INDUSTRIAL INSPECTION SERVICES

APPLICATION OF PHASED ARRAY SECTORIAL SCANNING (PASS) [1] TO DETERMINE CHECK VALVE OPERATIONAL READINESS AT THE PALO VERDE NUCLEAR STATION

[1] PASS and PASS Visualization Software Patent Pending

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ABSTRACT

The reliability of check valves is paramount to the safe operation of the plant systems. This paper provides a description of the benefits of applying advance phased array techniques to establish the operational readiness of swing check valves in the static or dynamic operational modes. In addition a utility model perspective is described on how the Phased Array Sectorial Scanning (PASS) data assessments can be utilized to support operational predictive maintenance decisions. A collaborative effort between Arizona Public Service Co., Palo Verde Nuclear Generating Station and Industrial Inspection & Analysis (IIA) was realized when IIA personnel applied Phased Array Sequence Scanning techniques to swing check valves operating in the closed static position and three identical valves operating in the dynamic open positions in Units 1, 2, and 3 respectively.

I. INTRODUCTION

Conventional ultrasonic examination techniques have long been applied to a variety of components in an effort to determine the structural integrity and operational readiness. The ultrasonic examinations typically are applied to detect and size both fabrication and service induced defects. Defects such as cracks, buried and near-surface welding flaws, minimum wall thickness, degraded material properties, and other anomalies affecting structural integrity all have been evaluated using conventional ultrasonic techniques.

Industrial ultrasonic applications date back to the early 1950s. Moving forward to the 1960s, the development of ultrasonic phased array systems were first seen as a result of research efforts and the development of transducers with multiple elements allowing for the control of ultrasonic beams. From a commercial perspective, the first phased array systems for use in medical diagnostic applications appeared in the mid 1970s. In the last decade and a half, the industrial applications have evolved. This rapid development of associated technologies that drive the phased array systems is responsible for the trend. In 2012, IIA launched a research and development program to investigate the applications of phased array ultrasonic to components not typically considered ideal configurations. The components include swing-check, piston, dual-disc, tilting-disc, gate, and globe-valves and pump impeller movements. IIA's goal was to leverage its existing phased array qualifications for reactor-vessel dissimilar and similar metal welds to applications outside of what is considered typical.

II. DEFINITION OF IIA PHASED ARRAY SECTORIAL SCANNING (PASS)

Phased array ultrasonic is a method of generating and receiving ultrasound. Sweeping beams are generated by the use of multiple element probes and electronic time delays thus creating constructive and destructive interferences. The delays are programmed to generate beams at a given angle in relation to a target. The PASS technique uses phased array probes to capture the interaction of the sound waves with the valve components assemblies and/or body structure. Sound waves are propagated through the valve bonnet and body at strategic locations to target key components of the valve. The resulting sound beam interactions are in turn captured as a function of time and cataloged by site unit number, system, and valve serial number. The time-captured data is then post processed and analyzed. In terms of ultrasonic signature, a given valve condition in static or dynamic operation can now be captured and a signature database developed for each valve in each system. The PASS tests can be applied in any combination as follows:

• PASS Bidirectional Dynamic Test

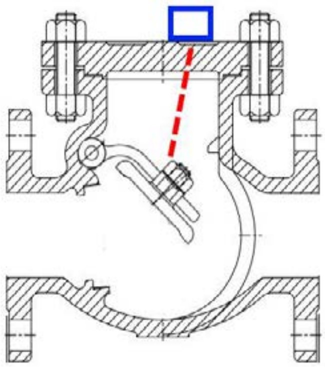

Figure 1

• PASS Valve Gas Detection Test

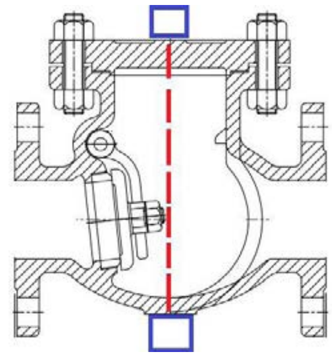

Figure 2

• PASS Valve Catastrophic and Foreign Material Detection Test

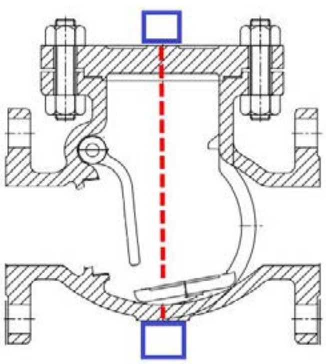

Figure 3

• PASS Nut Arm Vertical Measurement Test

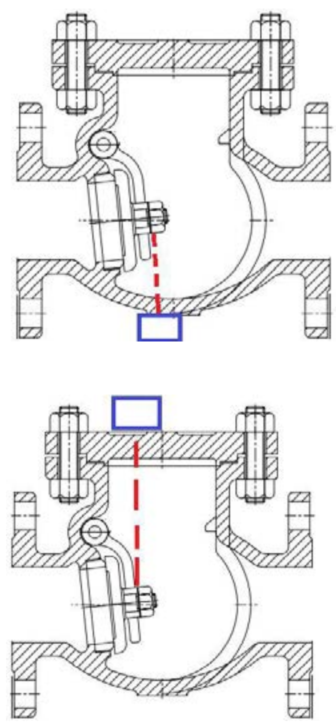

Figure 4

In combination these tests can provide high confidence data to support operational readiness and predictive maintenance decisions of a given valve.

III. DEFINITION OF IIA PASS BIDIRECTIONAL TEST

Operational readiness of a valve can be verified by exercising the valve to its designed open and closed limits. This test is known as a bidirectional test. When PASS testing is performed, during a bidirectional test, the data captured reflects the actual disc arm assembly at steady state closed position, movement dynamics, and open position. **Figure 5** below depicts a typical PASS Bidirectional test setup.

