DATA ANALYSIS FOR VALVE LEAK DETECTION OF NUCLEAR POWER PLANT SAFETY CRITICAL COMPONENTS

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ABSTRACT

A nuclear plant consists of several safety-related components. These safety-related components are tested periodically in order to verify their functionality when they are called upon to perform. The data acquired during periodic testing provides information about possible degradation of the equipment or device under test.

This research is focused on leak monitoring techniques to provide diagnostic information on the determination of valve aging and degradation. Several commercially available valve diagnostic-monitoring methods are evaluated, especially for the techniques based on measurements of acoustic emission, and accelerometer. The check valve is one of typical components being extensively used in safety systems of nuclear power plants. The failures of check valves have resulted in significant maintenance efforts, on occasion, have resulted in water hammer, over-pressurization of low-pressure systems, and damage to flow system components. In this paper, acoustic emission signals due to leak from check valves with artificial leakage and worn parts are investigated both analytically and experimentally. The results of advanced signal processing and de-noising techniques also have been identified.

Key Words: on-line monitoring, valve degradation, AE technique, accelerometer, pattern recognition

1. INTRODUCTION

A nuclear plant consists of several safety-related components. These safety-related components are tested periodically in order to verify their functionality when they are called upon to perform. The data acquired during periodic testing provide information about possible degradation of the equipment or device under test. Performance related parameters can be addressed in order to determine possible degradation. Thus, monitoring and diagnostics play an important role in avoiding the loss of functionality of safety-related components.

The check valve is one of typical components being extensively used in safety systems of nuclear power plants. The failures of check valves have resulted in significant maintenance efforts, on occasion, have resulted in water hammer, over-pressurization of low-pressure systems, and damage to flow system components. These failures have largely been attributed to severe degradation of internal parts such as hinge pin, arms, discs, and disc nut pins resulting from instability of check valve discs under normal plant operating conditions.

The purpose of this research is to identify and recommend methods of inspection, surveillance, and monitoring that would provide timely detection of valve degradation and service wear so that maintenance or replacement could be performed prior to loss of safety functions. This research is focused on leak monitoring techniques to provide diagnostic information on the determination of check valve aging and degradation. Several commercial diagnostic-monitoring methods are evaluated, especially for the techniques based on measurements of acoustic emission, and accelerometer. In this paper, acoustic emission signals due to leak from check valve with artificial leakage and worn parts are investigated both analytically and experimentally. The results of advanced signal processing and de-noising techniques also have been addressed.

To develop AE leak detection and location capabilities for check valve including liquid-filled pipeline, an artificial leakage and worn parts in check valve should be built. In order to classify the dynamic responses of AE signatures associated with typical failure modes of check valve, a systematic approach is performed in this study. The characteristics of AE signal responses of internal parts of check valves due to local aging and degradation are analyzed by extracting effective AE parameters [1].

2. FAILURE MECHANISM OF CHECK VALVES

1.1 Failure Mechanism of Check Valves

Check valves play a vital role in the operation of power plant components and systems. During one 10-year period of reporting, more than 5,000 check valve failures were recorded by the electric utility industry. A number of these failures resulted in damage to other plant components. In another words, check valve failures have been identified as important contributors to water hammer events, over-pressurization of low pressure systems. As with any other component, these valves must operate properly and reliably when called upon to perform their design function [2,3].

Although there are many possible failure mechanisms for check valve, the most common problems are due to system flow oscillations or system piping vibrations that induce check valve component wear, and often component failure. Most failures induce additional vibration from the valve body. The most common types of physical damage in check valves are a disc/seat wear, hinge/bushing wear, foreign object interference, improper assembly separated from the hinge pin, debris on disc, stud pin broken, disc nut loose, disc partially open, disc caught on inside of the seat ring, cracked disk, worn hinge pin, and bent hinge pin, disc, or hinge arm [4-7]. Fig. 1 shows the typical failure modes and structure of swing check valves.

Swing check valves are self-contained, self-actuating valves that have no external operator to indicate their internal position or movement. Therefore, a common practice followed widely in the nuclear industry consists of valve disassembly and inspection. It is very common in a nuclear plant for 10 to 30 valves to be disassembled per outage in 1980s. This particular preventive maintenance approach raises a number of serious questions such as, maintenance-induced failures, and prolonged outages. It becomes apparent that the introduction of nondestructive evaluation techniques will significantly reduce the cost of the preventive maintenance program.

