types and functions of expansion joints was compiled from industry publications. Failure information was compiled using a survey of utility plant operators, manufacturers’ experience, and industry-wide failure data. Aging testing and research were also completed on several types of rubber/fabric expansion joints.

A Technical Advisory Group composed of utility and manufacturing personnel provided a thorough review of the report.

Results

This guide provides personnel at nuclear power plants with a comprehensive treatment of expansion joint inspection and maintenance. The report will assist plant personnel in understanding the types and functions of expansion joints, operation and failure mechanisms of expansion joints, condition monitoring, and troubleshooting techniques. Maintenance, repair, and replacement issues are also discussed.

Applicable information for expansion joints at fossil fuel plants has been researched and is included in Appendix A of this report.

EPRI Perspective

The physical condition of fabric/rubber and metal expansion joints in power plants is important for continued reliability of the equipment. As such, appropriately timed inspections, repairs, and/or replacement of critical joints ensure the reliable operation of the expansion joint and the system in which it is installed.

The life of these types of expansion joints varies with the design, storage conditions, installation practices, application, and service of the joints. Premature failure of either fabric/rubber or metal in the expansion joints can be avoided by ensuring that loads and movements of the joints remain within the input parameters under which the joints were designed. Introduction of new loads and unanticipated movement, including vibration, can significantly shorten the life of the expansion joint.

This document will assist plant personnel in determining the design features of new or replacement joints required in the station as well as provide guidance in the handling, storage, installation, and inspection of these types of joints in the power plant.

Keywords

Metal expansion joint
Bellows
Rubber/fabric expansion joint

ABSTRACT

As the age of nuclear units approaches 25 years, the maintenance costs required for continued operation begin increasing. The condition of expansion joints in power plants is important for continued reliability of the equipment. The life of the expansion joints varies with the design, storage conditions, installation practices, application, and service of the joints. Appropriately timed inspections, repairs, and/or replacement of critical joints will ensure the reliable operation of the associated equipment.

Because of the many recent failures of expansion joints in nuclear stations and the survey responses from the EPRI Nuclear Maintenance Applications Center (NMAC) Site Coordinators in August 2000, a need to develop an expansion joint guide was identified. During the February 2001 NMAC Steering Committee meeting, the attendees voted unanimously to approve the expansion joint guide project, which resulted in the original edition of this technical report—a comprehensive guide for metal and rubber/fabric expansion joints.

NMAC revised and amended the report subsequent to conducting related research during 2002–2003 after the original report was published. This revision now includes the results of the research and additional guidance for determining the degree of aging and remaining life of certain types of expansion joints.

The purpose of the guide is to provide personnel at nuclear power plants with a comprehensive treatment of expansion joint inspection and maintenance. Applicable information for expansion joints at fossil fuel plants has been researched and is included in Appendix A of this report.

This guide provides a compilation of relevant information regarding the design, operation, and maintenance of expansion joints installed at nuclear power plants. Section 2 provides a tutorial regarding the different types of both metal and rubber/fabric expansion joints, as well as typical configurations of each type. Section 3 discusses failure modes of expansion joints and provides the results of plant-operating experience regarding the failure history of expansion joints. Sections 4 and 5 provide guidance for condition-based monitoring and troubleshooting, respectively.

Section 6 of the report discusses repair techniques for expansion joints, including some recent developments in the area of bellows weld repairs. Section 7 discusses several replacement issues—including life expectancy—and techniques for predicting remaining life of both metal and fabric expansion joints. The appendices provide supporting information.

Expansion joints installed in the following plant applications are typical of the expansion joints discussed in this report:

- Turbine extraction line piping expansion joints
- Condenser neck seal expansion joints
- Feedwater heater piping expansion joints
- Low-energy-piping expansion joints (for example, raw water and cooling water)
- Feedwater pump turbine exhaust joints
- Condensate pump expansion joints
- Turbine cross-over and cross-under piping expansion joints
- Diesel generator exhaust expansion joints
- Service water expansion joints

In general, the plant applications noted in the preceding list require the types of metal and/or rubber/fabric expansion joints discussed in this guide. Expansion joints installed in the following plant applications are not necessarily discussed in this report:

- Instrumentation line expansion joints
- Main steam piping expansion joints
- Building expansion joints
- Air-handling duct expansion joints for boiler and precipitator application (because this report is primarily a nuclear application guide)

However, some of the guidance provided in this report may be applicable on a case-by-case basis.

ACKNOWLEDGMENTS

The following individuals participated as members of the Technical Advisory Group during the development of this report and provided valuable assistance and plant-specific information during its development:

Basil Carney	Duke Power Company
John Davis	Carolina Power & Light
Francuzik Franciszek	Arizona Public Service
Steven Lefler	Duke Power Company
Rob Richard	Ontario Power Generation
Greg Shipley	Duke Power Company
Timothy Szumski	Arizona Public Service
Roy Felkner	US Bellows, Inc.
Jarod Hammar	Garlock Sealing Technologies
Larry Verner	Senior Flexonics Pathway

NMAC and the Technical Advisory Group were supported in this effort by

Sequoia Consulting Group, Inc.
8705 Percy Way
Knoxville, TN 37923

Principal Investigator
Michael Tulay

CONTENTS

1 INTRODUCTION 1-1
1.1 Issues 1-1
1.2 Purpose 1-1
1.3 Scope 1-1
1.3.1 Organization of the Guide 1-1
1.3.2 Scope of Expansion Joints Discussed in This Guide 1-2
1.4 Highlighting of Key Points 1-3
1.5 Definitions 1-3
1.5.1 Metal Expansion Joints 1-3
1.5.2 Rubber/Fabric Expansion Joints 1-6
1.6 Acronyms 1-13

2 FUNCTIONS, TYPES, AND APPLICATIONS OF EXPANSION JOINTS 2-1
2.1 Generic Functions of Expansion Joints 2-1
2.1.1 Motion of Expansion Joints and Types of Deflection 2-1
2.1.2 Other Design Variables for Expansion Joints 2-3
2.2 Types of Metal Expansion Joints 2-5
2.2.1 Single Expansion Joint 2-5
2.2.2 Double Expansion Joint 2-6
2.2.3 Universal Expansion Joint 2-6
2.2.4 Tied Universal Expansion Joint 2-7
2.2.5 Swing Expansion Joint 2-8
2.2.6 Hinged Expansion Joint 2-8
2.2.7 Gimbal Expansion Joint 2-8
2.2.8 Pressure-Balanced Expansion Joint 2-9
2.2.9 Special Features of Metal Expansion Joints 2-9
2.2.9.1 Multi-Ply and Redundant-Ply Bellows 2-9
2.2.9.2 End Connections and Other Features 2-10

2.3 Types of Rubber/Fabric Expansion Joints 2-10
2.3.1 Spool-Arch-Type Expansion Joints 2-11
2.3.1.1 Single-Arch-Type Expansion Joint....... 2-11
2.3.1.2 Multiple-Arch-Type Expansion Joints 2-11
2.3.1.3 Lightweight-Type Expansion Joints 2-12
2.3.1.4 Teflon (TFE/FEP)-Lined Expansion Joints....... 2-12
2.3.2 Reducer-Type Expansion Joints 2-12
2.3.3 Offset-Type Expansion Joints 2-14
2.3.4 Sleeve-Type Expansion Joints....... 2-15
2.3.4.1 Sleeve-Type "Arch" Expansion Joint 2-15
2.3.4.2 Lightweight-Type Expansion Joints 2-16
2.3.4.3 Enlarged-End-Type Expansion Joints 2-16
2.3.5 Special-Flange-Type Expansion Joints 2-16
2.3.5.1 Expansion Joints With Van Stone Beaded-End Flanges 2-16
2.3.5.2 Enlarged-Flange-Type Expansion Joints....... 2-17
2.3.6 Designs for Reduction of Turbulence and Abrasion 2-18
2.3.6.1 Filled-Arch-Type Expansion Joints 2-18
2.3.6.2 Replacement-Liner-Type Expansion Joints 2-19
2.3.6.3 Top-Hat-Liner-Type Expansion Joints 2-20
2.3.7 Arch-Type Expansion Joint With Rectangular Flanges....... 2-20
2.3.8 U-Type Expansion Joints....... 2-21
2.3.8.1 External Full-Face Integral Flange Expansion Joint....... 2-21
2.3.8.2 Internal Full-Face Integral Flange Expansion Joint....... 2-22
2.3.8.3 Spool-Type, No-Arch Expansion Joint....... 2-23
2.3.9 Belt- (or Dogbone-) Type Expansion Joints....... 2-23
2.3.10 Molded, Spherical-Type Expansion Joints 2-24
2.3.10.1 Molded, Spherical-Type Expansion Joints With Solid, Floating Flange....... 2-24
2.3.10.2 Molded, Spherical-Type Expansion Joints With Integral Flanges....... 2-25
2.3.11 Wide-Arch-Type Expansion Joints 2-26
2.3.11.1 Wide-Arch-Type Expansion Joints With Non-Metal Reinforcement 2-26
2.3.11.2 Wide-Arch-Type Expansion Joints With Metal Reinforcement....... 2-27
2.4 Generic Type of Fabric (Ducting) Expansion Joints....... 2-28
2.5 Power Plant Applications....... 2-30
2.5.1 Metal Expansion Joints....... 2-30

2.5.2 Rubber/Fabric Expansion Joints 2-30
2.5.3 Fabric Expansion Joints 2-31

3 GENERIC OPERATION AND FAILURE MECHANISMS OF EXPANSION JOINTS 3-1
3.1 Theory of Operation 3-1
3.1.1 Metal Expansion Joints 3-1
3.1.2 Rubber/Fabric Expansion Joints 3-2
3.2 Failure Mechanisms of Metal Bellows 3-4
3.2.1 Circumferential Cracking 3-4
3.2.2 Squirm or Column Instability 3-4
3.3 Root Causes of Expansion Joint Failures 3-5
3.3.1 Improper Handling 3-5
3.3.2 Anchor Failure 3-6
3.3.3 Corrosion 3-6
3.3.4 Erosion 3-6
3.3.5 Excessive Flow Rate 3-7
3.3.6 Excessive Bellows Deflection 3-7
3.3.7 Fatigue 3-7
3.3.8 Improper Anchoring, Guiding, or Supporting 3-7
3.3.9 Improper Installation 3-8
3.3.10 Overpressurization 3-9
3.3.11 Torsion 3-9
3.3.12 Mechanical Vibration 3-9
3.3.13 Flow-Induced Vibration 3-9
3.3.14 Non-Uniform Temperature Distribution Around Bellows 3-9
3.3.15 Susceptibility to Failure Mechanisms for Different Types of Expansion Joints 3-10
3.4 Failure Data Obtained Through Industry Operating Experience 3-10
3.4.1 Metal Expansion Joint Failure Data 3-11
3.4.2 Rubber Expansion Joint Failure Data 3-13
3.5 Failure History From a Manufacturer's Perspective 3-14
3.5.1 Metal Expansion Joints 3-14
3.5.1.1 Most Common Types of Failures 3-14
3.5.1.2 Most Common Causes of Failures 3-15
3.5.2 Rubber/Fabric Expansion Joints 3-15

3.5.2.1 Most Common Types of Failures....3-15
3.5.2.2 Most Common Causes of Failures....3-16

***4* CONDITION-BASED MONITORING....4-1**
4.1 Preventive Maintenance Recommendations....4-1
4.1.1 Metal Expansion Joints....4-1
4.1.1.1 General Preventive Maintenance Measures....4-1
4.1.1.2 Metal Expansion Joints Inside the Condenser....4-2
4.1.1.3 Considerations for Nondestructive Examination of Bellows....4-3
4.1.2 Rubber/Fabric Expansion Joints....4-3
4.1.2.1 Inspection of the Cover....4-3
4.1.2.2 Inspection of Components Inside/Below the Cover....4-4

***5* TROUBLESHOOTING....5-1**
5.1 Generic Process....5-1
5.1.1 Variance From Design Parameters....5-2
5.2 Detailed Troubleshooting Guidance....5-2
5.2.1 Configuration of Piping System Guides/Anchors....5-3
5.2.1.1 Metal Expansion Joints....5-3
5.2.1.2 Rubber/Fabric Expansion Joints....5-3
5.2.2 Material Incompatibility and Misapplication....5-5
5.2.2.1 Metal Expansion Joints....5-5
5.2.2.2 Rubber/Fabric Expansion Joints....5-5
5.2.3 Installation Practices....5-8
5.3 Example of Troubleshooting....5-9
5.3.1 Problem Identification....5-9
5.3.2 Problem Cause Evaluation....5-10
5.3.3 OEDB Review....5-10
5.3.4 Problem Evaluation....5-11
5.3.5 Corrective Actions....5-11

***6* MAINTENANCE REPAIRS....6-1**
6.1 Metal Expansion Joints....6-1
6.1.1 Repair of Metal Bellows....6-1
6.1.2 Oversized Clamshells....6-1

6.1.3 Same-Size Clamshells....6-3
6.1.4 Other Welding Applications....6-4
6.2 Rubber/Fabric Expansion Joints....6-4

***7* REPLACEMENT ISSUES....7-1**
7.1 Cyclic Deflections and Cycle Life....7-1
7.2 Calculating Stresses Associated With Metal Bellows....7-1
7.3 Predicting Remaining Life of Metal Expansion Joints....7-2
7.3.1 Calculation Method....7-2
7.3.2 Nondestructive Examination With Dye-Penetrant....7-2
7.3.3 Nondestructive Examination of Wall Thickness....7-2
7.4 Predicting Remaining Life of Rubber Expansion Joints....7-3
7.4.1 Background of Related Research....7-3
7.4.2 Need for Further Investigation....7-3
7.4.2.1 Choice of Mechanical Tests....7-4
7.4.2.2 Accelerated Thermal Aging....7-4
7.4.2.3 Materials Tested....7-5
7.4.2.4 Test Results....7-5
7.4.2.5 Comparison to Field Results....7-9
7.4.2.6 Generic Implications of Materials Test Results....7-9
7.4.2.7 Conclusions....7-11
7.5 Extending Service Life of Certain Rubber/Fabric Expansion Joints....7-12

***8* REFERENCES....8-1**

***A* EXPANSION JOINT ISSUES SPECIFIC TO FOSSIL POWER PLANTS....A-1**
A.1 Overview....A-1
A.2 Failure History of Expansion Joints at Fossil Power Plants....A-2

***B* SPECIFICATION GUIDANCE FOR EXPANSION JOINTS....B-1**
B.1 Metal Expansion Joint....B-1
B.2 Rubber/Fabric Expansion Joint....B-4
B.3 Fabric (Ducting) Expansion Joints....B-5

***C* FAILURE DATA OF EXPANSION JOINTS....C-1**
C.1 Survey Questionnaire....C-1

C.2 Compilation of Survey Results C-3
C.3 Industry Failure Data for Metal Expansion Joints C-15
C.4 Failure Data for Rubber/Fabric Expansion Joints C-17

D INDENTER POLYMER AGING MONITOR D-1
D.1 Introduction D-1
D.2 Operation D-1
D.3 Indenter Data D-3

E AGING MANAGEMENT ASSESSMENT E-1
E.1 Introduction E-1
E.2 Discussion of Expansion Joints E-1
E.3 Operation Experience at the Plant E-2
E.4 Inputs From a Program at a Plant of Similar Design E-3
E.5 Follow-On Activities E-3

F LISTING OF KEY INFORMATION F-1

LIST OF FIGURES

Figure 2-1 Axial Movements of an Expansion Joint....2-2
Figure 2-2 Lateral Deflection of an Expansion Joint....2-2
Figure 2-3 Angular Rotation of an Expansion Joint....2-3
Figure 2-4 Torsional Deflection of an Expansion Joint....2-3
Figure 2-5 Generic Cross-Section of a Metal Expansion Joint....2-5
Figure 2-6 Single Expansion Joint....2-6
Figure 2-7 Double Expansion Joint....2-6
Figure 2-8 Universal Expansion Joint....2-7
Figure 2-9 Tied Universal Expansion Joint....2-7
Figure 2-10 Swing Expansion Joint....2-8
Figure 2-11 Hinged Expansion Joint....2-8
Figure 2-12 Gimbal Expansion Joint....2-9
Figure 2-13 Pressure-Balanced Expansion Joint....2-9
Figure 2-14 Single-Arch-Type Expansion Joint....2-11
Figure 2-15 Multiple-Arch-Type Expansion Joint....2-12
Figure 2-16 Concentric Design of Reducer-Type Expansion Joint....2-13
Figure 2-17 Eccentric Design of Reducer-Type Expansion Joint....2-14
Figure 2-18 Offset-Type Expansion Joint....2-15
Figure 2-19 Sleeve-Type Expansion Joint....2-16
Figure 2-20 Expansion Joint With Van Stone Beaded-End Flange....2-17
Figure 2-21 Enlarged-Flange-Type Expansion Joint....2-18
Figure 2-22 Filled-Arch-Type Expansion Joint....2-19
Figure 2-23 Replacement-Liner-Type Expansion Joint....2-19
Figure 2-24 Top-Hat-Liner-Type Expansion Joint....2-20
Figure 2-25 Arch-Type Expansion Joint With Rectangular Flanges....2-21
Figure 2-26 External Full-Face Integral Flange Expansion Joint....2-22
Figure 2-27 Internal Full-Face Integral Flange Joint....2-22
Figure 2-28 Spool-Type, No-Arch Expansion Joint....2-23
Figure 2-29 Belt-Type Expansion Joint....2-24
Figure 2-30 Molded, Spherical-Type Expansion Joint With Solid, Floating Flanges....2-25
Figure 2-31 Molded, Spherical-Type Expansion Joint With Integral Flanges....2-26
Figure 2-32 Wide-Arch-Type Expansion Joints With Non-Metal Reinforcement....2-27

Figure 2-33 Wide-Arch-Type Expansion Joints With Metal Reinforcement 2-28
Figure 2-34 Typical Fabric (Ducting) Expansion Joint Components 2-28
Figure 3-1 Column Instability or Squirm 3-5
Figure 3-2 Common Failures of Metal Expansion Joints 3-11
Figure 3-3 Common Causes of Metal Expansion Joint Failures 3-12
Figure 3-4 Extraction Steam Expansion Joint With Cracked Liner 3-12
Figure 3-5 Condenser Expansion Joint With Cracked Bellows 3-13
Figure 3-6 Common Failures of Rubber Expansion Joints 3-13
Figure 3-7 Common Causes of Rubber Expansion Joint Failures 3-14
Figure 3-8 Common Types and Locations of Failures of Metal Expansion Joints 3-14
Figure 5-1 Generic Troubleshooting Process for Expansion Joint Failures – Preliminary Evaluation 5-1
Figure 5-2 Generic Troubleshooting Process for Expansion Joint Failures – Detailed Evaluation 5-2
Figure 5-3 Failure of Expansion Joint 1HF11 5-10
Figure 5-4 Failure of Expansion Joint 1HF11 5-10
Figure 6-1 Oversize Clamshell Bellows 6-2
Figure 6-2 Same-Size Clamshell Bellows 6-3
Figure 7-1 Holz EPDM Durometer versus Elongation at Break (EatB) 7-6
Figure 7-2 Holz EPDM Indenter Modulus (IM) versus EatB 7-6
Figure 7-3 Garlock EPDM Durometer versus EatB 7-7
Figure 7-4 Garlock EPDM IM versus EatB 7-8
Figure 7-5 Garlock Chlorobutyl Durometer versus EatB 7-8
Figure 7-6 Garlock Chlorobutyl IM versus EatB 7-9
Figure A-1 Layout of Ducting for a Typical Boiler A-1
Figure D-1 Indenter's Principle of Operation Concept D-1
Figure D-2 Indenter System with 25-Foot (7.6 m) Extension Cable, Adaptors, and Calibration Bench D-2
Figure D-3 Cable Clamp with Specimen Clamped for Test D-2
Figure D-4 Typical Indenter Plot for Mildly Aged Hypalon Cable Material D-3
Figure D-5 IM and EatB versus Thermal Aging at 248°F (120°C) for Hypalon Cable Material D-4

LIST OF TABLES

Table 3-1 Susceptibility to Failure for Different Types of Expansion Joints............................3-10
Table 5-1 Detailed Troubleshooting Guidance for Rubber/Fabric Expansion Joints 5-4
Table 5-2 Common Metallurgical Problems and Troubleshooting 5-5
Table 5-3 Temperature Class of Materials Used in Expansion Joints......................................5-6
Table 5-4 List of Elastomers Used in Expansion Joints...5-7
Table 5-5 Installation Practices Leading to Failure of Metal Expansion Joint 5-8
Table 5-6 Installation Practices Leading to Failure of Rubber/Fabric Expansion Joint.............5-8

1 INTRODUCTION

1.1 Issues

As the age of nuclear units approaches 25 years, the maintenance costs required for continued operation begins increasing. The condition of expansion joints in the plants is important for continued reliability of the equipment. The life of the expansion joints varies with the design, storage conditions, installation practices, application, and service of the joints. Appropriately timed inspections, repairs, and/or replacement of critical joints will ensure reliable operation of the associated equipment.

Because of the many recent failures of expansion joints in nuclear stations and the survey responses from the EPRI Nuclear Maintenance Applications Center (NMAC) Site Coordinators in August 2000, a need to develop an expansion joint guide was identified. During the February 2001 NMAC Steering Committee meeting, the attendees voted unanimously to approve the expansion joint guide project, which resulted in this technical report—a comprehensive guide for metal and rubber/fabric expansion joints.

1.2 Purpose

The purpose of the original guide was to provide personnel at nuclear power plants with a comprehensive treatment of expansion joints inspection and maintenance. Applicable information for expansion joints at fossil fuel plants was researched and was included in Appendix A of this report.

NMAC revised and amended the report subsequent to conducting related research during 2002–2003 after the original report was published. This revision now includes the results of the research and additional guidance for determining the degree of aging and remaining life of certain types of expansion joints.

1.3 Scope

1.3.1 Organization of the Guide

This guide provides a compilation of relevant information regarding the design, operation and maintenance of expansion joints installed at nuclear power plants. Section 2 provides a tutorial regarding the different types of both metal and rubber/fabric expansion joints, as well as typical configurations of each type. Section 3 discusses failure modes of expansion joints and provides the results of plant-operating experience regarding the failure history of expansion joints. Sections 4 and 5 provide guidance for condition-based monitoring and troubleshooting, respectively.

Section 6 of the report discusses repair techniques for expansion joints, including some recent developments in the area of bellows weld repairs. Section 7 discusses several replacement issues—including life expectancy—and techniques for predicting remaining life of both metal and fabric expansion joints. The appendices provide supporting information.

1.3.2 Scope of Expansion Joints Discussed in This Guide

Expansion joints installed in the following plant applications are typical of the expansion joints discussed in this report:

- Turbine extraction line piping expansion joints
- Condenser neck seal expansion joints
- Feedwater heater piping expansion joints
- Low-energy-piping expansion joints (for example, raw water, cooling water)
- Feedwater pump turbine exhaust expansion joints
- Condensate pump expansion joints
- Turbine cross-over and cross-under piping expansion joints
- Diesel generator exhaust expansion joints
- Service water expansion joints

In general, the plant applications noted above require the types of metal and/or rubber/fabric expansion joints discussed in this guide. Expansion joints installed in the following plant applications are not necessarily discussed in this report:

- Instrumentation lines
- Main steam piping joints
- Building expansion joints
- Air handling duct expansion joints for boiler and precipitator application (because this report is primarily a nuclear application guide)

However, some of the guidance provided in this report may be applicable on a case-by-case basis.

1.4 Highlighting of Key Points

Throughout this report, key information is summarized in "Key Points." Key Points are bold lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to take action for the benefit of their plant. The information included in these Key Points was selected by NMAC personnel, consultants, and utility personnel who prepared and reviewed this report.

The Key Points are organized according to the three categories: O&M (operating and maintenance) costs, technical, and human performance. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Key Human Performance Point

Denotes information that requires personnel action or consideration to prevent injury or damage or to ease completion of the task.

Appendix F contains a listing of all Key Points in each category. The listing restates each Key Point and provides reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information that the writers of this guide believe would benefit their plants.

1.5 Definitions

1.5.1 Metal Expansion Joints

EPRI has adopted and encourages the use of the definitions of expansion joint components and related equipment as published by the Expansion Joint Manufacturers Association (EJMA). The definitions in this report are taken, in part, from the seventh edition of the EJMA Standards.

Anchor (main) – A main anchor is the one that must withstand the full bellows thrust because of flow, piping forces, and other piping loads, but not the thrust because of pressure.

Anchor (intermediate) – An intermediate anchor is one that must withstand the bellows thrust because of pressure, flow, spring forces, and all other piping loads. A main anchor base for connection to the anchor structure can be furnished as an integral part of a single or double expansion joint, if desired. The expansion joint manufacturer must be advised of the magnitude and direction of all forces and moments which will be imposed upon the anchor base, so that it can be adequately designed to suit the specific application.

Anchor (directional) – A directional or sliding anchor is one that is designed to absorb loading in one direction while permitting motion in another. It may be either a main or intermediate anchor, depending upon the application involved. When designed for the purpose, a directional anchor may also function as a pipe alignment guide. In the design of a directional anchor, an effort should be made to minimize the friction between its moving or sliding parts, because this will reduce the loading on the piping and equipment and ensure proper function of the anchor.

Bellows – The flexible element of an expansion joint consisting of one or more convolutions and the end tangents.

Control rods (metal expansion joints) – Devices, usually in the form of rods or bars, attached to the expansion joint assembly whose primary function is to distribute movement between the two bellows of a universal expansion joint. Control rods are not designed to restrain pressure thrust.

Cover – A device used to provide protection of the exterior surface of the bellows of an expansion joint from foreign objects or mechanical damage. A cover is sometimes referred to as a shroud.

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

Equalizing and reinforcing rings – Devices used on some expansion joints that fit snugly in the roots of the convolutions. The primary purpose of these devices is to reinforce the bellows against internal pressure. Equalizing rings are made of cast iron, carbon steel, stainless steel, or other suitable alloy, and are shaped, approximately, as a “T” in cross section. Reinforcing rings are fabricated from tubing or solid round bars of carbon steel, stainless steel, or other suitable alloys.

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

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

Hinge – A device consisting of a pin through two plates that is attached in pairs to the ends of an expansion joint to permit angular rotation in one plane only. The hinges and hinge pins are designed to restrain the thrust of the expansion joint due to internal pressure and extraneous forces, where applicable.

Internal sleeve – A device that minimizes contact between the inner surface of the bellows of an expansion joint and the fluid flowing through it. These devices have also been referred to as liners, telescoping sleeves, and other similar names.

Limit rods – Devices, usually in the form of rods or bars, attached to the expansion joint assembly whose primary function is to restrict the bellows movement range (that is, axial, lateral, and angular) during normal operation. They are designed to prevent over-extension or over-compression of the bellows while restraining the full pressure loading and dynamic forces generated by a main anchor failure. Note: For rubber/fabric expansion joints, this term is often referred to as "control rods."

Multi-ply bellows – A bellows manufactured from more than a single ply of sheet material.

Pantograph linkages – A scissor-like device. A special form of control rod attached to the expansion joint assembly whose primary function is to positively distribute the movement equally between the two bellows of the universal joint throughout its full range of movement. Pantograph linkages, like control rods, are not designed to restrain pressure thrusts.

Pipe alignment guide – A pipe alignment guide is a form of framework fastened to some rigid part of the installation that permits the pipeline to move freely along the axis of the pipe.

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

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 or angular rotation resulting from L- or Z-shaped piping configurations.

Pressure thrust – A static axial thrust attributable to internal pressure in the expansion joint, normally measured in pounds. Static thrust is one component of force when calculating the main anchor loads and can be quite large.

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

Redundant-ply bellows – A bellows manufactured with multiple plies, but with each ply being sufficient to act alone in providing sufficient thickness for pressure design.

Shipping devices – Rigid support devices installed on an expansion joint to maintain the overall length of the assembly for shipment. These devices may also be used to precompress, pre-extend or laterally offset the bellows.

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

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

Weld ends – The ends of an expansion joint equipped with pipe suitably beveled for welding to adjacent equipment or piping.

1.5.2 Rubber/Fabric Expansion Joints

EPRI has adopted and encourages the use of the definitions of expansion joint components and related equipment as published by the Fluid Systems Association (FSA). The selected definitions in this report are taken, in part, from the sixth edition of the FSA Technical Handbook. The user should refer to this handbook for a complete glossary of terms.

Abrasion resistance – The ability to withstand the wearing effect of a rubbing surface. In elastomers, abrasion is a complicated process, often affected more by compounding and curing than by the elastomer. Soft, resilient compounds, such as pure gum rubber, are frequently specified.

Adhesion – The strength of bond between cured rubber surfaces or cured rubber surface and a non-rubber surface.

Ambient temperature – The environment temperature surrounding the object under consideration.

Anchor – Terminal point or fixed point in a piping system from which directional movement occurs.

Angular movement – The movement that occurs when one flange of the expansion joint is moved to an out-of-parallel position with the other flange. Such movement is measured in degrees.

Arch – That portion of an expansion joint that accommodates the movement of the joint.

Atmospheric cracking – Cracks produced on surface of rubber articles by exposure to atmospheric conditions, especially sunlight, ozone, and pollution.

Axial compression – The dimensional shortening of an expansion joint parallel to its longitudinal axis. Such movement is measured in inches or millimeters and usually caused by thermal expansion of the piping/ducting system.

Axial elongation – The dimensional lengthening of an expansion joint parallel to its longitudinal axis. Such movement is measured in inches or millimeters.

Back-Up Bars – Metal bars used for the purpose of clamping a rectangular/square expansion joint to mating ductwork.

Bellows – That portion of an expansion joint that accommodates the movement of the joint convoluted or flat.

Belt-type expansion joint – An expansion joint in which the flexible bellows portion of the joint is made flat and bolted or clamped to metal adapter flanges or frames.

Bending module – A force required to induce bending around a given radius; hence a measure of stiffness.

Blister – A raised spot on the surface or a separation between layers, usually forming a void or air-filled space in the rubber article.

Bloom – A natural discoloration or change in appearance of the surface of a rubber product caused by the migration of a liquid or solid to the surface.

Blown tube/body/cover – A soft area caused by porosity below the surface.

Bolt hole pattern or drill pattern – The systematic location of bolt holes in the expansion joint flanges where joint is to be bolted to mating flanges.

Bolt-in baffle/flow liners – A baffle that is designed to be bolted to the breach flange. (Note: Bolt-in baffles/flow liners require the use of a seal gasket.)

Boot or belt – The flexible element of an expansion joint usually consisting of rubber and rubber-coated fabric.

Bore – A fluid passageway normally located on the inside diameter of the expansion joint.

Breach opening or duct face-to-face distance – The distance between the mating duct flanges in which the joint is to be installed.

Breaker fabric – Transition fabric between the tube and carcass.

Burst test – A test to measure the pressure at which a sample expansion joint bursts.

Capped end – A seal on the end of a sleeve joint or flange to protect internal reinforcement.

Cemented edge – An application of cement around the edges of an expansion joint with or without internal reinforcement for protection or adhesion.

Chalking – Formation of a powdery surface condition because of disintegration of surface binder or elastomer, which was, in turn, created by weathering or other destructive environments.

Checking – The short, shallow cracks on the surface of a rubber product resulting from damaging action of environmental conditions.

Clamp bars – Same as back-up bars.

Coefficient of thermal expansion – Average expansion per degree over a stated temperature range, expressed in a fraction of initial dimension.

Cold flow – Continued deformation under stress.

Compression set – The deformation that remains in rubber after it has been subjected to and released from a specific compressive stress for a definite period of time, at a prescribed temperature.

Concurrent movements – Combination of two or more types (axial or lateral) of movement.

Conductive – A rubber having qualities of conducting or transmitting heat or electricity, most generally applied to rubber products capable of conducting static electricity.

Control rods or units – Devices usually in the form of tie rods attached to the expansion joint assembly whose primary function is to restrict the bellows' axial movement range during normal operation. In the event of a main anchor failure, they are designed to prevent bellows' over-extension or over-compression while absorbing the static pressure thrust at the expansion joint generated by the anchor failure.

Cover – The outermost ply of material of an elastomeric expansion joint.

Design pressure/vacuum – The pressure or vacuum condition that exists during system start-up and/or shut-down operations. During this cyclic phase in the system, both pressure and vacuum conditions may occur.

Design temperature – The maximum or most severe high or low temperature that the system may reach during normal operating conditions.

Diameter, inside – The length of a straight line through the geometric center and terminating at the inner periphery of an expansion joint.

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

Drill pattern – The systematic location of bolt holes on the mating flange to which the expansion joint will be attached. Usually meets a specific specification.

Duck – A durable, closely woven fabric.

Durometer – A measurement of the hardness of the rubber.

Eccentricity – A condition in which the inside and outside of two diameters deviate from a common center.

Elasticity – The ability to return to the original shape after removal of load without regard to the rate of return.

Elastomer – An elastic rubber-like material that, in the vulcanized state and at room temperature, can be stretched repeatedly to at least twice its original length. Upon release of the stress, this material will immediately return to approximately its original length.

Electrical resistivity – The resistance between opposite parallel faces of material having a unit length and unit cross-section. Typically measured in Ohms/cm.

Elongation – Increase in length expressed numerically as a fraction or a percentage of initial length.

Enlarged end – An end with inside diameter greater than that of the main body of an expansion joint.

Excursion temperature – The temperature the system could reach during an equipment failure. Excursion temperature should be defined by maximum temperature and time duration of excursion.

Face-to-face (F/F) – Dimension between the pipe flange faces to which the expansion joint will be bolted. This is also the length of the expansion joint when the system is in the cold position.

Fatigue – The weakening or deterioration of a material caused by a repetition of stress or strain.

Flanged end – Turned up or raised end made so that it can be bolted to an adjacent flange.

Flanges – That part of an expansion joint used for fastening the joint into the system. Can be either metal or same material as the bellows.

Flex cracking – A surface cracking induced by repeated bending or flexing.

Flex life – The relative ability of a rubber article to withstand cyclical bending stresses.

Floating flange – Metal flange that is grooved to contain the bead on each end of an expansion joint. The flange floats until lined up with mating bolt holes and bolted in place, and is used on spherical expansion joints.

Flow direction – Direction of media (for example, fluid, gas, air) movement through the system.

Flow liner (baffle) – A metal shield that is designed to protect the expansion joint from the abrasive media in the stream and to reduce flutter caused by the air turbulence in the gas stream. Flow liners/baffles may be welded or bolted into position.

Force pounds – The total load required to deflect an expansion joint a distance equal to the maximum rated movement of the product.

Free length – The linear measurement before being subjected to a load or force.

Friction – A rubber compound applied to and impregnating a fabric. Usually by means of a calender with rolls running at different surface speed; hence the name “friction.” The process is called “fractioning.”

Frictioned fabric – A fabric with a surface treatment that will bond two surfaces together when interposed between the surfaces. Also may be used to adhere to only one surface.