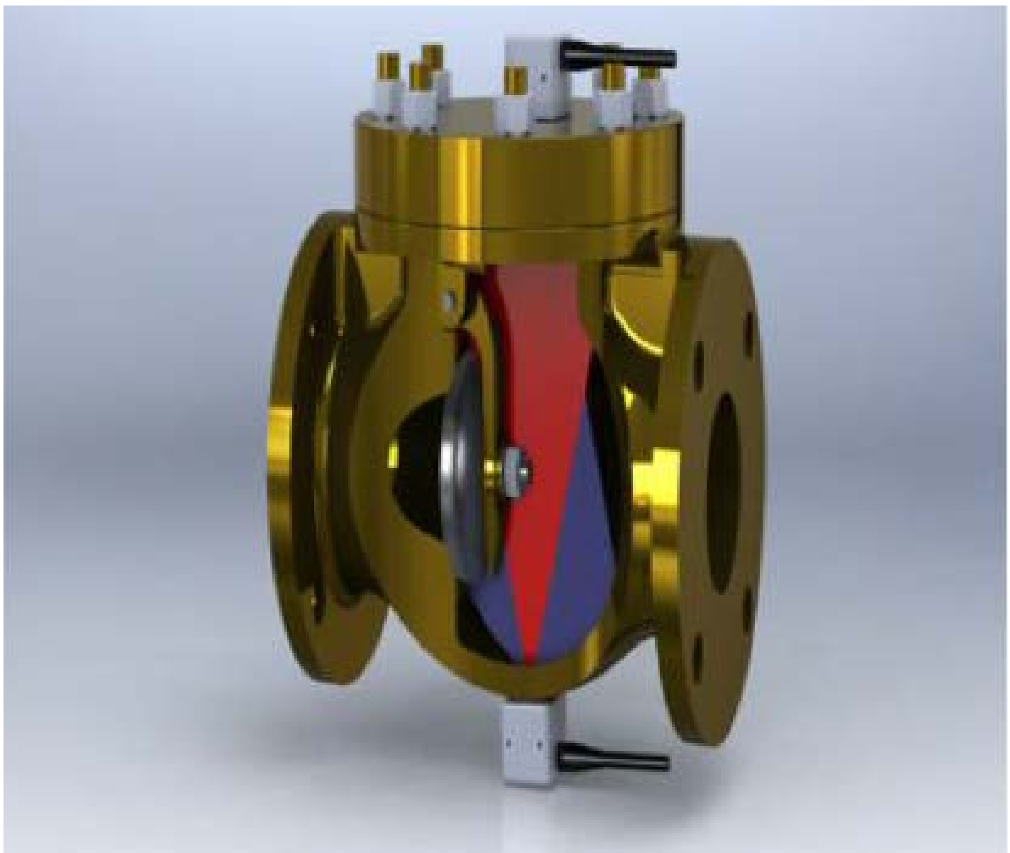

Figure 5: Check Valve 3D model with Phased Array Transducers

During bidirectional testing, the data from multiple angles is captured in RAW ultrasonic form as depicted in **Figure 6**. Analysis from data can be performed in single or merged combining all angles.

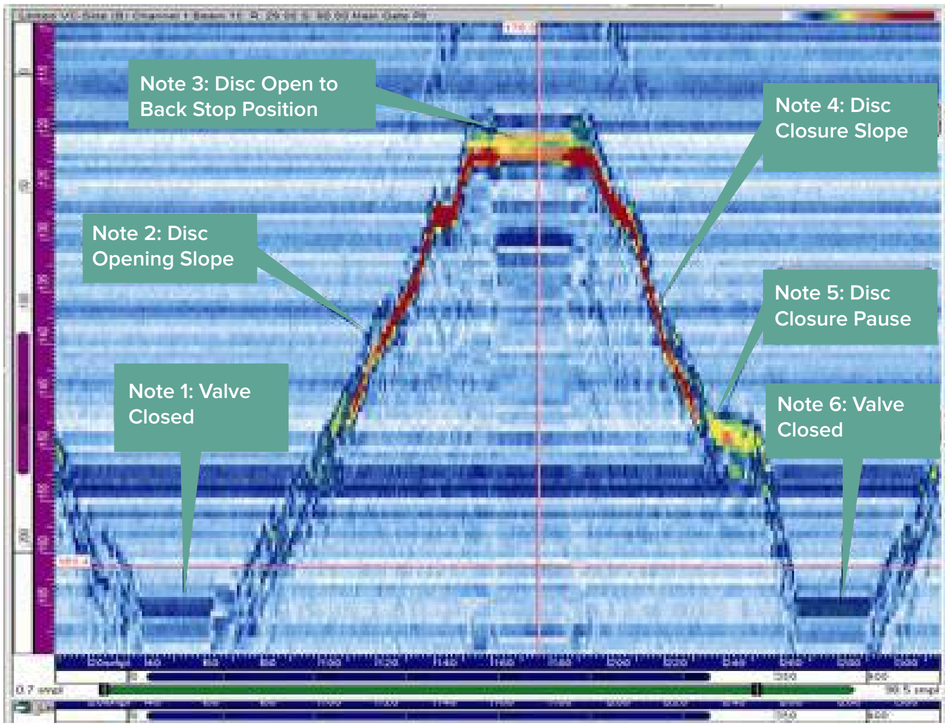

Figure 6: Position of the disk and arm as a function of time

Note 1: When the valve is situated in the closed position, lower amplitude ultrasonic reflections (amplitude refers to the amount of energy reflected) can be seen as a result of sound waves interacting with the disc and arm assembly. In the closed position, ultrasonic beam miss orientation angles are higher and result in less energy reflection. A misorientation beam angle is any beam angle which does not strike the target at perpendicular. However sufficient echo response is seen to form a flat base line as indicated by the note pointer. The flat line indicates the valve disc is sitting in a steady state closed position.

Note 2: As the disc/arm assembly rises to the open position, a slope is recorded. The vertical slope angle indicates how fast the disc arm assembly moves from closed to open position at the backstop. A steep vertical slope would indicate a fast time to backstop opening. Since flow rate is being captured and synchronized with the PASS test, the data can be considered as part of the final analysis.

Note 3: When the disc reaches the backstop at the end of the slope, a horizontal line can be seen forming at a given distance. Note that the amplitude has also moved from blue to red indicating higher amplitude. The higher amplitude is attributed to the misorientation angles of the ultrasonic beams being reduced by the movement of the disc arm assembly. More ultrasound energy is now being reflected. Also note that the signal is flatlined indicating a complete open to backstop position and no fluttering is indicated. Fluttering at any point during the test can indicate pin wear. This topic is discussed further in the comparative data section.

Note 4 & 5:
This closure slope represents the time it takes for the valve to reach its closed position. In this case a slight pause can be seen near the mid-slope. The slight delay could be indicative of pin wear or other abnormal conditions, perhaps a precursor to a valve in need of maintenance or monitoring more frequently. This topic is discussed later in the comparative analysis section.

Note 6:
Here we see the valve returning to the steady state closed position. When the valve is situated in the closed position, lower amplitude ultrasonic reflections can be seen again as when the test was initiated. The flat line is indicative that no fluttering or leakage is detected by PASS, indicating that the valve has returned to the closed position.

COMPARATIVE ANALYSIS OF PASS TEST SEQUENCES

In this comparative analysis, shown in **Figure 7**, we can see the data results of four PASS test sequences conducted on a four inch swing check valve mounted in the horizontal position. The intent was to simulate the behavior under four different conditions during a series of bidirectional experiments conducted with the same valve. The tests were conducted on the IIA flow loop developed for PASS research. The flow loop is capable of 550 gallons per minute and is programmable using a variable frequency controller which allows the programming of different flow conditions.

Test Sequence 1
In this test sequence the valve opens steadily to the maximum open position. A slight delay in closing can be observed in the slope. Typically the bidirectional test cycle can be performed once or twice. It depends on the sites technical specification or procedures controlling the test. A second test provides a repeatability observation on valve behavior. In this test sequence we can conclude that the valve reached its design maximum open position and returned to its closed position. A slight delay during the closure can be indicative of first signs of abnormal behavior. The delay observation is considered aberrant and a recommendation can be made to monitor the valve more frequently.

Test Sequence 2
In this test sequence the valve opens and closes steadily to the minimum and maximum positions. No aberrant behavior is noted in the open and closure slopes. This test sequence represents an expected valve design behavior. It can be concluded that operational readiness can be supported by this data.

Test Sequence 3
In this test sequence the valve aberrant behavior is immediately detected. At the steady state closed position fluttering can be observed. The valve opens to the maximum position but is accompanied by a fluttering condition. The fluttering condition can also be seen during the closed position and in the closure slope. In addition a slight closure delay is observed. It can be concluded that the PASS data does not support operational readiness of this valve. Excessive pin wear can induce this type of fluttering behavior. A recommendation for proactive maintenance is supported by the UT data.

Test Sequence 4
In this test sequence the valve opens and closes steadily to the minimum and maximum positions. No aberrant behavior is noted in the open and closure slopes. This test sequence represents an expected valve design behavior. It can be concluded that operational readiness can be supported by this data.

