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Susceptibility of Valve Applications to Failure of the Stem-to-Disk Connection

2020 TECHNICAL REPORT

Susceptibility of Valve Applications to Failure of the Stem-to-Disk Connection (Non-Proprietary Version)

3002019621

Final Report, September 2020

EPRI Project Manager
T. Walker

All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

YES (NO) ✓

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THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

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ABSTRACT

Nuclear power plants in the United States (US) perform position verification testing of certain valves, as required by the ASME Operation and Maintenance (OM) Code, to "verify that valve operation is accurately indicated." However, this testing does not necessarily verify that the valve's stem-to-disk connection is intact because only valve stem movement is verified. If the stem-to-disk connection were failed, the disk may not move as the stem travels or may move due to flow-induced forces even though it is not connected to the stem. Therefore, supplemental verification methods must be used if a direct indication of an intact stem-to-disk connection is needed.

The need for such supplemental verification should be based on several factors, including the importance of the valve and its susceptibility to stem-to-disk separation in the installed application. Susceptibility is primarily related to the stem-to-disk connection design and the valve service conditions. If supplemental verification is needed, then the verification interval should also be based on factors such as importance and susceptibility. The supplemental verification method should be selected based on its effectiveness for the valve type and application.

This document reviews valve stem-to-disk connection designs, and plant operating experience with those designs, to evaluate their susceptibility to stem-to-disk separation under different operating conditions. Verification methods that can be used to provide a direct indication that the stem-to-disk connection is intact for various valve types are also discussed. This document does not recommend supplemental verification intervals; however, it does provide some information that may be useful in selecting an interval. This document covers valve stem-to-disk connection designs used in typical power-operated and manually operated valves. It does not specifically address check valves or relief valves.

Keywords

Stem failure
Stem separation
Stem-to-disk failure
Valves

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EXECUTIVE SUMMARY

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PRIMARY AUDIENCE: Valve Component Engineers, Inservice Testing Engineers

SECONDARY AUDIENCE: System Engineers

KEY RESEARCH QUESTION

The need for supplemental verification that a valve's disk has not separated from the stem, and the interval at which it is performed, should be based on several factors, including the importance of the valve and its susceptibility to stem-to-disk separation in the installed application. Decades of operating experience in nuclear power plants can provide insights into the failures that have occurred and therefore the susceptibility of the various stem-to-disk connection designs. A detailed review of this operating experience is needed.

RESEARCH OVERVIEW

This document reviews valve stem-to-disk connection designs and uses primarily industry operating experience over a 43-year period to evaluate their susceptibility to stem-to-disk separation under different operating conditions. It also discusses verification methods that can be used to provide a direct indication that the stem-to-disk connection is intact for various valve types (i.e., supplemental verification). It does not recommend supplemental verification intervals but does provide some information that may be useful in selecting an interval. Although the operating experience reviewed is for US nuclear power plants, the results can be applied to any valves with stem-to-disk connection designs matching those evaluated in this document.

KEY FINDINGS

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WHY THIS MATTERS

Susceptibility is an importance consideration when determining the need for supplemental verification that a valve's disk has not separated from the stem and the interval at which such supplemental verification should be performed.

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EXECUTIVE SUMMARY

HOW TO APPLY RESULTS

The results in this document can be used, along with other considerations such as the importance of the valve application, to develop a supplemental verification approach for valves in a nuclear power plant. Note that there may be regulatory requirements that need to be considered when developing such an approach.

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1 INTRODUCTION

1.1 Background

Nuclear power plants in the United States (US) perform position verification testing of certain valves, as required by the ASME Operation and Maintenance (OM) Code, to "verify that valve operation is accurately indicated." However, this testing does not necessarily verify that the valve's stem-to-disk connection is intact because only valve stem movement is verified. If the stem-to-disk connection were failed, the disk may not move as the stem travels or may move due to flow-induced forces even though it is not connected to the stem. Therefore, supplemental verification methods must be used if a *direct indication* of an intact stem-to-disk connection is needed.

The need for such supplemental verification should be based on several factors, including the importance of the valve and its susceptibility to stem-to-disk separation in the installed application. Susceptibility is primarily related to the stem-to-disk connection design and the valve service conditions. If supplemental verification is needed, then the verification interval should also be based on factors such as importance and susceptibility. The supplemental verification method should be selected based on its effectiveness for the valve type and application.

1.2 Purpose

The purpose of this document is to review valve stem-to-disk connection designs, and plant operating experience with those designs, to evaluate their susceptibility to stem-to-disk separation under different operating conditions. Verification methods that can be used to provide a direct indication that the stem-to-disk connection is intact for various valve types are also discussed. This document does not recommend supplemental verification intervals; however, it does provide some information that may be useful in selecting an interval. This document covers valve stem-to-disk connection designs used in typical power-operated and manually operated valves. It does not specifically address check valves or relief valves.

1.3 Report Outline

Section 2 reviews United States nuclear power plant operating experience with stem-to-disk separation events to determine what failures have occurred in the past. Section 3 describes common stem-to-disk connection designs used on valves in the nuclear power industry and evaluates their susceptibility to stem-to-disk separation in different valve applications. Section 4 discusses methods that can be used to provide a direct indication that the stem-to-disk connection is intact for various valve types. Section 5 provides information to help estimate the effect of the

supplemental verification interval on the probability of failure of a valve. Section 6 summarizes this report. Section 7 contains a list of references. Appendix A summarizes key information from power plant operating experience reports related to valve stem-to-disk separation events.

1.4 Abbreviations

The following abbreviations are used in this document

Abbreviation	Description
ADDD	Anchor/Darling double disk gate valve
AOV	Air-operated valve
BWROG	Boiling Water Reactor Owners Group
EPRI	Electric Power Research Institute
FIN	Fisher information notice
FTC	Failure to close
FTO	Failure to open
FTO/C	Failure to open or close
GL	Generic letter
HOV	Hydraulically-operated valve
IN	Information notice
INPO	Institute of Nuclear Power Operations
IRIS	Industry Reporting Information System
MOV	Motor-operated valve
MSIV	Main steam isolation valve
NRC	Nuclear Regulatory Commission
OE	Operating experience
PL	Pressure locking
PRA	Probabilistic risk assessment
SOP	Spurious operation
SOV	Solenoid-operated valve
TB	Thermal binding
UNK	Unknown
US	United States
VTRG	Valve Technical Resolution Group

2
REVIEW OF OPERATING EXPERIENCE

This section reviews United States (US) nuclear power plant operating experience with stem-to-disk separation events to determine past failures. The results of this review are used to identify failure types for the various stem-to-disk connection designs in Section 3. Key information from power plant operating experience reports related to valve stem-to-disk separation is provided in Appendix A.

