The Development of a Non-Intrusive Test of Check Valve Using Acoustics and Magnetics

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Abstract

Check valves used in industrial and Nuclear Power Plant safety systems are susceptible to failure modes generally associated with wear of internal parts. Specifically, hinge pins, disc studs, pistons, and other mechanical parts may degrade over time , and in some cases, may which might produce a disabling event leading to plant or process shutdown. The primary diagnostic technique in the past has been to disassemble the valves. This procedure is costly, time consuming, and in the nuclear industry, it can lead to radiation exposure in some situations. Additionally repair and reassembly of a valve does not ensure proper operation. Non-intrusive diagnostic technologies including acoustic and magnetics with a digital signal analysis allow to evaluate check valve performance without a disassembly and is able to help the user detect degraded valve conditions.

Ⅰ. Introduction

A check valve is a self-actuating, flow-limiting device. Its principal moving part, the disk assembly, consists of a disk supported by a hinged arm. Fig. 1 shows the design of a typical swing check valve. In the fully opened condition, dynamic pressure from the flowing fluid on the disk is enough to overcome its weight keeping the disk arm pressed against a back stop. As the flow velocity decreases the disk assembly moves to a new equilibrium position. When the velocity is low enough, the disk assembly will be seated. Recent studies carried out by EPRI, NRC found that many of these safety-related valves were not functioning properly. A typical nuclear plant has between 60 and 130 safety related check valves in size 50 and 762 mm. Typical problems found in these valves included missing discs, disk flutter, backstop tapping, seat tapping disk pin and hinge pin wear, and flow leakage due to seating corrosion. Each of these problems can lead to undesirable consequence in the operation of the nuclear plant. Since these check valves are safety-related periodic monitoring and testing are essential and required by the Korea Nuclear Safety Institute mission per KINS-G-018. To meet this requirement check valve has been disassembled, visually inspected, and then reassembled.

The disadvantages of this process are that it is time consuming and the work must often be done in highly radioactive, restrictive spaces. In response to the needs, various equipment to test and monitor check valves has been intrusively developed. This paper describes the intrusive method of techniques for detecting check valve degradation or failure in service. The intrusive method uses a combination of acoustics of the noise generated inside the valve during its operation and ultrasonics or magnetics of sensing a position of disc.

It was shown that the ultrasonics sensor not only can quantitatively determine the disc opening angle but also can be used to determine such dynamic parameters as flutter resulting from the looseness of hinge pin/bushing.[1]

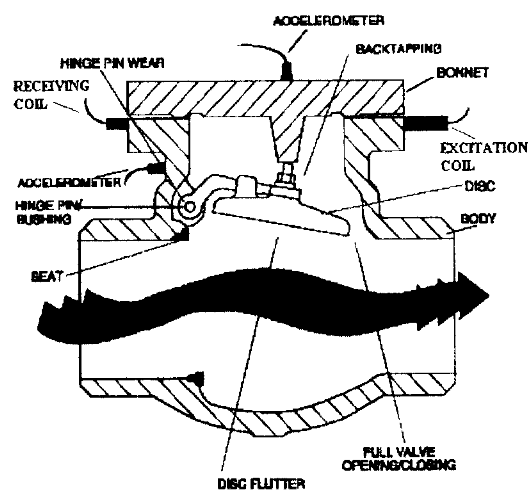

Figure 1. Swing check valve

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However, there are two major drawbacks of the ultrasonics sensor. First if the valve is not carrying a ultrasonic transmitting fluid medium such as water, the ultrasonics cannot be used. Second, if the valve is made of thick coarse-grained, cast stainless steel through which ultrasonics cannot penetrate, again the sensors cannot be used. Thus, to accomplish the good of non-intrusive monitoring of stainless steel valves carrying any fluid, magnetic techniques is developed.

Ⅱ. Non-intrusive Method of Check Valve Test

2.1 Impact wave in acoustics and eddy current in magnetics.

An acoustic wave is also generated by a mechanical impact. At long distance Lamb wave is transmitted through a thin material following impacts. A Hertz theory is based on the Lamb wave (plate wave) for loose part monitoring in nuclear plants. In case of a short distance and a thick material, a mechanical impact causes a variety of wave which is categorized as a shear wave and a longitudinal wave. These waves can exist only in solids where the dimensions in all directions are much greater than the wavelength. The longitudinal wave is appropriate for the check valve diagnostic to differentiate between the backtapping and the fretting. A longitudinal wave has particle displacements only in the direction of wave propagation. Pure longitudinal waves a constant velocity of about 5,800 m/sec in steel. Transverse waves are shear waves associated with deformations that do not produces a change in elemental volume. The transverse wave velocity in steel is about 3,100 m/sec. Plane transverse waves generally occur in bodies that are large compared to the wavelength in all directions.

