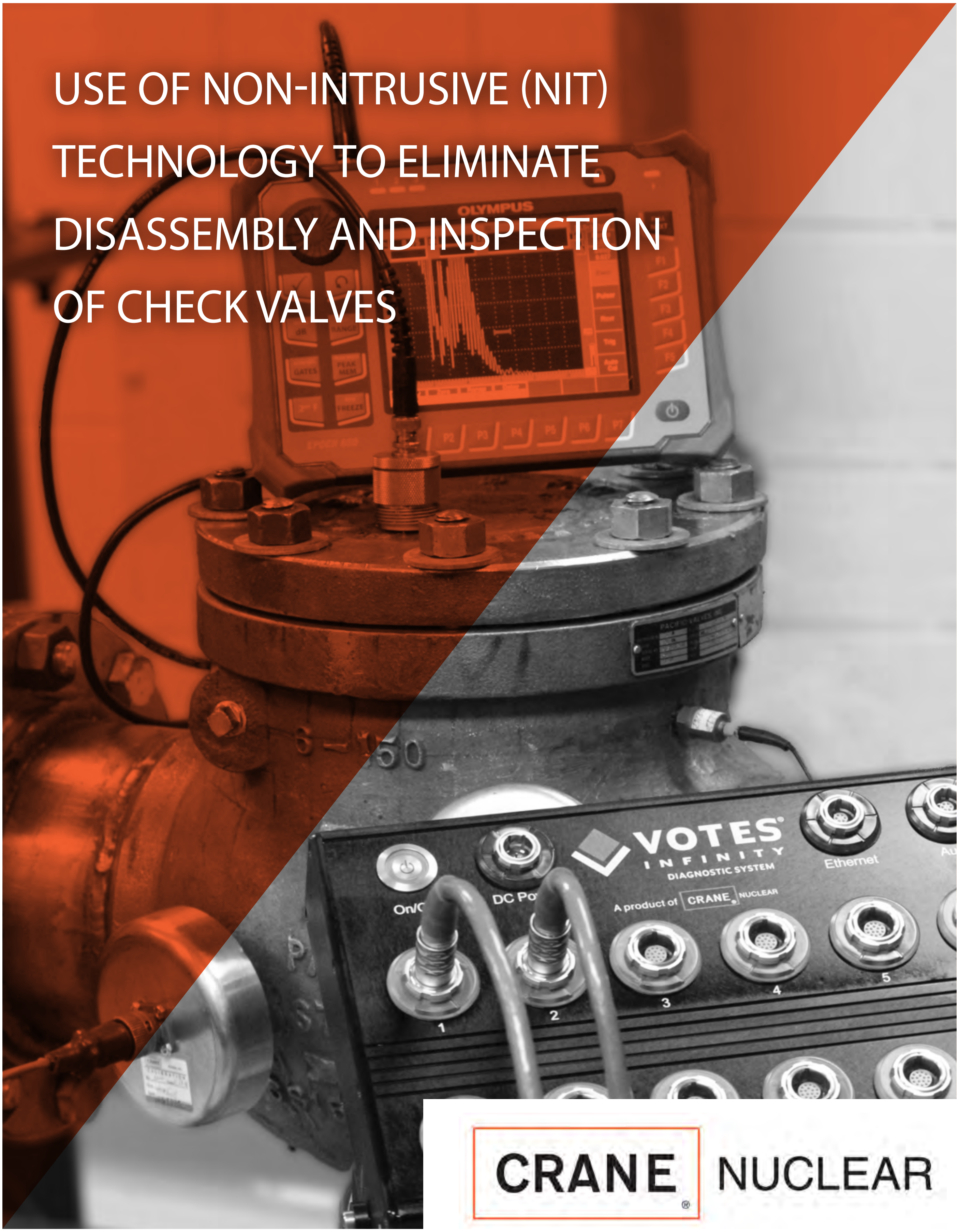
USE OF NON-INTRUSIVE (NIT) TECHNOLOGY TO ELIMINATE DISASSEMBLY AND INSPECTION OF CHECK VALVES



