KAERI/RR-1660/96

KR9700239

원전 배관의 열성층화 감시 기술 개발

Development of Monitoring Technique for Thermal Stratification in Nuclear Plant Piping

1996. 12.

한국원자력연구소

29-01

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제 출 문

한국 원자력 연구소장 귀하

본 보고서를 원전 기술 개발 과제 "원전 배관 열성층화 감시 기술 개발" 최종 보고서로 제출 합니다.

1996년 12월 15일

연구실명: 응용그룹 비파괴 평가팀
시스템구조검사분야/기술 개발분야

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요 약 문

I. 제목 : 원전 배관의 열성층화 감시 기술 개발

II 연구 목적 및 중요성

현재 원자력발전소에서는 NRC 권고에 따라 열성층화 발생 가능 배관에 대하여 conventional 비파괴검사를 수행하고 있으나 이것은 이미 열성층화의 지속으로 인한 outside open된 열피로 균열을 검출하는데 적합할 뿐이며 근본적인 문제 해결 방법은 되지 못한다. 열피로 균열을 검출했을 경우 관련 배관의 결함을 제거하는 보수 작업이 뒤따라야 하므로 보수에 많은 어려움과 비용이 소요되게 된다. 따라서 본 연구의 목적은 열성층화 감시 장치를 개발하여 영광1, 2호기에 설치함으로써 한국 원전에 대한 열성층화 현상을 조사하고 감시 장치의 타호기 적용 , special UT 검사 부위 와 주기 결정, 원전의 실시간 피로 감시를 위한 응력 해석 프로그램에 이용하고자 한다. 또한 열성층화를 유발하는 결함 역지 밸브에 대하여 비해체법(Non-Intrusive Method)을 이용한 성능 진단법중 음향 발생법, 자기법을 개발하여 열성층화 현상을 근본적으로 예방하는 데있다.

III 연구 내용 및 범위 :

본 연구에 있어서는 1차년도에 개발한 열성층화 감시 장치(TSMS)를 배관의 열성층화 예상 부위에 설치하여 NRC-Bulletin 88-11, 08의 요구사항을 만족하고 가동중인 원전의 열성층화 현상을 조사하여 배관의 건전성 확보를 위한 밸브의 보수, special UT 검사 주기 결정 및 응력 해석에 이용토록하며 열성층화 현상을 유발하는 밸브 누설 및 밸브 성능 저하를 진단할 수 있는 비해체법(Non-Instrusive)을 개발하고자 한다.

본 연구에 있어서 단계별 목표는 다음과 같다.

- 감시 프로그램 개발 및 영광 1,2호기 원전에 감시 장치로 부터 데이터를 수집하여 열성층화 현상의 조사, 특수 초음파 검사 주기결정 및 응력 해석 프로그램 활용

- 비해체법(Non-Intrusive Method)중 음향발생법, 자기법을 이용한 밸브 성능진단법을 개발.

IV. 연구 결과및 활용에 대한 건의

1. 2 차년도

가. 영광 1.2호기 비상냉각계통(ECCS) 열성층화 현상를 조사한 결과 배관의 상하 온도범위가 50° C 로 TASCS의 값과 비교한 결과 열성층화 현상이 심하지 않음.

나. 가압기 밀림관(surge line) 열성층화 현상을 조사한 결과 RCS heat up시 배관의 상하 온도 범위가 79.2° C로 나타남으로써 Trojon 발전소의 온도 변위의 결과보다 차이가 작음.

다. 특수 초음파 검사 수행 부위표 작성

다. 자기법 및 음향 발생법을 이용한 역지 밸브 진단법의 개발로 초음파 방법으로 수행이 어려운 밸브 내부에 물이 없는 상태 및 스테인레스 스틸(stainless steel)로 만들어진 역지 밸브를 비해체법으로 진단할 수 있음.

2. 활용에 대한 건의사항

열성층화는 밸브의 누설및 성능 저하로 말미암아 발생한다. 따라서 밸브를 해체하지 않고 빠른 시간내에 성능을 진단할 수 있는 기술이 필요하다. 이러한 기술을 실용화 할 수 있는 장비개발을 위하여 계속적인 연구가 필요하며 다음 사항을 활용 할 수 있도록 건의한다.