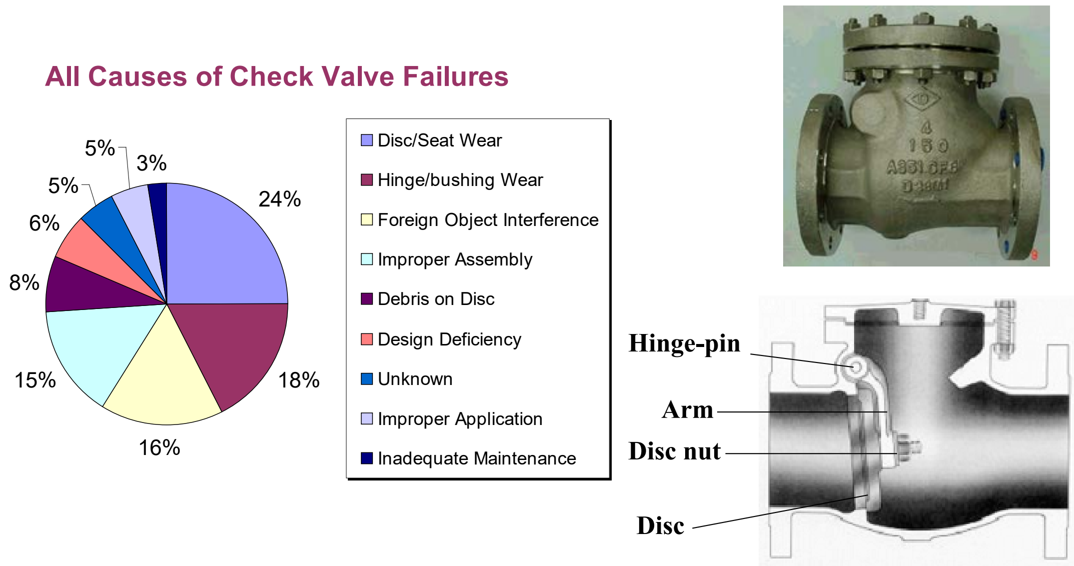


Fig. 1 The typical failure modes and structure of swing check valves.

1.2 Failure Simulation of Check Valve

The test loop was manufactured and experimented to get information of the characteristic of signal when the failure occurs. Fig. 2 shows the DVI(Direct Vessel Injection) test loop. In DVI test loop, a check valve is installed to prevent the reverse flow from the high pressurized area (primary system) to the low pressurized area. The check valve can simulate local degradation under operation in a number of ways in DVI Test Loop. For validating the suggested fusion sensor methodology, we designed a DVI hydraulic test loop including a typical swing check valve as shown in Fig 2. The test loop is designed to identify the mechanical failures of a check valve in the case that the reverse backward leakage flows are induced through a failed section in the check valve with disk wear or an inserted foreign object.

Disk wear means the disk was worn to some flaw, so the backward leakage flows are induced through the flaws. When the foreign object is inserted, the disk is not fully closed. The backward leakage flows through the open section in the check valve. Therefore, the predictive case, "Disc/seat were", "Foreign Object interface", are experimented. Fig 3 shows the picture of artificial failure of check valve.

The test check valves examined in this study are constructed of swing type check valve in Fig.3. The acoustic emission testing of check valve under controlled flow loop conditions and with the introduction of various implanted defects that simulated severe aging and service wear was performed. The check valve degradations used in the tests are listed in Table I. Fig. 3 shows the typical artificial defects of check valve.

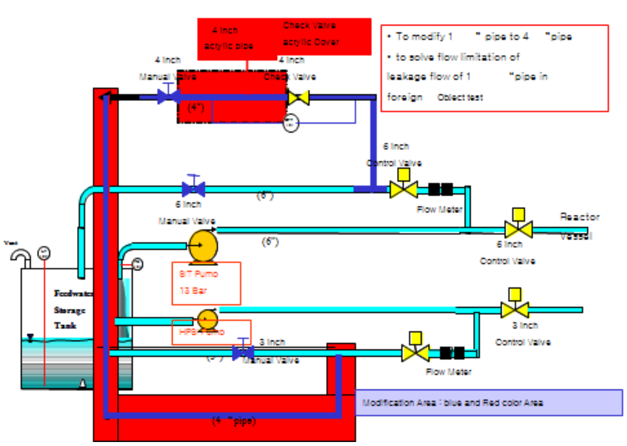
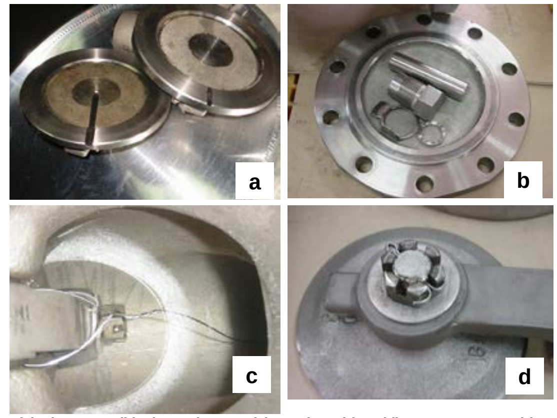