The amplitude of impact point (2-1) and sense point (2-2) can be defined as the equation.[6]

$$A_r = A_{max}\, r^{-J} \tag{2.1}$$

$$A_r = A_{max} \exp^{-rJ} \tag{2.2}$$

where A_r, A_{max}, r, and J are maximum amplitude at distance r, maximum amplitude at impact point, distance between sensors and source, and decay coefficient, respectively. Fig. 2 shows the circuit of an accelerometer from gravity originated in impacts to voltage. Burst type acoustic signal can be described by relatively simple parameter. The signal amplitude is much higher than the background and is of short duration. Magnetics is dependent on the principles of electromagnetic induction for inducing eddy currents with a part placed in or adjacent to one or more induction sensor coils. The disk moving is a result of I^2R gains caused by the flow of eddy currents in the valve. Namely, the disk opening/closing in the check valve produces the eddy current between the induction coil and sensors.[7]

From Oersted's discovery, a magnetics flux Φ_E exists around a excitation coil carrying current proportional to the number of turns in the coil N_E and the current I_E

$$\Phi_E \propto N_E I_E \tag{2.3}$$

Faraday's law states a voltage V_{s1} is induced in the valve body when there is a changing magnetics field.

$$V_{s1} = N_E \frac{d\Phi_E}{dt} \tag{2.4}$$

where $\frac{d\Phi_E}{dt}$ is the rate of change in Φ_E with time. Since coil current varies sinusoidally with time, total magnetic flux in the coil also varies sinusoidally,

$$\Phi_E = \Phi_o \sin \omega t \tag{2.5}$$

where Φ_o is the magnetic flux corresponding to I_o. The induced voltage as described by equation (2.4) results in

$$V_{s1} = -N_E\, \omega\, \Phi_o \cos \omega t \tag{2.6}$$

which also varies periodically with time. When the disk is seated, sensor coils are located to detect a current I_{s1} induced by a magnetics flux Φ_{s1} according to Ohm's law which states the relationship between a inducing voltages V_{s1} and a disc' impedance Z_{s1}, as below equations.

$$I_{s1} = \frac{V_{s1}}{Z_{s1}} \tag{2.7}$$

$$\Phi_{s1} \propto -I_{s1} \tag{2.8}$$

$$Z_{s1} \propto \Phi_{s1} \tag{2.9}$$

When the disc moves back and forth, disc impedance will change from Z_{s1} to Z_{s2} by magnetics flux Φ_{s2}. Consequently, current change I_{s2} results in voltage V_{s2}. These induced currents are known as eddy currents because of their circulatory. Fig. 3 shows how react magnetic sensor with eddy current

$$\Phi_{s2} \propto -I_{s2} \tag{2.10}$$

$$Z_{s2} \propto \Phi_{s2} \tag{2.11}$$

$$V_{s2} = Z_{s2} I_{s2} \tag{2.12}$$

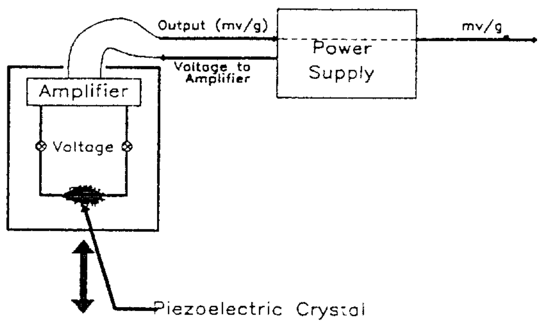

Figure 2. The simple circuit of an accelerometer

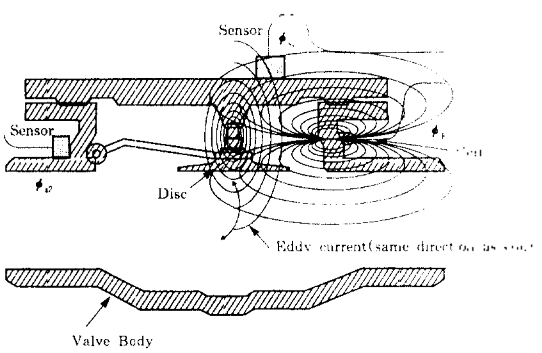

Figure 3. How to work magnetic sensor and coil

2.2 Accelerometer and AC Magnetic placement

The correct placement and use of accelerometers and ac magnetics for acoustic monitoring and position detection is one of the most critical aspects of testing and depends on the type of check valve being analyzed and events that to be monitored. It is imperative that the check valve be instrumented correctly for proper assessment of its condition. This section will explain the recommended placement of accelerometers and AC magnetic coils for the swing check valves prior to position accelerometers and AC magnetic coils on check valves. Prior to position accelerometers and AC magnetic coils in check valves, certain elements need to be considered; operation characteristics of the valve, potential degradation of anomalies and anticipated acoustic levels in order to set accelerometer ranges properly.