가. 영광 원전 배관에 대한 열성층화 예상부위 선정 자료 및 결과는 PWR형 타운전호기에 대한 자료로 사용될 수 있다.

나. 기계구조개발실에서 수행한 "원전 1차 계통 부품의 기계공학적 감시 시스템 개발"과제에서 개발한 배관 균열 감시 프로그램은 열성층화 감시 장치 (TSMS)에서 취득한 자료를 활용 할 수 있다.

다. TSMS에서 취득한 자료를 분석하여 특수 초음파 검사(special UT) 수행 부위와 검사 주기 결정에 이용될 수 있다.

라. 비해체법을 이용한 역지밸브의 성능 진단법은 밸브의 비정상 동작을 조기에 쉽게 감지 할 수 있어 앞으로 관련 규격 사항 ASME-OM code IST-C" Inservice exercising tests for category check valves," 1994을 만족 할 수 있다.

SUMMARY

I. Project Title

The Development of Monitoring Technique for Thermal Stratification in Piping

II. Objective and Importance of the Project

Several incidents in foreign Nuclear Power Plants resulting from unpredicted thermal loading have resulted in significant concern over some crack caused by the thermal stratification in the connection to the reactor coolant system and surge line. U.S NRC bulletin 88-08 and 88-11 have been issued following incidents, which asked each utility to set up a countmeasures-program for thermal stratification problem in pipes.

The conventional nondestructive testing has been performed in those area which are susceptible to thermal stress crack since NRC issued the bulletins. In addition to that, it is necessary to set up a monitoring system to prevent severe thermal stress to pipes in early stages and to develop the non-intrusive techniques to diagnose the check valve because the thermal stratification

has been caused by the malfunction of the check valve in ECCS piping. The nonintrusive method has been developed with acoustics and magnetics for the test of check valve.

III. Scope and Contents of the Project

Thermal Stratification Monitoring System(Hereafter TSMS) has been designed and installed at ECCS line permanently and at surge line temporally in Younggwang-Nulcear Power Plant. The data originated from TSMS is useful for the arrangement of a special NDT program and stress analysis. Finally, the diagnostic techniques for check valve is developed using acoustics and magentics.

1. The Scope of the first phase

   a. YG-2 thermal stratification survey in ECCS and surge line pipes
   b. Table of exam-list for a special UT

2. The scope of the 2nd phase

   a. The development of the non-intrusive method for diagnosing check valve with acoustics and magnetics

b. Draft the procedure of the check valve test using acoustics and magnetics

IV. Results and Proposal for Applications

1. Results

a. Highly vulnerable area to thermal stratification has been chosen. 11 points is available for another PWR nuclear units and the points of a special UT has been tabled.

b. The data of thermal stratification acquired permanently in ECCS and temporally in surge line is acceptable comparing to TASCS project's result

c. 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. The magnet sensors can be used to detect the disc frequencies of stainless steel check valve on which the ultrasonics transducers can not be used.

2. Proposal for Applications

The process of the selection of the thermal stratification point in YG-1,2 would be helpful to application to the other plants. The data taken from TSMS in both ECCS and surge line can be used as basic data for the project "Development of Operating Transients Monitoring System for Primary Components of Nuclear Power Plants" performed by Dept. of Mechanical Structure Development, KAERI. Thermal stratification analysis data can be a useful tool to set up a special NDT program and to run stress analysis program. TSMS is monitoring the thermal stratification phenomena to keep the pipe integrity during operation. Also, the diagnostic techniques for check valve using the acoustics and magnetics is developed because the thermal stratification occurred by the malfunction of check valve in ECCS pipe. Additionally, internal leakage is detected by the dB of power spectral density. As the intrusive method is available in the check valve test, ASME-OM code IST-C" Inservice exercising tests for category check valves," 1994 will be able to be achievable.