Note that, in reviewing operating experience, all available information is reviewed, regardless of the importance of the valve (e.g., failures of both safety-related and non-safety-related valves are considered). The reason is that the intent of this review is to obtain an indication of the susceptibility to stem-to-disk separation of specific stem-to-disk connection designs in different applications; failures of non-important valves can provide insight into potential failure of important valves with similar designs and in similar applications. It is expected that, in applying the results in this document, the importance of the valve application will be considered in deciding whether and how often to perform supplemental verification.

2.1 Overall Valve Failure Rates

The NRC monitors current "industry-average" nuclear power plant equipment performance on its website *Industry Average Parameter Estimates*. This website currently contains component reliability data through 2015, based on data from INPO. The Component Reliability Data Sheets on this website summarize failure data for various component types, including valves. The failure data is categorized by failure mode (e.g., failure to open), and the details of the failure (such as whether it was due to a stem-to-disk separation) are not included. This data is used by the NRC as input to their Standardized Plant Analysis Risk models and by nuclear plants in their Probabilistic Risk Assessment (PRA) models and provides a reference point against which the stem-to-disk failure data summarized later in this section can be compared.

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Table 2-1
Total Valve Failures from NRC Component Reliability Data Sheets from 1998 to 2015

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2.2 NRC Generic Correspondence

The sections below discuss NRC generic correspondence related to stem-to-disk separation events.

2.2.1 NRC Information Notice 2006-15

IN 2006-15 (*Vibration-Induced Degradation and Failure of Safety-Related Valves*) describes a 2003 failure at the Vogtle Electric Generating Plant of a 4-inch (10 cm) Fisher pilot-operated globe valve with a bolted stem-to-disk connection. The failure was attributed to flow-induced metal fatigue of the cotter pin intended to secure the nut to the valve stem. Once the cotter pin failed, the nut backed off completely and caused the disk to separate from the stem. A similar failure had also occurred at Vogtle in 1989. Fisher had previously issued (in 1988) an advisory related to this failure mechanism for selected Fisher valve models, recommending that all affected valves be disassembled and inspected. Possible failure contributors identified were:

- Re-use of the anti-rotation star washer with bend-up tabs, leading to fatigue failure of the tabs
- Improper replacement or re-use of the cotter pin, leading to fatigue failure

A possible corrective action identified in the IN is to stake the threads to retain the nut rather than using a star washer or cotter pin.

2.2.2 NRC Information Notice 2005-23

IN 2005-23 (*Vibration-Induced Degradation of Butterfly Valves*) describes a 2005 failure at the San Onofre Nuclear Generating Station of an 18-inch (46 cm) Fisher butterfly valve with a pinned stem-to-disk connection. The failure resulted from the loss of the two taper pins that connected the disk to the stem. The reason for the loss of the taper pins could not be determined. The corrective action was to stake the pins to the valve disk, rather than relying on the interference fit to keep the pins in place. In five prior instances at the same plant, 28-inch (71 cm) Fisher butterfly valves were found with one of the two taper pins missing, which can cause leakage past the valve disk. The IN also mentions similar failures that had occurred with butterfly valves from other manufacturers at Turkey Point and Davis-Besse.

2.2.3 NRC Information Notice 84-48, Including Supplement 1

IN 84-48 and its supplement describe stem-to-disk failures that occurred at Salem Nuclear Station. An extent of condition review following a stem-to-disk failure of a Rockwell globe valve identified multiple failures, or imminent failures, of similar valves. Two causes were identified:

- Stress corrosion cracking of the stem resulting from high stresses due to backseating. According to the IN, the vendor's recommended corrective action was to limit the force applied when backseating.
- Partially unscrewing of the disk from the disk nut following fracture of the welds used to "thermally upset" the threads due to loads associated with cavitation in severe throttling service. According to the IN, the vendor's recommended corrective action was to install smaller valves so that the valve disk would be in a mid-position or a more fully open position at the required flow rate.

2.3 Anchor/Darling Double-Disk Gate Valve Failures

Multiple stem-to-disk separation events associated with Anchor/Darling double disk (ADDD) gate valves have occurred in the nuclear industry, which led to three 10 CFR Part 21 notifications – two from Flowserve (the current owner of the ADDD product line; see References 6 and 12) and one from Tennessee Valley Authority (Reference 7) – and NRC Information Notice 2017-03 (Reference 1). In response, the Boiling Water Reactor Owners' Group (BWROG) Valve Technical Resolution Group (VTRG) prepared TP16-1-112, *Recommendations to Resolve Flowserve 10CFR Part 21 Notification Affecting Anchor Darling Double Disc Gate Valve Wedge Pin Failures (Revision 5)* (Reference 4), which summarizes the issues and recommended corrective actions to address currently installed valves using a risk-informed approach. For the ADDD design, the most prevalent stem-to-disk connection design is threaded and pinned (see Section 3.2.10), although some of these valves have T-Head/T-Slot connections. The purpose of the pin is not to react the maximum expected applied stem loads (e.g., thrust and torque) but to prevent the stem from unscrewing from the upper wedge. Accordingly, the stem must be torqued (i.e., preloaded) into the upper wedge with a torque that is greater than the maximum applied stem loads to avoid overload of the pin. The failure sequence for these valves is typically as follows:

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The BWROG paper provides guidance for screening, evaluating, and repairing ADDD gate valves to address the potential for stem-to-disk separation, and this document does not replace or supersede any guidance in the BWROG paper.

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2.4 Fisher Information Notices

The following Fisher Information Notices (FINs) relate to possible stem-to-disk failures for certain Fisher butterfly valves:

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2.5 Stem-to-Disk Separation Events

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Figure 2-1
Failures Per Year by Safety Classification and Actuator Type from INPO IRIS Database

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Figure 2-2
Total Stem-to-Disk Failures by Year from INPO IRIS Database

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Figure 2-3
Average Stem-to-Disk Failures per Year by Decade from INPO IRIS Database

Figure 2-4 shows the distribution of failures by stem-to-disk connection design (see Section 3), and

Figure 2-5 shows the annual failure rates by stem-to-disk connection design. Table 2-2 also shows the annual failure rates, along with the number of failures for each design and the percentage of the overall valve failure rate in Section 2.1 for each design.