Hardness – Property or extent of being hard. Measured by extent of failure of the indenter point of any one of a number of standard hardness testing instruments to penetrate the product.

Heat resistance – The ability of rubber articles to resist the deteriorating effects of elevated temperatures.

Helix – Shape formed by spiraling a wire or other reinforcement around the cylindrical body of a rubber pipe.

Hydraulic pressure – A force exerted through fluids.

Inner ply – The inside ply of a multiple-layered joint.

Installed face-to-face distance – The distance between the expansion joint flanges after installation when the system is in the cold (off) position.

Integrally-flanged-type expansion joint – An expansion joint in which the joint flanges are made of he same rubber and fabric as the body of the joint.

Lateral deflection of lateral movement – The relating displacement of the two ends of the expansion joint perpendicular to its longitudinal axis. Lateral movement is usually caused by the thermal expansion of the ducting system and measured in inches or millimeters.

Lateral offset – The offset distance between two adjacent flanges or faces. Can be attributable to misalignment or by design to compensate for excessive displacement in the opposite direction during cycling.

Main anchor – A main anchor is one that must withstand all of the thrust attributable to pressure, flow, and spring forces of the system.

Mandrel – A form used for sizing and to support the expansion joint during fabrication and/or vulcanization. It may be rigid or flexible.

Mandrel built – An expansion joint fabricated and/or vulcanized on a mandrel.

Manufactured face-to-face (F/F) of expansion joint – The manufactured length of the joint measured from joint flange face to flange face. The joint may be set into a breach opening that is less than the manufactured F/F of the joint to allow for axial extension.

Manufactured flange-to-flange dimension – The manufactured width of the joint measured from joint flange face to flange face.

Maximum burst – The theoretical (predetermined) burst pressure of an expansion joint.

Misalignment – The out-of-line condition that exists between the adjacent faces of the flanges.

Molded-type expansion joint – An expansion joint in which the entire wall of the joint is molded into a “U” or convoluted configuration. The joint is manufactured by a molding process.

Movements – The dimensional changes that the expansion joint is designed to absorb, such as those resulting from thermal expansion or contraction.

Non-metal expansion joint – Expansion joint that uses flexible, non-metal material to accommodate joint movements.

Oil resistant – The ability to withstand the deteriorating effects of oil (generally refers to petroleum) on the physical properties.

Oil swell – The change in volume of rubber attributable to absorption of oil.

Operating pressure/vacuum – The pressure or vacuum condition that occurs during normal performance. This should be pressure or vacuum, not both.

Operating temperature – The temperature at which the system will generally operate during normal conditions.

Permeability – The ability of a fluid or gas to pass through an elastomer.

Permanent set – The deformation remaining after a specimen has been stressed in tension or compression a prescribed amount for a definite period and released for a definite period.

Pipe alignment guide – A pipe alignment guide is framework fastened to some rigid part of the installation that permits the pipeline to move freely in only one direction along the axis of the pipe. Pie alignment guides are designed primarily for used in applications to prevent lateral deflection and angular rotation.

Ply – One concentric layer or ring of material, such as fabric plies in an expansion joint.

Pre-compression – Compressing the expansion joint (shortening the F/F) so that in the cold position the joint has a given amount of compression set into the joint. The purpose of pre-compression is to allow for unexpected or additional axial extension. This is performed at the job site.

Pre-set – Dimension that joints are deflected to ensure that desired movements will take place.

Pressure – Force per unit area, usually expressed in pounds per square inch (PSI) or kilograms per square centimeter.

Pressure (absolute) – The pressure above zero absolute. (that is, the sum of atmospheric and gage pressure)

Pressure (atmospheric) – Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 lb/square inch [1 atmosphere or 1.034 kg/square cm] absolute).

Pressure (gage) – Pressure differential above or below atmospheric pressure. (Expressed as lb/square inch gage, or PSIG)

Resultant movement – The net effect of concurrent movement.

Retaining rings – Segmented metal rings installed directly against the back of the expansion joint flange and bolted through to the metal flange of the pipe.

Reversion – The change that occurs in vulcanized rubber as the result of chemical attack or elevated temperatures, usually resulting in a gummy or semi-plastic mass.

Service test – A test in which the expansion joint is operated under service conditions in the actual equipment.

Soft end – An end in which the rigid reinforcement of the body (usually wire) is omitted.

Specific gravity – The ratio of the weight of a given substance to the weight of an equal volume of water at a specified temperature.

Spring rate – The force in pounds required to deflect an expansion joint 1 inch in compression and elongation or in a lateral direction.

Static wire – A wire incorporated in an expansion joint for conducting or transmitting static electricity.

Straight end – An end with inside diameter the same as that of the main body.

Surge pressure – Operating pressure plus the increment above operating pressure that the expansion joint will be subjected to for a very short time period. Surge pressure is typically attributable to pump starts, valve closing, and other similar phenomena.

Tensile strength – The force required to rupture a specimen. “Dumbell” specimens are cut from flat stock by die of specified shape. Large elongations require special considerations in holding specimens and measuring the test results.

Thermal movements – Movements created within the piping system by thermal expansion. Can be axial, lateral, or torsional.

Tolerance – The upper and lower limits between which a dimension must be held.

Torque – A force that either attempts, or actually does produce, rotation.

Torsional rotation – The twisting of one end of an expansion joint with respect to the other end about its longitudinal axis. Such movement being measured in degrees as is angular rotation.

Tube – The inner ply of the expansion joint that is in direct contact with the system media.

Under gauge – Thinner than the thickness specified.

Van stone joint – A loose, rotating-type flange, sometimes call a lap-joint flange.

Vulcanization – An irreversible process during which a rubber compound, through a change in its chemical structure becomes less plastic and more resistant to swelling by organic liquids and its elastic properties are conferred, improved, or extended over a greater range of temperature.

Weathering – The surface deterioration of a rubber article during outdoor exposure, such as cracking, crazing, or chalking.

Wire Reinforced – A product containing metal wire to give added strength, increased dimensional stability, or crush resistance.

Wrap marks – Impressions left on the cover surface by the material used to wrap the expansion joint during vulcanization. Usually shows characteristics of a woven pattern and wrapper width edge marks.

1.6 Acronyms

ANSI – American National Standards Institute

ASME – American Society of Mechanical Engineers

ASTM – American Society for Testing Materials

AWG – American Wire Gauge

EatB – Elongation at break

EJMA – Expansion Joint Manufacturers Association, Inc.

EPDM – Ethylene propylene diene monomer

FEP – Fluoro ethylene propylene (polymers)

FSA – Fluid Sealing Association

GRS – Gum rubber synthetic

ID – Inside diameter

IM – Indenter modulus

INPO – Institute for Nuclear Power Operations

ISA – Instrument Society of America

MARF – Modification Action Request Form

MCE – Mechanical/Civil Engineering Group

NDE – Nondestructive examination

NMAC – Nuclear Maintenance Applications Center

NPRDS – Nuclear Parts Reliability Data System

NSSS – Nuclear Steam Supply System

OD – Outside diameter

OEDB – Operational experience data base

PSE – Plant Support Engineering

PSI – Pounds per square inch

PSIG – Pounds per square inch gage

PVC – Polyvinyl chloride

RMA – Rubber Manufacturing Association

RRAC – Repair and Replacement Applications Center

SBR – Styrene butadiene rubber

SCC – Stress corrosion cracking

TPE – Poly-tetra propylene ethylene

USNRC – United States Nuclear Regulatory Commission

2
FUNCTIONS, TYPES, AND APPLICATIONS OF EXPANSION JOINTS

2.1 Generic Functions of Expansion Joints

The general function of an expansion joint is to absorb dimensional changes, such as those caused by thermal expansion or contraction of a pipeline, duct, or vessel. The motion that an expansion joint may be subjected to will vary from application to application and is discussed in the following section.

2.1.1 Motion of Expansion Joints and Types of Deflection

To properly apply expansion joints to piping systems, it is necessary to understand not only how the pipe flexes but also how the various types of expansion joints function and what the designs are capable of doing. It may be relatively easy to visualize that deflections may result from thermal expansion or the movements and vibrations of equipment and structures; however, all expansion joints do not accept the same types of deflection. Many can accept certain loads and moments, while other are incapable of resisting externally applied forces. Understanding the type, magnitude, and direction of these forces and deflections is critical, not only to the safety of the system but also to its cost.

The various dimensional changes that an expansion joint is required to absorb, such as those resulting from thermal changes in a piping system, are described in the following paragraphs.

Axial motion is motion occurring parallel to the centerline of the bellows and can be either extension or compression. Compression is the axial deflection that shortens the bellows length. Often confusion occurs because thermal expansion in the piping will cause the expansion joint to be compressed. The specification for an expansion joint should always state the movements as they affect the expansion joint, and not as they are produced by the system.

Key Technical Point

Often confusion occurs because thermal expansion in the piping will cause the expansion joint to be compressed. The specification for an expansion joint should always state the movements as they affect the expansion joint, and not as they are produced by the system.

Extension is the axial deflection that stretches the expansion joint. Piping that is operating at temperatures lower than ambient, such as in cryogenic system, will contract, causing the expansion joint to stretch or experience extension. Axial movements are illustrated in Figure 2-1.

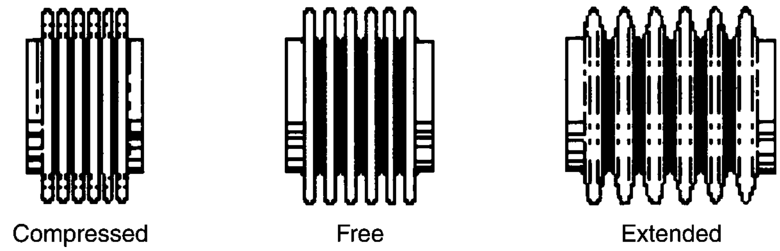


Figure 2-1
Axial Movements of an Expansion Joint (Courtesy of Piping Technology & Products, Inc.)

Lateral deflection, also known as parallel offset or transverse deflection, is motion that occurs perpendicular, or at right angles to the centerline of the bellows. This movement occurs with both of the ends of the expansion joint remaining parallel to each other, with their centerlines being displaced, or no longer coincident. Lateral deflection can occur along one or more lateral axis simultaneously. Because an expansion joint is round, these various deflections must be resolved into a single resultant lateral deflection, if the bellows is to be properly selected in terms of the rated lateral deflection shown in most manufacturers' catalogs. The magnitude of the resultant lateral deflection is the square root of the sum of the squares of the individual deflections. The planes of the various deflections must also be clearly understood if the expansion joint is to contain structural components such as hinges, which may inhibit movements in certain directions, and if the individual deflections can occur separately during the life of the expansion joint. Lateral movement is illustrated in Figure 2-2.

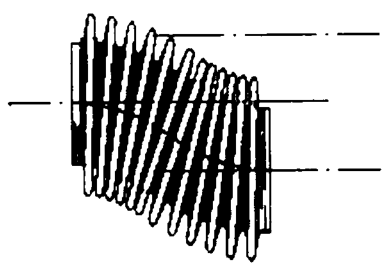


Figure 2-2
Lateral Deflection of an Expansion Joint (Courtesy of Piping Technology & Products, Inc.)

Angular deflection is the bending of an expansion joint along its centerline, and is illustrated in Figure 2-3. Angular deflection can occur in any plane that passes through the centerline, but the plane should be clearly indicated if the expansion joint is more complicated than the simplest type (that is, only a bellows with flanges or pipe ends). As in lateral movements, piping analyses may reveal angular deflections occurring in more than one plane. With angular deflection, the basis for the proper selection is the maximum of the various deflections, and not the vector sum as in the lateral case. Multiple angular deflections in multiple planes produce a single angular deflection in a single resultant plane. As in lateral deflection, this plane must be understood if structural components are to be used.

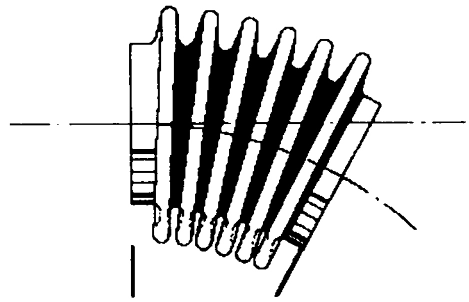


Figure 2-3
Angular Rotation of an Expansion Joint (Courtesy of Piping Technology & Products, Inc.)

As illustrated in Figure 2-4, torsional deflection refers to twisting one end of the bellows with respect to the other end, about the bellows centerline. Metal expansion joints are not normally expected to accept torsional deflection, because the bellows is essentially inflexible in this direction.

Key Technical Point

Metal expansion joints are not normally expected to accept torsional deflection, because the bellows is essentially inflexible in this direction.

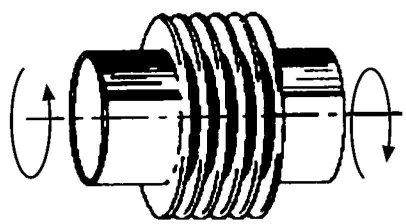


Figure 2-4
Torsional Deflection of an Expansion Joint (Courtesy of Piping Technology & Products, Inc.)

2.1.2 Other Design Variables for Expansion Joints

In addition to the expected movement to which the expansion joint will be subjected, the design variables (shown in the following bulleted list) should also be specified to the manufacturer.

Size – Size refers to the diameter of the pipeline (or dimensions of the duct in the case of rectangular joints) into which the expansion joint is to be installed. The size of an expansion joint affects its pressure-rating capabilities, as well as its ability to absorb certain types of movements.

Flowing medium – The substances that will come in contact with the expansion joint should be specified. In cases where excessive erosion or corrosion potential exists or, in cases where high-viscosity substances are being transported, special material and accessories should be specified.

When piping systems containing expansion joints are cleaned periodically, the cleaning solution must be compatible with the bellows material.

Internal and external fluid flow rates – The rate of flow of the medium passing through the expansion joint will effect the velocity of the fluid, its resulting thrust forces upon the piping system, and the rate at which the flowing medium can erode the inside surfaces of the joint. The flow rate should be included in the design specification. The maximum allowable flow velocity past a bellows' convolutions can be calculated. Velocities in excess of this require that a liner be used on the inside of the expansion joint or a cover be used on the outside of the expansion joint.

Pressure – Pressure is possibly the most important factor 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. While the determination of pressure requirements is important, care should be exercised to ensure that these specified pressures are not increased by unreasonable safety factors as this could result in a design that may not adequately satisfy other performance characteristics.

Temperature – The operating temperature of the expansion joint will affect its pressure capacity, cycle life, stability, and material requirements. All possible temperature sources should be investigated when determining minimum and maximum temperature requirements. In so doing, however, it is important that only those temperatures occurring at the expansion joint location itself be specified. Specifying temperature remote from the expansion joint may unnecessarily result in the need for special materials at additional expense.

Key Technical Point

Specifying temperature remote from the expansion joint may unnecessarily result in the need for special materials at additional expense.

External temperatures, especially ones that are not uniformly distributed around the bellows, also can affect bellows longevity.

Vibration – The predicted amplitude and frequency of external mechanical vibrations to be imposed on the bellows, such as caused by reciprocating or pulsating machinery, should be a design input and be specified. The expansion joint must subsequently be designed to avoid the resonant vibration of the bellows to preclude the possibility of sudden fatigue failure.

Appendix B of this report provides additional guidance when specifying various types of metal and fabric expansion joints.

2.2 Types of Metal Expansion Joints

Figure 2-5 illustrates a cross-sectional view of a metal expansion joint and notes the basic elements comprising one of these devices.

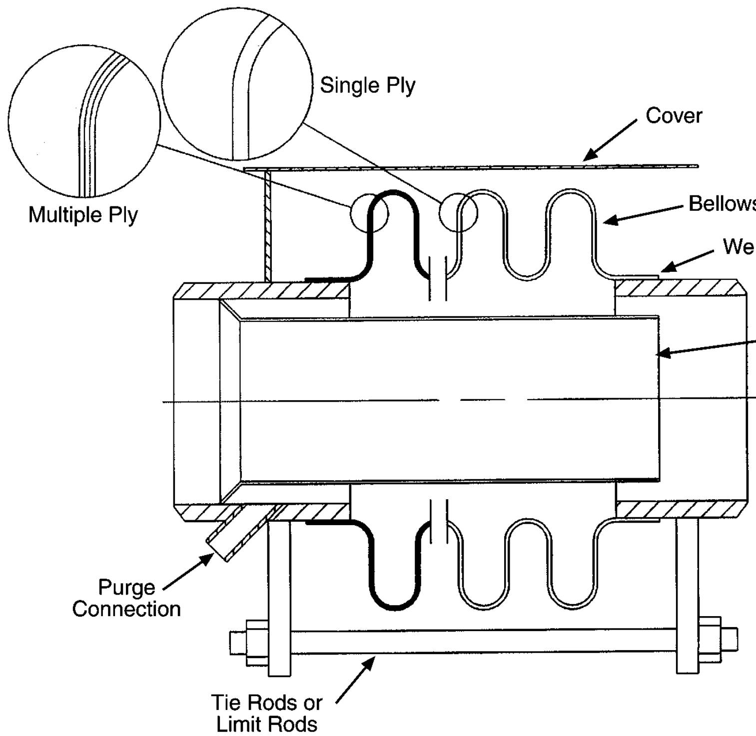


Figure 2-5
Generic Cross-Section of a Metal Expansion Joint

The following information has been excerpted from *A Practical Guide to Expansion Joints* published by the Expansion Joint Manufacturers Association, Inc.

There are several different types of metal expansion joints. Each is designed to operate under a specific set of design conditions. The following is a listing of the most basic types of metal expansion joint designs, along with a brief description of their features and application requirements.

2.2.1 Single Expansion Joint

This is the simplest form of expansion joint. Figure 2-6 illustrates a single-bellows construction, which absorbs movement of the pipe section into which it is installed.

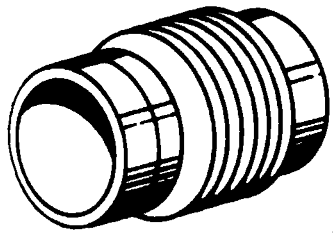


Figure 2-6
Single Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.2 Double Expansion Joint

Figure 2-7 illustrates a double expansion joint that consists of two bellows jointed by a common connector that is anchored to some rigid part of the installation by means of an anchor base. The anchor base may be attached to the common connector either at installation or time of manufacture. Each bellows of a double expansion joint functions independently as a single unit. Double bellows expansion joins should not be confused with universal expansion joints.

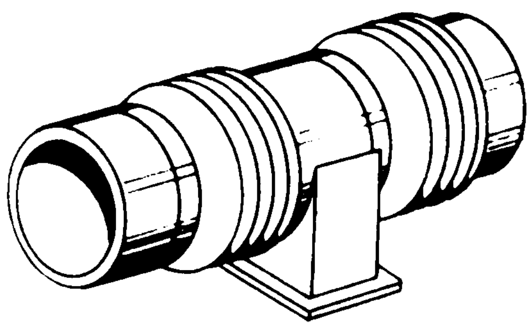


Figure 2-7
Double Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.3 Universal Expansion Joint

Figure 2-8 illustrates a universal expansion joint containing two bellows joined by a common connector for the purpose of absorbing any combination of three basic movements (that is, axial motion, lateral deflection, and angular rotation). A universal expansion joint is used, in cases, to accommodate greater amounts of lateral movement than can be absorbed by a single expansion joint.

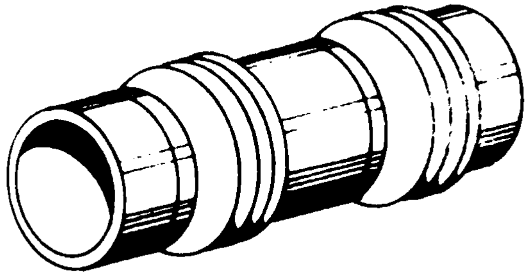


Figure 2-8
Universal Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.4 Tied Universal Expansion Joint

Figure 2-9 illustrates a tied universal expansion joint, used when it is necessary for the assembly to eliminate pressure thrust forces from the piping system. In this design, the expansion joint will absorb lateral movement and will not absorb any axial movement external to the tied length.

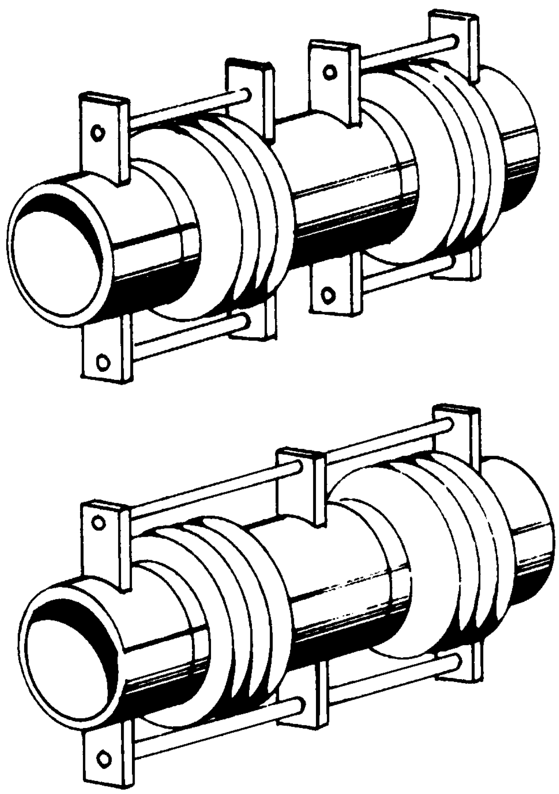


Figure 2-9
Tied Universal Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.5 Swing Expansion Joint

Figure 2-10 illustrates a swing expansion joint designed to absorb lateral deflection and/or angular rotation in one plane only by the use of swing bars, each of which is pinned at or near the ends of the unit.

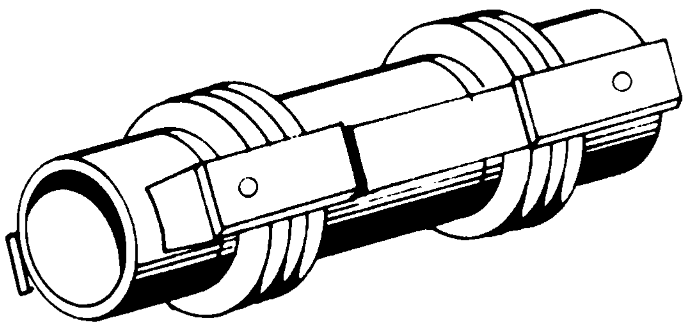


Figure 2-10
Swing Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.6 Hinged Expansion Joint

Figure 2-11 illustrates a hinged expansion joint containing one bellows and designed to permit angular rotation in one plane only by the use of a pair of pins running through plates attached to the expansion joint ends. Hinged expansion joints are typically used in sets of two or three to function properly.

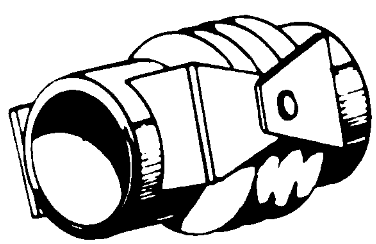


Figure 2-11
Hinged Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.7 Gimbal Expansion Joint

Figure 2-12 illustrates a gimbal expansion joint designed to permit angular rotation in any plane by the use of two pairs of hinges affixed to a common floating gimbal ring.

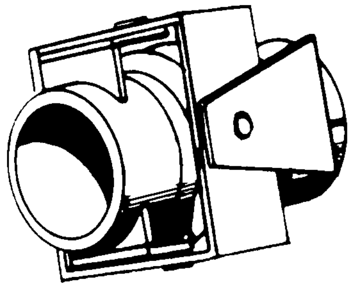


Figure 2-12
Gimbal Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.8 Pressure-Balanced Expansion Joint

Figure 2-13 illustrates a pressure-balanced expansion joint designed to absorb axial movement and/or lateral deflection while retaining the bellows pressure thrust force by means of the devices interconnecting the flow bellows with an opposed bellows also subjected to line pressure. This type of joint is typically installed where a change of direction occurs in a run of pipe, although “in-line” pressure-balanced expansion joints are also available.

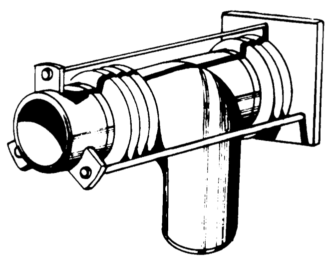


Figure 2-13
Pressure-Balanced Expansion Joint (Courtesy of Expansion Joint Manufacturers Association, Inc.)

2.2.9 Special Features of Metal Expansion Joints

2.2.9.1 Multi-Ply and Redundant-Ply Bellows

Most bellows are manufactured from a single ply of sheet material of sufficient thickness to limit the circumferential stress to be below the maximum allowable limit. However, when increase cycle life or a less-stiff bellows is required, a bellows may be manufactured having two or more thinner plies, that when taken together, provide the same pressure capacity but distribute the bending stresses among the plies. The maximum bending stress in each ply is greatly reduced, resulting in a much better fatigue resistance.

Redundant-ply bellows differ from multi-ply bellows in that each ply of a redundant-ply bellows is sufficient to act alone in providing sufficient thickness for pressure design. No advantage is typically gained in fatigue resistance, and the bellows is stiffer than a single-ply bellows designed for the same design pressure. The advantage of redundant-ply bellows is they are fitted with monitor connections that tap the interface between the inner and outer plies. If a leak occurs in the bellows, it registers through the monitor connection. The redundant ply maintains the pressure boundary until the bellows can be replaced during a scheduled outage.

2.2.9.2 End Connections and Other Features

Each of the types of metal expansion joints described in Section 2.2 can be provided with a variety of end connections. The illustrations typically show welded ends, but the expansion joints shown are also available with flanges or other connections as may be required for various types of installations. They may be equipped with one or more or the following features, as appropriate and as defined in Section 1.5 of this report:

- Liners
- Covers
- Tie rods
- Limit rods
- Control rods
- Reinforcement
- Purge connections

2.3 Types of Rubber/Fabric Expansion Joints

Elastomeric expansion joints are constructed with seamless, leak-proof tubes to prevent confined fluids from penetrating and damaging the body portion. Tubes extend the length of the bore and continue to the outside diameter of the flange face.

Expansion joints are reinforced with various materials for high mechanical strength. Continuous strands of wire, steel rings, and/or rubber-coated fabric plies are the reinforcing members of the expansion joint.

The exterior cover of the expansion joint is made from an elastomer that may, or may not, be the same as that used in the remainder depending on environmental conditions. The cover is used for protection against mechanical damage and provides resistance to attack from chemicals, oils, fumes, ozone, sunlight, and other similar substances, that may be a product of the environment.

Arches can be filled with soft-durometer elastomers to avoid accumulation of sediment and provide a smooth bore.

The following information is provided courtesy of Non-Metallic Expansion Joint Division of the Fluid Sealing Association. The information is an excerpt from their technical handbook *Non-Metallic Expansion Joints and Flexible Pipe Connectors, 6th Edition*. Note that the dimensions indicated by letters in the figures in this section are dictated by the design of the joint.

2.3.1 Spool-Arch-Type Expansion Joints

A full-face, integral flange design is available in both single-arch-type and multiple-arch-type expansion joints. These types are available in several construction design series, based on the application pressure requirements. The arch refers to the hump(s) between the flanges that allow the joint to move and absorb movement as necessary.

2.3.1.1 Single-Arch-Type Expansion Joint

Figure 2-14 illustrates that the construction is of fabric and rubber, reinforced with metal rings or wire. The full-face flanges are integral with the body of the joint and drilled to conform to the bolt pattern of the companion metal flanges of the pipeline. The type of rubber face flange is of sufficient thickness to form a tight seal against the metal flanges without the use of gaskets.

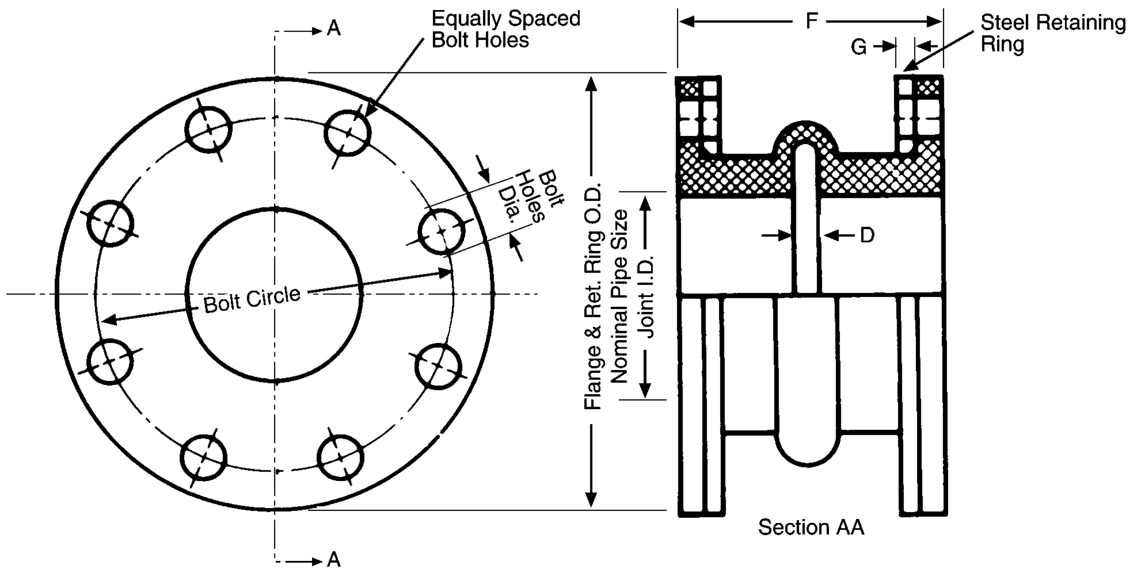


Figure 2-14
Single-Arch-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.1.2 Multiple-Arch-Type Expansion Joints

Expansion joints with two or more arches may be manufactured to accommodate movements greater than those of which a singe-arch-type expansion joint is capable. Multiple-arch expansion joints are a series of standard-sized arches and are capable of movements of a single arch multiplied by the number of arches. As illustrated in Figure 2-15, the minimum length of the expansion joint is dependent upon the number of arches. To maintain lateral stability and prevent sagging when the expansion joint is installed in a horizontal position, a maximum of four arches is recommended.

Key Technical Point

To maintain lateral stability and prevent sagging when the multiple-arch-type expansion joint is installed in a horizontal position, a maximum of four arches is recommended.

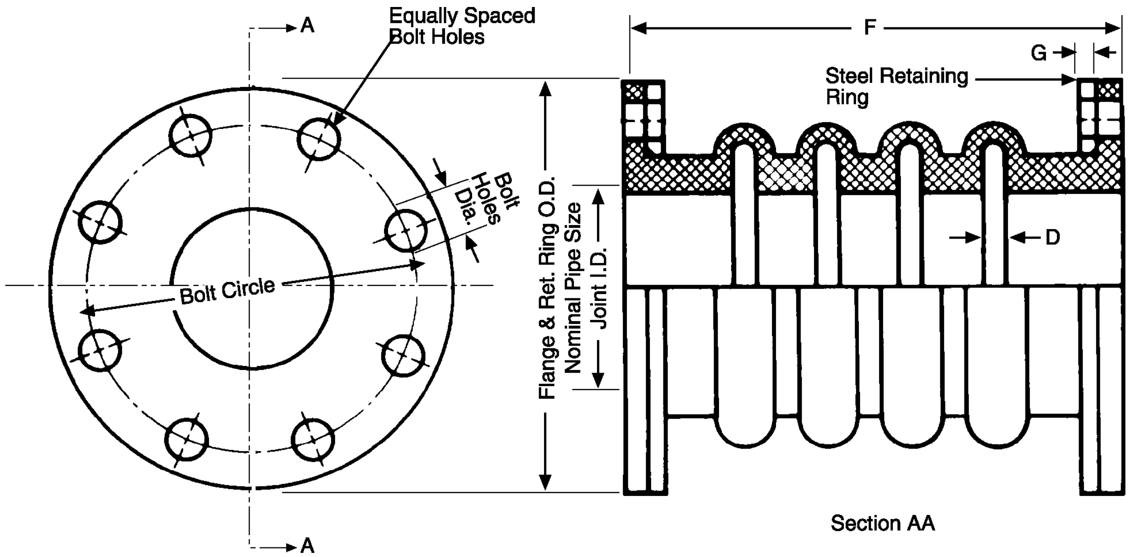


Figure 2-15
Multiple-Arch-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.1.3 Lightweight-Type Expansion Joints

Both the single-arch-type and the multiple-arch-type expansion joints are available in a lightweight series from most manufacturers. Dimensionally the same as the standard product, except for reduced body thickness, this series is designed for lower pressure and vacuum applications.

2.3.1.4 Teflon (TFE/FEP)-Lined Expansion Joints

Spool-arch-type expansion joints are available in many standard pipe sizes with Teflon® liner of TPE and/or FEP. These liners are fabricated as an integral part of the expansion joint during manufacture and cover all wetted surfaces in the tube and flange areas. Teflon provides exceptional resistance to almost all chemicals within the temperature range of the expansion joint body construction. Filled arches (see section 2.3.6.1) are typically not available.

2.3.2 Reducer-Type Expansion Joints

Reducer-type expansion joints (that is, expansion joints with a taper) are used to connect piping of unequal diameters. These expansion joints may be manufactured in a *concentric* design (with the axis of each end concentric with each other) or in an *eccentric* design (having the axis of each end offset from each other). The concentric design of reducer-type expansion joint is shown in Figures 2-16. The eccentric design of reducer-type expansion joint is shown in Figure 2-17. Tapers in excess of 15 degrees are not recommended.

Key Technical Point

Tapers in excess of 15 degrees are not recommended for reducer-type expansion joints.

