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EVALUATION OF CHECK VALVE MONITORING METHODS*

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EVALUATION OF CHECK VALVE MONITORING METHODS*

H. D. Haynes

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ABSTRACT

Check valves are used extensively in nuclear plant safety systems and balance-of-plant (BOP) systems. Their failures have resulted in significant maintenance efforts and, on occasion, have resulted in water hammer, overpressurization of low-pressure systems and damage to flow system components. Consequently, in recent years check valves have received considerable attention by the Nuclear Regulatory Commission (NRC) and the nuclear power industry. Oak Ridge National Laboratory (ORNL) is carrying out a comprehensive two phase aging assessment of check valves in support of the Nuclear Plant Aging Research (NPAR) program.

As part of the second phase, ORNL is evaluating several developmental and/or commercially available check valve diagnostic monitoring methods; in particular, those based on measurements of acoustic emission, ultrasonics, and magnetic flux. These three methods were found to provide different (and complementary) diagnostic information. The combination of acoustic emission with either ultrasonic or magnetic flux monitoring yields a monitoring system that succeeds in providing sensitivity to detect all major check valve operating conditions. All three methods are still under development and should improve in many respects as a result of further testing and evaluation.

INTRODUCTION

Background

Check valves are used extensively in nuclear plant safety systems and balance-of-plant (BOP) systems. Their failures have resulted in significant maintenance efforts and, on occasion, have resulted in water hammer, overpressurization of low-pressure systems and damage to flow system components. These failures have largely been attributed to severe degradation of internal parts (i.e., hinge pins, hinge arms, discs, and disc nut pins) resulting from instability (flutter) of check valve discs under normal plant operating conditions. Check valve instability may be a result of misapplication (using

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oversized valves) and exacerbated by low flow conditions and/or upstream flow disturbances. [1] Present surveillance requirements for check valves have been inadequate for timely detection and trending of such degradation, because neither the flutter nor the resulting wear can be detected prior to failure.

Oak Ridge National Laboratory (ORNL) is carrying out a comprehensive two phase aging assessment of check valves in support of the NRC Nuclear Plant Aging Research (NPAR) program. ORNL check valve research provides information applicable to the NRC inspection and regulation of nuclear power plants, the ASME Pressure Vessel Code, the ASME Operation and Maintenance (O&M) Standard, and the resolution of NRC generic issues. It also is consistent with the objectives of the recently organized Nuclear Industry Check Valve Group (NIC) in coordinating the nuclear industry response to the Significant Operating Experience Report (SOER 86-03) prepared by the Institute of Nuclear Power Operations (INPO). SOER 86-03 recommends that nuclear power plants establish a preventative maintenance program to ensure check valve reliability which should include periodic testing, surveillance monitoring, and/or disassembly and inspection.

Objective and Scope

The primary objective of the check valve aging assessment program is to identify and recommend methods of inspection, surveillance, and monitoring that would provide timely detection of check valve degradation and service wear (aging) so that maintenance or replacement can be performed prior to loss of safety function(s). In that regard, ORNL has been carrying out an evaluation of several developmental and/or commercially available check valve diagnostic monitoring methods, in particular, those based on measurements of acoustic emission, ultrasonics, and magnetic flux. The evaluations in each case have focused on the capability of each method to provide diagnostic information useful in determining check valve aging and service wear effects (degradation), check valve failures, and undesirable operating modes.

A description of each monitoring method is provided in this paper including examples of test data acquired under controlled laboratory conditions. In some cases, field test data acquired in-situ are also presented. The methods are compared and suggested areas in need of further development are identified.

CHECK VALVE FUNCTION AND TYPES

Check valves are used extensively within nuclear power plants. The function of a check valve is simply to open and thus permit flow in only one direction. When the flow stops or reverses direction, the check valve closes. Check valves are self actuating - that is they require no external mechanical or electrical signal to either open or close. As a result, most check valves have no capability to be actuated other than by changing flow through the valve. Several types of check valves are commonly used, such as the swing, piston-lift, ball, and stop-check designs. The differences between types pertain to the type of obturator used. The discussions presented in this paper refer entirely to the

swing check valve, shown in Figure 1. However, all monitoring methods described herein have the potential for being applied to other check valve types.