When instrumenting a swing check valve, accelerometer data should monitor back stop, bonnet, valve seat, and the hinge pin impacts or running. Two accelerometers are adequate for this purpose. Fig. 4 shows the typical sensor location. One accelerometer should be placed on the bonnet of the check valve in the vertical direction in order to monitor for back stop impacts. In addition, hinge pin and disc stud impacting and rubs will also be captured. The second accelerometer should be placed in the area of the hinge pin in a horizontal direction.

This accelerometer will be primarily used to detect valve closures impacts as well as detecting hinge pin and disc stud acoustic emissions. In addition to monitoring the swing check valve for acoustics, it is also critical to monitor disk motion and position. The AC magnetic sensors are used for this purpose. These sensors should be positioned on the bonnet flange in the horizontal direction parallel to the flow. It is preferred, but not imperative to place the excitation coil downstream of the flow and the receiving coils should be 180° from the excitation coil. Both coils need to be placed below the flange split as possible.

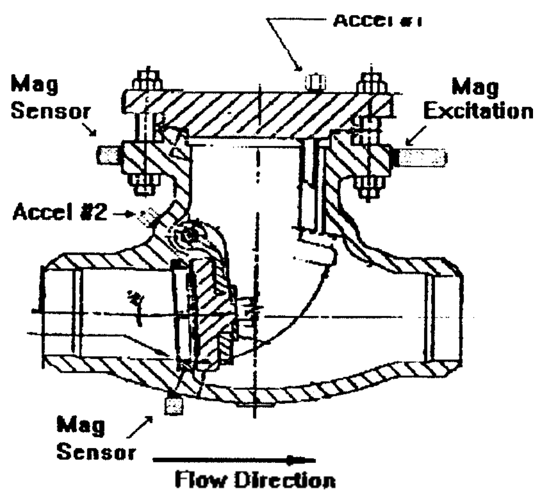

Figure 4. Typical sensors location

Ⅲ. Experiment

The experiment mainly consists of two parts. One is acoustic channel board which contains all circuity for converting up to two accelerometer charge signals to voltage signals. The nominal sensitivity of the accelerometer is 17 pC/g. This charge is converted to voltage (22mv/g) and temperature range from −54℃ to 371℃. The other is magnetic channel board which sends AC current to the excitation coil, creating a magnetic field both outside and inside of the valve body. This signal is detected at the opposite side of the valve body by the magnetic sensor and compared to a reference signal. Both amplitude and phase are monitored, filtered, demodulated, so that information about the position of the valve's internal parts can be extracted. The magnetic sensors are attached to 150 mm stainless steel swing check valve.

The check valve acoustics system is used to diagnose a 150 mm stainless-steel swing check valve installed to safety injection system in a Younggwang nuclear power plant unit 1 as shown in Fig. 5. No. 055, 058 and 059 of swing check valves are inspected visually. An internal corrosion is detected in hinge pins and seats. Three valves is replaced by new ones. Data acquisition is performered both before and after replacements with pump start/pump stop to differentiate between the old one and the new one. The acoustic noises that are present in check valves during operation can be divided into several types. In order to ascertain three kinds of signal, data is also acquired in the Liberty Technology Inc's Lab without pump strat and pump trip as shown in Fig. 6.

Figure 5. V055 check valve of YG unit 1

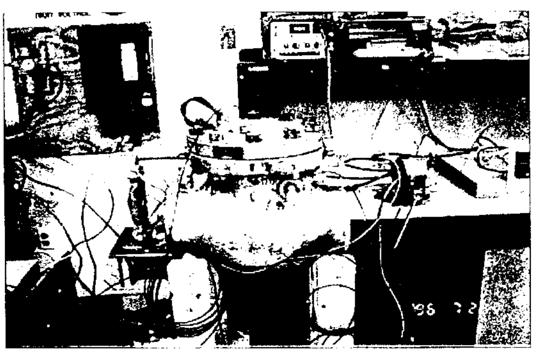

Figure 6. Swing check valve in Liberty Technologies. Inc

Ⅳ. Data Interpretation

4.1 Acoustics

In a typical test-run, about 60 seconds of data is acquired. The acoustic can be categorized as three types of noise. The first type, refered to as metal to metal impacts, is most often appeared when the check valve disk opens under flow and hits its back stop. Similarly, this type of impact can be observed during closing stroke as the disk impacts the seat. Fig. 7 is an example of mechanical impact.