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Figure 2-4
Distribution of Failures from INPO IRIS Database by Stem-to-Disk Connection Design

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Figure 2-5
Failures per Year by Stem-to-Disk Connection Design from INPO IRIS Database (1977-2019)

Table 2-2
Failure Rates by Stem-to-Disk Connection Design from INPO IRIS Database (1977-2019)

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3
EVALUATION OF STEM-TO-DISK CONNECTION DESIGNS

This section describes common stem-to-disk connection designs used on valves in the nuclear power industry and evaluates their susceptibility to stem-to-disk separation, based on the results of the operating experience review in Section 2.

3.1 Special Considerations

Stem-to-disk connection failures in the past have occurred due to specific design, maintenance, or application issues that are now recognized and have known corrective actions. These issues require special consideration, as discussed in the sections below, to minimize the potential for these failures.

3.1.1 Pressure Locking and Thermal Binding

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Figure 3-1
Pressure Locking and Thermal Binding Failures by Year

3.1.2 Material Incompatibility

Almost any valve is subject to stem-to-disk failure, and other potential failures, if the valve materials are not compatible with the fluid medium. General wastage due to corrosion, particularly in raw (untreated) water environments can reduce the strength of the valve parts below operating loads and result in component failure. Wastage can also reduce component material to the point that the stem-to-disk connection is no longer effective (e.g., the T-head is not held within the T-slot).

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3.1.3 Overload Due to Backseating

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Figure 3-2
Overload During Backseating Failures by Year

3.1.4 Severe Throttling Service

As discussed in Section 2.2.3, valves that are installed in applications that involve throttling under severe conditions, such as with high flow and/or high temperature fluids, should be specifically designed for the application. Otherwise, cavitation and fluid flashing can occur and lead to severe vibration or damage to internal valve components, which can cause stem-to-disk failure. Anti-cavitation trim options are available from several vendors. Valves installed in severe throttling service applications should be properly designed such that failure due to cavitation and flashing is not an issue.

3.1.5 Re-Use of Damaged Position-Retention Devices

As discussed in Section 2.2.1, re-use of a position-retention device that has already been subjected to in-service stresses can lead to premature failure. Maintenance procedures should provide adequate guidance for inspecting position-retention devices and replacing them when warranted.

3.1.6 Poor Maintenance Practices

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3.1.7 Globe Valve Main Steam Isolation Valves

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3.2 Stem-to-Disk Connection Designs

The sections below discuss each stem-to-disk connection design evaluated in this document, in order of increasing annual failure rate.

3.2.1 Keyed

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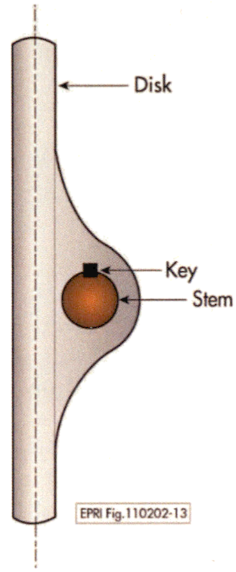

Figure 3-3
Keyed – Butterfly Valve

3.2.2 Socketed/Splined

In a socketed ball valve design, the end of the stem has a rectangular cross-section that fits into a rectangular hole in the ball (Figure 3-4). In a splined eccentric plug valve design, the end of the stem is splined and mates with splines in the plug (Figure 3-5).

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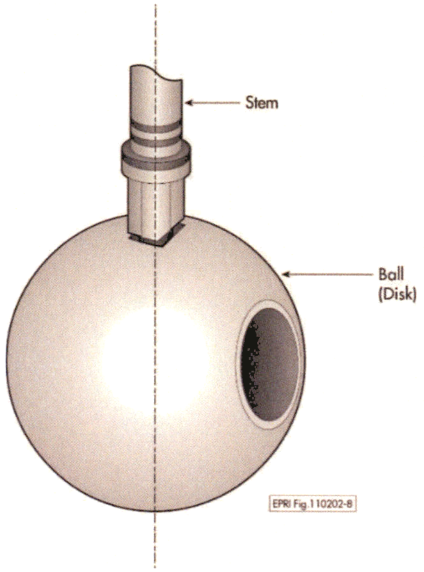

Figure 3-4
Socketed – Ball Valve

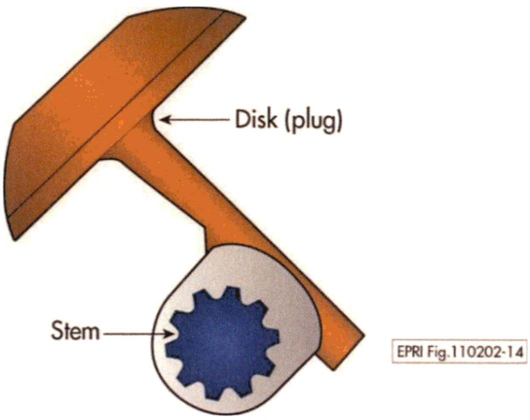

Figure 3-5
Splined – Eccentric Plug Valve

3.2.3 Integral/Single Piece

Integral/single piece designs have a disk and stem that are machined from the same bar stock. This design is used primarily in small globe valves (Figure 3-6), plug valves (Figure 3-7), and double-seated globe valves (Figure 3-8).

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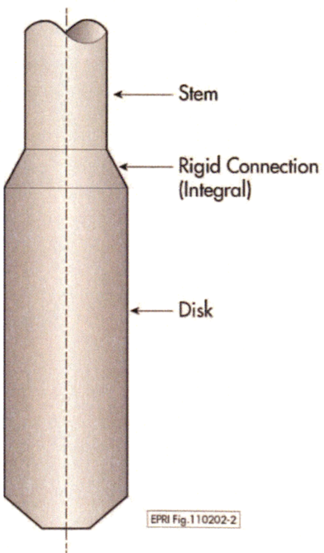

