Check Valve Diagnosis by Sectorial Scanning Phased Array Ultrasonic Technique

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Abstract. Check valves plays as security elements allowing flow path on one direction preventing the opposite direction. These valves are actioned by the flow passing through them. Their main functionalities are: as an isolation of the containment building at Nuclear power plant, to separate systems that works under different pressures and to preserve turbo pumps or motor pumps at industrial facilities. Due to the inherent features of its performance, failures or malfunction can be hidden during the plants operation, affecting to Security, so they have to be regularly inspected. Most common techniques used so far, are magnetic flow and Sound emission.

Tecnatom has developed a new ultrasonic technique for check valve diagnosis. This technique is based on pulse-echo with a phased array transducer. The transducer is located directly on the valve surface and the focal rules are configured to obtain a sectorial scan with the appropriate aperture according to the size of the valve to be inspected. Beams generated for the focal laws have to cover the position of the internals and the path where they have to move.

Tecnatom has implemented this ultrasonic technique for evaluate two valve simultaneously in the system VITER-2.0 +PAUT. This system integrates accelerometer, magnetic sensors and PAUT probe. The hardware is being controlled by a computer connected via Ethernet to the equipment VITE-R 2.0 (accelerometer, magnetic sensor and displacement sensor) and to the SONIA COMPACT equipment. Cables for this connection will be 50 meters large as maximum. For each valve to be analyzed one FPA-128M (PAUT) will be used, which is connected to the SONIA COMPACT system via optical fibre, being approximately 10 meters length. From the functional point of view, the incorporation of ultrasonic technique to VITE-R 2.0 system allows a dynamic tracking of internal component position and improves analysis capability over the operability of the valve.

In the present work the results obtained for check valve diagnosis with the new ultrasonic technique are presented and analyzed considering different internal component problems.
1. Introduction

Check valves are driven by the flow passing through them and are commonly used as safety elements. Given their operational characteristics, any faults or failures affecting them may remain concealed during plant operation, which requires them to be periodically inspected. The methods most commonly used to date for their diagnosis are the magnetic flux (MF) and acoustic emission (AE) techniques. [1]. Fig.1 shows schematically the movement of the internals of a typical check valve.

In diagnosing check valves it is of interest to determine the conditions of attachment, movement and status of the valve internals (disc, Hinge Arm and Hinge pin). This has led to the development of phased array ultrasonic techniques (PAUT) [2] for check valve diagnosis, due to their capacity to provide direct information on the position and status of movement of the internals.

In this respect, Tecnatom has developed and implemented a new technique for the diagnosis of check valves based on phased array ultrasonics, in which the ultrasonic waves generated by the set of focal laws propagate through the interior of the valve, scanning the positions of the internals and the trajectory they follow when the valves are actuated.

By implementing this new PAUT technique for check valve diagnosis and integrating it with conventional MF and AE techniques, Tecnatom has managed to develop the most powerful equipment on the market for this type of inspections.

The VITE-R 2.0+FPA-128M diagnosis system is capable of simultaneously analysing two valves located at distances of up to 50 metres one from the other. For conventional techniques the system incorporates five channels per valve: three for accelerometers, one for magnetic sensors and an auxiliary channel that may be used to couple a displacement sensor to the system. The PAUT technique has been integrated making use of the modularity, versatility and flexibility of the Tecnatom UT electronics. For the PAUT technique the system is equipped with two FPA-128M modules that allow work to be carried out on the valves in parallel.

The attachment and status of the internals inside the valve may not be adequate, due to operating wear and/or maintenance deficiencies, and this may generate unusual signals that will be difficult to interpret if not duly studied. For this reason, a study has been performed considering different types of problems affecting the internal components and the ultrasonic response has been analysed in comparison to the rest of the VITER-2.0 + FPA-128M system sensors. The present paper describes the results obtained from this study and those obtained during actual inspections.