Opening and closing impacts exist when the valve is going through a transient flow condition. As the valve opens as a result of flow, and if the flow change is large enough, the check valve disc hits the back stop. This impact is characterized by a large sharp spike followed by progressively small spikes. This is a result of excitation of the valve's natural frequencies. The amplitude of these frequencies decays over a short time period. This signature, shown in Fig 8 is refered to as ring down. This spike reveals impact wave forms with durations of 10ms to 20ms.

Figure 7. Metal to metal impact

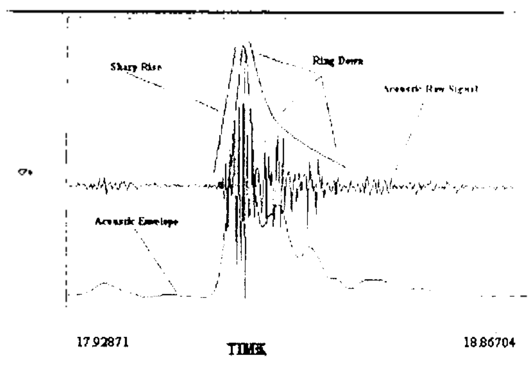

Figure 8. Opening impact from swing check valve showing metal to metal impact

This valve is higher than cavitation less than 5ms, a particular flow phenomenon exists when a low pressure zone is formed inside the check valve usually on the down stream side.

The second is a type of acoustic noise found in check valves results from mechanical rubs(fretting, rocking) between adjacent valve parts. Mechanical rubs observe when the valve is in motion. These signals become more obvious when looseness is present in the valve. Fig. 9 is a common example of a mechanical rub.

Mechanical rubs are characterized as a mechanical looseness between parts such as the hinge pin and disc assembly on a swing check valve. Mechanical rubs exhibit a gradual rise and fall off in the acoustic signature, indicating hardly mechanical ring down, rather the mechanical parts are damping the effects of the impacts as shown in Fig. 10.

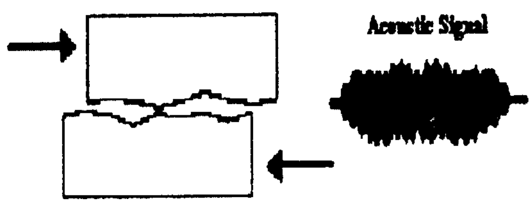

Figure 9. Signature showing metal to metal rubs

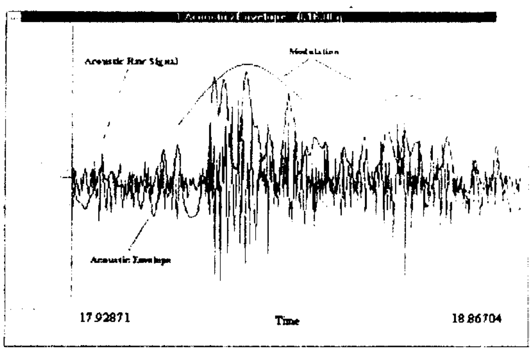

Figure 10. Signature showing metal to metal rubs

The third category of mechanical impacts is produced by worn internal parts of the check valve. Wear in a swing check valve usually occurs between the hinge pin and disc stud, and their respective mounting surfaces. As this wearness increases, the parts can move more freely, This leads to larger and more frequent impacts between these parts. An example of this condition of the V055 valve

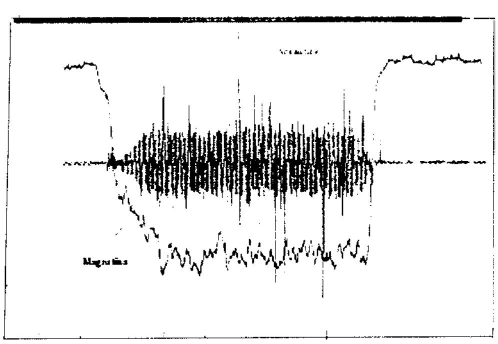

Figure 11. Swing check valve with worn hinge pin

is shown in Fig. 11 (the V055 valve with a worn hinge pin) and Fig. 12 (a new swing check valve). It is noticeable that the acoustic of Fig. 11 appears more impacts of significantly greater amplitude.