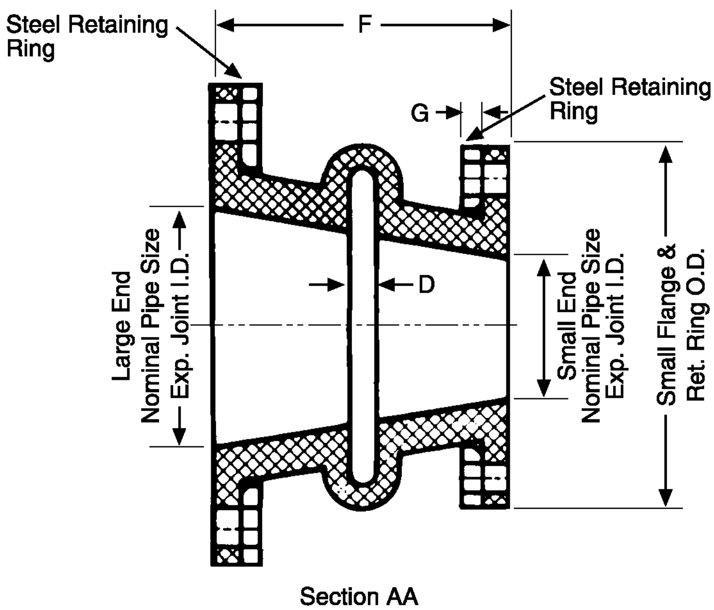


Figure 2-16
Concentric Design of Reducer-Type Expansion Joint (Courtesy of Fluid Sealing Association)

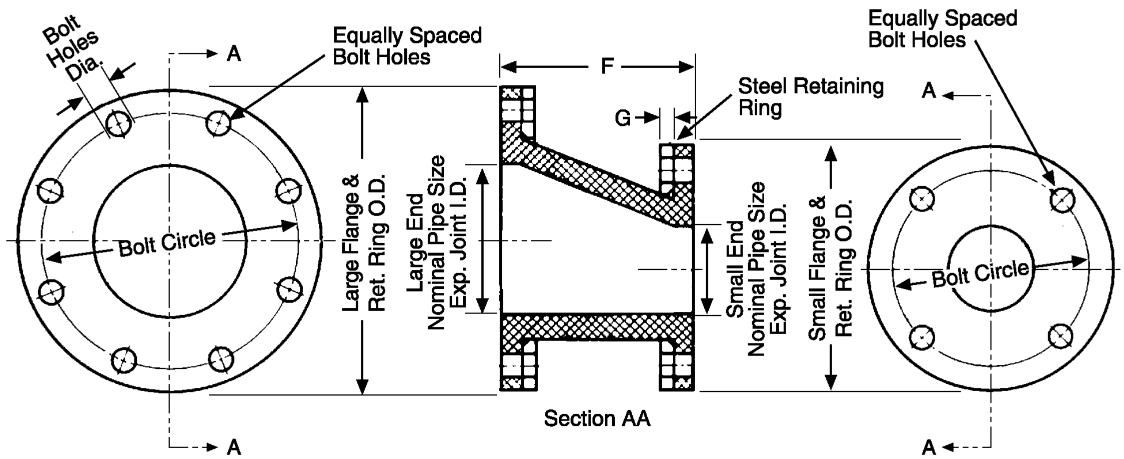


Figure 2-17
Eccentric Design of Reducer-Type Expansion Joint (Courtesy of Fluid Sealing Association)

Recommendations concerning the degree of taper and working pressure should be obtained from the manufacturer. Normally, pressures are based on the larger of the two inside dimensions, whereas movement is based on the smaller of the two inside dimensions. This type of expansion joint is available with or without arches.

2.3.3 Offset-Type Expansion Joints

Offset-type expansion joints are custom built to specifications to compensate for initial misalignment and non-parallelism of the axis of the piping to be connected. As illustrated in Figure 2-18, offset-type expansion joints are sometimes used in close quarters where available space makes it impractical to correct misalignment with conventional piping. Generally, the manufacturer will assume drilling flanges according to pipe size of flanges when not specified otherwise. It is recommended that complete drawings and specifications accompany inquiries or orders for offset-type expansion joints.

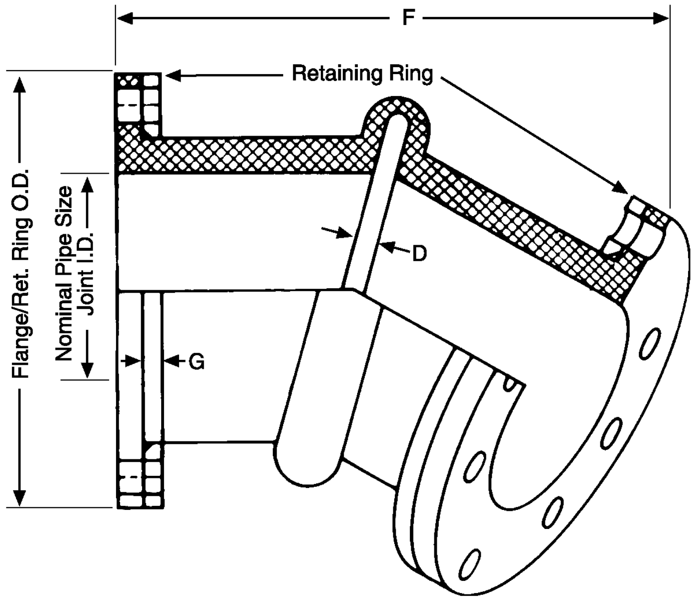


Figure 2-18
Offset-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.4 Sleeve-Type Expansion Joints

A sleeve design is available in both single- and multiple-arch-type expansion joints. Both types are available in several construction design series, based on the application pressure and flexibility requirements.

2.3.4.1 Sleeve-Type “Arch” Expansion Joint

This joint is similar to the single-arch-type and multiple-arch-type expansion joints except that the clamped sleeve ends have an inside diameter dimension that is equal to the outside diameter dimension of the pipe. These joints are designed to slip over the straight ends of the open pipe and be held securely in place with clamps. An example of sleeve-type expansion joint is illustrated in Figure 2-19. This type of joint is recommended only for low-to-medium pressure and vacuum service because of the difficulty of obtaining adequate clamp sealing.

Key Technical Point

A sleeve-type expansion joint is recommended only for low-to-medium pressure and vacuum service because of the difficulty of obtaining adequate clamp sealing.

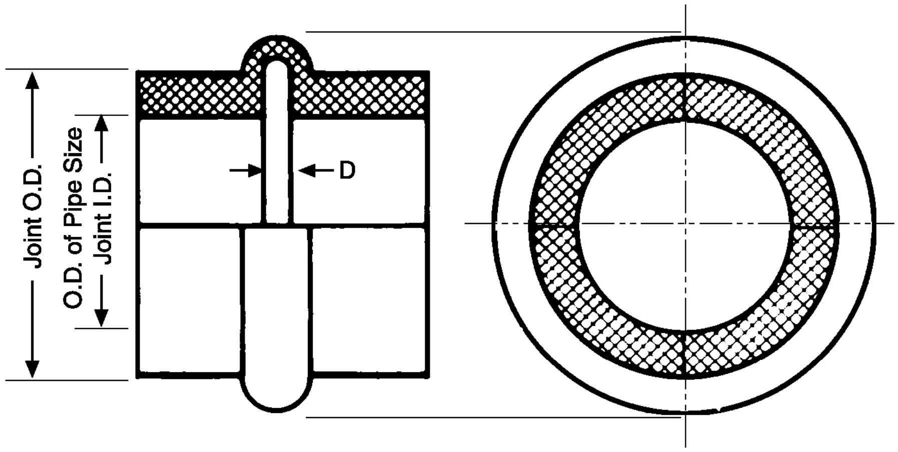


Figure 2-19
Sleeve-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.4.2 Lightweight-Type Expansion Joints

Dimensionally, this type of expansion joint is the same as the sleeve type, except for reduced body thickness. This series is designed for very low pressure and vacuum applications. Expansion joints are available in single-arch-type and multiple-arch-type expansion joints. This type generally offers greater flexibility than the sleeve-type expansion joint.

2.3.4.3 Enlarged-End-Type Expansion Joints

This expansion joint can be manufactured in the same design as the sleeve-type and lightweight-type expansion joints. The sleeve ends on this design are the same ID dimension as the OD of the pipe, while the rest of the joint is the same dimension as the ID of the pipe. This design can be manufactured with a filled arch (see section 2.3.6.1) to reduce possible turbulence and to prevent collection of solid material in the arch.

2.3.5 Special-Flange-Type Expansion Joints

Most of the rubber expansion joints discussed in this section are available with modifications to the flanges. These modifications include Van Stone beaded ends, enlarged flanges, different drill patterns and weld-end stubs.

2.3.5.1 Expansion Joints With Van Stone Beaded-End Flanges

As illustrated in Figure 2-20, the construction of this joint is the same as the spool-arch-type expansion joint except that the ends are specially designed flanges containing built-in steel rings. They are often specified for Duriron or Haveg piping systems. Special split steel flanges should be used with this design in place of standard retaining rings. This type joint is also available without arch(es).

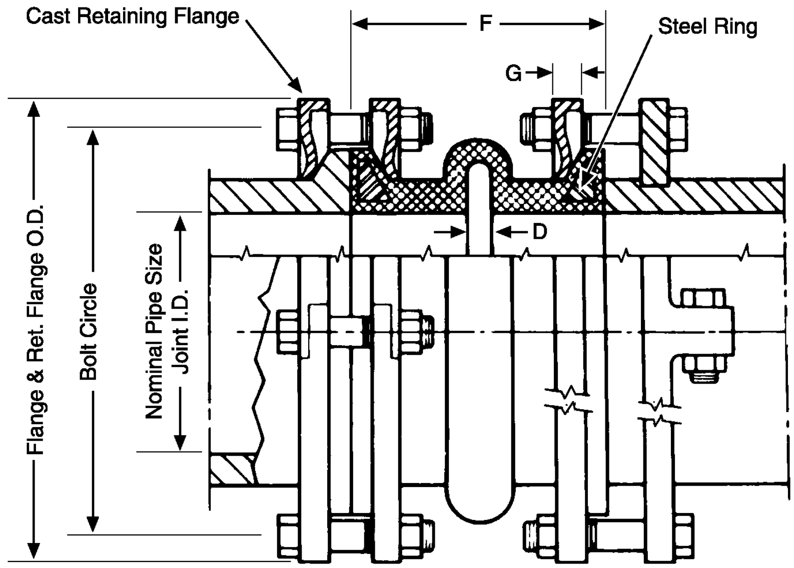


Figure 2-20
Expansion Joint With Van Stone Beaded-End Flange (Courtesy of Fluid Sealing Association)

2.3.5.2 Enlarged-Flange-Type Expansion Joints

Expansion joints using a full-face integral flange design can be furnished with an enlarged flange on one end. As illustrated in Figure 2-21, an 8-in. (20.32-cm) expansion joint can be fabricated with a flange to mate to an 8-in. (20.32-cm) pipe flange on one end; and a 12-in. (30.48-cm) flange on the other end to mate to a 12-in. (30.48-cm) pipe flange. Additionally, drilling of different specifications may be furnished. For example, an expansion joint can be furnished with one end drilled to ANSI B16.5, Class 150, and the other end drilled to MIL-F-20042C.

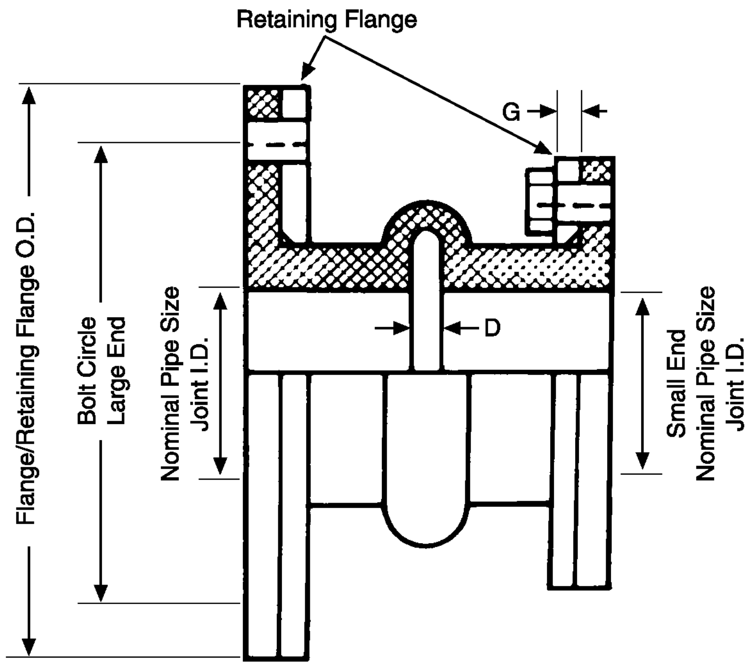


Figure 2-21
Enlarged-Flange-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.6 Designs for Reduction of Turbulence and Abrasion

The open-arch design of the standard spool-type expansion joint may be modified to reduce possible turbulence and to prevent the collection of solid materials that may settle from the solution handled and remain in the archway. Typically, a wider, shallower arch can be used.

2.3.6.1 Filled-Arch-Type Expansion Joints

The filled-arch-type expansion joint is the basic arch-type expansion joint with a bonded-in-place soft rubber filler to provide a smooth interior bore. As illustrated in Figure 2-22, filled arch joints also have a seamless tube so the arch filler cannot be dislodged during service. Filled arches, built as an integral part of the carcass, decrease the flexibility of the joint and should be used only when necessary. Movements of expansion joints with filled arches are limited to 50% of the normal movements of comparable size expansion joints with unfilled (open) arches.

Key Technical Point

Filled arches, built as an integral part of the carcass, decrease the flexibility of the joint and should be used only when necessary. Movements of expansion joints with filled arches are limited to 50% of the normal movements of comparable size expansion joints with unfilled (open) arches.

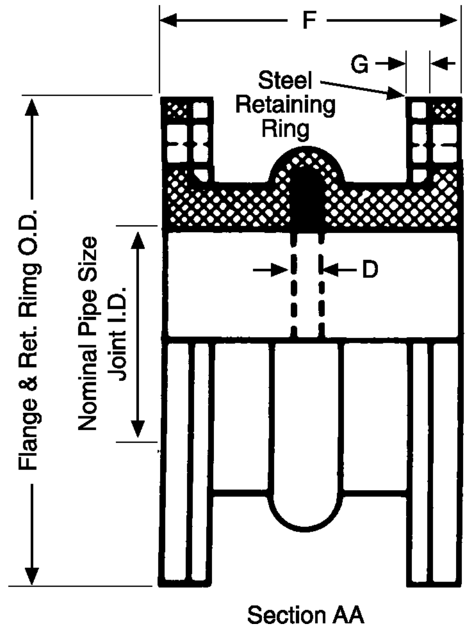


Figure 2-22
Filled-Arch-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.6.2 Replacement-Liner-Type Expansion Joints

As illustrated in Figure 2-23, a separate flanged elastomeric liner, dimensioned to the ID of the expansion joint, can provide the same advantages as the filled arch type, except movements are not reduced. This type of joint is not recommended for vacuum applications.

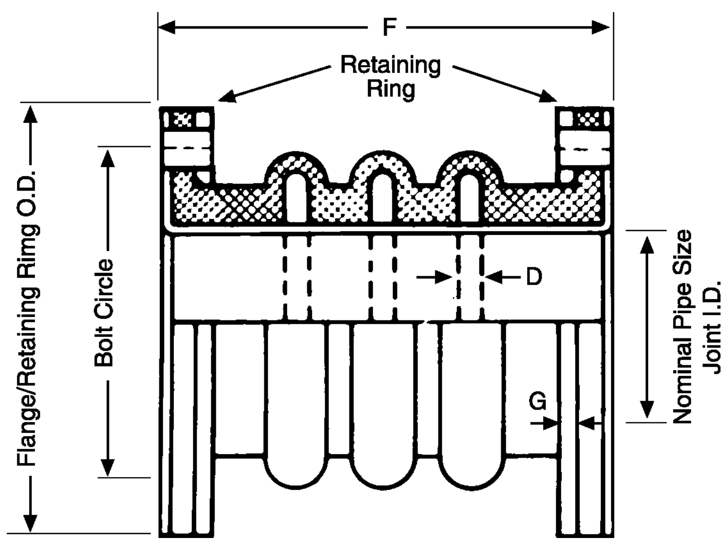


Figure 2-23
Replacement-Liner-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.6.3 Top-Hat-Liner-Type Expansion Joints

As illustrated in Figure 2-24, this product consists of a sleeve extending through the bore of the expansion joint with a Van Stone flange or a full-face flange on one end. Constructed of hard rubber, metal or TFE, it reduces frictional wear of the expansion joint and provides smooth flow, reducing turbulence.

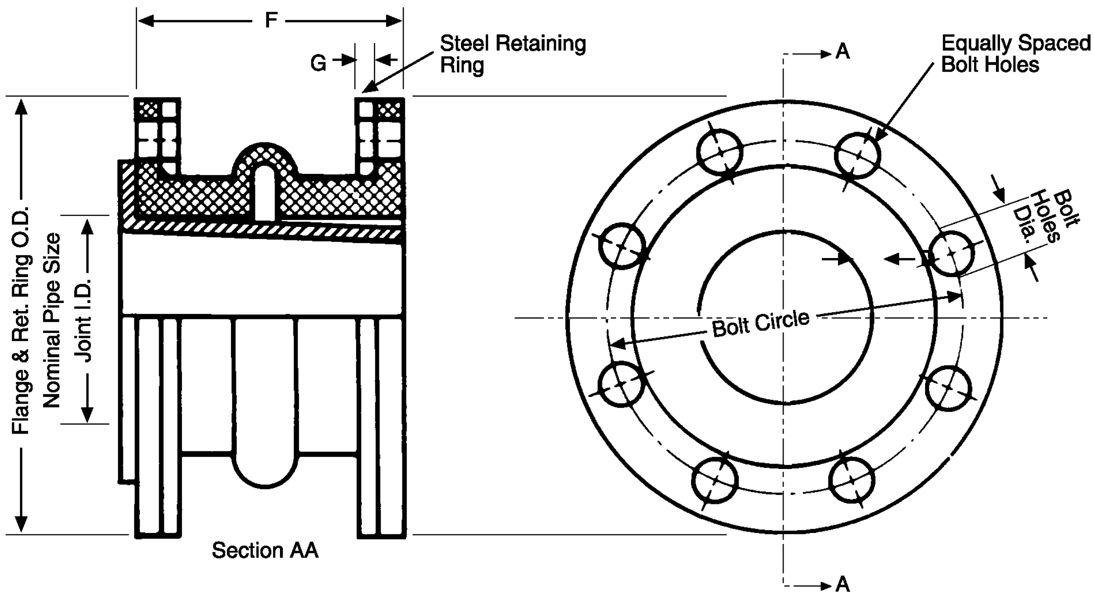


Figure 2-24
Top-Hat-Liner-Type Expansion Joint (Courtesy of Fluid Sealing Association)

Flow liners are normally bolted in with flange and extend to the OD of the joint. The length of the liner is typically shorter than the joint to allow for compression.

2.3.7 Arch-Type Expansion Joint With Rectangular Flanges

Figure 2-25 illustrates a custom made flexible connector for use with rectangular flanges on low-pressure service. The arch design accommodates greater movement than the U-type expansion joint discussed in the following section.

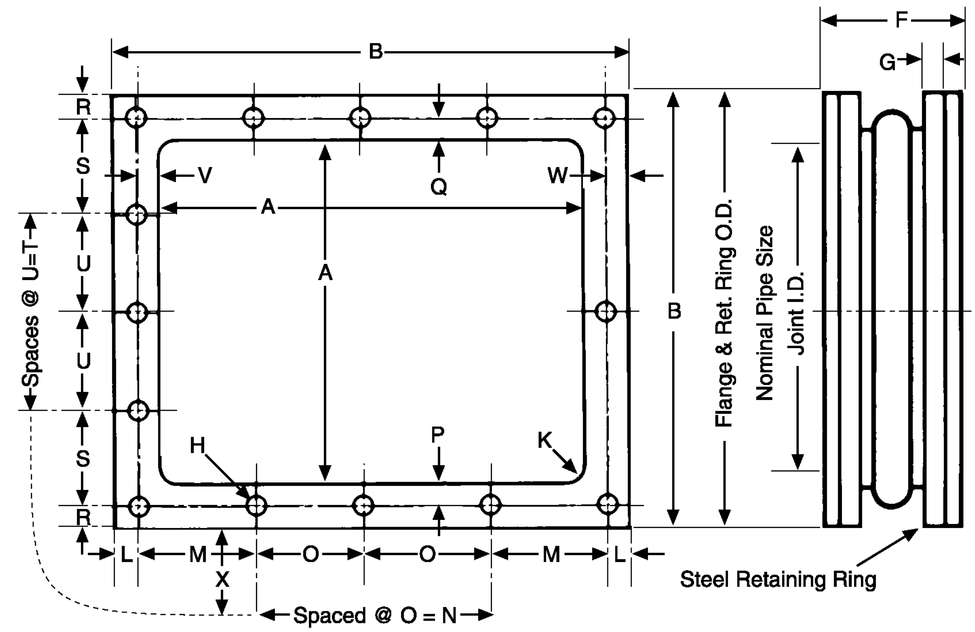


Figure 2-25
Arch-Type Expansion Joint With Rectangular Flanges (Courtesy of Fluid Sealing Association)

2.3.8 U-Type Expansion Joints

U-type expansion joints are available for low-pressure applications in external and internal flange design and for higher-pressure and full-vacuum service in a no-arch modification of the single-arch-type expansion joint. These types of expansion joints can also accommodate short face-to-face dimensions and can offer staggered drilling.

2.3.8.1 External Full-Face Integral Flange Expansion Joint

Figure 2-26 illustrates this type of joint that is a lightweight, custom-made flexible joint often used between the turbine and the condenser. It is constructed of plies of rubber and fabric usually without metal reinforcement. The joint is recommended for full-vacuum service or a maximum pressure of 25 psig. Flange drilling may be staggered to facilitate installation and tightening of bolts. The joint is securely bolted in place with conventional retaining rings for vacuum service or special support rings for pressure service. The joint may be rectangular, round, or oval in shape.

Key Technical Point

External full-face integral flange expansions joints are recommended for full-vacuum service or a maximum of 25 psig (172 kPa).

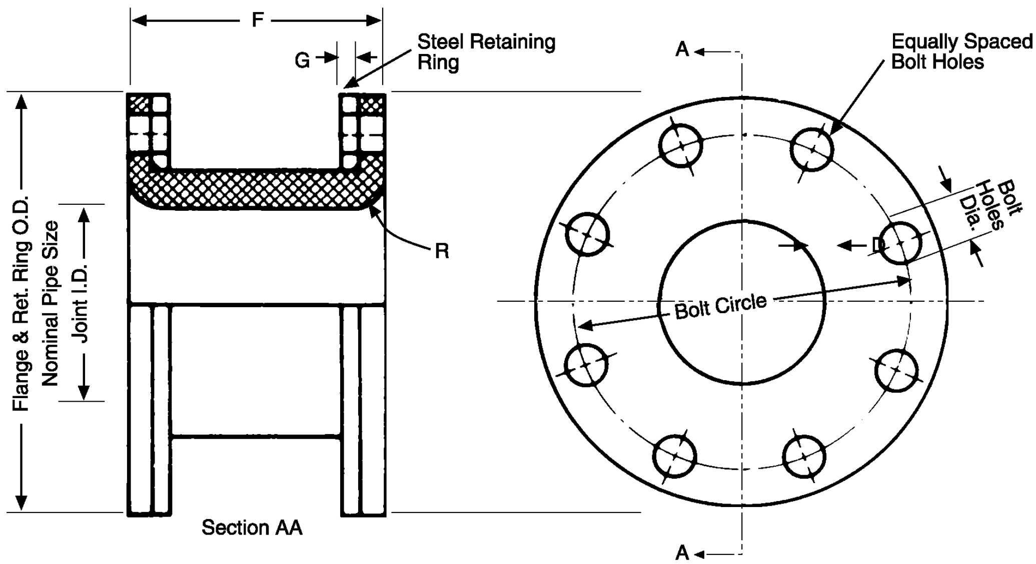


Figure 2-26
External Full-Face Integral Flange Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.8.2 Internal Full-Face Integral Flange Expansion Joint

This joint is similar to the external flange expansion joint except that conventional retaining rings are used for pressure service and special support rings are used for vacuum service. This joint may be rectangular, round, or oval in shape. Figure 2-27 depicts a rectangular version with special support rings.

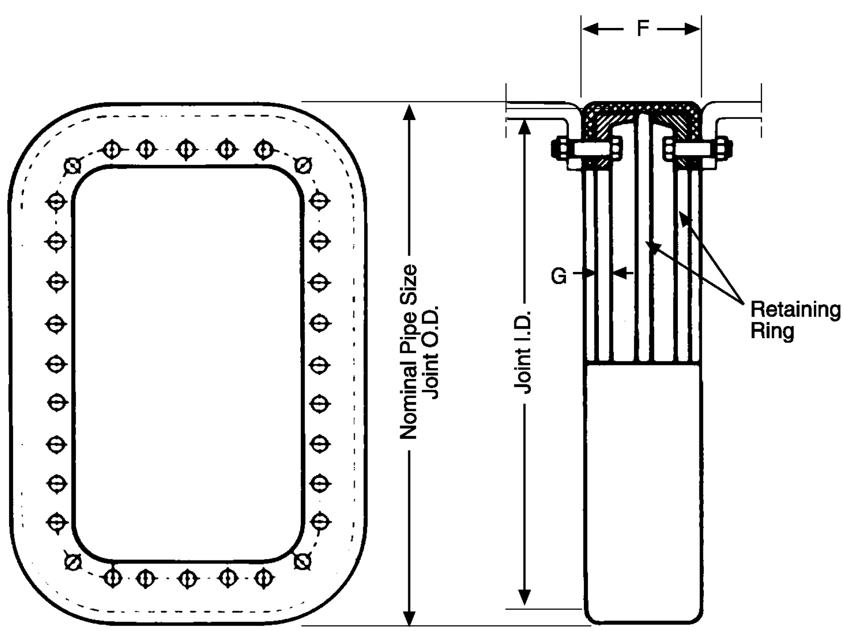


Figure 2-27
Internal Full-Face Integral Flange Joint (Courtesy of Fluid Sealing Association)

2.3.8.3 Spool-Type, No-Arch Expansion Joint

As illustrated in Figure 2-28, the construction of this expansion joint is the same as the single-arch-type expansion joint, except modified to eliminate the arch. This joint is not recommended for movement, but it will absorb vibration and sound.

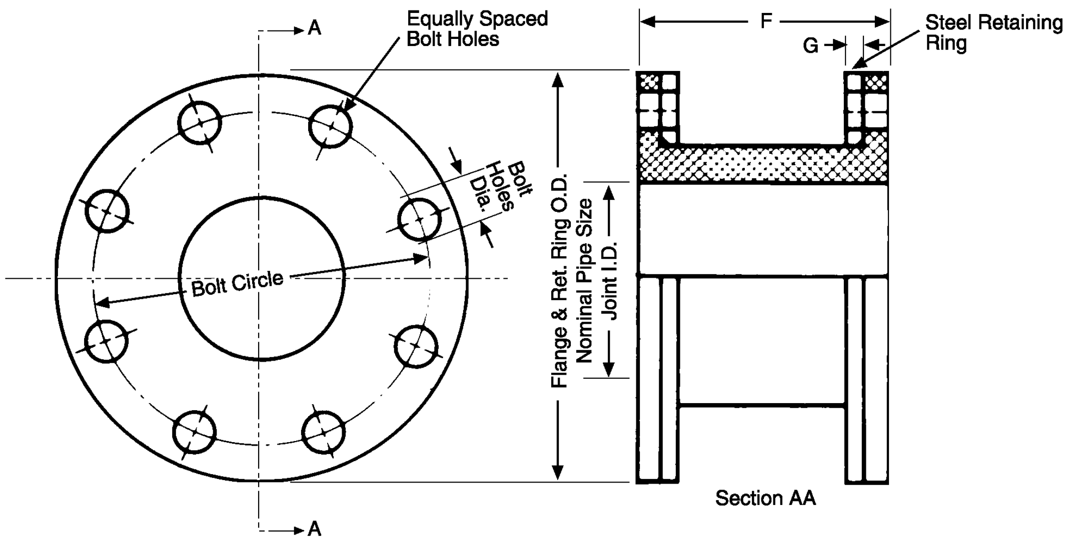


Figure 2-28
Spool-Type, No-Arch Expansion Joint (Courtesy of Fluid Sealing Association)

> **Key Technical Point**
>
> **Spool-type, no-arch expansion joints are not recommended for movement, but will absorb vibration and sound.**

2.3.9 Belt- (or Dogbone-) Type Expansion Joints

Figure 2-29 illustrates a molded construction of plies of rubber-impregnated fabric, rubber-covered and spliced endless, to a specified peripheral dimension. This expansion joint is used as a flexible connection in power plants on condensers. These items are designed for compression and lateral movements for full-vacuum service and a maximum pressure of 15 psig. These joints must be used with special clamping devices normally furnished by the condenser equipment manufacturer.

> **Key Technical Point**
>
> **Belt- (or dogbone-) type expansion joints are designed for compression and lateral movements for full vacuum service and a maximum pressure of 15 psig (103 kPa).**

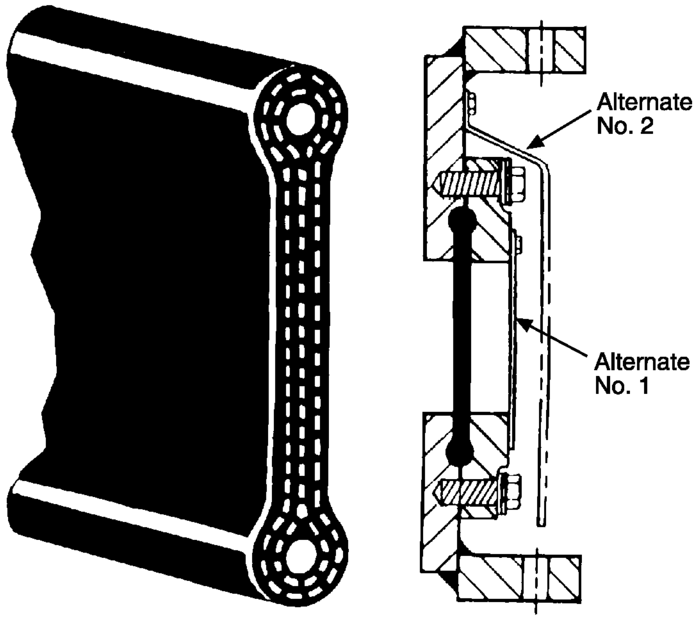


Figure 2-29
Belt-Type Expansion Joint (Courtesy of Fluid Sealing Association)

2.3.10 Molded, Spherical-Type Expansion Joints

A molded, spherical design is manufactured in two ways. One type uses solid floating metal flanges. The other type has full-face integral flanges. The design incorporates a long-radius arch, providing additional movement capabilities when compared to other types. The arch is self-cleaning, eliminating the need for filled-arch-type construction. These types are recommended for basically the same applications as the spool-arch-type expansion joints.

2.3.10.1 Molded, Spherical-Type Expansion Joints With Solid, Floating Flange

Figure 2-30 illustrates the molded, spherical design using standard construction details except that the carcass does not contain metal reinforcement. Using a special weave fabric for reinforcement, the spherical shape offers a high burst pressure. Movements and pressure ratings should be obtained from the manufacturer. These joints are typically furnished complete with solid, floating flanges, and the design is generally available for pipe sizes less than 30 in. (76.2 cm) in diameter and in single- or double-arch designs. Floating-flange designs are typically used to accommodate torsional misalignment.

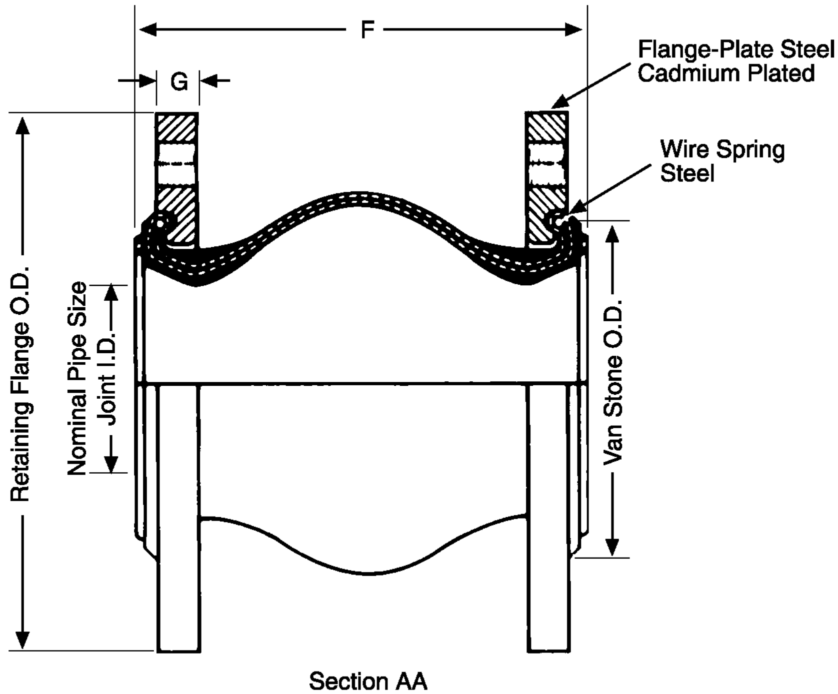


Figure 2-30
Molded, Spherical-Type Expansion Joint With Solid, Floating Flanges (Courtesy of Fluid Sealing Association)

2.3.10.2 Molded, Spherical-Type Expansion Joints With Integral Flanges

Figure 2-31 illustrates a molded, spherical-type expansion joint with integral flanges. This type is basically the same as the floating flange spherical type except full-face flanges are integral with the body of the joint. Pressure-resisting hoop strength is a function of the special weave fabric and its placement in the body, as well as the design of the retaining rings. Special retaining rings are sometimes required.

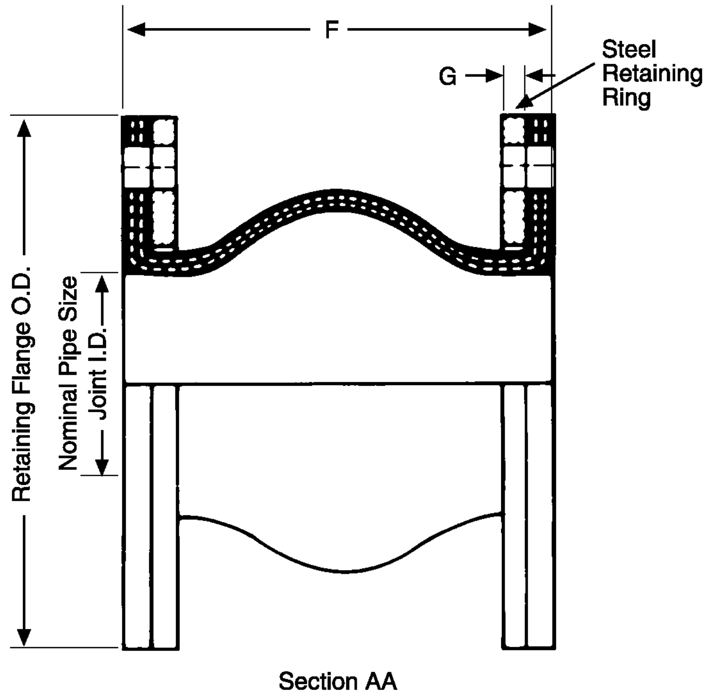


Figure 2-31
Molded, Spherical-Type Expansion Joint With Integral Flanges (Courtesy of Fluid Sealing Association)

2.3.11 Wide-Arch-Type Expansion Joints

This type of expansion joint, similar to the spool-arch-type expansion joint, is available in a metal reinforced and a non-metal reinforced design. Generally, the wide-arch-type expansion joint features greater movements than the standard spool-arch-type expansion joint.