Figure 3-6 Integral/Single Piece – Globe Valve

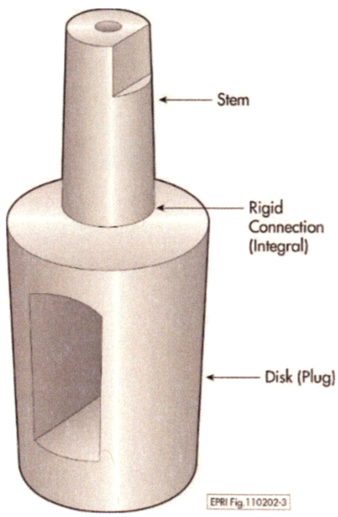

Figure 3-7 Integral/Single Piece – Plug Valve

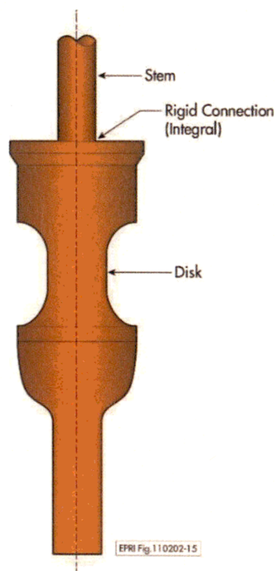

Figure 3-8 Integral/Single Piece – Double Seated Globe Valve

3.2.4 Threaded and Welded

In this design, the stem is threaded into the valve disk or plug and then welded to the disk/plug (Figure 3-9). This design in used primarily in gate and globe valves and is potentially susceptible to the following key failures:

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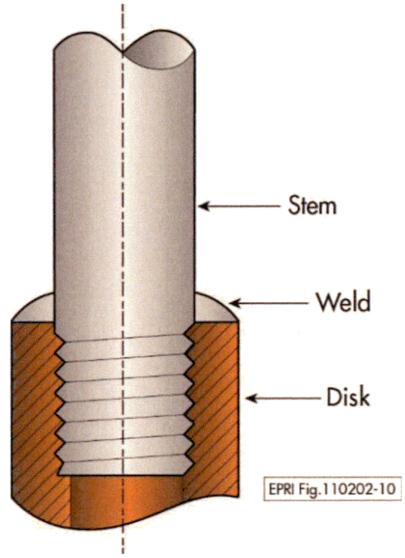

Figure 3-9
Threaded and Welded – Gate Valve

3.2.5 Captured and Free

In this design, the end of the stem is captured by a sleeve that is threaded into the top of the disk and then welded (or otherwise secured) to the disk (Figure 3-10). There is a clearance between the stem and the sleeve/disk such that the stem has some axial freedom of movement relative to the disk. This design is used primarily in globe valves.

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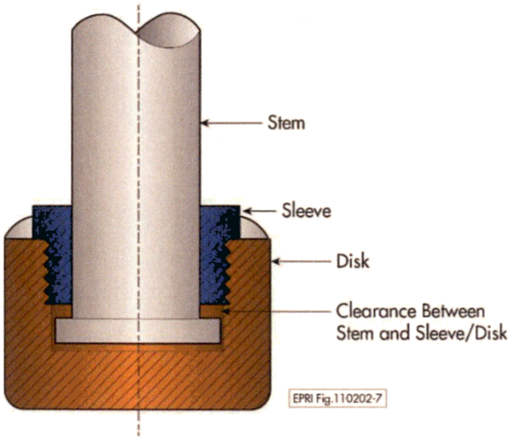

Figure 3-10
Captured and Free – Globe Valve

3.2.6 Bolted

In this design, the end of the stem is threaded, and the disk is rigidly attached to the stem with a clamping nut (Figure 3 11). There is typically a locking device on the nut, such as a cotter pin, star washer, or weld. This design is used primarily in globe valves and is potentially susceptible to the following key failures:

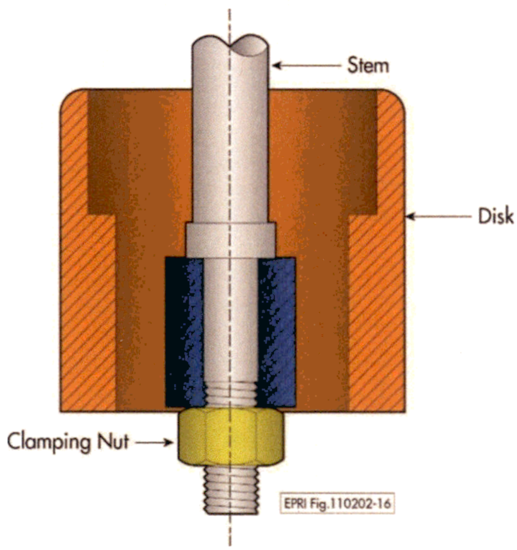

Figure 3-11
Bolted – Globe Valve

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3.2.7 Captured and Clamped

This design is the same as the captured and free design except that the stem T-head is "clamped" between the sleeve and disk such that the stem T-head cannot move relative to the sleeve/disk in

the direction of motion (Figure 3-12). The valve stem may have a spherically machined head. This design is used primarily in globe valves.

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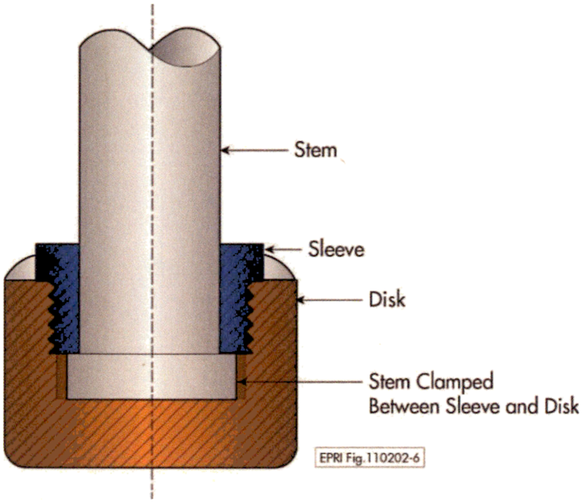

Figure 3-12
Captured and Clamped – Globe Valve

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Figure 3-13
Failures by Year for Captured and Clamped Designs

The failures that have occurred are discussed in the bullets below.

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3.2.8 Pinned

In this design, which is used in many butterfly designs, the disk is pinned to the stem at the top and a stub shaft or trunnion at the bottom (

). This design is potentially susceptible to the following key failures:

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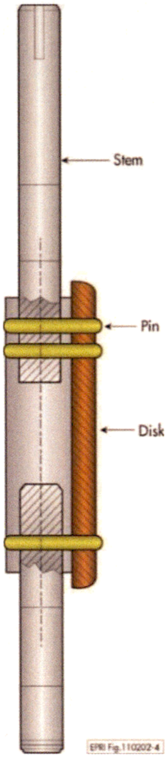

Figure 3-14
Pinned – Butterfly Valve

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Figure 3-15
Failures by Year for Pinned Designs

The 44 failures that have occurred are discussed in the bullets below.