Fig. 2. DVI test loop.



(a) Disc wear (b) Hinge pin wear (c) Foreign object (d) Improper assembly

Fig. 3. The artificial defects of check valve.

Table I. Check valve degradations used in the leak test

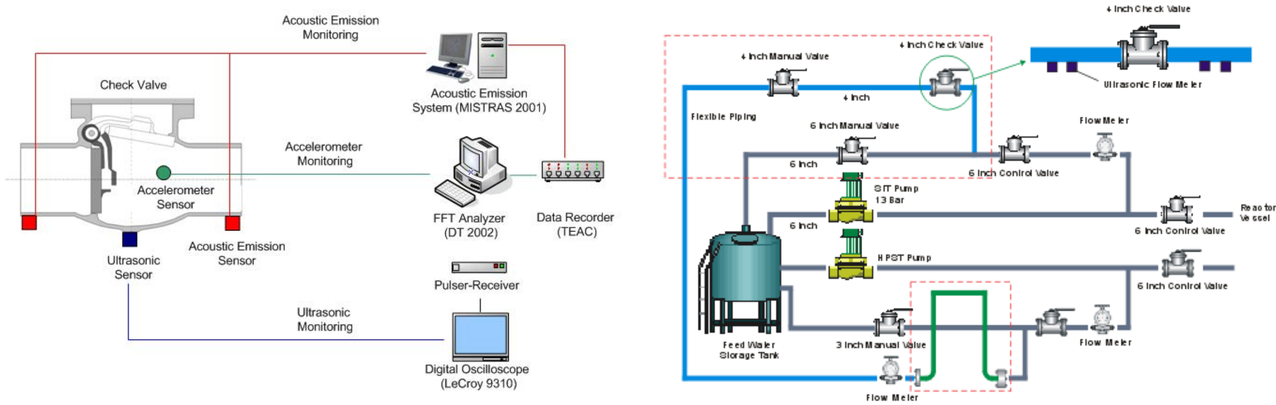
Valve with new and artificial worn disk (0, 25, 50 and 70%)
: reduction in diameter of the disc - (1.0, 2.0 and 3.0mm round cutting)
Valve with artificial leakage (0, 25, 50 and 70%)
: foreign object interference - (1.0, 1.2 and 1.6 mm welding rod)
Valve with new and artificial worn disk (0, 25, 50 and 70%)
: reduction in diameter of the hinge pin - (1.0, 2.0 and 3.0mm dia. reduction)
Valve with artificial leakage (0, 25, 50 and 70%)
: improper assembly - (Disc Pin loss caused by displacing disc from arm)
Loop condition - (0, 3, 6, 9bar/ 1060, 1300 and 1700 rpm)

3. EXPERIMENT FOR TESTING FAILURE OF CHECK VALVE

The purpose of this experiment is chiefly to collect baseline data that measured background noise level and leakage level of field for swing type check valve. This experiment was performed with three methods such as acoustic emission, ultrasonic, and accelerometer. As compared with vibration monitoring, which involves the detection of elastic wave at audio frequency (low frequency), the AE technique involves the detection of elastic waves at ultrasonic frequency (high frequency). A schematic diagram of the AE installation is shown in Fig. 4. The AE signals are detected with AE sensors attached at the center of the check valve. These AE signals detected from the sensors are amplified by a preamplifier, which had a fixed gain of 40dB. After passing through a band pass filter of 100 to 1200 kHz, to remove the electrical and mechanical background noise, the signals are amplified by the main amplifier (40dB). The AE parameters, such as AE r.m.s, energy, and frequency of AE signals, are analyzed in the AE system. In addition, a digital oscilloscope is used to analyze the AE signal waveform. Also, AE data will be collected and compared with different sensors, such as accelerometer and ultrasonic and different operating conditions.