2.3.11.1 Wide-Arch-Type Expansion Joints With Non-Metal Reinforcement

Figure 2-32 illustrates a non-metal reinforced design that is constructed similar to the spool-arch-type design except the carcass does not contain wire or metal-ring reinforcement. Pressure resistance is accomplished through the use of a special external flanged retaining ring furnished with the joint.

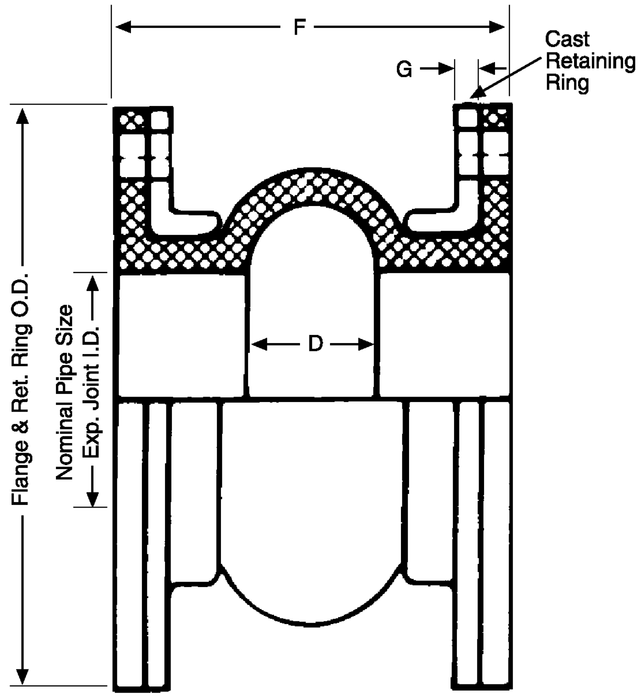


Figure 2-32
Wide-Arch-Type Expansion Joints With Non-Metal Reinforcement (Courtesy of Fluid Sealing Association)

2.3.11.2 Wide-Arch-Type Expansion Joints With Metal Reinforcement

Figure 2-33 illustrates a metal wide-arch-type expansion joints with metal reinforcement that is a molded version of the spool arch type using solid steel rings in the carcass, at the base of the arch. The reduced body thickness requires special retaining rings available from the manufacturer.

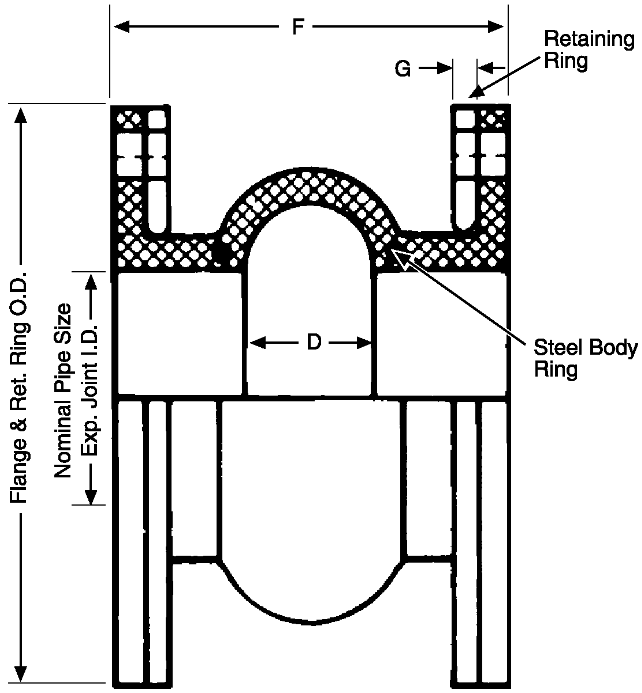


Figure 2-33
Wide-Arch-Type Expansion Joints With Metal Reinforcement (Courtesy of Fluid Sealing Association)

2.4 Generic Type of Fabric (Ducting) Expansion Joints

The following information is courtesy of Senior Flexonics Pathway.

Figure 2-34 illustrates the basic joint components comprising a typical fabric (ducting) expansion joint. Descriptions of the components follow the figure.

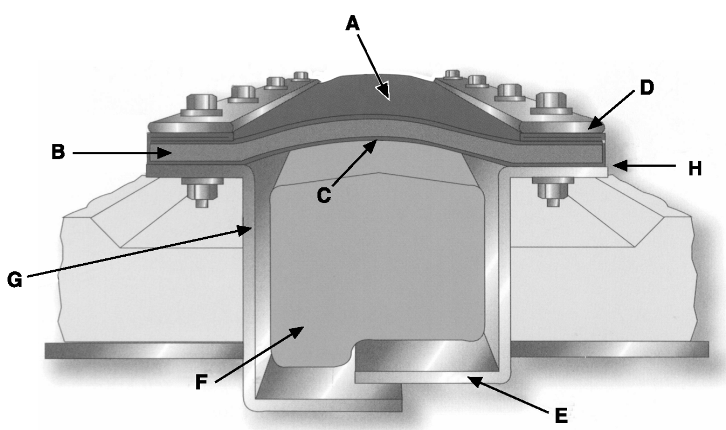


Figure 2-34
Typical Fabric (Ducting) Expansion Joint Components

Gas seal membrane (A) – The gas seal membrane is intended to withstand system pressure and be resistant to chemical attack from the interior and the exterior. The gas seal must also have the flexibility to absorb thermal movements. Depending on system temperature, it may require additional thermal protection.

Insulating layers (B) – The insulating layer provide a thermal barrier to ensure that the inside surface temperature of the gas seal membrane does not exceed its maximum service temperature. The insulating layer can also reduce condensation caused by the gas stream coming in contract with the “cool” surface of an uninsulated gas seal membrane.

Insulating retainer layer (C) – This layer is provided to keep the insulating layers in place to maintain thermal integrity. The retaining layer must be capable of withstanding gas stream temperatures and must be chemically compatible with system media.

Back up bars (D) – Back up bars, positioned at the flange attachment, use clamping pressure to create the fabric-to-duct seal and restrain the fabric when it is subjected to the system pressure. The thickness and width of the back up bars should be sufficient to perform this function with the bolt spacing being used. The edges of the back up bars should have a radius to preclude cutting of the fabric.

Metal liner or baffle (E) – A liner is designed to protect the gas seal membrane and insulating layers of the flexible element from abrasive particles, which may be present in the gas stream. A liner is also used to reduce flutter of the fabric element caused by turbulence, to help control the accumulation of dust or ash in the expansion joint cavity, and to reduce the temperature of the flexible element.

Accumulation bag (F) – An accumulation bag is intended to deter fly ash from building up in the expansion joint cavity. It is typically used, in conjunction with a liner, in duct runs from boilers to air-clean-up equipment such as precipitators, scrubbers and bag houses, or whenever high amounts of dust or ash are present in the gas. A fly-ash barrier must be capable of retaining its strength and flexibility while being exposed to maximum system temperatures and media.

Fabric attachment flanges (G) – Fabric attachment flanges are required to connect the flexible element to the ductwork. Properly designed, they can be attached directly to the duct work and thus eliminate the necessity for an adjoining duct flange. Flanges can be designed with a “landing bar” duct attachment that allows some installation misalignment without affecting the flexible element. The flanges establish the stand-off height of the fabric that is necessary to achieve thermal integrity during all movement conditions. The edges of the flanges in contact with the gas seal membrane should also have a radius to prevent damage.

Gasket (H) – Certain single-ply belt designs may require flexible, chemically inert gaskets.

2.5 Power Plant Applications

2.5.1 Metal Expansion Joints

Metal expansion joints can be used in many applications with only a few general limitations. Temperatures should be less than 800°F (426.7°C) and the pressure should be less than 300 psig (2068 kPa). Metal expansion joints are commonly installed inside the condenser on steam extraction lines, or in the American Society of Mechanical Engineers (ASME) code safety relief valve discharge line above the pressurizer in the reactor building.

Key Technical Point

Metal expansions joints can be used in many applications with only a few general limitations. Temperatures should be less than 800 °F (427 °C) and the pressure should be less than 300 psig (2068 kPa).

As described in Section 2.2 of this report, there are several different design configurations of metal expansion joints, but they all basically consist of a minimum of two pieces of pipe, a thin-walled, convoluted metal tube, and in some cases a thin-walled inner liner. The pipe provides a means of welding the expansion joint in place. The convolutions allow movement. The inner liner protects the convolutions from excessive velocity and wear because of fluid flow, and aids in reducing turbulence by providing a smooth contact surface with the fluid. Some expansion joints have multiple plies of bellows as well as multiple bellows in a single assembly. Lagging is often provided on the exterior of the bellows for protection. For service such as inside the condenser, the inner liner may be up to 0.25-in. (0.635-cm) thick. When used in water systems, such as service water, the possibility of galvanic corrosion should be considered.

Key Technical Point

When metal expansion joints are used in water systems, such as service water, the possibility of galvanic corrosion should be considered.

2.5.2 Rubber/Fabric Expansion Joints

Rubber expansion joints are generally used on low-pressure water lines and air ducting. They typically have a temperature limit of 250°F (121.1°C)—400°F (204.4°C) max—and a pressure range of 26 in. (66 cm) of mercury (vacuum) to 250 psig (1724 kPa). The pressure rating is dependent upon the size of the expansion joint. The smaller sizes of expansion joints are capable of handling a wider range of pressure.

Rubber expansion joints are provided by the manufacturer with either a flange end or weld end. Rubber expansion joints are made up of a tube, a core, and a cover. The tube is constructed of rubber and is in contact with the fluid. The tube serves to provide pressure containment. The core is constructed of fabric and provides structural integrity for all of the expansion joint loads. The cover is located on the outside surface of the expansion joint and it serves only to protect the core. The typical construction for a rubber expansion joint is a fiber-reinforced rubber structure with a single arch in the center. Flanged rubber expansion joints have molded rubber flanges at each end and typically require a metal backing ring when bolted to a flange. The design for this flange is based on either an ANSI 125- or 150-pound-class flange (56.7- or 68-kg). When installing rubber expansion joints, the bolts should be torqued to the manufacturer's recommended values.

Key Technical Point

When installing rubber expansion joints, the bolts should be torqued to the manufacturer's recommended values.

2.5.3 Fabric Expansion Joints

Fabric expansion joints are generally used in low-pressure air ducting. They can be provided in different configurations to accommodate either rectangular or circular ducts. Fabric expansion joints are typically provided by the manufacturer with flanged ends. The fabric sheet is typically held to each flange using bolted flange rings that press the edge of the fabric between the flange and the ring. This feature allows the fabric sheet to be replaced if it becomes damaged or torn.

Typical applications for fabric expansion joints are described in more detail in Appendix A of this report.

3
GENERIC OPERATION AND FAILURE MECHANISMS OF EXPANSION JOINTS

3.1 Theory of Operation

3.1.1 Metal Expansion Joints

The metal bellows is the flexible element of the expansion joint. It must be strong enough circumferentially to withstand the pressure and flexible enough longitudinally to accept the deflections for which it was designed, and as repetitively as necessary with minimum resistance. This strength with flexibility is a unique design problem that is not often found in other power plant components.

Most engineered structures are designed to inhibit deflection when acted upon by outside forces. Because the bellows must accept deflections repetitively, and deflection result in stresses, these stresses must be kept as low as possible so that the repeated deflections will not result in premature fatigue failures. Reducing bending stress resulting from a given deflection is easily achieved by simply reducing the thickness of the bending member, which in the case of the bellows, is the convolution. However, to withstand the pressure, the convolution, which is also a pressure vessel, must have thickness great enough that the pressure-induced membrane stresses are equal to or less than the allowable stress levels of the materials at the design temperatures. This conflicting need for thickness for pressure and thinness for flexibility is the unique design problem faced by expansion joint designers and manufacturers.

Bellows are not springs, in that most of their deflections produce bending stresses in excess of the materials' yield strength. Understanding how various materials perform and their capabilities in the "plastic" deformation region is key to ensuring the bellows is designed properly for the application.

That bellows routinely operate "plastically" should not be a cause for concern, because most of the materials from which bellows are made share similar highly ductile characteristics. In particular, the endurance limit of these materials, which can be loosely described as the stress at which failure will occur at ten million cycles of repeated stressing, is nearly the same as their yield stress, or the point at which permanent deformation will occur. A bellows that is required to withstand 3000 cycles of a given deflection and pressure, and which ultimately fails after 10,000 cycles, has certainly demonstrated more than acceptable performance. However, it has experienced, during each and every cycle, bending stresses far in excess of the endurance limit and therefore the yield stress, and once deflected, would not have returned on their own to their original undeflected length or shape, as a spring is expected to do. In other words, the bellows would have “taken a set.”

3.1.2 Rubber/Fabric Expansion Joints

A rubber expansion joint is a flexible connector fabricated of natural or synthetic elastomers and fabrics, and if necessary, metal reinforcement to provide stress relief in piping systems because of thermal and mechanical vibration and/or movements.

Rubber expansion joints provide time-tested ways to:

- Accommodate movement in piping runs
- Protect piping from expansion and contraction
- Ensure efficient and economical on-stream operations
- Withstand pressure loads
- Reduce noise
- Isolate vibration
- Compensate for misalignment after plants go on line
- Prolong the life of motive equipment

Rubber expansion joint are used in all systems conveying fluids under pressure and/or vacuum at various temperatures, such as:

- Heating, ventilating systems, and air condition
- Central and ancillary power generation stations
- Sewage disposal and water-treatment plants
- Process piping

Engineers can solve anticipated problems of vibration, noise, shock, corrosion, abrasion, stresses, and space by incorporating rubber expansion joints into designed piping systems. The following are some common functions performed by rubber/fabric expansion joints installed in piping systems.

- **Reduce vibration –** Rubber expansion joints isolate or reduce vibration caused by equipment. Some equipment requires more vibration control than others. Reciprocating pumps and compressors, for example, generate greater unbalanced forces than centrifugal equipment. However, rubber pipe and expansion joints dampen undesirable disturbances including harmonic overtones and vibrations caused by centrifugal pump and fan blade frequency. This is based on actual tests conducted by a nationally recognized independent testing laboratory. Rubber expansion joints reduce transmission of vibration and protect equipment from the adverse effects of vibration.

- **Dampen sound transmission –** Subsequent to going on line, normal wear, corrosion, abrasion, and erosion eventually bring about imbalance in motive equipment, generation of undesirable noises transmitted to occupied areas. Rubber expansion joints tend to dampen transmission of sound because of the steel-rubber interface of joints and mating flanges. Thick-walled rubber expansion joints, compared with their metal counterparts, reduce considerably the transmission of sound.
- **Compensate lateral, torsional, and angular movements –** Pumps, compressors, fans, piping, and related equipment move out of alignment because of wear, load stresses, relaxation, and settling of supporting foundations. Rubber expansion joints compensate for lateral, torsional, and angular movements, preventing damage and undue downtime of plant operations.
- **Compensate axial movements –** Expansion and contraction movements because of thermal changes or hydraulic surge effects are compensated for with strategically located rubber expansion joints. They act as a helix spring, compensating for axial movements.

The industry has allied itself with designer, architects, contractor and erectors in designing and fabricating rubber expansion joint under rigid standards to meet present day operating conditions. The industry has kept abreast of the technological advances in rubber compounding and synthetic fabrics to provide rubber expansion joints having advantages not available in other materials. Though not intended to be a comprehensive list, the following are some advantages that may be achieved by employing a rubber/fabric expansion joint in a piping system.

- **Minimal face-to-face dimensions –** Minimal face-to-face dimensions in rubber expansion joints offer untold economies compared with costly expansion bends or loops. The relative cost of the pipe itself may be less or no more than a rubber expansion joint; however, total costs are higher when considering plant space, installation labor, supports, and pressure drops.
- **Lightweight –** Rubber expansion joints are relatively light in weight, require little to no special handling equipment to position, contributing to lower installation costs.
- **Low movement force required –** The inherent flexibility of rubber expansion joints permits almost unlimited flexing to recover from imposed movements, requiring relatively less force to move, thus preventing damage to motive equipment.
- **Reduced fatigue factor –** The inherent characteristics of natural and synthetic elastomers are not subject to breakdown or embrittlement and prevent any electrolytic action because of the steel-rubber interface of joints and mating flanges.
- **Reduced heat loss –** Rubber expansion joints reduce heat loss, giving long maintenance-free service. The added piping required for loops contribute to higher operating costs after going on line due because of increased heat losses.
- **Corrosion, erosion resistant –** A wide variety of natural, synthetic and special-purpose elastomers and fabrics are available to the industry. Materials are tested and combined to meet a wide range of practical pressure/temperature operating conditions, corrosive attack, abrasion and erosion. Standard and special sizes of rubber expansion joints are available with TFE/FEP liners, fabricated to the configurations of the joint body, as added insurance against corrosive attack. Teflon® possesses unusual and unique characteristics of thermal stability,

non-sticking surface, extremely low coefficient of friction, and resistance to practically all-corrosive fluids and forms of chemical attack.

- **No Gaskets –** Elastomeric expansion joints are supplied with flanges of vulcanized rubber and fabric integrated with the tube, making the use of gaskets unnecessary. The sealing surfaces of the expansion joint equalize uneven surfaces of the pipe flange to provide a fluid-and-gas tight seal. A ring gasket may be required for raised face flanges.
- **Acoustical impedance –** Elastomeric expansion joints significantly reduce noise transmission in piping systems because the elastomeric composition of the joint acts as a dampener that absorbs the greatest percentage of noise and vibration.
- **Greater shock resistance –** The elastomeric type expansion joints provide good resistance against shock stress from excessive hydraulic surge, water hammer, or pump cavitation.

3.2 Failure Mechanisms of Metal Bellows

3.2.1 Circumferential Cracking

A metal bellows may fail by circumferential cracking resulting from cyclic bending stresses, or fatigue. Because the best design is a compromise, or balance, between pressure strength and flexibility considerations, one can conclude that their designs have had lower margins of safety regarding fatigue than they had regarding pressure strength.

3.2.2 Squirm or Column Instability

As described in Section 3.2.1, all metal bellows have a critical pressure at which they become unstable. Instability can occur in either of two modes, column instability (or squirm), or in-plane deformation of the convolution sidewall. As illustrated in Figure 3-1, squirm is the phenomenon whereby the centerline of a straight bellows develops a sideways or lateral bow.

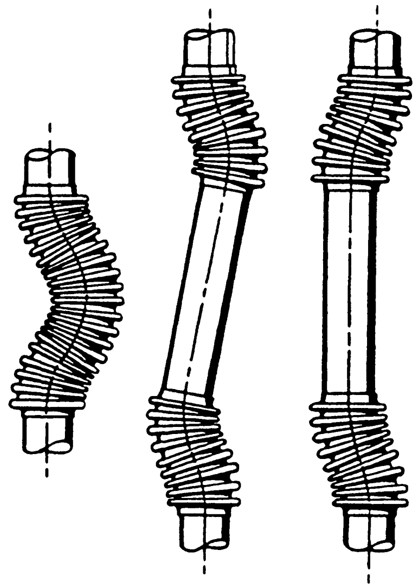


Figure 3-1
Column Instability or Squirm (Courtesy of Expansion Joint Manufacturers Association, Inc.)

The critical pressure at which this instability occurs is a direct function of the diameter and spring rate and an inverse function of its length. If the bellows is bent, or angulated, the centerline can begin to move away from the center of the curvature. In each case, the effective length of the bellows increase, lowering the material available to withstand the pressure, thereby increasing the hoop stresses. As the length increases, the tendency to squirm increases and the stresses become higher and higher until catastrophic failure occurs. A simple way to visualize this phenomenon is to remember that the bellows is a cylinder of given volume. Because a bellows is flexible in the axial direction, it can increase its volume by increasing the length of its centerline. With the ends fixed, it does so by simulating the appearance of a buckling column.

3.3 Root Causes of Expansion Joint Failures

The following is a listing of some of the common root causes of expansion joint failures. Some are attributed to improper actions after the expansion joint has been designed, and some can be attributed to issues that may not have been addressed during the design of the item. Section 3.4 of this report provides plant operating experience regarding actual expansion joint failures.

3.3.1 Improper Handling

One of the most frequent causes of expansion joint failure is damage incurred during the shipping, storage, or handling of the item. Bellows are frequently damaged from being struck by hard objects such as tools, chains, forklifts, and other adjacent structures as a result of improper handling. Any denting or gouging of the bellows can severely affect the performance of the bellows and lead to premature failure. Weld splatter can also damage the thin bellows material.

Key Technical Point

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.

3.3.2 Anchor Failure

Anchor failure can be catastrophic, resulting in total, immediate failure of the bellows and damage to the piping system. Partial anchor failure may cause the bellows to respond differently to movements because of thermal expansion/contraction of the piping system. This will subsequently cause the expansion joint to operate outside of design parameters and prematurely develop fatigue cracks and leaks. In many cases, complete anchor failures can result in a catastrophic failure of the expansion joint.

3.3.3 Corrosion

Corrosion is a problem that affects many aging bellows, although some types of corrosion such as stress corrosion cracking can occur rather quickly. 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:

- Intergranular stress corrosion – A type of corrosion evidenced by cracking and results because of stress and a corrosive environment, particularly halogens. This type of corrosion is characterized by a preferential attack along the grain boundaries in metal.
- Pitting – A localized attack on metal.
- General corrosion.
- Galvanic 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 in caustic environments. High-nickel alloys are also subject to sulfur-induced corrosion.

Key Technical Point

Bellows fabricated from 300-series stainless steels are particularly subject to stress corrosion cracking. High nickel alloys are also subject to sulfur-induced corrosion.

3.3.4 Erosion

Erosion is a problem that effects bellows that are subjected to high flow velocities, abrasive media, or turbulent flow. Over time, the effect of erosion will cause 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.

3.3.5 Excessive Flow Rate

The maximum allowable flow velocity past an unprotected bellows can be calculated. Excessive flow velocities may induce resonant vibration in the convolutions, resulting in premature failure.

3.3.6 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 value will result in a reduced cycle life and premature failure.

3.3.7 Fatigue

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

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

Key Technical Point

Generally, the bellows designs have a larger safety factor with respect to pressure strength than they do with respect to flexibility because of safety precautions. Premature fatigue damage can result from virtually any load or stress concentration outside of the allowable design values.

3.3.8 Improper Anchoring, Guiding, or Supporting

Proper application of pipe restraint is essential to good bellows performance. These restraints allow movement only in directions intended by the designer. The design of pipe restraint must take into account the forces resulting from the bellows pressure thrust, any hydraulic thrust, the bending of the pipe segment and the spring rate of the bellows. Many designers often 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 in case of a vacuum.

If adequate main anchors cannot be provided to absorb the pressure thrust, then the bellows should be equipped with tie rods, or other pressure restraining hardware such as hinges or gimbals. When a bellows is used primarily for axial movements, a good rule of thumb is to locate the bellows adjacent to a main anchor, 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.

Key Technical Point

When a bellows is used primarily for axial movements, a good rule of thumb is to locate the bellows adjacent to a main anchor, 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.

In many cases, complete anchor failures can result in a catastrophic failure of the expansion joint. Care should be taken to ensure pressure thrusts are correctly factored into the design of anchoring systems.

3.3.9 Improper Installation

A common error associated with bellows installation is moving the expansion joint to make up for misalignment that has not been accounted for in the design.

Key Technical Point

A common error associated with bellows installation is moving the expansion joint to make up for misalignment that has not been accounted for in the design.

Any compression, extension, offset rotation and especially torsion that has not been anticipated in the design can substantially reduce the cycle life of the bellows. It should be emphasized that the piping should fit the bellows and not vice versa.

Key Technical Point

It should be emphasized that the piping should fit the bellows and not vice versa.

Normally, a tolerance is provided that 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.

Key Technical Point

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 the flow direction. If a bellows is installed in the wrong orientation, then turbulent flow could result and cause unwanted vibrations or excessive erosion that could damage the bellows.

Key Technical Point

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.

3.3.10 Overpressurization

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

3.3.11 Torsion

Bellows are typically not designed to accept any amount of torsion. Twisting of the bellows should be prevented or the bellows will fail prematurely.

Key Technical Point

Bellows are typically not designed to accept any amount of torsion. Twisting of the bellows should be prevented or the bellows will fail prematurely.

3.3.12 Mechanical Vibration

Excessive vibration in a system can lead to high cycle fatigue cracking and subsequent failure. Vibration is usually the result of system components. 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 assembly.

Key Technical Point

In general, very low-amplitude vibration should not harm most expansion joints but high-amplitude vibration will destroy a bellows assembly.

3.3.13 Flow-Induced Vibration

Vibration can be the result of turbulent flow or high velocity 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.

3.3.14 Non-Uniform Temperature Distribution Around Bellows

If external steam flow, perpendicular to the pipe centerline, passes a bellows, the flow separates at some point on the bellows circumference. The surface of the bellows upstream of the separation point is steam-cooled, while the downstream surfaces are not. Particularly, in condenser expansion joints, this phenomenon can cause a thermal stress (hoop stress) at the separation point, which can subsequently lead to axial bellows cracks. External covers/shields are often provided to minimize the occurrence of this failure mechanism.

3.3.15 Susceptibility to Failure Mechanisms for Different Types of Expansion Joints

Table 3-1 summarizes the susceptibility to different types of failure mechanisms for the types of expansion joints discussed in this guide. The table may not reflect actual plant conditions and should not be used to predict failures of installed equipment.

Table 3-1
Susceptibility to Failure for Different Types of Expansion Joints

Failure Mechanism	Susceptibility to Failure Mechanism	
	Metal Expansion Joints	Rubber/Fabric Expansion Joints
Rupture	High	Medium
Crack	High	Low
Leak	Medium	High
Deformation	Medium	Medium
Wall thinning	Low	Low
Tie rod failure	Low	Low, if applicable
Pinhole leak	Low	Low
Liner tear	Low	Low
Liner crack	Low	Low
Material degradation	Not applicable	Low
Implosion	Low	Low
Tear	Not applicable	Low
Corrosion	Medium	Low (internal metal components)

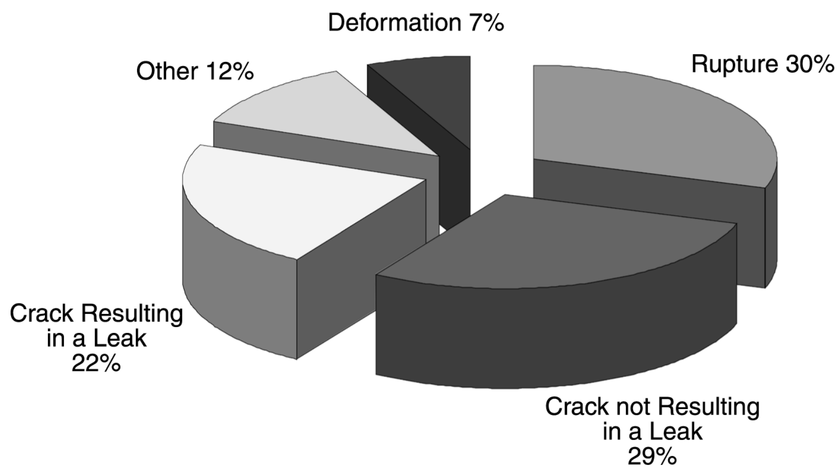
3.4 Failure Data Obtained Through Industry Operating Experience

During the development of this report information was provided by nuclear plant licensees regarding operating experience of both metal and rubber expansion joints. The data were analyzed to determine the types of failures most commonly seen in expansion joints, and the types of causes leading to these failures. In addition to current utility feedback, failure data were provided that resulted from compilations of industry-wide sources.

Appendix C of this report includes a copy of the questionnaire that was provided to utility personnel, and a compilation of their responses. The appendix also includes a summary of the industry-wide failure data that were provided by utility personnel during the preparation of this report.

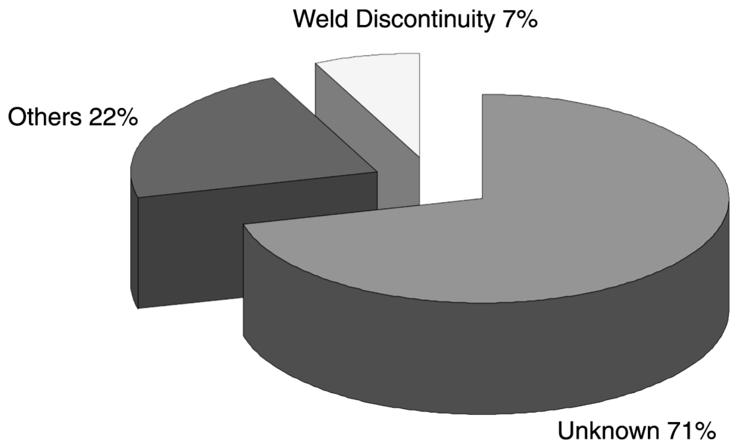
3.4.1 Metal Expansion Joint Failure Data

Figures 3-2 and 3-3 illustrate the most common failures and causes associated with metal expansion joints installed in nuclear power plants. The data from which these charts were derived comprised information from 41 documented failures occurring at 25 different nuclear units. The failures dated back to 1982 and were obtained through data searches on the INPO NPRDS.



Note: Other failures category includes wall thinning, tie rod failure, pinhole leak, liner tear, and liner crack.

Figure 3-2
Common Failures of Metal Expansion Joints



Note: Other causes of failures included water hammer, manufacturing defect, galvanic corrosion, erosion, design, damaged, cyclic fatigue & vibration, crevice corrosion, and corrosion. The unknown failures could include those same causes.

Figure 3-3
Common Causes of Metal Expansion Joint Failures

Figures 3-4 and 3-5 illustrate actual failures of metal expansion joints. Figure 3-4 depicts a cracked liner on an extraction steam expansion joint.

Figure 3-4
Extraction Steam Expansion Joint With Cracked Liner (Courtesy of Progress Energy)

Figure 3-5 depicts a severely cracked bellows on a condenser expansion joint.

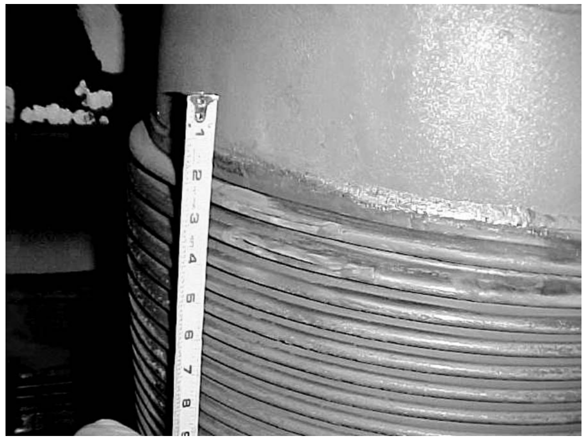
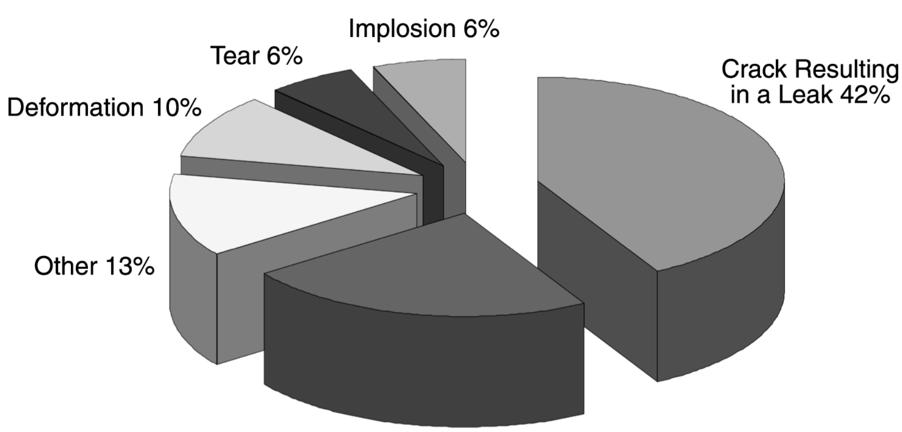


Figure 3-5
Condenser Expansion Joint With Cracked Bellows (Courtesy of Progress Energy)

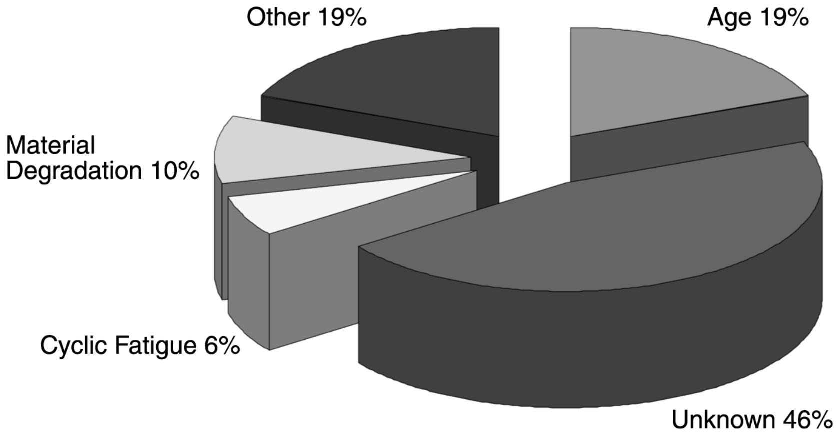
3.4.2 Rubber Expansion Joint Failure Data

Figures 3-6 and 3-7 illustrate the most common failures and causes associated with rubber expansion joints installed in nuclear power plant applications. The data from which these charts were derived comprised information from 31 documented failures occurring at 22 different nuclear units. The failures dated back to 1977 and were obtained through data searches on the INPO NPRDS.



Note: Other failures included pinhole leak, liner hole, and degradation.

Figure 3-6
Common Failures of Rubber Expansion Joints



Note: Other causes of failures included water hammer, overpressurization, high temperature, excessive forces, and erosion. The unknown causes of failures could include those same causes.

Figure 3-7
Common Causes of Rubber Expansion Joint Failures

3.5 Failure History From a Manufacturer's Perspective

The following information is based on surveys and interviews conducted with various manufacturers of expansion joints during the development of this report.

3.5.1 Metal Expansion Joints

3.5.1.1 Most Common Types of Failures

Figure 3-8 illustrates the most common types of failures for metal expansion joints based on the experience of manufacturers. Descriptions of the failures follow the figure.