CRANE NUCLEAR

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INTRODUCTION

The ASME OM Code, "Operation and Maintenance of Nuclear Power Plants" identifies maintenance and testing requirements for many safety-related components used in nuclear power plants. Subsection ISTC, "Inservice Testing of Valves in Water-Cooled Reactor Nuclear Power Plants," identifies specific testing requirements for check valves. Specifically, ISTC allows licensees to replace disassembly and inspection with a condition monitoring program as described in Division 1, Mandatory Appendix II of the OM code. Disassembly and inspection (D&I) of check valves has been widely adopted as an acceptable means to meet code requirements for check valves used in nuclear power plant applications where flow testing is difficult to establish, not possible, or provides inconclusive results.

As an alternative to D&I, non-intrusive testing (NIT) also provides a proven and accepted method of detecting check valve degradations, precursors to failure, and documenting performance capability required by the OM code. NIT consists of using acoustics, eddy current and ultrasonic methodologies to verify check valve disc movement and position. CRANE Nuclear has pioneered the application of these methodologies for determining check valve performance. With over thirty years of NIT experience, CRANE Nuclear has helped multiple nuclear utilities adopt NIT and transition from D&I with significant savings in cost, time, and dose.

This white paper discusses the application of NIT methodologies and the need for proper implementation of NIT to ensure ASME Code Appendix II check valve programs deliver the desired results without the high cost of D&I for as many valves as possible.

NIT is a proven and accepted methodology. The cost of performing NIT is approximately 1/8th the cost of D&I.

PROBLEM STATEMENT & OPPORTUNITY

Nuclear power plants face strong competition from subsidized renewable energy sources and low-cost natural gas. In order to remain competitive, the nuclear industry must evaluate spending on maintenance, capital, and fuel, while ensuring that safety and performance are not compromised. As a result, innovative testing solutions that reduce cost burden while ensuring asset integrity deliver very important performance improvement opportunities to nuclear power generators.

Check valve D&I was adopted to ensure operability per the requirements of the ASME OM Code.[1] While D&I meets these requirements it consumes personnel and requires extensive man-hours, advance planning, scheduling time, radiation exposure, and the potential for human errors.

The ASME OM Code Appendix II offers an opportunity to develop and deploy NIT based check valve condition monitoring that is a cost-effective alternative to D&I to satisfy in-service testing (IST) requirements.[1] In addition to the efficiencies gained through testing, Appendix II also allows IST interval extensions (up to 16 years for a group of four check valves) based on data trends and valve performance. The main acceptable approaches allowed under the program include traditional flow measurements that confirm check valve position, D&I, and NIT. Further, recent guidance from industry bodies such as EPRI has recognized NIT to be an acceptable replacement for D&I. This guidance can also be found in the most recent 2019 EPRI Check Valve Application and Maintenance Guide.

> While D&I meets requirements of ISTC it consumes personnel and requires extensive man-hours, advance planning, scheduling time, radiation exposure and the potential for human errors.

BACKGROUND

REGULATORY HISTORY AND GUIDANCE

Given the critical roles that check valves play in the safe and efficient operation of nuclear power plants, several documents have been published discussing check valve performance, operability, and safety. The main documents are NRC's GL 89-04, INPO's SOER 86-03, and the recent ASME OM Code Appendix II.

The intent of NRC GL 89-04 was to ensure certain check valves remain fully capable of performing as intended, which in some cases requires establishing maximum required accident flow through the valve as part of the test process.[2] However, full flow testing proved to be impractical for some valves and created risk of damaging plant equipment. Consequently, alternate techniques such as D&I were considered. Today, D&I is still widely used throughout the industry.