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I. Introduction

In according to NRC bulletin 88-08, 88-11, conventional non-destrustive testing has been performed on the area which is susceptible to thermal stratification in nuclear power plant[1,2]. The performance, however, is not fundamental countmeasures to prevent the causes of themal crack due to thermal stress. Even though the crack is found, it is likely to be diffcult to repair it. Therefore, it is necessary to set up the monitoring system to detect early the phenomena to cause the thermal crack. Originally, the thermal stratification results from valve leakage adjacent to RCS line. In this project, thermal stratification monitoring system is developed to survey the kind of a symptom. The survey has been performed in PZR surge line and ECCS line. It is crucial to diagnose to check valve under malfunction resulting in leakage resulted in thermal crack. Check valves used in industrial and Nuclear Power Plant safety systems are susceptible to failure types generally associated with wear of internal parts. Specifically, hinge pins, disc studs, pistons, and other mechanical parts may degenerate over time that in some cases can produce a disabling occurence 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, can lead to radiation exposure in some situations.

Recent studies carried out by EPRI, NRC discovered that many of these safety-related valves were not functioning properly. Typical problems found in these valves included missing disks, 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 KINS-G-018. To meet this requirement, check valve has been disassembled, visually inspected, and then reassembled.

In response to the requirments, various equipment to test and monitor check valves has been intrusively developed. This paper describes the intrusive method of techniques for detecting not only check valve degradation or failure in service but also internal leakage using power spectral density.

II. Data of thermal stratification

2.1 Thermal stratification

Several incidents in neclear industry, resulting from suddenly thermal loading have caused severe concerns over the crucial effects of thermal stratification, srtiping, and cycling in piping system. U.S NRC bulletin 88-08 and 88-11 have been fowarded following incidents in the PWR various unisolable piping sections and PWR pressurizer surge lines. As a result, significant efforts have been expended by nuclear power plant. These include pipe inspections, monitoring program valve test with a nonintrusive method and valve leakage detection.

Thermal stratification is the separation of hot and cold fluids typically in a horizontal or nearly horizontal pipe as a result of buoyancy effects, caused by small flow rates such as those found in pressurizer surge lines and lines subject to valve leakage. Cycling is the variation of stratification related loaded with time. These variation result in load cycles which could subsequently result in fatigue failures. Striping is localized flucttering thermal loads. Under certain flow conditions, the hot/cold interfaces in stratificated pipe flow fluctuates in a wave-like fashion. Turbulent penetration is the secondary turbulence in connected branch lines caused by turbulent flow in the reactor coolant loop. It has a strong infulence in thermal boundary conditions and cycling behavior in stratificated flow

Lines susceptible to thermal stress vary depending on the number of reactor coolants loops, the ages of the design

● PZR surge line This issue is the subject of NRC Bulletin 88-08 Supplement 3.

● Safety Injection System (SIS) : The high head safety injection systems are most common. In three loop designs, this includes six connections to the reactor coolant system (RCS) through 6" nozzles.

● Chemical Volume and Control System (CVCS) : The auxiliary spray and charging system are commonly susceptible systems in all design types. This affects two connections to the RCS and one connection to the main spray line.

● Residual Heat Removal(RHR) : Based on the failure at the Genkai plant the RHR suction lines were considered. This issue is the subject of NRC Bulletin 88-08 Supplement 3.

When the valve leaks, the themal stratification line in ECCS as below can be listed in the Younggwang 1,2 and Kori 3,4 nuclear power plant.[3,4]

(1) RHR RECIRCULATION LOOP 1 (Outleakage)

- HV 102 Upstream

(2) RHR RECIRCULATION LOOP 3 (Outleakage)

- HV 201 Upstream

(3) SIS HOT LEG INJECTION LOOP 1 (Crossleakage)

- V058 Downstream

(4) SIS HOT LEG INJECTION LOOP 2 (Crossleakage)

- V059 Downstream

(5) SIS HIGH PR. LOOP 3 (Inleakage)

- V060 Downstream

(6) SIS COLD LEG INJECTION LOOP 1 (Crossleakage)

- V057 Downstream

(7) SIS COLD LEG INJECTION LOOP 2 (Crossleakage)

- V056 Downstream

(8) SIS COLD LEG INJECTION LOOP 3 (Crossleakage)

- V055 Downstream

(9) SIS ACCUMULATOR A, (Outleakage)

- V073 Downstream

(10) SIS ACCUMULATOR B, (Outleakage)

- V074 Downstream

(11) SIS ACCUMULATOR C, (Outleakage)

- V075 Downstream

(12) CVCS NORMAL CHG A - V093 Downstream

(13) CVCS NORMAL CHG B- V092 Downstream

2.2 Data of the thermal point

In order to alarm early the phenomena of the thermal stratification, TSMS(thermal stratification monitoring system) (Fig.1) is develpoed. Now that the basic data of pipes of temperature is acquired, it is possible to keep the pipe the integrity in following the analysis of data and the analysis of thermal stress. Consequently, the frequency of a special UT requested by the KINS is dependent on the data originated from the survey is performed on both the PZR surge and ECCS line.