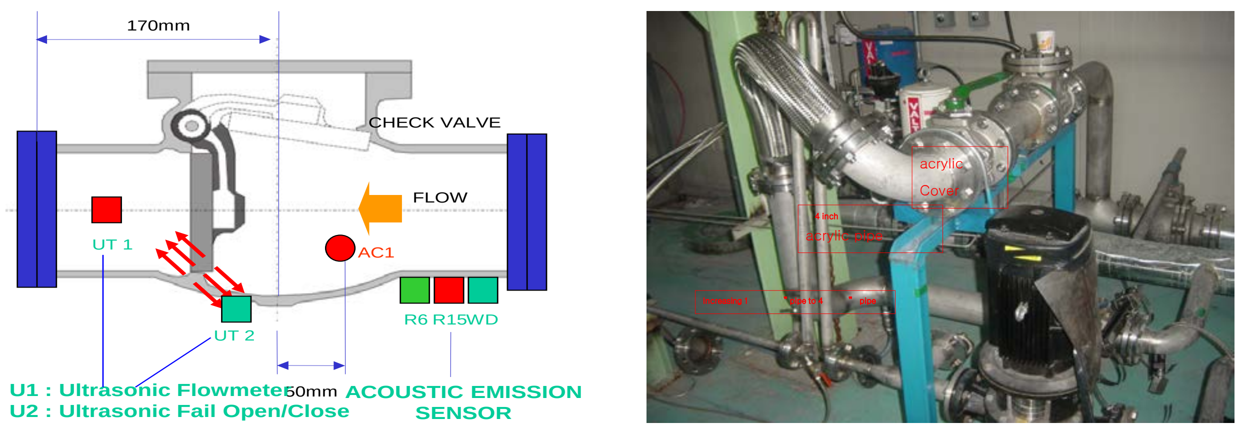
AE data of the wide band (WD) sensor was recorded at a 2Msample/sec rate, and AE data of the resonance (R15) sensor was recorded at a 1Msample/sec rate. Each data contains approximately 60 seconds of data. The overall amplitude level of the signal varies just a little during this time.

Fig. 4 provides a simplified drawing that illustrates the basic operation of the condition monitoring. Fig. 5 shows the positions of AE sensors and actual photograph.



(a) Experimental set-up (b) DVI test loop

Fig. 4. The schematic diagram of the condition monitoring test.



(a) Sensor position (b) Photograph

Fig. 5. AE sensor position for condition monitoring in 4 inch check valve.

4. RESULTS AND DISCUSSION FAILURE

Fig. 6 and 7 address the AE r.m.s data obtained from disc wear and foreign objective. That is, Fig. 6 shows the typical AE r.m.s values and corresponding pressures (or rpm) obtained from disc wear of check valve, and Fig. 7 shows the typical AE r.m.s values and corresponding pressures (or rpm) obtained from foreign objective of check valve.

It appears that energy in the signal is stabilized over a minute of recording time. This is because pump was stabilized enough before the recording data. However, as shown in Fig. 6, AE r.m.s increases as the pressure (or rpm) in the same leak size increase, and this is because leak rate increases as the pressure increases. As shown in Fig. 7, AE r.m.s values also increase as leak size increases.

It is desirable to obtain some estimates of the flow rate for a leak. This information is difficult to obtain directly from acoustic intensity data because the amplitude of the acoustic signal varies with geometry and temperature for a given flow rate. Thus, other characteristics of the signals must be examined. One possible way is to monitor the variation in the r.m.s signal with time.

Fig. 8 presents the data between acoustic r.m.s data and flow rate obtained from disc wear and foreign objective. Flow rates through the leak were measured by means of ultrasonic flow meter. As shown in Fig. 8(a) and 8(b), a linear relationship is observed. The analyses of the results suggest that acoustic signals depend on leak rate.

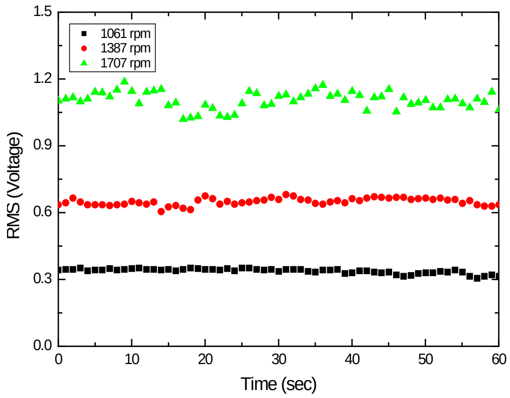
Fig. 9 shows the typical AE waveform and its spectra that obtained from pump. A primary peak with high amplitude is observed at about 90-100 kHz, and readily identified in the frequency range from 300 and 450 kHz. These signals will not provide serious effects on the detection of leaks.