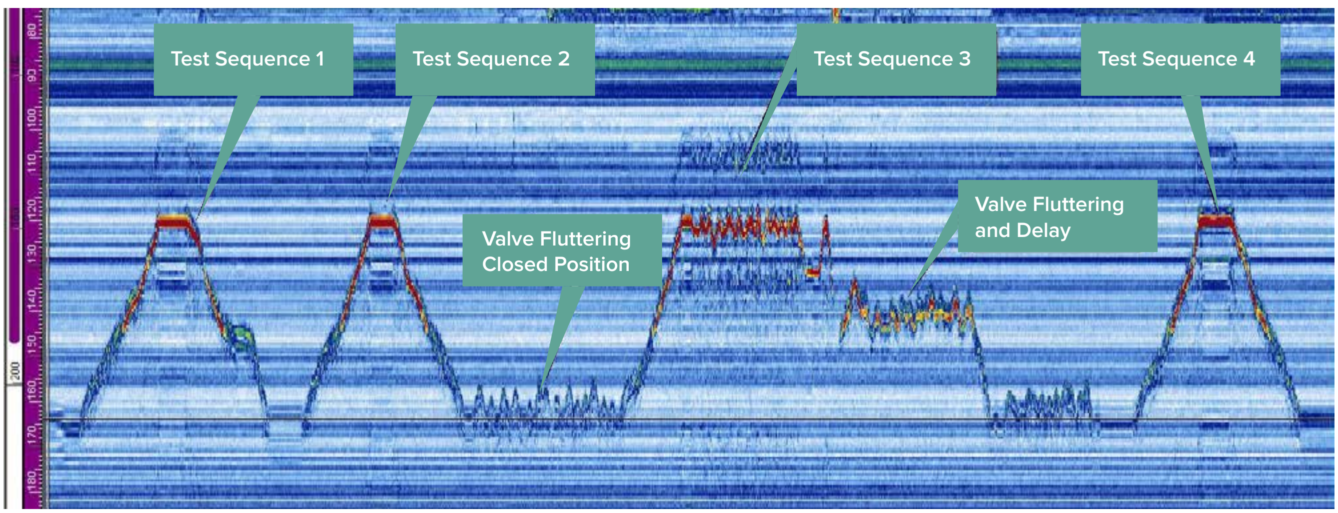

Figure 7: Comparative Analysis of PASS Sequences

IV. DEFINITION OF IIA PASS VISUALIZATION SOFTWARE

IIA recognized the need to make raw ultrasonic data user-friendly. Most ultrasonic data requires analysis by experienced or certified personnel in ultrasonic discipline. Recognizing this as a challenge, the PASS Visualization Software platform was developed. The intent was to provide an analysis bridge between raw ultrasonic data and valve experts not trained in the ultrasonic discipline. PASS visualization software accomplished this goal by developing a 3-dimensional parametric valve model and constraining the raw ultrasonic data to the model. This interactive approach provides check valve engineers a comprehensive method to recreate the examination results as they occurred in the field. The valve dynamics can now be observed measured and compared to similar valve model ultrasonic signatures. Trendable attributes such as disc flutter, disc travel angle, and disc travel velocity can be measured and saved for future comparisons. The potential now exist for fleet wide comparison of static and dynamic ultrasonic signatures where valves are in service in similar systems and functional roles. **Figure 8** below shows the IIA PASS Visualization Software 2D interface.

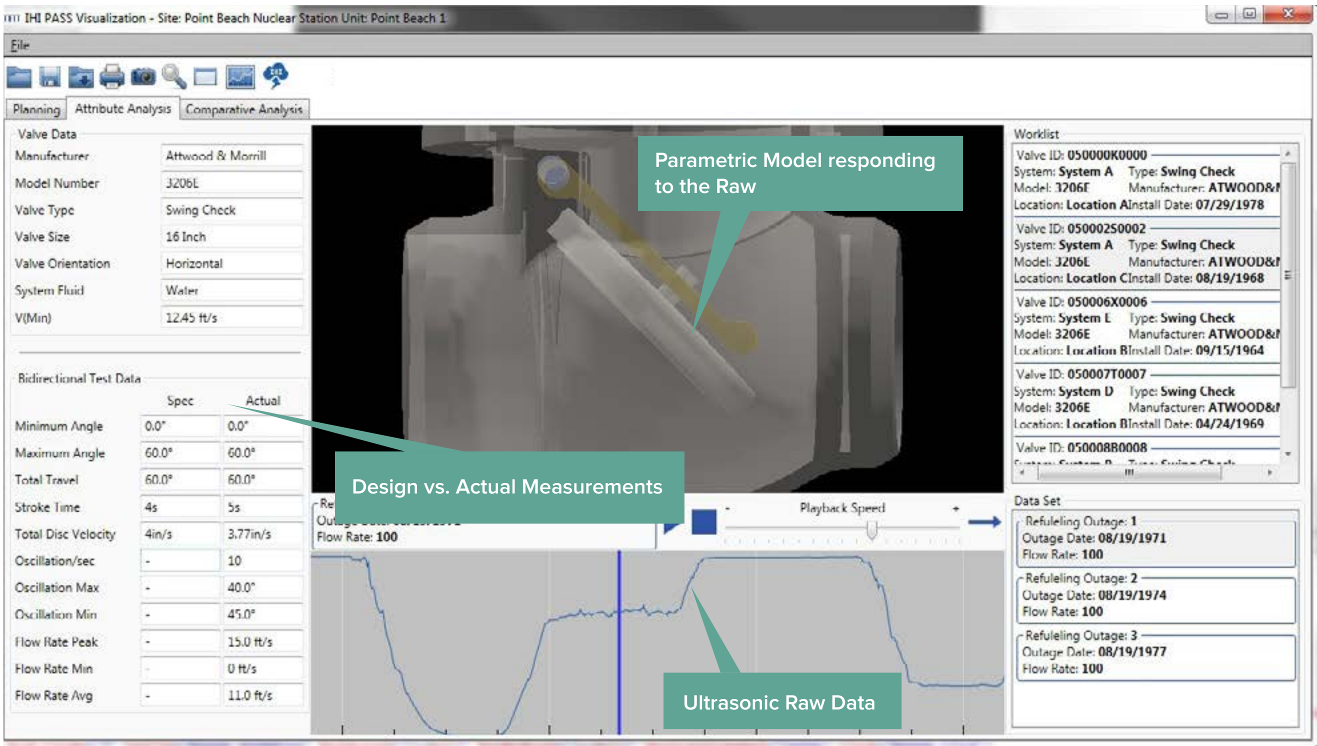

Figure 8: PASS Visualization 2D Interface

In the PASS 3D visualization software interface shown on **Figure 9**, the disc/arm assemblies are superimposed within the valve model. The data demonstrates test sequence simulation from July 8, 1995 and June 28, 2001. The blue disc represents the 1995 data and concurrently the red disc represents the 2001 data. This interface allows check valve engineers to assess the differences in valve behavior between test sequences taken during different outages. From this analysis engineers can make important decisions regarding operational readiness or predictive maintenance.