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3.2.9 T-Head/T-Slot

T-head/T-slot designs have a T-head on the end of the stem that fits into a T-slot at the top of the disk. This design is used primarily in solid and flexible wedge gate valves (**Error! Reference source not found.**). Variants of this design are also used in Westinghouse and Edward Equiwedge gate valves.

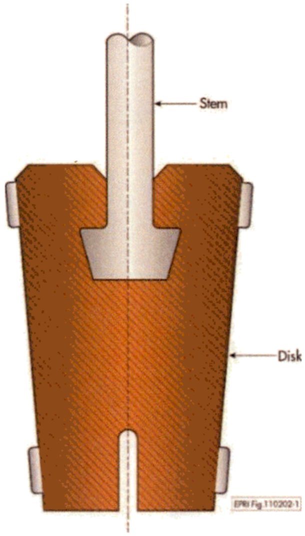

Figure 3-16
T-Head/T-Slot – Wedge Gate Valve

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Figure 3-17
Failures by Year for T-Head/T-Slot Designs

The 45 failures that have occurred are discussed in the bullets below.

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3.2.10 Threaded and Pinned

In this design, the stem is screwed into the valve disk or plug and then pinned to the disk/plug. This design in used in many globe valves (Figure 3-18) and in some gate valves (Figure 3-19). The pin is typically intended only as a locking device and is not designed to react the maximum load applied to the valve stem. To ensure the pin is not overloaded, the stem must be properly torqued into the disk, with a preload that exceeds the maximum expected stem load, before installing the pin. (see Section 2.3.) This design is potentially susceptible to the following key failures:

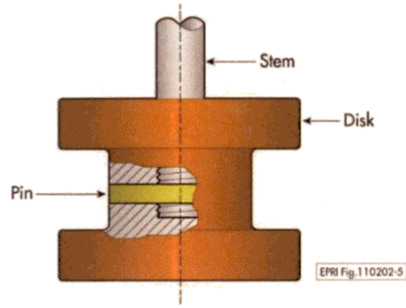

Figure 3-18
Threaded and Pinned – Globe Valve

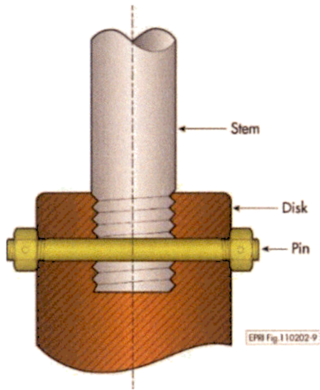

Figure 3-19
Threaded and Pinned – Gate Valve

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Figure 3-20
Failures by Year for Threaded and Pinned Designs

The failures that have occurred are discussed in the bullets below.

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3.3 Hermetically Sealed Valve Designs

For hermetically sealed valve designs, such as the one shown in Figure 3-21, the valve disk is not connected to the stem; a diaphragm is used to provide a pressure boundary, and the stem pushes

on the diaphragm to move the disk toward the closed position. A spring moves the disk in the open direction when the stem is raised. For these designs, there is no stem-to-disk connection to fail; however, there are other potential failure modes that could cause the valve disk to fail to move for an opening stroke, such as failure of the spring and binding of the disk in the valve body.

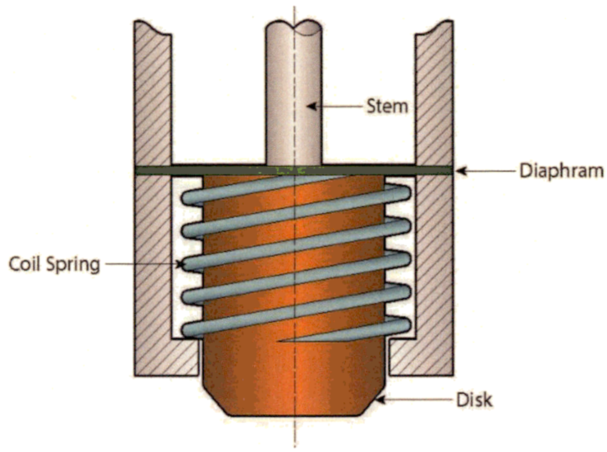

Figure 3-21
Typical Stem and Disk Arrangement for Hermetically Sealed Valve

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3.4 Summary

Figure 3-22 summarizes the failures by stem-to-disk design for the four designs with the most failures and breaks the failures down into groups, as discussed in the sections above, based on characteristics such as valve type, failure cause, and operating conditions.

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Figure 3-22
Summary of Failures from INPO IRIS Database for Susceptible Stem-to-Disk Connection Designs

4
METHODS TO VERIFY STEM-TO-DISK CONNECTION

This section discusses methods that can be used to provide a *direct indication* that the stem-to-disk connection is intact for various valve types. The following valves types are covered:

- Wedge gate valves
- Non-wedging gate valves
- Globe valves
- Butterfly valves
- Ball valves
- Plug valves

4.1 Normal Plant Operation

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4.2 Pressure or Flow Indications

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4.3 Diagnostic Testing

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4.4 Valve Internal Inspection

This method involves disassembly and inspection of the valve, including complete disassembly of the stem-to-disk connection, including any pins or keys. This method provides a direct visual indication that the stem-to-disk connection is intact and is effective for all valve types.

4.5 Other Methods

Listed below are other methods that should provide a direct indication that the stem-to-disk connection is intact.

4.5.1.1 Radiography

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4.5.1.2 Motor Control Center Measurements

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5 EFFECT OF SUPPLEMENTAL VERIFICATION ON THE PROBABILTY OF FAILURE

This document does not provide specific recommendations as to whether supplemental verification should be used for a specific valve application or at what interval it should be performed. However, this section discusses some considerations related to making these decisions and presents equations for estimating the effect of the supplemental verification interval on the probability of failure for a specific valve application.

Stem-to-disk separation is typically a sudden failure. Although the failure may result from degradation that occurred over a long period of time, the valve may not exhibit symptoms prior to failure that can be monitored and trended to predict or identify impending failure. Accordingly, condition monitoring tasks would generally not be effective for monitoring and predicting potential stem-to-disk failures. Some method of verifying whether a failure has occurred is needed, such as one of the methods discussed in Section 4.

Unless the stem-to-disk failure results in a change in plant operating conditions that alerts plant operators, the failure is a *hidden* (or latent) failure. For hidden failures, the maintenance strategy typically used is to perform a *failure-finding* task designed to determine whether the hidden failure has occurred. Such failure-finding tasks reduce the probability of failure and therefore reduce the risk of failure. In addition, identifying and evaluating hidden failures allows corrective actions to be implemented to prevent recurrence and to reduce the likelihood of a similar failure of another valve through the extent of condition process. The supplemental verification methods discussed in Section 4 are essentially failure-finding tasks, and their effectiveness in reducing the probability of a stem-to-disk failure can be estimated as discussed below.