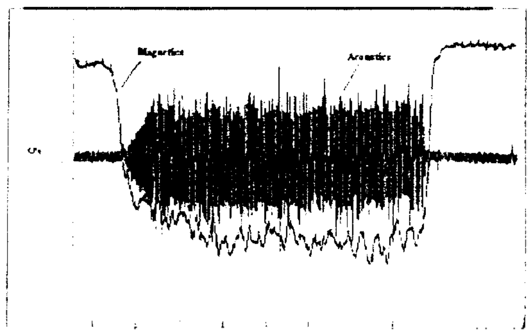

Figure 12. Swing check valve in a new condition

4.2 Magnetics

In this application, two AC current elements are placed externally on the 150 mm swing check valve body when the disc starts to move, eddy currents induced in the elements perturb the inductances and therefore total impedance is changed in elements. A current passes through the circuit and the voltage generated is related to the position of disc assembly. The AC magnetics coils is positioned on the bonnet flange parallel to the flow. The excitation coil is attached to the downstream of the flow. The receiving coil is settled in from 180° the excitation coil. Because eddy currents are highly non-linear, qualitative information on the disc opening angle can be derived from this voltage.

Fig. 13. shows the induced current signature as a function of time as the valve disc opened, hit the backstop, stayed in the fully opened(O11) position, then closed with a distinct seat impact(C10).

It shows the disc fluttered at a frequency of about 2.0

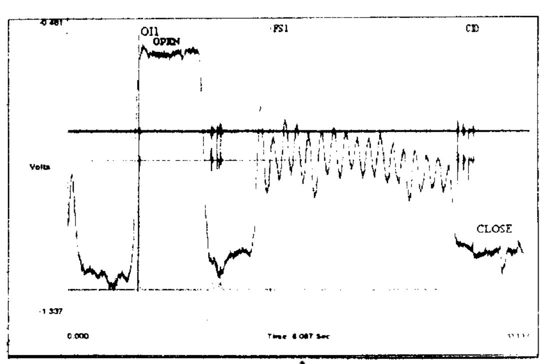

Figure 13. Magnectics time trace showing disc opened and fluttering

Hz (FS1). However, quantitative flutter amplitude cannot be derived from the signature as the induced voltage is not a linear function of disc displacement

V. Conclusion

Applying a togetherness of acoustics and magnetics signal, it is possible to determine the parameters of the function of the check valve internals without disassembling it. This series of tests shows that the accelemeters can be used to measure and to differentiate the three types of impacts; metal to metal impacts mechanical rubs, and worn internal parts and the magnet sensors can be used to detect the disc frequencies of stainless steel check on which the ultrasonics transducers can not be used.

It can be used to detect qualitatively the severity of disc flutter and to measure the disc position. These techniques would be helpful to meet the requirements and set-up the check valve test program effectively without consuming overhaul period.

References

1. Au-Yang, M. K., et. al. "Acoustic and ultrasonic signals as diagnostic tools for check valves," *Journal of Pressure Vessel Technology*, Vol. 115, pp. 135-141, May 1993.
2. C. M. Sim and K. S. Yoon "Non-intrusive method using acoustics, ultrasonics, magnetics on check valve," *Proc. Korea/Germany Workshop on the Monitoring/Diagnostics* Korea, June 1996.
3. ASME-OM code subsection I IST-C "In service exercising tests for category check valves," 1994 Addenda.
4. H. D. Haynes "Recent Improvements in Check-Valve Monitoring Methods," *Proceeding of the U.S Nuclear Regulatory Commission 18th Water Reactor Safety Information Meeting* Vol. 3, pp. 403-430, Oct. 22-24 1990.
5. *Application Guidelines for Check Valves in Nuclear Power Plants*, EPRI NP 5479 Jan. 1988.
6. *Acoustic Emission Testing*, Vol. 5, ASNT, 1988.
7. V. S. Cecco, *Eddy Current Testing Manual on Eddy Current Method*, Vol. 1, AECL, 1981.

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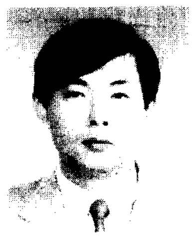

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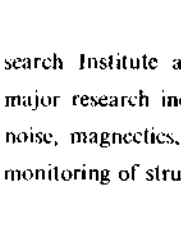

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