Institute of Nuclear Power Operations (INPO) SOER 86-03, highlighted widespread check valve related problems observed by the industry during the 1980s. The intent of SOER 86-03 was to provide guidance on establishing maintenance procedures to address commonly observed failures such as those caused by water hammer, over pressurization, and steam binding. Periodic testing and surveillance monitoring were recommended as part of the maintenance program and SOER 86-03 became one of the initial guidance documents that served as a foundation for NIT diagnostics.[3]

ASME OM Code Appendix II allows sites to implement condition monitoring programs and extend test interval frequencies based on valve performance, trendable data, and verification of bi-directional valve function. Furthermore, ASME OM Code Appendix II allows each valve, or group of valves, to be treated differently based on data, unlike IST which is schedule-based often forcing unnecessary D&I of valves regardless of condition.

ASME OM Code Appendix II allows sites to extend test intervals based on valve condition.

HOW NIT WORKS

There are three main check valve NIT approaches that can be used to ensure accurate and reliable results: acoustics, ultrasonics, and eddy current.

Acoustic technology passively "listens" to vibrations internal to the check valve received by a piezoelectric accelerometer. The vibrations are converted to an electrical signal for display by the software. Acoustic attributes that can be captured, trended, and evaluated include impact magnitude, impact rate, and frequency of occurrence utilizing common Fast Fourier Transform (FFT) analytical methods. Acoustics can be used to trend changes in valve performance over time, or the immediate detection of metal-to-metal impacts that may be the result of accelerated wear and/or excessive internal valve clearances.

Ultrasonic technology actively "looks" by sending high frequency sound waves through the valve wall and internal liquid medium. These sound waves interact with the check valve obturator (disc, piston, etc.). The sound waves are reflected back and converted to a raw signal in the acquisition software. The raw signal is converted to disc angular velocity and open angle. Both attributes can be trended over time to determine whether changes are occurring. The angular velocity also assigns a specific "stability classification" (proprietary to CRANE) that allows the user to determine the optimum testing and maintenance interval for each valve or group of valves.

Eddy Current is also an active "look" technology that relies on the generation of surface eddy currents. These eddy currents surround the check valve and collapse as the valve internals move through the field. Changes in position are recorded as a (voltage) change. The overall result is a trendable attribute that can determine changes in check valve performance characteristics.

A combination of acoustics, ultrasonics and eddy current allow for the most accurate test results.

RISKS OF USING ACOUSTICS IN ISOLATION

Although acoustics is a valuable methodology, it can also lead to costly incorrect conclusions if used in isolation. In 2000, NRC IN 2000-21 was issued to address a failed check valve that was incorrectly determined to be satisfactory through the use of NIT. The root cause was identified as the sole use of acoustic technology during a test and subsequent misinterpretation of the data.[4] This mistake resulted in an extended plant shut down and subsequent investigation ultimately costing the utility millions of dollars. CRANE Nuclear recommends the use of two technologies for overall condition assessment since acoustics alone can be misinterpreted. Each technology must be capable of complementing each other. The magnitude of an acoustic event alone can lead to an incorrect conclusion when the origin of the acoustic event is not known, thus leading to a misdiagnosis. A "look" technology, such as ultrasonics or eddy current, helps determine the origin of the acoustic activity, thus leading to a true understanding of the acoustic data.

Figure 1 below demonstrates how acoustic technology can be misleading when supporting data is not available. In this example, the disc traveled from the close position to the open position upon initiation of flow. While the first 2 graphs depicting the results of the acoustic signal identify an acoustic event midway through the graph, we can see from the eddy current results that it was not an opening impact, and there was no evidence of disc movement from the closed position until after the acoustic event. Upon investigation, it was determined that the acoustic event was caused by a nearby control valve being used to initiate flow.