5.1 Estimate the Effect of Supplemental Verification on Reliability

The following approach can be used to estimate the effect of the supplemental verification interval on the probability of failure for a valve, whether the supplemental varication is normal plant operation or one of the other methods discussed in Section 4.

If the failure rate of a component is constant, the probability of failure (P) over a period of time is related to the failure rate by the following exponential failure distribution equation.

$$P = 1 - e^{-\lambda t} \quad \textbf{Eq. 5-1}$$

Where:

λ: Failure rate (failures/year)

t: Period of time (years)

For example, for a failure rate of 0.1 failures per year, the probability of failure over a 40-year period is:

$$P = 1 - e^{-(0.1)(40)} = 98.2\% \qquad \textbf{Eq. 5-2}$$

Figure 5-1 is a plot of probability of failure over time for a failure rate of 0.1 failures/year.

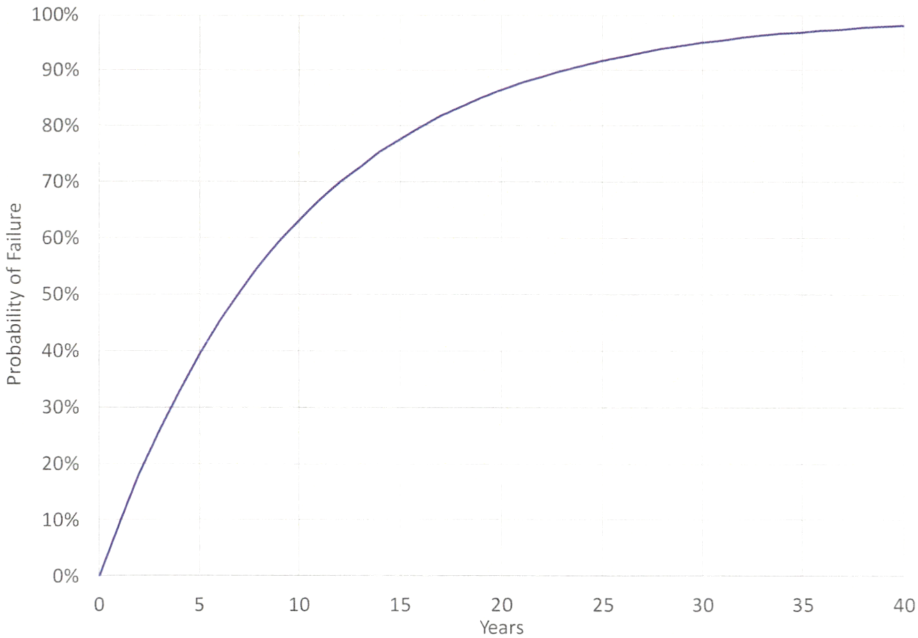

Figure 5-1
Probability of Failure Over Time for a Failure Rate of 0.1 Failures per Year

Failure-finding tasks reduce the probability of failure because each time the task is performed, the probability of failure <u>at that time</u> is zero. For example, Figure 5-2 compares the probability of failure over time with no failure-finding task and with a failure-finding task performed every ten years, for a failure rate of 0.1 failures/year.

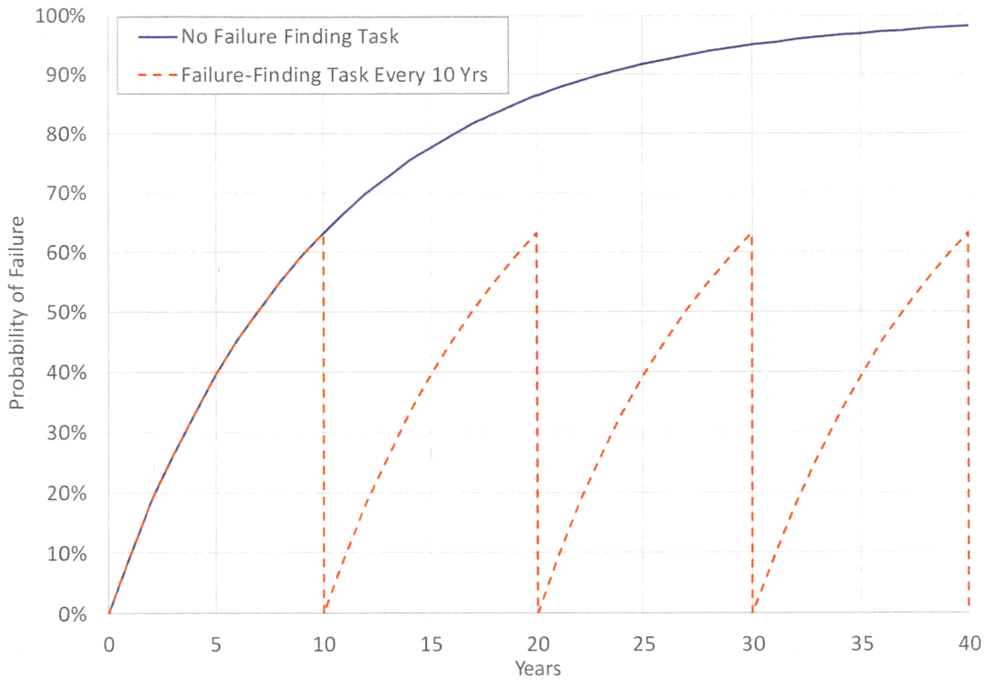

Figure 5-2
Probability of Failure Over Time for a Failure Rate of 0.1 Failures per Year with No Failure-Finding Task and Failure-Finding Task Every 10 Years

With the failure-finding task, the *average* probability of failure over the life of the component is approximately one-half the probability of failure just prior to performing the task, per the equation below (where T is the failure-finding task interval).

$$\mathrm{P} = \frac{1}{2}(P) = \frac{1}{2}\left(1 - e^{-\lambda T}\right) \quad \textbf{Eq. 5-3}$$

In a population of components, such as valves in a nuclear power plant, the *actual* probability of failure will be close to the *average* probability of failure. For the example in Figure 5-2 (failure rate of 0.1 failures/year), the average probability of failure is 31.6% if a failure-finding task is performed every 10 years, as shown by the dashed line in Figure 5-3.