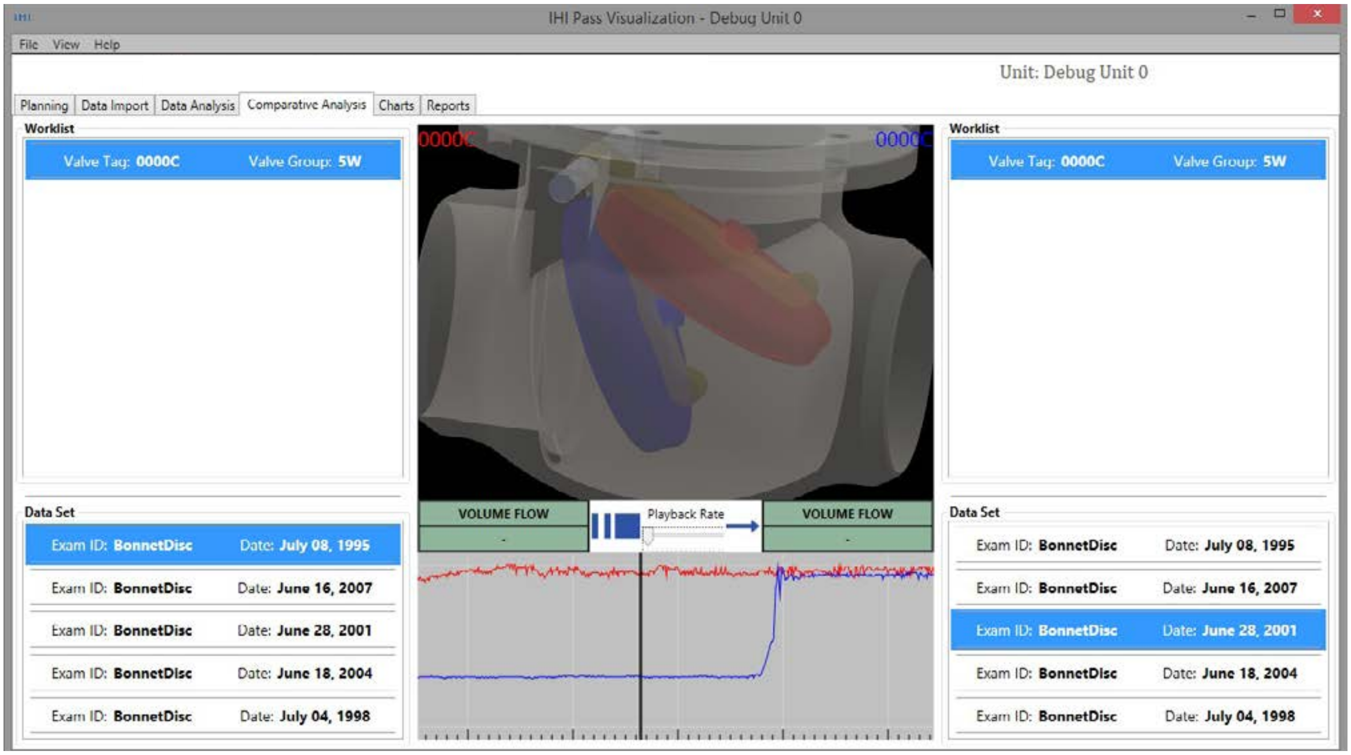

Figure 9: PASS Visualization 3D Interface

V. DEFINITION OF PASS GAS DETECTION TEST

In certain situations, gas is known to exist in plant piping systems. The gas pocket between the fluid and the bonnet will impede the ultrasonic waves. PASS uses two probes, as shown in **Figure 10**, to project sound waves into the bonnet, which in turn propagate through the fluid and exit through the bottom valve body. Since bonnet and body probes are programmed as receivers and transmitters, correlating signals will be seen if the valve is full of fluid. Essentially, the sound waves have completed the trip from the bottom of the valve to the top of the valve and vice versa.

When a gas pocket exists in the valve body, no signals will be detected by the receiving probes since the sound propagation has been stopped by the gas interface. For this type of scenario PASS reprograms the probes in the pulse echo mode. Each probe will now transmit and receive its own sound waves. In this mode the signal from to the water-gas interface can be seen by the body probe located on the bottom of the valve. By calculating the time of flight to the gas-fluid interface and considering the valves' vertical dimensions, the size of the gas pocket can be determined.

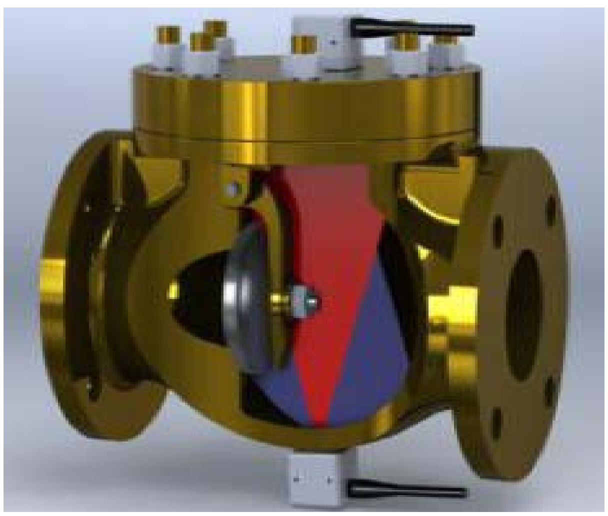

Figure 10: Gas Pocket Detection Mode

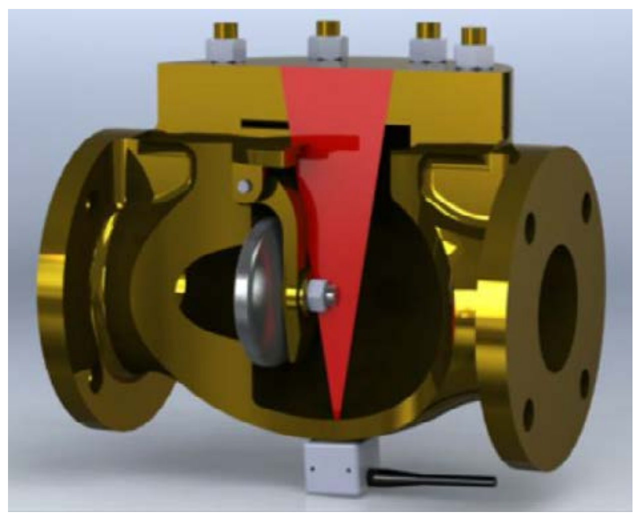

Figure 11: Gas Pocket Sizing Detection Mode

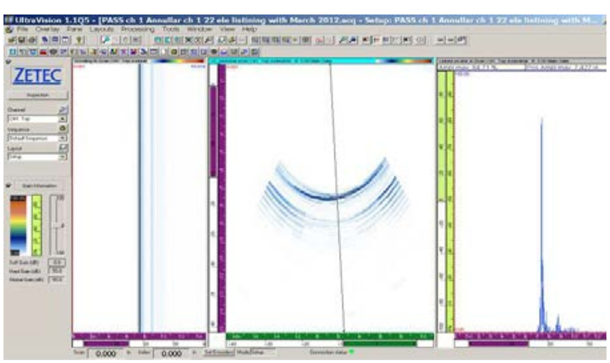

Figure 12: Signal projection with no interference

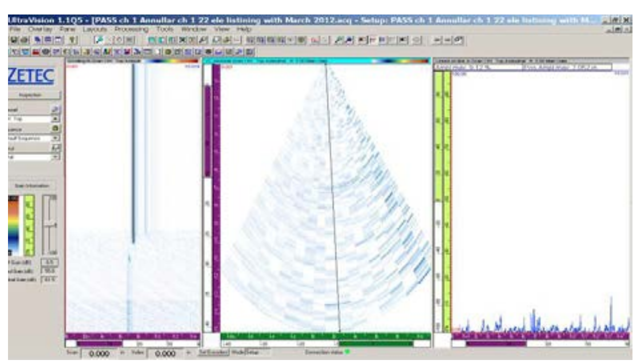

Figure 13: Signal projection with gas pocket interference

VI. DEFINITION OF PASS CATASTROPHIC FAILURE AND FME ASSESSMENT TEST

A catastrophic failure is defined as a total disengagement of the disk due to a stud, nut, or pin failure. The first scenario depicted in **Figure 14** simulates this failure condition in which minimum to no flow status. The disk assembly will lie at the bottom of the valve and possibly show subtle movements as a function of flow rate. In the second scenario, **Figure 15** simulates a high flow condition where the disk is lifted and held against internal flange port.