Figure 1: Check Valve Open Stroke

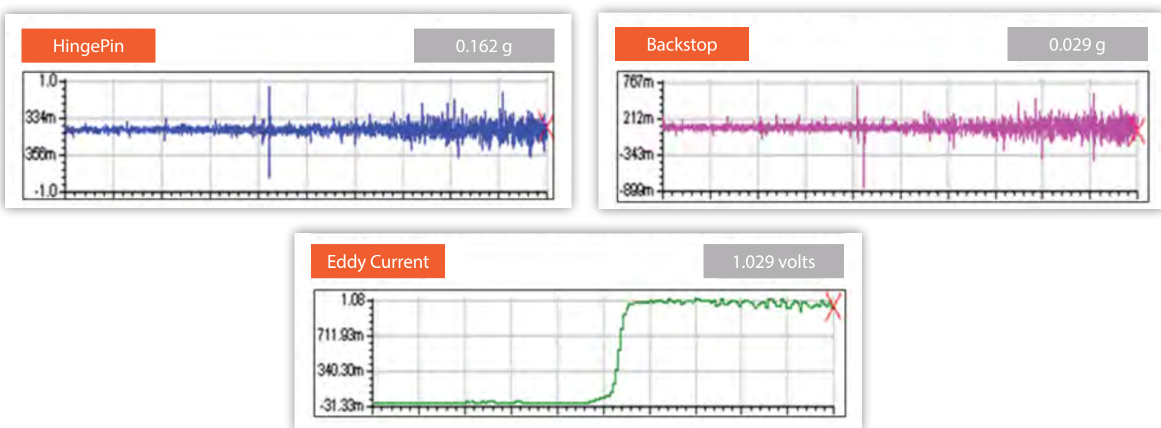
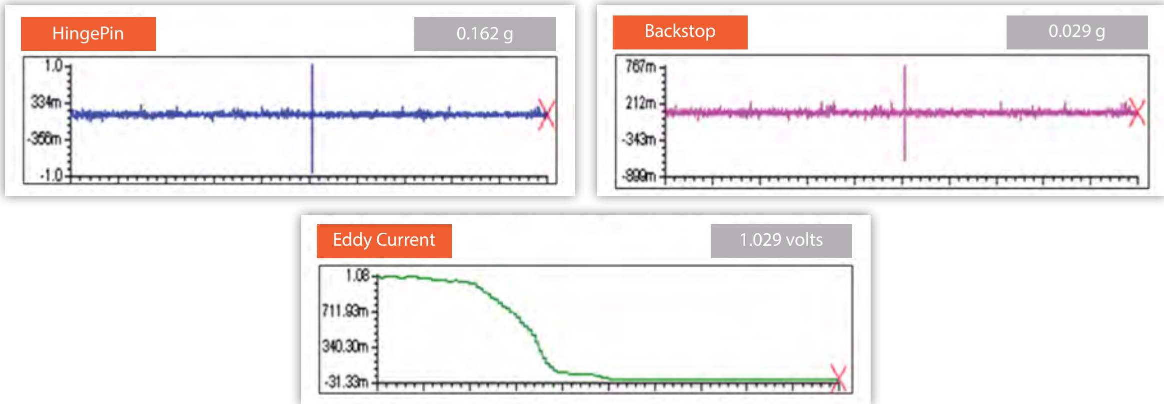


Figure 2 below is an example of acoustics being used properly in conjunction with a "look" technology. Eddy current indicates the disc is traveling from an open position to a close position upon cessation of flow. In this case, acoustics show the seating impact in the first 2 graphs, which is confirmed with the eddy current results in the same time domain.

Figure 2: Check Valve Close Stroke



Although acoustics is a valuable methodology, it can also lead to costly incorrect conclusions if used in isolation.

WHAT DISASSEMBLY & INSPECTION INVOLVES

D&I was the first approach established for the purposes of evaluating the condition of a check valve. Typically, complete disassembly followed by inspections involves evaluation of dimensions, wear of parts, and movement of internals.