Fig. 10 presents the typical AE waveform and its spectra that obtained from resonance (R15) AE sensors in disc wear and foreign objective. The waveforms reveal the continuous random fluctuations, which are the characteristics of leak induced AE. The plots were generated from 1024 data samples of waveforms.

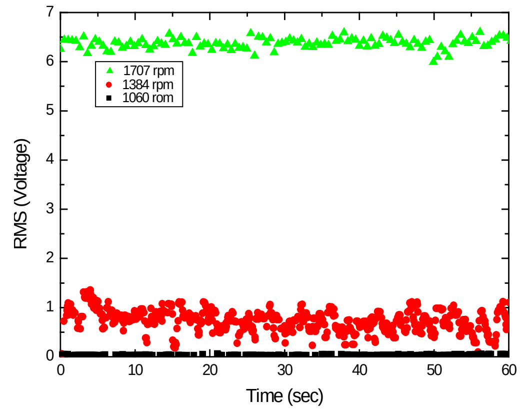
As compared disc wear [Fig. 10(a)] with foreign objective [Fig. 10(b)], the frequency range of leak signals between disc wear and foreign objective are significantly different. That is, it is significant that for the three spectra results obtained from disc wear shown in Fig. 10, all have the same general shapes, whereas the spectra results obtained from foreign objective have different shaped spectra compared with disc wear.

The spectrum of disc wear is readily identified in the frequency range from 150 to 250 kHz, whereas the peaks that are present only in the foreign objective spectrum are identified in the frequency range from 100 to 150 kHz.

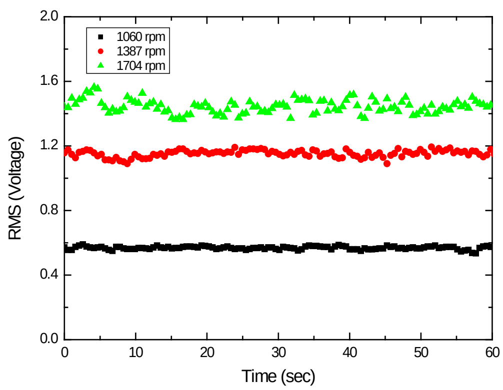
We seek to optimize the sensor position and frequency for leak detection in the field, as comparing data from such a wide band frequency (WD) and narrow band frequency (R15). It also confirmed that frequency range of leak signals between disc wear and foreign objective are significantly different in the case of wide band frequency (WD). Fig. 11 presents the typical AE waveform and its spectra that obtained from resonance (WD) AE sensors in disc wear and foreign objective.