Effect of Supplemental Verification on the Probabilty of Failure

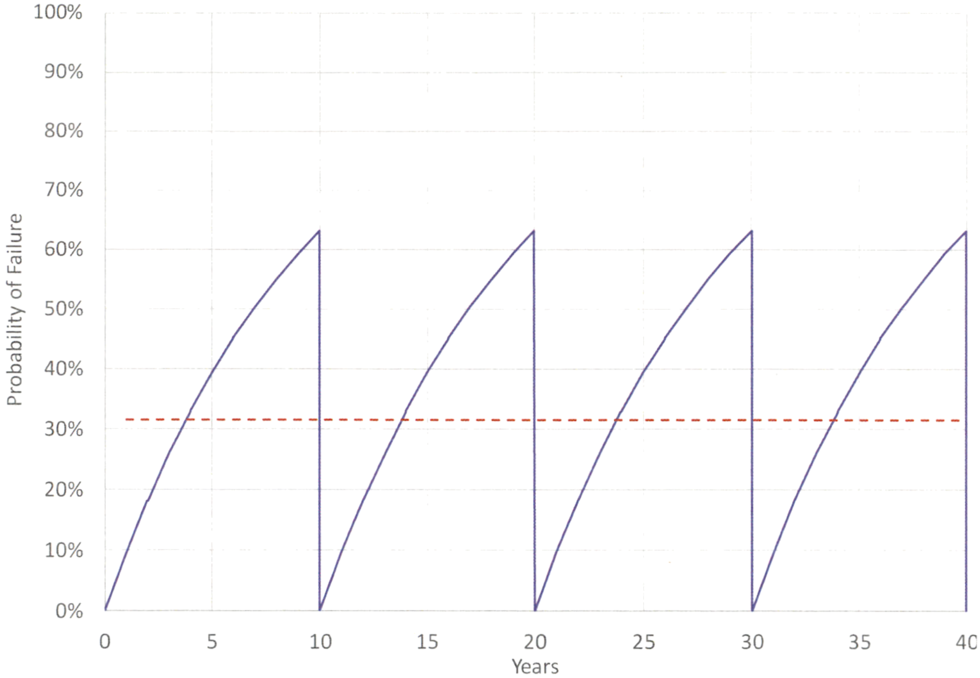

Figure 5-3
Probability of Failure Over Time and Average Probability of Failure for a Failure Rate of 0.1 Failures per Year with Failure-Finding Task Every 10 Years

5.2 Examples for Stem-to-Disk Connection Supplemental Verification

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Figure 5-4
Probability of Stem-to-Disk Failure Over Time with No Stem-to-Disk Connection Verification and with Stem-to-Disk Connection Verification Every 2, 6, and 10 Years

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6 SUMMARY

This document reviews valve stem-to-disk connection designs and uses primarily industry operating experience over a 43-year period to evaluate their susceptibility to stem-to-disk separation under different operating conditions. It also discusses verification methods that can be used to provide a direct indication that the stem-to-disk connection in intact for various valve types (i.e., supplemental verification). It does not recommend supplemental verification intervals but does provide some information that may be useful in selecting an interval. The key results are summarized in the sections below.

6.1 Overall Stem-to-Disk Separation Failure Rate

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6.2 Susceptibility of Specific Stem-to-Disk Connection Designs

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6.2.1 Hermetically Sealed Valve Designs

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6.3 Supplemental Verification Methods

This document discusses various methods that can be used to provide a direct indication that the stem-to-disk connection is intact for various valve types. In general:

- Normal plant operation may serve as supplemental verification for valves that actively control a process parameter during plant operation and valves that are stroked with flow and differential pressure as part of normal plant operation, assuming the design and installation are not such that disk travel is fully flow-assisted in the opening direction.

- Stroking the valve while monitoring system pressure and/or flow is effective for wedge gate valves, non-wedging gate valves, globe valves tested with flow over the seat, butterfly valves, ball valves, and plug valves.
- Diagnostic testing is effective for wedge gate valves (as long as a "baseline" unwedging thrust is established) and butterfly valves (as long as a distinctive seating profile exists and a "baseline" seat load is established). To use diagnostic testing for other valve types, additional justification would be needed.
- Valve internal inspection is effective for all valve types.
- Radiography and other non-intrusive diagnostic methods should be effective for most valve types, unless there are internal components (such as pins) that are not visible in the image generated.
- Measurements taken at the motor control center may be effective; however, additional work would be needed to justify this approach.

6.4 Effectiveness of Supplemental Verification

Supplemental verification, as discussed in this document, is a failure-finding task, designed to determine whether a stem-to-disk failure has occurred. A method is provided in Section 5.1 for estimating the effect of the supplemental verification interval on the probability of failure of a valve.

6.5 Plant Responsibilities When Using this Document

To apply the results in this document related to stem-to-disk separation susceptibility, plants must address the following considerations:

1. Valve materials should be compatible with the fluid medium such that significant corrosion will not occur, particularly for the stem, disk and any position-retention or anti-rotation devices and particularly for valves in raw (untreated) water systems. See Section 3.1.2.
2. Valves installed in severe throttling service applications should be properly designed such that failure due to cavitation and flashing is not an issue. See Section 3.1.4.
3. Maintenance procedures should provide adequate guidance for inspecting position-retention devices and replacing them when warranted. See Section 3.1.5.
4. Maintenance procedures should provide adequate guidance for installing pins and other position-retention devices to avoid loss of stem preload and/or backing out of the device. See Section 3.1.6.
5. Globe valve MSIVs are unique, pilot-operated globe valve designs that are not thoroughly evaluated for potential failure in this document. The MSIV vendor should be contacted to ensure that all available upgrades and modifications to address vibration issues and potential stem-to-disk separation have been evaluated and implemented, as appropriate. In addition, plants that have Atwood & Morrill MSIVs should review the July 30, 1999 letter from Atwood & Morrill, which identifies potential failures due to inadequate anti-rotation restraint of the threaded connection between the pilot poppet and the pilot poppet nut and included a recommended design fix, and ensure appropriate corrective actions have been taken.

In addition, plants should continue to address the following considerations, which appear, based on the operating experience review, to have been adequately addressed by previous industry efforts.