The task of disassembling and inspecting each valve is labor intensive and associated with the activities below:

Table 1: Disassembly and Inspection Cost Breakdown

Work Item	Estimated Man-Hours (MH)	Cost at $100/MH
Planning, evaluation, scheduling, preparation	30MH	$3,000
Scaffolding setup & teardown, insulation removal & reinstall	14MH	$1,400
Clearance – preparation, support, removal, RP support	50MH	$5,000
Parts Cost	N/A	$1,500
Inspections, Post Maintenance Testing, review, closure	28MH	$2,800
Total Cost Per Valve		$13,700
Potential Cost of Maintenance Induced Errors (e.g. incorrect reinstallation)	10MH	$10,000
D&I cost range per valve		$13.7K - $23.7K
D&I cost across a typical population of valves	6 — valves per refuel	$112,200

Time/Cost studies from various nuclear sites in the United States utilizing D&I.

The cost of D&I on a per valve basis ranges between $13.7K to $23.7K. Assuming a typical population of six IST valves are inspected, this cost is approximately $112.2K per refuel. Other considerations from D&I operating experience (OE) not taken into account include; delays due to engineering evaluations, parts shortages, FME occurrences, injury, clearance and procedure violations. There is also an increased risk of component damage caused by excessive force on bonnet bolts that causes them to break, incorrect reassembly, or parts being dropped in the system causing fuel damage during operation. D&I activities also add inefficiencies to overall outage performance.

Since NIT is non-intrusive, several of the issues and challenges associated with D&I can be eliminated or significantly reduced. The next section examines how NIT can show payback within one refuel cycle and reduce D&I costs significantly.

Often D&I is undertaken as a result of periodic verification instead of data trends leading to costly and unnecessary disassembly.

THE CNI SOLUTION

DELIVERING VALUE WITH CHECK VALVE NIT

CRANE Nuclear began development of NIT technologies in 1989 and devoted extensive hours of R&D to its implementation. CRANE Nuclear has also participated in numerous industry studies conducted by the Nuclear Industry Check Valve (NIC) group. With over 30 years of experience, CRANE Nuclear is positioned to be a full-service solution provider of check valve diagnostic equipment and services to the commercial nuclear power industry.

One of the biggest benefits is the cost savings associated with transitioning from D&I to NIT. With NIT, sites can reduce their cost to 1/8 compared to D&I resulting in a payback within one refueling cycle. The cost savings come mainly from a reduction in resources necessary to perform the testing compared to conducting D&I. The table below shows the cost breakdown of performing NIT for a test population of six valves performed over a period of 3-days including costs related to securing vendor support to execute NIT:

Table 2: Non-Intrusive Testing Cost Breakdown

Work Item	Estimated Man-Hours (MH)	Cost at $100/MH
Package Planning, scheduling, operations support	30MH	$3,000
HP Support	12MH	$1,200
Supervision	12MH	$1,200
Engineering – review and evaluation	6MH	$600
NIT vendor support service charges for NIT – mod/de-mob, per-diem, service rate, other one-time charges	3 days	$8,500
NIT Cost across Six (6) Valves		$14,500
D&I Cost across Six (6) Valves		$112,200*
NIT Cost vs. D&I Cost		1/8th Cost of D&I

*Table 1

In addition to the cost savings realized from adopting NIT, by aligning with ASME OM Code Appendix II, sites are able to extend their testing intervals, further reducing their cost. ASME OM Code Appendix II allows for extensions of up to 16 years for a group of 4 valves.[1] The frequency extensions depend on the number of valves in a group and valve performance based on favorable review of trendable attributes.

Table 3 below shows an example of how the test intervals can be extended.