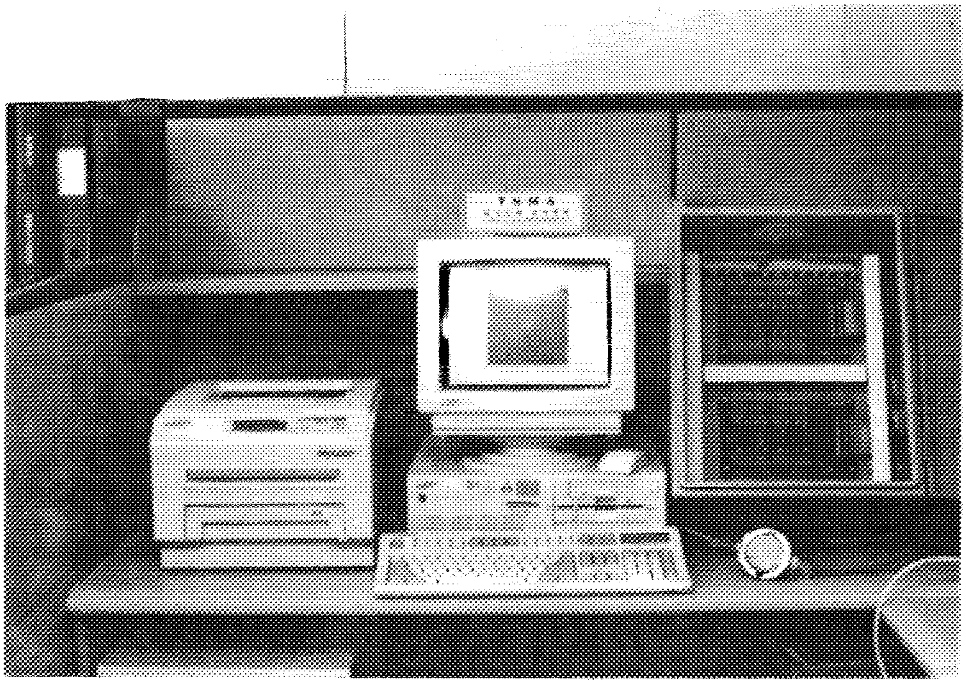


Figure 1. Thermal stratification monitoring system.