1. Plants should continue to monitor for potential PL/TB issues and address any issues found. See Section 3.1.1.
2. If a valve is backseated, the applied loads should be verified to be below the weak link of the stressed components. See Section 3.1.3.
3. Maintenance procedures should provide adequate guidance for installing stem-to-disk pins and keys (quarter-turn valves) and for applying appropriate position-retention/locking techniques, such as staking. See Section 3.2.1.
4. NRC Information Notice 2006-15 discusses failures of 4-inch (10 cm) Fisher pilot-operated globe valves with a bolted stem-to-disk connection. Fisher had previously issued a 1988 advisory related to this issue. Any guidance or recommendations in the NRC information notice and the Fisher advisory should be incorporated into the appropriate plant procedures and processes. See Section 2.2.1 and 0.

6.5.1 Responding to Stem-to-Disk Separation Failures

This report concludes that some valve applications are essentially not susceptible to stem-to-disk separation failures. It is important to note that failures can still occur. Some of these failures may be random or isolated (e.g., a manufacturing defect), and some may be due to more generic issues (e.g., design or installation flaws). It is expected that users of this document will continue to evaluate any stem-to-disk separation failures at their plant, and around the industry as applicable, for generic issues that may require corrective actions for the failed valve and for any other valves determined to be within the extent of condition. Users are also responsible for evaluating any needed changes in the susceptibility classification based on the generic issue and the schedule for implementation of corrective actions.

7 REFERENCES

1. NRC Information Notice 2017-03, *Anchor/Darling Double Disc Gate Valve Wedge Pin and Stem-Disc Separation Failures*, June 15, 2017.
2. *Evaluation Guide for Valve Thrust and Torque Requirements*. EPRI, Palo Alto, CA: 2016. 3002008055.
3. *Nuclear Maintenance Applications Center: Application Guide for Motor-Operated Valves – Revision 3, Volume 1: Rising Stem Valves*. EPRI, Palo Alto, CA: 2016. 3002008045.
4. BWROG Document TP16-1-112, *Recommendations to Resolve Flowserve 10CFR Part 21 Notification Affecting Anchor Darling Double Disc Gate Valve Wedge Pin Failures (Revision 5)*, November 2019.
5. Flowserve Letter to US Nuclear Regulatory Commission Document Control Desk, *Wedge Pin Failure of an Anchor/Darling Double- Disc Gate Valve at Browns Ferry Nuclear Plant Unit 1*, Dated February 25, 2013.
6. Flowserve Letter to US Nuclear Regulatory Commission Document Control Desk, *Stem-Wedge Separation of an Anchor/Darling Double Disc Gate Valve at Exelon, LaSalle County Station, Unit 2, February 2017*, Dated July 11, 2017.
7. TVA Letter to US Nuclear Regulatory Commission Document Control Desk, *Anti-Rotation Pin Failure in Anchor Darling (Flowserve) Double Disc Gate Valve*, Dated January 4, 2013.
8. Fisher Information Notice (FIN) 93-03, *Possible Butterfly Valve Taper Pin Failures*, October 13, 1993.
9. Fisher Information Notice (FIN) 93-03, Supplement 1, *Possible Butterfly Valve Taper Pin Failures*, October 10, 2005.
10. Fisher Information Notice (FIN) 2019-01, *Mechanical Setting of Disk/Stem Taper Pins*, August 23, 2019.
11. *Nuclear Maintenance Applications Center: Main Steam Isolation Valve Maintenance Guide: Update to 1010012*. EPRI, Palo Alto, CA: 2016. 3002009411.
12. Flowserve Letter from James P. Tucker to the US Nuclear Regulatory Commission Document Control Desk, *Wedge Pin Failure of an Anchor/Darling Double- Disc Gate Valve at Browns Ferry Nuclear Plant Unit 1*, dated February 25, 2013.

A
STEM-TO-DISK SEPARATION OPERATING EXPERIENCE

Stem-to-disk separation events were identified by searching the INPO IRIS operating experience (OE) database and other available industry documents, such as NRC information notices and Reference 4. The following search terms were used for the IRIS searches:

- Stem separation
- Butterfly valve disk key shear
- Butterfly valve disk pin

Table A-1 through

Table A-11 summarize key information about the events identified. The failure type is a brief description of the failure focusing primarily on the failure mechanism and not necessarily the cause. The causes are discussed in more detail in Section 3.2. The following failure types are used:

- Pin or key sheared (1/4-turn valves)
- Pin or key backed out (1/4-turn valves)
- Pin sheared/fretting of threads
- Weld failed/fretting of threads
- Pin sheared/unscrewing
- Weld failed/unscrewing
- Overload due to corrosion
- Overload during backseating (see Section 3.1.3)
- Vibration/flow velocity (used for failures for which vibration was identified as the cause and no failure mechanism was identified)
- Loss of cotter pin/unscrewing
- Thermal binding (see Section 3.1.1)
- Pressure locking (see Section 3.1.1)
- Unknown (UNK)

- Other

A-10
-to-Disk Separation Failures from INPO IRIS Database for Threaded and Welded Designs

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A-11
-to-Disk Separation Failures from INPO IRIS Database for Unknown Designs

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Table A-1
Stem-to-Disk Separation Failures from INPO IRIS Database for Bolted Designs

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Table A-2
Stem-to-Disk Separation Failures from INPO IRIS Database for Captured and Clamped Designs

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EPRI Proprietary Information (S)

Table A-3
Stem-to-Disk Separation Failures from INPO IRIS Database for Captured and Free Designs

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EPRI Proprietary Information (S)

Table A-4
Stem-to-Disk Separation Failures from INPO IRIS Database for Integral/Single Piece Designs

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EPRI Proprietary Information (S)

Table A-5
Stem-to-Disk Separation Failures from INPO IRIS Database for Other Designs

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EPRI Proprietary Information (S)

Table A-6
Stem-to-Disk Separation Failures from INPO IRIS Database for Pinned Designs

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EPRI Proprietary Information (TS)

Table A-7
Stem-to-Disk Separation Failures from INPO IRIS Database for Socketed/Splined Designs

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EPRI Proprietary Information (TS)

Table A-8
Stem-to-Disk Separation Failures from INPO IRIS Database for T-Head/T-Slot Designs

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EPRI Proprietary Information (TS)

Table A-9
Stem-to-Disk Separation Failures from INPO IRIS Database for Threaded and Pinned Designs

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EPRI Proprietary Information (TS)

Table A-10
Stem-to-Disk Separation Failures from INPO IRIS Database for Threaded and Welded Designs

Table Deleted
EPRI Proprietary Information (S)

Table A-11
Stem-to-Disk Separation Failures from INPO IRIS Database for Unknown Designs

Table Deleted
EPRI Proprietary Information (S)

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