Table 3: ASME OM Appendix II Allowable Extensions

Group of 1	ASME OM CODE APPENDIX II ALLOWABLE EXTENSIONS														
Refuel Cycle (24 months)	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048
VALVE A (Current State)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
VALVE A (Future State)	X	↔	X	↔	↔	X	↔	↔	↔	X	↔	↔	↔	↔	X

In this example 14 D&I per valve were replaced with 4 NIT over a 28-year period

Group of 2	ASME OM CODE APPENDIX II ALLOWABLE EXTENSIONS														
Refuel Cycle (24 months)	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048
VALVE A (Future State)	X	↔	X	↔	↔	X	↔	↔	↔	X	↔	↔	↔	↔	X
VALVE B (Future State)		X	↔	X	↔	↔	X	↔	↔	↔	X	↔	↔	↔	↔

Theoretical example of 2 groups of valves with testing interval extensions through Appendix II.

> ASME OM Code Appendix II allows for extensions of up to 16 years for a group of 4 valves.

HOW TRENDABLE ATTRIBUTES EXTEND TEST INTERVAL FREQUENCIES

Trendable attributes are a requirement of ASME OM Code Appendix II in order to extend the test interval frequency. They are defined in ASME OM Code Appendix II as "an owner selected parameter of a check valve test or examination which can be used to monitor component degradation with the intent of ensuring the component is capable of performing its intended function."[1]

In addition to ASME OM Code Appendix II, the NIC testing program has proven that trending from a known condition can determine changes that result from wear.[3] CRANE Nuclear has invested significant resources in analyzing the attributes to be trended in order to provide the most accurate assessment of valve health. These are angular velocity and disc position with ultrasonics, impact rate, magnitude and frequency through acoustics, and stroke time and stroke delta through eddy current technology.

Table 1 shows the stability classification, based on the CRANE proprietary assessment of valve stability using ultrasonics. This represents the amount of disc flutter at a specific flow rate, which is determined from total disc movement. The disc stability classification approach was developed to assess check valve oscillations when check valves are not pinned firmly against the internal backstop by system flow. This condition often occurs when plant systems are operated at conditions where the flow rate cannot lift the disc to the full open position such as during periods of reduced power output.

Table 1: Disc Stability Classification

STABILITY NUMBER (deg/sec)	EVALUATION	EXPLANATION
0 - 4	Stable	Represents check valve discs that are either firmly against the backstop (0 deg/sec) or are displaying ordinary flow induced oscillations. Valves in the category will experience only normal (low) internal wear.
>4 - 11	Unstable	Represents check valve discs that are neither clearly stable nor excessive. Typically valves in this range are operating under less than ideal flow conditions. Abnormal wear rates are possible depending on the system and operational history.
>11	Excessive	Represents valves that are experiencing abnormal or destructive flutter. The valves are incorrectly sized, misapplied or are operating at destructive flow rates. Accelerated wear can be expected if the valve continues to operate under these conditions. Valve failure is possible.

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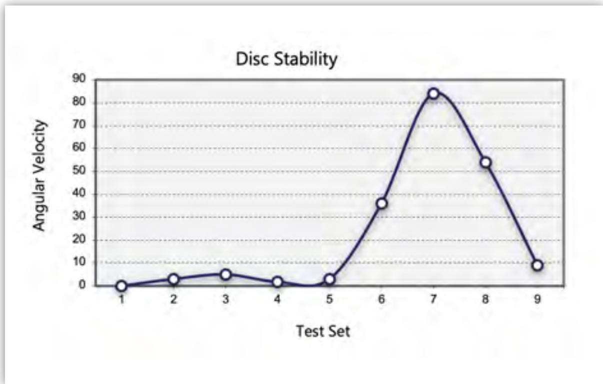
Below is an example from an 18" Walworth double disc swing check valve, that demonstrates degradation detection as a result of correctly applying trendable attributes.

Figure 3: Disc Stability



X axis: Time in 2-year intervals
Y axis: Disc oscillations in degrees/sec

Figure 3 shows disc stability as part of the ultrasonics testing over a period of eighteen years. The first five data points indicate a stable state of the valve (between 0-4 degrees/sec). Points 6-9 indicate variations in disc stability with some points being extremely unstable, indicating abrupt changes in operating characteristics. Root cause investigation yielded valve instability was the result of the plant power upgrade, which caused the valve to see flow variation leading to abnormal wear.