2. PAUT technique

The ultrasonic technique is based on pulse-echo performance using a phased array probe. The probe is positioned directly on the surface of the valve and the focal laws are configured to obtain a sector scan with an appropriate aperture depending on the size of the...
valve to be inspected. The beams generated by the focal laws cover the position of the internals and the path followed by them when the valve is actuated. Fig.2 shows a CIVA simulation of the acoustic field generated inside a typical check valve for three focal laws. These simulations showed that the beams generated intercepted the positions of the internals for the different geometries of the valves to be inspected.

![Fig.2. Modelling for different focal laws in a valve interior](image)

The inspection configuration will depend on the geometry and size of the valve to be diagnosed. The higher the number of focal laws and the larger the size of the valve to be diagnosed, the smaller will be the optimum PRF. This creates a compromise between the accuracy in depth and that of the time available to determine the position of the internals. When the valve is actuated, the echoes from the internals are displaced along a focal law or from one such law to another. Fig.3 shows the trail left by the internals on a scroll view for one focal law and the corresponding position on the uncorrected S-Scan view.

![Fig.3. Evaluation view. a) S-Scan prior to actuation, b) S-Scan with disc open and c) Scroll view of focal law 9 showing the evolution with time of the internals](image)

The configuration of the focal laws should be undertaken on the basis of the following factors:

- Valve size
- Valve geometry
- Point of access for ultrasounds (effective probe position)

Fig.4 shows some of these ultrasound access points for inspection performance. The positioning of the probes at these points is performed using a specific attachment system and fabric flanges.
3. VITE-R 2.0 + FPA-128 system

The VITE-R 2.0 + FPA-128M system integrates the accelerometers, the magnetic sensors and the PAUT probe on a single computer-controlled platform. The connections between the different electronics and the computer are via Ethernet. An FPA-128M (PAUT) module is used for each valve to be diagnosed, connected to the SONIA COMPACT electronics by means of an optical fibre measuring approximately 20 metres. The PA probes are connected to the FPA-128M modules by a cable measuring 5 metres. With this configuration, the valves to be inspected may be separated by a maximum distance of 50 metres. Fig.5 shows a diagram of the connection of the system. The entire system is designed to operate in high radiation environments.

The acquisition software manages the diagnosis by means of accelerometers, magnetic sensors and ultrasonics. In this paper we will focus on the ultrasonic part of the inspection, using the remaining sensors only as references. Fig.6 shows the evaluation interface; the measurements performed using conventional sensors are shown on the left-hand side of the screen and those performed using PA sensors on the right.
4. Tests performed and results

The present paper shows the results obtained from two types of tests: 1-validation tests performed in a controlled environment (Tecnatom test loop) and 2-tests performed under real-world conditions.

4.1 Validation tests

Problems affecting check valves are caused mainly by anomalies in the behaviour of the internals. The objective of the tests performed in a controlled environment (Tecnatom test loop) has been to check the response of the PAUT technique to the different possible valve internals anomalies. The internals that may be monitored are set out below and may be seen in Fig.7:

- a. Disc
- b. Hinge ping
- c. Hinge ping caps
- d. Disc Stud
- e. Hinge Arm

The following are some of the problems that may be encountered during valve diagnosis:
- Inappropriate positioning or failure of the Hinge ping caps, which may cause constant disc oscillations during the passage of the flow and corresponding wear of the valve internals, giving rise to actuation faults and possible leakage.
- Hinge ping play
- Breaking of the Hinge ping, the disc being left loose inside the valve body.
- Breaking of the Hinge Arm, leaving part of the internals loose inside the valve body, with random movements in response to flow.

- Play in attachment of the disc to the Hinge Arm, possibly causing oscillatory movements and rotations of the disc.

Fig.8 shows the configurations of correctly positioned internals (Fig.8 a) and incorrectly seated internals, equivalent to breaking of the Hinge Arm (Fig.8 b).

The response obtained from the PAUT sensors is very clear when the internals are correctly positioned and agrees with the measurements from the acoustic and magnetic sensors. Fig.9 shows a comparison of the response of the PAUT sensor (Fig.9 a) with the response of the acoustic (Fig.9 b) and magnetic (Fig.9 c) sensors. The latter shows the closed and open disc statuses, the opening-closing times and the recovery of the echoes existing prior to actuation of the valve, implying the return of the internals to their original position. The coincidence with the indications provided by the other sensors on closing and opening may also be appreciated.