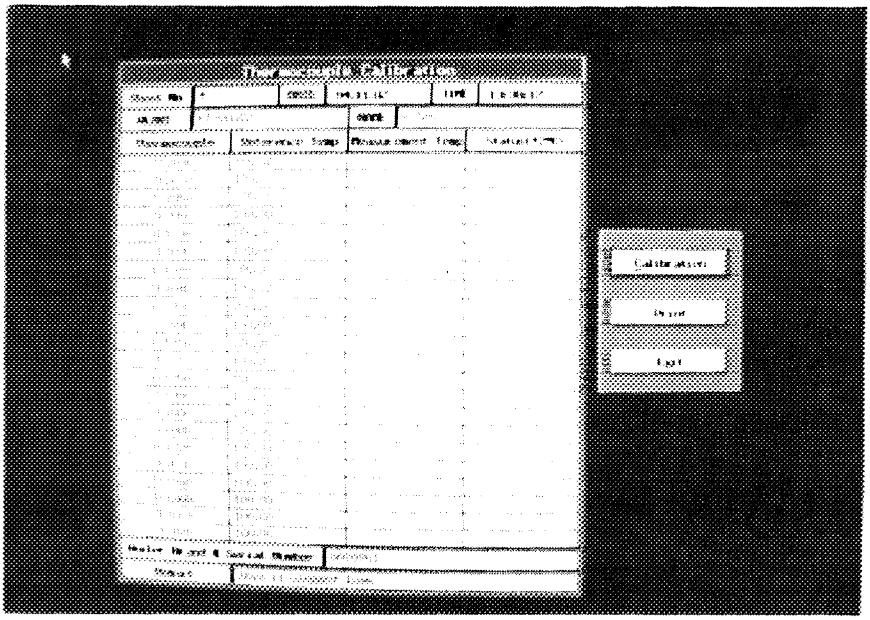


Figure 2. Thermocouple calibration sheet

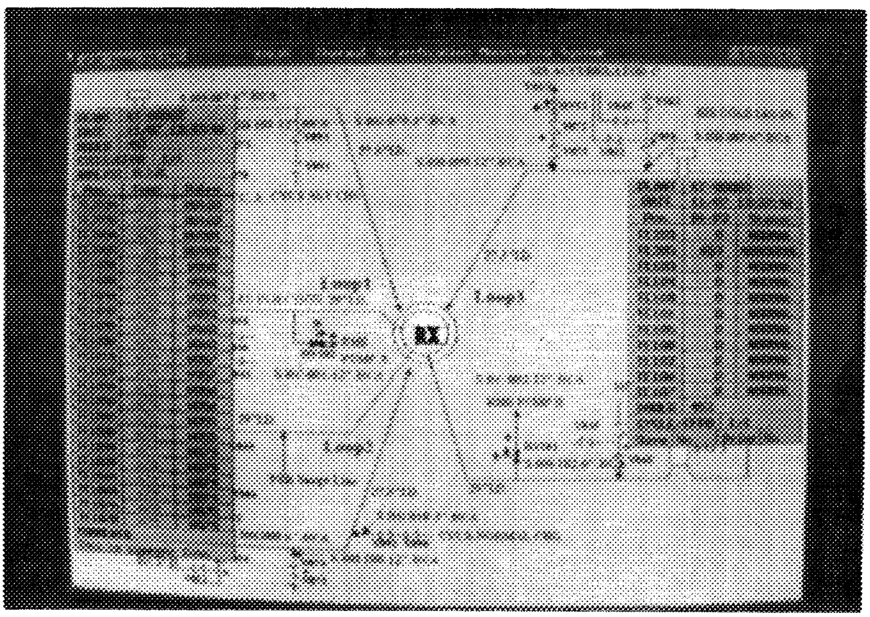


Figure 3. Data management software program

2.1 PZR surge line.[4,5]

The thermocouple attached to pipe up and down is used to measure the temperature relating to thermal stratification occured at PZR surge line. This data acquired for the start up and the full power is helpful to set up the countmeasures in Younggawng 1. The data is listed in table 1. While RCS heat up, the difference of thermocouple 9, 10 exhibit maximumly 79.2 ° C. Before the up and down of a surge pipe is coming to the the balance of thermal , the temperature of RCS is highly going up. Therfore, the difference occurred at those point. When the 100% of power is availiable, thermocouple 5, 6 in diffenence appears 42.1 ° C at maximum figure.

Now that the temperature of RCS becomes stable, the range of difference becomes narrow comparing to Trojon's data. Accordingly, it is not serious in the Younggwang site.