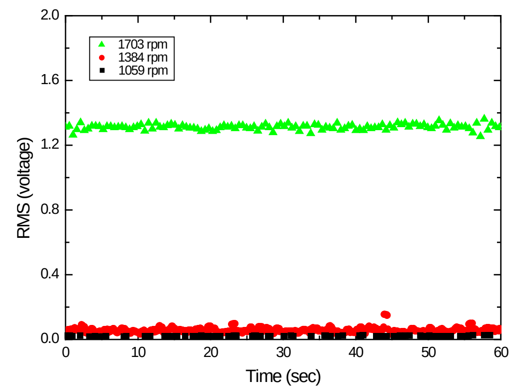
(a) Disc wear 1.0 mm



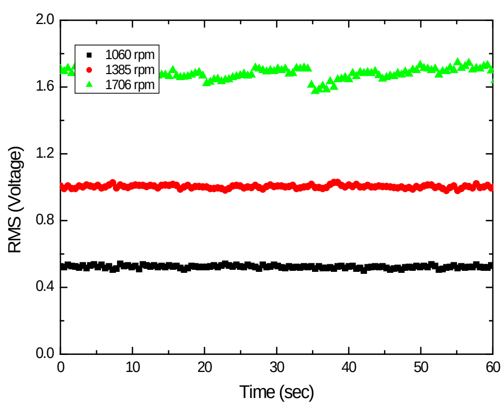
(a) Foreign objective 1.0 mm



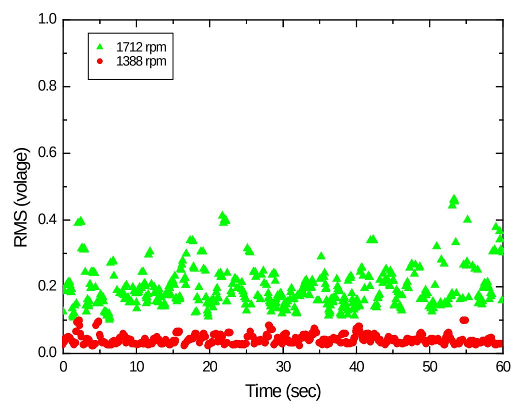
(b) Disc wear 2.0 mm



(b) Foreign objective 1.2 mm



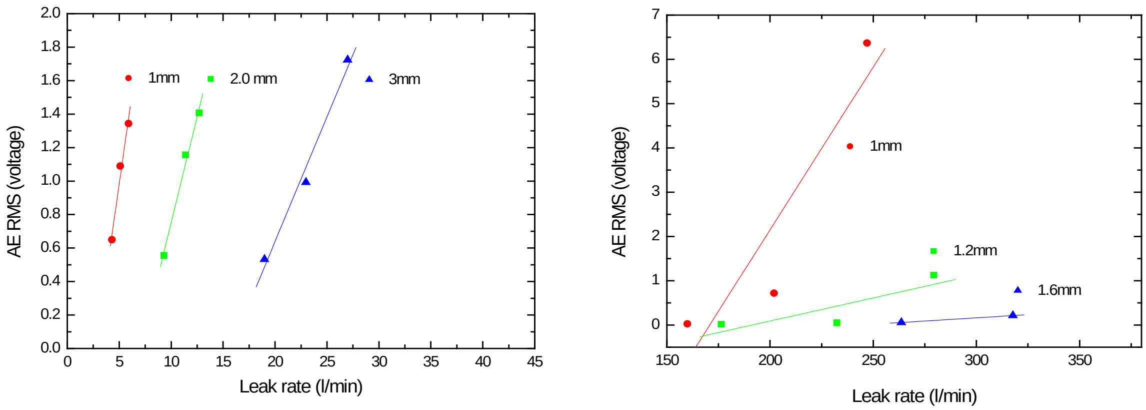
(c) Disc wear 3.0 mm



(c) Foreign objective 1.6 mm

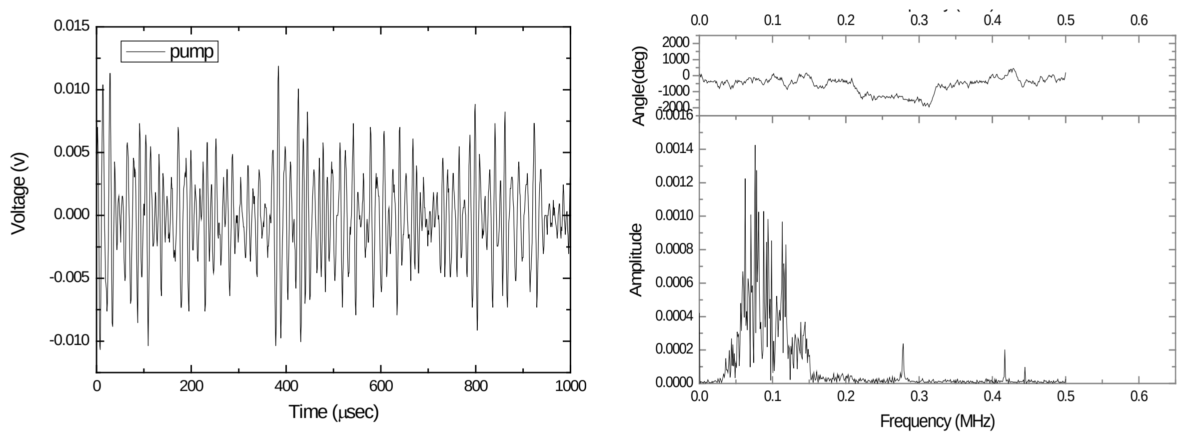
Fig. 6. The AE r.m.s values obtained from disc wear.

Fig. 7. The AE r.m.s values obtained from foreign objective.



(a) Disc wear (1.0, 2.0, 3.0 mm) (b) Foreign objective (1.0, 1.2, 1.6 mm)

Fig. 8. The AE r.m.s value vs. leak rate.