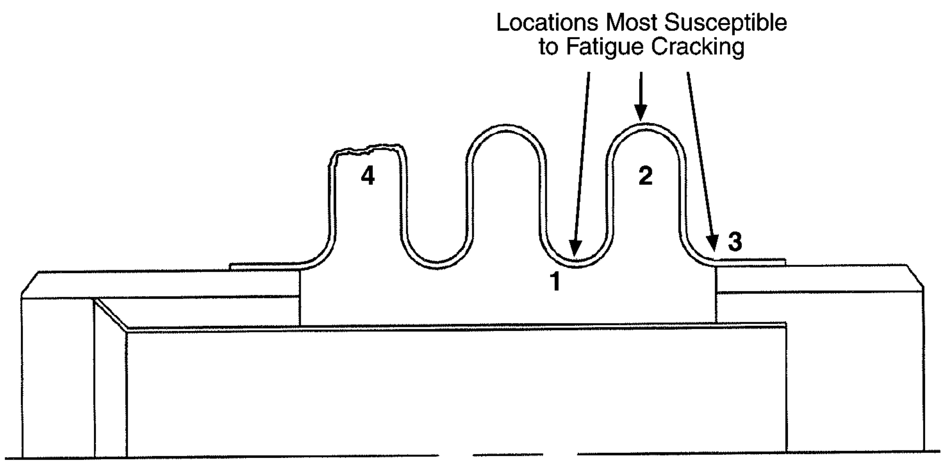


Figure 3-8
Common Types and Locations of Failures of Metal Expansion Joints

1. Cracks near the base of the outermost and second outermost convolutes
2. Cracks at the top of the outermost and second outermost convolutes
3. Cracks in the bellows attachment weld (spool piece to bellows)
4. Permanent deformation of the bellows

3.5.1.2 Most Common Causes of Failures

The most common causes of failure in metal expansion joints include:

- Improper handling, shipping or installation resulting in dents, gouges, or bends
- Improper anchoring, guiding, or support of piping system:
  - Anchors, guides, and pipe supports had been modified, relocated, or removed, subsequently altering the lateral, angular, and torsional movement of the piping system.
  - Anchors, guides, and pipe supports had failed (that is, cracked or permanently deformed), subsequently altering the movement of the piping system.
- Improper application of the expansion joint (used in an application in which it was not suitable):
  - Expansion joint was not provided with a cover but was used in an application where it was exposed to both inside and outside flow.
  - The outside flow caused the unprotected bellows to develop cracks and to prematurely wear.
- Design inadequacies (inadequate specification of design requirements resulting in an unsuitable design) (for example, upset design conditions of pressure, temperature, and flow rate were not specified to the manufacturer)
- Misalignment of piping system at the time of installation
- Corrosion

3.5.2 Rubber/Fabric Expansion Joints

3.5.2.1 Most Common Types of Failures

The most common types of failure in rubber/fabric expansion joints include:

- Cracks/tears in the rubber/fabric
- Loss of physical properties of the rubber/fabric

3.5.2.2 Most Common Causes of Failures

The most common cause of failures in rubber/fabric expansion joints include:

- Misalignment of piping system at the time of installation causing excessive movement (for example, a rubber expansion joint was installed in a system with nearly 0.5 in. [1.27 cm] of lateral pipe misalignment, resulting in movement and stress fatigue that was not anticipated when the expansion joint was designed)

Key Technical Point

Excessive movement and/or misalignment is the leading cause of failure for rubber/fabric expansion joints.

- Improper application of the expansion joint (for example, an expansion joint was used in an application where the fluid was not compatible with the type of rubber furnished)
- Design inadequacies (inadequate specification of design requirements resulting in an unsuitable design):
  - Increased operating temperature resulted in a different chemistry of the fluid, which subsequently caused the rubber to corrode and collect particulate in the arch.
  - Unanticipated increased levels of abrasive particulate accelerated the erosive wear on the fabric of an expansion joint, resulting in catastrophic failure of the composite fabric belt.

4
CONDITION-BASED MONITORING

4.1 Preventive Maintenance Recommendations

The results of an industry survey that was conducted during the development of this guide suggest that there were few licensees who had established a formal preventive maintenance program for expansion joints. Some indicated that they were in the process of establishing a program; however, they were not yet able to provide specifics of the scope and methodology of the program.

Fundamental to any preventive maintenance program is knowledge of original design parameters such as system pressure and temperature, operating deflections, as well as factory presets/offsets designed into the expansion joint.

4.1.1 Metal Expansion Joints

4.1.1.1 General Preventive Maintenance Measures

The following activities are recommended as general preventive maintenance measures to identify premature failure or accelerated degradation:

- Identify any signs of rubbing. If there are any signs of rubbing between the convolutions, then the bellows is being deflected beyond its design capacity and eventually a hole will be worn in the expansion joint.
- Determine whether the gap between adjacent bellows convolutes is symmetrical along the length of the bellows. When properly installed, the gap should be symmetrical over the length of expansion joint, and there should be no indication of bellows deformation/distortion.
- Identify any rattling sound indicating that something is loose inside. This could indicate that the inner liner has broken free. If it is permitted to rattle around, eventually a hole will be worn in the bellows from the inside.
- Identify any discoloration that suggests that the expansion joint has been overheated.
- Inspect all tie rods and bolting to ensure that they are still properly assembled. Depending on the purpose of the tie rods, they may be either tight or loose within approximately 0.25 in. (0.635 cm) of movement.

- Verify that flexible components are within acceptable axial and lateral displacements. These measurements may be difficult to obtain but can be estimated using straight edges across the bellows convolute(s).
- Verify that there is adequate clearance between the outer cover and the bellows. (Some designs include an "eddy ring" at the bottom of the bellows to ensure that there is no contact between the bellows and the cover. The most critical clearance is between the bellows and the cover, not between the eddy ring and the cover.)
- Verify that there is no evidence of steam impingement because of leakage.

4.1.1.2 Metal Expansion Joints Inside the Condenser

An inspection of expansion joints inside the condenser is recommended before closing the condenser hatches. This inspection is intended to ensure that equipment is properly installed. Part of this inspection should ensure that the metal cover (the metal surrounding the outside of the bellows) is in place. This inspection may include visual examination of the cover bolting and/or attachment devises (for example, ensuring that tack welds are intact, attaching clips are secure, and no cracks in clip welds). This inspection is typically performed by an engineer or maintenance technician, and is often performed early during each refueling outage because the results could cause additional condenser work. A visual inspection of the covers should verify that the bolts are in place and that the nuts have not started to loosen, and can be performed from the tops of the tubes using a strong light. A visual inspection of the bellows can be performed to identify cracks, if the cover can be removed.

A closer inspection may be performed with scaffolding installed at the expansion joints and checking the torque of each bolt. Expansion joints that are equipped with dual-ply bellows and a test connection should be pressure tested during each outage. (Note that fatigue failures are difficult to predict and that testing/inspection alone will not prevent an impending failure.)

As with main condenser walls, a cold alignment check should be performed on extraction lines to ensure that permanent deformation because in-service forces have not exceeded the maximum out-of-alignment acceptance criteria. This alignment check should be performed after the first cycle on a new installation, and at least every five refueling cycles thereafter. During outages, when scaffolding is impractical, a quick inspection using a ladder and fall protection (for example, two lanyards) should be considered. Using a mirror, an inspection can be performed to ensure that no rubbing exists because of misalignment while in service.

Key Technical Point

As with main condenser walls, a cold alignment check should be performed on extraction lines to ensure that permanent deformation because in-service forces have not exceeded the maximum out-of-alignment acceptance criteria. This alignment check should be performed after the first cycle on a new installation, and at least every five refueling cycles thereafter.

4.1.1.3 Considerations for Nondestructive Examination of Bellows

The only inspection technique available for detecting fatigue cracks is dye-penetrant testing (PT). Although it is likely that a crack, once detectable, would proceed through the thin bellows material in short time, PT should be considered on bellows with 10 to 15 years of service life when scaffolding has already been erected for other activities.

Concurrent with each LP turbine rotor removal and inspection, ID boroscopic inspection should be performed on each expansion joint. The liner to stub end weld should be carefully inspected to look for cracking or evidence of erosion that might lead to a liner becoming detached. Any damage to the inner liner should constitute sufficient reason for replacement of the joint assembly.

Where physically possible, an articulated fiber-optic scope may be used, and an inspection can be performed between the inner liner and bellows. To facilitate these types of inspections, some utilities have installed an inspection port upstream of the expansion joint installation field weld. When performing these inspections, care should be taken not to cause the scope to become lodged in place or entangled in the inner liner. Again, any evidence of rubbing should be considered sufficient reason to replace the joint assembly.

4.1.2 Rubber/Fabric Expansion Joints

4.1.2.1 Inspection of the Cover

Inspections are usually performed from outside of the expansion joint because access to the inside is limited by plant operation and is often limited by the system design. Unfortunately, inspections made from the outside only afford the opportunity to directly inspect the cover, which is the least important component part of the expansion joint assembly. However, the condition of the cover can provide information on the condition of the expansion joint core and tube.

The following expansion-joint-cover indications are unacceptable and typically indicate that the expansion joint be replaced:

- Fabric of the expansion joint core is exposed or torn.
- Deterioration of the rubber cover (cover is soft or gummy).
- Metal reinforcement in the core is visible through the cover.
- Leakage is occurring from any surface (except flange seating surface).

The following expansion-joint-cover indications are usually acceptable after evaluation and repairs where required:

- Cracking or crazing of outer cover. (The core is not exposed.) Cracks that would allow moisture into the core should be repaired to provide protection of the core. Minor crazing and cracking of the cover is acceptable and should be monitored for further degradation as the expansion joint ages.
- Flattening of bellows arch has occurred or there is distortion of the arch. Some expansion joint deformation is acceptable. Distortion or excessive flattening of the expansion joint arch requires that an inspection be performed to verify that the expansion joint displacements are within design limits.
- Some blisters in the tube are acceptable. Large blisters or any blisters containing process fluid are unacceptable and indicate that there is a problem with the tube.
- Leakage from flange seating surfaces requires that all bolts be retightened and requires verification that washers are used under all bolt heads.

4.1.2.2 Inspection of Components Inside/Below the Cover

The following activities are recommended as general preventive maintenance measures to identify premature failure or accelerated degradation. An inspection should be performed inside the expansion joint when possible to examine the condition of the tube. Inside inspection of the tube will be limited in cases where the expansion joint is designed with a filled arch.

- Visually examine the outer surface, looking for scale, flakes, cracks, cuts, and tears. This inspection is intended to assess the overall condition of the expansion joint. The cracks, cuts, or other breaks are used to estimate the remaining life of the expansion joint. The depth of the cracks should be estimated (surface cracks are typically not a serious concern). However, if the fibers of the core are exposed, then replacement of the rubber expansion joint is recommended.

Key Technical Point

Typically, if the fibers of the core are exposed, then replacement of the rubber expansion joint is recommended.

Cracking, checking, or crazing may not be serious if only the outer cover is involved and the fabric is not exposed. If necessary, repair the cover on-site with rubber cement where cracks are minor. Cracking where the fabric is exposed and torn indicates the expansion joint should be replaced (dimensions should be verified before replacement).

Such cracking is usually the result of excess extension or angular or lateral movements, and is usually identified by the following:

 – A flattening of the arch
 – Cracks at the base of the arch
 – Cracks at the base of the flange

- Visually inspect for signs of paint or other coatings that could be harmful to the expansion joint. Identify the presence of any insulation that could affect proper operation.
- Visually inspect for blisters, deformation, and ply separation. Some blisters or deformations, when on the external portions of an expansion joint, may not affect the proper performance of the expansion joint. These blisters or deformation are cosmetic in nature and do not require repair. If major blisters, deformation, and/or ply separations exist in the tube, the expansion joint should be replaced as soon as possible. Ply separation at the flange OD can sometimes be observed and is not a cause for replacement of the expansion joint.
- Visually inspect to verify that the installation is correct and that there is no excessive misalignment between the flanges and that the installed face-to-face dimension is correct. Check for overelongation, overcompression, and lateral or angular misalignment.
- Inspect the deeper appearing cracks on each expansion joint by placing a finger on the crack to gauge any differential motion between the two sides of the crack. This can be an indication that the crack is starting to affect the inner fiber core and can be an indication that the service life is nearly expired.
- The arch of the surrounding areas should be depressed to locate soft spots that may indicate separation of the cover from the core, or indicate separation between layers of the core. If soft spots are found, then they may be an indication that the service life is nearly expired.
- Inspect any bolting material to ensure that it is not making contact with the surface of the expansion joint. If the bolts contact the expansion joint, then it is possible that the arch will be cut by contact with the bolting during service. This visual inspection should also consider the rubber flange connection to ensure the bolts have not been overtightened. This may be indicated by excessive bulging of the rubber as it was compressed.
- Visually inspect the inside of the expansion joint each time it is accessed to determine if any erosion has occurred on the flexible pipe component. Internal inspections may be complicated by any internal piping coatings that may have been applied.
- Visually inspect the rubber for deterioration. If the rubber feels soft or gummy, plan to replace the expansion joint as soon as possible.

5
TROUBLESHOOTING

5.1 Generic Process

Figures 5-1 and 5-2 illustrate a generic process for troubleshooting failures of expansion joints. The process is consistent with the methodology described in EPRI Report 1003093, *System and Equipment Troubleshooting Guidance,* but is modified slightly to make it most applicable to expansion joints.

The process basically involves investigating four aspects of the expansion joint— (1) variance from design parameters, (2) system guide/anchoring configuration, (3) metallurgical problems, and (4) installation practices. As illustrated in Figure 5-1, investigating any variance from design parameters should be an integral piece of the preliminary evaluation.

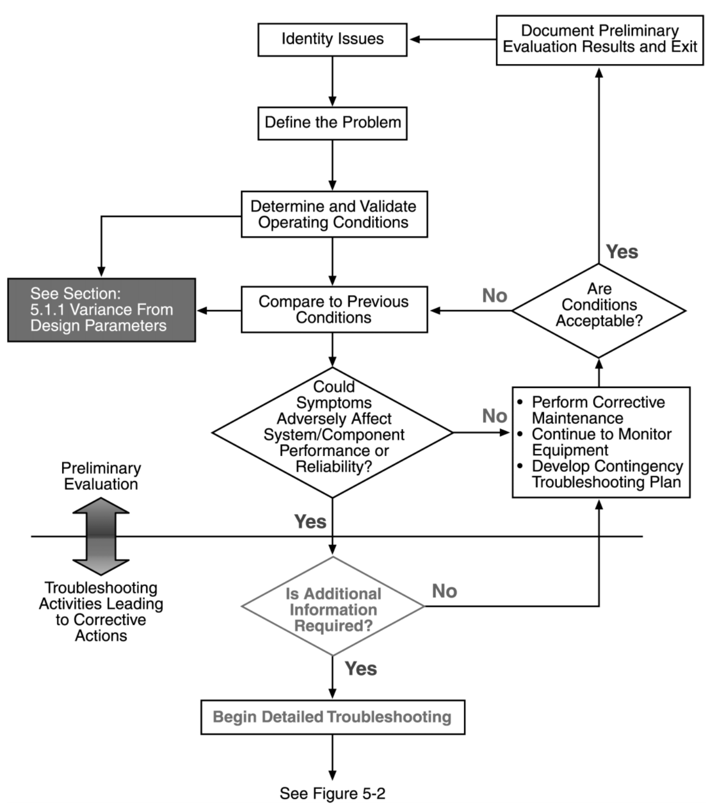


Figure 5-1
Generic Troubleshooting Process for Expansion Joint Failures – Preliminary Evaluation

5.1.1 Variance From Design Parameters

The first step when troubleshooting a failure of an expansion joint is to determine if there is any variance from design parameters. Specifically, the licensee should determine if the expansion joint was used in an application suitable for its design, and whether it was exposed to different pressure, temperature, fluid (for example, viscosity, chemical composition, abrasion, particulate, leachable halogens), flow rate, operating deflections, or ambient conditions than those specified to the manufacturer. The licensee should also determine if the design includes any factory presets/offsets.

5.2 Detailed Troubleshooting Guidance

Figure 5-2 illustrates additional issues that should be investigated during the detailed troubleshooting effort.

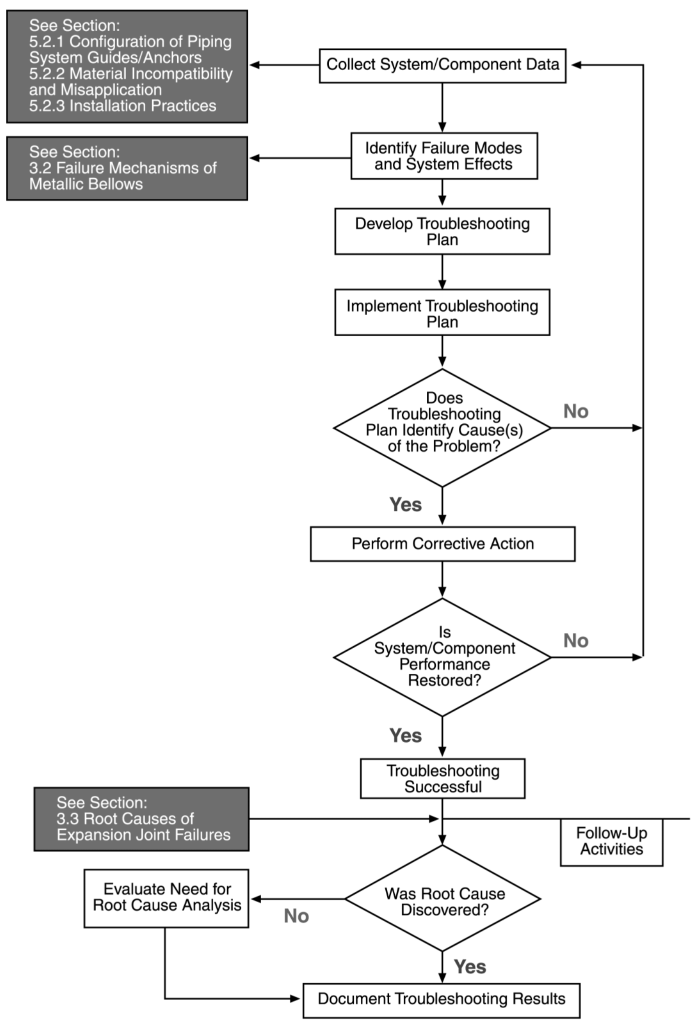


Figure 5-2
Generic Troubleshooting Process for Expansion Joint Failures – Detailed Evaluation

5.2.1 Configuration of Piping System Guides/Anchors

The next step is to determine if there have been any modifications (planned or inadvertent) to the piping system guide and anchor configurations.

5.2.1.1 Metal Expansion Joints

For metal expansion joints, most often the following aspects of the configuration should be checked:

- Tightness and torque of bolting members
- Removal or loss of bolting hardware
- Removal or loss of pipe anchors
- Failure of pipe anchors or guides (that is, cracking, corrosion, or other similar deterioration)
- Relocation of pipe anchors or guides
- Addition of pipe anchors that have restrained or altered the movement of the piping system
- Evidence of vibration

5.2.1.2 Rubber/Fabric Expansion Joints

Elastomeric expansion joints will show signs of premature wear as a result of many factors. Old age is one of the most common reasons for wear; however, misalignment is another factor that will cause significant damage to an expansion joint. Table 5-1 provides a number typical signs of premature wear and their causes that can lead to degraded performance of the expansion joint.

Table 5-1
Detailed Troubleshooting Guidance for Rubber/Fabric Expansion Joints

Symptom	Possible Causes of Problem
Cracking at base of arch	Usually a sign of overcompression.
	Check for any fabric that is exposed.
	Check for proper pipe alignment within ± 0.125 in. (0.318 cm).
Cracking at base of flange	Usually a sign of overelongation.
	Check for any fabric that is exposed.
	Check for proper pipe alignment within ± 0.125 in. (0.318 cm).
Leaking at the flange	Bolts may need tightening. Following initial installation the bolts should be retorqued at least after one week and periodically check thereafter. (OD of expansion joint flange should bulge out or dimple in slightly.)
	Mating flange surface may have excessive grooves, scratches, and/or distorted areas.
	Expansion joint may have been overextended at point of installation or operation. Control units may be necessary to keep the expansion joint within the design parameters.
	Retaining rings may be warped or corroded.
Weeping at bolt holes	If accessible, check the integrity of the tube portion of the expansion joint. If cracks exist the media has reached the fabric reinforcement and has wicked through to the bolt holes.
Excessive ballooning	Check operating pressure in relation to design pressure.
	Strengthening members of the expansion may have broken down over time.
	Temperature may be excessive.

Additional observations that may impact the performance of the expansion joint are:

- Cover portion may feel hard and brittle because of excessive heat or old age.
- The arch may become inconsistent caused by the migration of body rings.
- Cover or OD of flange may feel tacky because of chemical or ozone attack from the surrounding environment.
- OD of flange may split if the bolts are torqued inconsistently or too far.
- If the joint is seeing concurrent movements, the cover will begin to delaminate.

5.2.2 Material Incompatibility and Misapplication

5.2.2.1 Metal Expansion Joints

Table 5-2 illustrates various failure mechanisms and metallurgical type problems common to metal expansion joints. The table should assist in troubleshooting the cause of metallurgical failure and offers proposed solutions.

Table 5-2
Common Metallurgical Problems and Troubleshooting (Courtesy of Senior Flexonics Pathway)

Failure Mechanisms	Cause	Frequently Used Solutions
Chloride stress corrosion cracking	Chlorides acting on highly stressed austenitic stain steel bellows.	Use a high-nickel alloy such as 600 or alloy 625.
Carbide precipitation	Chromium carbides form in unstabilized stainless steels (T304, T316) at high temperatures (greater than 700 °F or 371 °C) causing loss of corrosion resistance at the grain boundaries.	Use a stabilized stainless steel (T321 or T347) or a low-carbon stainless steel (T304L) or another high-alloy material that is less affected by carbide precipitation.
Pitting corrosion	Electrochemical action causes hole to form in a bellows, usually from chlorides and acids.	Use a bellows material containing molybdenum T316, Alloy 825, Alloy 625) or one of the specialty materials such as zirconium tantalum or titanium.
Dew point corrosion	Liquid acid precipitates out of a sulfur-rich flue gas stream in contact with the bellows element that operates just below the dew point for acid formation.	Insulate the bellows to ensure that it operates above dew point in service or install a “hot blanket” to maintain a constant bellows skin temperature that is above dew point.
Galvanic corrosion	Dissimilar metals interacting under certain water chemistry conditions.	Employ an expansion joint that comprises of all stainless steel components. Modify the physical configuration by eliminating the crevice (success may be dependent on corrosion and flow conditions).

5.2.2.2 Rubber/Fabric Expansion Joints

Table 5-3 lists the temperature class of materials used in rubber/fabric expansion joints. Use of materials in applications exceeding design temperature limits can greatly contribute to the premature failure of rubber/fabric expansion joints.

Table 5-3
Temperature Class of Materials Used in Expansion Joints (Courtesy of Fluid Sealing Association)

Type of Elastomer	Class	Type of Fabric	Class
Gum rubber	Class I	Cotton	Class I
Natural rubber	Class I	Rayon	Class I
SBR/GRS/Buna-N	Class I	Nylon	Class II
Neoprene	Class II	Polyester	Class III
Buna-N/Nitrile	Class II	Fiberglass	Class III
Hypalon®	Class II	Kevlar	Class III
Butyl	Class II	Nomex	Class III
Chlorobutyl	Class III		
EPDM	Class III		
Viton®/Fluorel®	Class III		
Silicone	Class III		
Teflon®/TFE/FEP	Class III		

Key:
Standard Class I: Recommended for temperatures less than 180 °F (82.2 °C).
Standard Class II:Recommended for temperatures less than 230 °F (110 °C).
Standard Class III: Recommended for temperature greater than 230 °F (110 °C).

Notes:
Material combinations are available for temperatures less than 400 °F (204 °C).
Hypalon®, Teflon®, and Viton® are registered trademarks of DuPont Dow Elastomers L.L.C.
Fluorel® is a registered trademark of Dyneon.

Table 5-4 provides a comparison of elastomer physical and chemical properties for various applications of rubber/fabric expansion joints.

Table 5-4
List of Elastomers Used in Expansion Joints (Courtesy of Fluid Sealing Association)

Common Name	Water	Chemical	Animal & Vegetable Oil	Alkali, Concentrated	Alkali, Dilute	Oil & Gasoline	Lacquers	Oxygenated Hydroxides	Aromatic Hydroxides	Alphatic Hydroxides	Acid, Concentrated	Acid, Dilute	Swelling in Oil	Radiation	Water Absorption	Electrical Insulation	Dielectric Strength	Tensile Strength	Compression Set	Rebound - Cold	Rebound - Hot	Dynamic	Impermeability	Abrasion	Tear	Flame	Cold	Heat	Oxidation	Sunlight	Weather	Ozone
Neoprene	4	3	4	0	4	4	0	1	2	3	4	6	4	5	4	3	5	4	2	4	5	2	4	5	4	4	4	4	5	5	6	5
Gum Rubber	5	3	X	X	X	0	0	4	0	0	3	3	0	6	5	5	6	6	4	6	6	6	2	7	5	0	5	2	4	0	2	0
Natural Rubber	5	3	X	X	X	0	0	4	0	0	3	3	0	6	5	5	6	6	4	6	6	6	2	6	5	0	5	2	4	0	2	0
Butyl	5	6	5	4	4	0	3	4	0	0	4	6	0	4	5	5	5	4	3	0	5	2	6	4	4	0	4	5	6	5	5	6
Chlorobutyl	5	6	5	4	4	0	3	4	0	0	4	6	0	4	5	5	5	4	3	0	5	2	6	4	4	0	4	5	6	5	5	6
Buna-N/Nitrile	4	3	5	0	4	5	2	0	4	6	4	4	5	5	4	1	0	5	5	4	4	5	4	4	3	0	3	4	4	0	2	2
SBR/GRS/Buna-N	5	3	X	2	4	0	0	4	0	0	3	3	0	6	5	5	4	5	4	4	4	4	2	5	3	0	5	3	2	0	2	0
Hypalon®	5	6	4	4	4	4	3	1	2	3	4	6	4	5	4	3	5	2	2	2	4	2	4	4	3	4	4	4	6	7	6	7
Viton®/Fluorel®	5	6	6	0	4	6	1	0	6	6	6	5	6	5	5	3	5	5	6	2	4	5	5	5	2	6	2	7	7	7	7	7
EPDM	5	6	5	6	6	0	3	6	0	0	4	6	0	7	6	6	7	5	4	6	6	5	4	5	4	0	5	6	6	7	6	7
Teflon®/TFE/FEP	7	7	7	7	7	7	7	7	7	7	7	7	7	3	7	X	X	X	X	X	X	X	X	4	X	X	X	7	7	7	7	7
Silicone	5	5	5	0	2	X	0	2	0	0	2	6	2	5	6	6	4	0	3	6	6	0	2	0	2	2	6	7	6	6	6	6

Rating Scale Code:
7 – Outstanding
6 – Excellent
5 – Very Good
4 – Good
3 – Fair to Good
2 – Fair
1 – Poor to Fair
0 – Poor
X – Performance data should be obtained from the manufacturer.

5.2.3 Installation Practices

Premature failure of expansion joints may be a result of improper installation practices. Table 5-5 provides a checklist that may be used to determine possible causes for the failure of the expansion joint.

Table 5-5
Installation Practices Leading to Failure of Metal Expansion Joint

Is there evidence of advertent extension, offset, or compression of the expansion joint to fit the piping system?
Is there evidence of dents, weld splatter, arc strikes on the bellows?
Is the orientation of the expansion joint with the flow arrow?
Have all shipping devices and rods been properly removed?
Is the liner installed in the correct orientation relative to the flow direction?
Is there evidence of foreign material lodged between the convolutions of the bellows?
Is there evidence of physical damage during storage?

Table 5-6
Installation Practices Leading to Failure of Rubber/Fabric Expansion Joint

Is there evidence of excessive advertent extension, offset, or compression of the expansion joint to fit the piping system? Typically any misalignment should be less than 0.125 in. (0.318 cm) for an application using a rubber expansion joint.
Is there evidence of weld splatter, arc strikes on the rubber or fabric?
Have all shipping devices and rods been properly removed? These are not commonly supplied with rubber/fabric joints but should still be considered.
Is there evidence of foreign material lodged near or puncturing the rubber/fabric?
Is there evidence of physical damage during storage?
Is there evidence of over-tightening of flange or retaining ring bolts?
Horizontal/vertical installation: With both vertical and horizontal applications of larger ID expansion joints, they must first be maneuvered into position with the use of cloth slings. Be sure to loop the cloth slings on the outside of the expansion joint and on either side of the arch to prevent damage. Be sure to lubricate flanges to aid in the ease of installation.

Table 5-6 (cont.)
Installation Practices Leading to Failure of Rubber/Fabric Expansion Joint

Piping misalignment: Rubber/fabric expansion joints can be made to size for particular lateral, angular, and torsional misalignments. For expansion joints with 36-in. (91.4 cm) IDs and misalignments from 0.25 to 0.375 in. (0.635 to 0.953 cm), the expansion joint may be pulled into place with a cloth sling and/or the bolt holes may be oversized. These same techniques may be used on expansion joints with IDs larger than 36 in. and misalignments between 0.5 and 0.625 in (1.27 and 1.59 cm). Greater misalignments will require special construction and/or drilling procedures.
Bolting sequence: The recommended bolting pattern is to start at a given point, hand tighten nut, go directly across and repeat process. Continue to tighten each nut rotating in a star pattern. After each nut has been snugged into position then gradually torque each following the same rotation. Continue this process until the edge of the expansion joint either slightly dimples in or bulges out. The objective is to bolt the entire retaining ring segment evenly and to compress the rubber flanges as uniformly as possible. The use of flat steel washers will help obtain an effective seal where the retaining rings are split.
Maintaining seal: Check bolt tightness at least one week after going on line and periodically thereafter. As any rubber like material takes a set after a period of compression, the bolts may loosen and require retorquing. It is particularly important to check bolts during temperature cycles or during shutdown times.
Control units: Control units should be evenly distributed around the bolt circle of the expansion joint. The triangular plate of the control unit is bolted to the outside of the steel pipe flange using 0.125 to 0.25 in. (0.318 to 0.635 cm) smaller diameter than the lower holes in the control unit plate. Insert control rods with washers through the top hole of the first triangular plate. Place compression sleeve (if required) over the control rod. Insert control rod through second triangular plate. Place washers and hex nuts on the end of control unit rod. The control unit rod setting is equal to the combined dimensions of the expansion joint face to face, pipe flange thickness, control unit plate thickness, washer thickness, plus the maximum elongation parameters of the expansion joint. After control units are fully assembled the exposed threads should be staked next to the nut to prevent loosening.

5.3 Example of Troubleshooting

This section provides an example of successfully troubleshooting a problem with an expansion joint and taking appropriate corrective action. This example is provided for illustrative purposes only and may not be directly applicable to all plant-specific conditions or designs.

5.3.1 Problem Identification

During the condenser expansion joint inspection, it was discovered that expansion joint 1HF11 had failed. Expansion joint 1HF11 is located in an extraction line from the turbine to the “F” heater. The bellows appeared to have blown out in a semi-catastrophic fashion. There appeared to be no damage to adjacent components. Figures 5-3 and 5-4 illustrate the nature of the catastrophic failure.

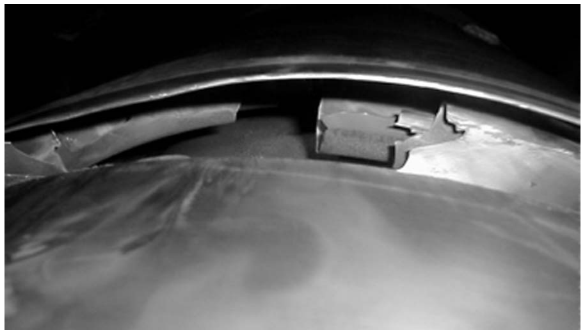


Figure 5-3
Failure of Expansion Joint 1HF11 (Courtesy of Duke Power)

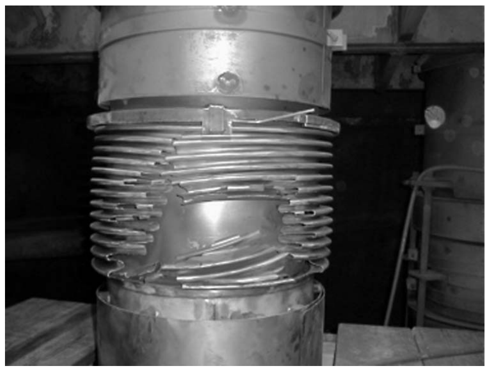


Figure 5-4
Failure of Expansion Joint 1HF11 (Courtesy of Duke Power)

Work request 98154328 was originated to remove the lagging and shrouds from the joint to further inspect the damage and confirm the configuration of the joint before ordering a replacement.

At the time it was unknown what caused the failure. Human error was not involved.

5.3.2 Problem Cause Evaluation

Component aging was the category selected for the cause of this failure.

5.3.3 OEDB Review

An OEDB search for “condenser,” “expansion,” and “joint” returned 38 items, with seven items relating to metal expansion joint failures. An OEDB search for “extraction,” “expansion,” and “joint” returned 11 items, but with no additional items relating to metal expansion joint failures.

Where a cause of the failure is given, the predominant failure mode appeared to be high-cycle fatigue of the bellows.

5.3.4 Problem Evaluation

Expansion joint 1HF11 is an extraction line from the 11^{th} stage of turbine 1C to connection 3 on heater 1F3 in the condenser. Expansion joint 1HF11 was a single-bellows, single-ply, ASTM A-240, type-321 expansion joint.

Minor modification CE 70597 modified expansion joint 1HF11 to replace the original single-bellows, single-ply expansion joint with a single-bellows, double-ply, ASTM B-443, type-625 expansion joint. The type-625 material was expected to have greater fatigue and endurance limits. The double-ply arrangement should perform better if high-frequency vibration is present and has a better low-frequency fatigue life.

Note that the failure of expansion joint 1HF11 is the first failure of this type and orientation in the condensers. Expansion joint 1HF11 is a vertical, single-bellows, and single-ply expansion joint. Previous expansion joint failures in the condensers have occurred in the horizontal, double-bellows expansion joints located in extraction piping “E” between heaters “F” and “G.”

The joint was sent to the metallurgy laboratory (Met Lab) for evaluation to determine the actual failure mode(s).

As stated in the problem description, this is a mechanical failure and no human performance issues were involved.

A corrective action will be assigned to site Civil Engineering to track the Met Lab evaluation and originate further appropriate corrective actions based on the Met Lab results.

5.3.5 Corrective Actions

The corrective actions include:

1. Site Civil Engineering to track the Met Lab evaluation and originate further appropriate corrective actions (if required) based on the Met Lab results.
2. MCE - Civil to develop a Modification Action Request Form (MARF) package to replace the existing single-ply bellows “F” and “G” condenser expansion joints with double-ply bellows (possibly ASTM B-443, type-625 material) expansion joints for improved fatigue strength. The new joints should have enhancements for future inspections (test connections and removable shrouds). It is also recommend that a removable door/hatch, sized for the largest expansion joint, be provided on each condenser to reduce outage replacement time.