ACOUSTIC EMISSION MONITORING

Basic Principles

Acoustic emissions (pressure waves) can be generated in a variety of ways. Of particular interest are those generated either when solids contact each other or when liquids or gases flow through pipes and fittings. Acoustic emissions are detected by sensors which respond to pressure waves over a wide range of frequencies, such as piezoelectric-type accelerometers or microphones. Signal conditioning electronics can be used to amplify selected acoustic noise signals while attenuating, e.g., unwanted environmental background noise. Analyses of acoustic emission signals obtained from check valves can be used to monitor check valve disc position, movement, and mechanical condition, as well as internal flow/leakage through the valve.

Detection of Valve Disc Movement

Acoustic emission has been shown to detect check valve disc movement. As an example, Duke Power Company [2] installed an acoustic sensor on top of a 10-inch cold leg accumulator discharge check valve. A schematic representation of the installation is illustrated in Figure 2. After initially charging the accumulator to 100 psig, the motor-operated discharge valve was cycled. The acoustic sensor output during this cycling was processed and displayed on a strip chart recorder. The resulting acoustic signature (Figure 2) shows that the sensor detected the metal-to-metal contact occurring at the end of both the opening and closing strokes.

Duke Power Company has also carried out check valve acoustic emission testing under controlled flow loop conditions and with the introduction of various implanted defects which simulated severe aging and service wear [3]. Accelerometers were strapped to the bodies of three check valves in a manner depicted by Figure 3. The following discussion summarizes the results obtained from those tests.

Tapping of the valve disc against its backstop was easily detected and distinguished from background flow noise as shown in Figure 4. In addition, by using two (or more) valve mounted acoustic sensors, Duke Power was able to approximately locate the source of the tapping based on a comparison of the "time of arrival" of the acoustic signals acquired from the two sensors. An example of this technique is shown in Figure 5.

By using the acoustic emission check valve monitoring method demonstrated by Duke Power Company, it appears likely that the following check valve operational conditions can be determined:

- * Valve rapid opening (backseat impact)
- * Valve disc tapping during reduced flow
- * Hinge arm tapping during reduced flow

* Valve rapid closing (seat impact)

Although a fully open check valve could be assumed by the existence of flow noise without the presence of tapping, the absence of detectable tapping noise is itself no guarantee that the check valve is fully open since the valve disc may be oscillating without tapping in mid-stroke or have fallen off and be in a position that prevents it from impacting the valve body at any location.

Several tests were carried out by Duke Power Company on an 8-inch check valve in new condition and with simulated degradation. Hinge pin diameters and disc/hinge arm clearances were both varied during valve cycle tests that generated acoustic emission signatures during opening and closing.

Valve closures with new and artificially worn hinge pins are illustrated in Figure 6 and show that, with the worn hinge pins, an acoustic transient preceded the seat impact. This transient may result from impact between the hinge pin and hinge arm surfaces as a result of the increased clearance between these two parts.

A similar transient event occurred as a result of increased clearance between the disc stud and hinge arm as illustrated in Figure 7. Also shown is a closure of a check valve having both a worn hinge pin and a loose disc/hinge arm connection.

Qualitative Leak Detection

Acoustic emission techniques have long been used to detect fluid leaking through a valve. Philadelphia Electric Company (PECO) has been utilizing acoustic techniques to detect valve leakage in their nuclear power plants since 1974 [4]. Their test procedure consists of acquiring two sets of valve acoustic emission readings, one while unpressurized and one with a pressure difference across the (closed) disc. The acoustic noise associated with a leaking valve is then determined based on the difference in readings.

PECO has had good success with a portable, battery-powered data acquisition unit for leakage monitoring. The acoustic data collected from baseline (unpressurized) and pressurized tests are downloaded into a computer for analysis, trending, and archiving.

Leak Quantification

It is not possible at present to quantify the absolute leak rate (e.g., in gpm) through a valve from acoustic measurements alone. However, once a leak has been detected, its growth will result in an increase in acoustic amplitude. One study by PECO correlated acoustic amplitude with leak rate through packing glands of similar valves in the same operating environment [5]. The results showed that a linear relationship existed between external leak rate and the acoustic amplitude. It is likely that changes in internal check valve leakage could be quantified in a similar manner.