(a) typical waveform (b) acoustic spectrum (FFT)

Fig. 9. Typical waveform and its spectrum obtained from pump noise.

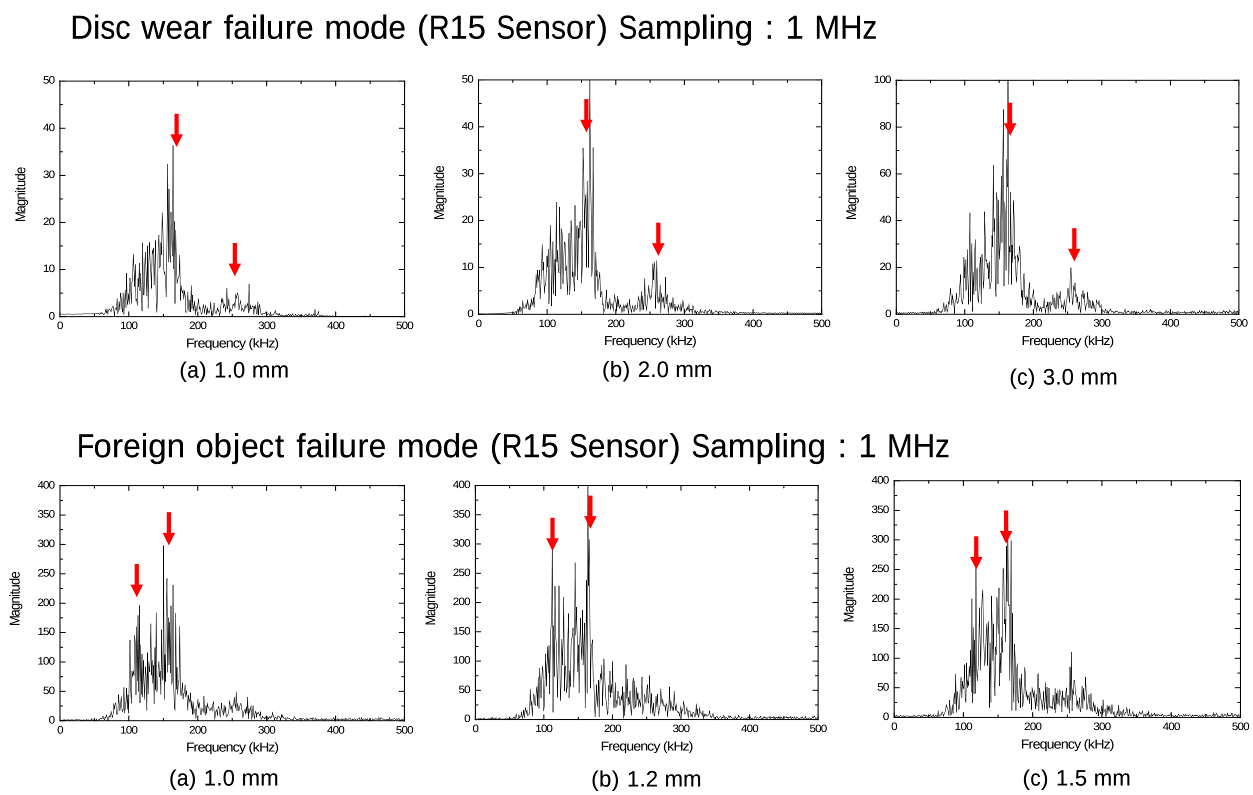


Fig. 10. Comparison of spectrums between disc wear and foreign objective (R15).