Figure 14: Catastrophic Disk Failure as Seen with No Flow Condition (Disk Lying at Bottom)

Figure 15: Catastrophic Disk Failure as Seen with High Flow Condition (Disk Is Lifted)

When a large interference item, such as a disc, is lying at the bottom of the valve, the ultrasonic signal will be totally blocked from the receiving probe. The sound waves cannot complete the trip from the bottom to the top of the valve and vice versa.

PASS utilizes the same probe test configuration used to detect gas pockets as shown in **Figure 18**. Two probes are programmed in transmit and receive mode. When no interference, i.e. gas, or disc exist, the ultrasound waves complete the path from one probe to the other as shown in **Figure 16**. The high amplitude signal in A-scan shows that no obstruction along the time of flight path. This would indicate, with high confidence, that the valve bowl area is clear of foreign material or gas interference.

When the disc is lying at the bottom of the valve, sound will not propagate from the transmitter to the receiving probe and therefore no signal will be detected (A-scan, on **Figure 17**, shows lack of the time of flight peak).

The lack of the peak amplitude response could lead to two possible scenarios: either there is gas at the top of the valve or there is a foreign material at the bottom of the valve bowl (**Figure 19**).

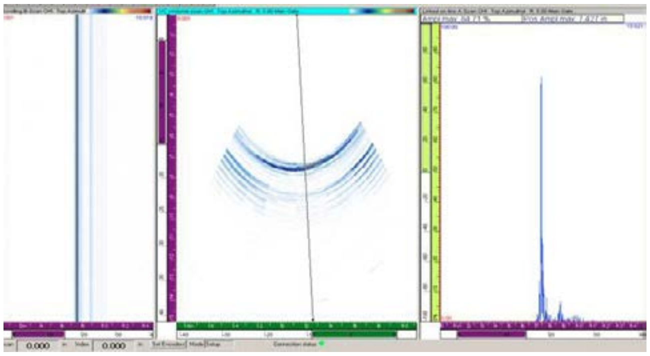

Figure 16: Signal projection with no interference

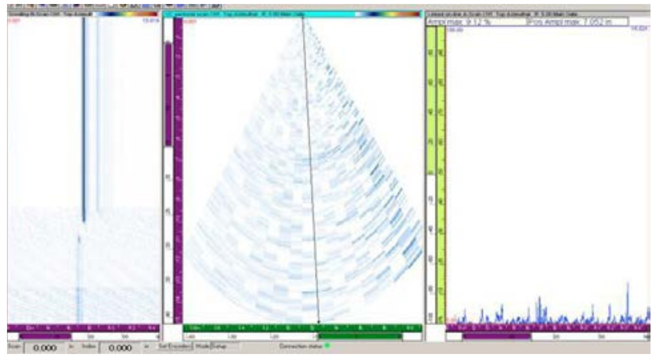

Figure 17: Signal projection with gas or disc interference

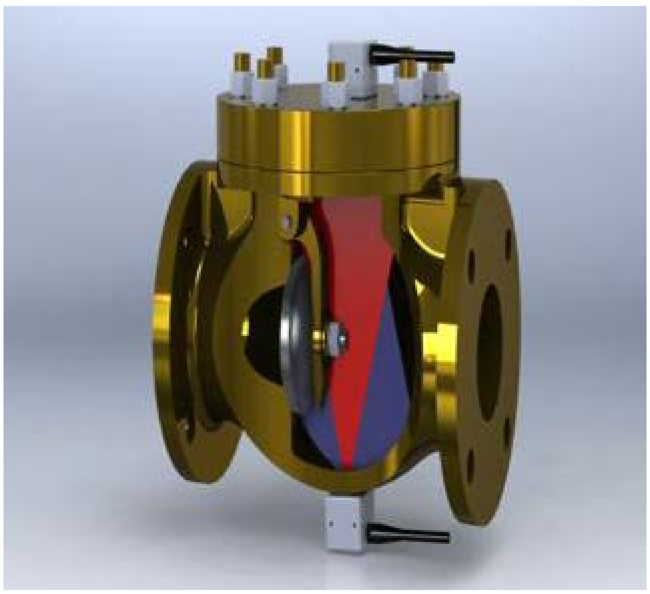

Figure 18: Signal projection with no interference

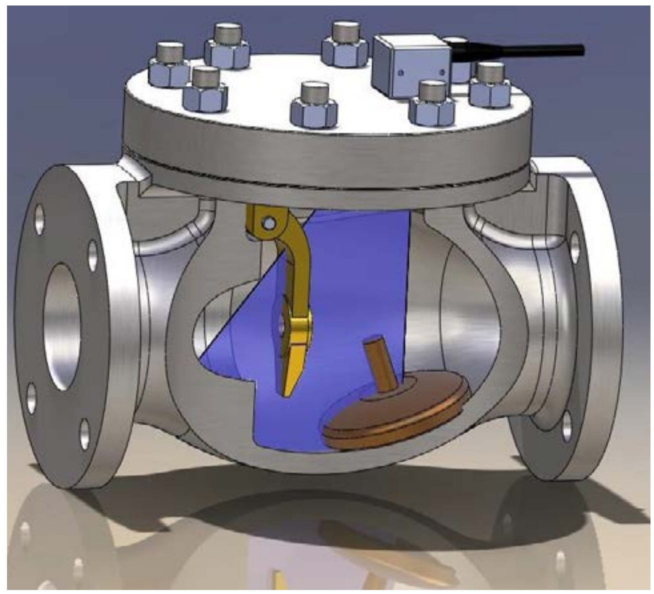

Figure 19: Arm Disc Retaining Nut Assembly Vertical Position Test

VII. DEFINITION ARM/DISC RETAINING NUT ASSEMBLY VERTICAL POSITION TEST

The purpose of this test is to assess the arm/disk assembly condition and to provide a vertical measurement from the bonnet or body to the nut location. This dimension can then be compared to design drawings. Any variations can indicate wear in the arm-hole through which the disk stud attaches to the arm. This test requires the probe to be placed directly above the disk/arm assembly. The sound beams interact with the nut/arm assembly. The nut/arm assembly forms an ideal corner type geometry where the sound energy can reflect and typically generates high amplitude reflections. **Figure 20** and **Figure 21** are examples of the expected high amplitude signals. A secondary high amplitude signal can be seen and represents the sound interacting with corner type geometry form by the nut/stud threaded area.