Specialized Acoustic Leak Detection Equipment

Leak Detection Services, Inc., of Annapolis, Maryland, has developed an acoustic valve leak detector for use aboard U.S. Navy submarines which has also been used to detect internal valve leakage at several commercial nuclear and fossil power plants. The device permits the operator to observe the acoustic emission signals on a meter and to record them on an X-Y plotter. The device provides capability for acquiring acoustic signals from two sensors simultaneously, one sensor mounted on the valve and the other mounted on the pipe about 10 pipe diameters away from the valve [6]. The two channel responses are then adjusted and the background noise signal (acquired by the pipe-mounted sensor) is electronically subtracted from the valve-mounted signal. A positive difference signature is a qualitative indication of a leaking valve.

Other vendors which supply specialized acoustic emission monitoring equipment for valve leak detection include Canus Corporation and TAPSCO, Inc.

ULTRASONIC INSPECTION

Basic Principles

Ultrasonic inspection involves the introduction of high-frequency sound waves into a part being examined and an analysis of the characteristics of the reflected beam. Presently a device (CHECKMATE™) is commercially available from Henze-Movats, Inc., which can determine disc position of a swing check valve using an ultrasonic inspection method.

Figure 8 provides a simplified drawing that illustrates the basic operation of the CHECKMATE™ system. Two ultrasonic transducers are used, one providing an excitation signal and the other providing receiving (sensing) capability [7]. The ultrasonic signal passes through the valve body where it is reflected by the disc towards the receiving transducer. The time required for transmission of the ultrasonic signal from the sending transducer to the receiving transducer, combined with the transducer pitch angles and other valve geometries, determines the instantaneous disc position.

CHECKMATE™ also utilizes signal processing equipment which filters out undesirable ultrasonic signal reflections present in the raw received signal so that the resultant processed signal provides a more easily interpreted valve disc position signature.

Detection of Valve Disc Movement

Figure 9 illustrates an ultrasonic system installed on a swing check valve in a flow loop. Figure 10 shows ultrasonic signatures taken from the valve with flows such that the valve was full open and partially open. Figure 11 illustrates the similarity between disc motion signatures acquired with the ultrasonic sensor and with a specially installed rotary variable differential transformer (RVDT) attached directly to the hinge pin to provide a direct measurement of disc position.

Diagnostic Capabilities

Ultrasonics can be used to detect the following operational modes [8]:

<u>Operational Mode</u>	<u>Signature Characteristic</u>
Full open or full closed	Steady signal
Free flutter	Smooth cyclic signal
Backstop tapping	Similar to free flutter, but with flattened upper peaks
Seat tapping	Similar to free flutter, but with flattened lower peaks

In addition to valve disc position indication, ultrasonic signatures may be able to provide other useful information related to check valve dynamics. For example, Henze-Movats claims that more thorough signature analysis can provide estimates of hinge pin wear rates and fatigue damage of valve internal parts.

MAGNETIC FLUX MONITORING

Basic Principles

Research carried out by ORNL as part of the NPAR phase 2 study of check valves has led to the identification of another new check valve diagnostic technique, Magnetic Flux Signature Analysis (MFSA). MFSA is based on correlating the magnetic field strength variations monitored on the outside of a check valve with the position of a permanent magnet placed on a moving part inside the check valve (Figure 12).

Proof-of-principle tests have utilized a Hall-effect gaussmeter probe outside of the check valve to detect the magnitude of the magnetic field produced by a small cylindrical or rectangular (bar) permanent magnet attached to the hinge arm. The Hall-effect probe detected both stationary and varying magnetic fields, and thus continuously monitored both the instantaneous position and the motion of the check valve disc.

Detection of Valve Disc Movement

MFSA provides the ability to monitor disc position through an entire valve stroke using one externally mounted sensor. A comparison of disc position measured mechanically (by an angular displacement transducer attached to the hinge pin) with that obtained by MFSA is shown in Figure 13 for a 3-inch swing check valve whose disc was moved manually. MFSA has been applied to several swing check valves ranging in size from 2- to 10-inches.