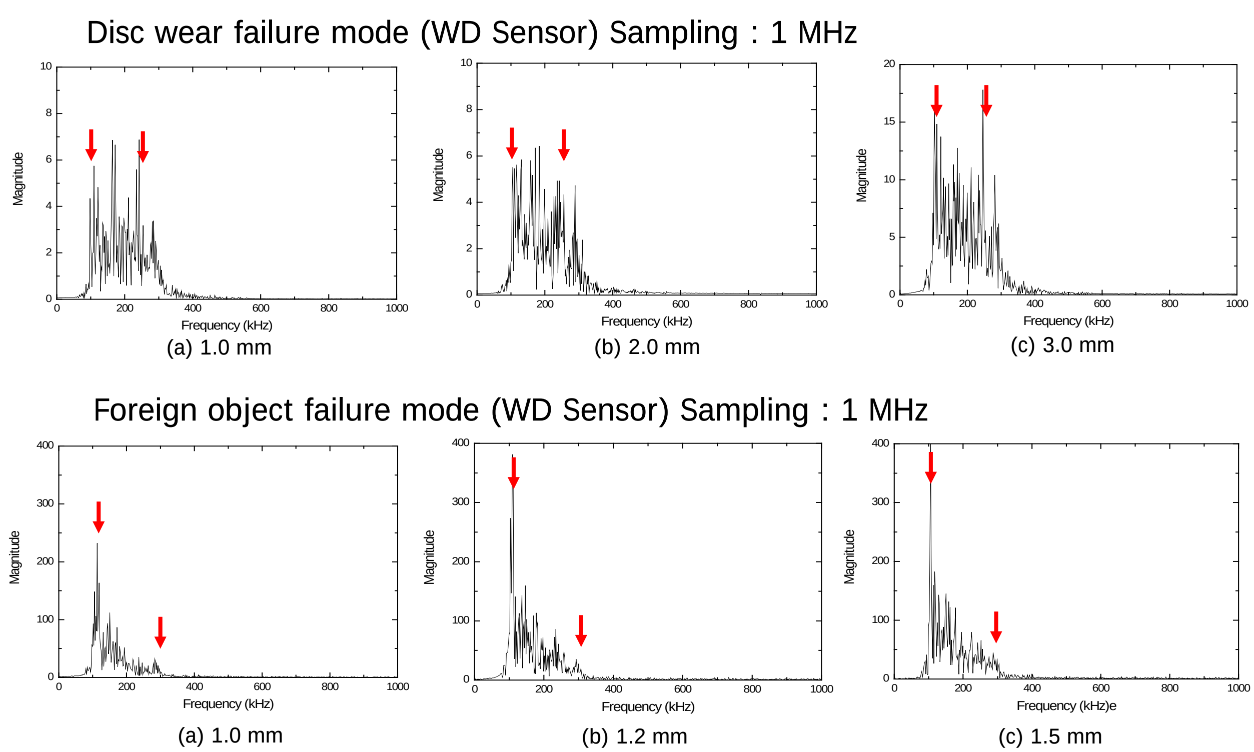


Fig. 11. Comparison of spectrums between disc wear and foreign objective (WD).

5. CONCLUSIONS

The primary objective of this research is to investigate the advanced condition monitoring systems based on acoustic emission detection that can provide timely detection of check valve degradation and service aging so that maintenance or replacement could be performed prior to loss of safety function.

Although the effectiveness of the standard for interpreting leak signals from the field has not been determined, the results of characterization of different leak sources and their behavior such as disc wear and foreign objective were successful.

It is certainly benefit, as we seek to optimize sensor position and frequency for leak detection in the field, to be able to compare data from such a wide band frequency and narrow band frequency. The spectrum of disc wear is readily identified in the frequency range from 150 to 250 kHz, whereas the peaks that are present only in the foreign objective spectrum are identified in the frequency range from 100 to 150 kHz. In addition, acoustic r.m.s. may provide quantitative information, particularly at low flow rate, where the flow may be relatively unstable.

6. REFERENCES

1. Ronnie K. Miller, Paul Mclntire: *Fundamentals of Acoustic Emission testing: Nondestructive Testing Handbook* (American Society for Nondestructive Testing, 1987)
2. [2] U.S. Nuclear Regulatory Commission, "Loss of ower and Water Hammer Event at SanOnofre, Unit, 1, on Nov. 21", *NUREG-1190*, (1985)
3. [3] S.H. Esteeck and Rosser,"Check Valve Water Hammer Characteristics", American Nuclear Society Meeting (1959)
4. [4] H.D. Haynes, et al., "Aging and Service Wear of Check Valves Used in Engineered Safety-Feature Systems of Nuclear Power Plants", *NUREG/CR-4302*, Vol. 2, (1991)
5. [5] U.S. Nuclear Regulatory Commission, "Nuclear Plant Aging Research (NPAR) Program Plan", *NUREG-1144-Rev.2*, NRC, June. 1991602-612, (1988)
6. [6] A.J. Pool, A. J. Porwit: *Prediction of Surge Pressure Form Check Valves for Nuclear* (American Socety of Mechanical Engineers, 1982)
7. [7] D.S. Kupperman, D. Prine: Application of Acoustic Leak Detection Technology for the Detection and Location of Leaks in Light Water Reactors (U.S. Nuclear Regulatory Commission, 1988)