Figure 4: Disc Open Angle

X axis: Time in 2-year intervals
Y axis: Disc angle in relationship to seat

Figure 4 shows disc open angle from ultrasonics testing. The first five data points of the graph indicate a relative average disc position as indicated by this valve's geometric drawing. From points 6 – 9, abrupt changes in the normal disc open angle of this valve are observed due to the plant power upgrade.

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Figure 5: Impact Rate

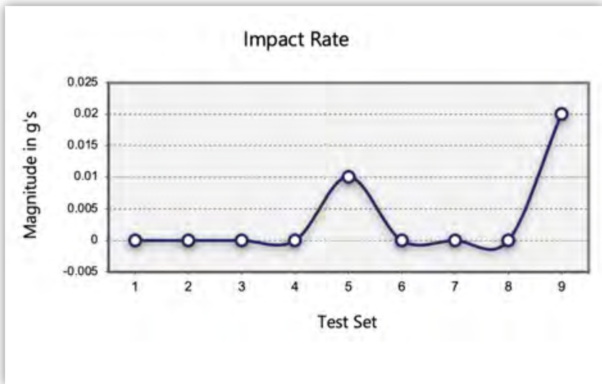


Figure 6: Backstop Impact RMS

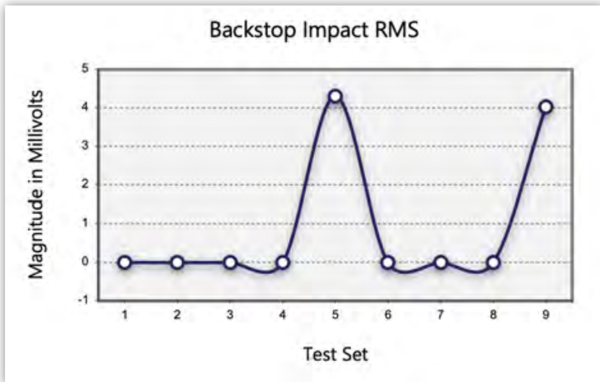


Figure 7: Hingepin Impact RMS

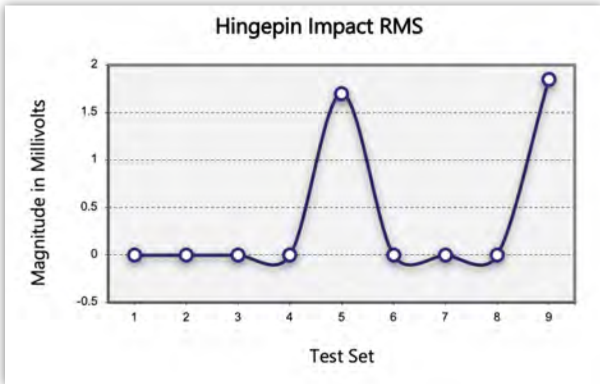
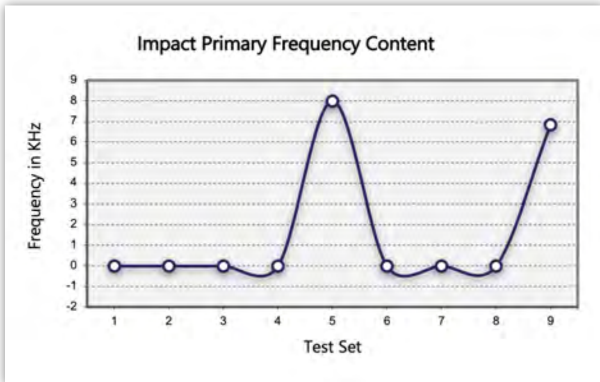


Figure 8: Impact Primary Frequency Content



Figures 5-8 X axis: Time in 2-year intervals
Figures 5-8 Y axis: Magnitude of impact vibration internal to the valve