If the internals are not correctly positioned on their support, they may move chaotically inside the valve or become attached inadequately due to the force of the flow. Fig.10 shows both cases, the images being taken on opening of the valve following pump actuation.
Fig. 10. Status of internals following actuation with the internals incorrectly seated. (a) disc moving inside valve, (b) disc trapped in outlet pipe with little movement

The response obtained for the case represented in Fig. 10a is shown in Fig. 11. The moments of opening and closing actuation are clearly appreciated for the three types of sensors, but in the case of both the PAUT and magnetic sensors, the behaviour does not indicate valve opening and there is no recovery of the initial echoes. In the case of the PAUT sensor, fixed echoes that were not present prior to actuation may be appreciated. This is a clear sign of the internals having occupied a fixed position due to the force of the flow.

Fig. 11. Valve response with internals incorrectly seated. a) PAUT sensor, b) counter-seated accelerometer, c) magnetic sensor

4.2 Real-world tests

Tests were performed under real-world conditions using valves of between 6” and 12”. Fig. 12 shows the positioning of the sensors in certain of the tested valves.
In order to determine the areas in which the PAUT probes should be positioned, the geometry and dimensions of the valves should be analysed, for which the availability of valve drawings would be very useful. The group of focal laws appropriate for each inspection is generated on the basis of this analysis. This is a crucial point in implementation of the technique, since the echoes generated by the internals may be confused with geometric rebounding and this would become apparent only after performance of the test if the preliminary analysis were incorrect.

The results obtained from a 6” valve are presented by way of an example of an actual inspection. The evolution of focal laws LF2, LF10 and LF14 is shown in Fig.13, the stages of closed valve, opening, open valve and closing being presented in each case. Three main moments in time are shown in the figure: at $t_1$, the valve has not yet been actuated; at $t_2$, the valve is open and at $t_3$, the valve is no longer being actuated and is closing. Also shown in the figure are three characteristic time intervals: $t_a$, the opening time, which is the time elapsing from the moment at which there are indications in the signal of movement of the internals to the moment at which counter-seating occurs; $t_e$, the time the ultrasonic signal takes to stabilise following opening, this being related to the end of turbulences inside the valve and the passage of a laminar flow; and $t_c$, the closing time, which is the time taken by the internals to recover their starting position.

In order to get an overall view of what happens to the internals, it is necessary to contrast the information from the Scroll UT views (Fig.13) with that provided by the S-Scan views (Fig.14). Fig.14 shows the S-Scan views for time instants $t_1$, $t_2$ and $t_3$, underlining the focal laws shown in Fig.13. The evolution of the echoes from the internals may be appreciated in this figure, and the meaning of each may be understood by observing the schematic diagram presented in Fig.15. Note that a geometric analysis of echo E3 might indicate the angle of opening of the disc.
Fig. 13. Evolution with time of the three focal laws (LF2, LF10 and LF14).

Fig. 14. Uncorrected S-scan at three moments characteristic of inspection performance. a) $t_1=10$ s valve closed, b) $t_2=45$ s valve open, c) $t_3=97.5$ s.
5. Conclusions

Tecnatom has developed a PAUT technique for the diagnosis of check valves. This has been integrated in the VITE-R 2.0 system using Tecnatom phased array electronics (FPA-128M). The development of software simultaneously controlling both sets of electronics allows all the sensors to be synchronised in time. The new PAUT technique has the advantage of providing a direct reference of the position of the internals at each moment in time through the reflection of ultrasonic beams and is a valuable complement to the valve diagnosis system based on accelerometers and magnetic sensors. Diagnoses have been performed on operating valves at plants, ratifying the performance of the technique presented herein. With the integration of these three techniques, Tecnatom is currently able to provide the most complete system available on the market for the inspection of check valves.

References