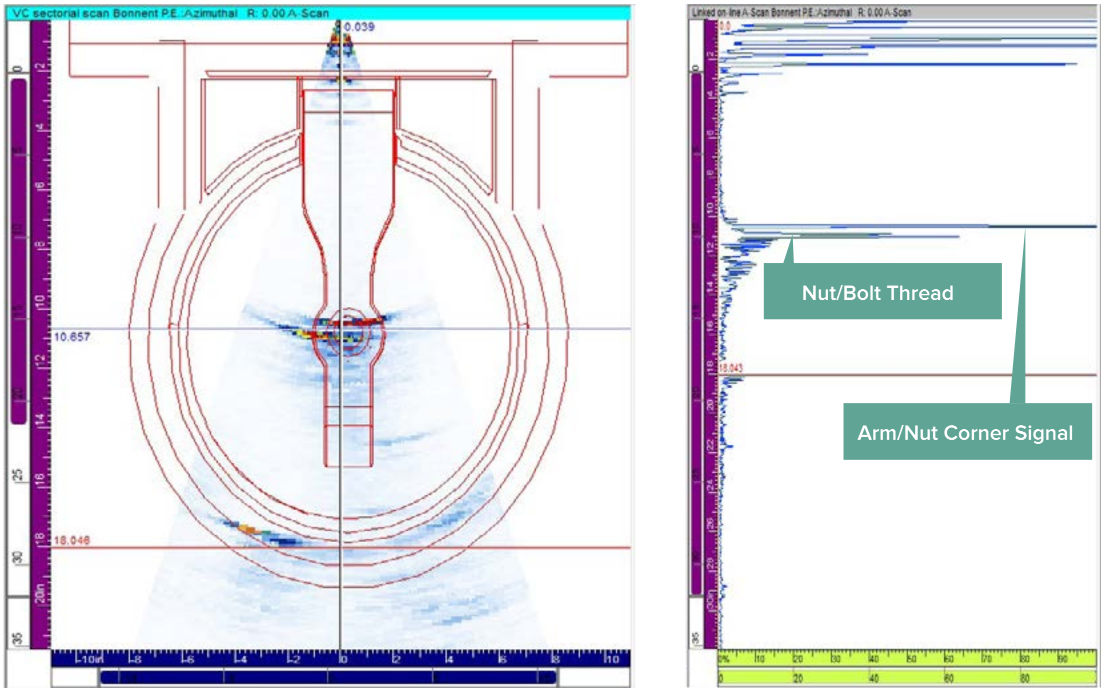

Figure 20: End view of Valve Ultrasonic Interaction

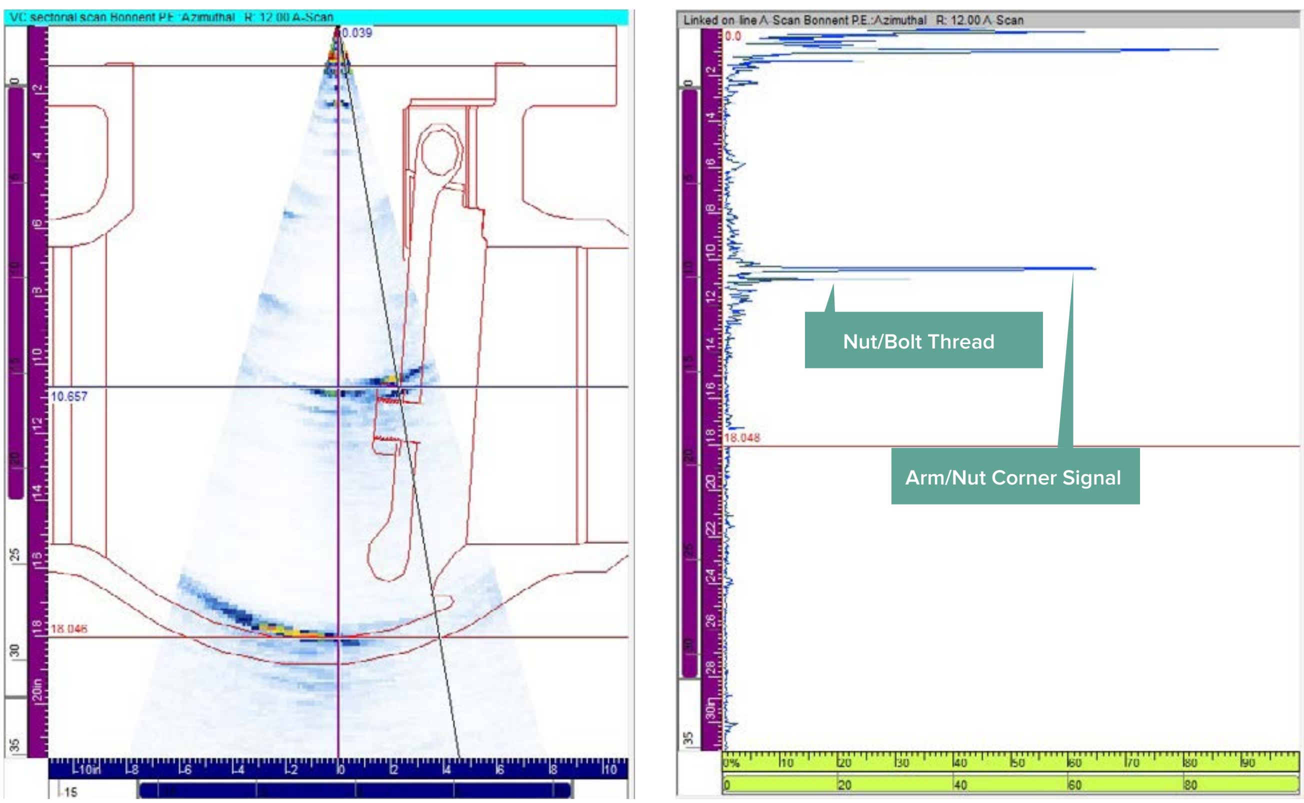

Figure 21: Side view of Valve Ultrasonic Interaction

VIII. IIA PASS APPLICATION AT THE PALO VERDE NUCLEAR STATIONS

A collaborative effort between Arizona Public Service Co., Palo Verde plants and IIA Nuclear Services was realized when IIA personnel applied Phased Array Sequence Scanning techniques to swing check valves selected by Palo Verde. The PASS examinations were applied to two valves operating in the closed static position with no flow and three identical valves operating in the open positions with constant flow rates in Units 1, 2, and 3. The following PASS non-intrusive tests were performed.

- PASS Bidirectional Dynamic Test
- PASS Valve Gas Detection Test
- PASS Valve Catastrophic and Foreign Material Detection Test
- PASS Nut Arm Vertical Measurement Test
- Flow Rate Measurements

Valves with Closed Disc Position No Flow

Valve 3PCHA-V177
During the field application of the PASS tests, discoveries were made regarding access to ideal probe positions to obtain data. Initial access examination found valve name plates on top of the bonnet. The name plates were located at various positions relative to the geometric center of the bonnet. In conducting the test of valve V177, Chemical and Volume Control check valve, the probe positions were adjusted in consideration of name plates. For example, for this valve the PASS nut/arm vertical measurement tests were conducted from the valve body.

In conducting the test of valve V177, evidence (**Figure 22**) showed that the valve was full of fluid, and no gas or foreign material was detected. Evidence showed that the arm and disc assembly was still intact. Readings from the UT data show that the Vertical Nut Position is within an acceptable range when compared against available design drawings **(Table 1)**.