6
MAINTENANCE REPAIRS

6.1 Metal Expansion Joints

6.1.1 Repair of Metal Bellows

EPRI Report 1001215 discusses the repair of metal bellows. The report highlights the results of research and development efforts conducted by the EPRI RRAC in 2000. Included are discussion relating to bellows design, types, sensitivities, material types, manufacturing methods, service life, damage mechanisms, current repair options offered by manufacturers, previous repair development efforts by ASME, and new repair development activities conducted by EPRI RRAC. Development activities were aimed at developing optimum welding techniques, parameters, and procedures.

These development activities were followed up with advanced welding repair method development in 2002, using plasma-arc welding technology. Fatigue testing is scheduled for late 2002 to evaluate the performance of the repairs under cyclic loading and to determine the overall effectiveness of the repair technique.

6.1.2 Oversized Clamshells

The best way to replace a leaking bellows on an expansion joint is to replace the entire expansion joint assembly or at least a portion of the expansion joint that includes weld ends. In this way, the installers can avoid making the delicate bellows attachment weld in the field. Making this weld requires that the pipe be cut to replace the leaking bellows. Often, it is not practical to cut the existing pipe or to remove the existing bellows element. The “oversize clamshell” is one approach to replacing these bellows. They are commonly found on containment penetration piping seals.

The first step in the design of the oversize clamshell is to verify the dimensions of the existing bellows and available space around the existing bellows. An oversize bellows and attachment rings (also known as standoffs) are then designed to fit the space available.

Figure 6-1 illustrates how the new bellows will have a larger area than the original. It should be verified that the increased pressure thrust caused by the larger bellows would not cause an unsafe load at the anchor points that restrain the expansion joint.

Key Technical Point

It should be verified that the increase pressure thrust caused by the larger oversize clamshell bellows would not cause an unsafe load at the anchor points that restrain the expansion joint.

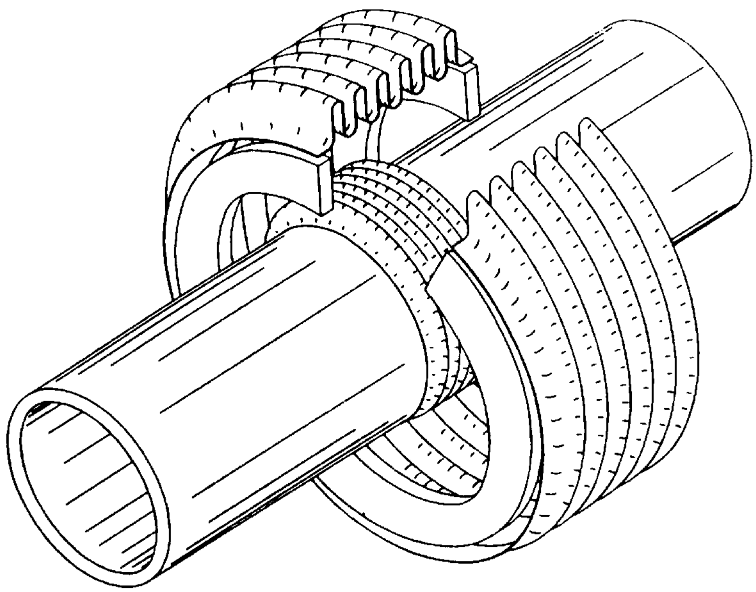


Figure 6-1
Oversize Clamshell Bellows (Courtesy of Senior Flexonics Pathway)

The oversize replacement bellows is then manufactured and cut in half longitudinally. The halves are match-marked to ensure a good fit. The new standoff rings are also cut in half and all weld surfaces are prepared for a weld design that is in accordance with the appropriate code. Threaded purge holes are put in the face of the standoff rings to allow for back-purging the longitudinal seam during field welding.

The first step in installing the oversize clamshell is to fit and tack the standoff rings. The oversize clamshell is then fit to the standoff rings. If possible, the inside of the new clamshell bellows is purged with the proper welding gas to ensure a good seam weld. When purging is not possible, a special flux is used to back the weld. Then the bellows is welded back together and the bellows are welded to the standoff rings. The purge holes in the standoff rings are capped to complete the assembly.

It is recommended where possible that all finished welds be inspected with a dye penetrant.

The oversize-clamshell procedure may be performed while the system is on line, depending on the process media operating temperature and other conditions. It is recommended however, that the actual installation be inspected before an on-line clamshell is executed.

All clamshell bellows must be of single-ply construction. A clamshell bellows can be fit with reinforcing rings for high-pressure service. The bellows can also be certified for use in pressure vessels stamped as being in compliance with ASME Section VIII code.

6.1.3 Same-Size Clamshells

When replacing nuclear containment penetration bellows and many other critical expansion joint bellows, it is not practical to cut the pipe to which the bellows is attached. The same-size clamshell is one approach to replacing these expansion joint elements. Figure 6-2 illustrates an example of a same-size clamshell bellows.

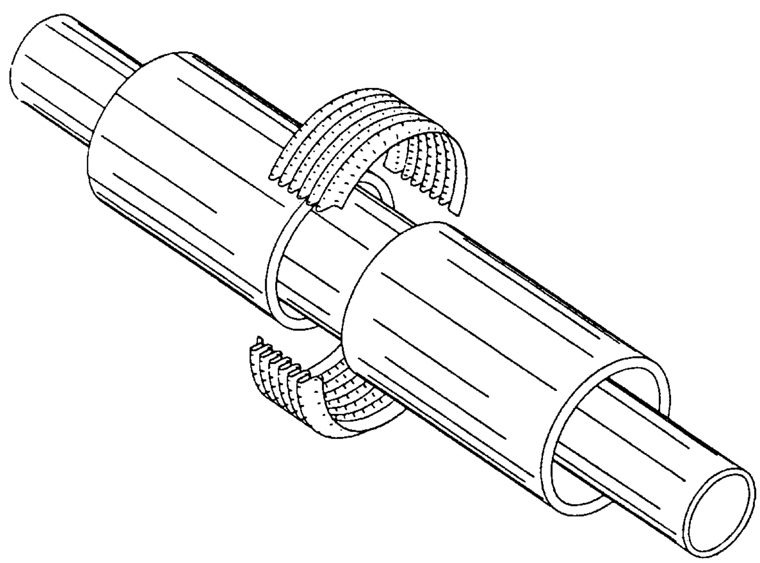


Figure 6-2
Same-Size Clamshell Bellows (Courtesy of Senior Flexonics Pathway)

The first step in the design of the same-size clamshell is to verify the dimensions of the existing bellows and then manufacture a replacement bellows identical to the original. The replacement bellows is cut in half longitudinally and match-marked for re-assembly.

The existing bellows is removed by grinding off the attachment weld and then cutting the bellows element in half longitudinally. The bellows attachment surface is ground to prepare the surface for the new same-size clamshell.

The factory-made item is then fitted to the prepared bellows attachment surface on the existing pipe. The inside of the new clamshell bellows is purged with the proper welding gas to ensure a good weld. Then the bellows is welded back together. The bellows attachment weld completes the assembly.

It is recommended where possible that all finished welds be inspected with a dye penetrant.

The same size clamshell installation cannot be performed while the system is pressurized. All clamshell bellows must be of single-ply construction. A clamshell bellows can be fit with reinforcing rings for high-pressure service. The bellows can also be certified for use in pressure vessels stamped as being in compliance with ASME Section VIII code.

Key Technical Point

The installation of same-size clamshell expansion joints cannot be performed while the system is pressurized.

6.1.4 Other Welding Applications

In some cases, a patch may be welded to the outside surface of a bellows that has developed a leak. The patch may alter the movement capabilities of the bellows, however, and should only be considered as a temporary repair.

Welding of the bellows seam weld is not recommended and cannot be performed in the field. Repairs of attachment welds can be performed in some cases depending on the extent of the cracks.

Key Technical Point

A patch may alter the movement capabilities of the bellows, however, and should only be considered as a temporary repair. Welding of the bellows seam weld is not recommended and cannot be performed in the field. Repairs of attachment welds can be performed in some cases depending on the extent of the cracks.

Additional information on welding applications can be found in the following:

- “Repair of Bellows Expansion Joints” in ASME PVP, Volume 51
- “Replacement Options for Damaged Bellows” in ASME PVP, Volume 83

6.2 Rubber/Fabric Expansion Joints

In most cases, the rubber portion of the worn or damaged expansion joint can be replaced with a new rubber piece. Repairs to the rubber tube with patches and glue are not recommended for rubber-type expansion joints.

Do not allow excess sealing compound, often used on belt-type (dogbone) expansion joints, to harden on the surface of the joint. Wipe excess sealing compound clean to avoid hardening because, after aging, the hardened sealing compound can crack and propagate cracks on the surface of the rubber belt-type expansion joint below.

Key Technical Point

Do not allow excess sealing compound, often used on belt-type (dogbone) expansion joints, to harden on the surface of the joint. Wipe excess sealing compound clean to avoid hardening because, after aging, the hardened sealing compound can crack and propagate cracks on the surface of the rubber belt-type expansion joint below.

Fabric expansion joints are typically designed to allow the removal and replacement of a damaged or severely torn fabric sheet. If the application is less than 5 psig (34.5 kPa), then small rips and tears in the fabric may be repaired using patches and glue.

7 REPLACEMENT ISSUES

7.1 Cyclic Deflections and Cycle Life

Most deflections are repeated a number of times during the life of the piping system, because the deflections usually are produced by changes in temperature that occur each time the system is started and stopped and from predictable variations in the way the system is used. Repetitions can also occur as a result of repetitive mechanical movements and from vibrations. Each time a deflection occurs the expansion joint experiences a cycle. The number of cycles is important to ensure the proper design of the expansion joint because each design has a finite but predictable life.

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 huge numbers of cycles in a short period of time. Because the bellows are metal structures, they have specific and predictable resonant frequencies, like the pitch of a tuning fork. When driven by outside vibrations of the same frequencies (or harmonics of them), they can magnify the incoming deflections until they exceed the yield strength of the bellows material and induce early fatigue failure. When a piping system is known to have equipment which can produce vibrations, such as pumps, fans, and other motor or turbine driven devices, their rotational speeds or frequencies should be provided to the manufacturer to ensure the expansion joint does not have a resonant or harmonic frequency that is close to those.

7.2 Calculating Stresses Associated With Metal Bellows

Calculating the stresses that a metal bellows will be exposed to during its operating life is primarily performed by manufacturer during the design of the expansion joint. The EJMA provides guidance on how to calculate these stresses, but each manufacturer typically employs various tools to perform the actual design and analysis.

In 2001, the Welding Research Council published Bulletin 466, *Behavior of Bellows,* which provides new insight regarding how bellows respond to internal pressure and displacement loads. Like the EJMA guidance, this information is most applicable to bellows designers and manufacturers.

7.3 Predicting Remaining Life of Metal Expansion Joints

Predicting the remaining life in a metal expansion joint is difficult because the life of the expansion joint is primarily dependent upon the number of cycles to which was designed, and the actual movements to which it has been exposed after installation. Most metal expansion joints are designed for a specified number of cycles in accordance with each licensee's application-specific requirements. Catalog items are typically designed for 2000 to 3000 cycles, depending on the manufacturer and type of expansion joint.

However, in most cases, licensees have not kept track of the number of cycles expansion joints have experienced over the years. As such, there are only a limited number of actions that can be taken today to estimate the remaining life of any given expansion joint.

7.3.1 Calculation Method

Depending on the system in which the expansion joint is installed, a calculation can be performed to estimate the total number of cycles the expansion joint has experienced to date. As noted above, most deflections are repeated a number of times during the life of the piping system. Deflections usually are produced by changes in temperature, which occur each time the system is started and stopped, and from predictable variations in the way the system is used. A review of system changes experienced during normal, upset, startup, and shutdown conditions can provide a rough estimate of the number of cycles the joint has experienced.

7.3.2 Nondestructive Examination With Dye-Penetrant

Dye penetrant examination can be employed to determine if there are any cracks forming on either the seam or attachment weld of a bellows. Cracking of the seam weld typically cannot be repaired in the field and provide an indication that the joint should be replaced soon. Cracks of the attachment weld have been successfully repaired in the field and may extend the life of an expansion joint to a limited degree. Stress corrosion cracking has been known to spread during repair welding and may not be repairable.

7.3.3 Nondestructive Examination of Wall Thickness

Techniques may be employed to nondestructively measure the wall thickness of the bellows at various points to determine wear of the bellows attributable to erosion or corrosion.

7.4 Predicting Remaining Life of Rubber Expansion Joints

7.4.1 Background of Related Research

Between 1995 and 1997, EPRI conducted research on the testing and aging of certain polymers used for cables installed in nuclear power plants. EPRI TR-105581, *Improved Conventional Testing of Power Plant Cables,* was prepared to develop improved condition-monitoring techniques for assessing the condition of the insulation and jacket polymers of power plant cables. The report identified a broad range of destructive and nondestructive diagnostic techniques that could be applied successfully to aged insulation and jacket materials. Many of the cable polymers (for example, EPR, EPDM, Hypalon, Neoprene) are also used in gaskets and seals. Accordingly, much of the cable polymer aging and condition-monitoring research is applicable to gaskets and seals. The techniques used to predict the age and remaining life of these polymeric compounds are directly applicable to the compounds used in expansion joints.

EPRI TR-104075, *Evaluation of Cable Polymer Aging Through Indenter Testing of In-Plant and Laboratory-Aged Specimens,* was prepared to document in-plant testing of the polymer indenter aging monitor and the development of life-projection methodology based on an accelerated-aging program. The report concluded that while the indenter methodology is not useful for all cable materials, it is applicable to most common cable types.

EPRI TR-106108, *Diagnostic Matrix for Evaluation of Low-Voltage Electrical Cables,* was prepared to provide power plant personnel with guidance in selection of appropriate tests that could be used to evaluate the condition of low-voltage cable systems. The report identified tests for evaluating the adequacy of installation, troubleshooting problems, evaluating aging and remaining service life, and performing post-service failure evaluations.

7.4.2 Need for Further Investigation

As a follow-on activity after the publication of the first edition of this report, NMAC continued to investigate the benefits of this technology and its application to rubber/fabric expansion joints. The results of the investigation showed that visual/tactile inspection of the surfaces of an expansion joint can identify conditions such as severe aging, delamination, cutting, and crazing. However, visual/tactile testing does not provide sufficient information to trend the changes in the mechanical properties of the polymers.

To provide data that can be trended on aging of these types of rubber/fabric expansion joints, NMAC, in cooperation with EPRI PSE, performed accelerated thermal aging and mechanical destructive and nondestructive testing on specimens of the types of rubber used in a number of typical expansion joints. The aging was performed incrementally, and the condition of the polymer was assessed at each increment.

7.4.2.1 Choice of Mechanical Tests

Elongation at break (EatB) is a traditional test for assessing polymer aging. It is a direct indication of the ability of the polymer to expand without failing. When severely aged, the types of rubber used in the expansion joints lose their ability to extend and will fail when subjected to tension. Given the purpose of expansion joints, EatB is a key method for assessing their condition. Unfortunately, EatB is a destructive test and is not suitable for composite materials containing chord plies.

Therefore, nondestructive tests that can be related to elongation at break are necessary. Durometry is one such test. A durometer has a spring-loaded anvil that is pressed against the surface of a polymer. The durometer anvil and load spring are sized to give hardness measurements appropriate for various rubbers and plastics. For this test program, a Type C durometer was used.

While durometry is simple to perform, it does not always provide sufficient resolution for aging assessment. Accordingly, a second nondestructive test was included in the program: indenter modulus (IM). The indenter is a more sophisticated device containing an anvil that is driven against the polymer wall at constant velocity. The anvil has a load cell that monitors the force imparted to the polymer wall. At a preset force, the anvil is retracted to prevent damage to the material under test. The change in force divided by the change in position during the test is the indenter modulus. For rubber materials, IM testing has been found to correlate closely with aging.

7.4.2.2 Accelerated Thermal Aging

The thermal aging performed in this test program was purposefully limited to ensure that very conservative endpoints were achieved. The goal was to prove that aging could be detected even when the polymer still had a high level of elongation capability remaining. The rubber materials tested in this program were known to have an initial EatB of 300% or more. The aging testing was designed to limit aging to a point where approximately 100% EatB remained. This is a very conservative end point for an expansion joint where the polymer is stretched only a few percent in service. The chord plies preclude large extensions during service. Accordingly, the polymer will never experience a stress that could cause a 100% elongation and using a 100% EatB limit is conservative and ensures that in-service failure would not occur.

The thermal aging was performed at 248°F (120°C), a commonly used aging temperature for the rubber types in the program. Rather than using fixed time intervals for the aging, the aging increments were based on achieving certain measurable changes as monitored by use of the indenter. This resulted in different intervals for each of the polymer types, but it removed some of the uncertainty in the degree of aging that results from using fixed intervals based on aging models.

7.4.2.3 Materials Tested

The following materials were included in the test program:

- Holz EPDM[1] rubber
- Garlock EPDM rubber
- Garlock chlorobutyl rubber

The two manufacturers noted above provided sheet specimens. Garlock provided materials that were cured as in manufacture. Holz provided a compound that needed to be cured prior to thermal aging by exposing the material to 290°F (143°C) for a short period. These sheet specimens are of the types used in actual expansion joints by these manufacturers. The sheets were approximately 1/8 inch (3 mm) thick. To allow EatB testing, dumbbell specimens were cut using a standard ASTM D412 Type C die. Due to the limited amount of material available, only 20 Holz specimens could be produced, while 25 specimens were cut for each of the Garlock materials. Scraps of the materials that occurred between the dumbbell cuts were used for durometer and indenter specimens. To allow the specimens to be removed when specific changes in properties were achieved, extra sacrificial specimens were placed in the aging ovens in advance of the main specimens. When the sacrificial specimens achieved the degree of aging desired, the associated set of main specimens was removed from the oven when they had been exposed for the same period as the sacrificial specimens.

An ASTM D2440 Type C durometer was used to perform all of the durometer tests.

7.4.2.4 Test Results

Figures 7-1 through 7-6 provide the plots of durometry versus EatB, and indenter modulus versus EatB for the three materials. The two nondestructive tests are compared to the EatB to allow their correlation to the property of interest to be verified. The data from all three of the tests are well within the bounds expected, and there were no anomalies.

The durometer measurements trended inversely with EatB as is expected. As materials harden (rising durometry measurement), their ability to extend decreases (falling EatB). Similarly, the indenter modulus measurements trended inversely with EatB for the same reason.

Holz EPDM

Figure 7-1 presents the durometry and EatB results for the Holz EPDM. The EatB drops in a nearly linear manner from 300 % to 110 % in the course of being aged at 120°C for 1032 hours (43 days). The durometry measurements behave inversely and increase from 31 to 50 in the same period. Note that the durometer scale starts at 20 to improve resolution.

[1] EPDM is ethylene propylene diene monomer or terpolymer, a type of compounded rubber.

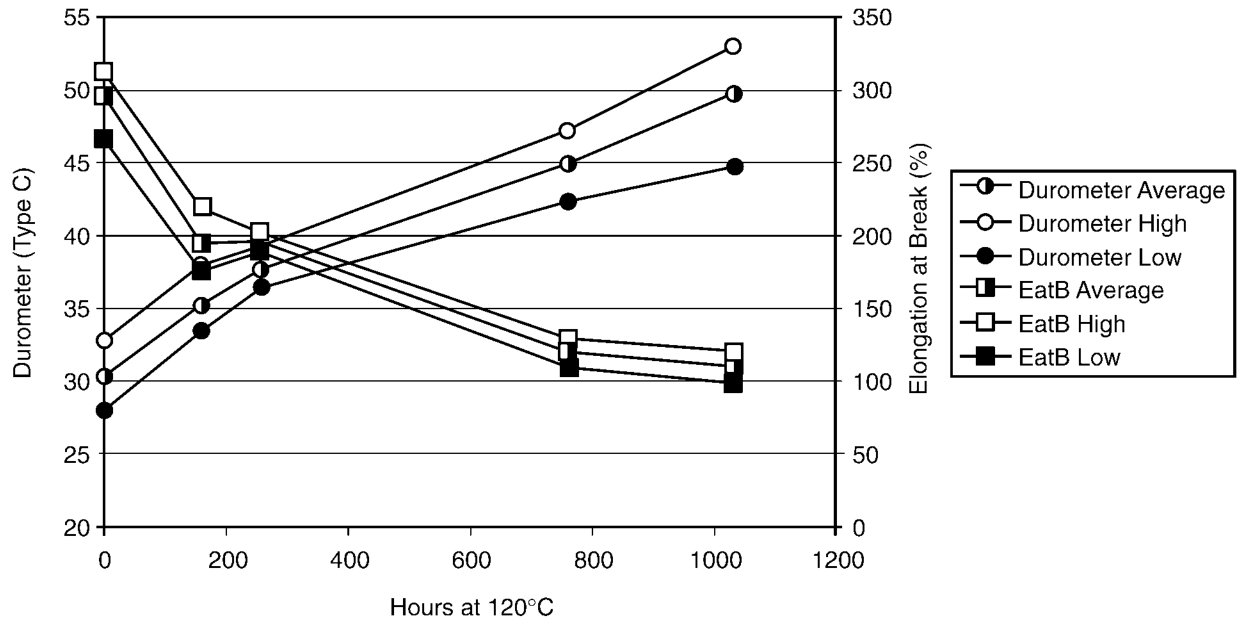


Figure 7-1
Holz EPDM Durometer versus Elongation at Break (EatB)

Figure 7-2 presents the indenter modulus versus EatB results for the same Holz EPDM. As with the durometry, the IM trends inversely with the EatB. The IM increases from 4.5 N/mm when unaged to 11 N/mm when aged for 1032 hours, a 240% increase.

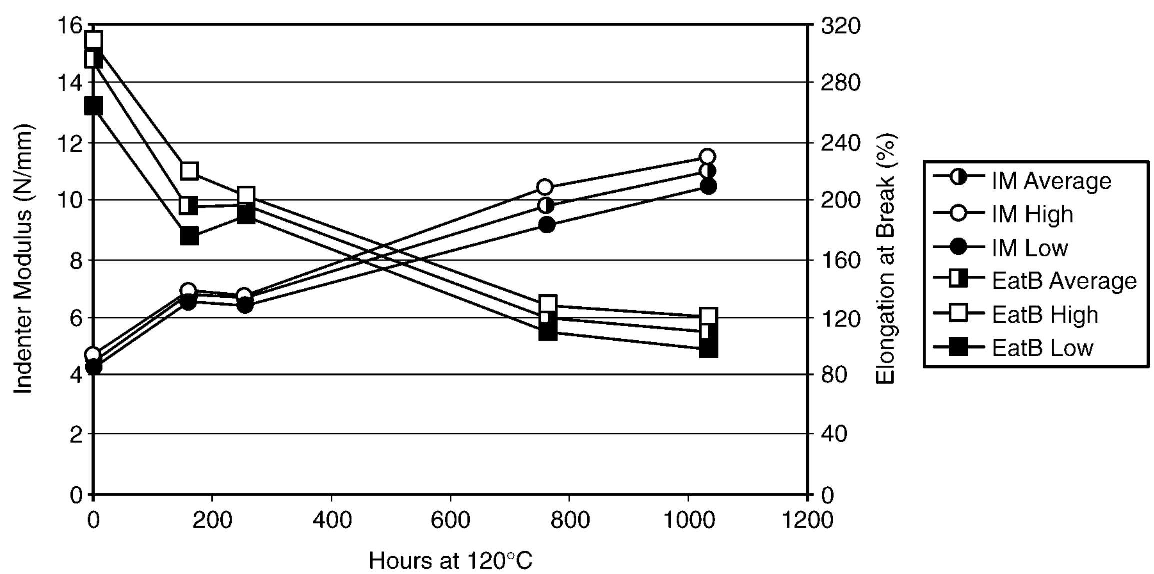


Figure 7-2
Holz EPDM Indenter Modulus (IM) versus EatB

Garlock EPDM

Figure 7-3 presents the durometry and EatB results for the Garlock EPDM. The durometry tracks inversely with EatB as is expected. However, for this Garlock EPDM compound, the change in EatB and durometry is not as linear with time. Rather there is a relatively steep rate of change early in aging with a smaller rate later. The EatB drops from 387% to 108% after 160 hours (6.7 days) at 120°C. The durometer measurements increase from 31.3 to 45.8 in the same period.

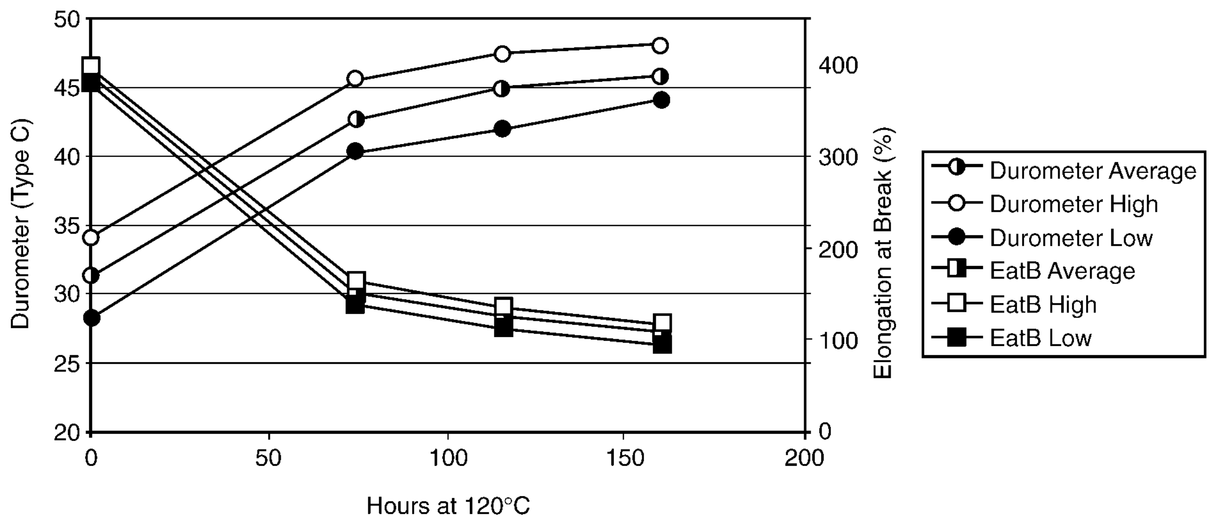


Figure 7-3
Garlock EPDM Durometer versus EatB

Figure 7-4 presents the IM versus EatB results for the same Garlock EPDM. The IM trends inversely with EatB. However, for this material, the IM changes linearly with time at stress providing a better indication of the degree of aging than the durometry does. The IM increases from 5.7 N/mm when unaged to 12.1 N/mm at 160 hours, an increase of 212%.

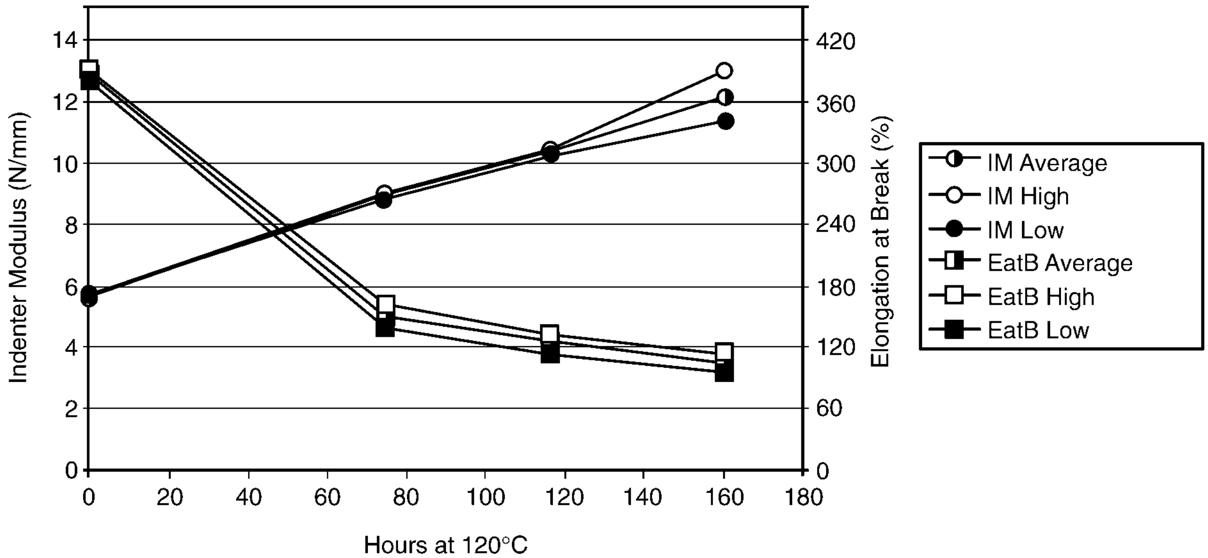


Figure 7-4
Garlock EPDM IM versus EatB

Garlock Chlorobutyl Rubber

Figure 7-5 presents the durometry and EatB results for the Garlock chlorobutyl rubber. The durometry tracks inversely with EatB as expected. However, as with the Garlock EPDM, the change in EatB and durometry for the chlorobutyl is not linear with time. Instead, there is a very steep rate of change early in aging with a much smaller rate later. The EatB decreases from 738% when unaged to 239% when aged for 714 hours (29.7 days). The durometry measurement increases from 36.1 to 50 under the same conditions. Note that the endpoint achieved for this material was 239%. The material has additional thermal life before it reaches the 100% EatB limit.

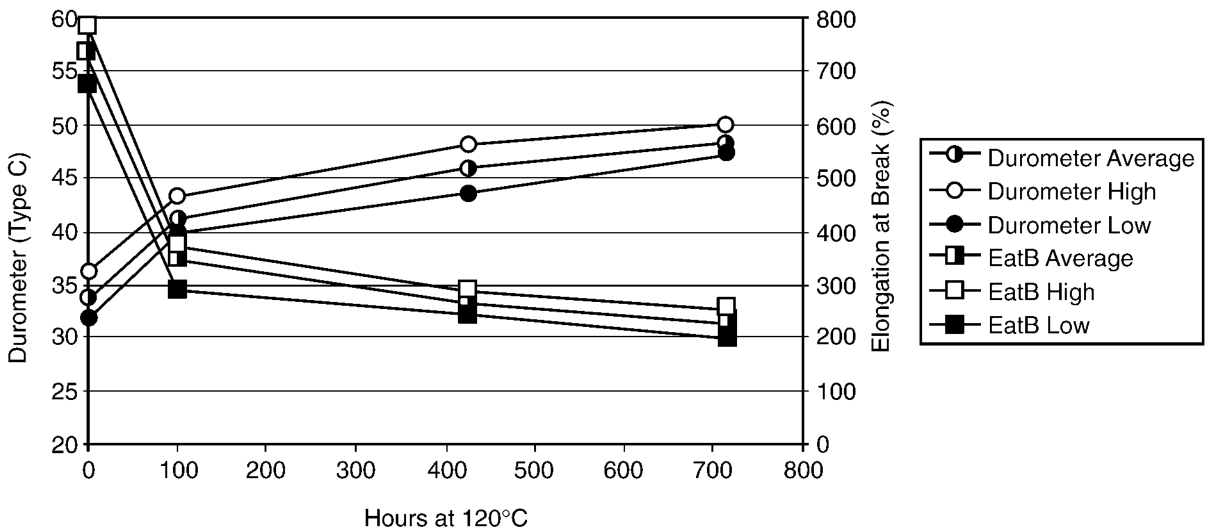


Figure 7-5
Garlock Chlorobutyl Durometer versus EatB

Figure 7-6 presents the IM versus EatB results for the same Garlock chlorobutyl rubber. The IM trends inversely with EatB. However, again for this material, the IM changes linearly, with time at stress providing a better indication of the degree of aging than durometry does. The IM increases from 6.6 N/mm when unaged to 12.7 N/mm at 714 hours, an increase of 190%.

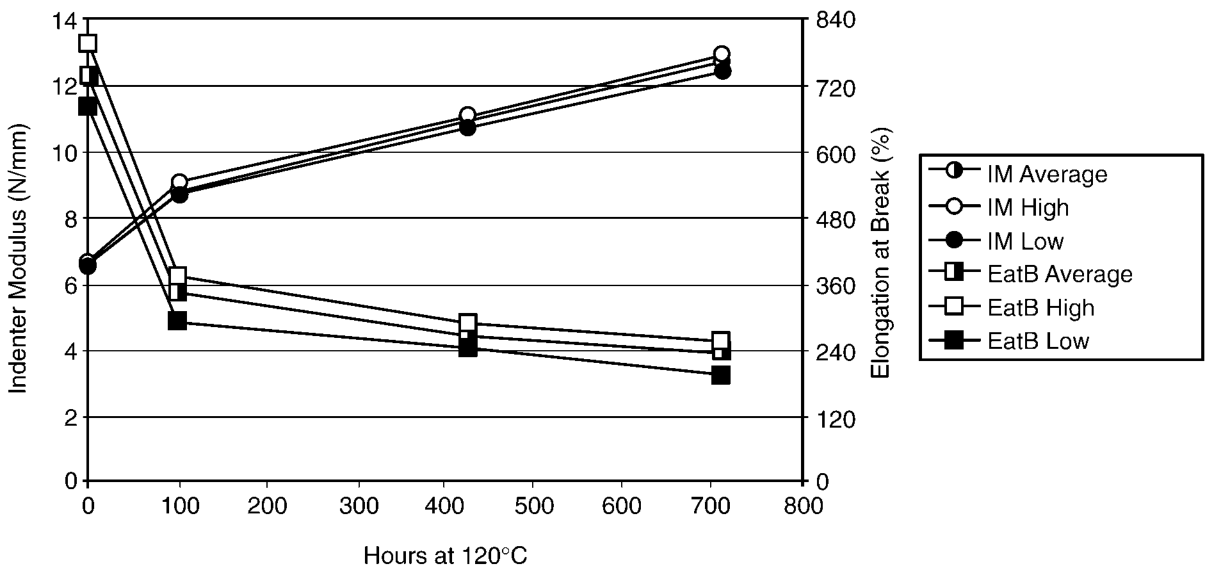


Figure 7-6
Garlock Chlorobutyl IM versus EatB

7.4.2.5 Comparison to Field Results

IM measurements were taken on large expansion joints that had been in circulating water system service with brackish river water.

Two Holz EPDM joints were tested. One had inside diameter IM measurements of 5.5 to 6 N/mm, and the other had 5.9 to 6.1 N/mm. Review of Figure 7-2 indicates that the joints had in excess of 200% EatB remaining and were in very good condition at the time of removal from service. These joints could have remained in service for an extended period.

The remaining joint was chlorobutyl rubber; however, there was no indication of the manufacturer. The IM measurement was 9.0 to 9.3 N/mm. Comparing the result to Figure 7-6 indicates that an EatB of 350% could be expected and that again the expansion joint was removed very early in the life of the chlorobutyl rubber.