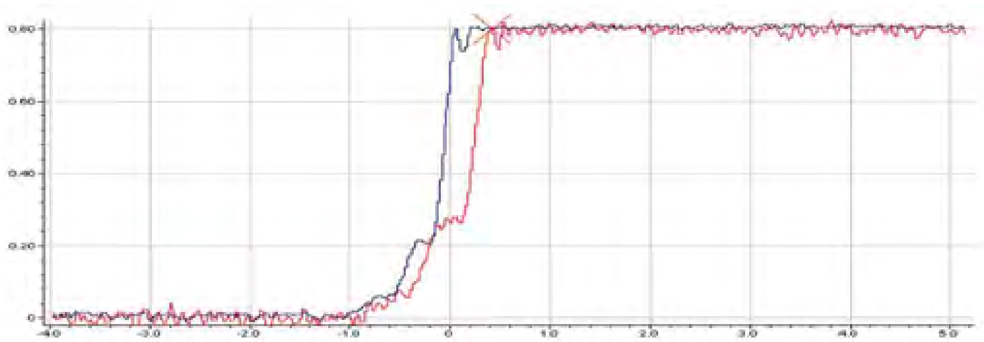
The graphs in Figures 5-8 above are results obtained from acoustics testing on the same valve. In the case of acoustics, zero activity indicates a stable internal position of the disc. Changes represent contact of internal parts that are not expected. Each of the acoustic trendable attributes indicate activity at point five and then zero activity until point nine. These results differ from the results of the ultrasonic testing (Figures 3 and 4). Looking at these results in conjunction with the ultrasonic test results, it was determined that point five was a backstop tap, without any significant concerns. At point nine, however, there was contact between the disc and the backstop. This was later confirmed as being a result of wear to the hinge bore. The results from the acoustic testing on this valve reinforce the need to use acoustics in conjunction with ultrasonics or eddy current to accurately interpret the results.

As a result of the NIT data for this valve, the valve was opened for inspection. Upon inspection, it was discovered that there was wear to the hinge pin bore due to elevated disc angular velocity (Photo 1). These findings confirmed the results found through NIT.

Photo 1: Check Valve Hinge Pin Bore Wear

In another example, the results of an eddy current test were analyzed for an 8" Stainless Steel Containment Spray Swing Check Valve. Figure 9 shows two tests done on the same valve over two years. Both tests show the same delta in voltage meaning that there are no changes in the performance of the valve and therefore there is no cause for concern.

Figure 9: Eddy Current Results



X axis: Time in seconds
Y axis: Voltage

Trendable attributes can provide an accurate assessment of valve health and set up the basis for test interval frequency extensions.

IMPLEMENTING NIT PROGRAM ON-SITE

CRANE Nuclear's proven and qualified check valve NIT methodologies have been used in check valve programs throughout the nuclear industry for decades. CRANE Nuclear's expertise is available to address the inefficiencies of any check valve program adding technical value while reducing cost and improving human performance.

With experienced personnel retiring, and constant turnover of positions, maintaining the right expertise is daunting, costly, and time consuming. CRANE Nuclear places emphasis on program development to code compliance, NIT strategy implementation, equipment training on Votes Infinity diagnostic system, application engineering, and data evaluation for tracking and trending. CRANE Nuclear works closely with site engineering, operations, and maintenance personnel to ensure that a sustainable check valve program is established.

CRANE Nuclear's expertise is available to establish and improve condition monitoring programs by adding technical value, reducing cost and improving human performance.

CONCLUSION

Establishing a condition monitoring program using Non-Intrusive Testing (NIT) enables conformity to code requirements while transitioning away from costly disassembly and inspection. It is important that a condition-monitoring program is created and deployed in a systematic way to ensure that results are sustainable. CRANE Nuclear's experience developing and deploying check valve NIT over several decades ensures that sites benefit from test interval frequency extensions through consistent use of trendable attributes, satisfying code and program requirements while reducing overall cost burden.

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