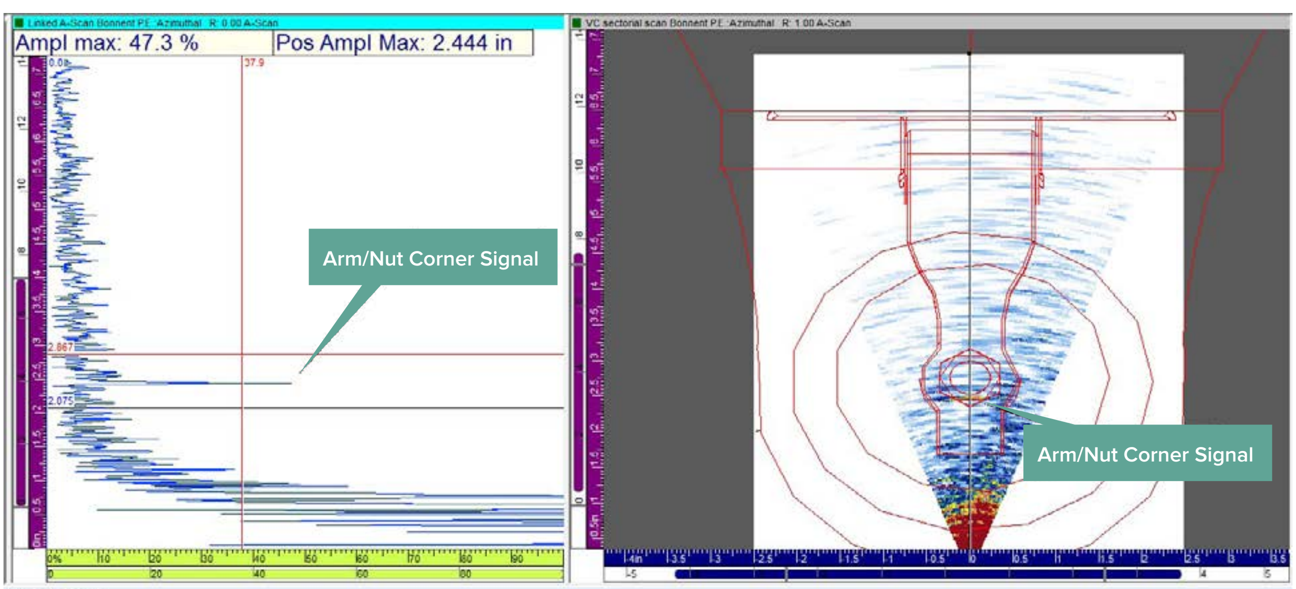

Figure 22: 3PCHA-V177 Data

In the test of valve V190 **(Figure 23**), Volume Control Tank bypass header check valve, evidence was found to show that the valve was full of fluid, and no gas was detected. Evidence showed that the arm and disc assembly was still intact. Readings from the UT data showed that the Vertical Nut Position was within an acceptable range when compared against available design drawings.

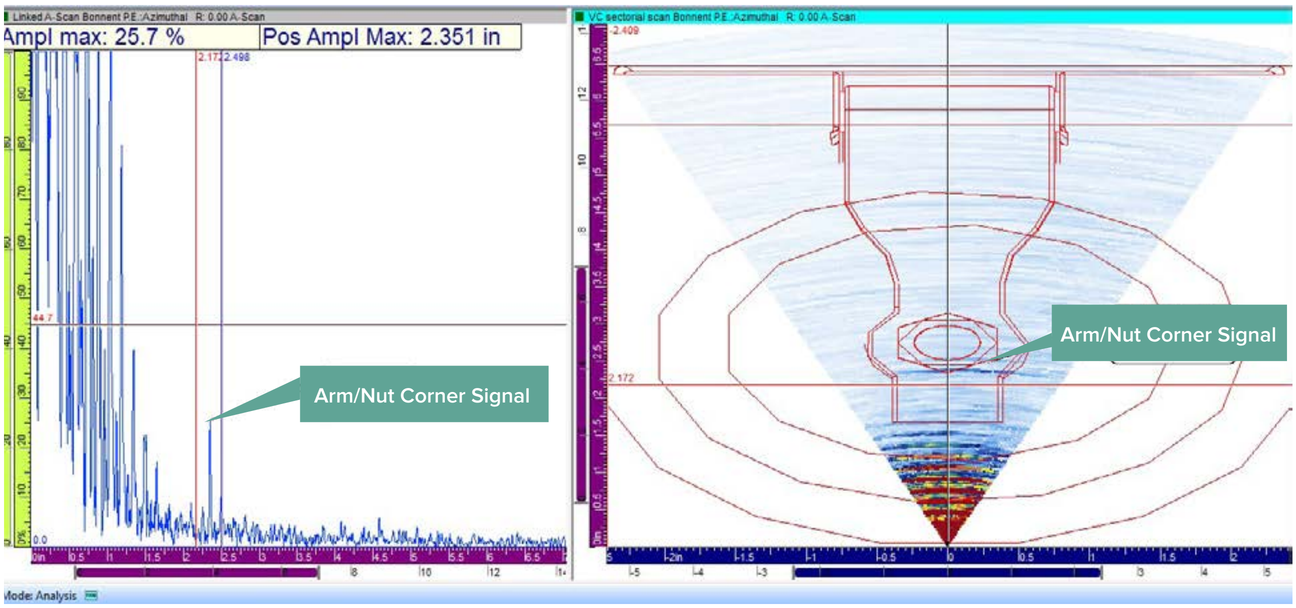

Figure 23: 3PCHA-V190 Data

STATIC TEST RESULTS

Valve No.	Valve Configuration Description	Examination Results
3PCHA-V190	3 inch Borg Warner Swing Check	No Gas Detected; No Catastrophic failure; Vertical Nut distance nominal
3PCHA-V177	3 inch Borg Warner Swing Check	No Gas Detected; No Catastrophic failure; Vertical Nut distance nominal

Table 1: Static Test Results of two valves from Palo Verde

VALVES OPERATING WITH OPEN DISC POSITION

Data was collected on valves 1PNCN-V020, 2PNCN-V020, and 3PNCN-V020, Essential Cooling Water Supply to Normal Chiller header check valve. The valves were operating in the open position with flow rate. PASS tests were conducted from the valve bonnet **(Figure 1)**. The raw data was processed and then analyzed in the PASS Visualization Software. The fluttering signals of all three valves were recorded and compared against each other. Two valves, 1PNCN and 2PNCN, had a similar fluttering pattern and were located in a mid-open position. However, valve 3PNCN had greater movement distance during a flutter cycle. Valve 3PNCN also registered a noticeably higher angular position in the valve body than the other two valves. A comparison of the flow rate data for each test showed that valve 3PNCN had over 1600 more gallons per minute due to operational conditions. Fluttering and open angle estimations are provided in **Table 2** below.

DYNAMIC DATA RESULTS

Valve No.	Valve Configuration Description	Average Flow Rate (gal/min)	Fluttering Estimation (cycles/sec)	Open Angle Estimated Range (degrees)
1PNCN-V020	20 inch Pacific Swing Check	6600	.5	30-40
2PNCN-V020	20 inch Pacific Swing Check	6400	1.5	40-50
3PNCN-V020	20 inch Pacific Swing Check	8200	1.5	40-50

Table 2: Dynamic Data Results of the valves from Palo Verde

1 PNCN-V020: The amplitude between cycles is relatively the same indicating the fluttering is minimal. For this discussion fluttering is defined as the valve's minimum to maximum angular disc/arm assembly movement as a result of flow and gravity interaction. The raw uncorrected data trace can be seen initiating at approximately a value of 52 inches (**Figure 24**).