7.4.2.6 Generic Implications of Materials Test Results

Two manufacturers' EPDM and one manufacturer's chlorobutyl rubber materials were tested in this project. The question exists: Are these results applicable to other manufacturers' products and different rubber materials? The aging curves developed in this project are typical for rubber materials based on experience with the same materials and other types of rubber used in cable jacketing and insulation. As the rubber ages, the EatB decreases gradually and the IM increases. Ethylene propylene rubber (a subset of the EPDM grouping), neoprene, and Hypalon all show this characteristic[2]. A limited survey was performed during the course of this project to identify the key rubber compounds used in nuclear plant rubber/fabric expansion joints. The list was:

- Buna-N/Nitrile
- Chlorobutyl
- Natural rubber
- Neoprene

Each of these rubber materials will have the characteristic of hardening with thermal aging. Each of the materials tested in the test program described here had an IM in the 4 to 6 N/mm range. The tightness of the range of IMs is not unexpected. The manufacturers have determined formulations that provide the correct level of toughness and flexibility, which in turn limits the range of initial hardness as can be seen from the IM results.

Based on the testing in this program as well as in programs related to cable materials, doubling of the initial IM relates to a significant degree of aging and loss of EatB. Accordingly, a generic rough rule for rubber expansion joints can be established based on this doubling of IM. If an initial IM value can be determined from testing at the time of initial installation or testing of an unaged expansion joint, an indication of the degree of aging for in-service expansion joints can be determined. If the in-service expansion joint has roughly the same IM as an unaged specimen, little thermal aging has occurred. If the IM has doubled, a significant degree of aging has occurred. Sufficient life remains in the expansion joint for it to be replaced at a convenient time in the future or for further testing to be performed that can establish the remaining life more accurately. IM results that are significantly greater than two times the original modulus indicate severe aging, and further use of the joint should be carefully considered.

If the initial IM cannot be determined for an installed rubber-lined expansion joint of the types listed above, an IM measurement in the range of 8–12 N/mm or higher could indicate that significant aging had occurred, and further steps to understand the degree of aging of the rubber would be desirable.

Thermal aging of expansion joints in low temperature applications (<135°F or 57.2°C) appears to occur very slowly; therefore, these joints can be expected to have a long life. Periodic visual and manual assessment coupled with IM testing should allow continued use of these joints for significantly longer than might have been expected.

[2] Data showing this characteristic are contained in the EPRI report *Cable Polymer Aging Database*, Version 1.0, 1001001.

Key O&M Cost Point

Thermal aging of expansion joints in low temperature applications (<135°F or 57.2°C) appears to occur very slowly; therefore, these joints can be expected to have a long life. Periodic visual and manual assessment coupled with IM testing should allow continued use of these joints for significantly longer than might have been expected.

7.4.2.7 Conclusions

The three materials tested are all amenable to assessment with nondestructive durometry and IM testing. For the Holz EPDM, both the durometer and IM measurements provide good indications of aging. For the Garlock EPDM and chlorobutyl rubber, the durometer provides some indication of aging, but the IM provides a more direct indication of the degree of aging with respect to degree of exposure to thermal aging.

Key Technical Point

For the Holz EPDM, both the durometer and IM measurements provide good indications of aging.

Key Technical Point

For the Garlock EPDM and chlorobutyl rubber, the durometer provides some indication of aging, but the IM provides a more direct indication of the degree of aging with respect to degree of exposure to thermal aging.

The results indicate that thermal deterioration of the materials is readily measurable and that discrimination between degrees of aging is relatively easy. However, monitoring the condition of the rubber liner must be combined with visual and tactile inspection, as described in Section 4.1.2 of this report, to provide a complete understanding of the condition of the expansion joints.

Key Technical Point

Monitoring the condition of the rubber liner must be combined with visual and tactile inspection to provide a complete understanding of the condition of the expansion joints.

Based on the results of this program and of tests of rubber materials used in electrical cables, the results of this program can be extended to a number of other types of rubber used in expansion joints. A rough rule of thumb that significant aging has occurred at twice the original IM seems appropriate. The materials will still have more than enough elongation properties at that point to ensure service, and sufficient service life should be available to allow the replacement to be performed at a convenient time rather than immediately. However, the doubling indicates that significant aging is underway. IMs that are significantly greater than a factor of two higher than the original are a cause for concern, and continued use of the expansion joint should be approached cautiously.

Key Technical Point

IMs that are significantly greater than a factor of two higher than the original are a cause for concern, and continued use of the expansion joint should be approached cautiously.

The results from expansion joints that had been removed from service based only on a time interval indicate that the service life could have been much longer if their life had been based on condition monitoring.

The Indenter Polymer Aging Monitor is an EPRI licensed technology. Appendix D of this report provides information on the device. Gary Toman (gtoman@epri.com) is the EPRI contact concerning the indenter and its use. Mr. Toman was the principal investigator for this testing program.

7.5 Extending Service Life of Certain Rubber/Fabric Expansion Joints

Appendix E of this report describes the assessment of extending the lives of large expansion joints used in a circulating water system. The assessment describes the items to be included in a visual/tactile assessment and implementation of a nondestructive, physical-property test to evaluate aging of the EPDM rubber lining.

The appendix describes how one nuclear utility was successful in developing a program for extending the service life of certain rubber/fabric expansion joints installed in their service water and circulating water systems. The licensee's premise was that manufacturers typically provide a rather conservative service life estimate because of the number of variables affecting the life expectancy. Some of these variables include service conditions (that is, temperature, pressure, media type, ambient environment, flow rate, anticipated deflections, and other), misalignment during installation, installation techniques, and storage conditions.

The licensee established a program that included the following basic elements:

- An inspection program for in-service expansion joints
- Post-service hydrostatic tests of expansion joints (on a sampling basis)
- Destructive examination of expansion joints removed from service (on a sampling basis)
- Measurement of the physical properties of elastomer samples removed during the destructive testing
- Accelerated aging tests of new elastomer material and of elastomer samples removed during destructive examination

The licensee then established acceptance criteria that, if met, could warrant the extended life of any given rubber expansion joint installed in these plant systems. The acceptance criteria were as follows:

- No significant, visible degradation, including cracking , erosion, delamination, water ingress to the fabric plies, or corrosion of the steel reinforcing rings.
- No leakage or abnormal deformation in the hydrostatic test.
- Average ultimate elongation of the elastomer samples is greater than 75% of the ultimate elongation for a new elastomer.
- Accelerated aging demonstrates there is significant service life remaining before the elastomer ultimate elongation is predicted to reach 75% of the ultimate elongation for a new elastomer.

The licensee concluded that service life of rubber expansion joints could in fact be estimated by an inspection and testing program. Specifically, the program enabled the licensee to extend the service life of EPDM rubber expansion joints used in untreated service water and circulating water systems from eight to fourteen years.

8
REFERENCES

"96-in. I.D. Circulating Water Expansion Joint Aging Management Assessment," EPRI Plant Support Engineering, EPRI, Palo Alto, CA: 2002.

A Practical Guide to Expansion Joints, Expansion Joint Manufacturers Association, Inc., Tarrytown, NY, 1985.

Becht, C. IV, *Behavior of Bellows,* Welding Research Council, New York, NY, Nov. 2001. Bulletin 466.

Design and Operating Guidelines for Nuclear Power Plant Condensers, EPRI, Palo Alto, CA: 1991. NP-7382.

Diagnostic Matrix for Evaluation of Low-Voltage Electrical Cables, EPRI, Palo Alto, CA: 1997. TR-106108.

Evaluation of Cable Polymer Aging Through Indenter Testing of In-Plant and Laboratory-Aged Specimens, EPRI, Palo Alto, CA: 1996. TR-104075.

Expansion Joints, U.S. Bellows, Inc., Houston, TX, Feb. 1997.

Improved Conventional Testing of Power Plant Cables, EPRI, Palo Alto, CA: 1995. TR-105581.

Merrick, E., O'Toole, W., and M. Malkmus, "Repair of Bellows Expansion Joints" in proceedings of Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engineering, and Solar Energy Divisions, Denver, CO, June, 1981.

Merrick, E., Reimus, W., O'Toole, W., and M. Bressler, "Replacement Options for Damaged Bellows" in proceedings of 1984 Pressure Vessels and Piping Conference and Exhibition, San Antonio, TX, June, 1984.

Non-Metallic Expansion Joints and Flexible Pipe Connectors, Sixth Edition, Non-Metallic Expansion Joint Division, Fluid Sealing Association, Wayne, PA, 1995.

"Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Facilities," *Code of Federal Regulations,* 10CFR50, Appendix B.

Repair of Metal Bellows, EPRI, Palo Alto, CA: 2000. 1001215.

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

System and Equipment Troubleshooting Guide, EPRI, Palo Alto, CA: 2001. 1003093.

Wilda, M., and J. Hibbard, *Extending the Service Life of Rubber Expansion Joints in Service Water and Circulating Water Systems*, Virginia Power and MPR Associates, Inc., Alexandria, VA.

A
EXPANSION JOINT ISSUES SPECIFIC TO FOSSIL POWER PLANTS

A.1 Overview

Figure A-1 illustrates the ducting layout for a typical boiler found in many fossil power plants. The figure depicts the numerous rectangular fabric-type expansion joints used in moving air to and from the boiler.

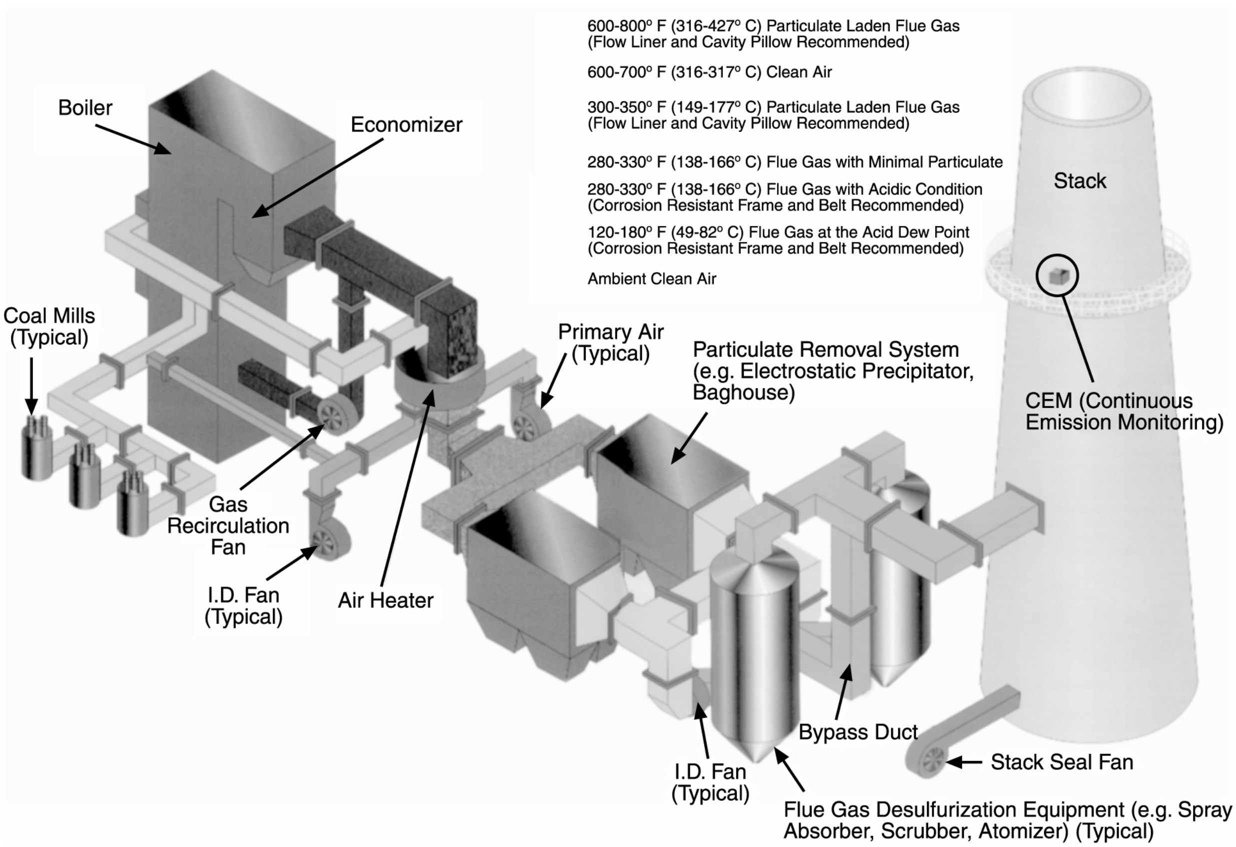


Figure A-1
Layout of Ducting for a Typical Boiler (Courtesy of Senior Flexonics Pathway)

A.2 Failure History of Expansion Joints at Fossil Power Plants

Table A-1 lists a compilation of expansion joints most susceptible to failure at fossil power stations. The list was compiled based on feedback received during a survey of fossil power plant maintenance and operations personnel.

Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description
Primary air fan ducting expansion and extraction	Silcoat cloth, skived PTFE strips, medium glass MAX LT, 25 ceramic	
Cold air pipe for extraction	Silcoat cloth, skived PTFE strips, medium glass MAX LT, 25 ceramic	
Blanket strip	ALU coated glass cloth and stainless steel mesh code 793201	
Cold air pipe	Rubber	
Precipitator inlet and outlet ducts	Rubber	
Air and gas ducts	All metal pinned and slotted	
Air heater bypass ducts	6-10 fabric	
Oxygen system and soot blowers	Metal	
Condenser neck expansion (dogbone)	Duck and rubber w/ fibrous core	Air in leakage.
Circulating water piping expansion	Esthan and rubber flanged	Developed cracks and failed.
Primary condensate pump suction expansion	Spool-type, rubber, single arch	Air in leakage.
Auxiliary condenser, condensate pump expansion	Polton and rubber flanged	Developed cracks and failed.
Economize an outlet expansion	Metal-cupped panel	Developed leaks from corrosion.
Precipitator inlet expansion	High-temperature fabric	Air in leakage.
Precipitator outlet expansion	High-temperature fabric	Air in leakage.
Coal mill primary air expansion	Metal expansion joint	Catastrophic failure (explosion).
Duct right after air preheater	Fabric	Water and ash over time eat the joint away.

Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description
Duct after precipitator before stack	Metal	Corrosion from water and ash.
Joints in ductwork that handle coal from feeder to coal mill	Accordion-style joints made of SS	Fail too frequently, because of movement and mill puffs, develops coal leaks.
Joints in ductwork from PA fans to crusher dryer inlet	High-temperature fabric style	Fail from mill puffs, blow the joint out.
Joints in large ductwork from ID fan outlet to stack inlet	High-temperature fabric style	Develops holes and fails too frequently, allows flue gas to escape.

B
SPECIFICATION GUIDANCE FOR EXPANSION JOINTS

B.1 Metal Expansion Joint

The following checklist is courtesy of the Expansion Joint Manufacturers Association Inc..

<table>
<tr><td>1</td><td colspan="2">Quantity</td><td></td></tr>
<tr><td>2</td><td colspan="2">Nominal size/ID/OD (in.)</td><td></td></tr>
<tr><td>3</td><td colspan="2">Expansion joint type</td><td></td></tr>
<tr><td>4a</td><td rowspan="3">Fluid information</td><td>Medium (gas/liquid)</td><td></td></tr>
<tr><td>4b</td><td>Velocity (ft./sec.)</td><td></td></tr>
<tr><td>4c</td><td>Flow direction</td><td></td></tr>
<tr><td>5</td><td colspan="2">Design pressure (psig.)</td><td></td></tr>
<tr><td>6</td><td colspan="2">Test pressure (psig.)</td><td></td></tr>
<tr><td>7a</td><td rowspan="3">Temperature</td><td>Design (°F)</td><td></td></tr>
<tr><td>7b</td><td>Max./min. (°F)</td><td></td></tr>
<tr><td>7c</td><td>Installation (°F)</td><td></td></tr>
<tr><td>8a</td><td rowspan="4">Maximum installation movement</td><td>Axial compression (in.)</td><td></td></tr>
<tr><td>8b</td><td>Axial extension (in.)</td><td></td></tr>
<tr><td>8c</td><td>Lateral (in.)</td><td></td></tr>
<tr><td>8d</td><td>Angular (degrees)</td><td></td></tr>
</table>

9a	Maximum design movements	Axial compression (in.)	
9b		Axial extension (in.)	
9c		Lateral (in.)	
9d		Angular (degrees)	
9e		No. of cycles	
10a	Operating fluctuations	Axial compression (in.)	
10b		Axial extension (in.)	
10c		Lateral (in.)	
10d		Angular (degrees)	
10e		No. of cycles	
11a	Materials of construction	Bellows	
11b		Liners	
11c		Cover	
11d		Pipe specification	
11e		Flange specification	
12	Rods (tie/limit/control)		
13	Pantographic linkage		
14	Anchor base (main/intermediate)		
15a	Dimensional limitations	Overall length (in.)	
15b		Outside diameter (in.)	
15c		Inside diameter (in.)	
16a	Spring rate limitations	Axial (lbs./in.)	
16b		Lateral (lbs./in.)	
16c		Angular (lbs./in./deg.)	
17	Installation position (horizontal/vertical)		

18a	Quality assurance requirements	Bellows	Long. seam	
18b		Weld NDE	Attach.	
18c		Pipe NDE		
18d		Design code		
18e		Partial data required		
18f				
18g				
19	Vibration (amplitude/frequency)			
20	Purge instrumentation connection			
21a	Special flange design	Facing		
21b		OD (in.)		
21c		ID (in.)		
21d		Thickness (in.)		
21e		BC diameter (in.)		
21f		No. holes		
21g		Size holes		
21h		Hole orientation		

Piping sketch:

B.2 Rubber/Fabric Expansion Joint

The following checklist is courtesy of the Fluid Sealing Association.

SIZE	PIPE SIZE OF APPLICATION: Nominal pipe size or the inside diameter of the connecting pipe flange.	Inches	
	INSTALLED LENGTH: The space between connecting pipe flanges. Indicate limitations, if any.	Inches	
FLOWING MEDIUM	FLOWING MEDIUM: Indicate chemical. If flowing medium is corrosive, abrasive, or viscous, explain in detail.		
	TYPE OF MEDIUM: Indicate if liquid, gas, slurry, solids, etc.		
	TEMPERATURE OF THE FLOWING MEDIUM: Indicate both operating and maximum temperatures at the expansion joint.	OPERATE °F	MAXIMUM °F
	TEMPERATURE OF THE SURROUNDING ATMOSPHERE: Indicate both minimum and maximum temperature of atmosphere at the expansion joint.	OPERATE °F	MAXIMUM °F
	TIME DURATION AT MAXIMUM TEMPERATURE: Indicate length of time.		
	VELOCITY OF FLOWING MEDIUM: In feet per minute.	FT/MIN	
PRESSURES	OPERATING PRESSURE AT THE JOINT: Actual pressure in which system works in normal conditions.	POSITIVE PSIG	NEGATIVE "Hg
	DESIGN PRESSURE OF THE SYSTEM: Highest/most severe pressure expected during operation.	POSITIVE PSIG	NEGATIVE "Hg
	SURGE PRESSURE OF THE SYSTEM: Increased pressure due to pump starts, valve closings, etc.	POSITIVE PSIG	NEGATIVE "Hg
	TEST PRESSURE OF THE SYSTEM: Hydrostatic test used to demonstrate system capability.	POSITIVE PSIG	NEGATIVE "Hg
	TYPE OF PRESSURE: Constant, intermittent, shock, pulsating, etc.		
MOVEMENTS	AXIAL COMPRESSION AT JOINT: In inches as a result of pipe extension/expansion	INCHES	
	ACTUAL ELONGATION AT JOINT: In inches as a result of pipe contraction	INCHES	
	LATERAL DEFLECTION AT JOINT: In inches	INCHES	
	ANGULAR MOVEMENT AT JOINT: In degrees	DEGREES	
	TORSIONAL MOVEMENT AT JOINT: In degrees	DEGREES	
MISCELLANEOUS	PIPE FLANGE DRILLING: Indicate specific standard such as 150# ANSI B16.5. If special, provide flange OD, bolt, circle, number and size	SPECIFICATION	
	MATING PIPE FLANGE THICKNESS: In inches	INCHES	
	LOCATION OF JOINT INSTALLATION: Indoors or outdoors		
	RETAINING RINGS: Are required on all installations. Reusable, they need not be ordered with replacement or spare expansion joints	YES OR NO	
	CONTROL UNIT ASSEMBLIES: Are recommended for use in all expansion joint applications. Control units must be used when piping support or anchoring is insufficient	YES OR NO	
	HYDROSTATIC TEST OF JOINT REQUIRED BY MANUFACTURER OF PRODUCT:	YES OR NO	

B.3 Fabric (Ducting) Expansion Joints

The following checklist is courtesy of Senior Flexonics Pathway.

Item or Tag Number		
Quantity Required		
Expansion Joint Location (Fan Outlet, Stack, etc.)		
Expansion Joint Style/System		
SIZE	Duct Size Inside Dimension or Diameter	Inches
	Breach Opening	Inches
GAS	Flowing Media Air, Flue Gas, etc.	
	Flow Direction Up, Down, Horizontal, Angular Upward, Angular Downward	
	Flow Velocity	FPS
	Dust Load	PSF

PRESSURE	Design Pressure	NORMAL OPERATING	Inches Water Column
		MAXIMUM OPERATING	Inches Water Column
TEMPERATURE	Gas Temperature	Normal Operating	°F
		Design	°F
		Maximum Upset Excursion	°F
		Duration Per Upset	°F
	Ambient (Minimum/Maximum)		/ °F
MOVEMENTS	Axial Compression		
	Axial Extension		
	Lateral Offset (Perpendicular To Long Side)		
	Lateral Offset (Perpendicular To Short Side)		
	Other (Angular Or Torsional)		Degrees
DUCT	Duct Material (Gauge Or Thickness)		
	Internal Liner Material (Gauge Or Thickness)		

	Liner Material	Fwl – Field Welded	
		Swl – Shop Welded	
		Bfl – Bolted Flange	
Cavity Insulation Pillow Required			Yes Or No

C
FAILURE DATA OF EXPANSION JOINTS

This appendix provides an overview of the survey that was conducted of nuclear and fossil power plant personnel during the development of this report. Section C.1 is a copy of the questionnaire that was used. Section C.2 provides a compilation of utility responses. Sections C.3 and C.4 are compilations of failure history for metal and rubber/fabric expansion joints, respectively.

C.1 Survey Questionnaire

1. From a maintenance perspective, list the expansion joints that have resulted in the most problems at your plant.

Plant Application of Expansion Joint[a]	Type of Expansion Joint[b]	Problem Description[c]	Expansion Joint Manufacturer

Notes:
a. For example, turbine extraction line piping, condenser neck seal, feedwater heater piping, low-energy piping, reactor feedwater pump turbine exhaust, condensate, turbine cross-over and cross-under piping, diesel generator exhaust
b. For example, metal, rubber, fabric, single bellows, double expansion, universal, swing, hinged, gimbal, pressure-balanced
c. For example, catastrophic failure, difficult to maintain, defective equipment

2. Based on your plant experience, what area(s) of guidance about expansion joints would be most beneficial?

3. Have you installed replacement expansion joints in our plant in the last five years and were they direct replacements or a different design from the original?

4. If the joints installed in item 3 above were not the original design, please indicate the manufacturer and type of joint and the reasons for using this style (for example, unavailability of original type, costs, ease of replacement, new material)

5. A Technical Advisory Group (TAG) is being formed for this guide. Participation on the TAG usually involves attendance at one meeting (possibly two depending on the complexity of the guide) to review the first draft of the guide. Attendance at these meetings is not required as a TAG member but encouraged. The TAG members will also be involved in developing the guide through reviews and comments on the guide content. With the project basically beginning with this survey, the scheduled completion date is October 2002.

   Would you be willing to participate as a TAG member during the development of the guide? (Please circle one answer below and include your contact information)

   YES, Can attend one to two TAG meetings

   YES, Will review the guide but can not attend the TAG meeting

   NO

   NO, But, please keep me on distribution for updates and draft guidelines

Name:
Utility:
Plant site:
Telephone: (work) (fax)
E-mail address:

C.2 Compilation of Survey Results

The results of Question 2 were incorporated into the guide and are not included here.

Survey Question 1:

From a maintenance perspective, list the expansion joints that have resulted in the most problems at your plant.

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Nuclear	3-5A1 LP feed-water heater extraction steam supply piping	20" single metal bellows	Complete failure.	Badger Manufacturing
Nuclear	Condenser raw water supply and return piping	68" single-arch	Mostly from identified rot and two failures.	Badger Manufacturing
Nuclear	Condenser neck seal	Rubber with plies having dogbone cross-section	Failures because of overheating or decomposition.	Uniroyal
Fossil	Primary air fan ducting expansion and extraction	Silcoat cloth, skived PTFE strips, medium glass MAX LT, 25 ceramic		
Fossil	Cold air pipe for extraction	Silcoat cloth, skived PTFE strips, medium glass MAX LT, 25 ceramic		
Fossil	Blanket strip	ALU coated glass cloth and stainless steel mesh code 793201		
Fossil	Cold air pipe	Rubber		
Fossil	Precipitator inlet and outlet ducts	Rubber		
Fossil	Air and gas ducts	All metal pinned and slotted		

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Fossil	Air heater bypass ducts	6-10 fabric		
Fossil	Oxygen system and soot blowers	Metal		
Nuclear	Suction piping to the condensate system pumps	Rubber, spool "Arch" type	Numerous premature failures (collapsed/distorted carcass, internal delamination) because of vacuum conditions.	Goodall and Garlock
Nuclear	Low-energy piping—river and raw water systems at locations with system pressures of 35 psig or greater	Rubber, spool "Arch" type	Two catastrophic failures, plus numerous premature degradations because of manufacturing design weakness (the use of wire mess in lieu of steel rings for carcass reinforcement).	Goodall
Nuclear	Low-energy piping—raw water system (at pump discharge, 90 psig)	Rubber, spool "Arch" type	One occurrence of a joint being over elongated and leaking thru the bolt holes because of a pressure thrust. The root cause was because of insufficient restraint of the discharge piping.	Garlock
Fossil	Condenser neck expansion (dogbone)	Duck and rubber w/ fibrous core	Air in leakage.	Maryland Ship building & Orgolock Co.
Fossil	Circulating water piping expansion	Esthan and rubber flanged	Developed cracks and failed.	Uniroyal
Fossil	Primary condensate pump suction expansion	Spool-type rubber single arch	Air in leakage.	Goodall Rubber Co.

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Fossil	Auxiliary condenser, condensate pump expansion	Polton and rubber flanged	Developed cracks and failed.	Uniroyal
Fossil	Economize an outlet expansion	Metal cupped panel	Developed leaks from corrosion.	Combustion Engineering
Fossil	Precipitator inlet expansion	High-temp. fabric	Air in leakage.	Combustion Engineering
Fossil	Precipitator outlet expansion	High-temp. fabric	Air in leakage.	Combustion Engineering
Fossil	Coal mill primary air expansion	Metal expansion joint	Catastrophic failure (explosion).	Combustion Engineering
Nuclear	Extraction steam expansion joints inside the main condenser.	Metal, seven convolutions	Catastrophic failure.	Flexonics
Nuclear	Moisture separator (MSR) drain expansion joints	Metal, tied universal expansion joint	Develop leaks in the convolutions.	Flexonics
Nuclear	Extraction steam piping in the condenser	Metal-universal, pressure balanced, hinged and tie rod	Cracking and pinholes.	Sr Flexonics
Fossil	Duct right after air preheater	Fabric	Water and ash over time eat the joint away.	Darling
Fossil	Duct after precip before stack	Metal	Corrosion from water and ash.	Darling

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Nuclear	Condenser water box inlet and outlet piping	Rubber expansion joints	Joints have cracks and became sponge. Catastrophic failure was possible.	Uniroyal
Nuclear	Turbine extraction line expansion joints	Single metal bellows, two-ply	Complete failure because of bellows rubbing against outer cover and/or FIHV fatigue failure.	Pathway
Nuclear	Turbine casing to condenser shell expansion joint	SS bellows (not a dogbone)	No problems to date but I am interested on OE and other.	Not sure Westinghouse turbine and southwest Eng. condenser
Fossil	Joints in ductwork that handle coal from feeder to coal mill	Accordion-style joints made of SS	Fail too frequently, because of movement and mill puffs, develops coal leaks.	Babcock Borsig Power
Fossil	Joints in ductwork from PA fans to crusher dryer inlet.	High-temperature fabric style	Fail from mill puffs, blow the joint out.	Papco
Fossil	Joints in large ductwork from ID fan outlet to stack inlet	High-temperature fabric style	Develops holes and fails too frequently, allows flue gas to escape.	Papco
Nuclear	Extraction steam	Expansion bellows	Throughwall cracking by stress corrosion cracking/corrosion fatigue.	Process Engineering

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Nuclear	Condensate pump suction	Rubber	High dissolved oxygen after changeout.	Mercer
Nuclear	Turbine extraction line piping	Metal, single-ply	Old design with single-ply, SS bellows with thin shield, age of joints installed, difficult to maintain because of location in BWR condenser neck.	Tube Turns
Nuclear	Condensate pump suction	Rubber spool	Catastrophic failure	Holz
Nuclear	Circulation water system expansion joints at the pump outlets	Rubber, single-arch, non-filled arch, 54 to 72 in. (137 to 183 cm) diameter	Age-related degradation and failure. Intermittent leaks requiring flange bolt re-torque. 18 month or three year inspection PM, no replacement PM.	Original joints were Goodall, replacements have been Garlock.
Nuclear	Circulation water system expansion joints at the condenser inlet	Rubber, single-arch, non-filled arch, 54 to 72 in. (137 to 183 cm) diameter	Age-related degradation and failure. Intermittent leaks requiring flange bolt re-torque. 18 month or three year inspection PM, no replacement PM.	Original joints were Goodall, replacements have been Garlock.
Nuclear	Circulation water system expansion joints at the cooling tower inlet	Rubber, single-arch, non-filled arch, 54 to 72 in. (137 to 183 cm) diameter	Age-related degradation and failure. Intermittent leaks requiring flange bolt re-torque. 18 month or three year inspection PM, no replacement PM.	Original joints were Goodall, replacements have been Garlock.

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Nuclear	Circulation water system expansion joints at the condenser outlet	Rubber, single-arch, non-filled arch, 54 to 72 in. (137 to 183 cm) diameter	Age-related degradation and failure. Intermittent leaks requiring flange bolt re-torque. 18 month or three year inspection pm, no replacement pm.	Original joints were Goodall, replacements have been Garlock.
Nuclear	Condensate system, on pump inlet	Rubber, single, non-filled arch, 24 in. (61 cm)	Age-related failure. 3 year inspection pm, 10 year replacement pm.	Goodall
Nuclear	Control Room HVAC system boots (canvass connectors)	Field fabricated, glued neoprene canvass with metal band retainers	Age-related degradation. Semi-annual inspection pm, no replacement pm.	N/A
Nuclear	Low-pressure turbine top condenser turbine to condenser expansion joints	Rubber	Age-related degradation. 10.5 year replacement pm.	Unknown
Nuclear	Emergency diesel generator cooling water bellows	Metal bellows	Concern over age and installation, no problems were found with removed bellows.	Badger Industries
Nuclear	Service water supply heater	Press. balanced bellows(metal)-single bellows (metal)-rubber (u-type, no arches)	Cracked weld and corroded spool piece-stress cracking because of weld splatter-failed under vacuum service.	Tube-Turn-Pathway-Garlock
Nuclear	Turbine extraction line	Press. balanced bellows(metal)-single bellows (metal)-rubber (u-type, no arches)	Cracked weld and corroded spool piece-stress cracking because of weld splatter-failed under vacuum service.	Tube-Turn-Pathway-Garlock

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Nuclear	Condensate pump suction side	Press. balanced bellows(metal)-single bellows (metal)-rubber (u-type, no arches)	Cracked weld and corroded spool piece-stress cracking because of weld splatter-failed under vacuum service.	Tube-Turn-Pathway-Garlock
Nuclear	Low-pressure service water moderator cooling system	16 in. (41 cm) rubber (non-metal)	Rupture in 1984, resulted in service water leak in the moderator room (inside reactor building).	Uniroyal
Nuclear	Turbine neck (dogbone)	Rubber	Minor air in-leakage.	Felexicon
Nuclear	Extraction steam exp. joint	Rubber	Minor air in-leakage.	Felexicon
Nuclear	Extraction steam exp. joint	Metal	None.	Badger
Nuclear	Boiler gas outlet duct work	Metal/fabric	Erosion/corrosion/tearing/ burn-up.	OEM
Nuclear	Turbine condenser neck	Fabric	Tearing.	
Nuclear	Turbine cross-over	Metal	Cycle fatigue.	
Nuclear	Turbine extraction piping	Metal	Cycle fatigue/support failure.	
Nuclear	Turbine extraction line piping	Metal		
Nuclear	The worst being 8th and 9th point extraction to the 3rd and 4th point low-pressure heaters	Universal	Axial and circumferential bellows cracks.	Flexible Metal Hose

Type Plant	Plant Application of Expansion Joint	Type of Expansion Joint	Problem Description	Expansion Joint Manufacturer
Nuclear		Pressure balanced	Bellows to pipe weld cracks.	Senior Flexonics
Nuclear		Hinged and tie rod	We've also had a catastrophic failure in unit 2.	Expansion Joint Systems, Inc.

Note: Inclusion of the expansion joint manufacturer in no way implies that defective products caused the failures or that the manufacturers were in any way responsible for the equipment failure.

Survey Question 3:

Have you installed replacement expansion joints in our plant in the last five years and were they direct replacements or a different design from the original?

Survey Question 4:

If the joints installed in item 3 above were not the original design, please indicate the manufacturer and type of joint and the reasons for using this style (for example, unavailability of original type, costs, ease of replacement, new material).