MFSA also provides indication of disc flutter. This was demonstrated by tests carried out by ORNL on a 2-inch swing check valve, which was installed in a water flow loop. The acquired magnetic flux signatures (see Figure 14) showed that at a low flow rate (insufficient to open the valve fully), the disc

fluttered considerably in mid stroke, whereas at a higher flow rate, the same valve achieved a fully open and stable condition.

COMPARISON OF CHECK VALVE MONITORING METHODS

The preceding sections of this paper have provided descriptions of three check valve monitoring methods that are useful in determining check valve position, motion, and leak rate. These methods, based on acoustic emission, ultrasonic inspection, and magnetic flux monitoring, function according to different principles of operation and thus provide different (and complementary) diagnostic information. At present, the estimated capability of each monitoring method to detect various check valve operational conditions is given in Table 1 below. The methods are rated according to the following scale: P - poor or none, F - fair, G - good, E - excellent.

CHECK VALVE OPERATIONAL CONDITION	ACOUSTIC EMISSION	ULTRASONIC INSPECTION	MAGNETIC FLUX SIG. ANALYSIS
FULL OPEN	P	E	E
MID POSITION FLUTTERING	F	E	E
TAPPING			
detecting	E	G	G
locating	F	E	E
LEAKAGE	E	P	P

Table 1. Diagnostic Capability of Three Check Valve Monitoring Methods

Combined Diagnostic Techniques

As indicated in Table 1, while no single technique has the capability to detect all check valve operational conditions well, a combination of acoustic emission with either ultrasonic inspection or magnetic flux signature analysis can yield a monitoring system that succeeds in providing sensitivity to detect all major check valve operating conditions. Both acoustic/ultrasonic and acoustic/magnetic combinations have been tested.

The result of using a combination of an acoustic and an ultrasonic sensor is seen in Figures 15 and 16 [9] which compares data from the two sensors obtained for a check valve tapping its backstop and its seat respectively. In both tapping modes, the acoustic signature detected the tapping but not its location. The ultrasonic signature did not unambiguously detect the tapping, but, in conjunction with the acoustic signature, identified its location.

The combination of acoustic emission and magnetic flux monitoring also provides a useful monitoring system for check valves. This is illustrated by Figure 17, an example of test data acquired by ORNL on a check valve whose disc was moved manually to simulate disc fluttering at different portions of the stroke. Figures 18 and 19 [10] illustrate the response of acoustic emission and magnetic flux sensors to valve closing and opening, both with and without valve degradation.

A commercialized acoustic/magnetic check valve monitoring system is presently under development by Liberty Technology Center, Inc.

NUCLEAR INDUSTRY TESTS OF CHECK VALVE MONITORING METHODS

The three check valve monitoring methods described in this paper will be evaluated in a comprehensive test program which will be carried out early next year under the direction of the Nuclear Industry Check Valve Group (NIC). An assessment will be made of the capability of each monitoring method to detect disc position and motion, wear of valve internals and leakage. Each method will be also evaluated as to portability, repeatability, and applicability to different valve sizes, valve materials, and fluids. This test program, as well as other activities carried out by NIC, will likely make a significant contribution towards solving the check valve problems facing the nuclear industry today.

CONCLUSIONS

This paper has presented a description of three check valve monitoring methods that may be useful in determining check valve condition: disc position, disc motion, and seat leakage. None of the methods were capable of detecting all three parameters, although a combination of two methods was successful. All three methods are still under development and all should improve in capability to detect not only operating condition but degradations as a result of further testing and evaluation. The selection of a check valve monitoring method (or methods), based on the test program to be carried out by NIC, should lead to a greatly improved capability to monitor check valve performance in-situ, and should result in increased reliability of these important components of nuclear plants.

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Figure 1 Typical Swing Check Valve

Figure 2

Acoustic Signal vs. Time for a Ten Inch Check Valve
Tested by Duke Power Company in March, 1984

Taken from: W. M. Suslick, H. F. Parker, B. A. McDermott.
*Acoustic Emission Monitoring of Check Valve
Performance.* Presented at the EPRI Power
Plant Valves Symposium, October 11-12, 1988.
Charlotte, NC.