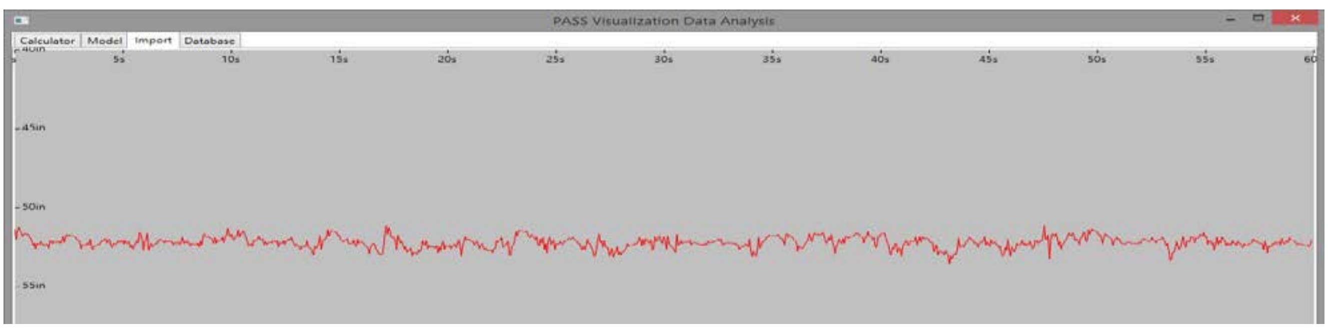

Figure 24: Time of Flight value of 52 with low fluttering

2 PNCN-V020: The amplitude between cycles is relatively the same indicating the fluttering is minimal. The raw uncorrected data trace can be seen initiating at approximately a value of 55 inches (**Figure 25**).

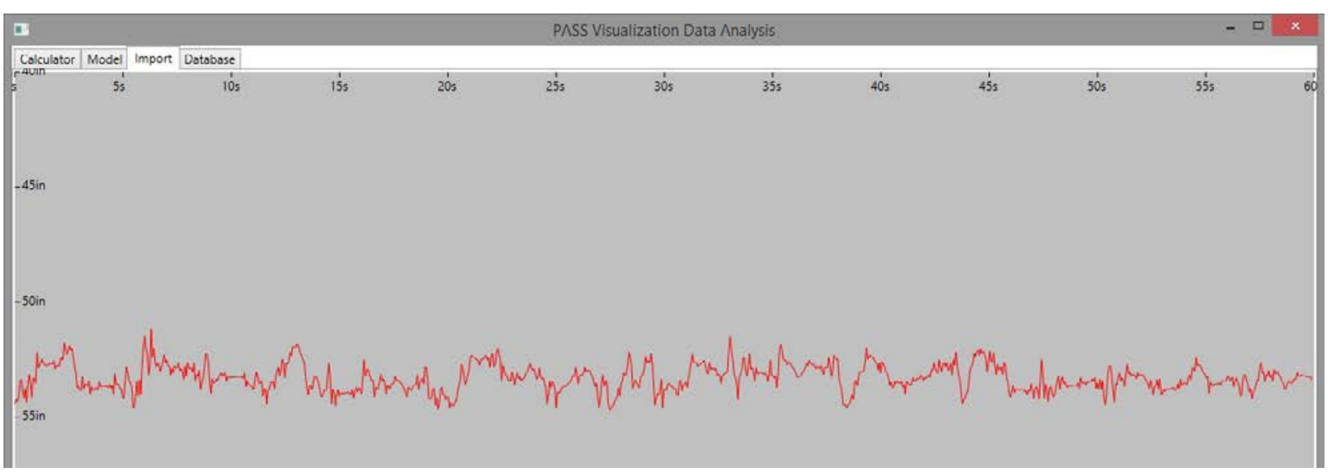

Figure 25: Time of Flight value of 55 with higher fluttering

3 PNCN-V020: The amplitude between cycles has increased, indicating the fluttering is greater. The raw uncorrected data trace can be seen initiating at approximately a value of 49 inches. The initiation of the trace reflects the time of flight distance from the ultrasonic probe sitting on the valve bonnet to the disc/arm assembly. The lower the value, the closer the disc/arm assembly is to the back stop. The trace initiation value of 49 inches correlates to a higher flow rate of 8200 GPM when compared to valves 1 PNCN-V020 and 2 PNCN-V020 (**Figure 26**).

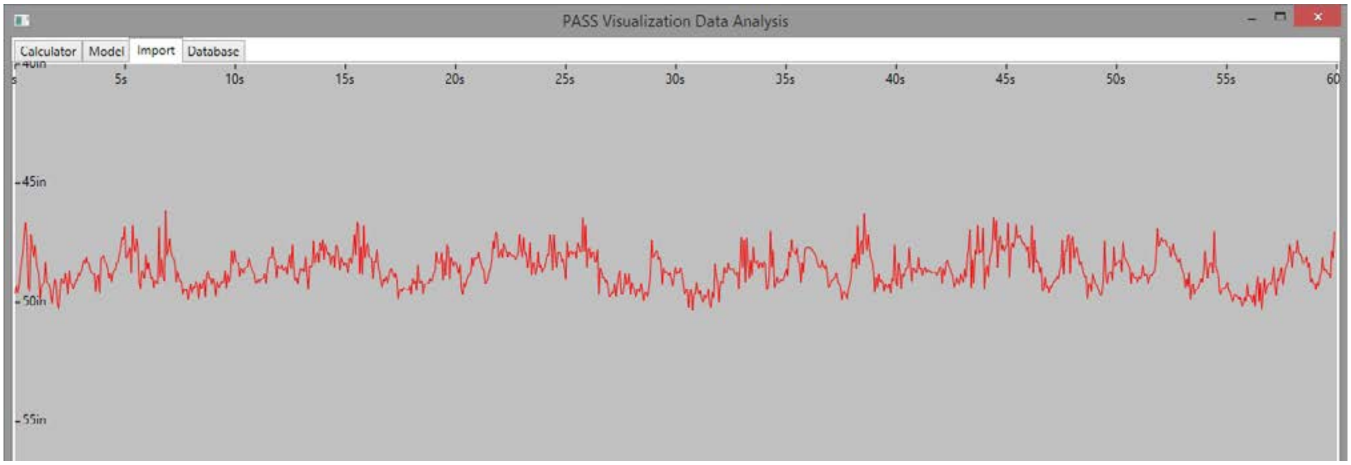

Figure 26: Time of Flight value 49 with higher amplitude fluttering

IX. CONCLUSION

Phased Array Sectorial Scanning (PASS) data was used at Palo Verde to meet ASME OM Code bidirectional requirements for check valves, as well as a tool to assess check valve condition and integrity. PASS was satisfactorily used on swing and tilting disc type valves, ranging in sizes from 3 to 20 inches and made of stainless and carbon steel. The technology was successful in the detection of gas intrusion between the fluid and bonnet. The data and information collected allowed for the extension of preventive maintenance activities while providing assurance of their operational readiness. PASS has allowed Palo Verde to better schedule and support the Predictable Repetitive Outage initiative as well as facilitate the transition of the Check Valve Program into a performance driven program. Currently, Palo Verde and IIA are pursuing the application of PASS techniques to assess the condition and/or integrity of the gate and globe valves population.

The application of PASS and PASS Visualization Software provides the potential to monitor valve condition anytime during the valve operational life cycle. By establishing baseline high confidence ultrasonic signatures of the valve condition (Static or Dynamic) the utility can now leverage this data to monitor the valve for aberrant signature changes. The PASS monitoring will allow the utility to make informed preventive and predictive maintenance decisions, as well as operational. PASS can provide the objective data for reducing the risk of unnecessary valve disassemblies and at the same time provide the basis for accelerating maintenance on valves presenting aberrant behavior. Furthermore the capture of PASS ultrasonic data signatures could contribute to establishing a comprehensive database that could be shared by the industry.

ACKNOWLEDGMENT

This paper has been developed in cooperation between Arizona Public Service Co., Palo Verde Nuclear Power Station and Industrial Inspection & Analysis

REFERENCES

None