Type Plant	Response to Survey Question 3	Response to Survey Question 4
Nuclear	One LP feedwater heater (FWH) extraction piping expansion joint was replaced with same design and manufacture however was 0.050-in. wall thickness versus 0.062 in. No explanation could be found as to why the thinner joint was supplied. Many condenser raw water rubber expansion joints have been replaced using alternative manufactures. Many condenser dogbone seals have been replaced using alternative supplier of similar design.	Purchase of metal expansion joint for LP FWH was based on availability and OEM. Purchase of large condenser rubber expansion joints were from manufactures as follows: Goodyear, General Rubber, Dynex, Unaflex, Proco, Mercer, Garlock. Condenser expansion joint design of each alternative manufactures differed to some degree in thickness, number of fabric plies, wire or bar supports, size of arch, and other. Labadie has attempted to standardize on one supplier for the 68-in., customized condenser expansion joints with Garlock. These are not the least expensive; however, they are believed to be the best purchase due to availability, construction, expected longer service life over others and the included free periodic field survey provided by Garlock/Draco. Custom expansion joints minimize labor required to install and will align better in piping that has lateral and face-to-face offsets. LaFavorite has supplied Labadie plant the same configuration with slightly different materials for condenser dogbone seals and field splicing

Type Plant	Response to Survey Question 3	Response to Survey Question 4
Fossil	No major problems experienced at plant in 30 years. Change on condition of joint.	Mall joints replaced by direct replacements no change from the original. Four primary air expansion joints replaced in last 5 years.
Nuclear	We have replaced 58 rubber expansion joints within the last five years with only two being a direct replacement.	There is an effort at my plant to replace all Goodall rubber expansion joints with Garlock joints to correct a design weakness that has been attributed to two catastrophic failures and numerous, premature degradation. The weakness is that the carcass of Goodall REJ's are reinforced with wire mesh instead of steel rings.
Fossil	Yes and they were direct replacement.	
Nuclear	By the end of 2002, Oconee will have replaced 15 rubber expansion joints. Of these, five were replaced because of changes in system design pressure so a different expansion joint had to be specified. The other ten replacements are exact replacements. For metal expansion joints, Oconee has replaced about 100 expansion joints. Of these only 12, MSR drain, were direct replacements. The others had various design changes, most of the changes were because of recommendations from the manufacturer. All of the metal expansions were originally supplied with an inner liner that was 50 mils thick. Because then the manufacturers have started recommending that for harsh environments, such as extraction steam, that the inner liner be 250 mils thick. Other changes were because of internal commitments; several years ago it was agreed that metal expansion joints were inside the condenser would be of the testable style. So more than 50 expansion joints on two units have the redundant bellows design.	See remarks in item # 3 above. I did not consider changing manufacturer as being a change from original design. If the replacement component looked like the original component and had the same design parameters it was a direct replacement even if the manufacturer changed. All of the replacement metal expansion joints were supplied by a vendor other than Flexonics because of cost and availability of expansion joints from Flexonics. The five rubber expansion joints that were replaced because of changes to system design pressure were supplied by a different vendor because the original supplier was not on the approved QA suppliers list for Duke Power. The remainder was supplied by the original manufacturers.
Nuclear	We have replaced four replacements. They were similar but not exact design.	The new bellows were made by Sr Flexonics and are their standard design.

Type Plant	Response to Survey Question 3	Response to Survey Question 4
Fossil	Direct replacements.	
Nuclear	We started to replace joints approximately 5 years ago. During next two refueling outages, we will replace all remaining joints.	New joints are manufactured by Garlock. Garlock makes custom joints for us with built in offset and nonstandard size if needed. The installation of custom fit joints is a lot easier.
Nuclear	Yes, same basic design but with additional enhancements such as two-ply vs. one-ply, inconel vs. SS, and other.	Pathway had several enhancements designed to increase bellows life – we incorporated all of them. They were: increased distance between outer cover and bellows, thicker inner liner, use of eddy ring at bottom of joint to prevent contact with outer cover as well as stop FIHV from steam outside bellows, inconel vs. SS bellows, two-ply vs. one-ply bellows, bellows design for greater piping offset.
Fossil	We have, and they've been direct replacements.	
Nuclear	Different material, different manufacturer.	Costs, Inconel 625 vs. 690
Nuclear	Original design.	
Nuclear	No.	N/A
Nuclear	Direct replacements.	
Nuclear	Yes, one circulation water main pump discharge rubber expansion joint was replaced with a custom fabricated joint. The replacement joint was fabricated to correct for flange misalignment that was out of spec by a factor of >2 and was evaluated to have an adverse impact on joint life span.	The CW replacement joint was manufactured by Garlock and custom fabricated. It is unknown if the original manufacturer, Goodall, makes custom fabricated joints.
Nuclear	Yes, control room HVAC duct canvass connectors were overworked with new canvass installed over the existing canvass per the original plant HVAC specifications.	

Type Plant	Response to Survey Question 3	Response to Survey Question 4
Nuclear	Yes, emergency diesel generator cooling water inlet and outlet bellows. The same company that made the original bellows manufactured the replacements.	
Nuclear	Yes and some were direct replacements; however in the last two years we have started using EPDM for the tube and cover to provide a longer service life.	We used the same manufacturer. The costs are approximately 10% to 15% higher but the service life is longer.
Nuclear	Yes. Direct replacement.	N/A
Nuclear	(1) Turbine neck expansion joint (dogbone). Different manufacturer similar design. (2) LP turbine extraction steam expansion joints. Different manufacturer similar design.	(1) Unavailability of original type (2) Came with new LP turbine rotor retrofit.
Nuclear	Yes to both questions.	Either looking for extended life or lower cost drove us to using different type joints.
Nuclear	We've done both. We've installed the same design and what we consider an enhanced design. The original designs are generally a universal joint with single-ply bellows, tie rods, an A321 stainless steel bellows material, internal shields and external shields. The enhanced design is a universal joint with multi-ply bellows, hinged, 316 (316L) bellows material and internal shields. Because of potential thermal cycling problems caused by external steam flow patterns, we're considering installing external bellows shields.	The manufacturer of the enhanced expansion joint design is Expansion Joint Systems, Inc. (Santee, CA). The enhanced design was selected because we felt the failure mechanism was system vibration. We later felt that maybe thermal cycling was a possibility. Based on this assumption, we're having the manufacturer model the thermal situation of our joints. If the calculated bellows stresses are unacceptable, we'll consider installing external bellows shields.

C.3 Industry Failure Data for Metal Expansion Joints

Plant	Age	Event Description
ANO 1	11	Leakage because of cracks in welds of low-pressure heater EXJ.
ANO 1		Cracked weld in feedwater EXJ upstream of pumps because of fatigue.
ANO 2	5	Crack found in 7A feedwater heater expansion joint.
ANO 2		24" crack in the water box expansion joint.
ANO 2		Crack found in 7B feedwater heater expansion joint.
Beaver Valley 2	2	Failed EXJ liner jammed pump impeller in component cooling system.
Beaver Valley 2	12	Water hammer in SW system deformed EXJ on SW pump.
Calvert Cliffs 2		Erosion of piping adjacent to EXJs in cold reheat piping.
Comanche Peak 1		Rupture of Htr drain pump EXJ because of weld discontinuity and fatigue cracking.
Farley 1		26" extraction EXJ bellows and cover failures (Manufacturer defect).
Farley 1		Failure of 24" EXJ in extraction line service inside of condenser.
Fukushima Daini		Failure of EXJ results in fatality.
Indian Point 2	18	20", condenser EXJ, extraction line, cyclic fatigue and vibration.
Indian Point 2	18	Failure of 20" extraction line EXJ in the condenser.
Indian Point 2		Failure of flexible connector in SW system at emergency diesel generators.
LaSalle 1		Failure of low-pressure heater extraction EXJs.
Maine Yankee		EXJ liner cracked with sections missing on exhaust of diesel turbocharger.
Maine Yankee		Failure of 20-in. extraction line, tandem EXJ.
Millstone 3	5	Pinhole leak in SW EXJ at pump discharge (corrosion from stagnant environ).
Millstone 3	11	Defective design for tie rods could damage EXJ.
Millstone 3		Leak in 8-in. EXJ at DG jacket water cooler in SW piping (crevice corrosion).
Millstone 3		DG cooler EXJ leaking.
Millstone 3	3	DG cooler EXJ leaking.

Failure Data of Expansion Joints

Plant	Age	Event Description
North Ana 2	7	Recirc. spray pump A EXJ badly deformed.
North Ana 2	7	Recirc. spray pump B EXJ badly deformed.
North Ana 2		Crack in exhaust EXJ for DG.
Oyster Creek		Leak in EXJ on discharge of relief valve to condenser piping.
Palo Verde 2		Failure of two 18-in. EXJs in extraction piping in condenser.
Peach Bottom	14	Leak in EXJ on the DG air receiver.
Salem 2	4	Leak in EXJ of DG turbocharger exhaust.
San Onofree		Damaged condensate pump expansion joint.
Seabrook 1		Leak in 10-in. EXJ of DG jacket water HX.
St. Lucie 2		2B intake CW Pump EXJ leaking excessively (galvanic corrosion).
Summer 1	9	Leak in DG cooler SW EXJ.
Surry 1		Failure of Htr drain pump EXJ because of overpressure results in fatality.
Surry 2		Leak in EXJ on SW line because of galvanic corrosion.
Vogtle 2		Damage found in the extraction EXJs inside condenser.
Waterford 3		Failure of extraction line EXJs inside of condenser.
Zion 1	19	Crack in EXJ seam weld of EDG cylinder expansion joint.
Zion 1	14	DG lube oil piping EXJ damaged and leaking (stepped on).
(Not provided)		Leak of SW EXJ.

C.4 Failure Data for Rubber/Fabric Expansion Joints

Plant	Age	Event Description
ANO 2	18	30-in. expansion joint condensate pump. Expansion joint inspected and found to have pinholes because of aging.
Beaver Valley		Expansion joint collapsed.
Beaver Valley 1	19	24-in. SW expansion joint ruptured because of erosion of tube (replaced in 85).
Beaver Valley 2	4	30-in. condensate pump suction expansion joint deformed and partially collapsed, no leakage.
Beaver Valley 2	10	30-in. suction expansion joint for condensate pump found to have pinhole leak.
Brunswick 1	14	Rupture of screen wash pump expansion joint.
Byron 1	7	Condensate pump expansion joint cover found torn 180 degrees.
Calvert Cliffs 1	3	24-in. suction side of condensate pump expansion joint – tube imploded and core of joint visible.
Clinton 1	4	Condenser water box over-pressurized, damage to water box expansion joint, no leakage.
Clinton 1	3	Inlet expansion joint to condenser leaking (1 cup/hr.), replaced expansion joint later outage.
Comanche Peak 1	8	Circulation pump expansion joint ruptured because of normal aging.
Cook 1	15	8-in., SW header. expansion joint leaked because of 4-in. gash in the joint, cause unknown.
Cook 2	9	Expansion joint in discharge header of essential service water pump ruptured because of degradation.
Crystal River 3	8	10-in., SW pump suction expansion joint failed – hole in joint, aging (12 yrs.).
Diablo Canyon 1,2	13	Two cooling system synthetic expansion joints experienced catastrophic failures.
Ft. St. Vrain 1	14	CCW expansion joint failed because of degradation, 54”, 15 years old.
Indian Point 3	12	30-in. condensate pump expansion joint leaking.
Indian Pt. 3	11	Expansion joint on suction side of condensate pump deformed and leaked because of degradation.
Indian Pt. 3	16	30-in. expansion joint on suction side of condensate pump had minor leakage (excessive forces).
Indian Pt. 3	17	Expansion joint on suction side of condensate pump deformed and leaked because of degradation.
Lasalle 1&2	1	108-in. cir. water pump expansion joint failed resulting in flooding (2000 gpm), water hammer.
Limerick 1	12	Leak in expansion joint on suction side of condensate pump.
Limerick 2		Leak on ESW expansion joint.
Millstone 2	2	24”-in.service water pump expansion joint had ballooned out because of leakage thru tube.

Failure Data of Expansion Joints

Plant	Age	Event Description
Sequoyah 1	13	Main feedwater pump turbine condenser pump expansion joint developed leak because of high temp.
St. Lucie 1	10	30-in., SW system, rubber, expansion joint ruptured because of aging and cyclic fatigue.
St. Lucie 1	14	Intake 30-in. cooling water expansion joint had through wall leak, aging.
VC Summer	11	36-in. expansion joint on suction side of condensate pump had a hole in liner with no leakage.
VC Summer	9	36-in. expansion joint on suction side of condensate pump developed leak, cyclic fatigue.
VC Summer	9	36-in. expansion joint on suction side of condensate pump developed leak, cyclic fatigue.
Turkey Point 3	16	30-in. suction expansion joint for condensate pump leaking.

D
INDENTER POLYMER AGING MONITOR

D.1 Introduction

The purpose of this appendix is to familiarize the reader with the operation and results of the indenter polymer aging monitor. Although this appendix discusses the use of this monitor from the perspective of cable testing, Appendix E of this report describes how this technology was applied to non-metallic components of thermal expansion joints.

The indenter, a portable instrument, measures the aging of rubber and soft plastic materials, especially cable insulation and jacket materials. The measurement is fully nondestructive and can be performed on energized cables. Successful testing has been performed in a number of nuclear plants in radiological and nonradiologically controlled areas.

Generally, the hardness of an insulation increases with aging. The indenter determines a modulus, a characteristic of hardness, of the material being tested. By monitoring the increase in the indenter modulus (IM), the aging of the cable insulation/jacket system can be monitored.

D.2 Operation

The indenter measures modulus by pressing an instrumented probe against the surface of the material under test. While traveling at a constant velocity, the probe measures the force exerted by the material. The probe retracts when the force reaches a value that is set so that no damage occurs to the material under test. Figure D-1 shows a diagram of the indenter's principle of operation. The modulus is the slope of the force versus the position curve during indenting.

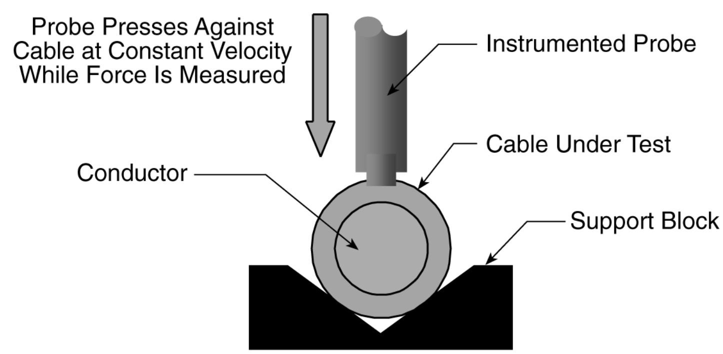


Figure D-1
Indenter's Principle of Operation Concept

Figure D-2 illustrates the indenter system: a portable computer, the control box, and the cable clamp containing the probe. The cable clamp has a rapid adjustment system to secure the cable to be tested. The clamp contains a precision drive for the probe, a load cell, ready and run lights, a test start switch, and an “abort” switch that allows the tester to stop the test and retract the probe.

Figure D-2
Indenter System with 25-Foot (7.6 m) Extension Cable, Adaptors, and Calibration Bench

The control box contains the batteries for the system, the control electronics, and the interface for the computer. The portable computer is a standard computer with a Microsoft Windows operating system. The clamp is connected to the control box by either a 4 ft. (1.2 m) or a 25 ft. (7.6 m) cable. The short control cable is for laboratory work. The long control cable is for field work that might require the control box to be at floor level, while the clamp is used to elevate cables in trays near the ceiling.

Figure D-3 illustrates the clamp with a 3/C, 16 AWG cable specimen in the jaw. Note that in the figure, the cable is bent only for illustrative purposes. The cable does not have to be distorted to perform a test. Even severely aged cables can be lifted for testing without causing damage.

Figure D-3
Cable Clamp with Specimen Clamped for Test

D.3 Indenter Data

Figure D-4 illustrates a plot from an indenter test session. Three measurements were made; the plot from the first measurement is shown. The plot is shown in terms of force versus displacement of the surface of the cable by the probe. The straight line segment of this plot is the force during indenting of the cable. The curved segment is the force during the retraction of the probe. The slope of the indenting curve is the IM.

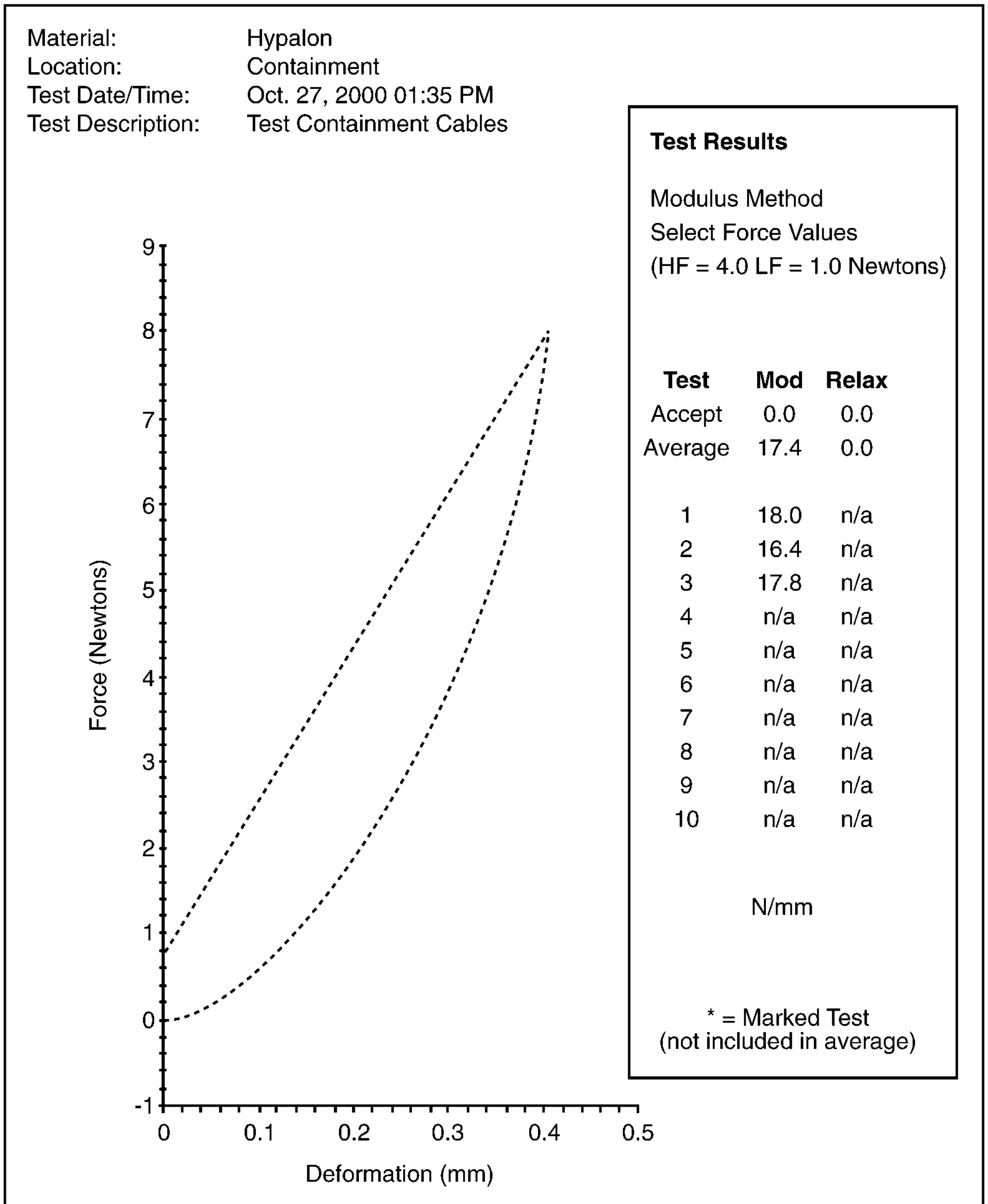


Figure D-4
Typical Indenter Plot for Mildly Aged Hypalon Cable Material

As cable materials harden through thermal and radiation exposure, the IM increases by as much as a factor of 10. This is true for Hypalon and neoprene, which are common cable jacket materials. These materials can be used as leading indicators of cable aging, especially from aging induced by the ambient environment of the cable. High ambient temperature conditions cause these jackets to harden and provide a leading indication of the aging of the insulation. The indenter also can track thermal degradation of natural rubber and polyvinyl chloride (PVC).

Figure D-5 illustrates a typical degradation curve for Hypalon. As the material ages from thermal exposure, the IM increases by a factor of approximately 6.5 from unaged, to zero EatB. Hypalon is a jacket material that is found on many types of cable used in the United States. Testing of Hypalon jackets provides an excellent indication of aging, and lack thereof, induced by thermal and radiation environments. Neoprene and PVC jackets and insulation have similar aging characteristics.

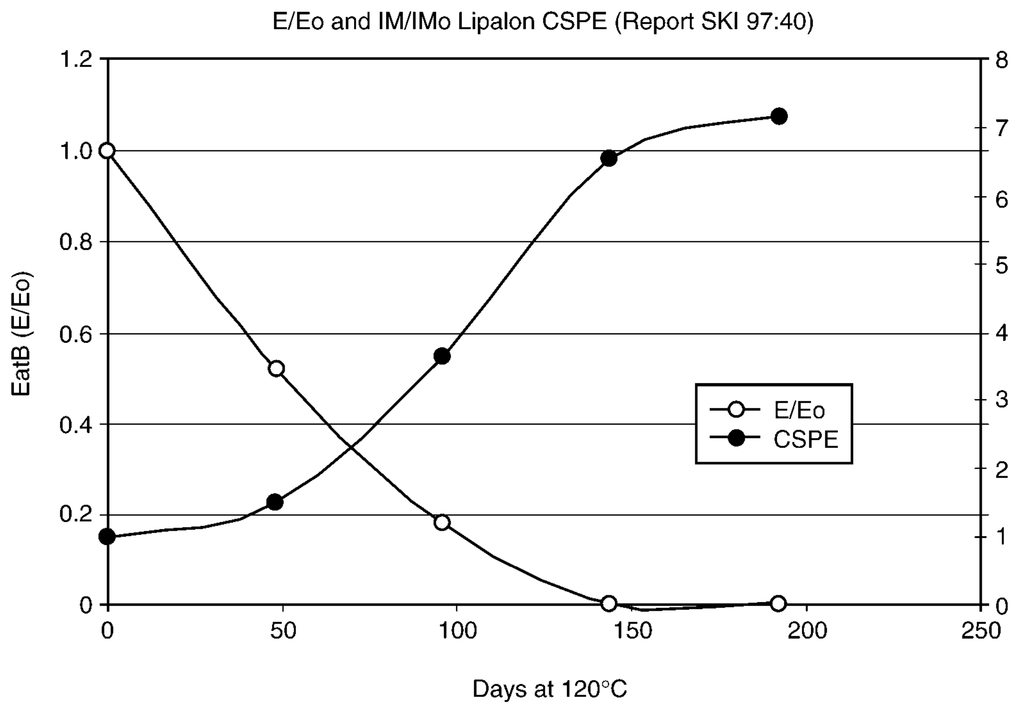


Figure D-5
IM and EatB versus Thermal Aging at 248°F (120°C) for Hypalon Cable Material

E
AGING MANAGEMENT ASSESSMENT

E.1 Introduction

This appendix describes the assessment of the possibility of extending the life of large expansion joints at a nuclear power plant through condition monitoring. There are twelve 96-in.-ID (243.8-cm-ID) circulating water expansion joints in use at the plant. Currently, these joints are being replaced on 10-year intervals for those with surfaces of chlorobutyl rubber and 14-year intervals for those with EPDM surfaces. Extending the service lives of these joints will achieve appreciable savings.

E.2 Discussion of Expansion Joints

The expansions joints are complex and are composed of an inner layer of EPDM, multiple layers of polyester cord each fixed with chlorobutyl rubber, carcass metal reinforcement rings to provide radial strength, and an outer layer of EPDM painted with blue epoxy. The arch of the gasket is filled with EPDM. There are flanges of the webbed composite that are clamped to the flange on the 96-in. (243.8-cm) circulating water pipes by steel rims and numerous 2-in.-diameter (5.1 cm) bolts around the circumference of the gasket.

There is nearly no vibration of the gasket during power operation. However, a key concern is misalignment between the gasket and the flanges of the mating pipes. The gaskets must be designed to fit the interface between the flanges of the condenser water box and the piping or the piping-to-piping interface. Mismatches between the gaskets and the flanges can put sufficient stress on the joints to cause delamination or damage that could lead to in-service failure or significantly shortened life. In addition, failure of the welds of the carcass reinforcement rings internal to the joint can lead to piercing of the joint by the ends of the ring. There appears to be two possible ring degradation mechanisms: weld failure from inadequate welds and corrosion should water penetrate the inner surface of the joint. Weld failure should be precluded with adequate quality control during manufacture. Water will not penetrate the joint unless a severe cut or crack occurs. Cracks should not occur unless there is a severe offset between the flanges of the piping and that of the joint, and/or the joint is allowed to age too long in service. Small cuts may occur in-service because of debris in the circulating water but should not propagate unless severe aging of the EPDM occurs.

Through cracks in the EPDM layer are undesirable because they could allow water to reach the carcass reinforcement rings or the layers of polyester cording leading to de-lamination.

Most degradation mechanisms for the joint progress slowly. The EPDM is exposed to low temperatures and will not age rapidly. Even if EPDM cuts occur, the deterioration of the reinforcement rings and delamination of the cord will progress slowly such that detection will be possible before failure. If left alone, such deterioration could lead to failure in a number of refueling cycles rather than in a fraction of a cycle.

E.3 Operation Experience at the Plant

The plant has had successful operation of chlorobutyl joints for up to 10 years and 12 to 14 years for EPDM joints. Only one rupture has occurred and that was related to failure of a metal strength ring, not the cording or the EPDM.

A few indenter[3] measurements were taken on some of the gaskets that have been removed from service. These are as follows:

Nenco Holz Rubber Co. Model 320 FA-777

Position	Indenter Modulus (N/mm [lb/in.])
Inner surface	6.6 [37.7]
Inner surface	5.5 [31.4]
Flange surface	5.5 [31.4]
Outer surface of arch	4.5 [25.7]

Chlorobutyl Joint (No Identification)

Position	Indenter Modulus (N/mm [lb/in.])
Inner surface	9.3 [53.1]
Inner surface	9.0 [51.4]
Flange surface	7.5 [42.8]
Outer surface of arch	7.8 [44.5]

[3] The indenter is a portable test device that presses a probe containing a load cell against the wall of a rubber or plastic component at a constant velocity. The probe stops and retracts when the force against the probe reaches a set limit that does not allow damage. The slope of the force versus position curve during the compression portion of the measurement is the indenter modulus.

Holz Joint

Position	Indenter Modulus (N/mm [lb/in.])
Inner surface	5.9 [33.7]
Inner surface	6.1 [34.8]
Flange surface	4.9 [28.0]
Outer surface of arch	4.5 [25.7]

A cutaway specimen of a typical Garlock EPDM joint indenter was tested, and the resulting Indenter modulus was 7.7 N/mm (44 lb/in.).

The indenter readings and the perceived feel of the Holz joints indicate that they are softer compounds than the Garlock EPDM and the chlorobutyl joint. This did not indicate a problem but, instead, indicated that the manufacture chose a softer EPDM compound to use.

The used joints that were examined indicated no significant deterioration of the inner and exterior surfaces. The indenter measurements are indicative of rubbers in early life rather than those with significant degradation. It should be noted that the inspection and indenter measurements were relatively cursory rather than detailed and were performed to get a perspective of the aging of the gaskets rather than to fully document the aging of the removed gaskets.

E.4 Inputs From a Program at a Plant of Similar Design

Input was received from an engineer from another plant who had attended training sessions by Garlock and had visited their manufacturing facilities. He described a number of conditions that may be observed from inspection of the inner and outer surface of the gaskets. These include hardening of the surfaces, cuts, cracks, and bubbles. Each of these conditions may indicate that significant deterioration has or may be occurring. Bubbles can be indicative of strength ring breakage or delamination. Small cuts on the inner surface generally are benign and do not propagate in properly installed gaskets. Small cracks on the outer surface also can be benign. All cracks should be documented and re-inspected to confirm that they are stable and not propagating. Large cracks are cause for concern especially if they reach or approach steel ring or cord layers.

E.5 Follow-On Activities

The inspection procedures from the sister plant should be reviewed for use. Plant personnel responsible for inspection of the expansion joints should attend Garlock training and if possible visit the manufacturing plant to more fully understand the construction of the joints.

Five joints are scheduled to be replaced during the 2003 refueling outage. If sufficient inspection data can be obtained before that outage, it may be possible to leave these joints in service. It appears that inspection at the start of that outage will not provide a large savings if the gaskets are left in place because of the large expenditures to prepare for the outage. However, if the gaskets can be evaluated in the fall of 2002 and the gaskets are found to have no significant signs of deterioration, they need not be replaced in 2003.

While hardening of the inner or outer surface polymer is not the only degradation mechanism and other degradation mechanisms appear to be significant, evaluation of the hardening of the gasket is possible with the indenter. The test is nondestructive. To support such testing, specimens removed from a new joint or slab specimens of the EPDM supplied by Garlock should be subjected to incremental thermal aging and elongation at break and indenter testing should be performed. At least five increments of aging should be included. The end point should be beyond the desired limits of aging for the material to ensure that there is latitude for making operating decisions on retention of the joints for service. The EPDM has an elongation at break in excess of 500%. The joints will function if the remaining absolute elongation is 50%. However, for conservatism, at least 100% absolute elongation at break should remain.

The durometer data from previous testing of Holz EPRM indicate that the hardness increases in an orderly manner as the EPDM in the joint ages. This result indicates that the indenter will satisfactorily monitor the aging of the inner and outer wall of the joint. The indenter results coupled with detailed physical inspections will provide an adequate basis for extending the life of the joints.

There may be a limitation on useful life of the joints not directly related to the joints themselves. That limitation may be corrosion of the circulation water piping flanges, which have required repairs in the past. Repair of the flanges may be required. Such repairs require removal of the joints to allow welding. When removed, handling can damage the gaskets and a spare should be available for replacement. Accordingly, while the joints may last 17 to 20 years as is desired, the metal flanges may be the life-limiting component of the system that could lead to replacement of the joints before the actual end of useful service life.

F
LISTING OF KEY INFORMATION

The following list provides the location of “Key Point” information in this report.

Key O&M Cost Point

Emphasizes information that will reduce purchase, operating, or maintenance costs.

Referenced Section	Key Point
7.4.2.6	Thermal aging of expansion joints in low temperature applications (<135°F or 57.2ºC) appears to occur very slowly. Therefore, these joints can be expected to have a long life. Periodic visual and manual assessment coupled with IM testing should allow continued use of these joints for significantly longer than might have been expected.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Referenced Section	Key Point
2.1.1	Often confusion occurs because thermal expansion in the piping will cause the expansion joint to be compressed. The specification for an expansion joint should always state the movements as they affect the expansion joint, and not as they are produced by the system.
2.1.1	Metal expansion joints are not normally expected to accept torsional deflection because the bellows is essentially inflexible in this direction.
2.1.2	Specifying temperature remote from the expansion joint may unnecessarily result in the need for special materials at additional expense.
2.3.1.2	To maintain lateral stability and prevent sagging when the multiple arch type expansion joint is installed in a horizontal position, a maximum number of four arches is recommended.

Referenced Section	Key Point
2.3.2	Tapers in excess of 15 degrees are not recommended for reducer-type expansion joints.
2.3.4.1	A sleeve-type of expansion joint is recommended only for low-to-medium pressure and vacuum service because of the difficulty of obtaining adequate clamp sealing.
2.3.6.1	Filled arches, built as an integral part of the carcass, decrease the flexibility of the joint and should be used only when necessary. Movements of expansion joints with filled arches are limited to 50% of the normal movements of comparable size expansion joints with unfilled (open) arches.
2.3.8.1	External full-face integral flange expansions joints are recommended for full-vacuum service or a maximum of 25 psig.
2.3.8.3	Spool-type, no-arch expansion joints are not recommended for movement, but will absorb vibration and sound.
2.3.9	Belt- (or dogbone-) type expansion joints are designed for compression and lateral movements for full vacuum service and a maximum pressure of 15 psig.
2.5.1	Metal expansions joints can be used in many applications with only a few general limitations. Temperatures should be less than 800°F and the pressure should be less than 300 psig.
2.5.1	When metal expansion joints are used in water systems, such as service water, the possibility of galvanic corrosion should be considered.
2.5.2	When installing rubber expansion joints, the bolts should be torqued to the manufacturer’s recommended values.
3.3.1	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.
3.3.3	Bellows fabricated from series-300 stainless steels are particularly subject to stress corrosion cracking. High nickel alloys are also subject to sulfur-induced corrosion.
3.3.7	Generally, the bellows designs have a larger safety factor with respect to pressure strength than they do with respect to flexibility because of safety precautions. Premature fatigue damage can result from virtually any load or stress concentration outside of the allowable design values.

Referenced Section	Key Point
3.3.8	When a bellows is used primarily for axial movements, a good rule of thumb is to locate the bellows adjacent to a main anchor, and 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.
3.3.9	A common error associated with bellows installation is moving the expansion joint to make up for misalignment that has not been accounted for in the design.
3.3.9	It should be emphasized that the piping should fit the bellows and not vice versa.
3.3.9	Field installation tolerances vary somewhat from one manufacturer to another, but typical figures are ±0.125 inches (0.318 cm) axial, ±0.125 inches lateral, and ±1.0 degree angular.
3.3.9	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.
3.3.11	Bellows are typically not designed to accept any amount of torsion. Twisting of the bellows should be prevented or the bellows will fail prematurely.
3.3.12	In general, very low-amplitude vibration should not harm most expansion joints but high-amplitude vibration will destroy a bellows assembly.
3.5.2.2	Excessive movement and/or misalignment are the leading causes of failure with rubber/fabric expansion joints.
4.1.1.2	As with main condenser walls, a cold alignment check should be performed on extraction lines to ensure that permanent deformation because of in-service forces has not exceeded the maximum out-of-alignment acceptance criteria. This alignment check should be performed after the first cycle on a new installation, and at least every five refueling cycles thereafter.
4.1.2.2	Typically if the fibers of the core are exposed, then replacement of the rubber expansion joint is recommended.
6.1.2	It should be verified that the increase pressure thrust caused by the larger, oversize-clamshell bellows will not cause an unsafe load at the anchor points that restrain the expansion joint.
6.1.3	The installation of same-size-clamshell expansion joints cannot be performed while the system is pressurized.

Referenced Section	Key Point
6.1.4	A patch may alter the movement capabilities of the bellows however, and should only be considered as a temporary repair. Welding of the bellows seam weld is not recommended and cannot be performed in the field. Repairs of attachment welds can be performed in some cases depending on the extent of the cracks.
6.2	Do not allow excess sealing compound, often used on belt-type (dogbone) expansion joints, to harden on the surface of the joint. Wipe excess sealing compound clean to avoid hardening, because after aging, the hardened sealing compound can crack and propagate cracks on the surface of the rubber belt-type expansion joint below.
7.4.2.7	For the Holz EPDM, both the durometer and indenter measurements provide good indications of aging.
7.4.2.7	For the Garlock EPDM and chlorobutyl rubber, the durometer provides some indication of aging, but the indenter provides a more direct indication of the degree of aging with respect to degree of exposure to thermal aging.
7.4.2.7	Monitoring the condition of the rubber liner must be combined with visual and tactile inspection to provide a complete understanding of the condition of the expansion joints.
7.4.2.7	IMs that are significantly greater than a factor of two higher than the original are a cause for concern, and continued use of the expansion joint should be approached cautiously.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage, or ease completion of the task.

Referenced Section	Key Human Performance Points
None	There are no key human performance points described in this report.

Program:

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

Printed on recycled paper in the United States of America

1008035

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com