Figure 3 Acoustic Emission Equipment (schematic representation)
Used by Duke Power Company in 1987 Flow Loop Tests

Taken from: W. M. Suslick, H. F. Parker, B. A. McDermott.
*Acoustic Emission Monitoring of Check Valve
Performance.* Presented at the EPRI Power
Plant Valves Symposium, October 11-12, 1988.
Charlotte, NC.

Figure 4 Acoustic Waveforms for a Check Valve During Unstable (tapping) and Stable (flow noise only) Operations

TAPPING LOCATION	SENSOR RESPONDING TO PRESSURE WAVE FIRST
HINGE PIN	THE ONE NEAREST THE HINGE PIN
BACKSTOP	THE ONE NEAREST THE BACKSTOP

Taken from: W. M. Suslick, H. F. Parker, B. A. McDermott.
*Acoustic Emission Monitoring of Check Valve
 Performance.* Presented at the EPRI Power
 Plant Valves Symposium, October 11-12, 1988.
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Performance.* Presented at the EPRI Power
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Figure 6 Check Valve Closures with New and Artificially Worn Hinge Pins

Acoustic emission waveform of swing
check valve closure with worn disc stud connection.

ACOUSTIC SIGNAL

TIME

Acoustic emission waveform of swing
check valve with worn hinge pin and disc arm connection.

ACOUSTIC SIGNAL

TIME

Taken from: W. M. Suslick, H. F. Parker, B. A. McDermott.
*Acoustic Emission Monitoring of Check Valve
Performance.* Presented at the EPRI Power
Plant Valves Symposium, October 11-12, 1988.
Charlotte, NC.

Figure 7 Check Valve Closures with Two
Artificially Worn Conditions

Figure 8 CHECKMATE™ System Basic Principle of Operation

*Used with the permission
of HENZE-MOVATS, Inc.*

TEST ID : 072089-V1
STROKE ID : Special Plot
PLOT DATE : 07-20-1989

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of HENZE-KOVATS, Inc.*

Figure 10 CHECKMATETM Signatures During Stable and Unstable Check Valve Operations

TEST ID : 072089-V1
STROKE ID : Special Plot
PLOT DATE : 07-20-1989

CHECKMATE VS. RVDT ON HINGE PIN

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of HENZE-KOVATS, Inc.*

Figure 11 Comparison of CHECKMATETM Signature with that from a RVDT
Installed on the Hinge Pin of a Check Valve

Figure 12 Magnetic Flux Signature Analysis (MFSA)
Principle of Operation

¹ measured mechanically (angular displacement transducer)

² gaussmeter probe installed on valve cap

Figure 13 Comparison of Magnetic Field Strength and Disc Angular Position Measurements

Figure 14 Use of MFSA to Detect Disc Instability (flutter)

TEST ID : 072089-V1
STROKE ID : Special Plot
PLOT DATE : 07-20-1989

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of HENZE-MOVATS, Inc.*

Figure 15 Checkmate and Acoustic Signatures for a Check Valve Undergoing Backstop Tapping

TEST ID : 072089-V1
STROKE ID : Special Plot
PLOT DATE : 07-20-1989

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of HENZE-NOVATS, Inc.*

Figure 16 Checkmate and Acoustic Signatures for a Check Valve Undergoing Seat Tapping

DISC MOVED MANUALLY

Figure 17

Magnetic Flux and Acoustic Signatures for a Check Valve Under Several Simulated Operational Conditions

VALVE OPENING

Taken from: J. W. McElroy. *Acoustic/Magnetic Test Techniques for Verifying Operation of Check Valves.*
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Figure 18 Acoustic Emission and Magnetic Flux Signatures for a
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Taken from: J. W. McElroy. *Acoustic/Magnetic Test Techniques for Verifying Operation of Check Valves*.
Presented at the ASME/NRC Symposium on
Inservice Testing of Pumps and Valves. Aug. 1-3, 1989.

Figure 19 Acoustic Emission and Magnetic Flux Signatures for a Check Valve Closure With and Without Degradation