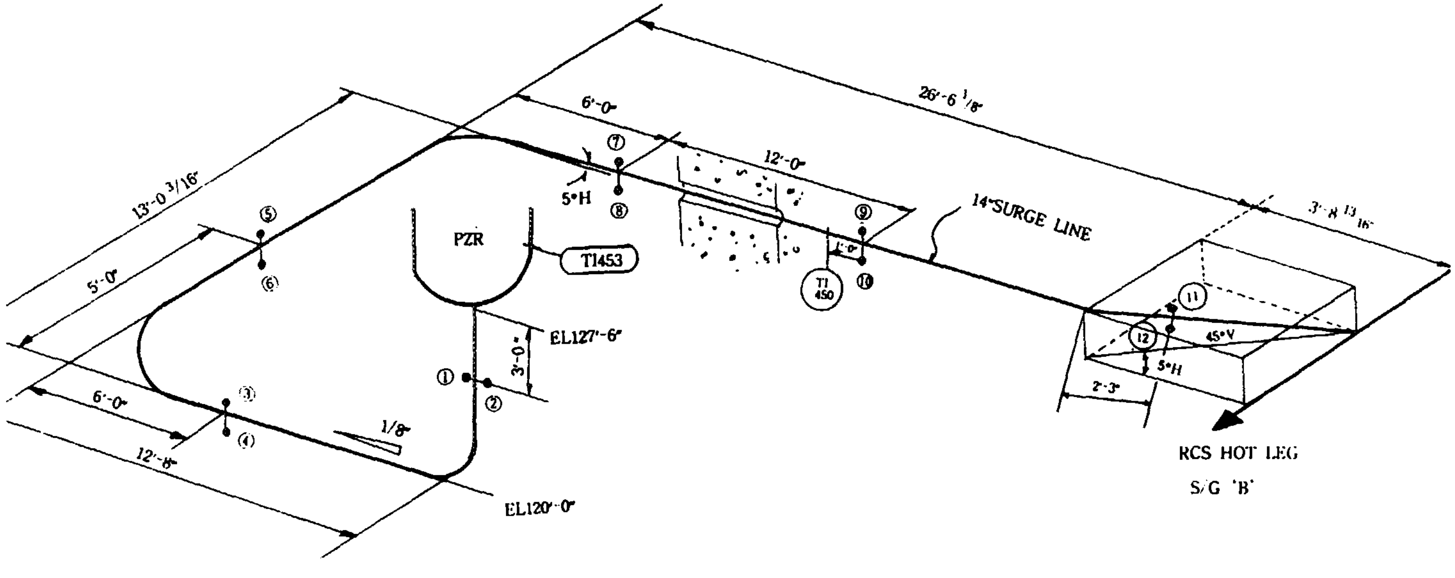
2.2 ECCS Line

TSMS mainly consists of skin type thermocouple connected to a panel with the conpensation cable. Data management software periodocally produces the data relating to the thermal stratification in 11 points. CVC line is excluded in the monitoring program.

That is why the phenomena is easily detected and the difference range is not severe. Since the range of differnce is within an allowable limit in according to TASCS (Thermal stratification cycling striping) project which has been conducted by EPRI and utilities since 1990. The range of difference between up and down is approximately 50 ° C equal to criterion reflected from TASCS 'result. The data is stored three times during the 100% of power following the 8th overhaul. For further survey, it is necessary to install more sensors circumferentially on the horizontal line. The sensors should be located at not only the weldment but also basemetal. Intuitively, one point at least needs more than 4 sensors. There are the alternative way to utilize a data logger which does not need cable to connect the pannel for out-side storage. When the overhaul start, the data logger removes and is connected on the computer program to release the data of temperature hidden in the logger for the 1 outage. Westinghouse has been running the thermal stratification program on the more than 50 nuclear power plants with a device of the data logger.[3]

Table 1. Surge line thermal difference data ⊿T:T1-T2, ° C

Time/No	95.9.30 16:13	22:26	10.1 02:26	11:25	13:25	15:25	11.18 10:25	11.19 14:00	11.25 9:59
1	87.3	104.3	178.4	229.6	228.2	225.9	345.6	345.6	345.6
2	87.6	105.4	178.9	230.3	229.7	228.1	348.0	348.0	348.0
⊿T	-0.3	-0.9	-0.5	-0.7	-1.5	-2.2	-2.4	-2.4	-2.4
3	86.8	103.1	175.7	227.8	226.4	225.5	343.7	343.8	343.7
4	88.2	93.8	145.9	196.9	231.7	198.2	343.4	343.7	343.5
⊿T	-1.4	9.3	29.8	30.9	-5.3	24.3	0.3	0.1	0.2
5	87.3	101.7	175.6	229.1	228.4	223.8	344.8	344.9	344.8
6	81.4	84.6	121.6	154.9	205.4	173.7	302.9	303.1	302.7
⊿T	5.9	17.1	54.5	74.2	22.9	50.1	41.9	41.8	42.1
7	87.8	102.7	177.6	230.2	230.7	224.7	347.0	347.1	347.1
8	87.1	88.7	118.4	151.8	200.8	178.2	331.3	331.3	331.2
⊿T	0.7	14	59.2	78.4	29.2	46.5	15.7	15.8	15.9
9	87.7	101.3	175.9	231.0	230.7	220.7	345.9	345.9	345.8
10	87.9	88.1	118.7	151.8	199.8	179.1	332.6	332.7	332.8
⊿T	-0.2	13.2	57.2	79.2	199.8	41.6	13.3	13.2	13
11	88.1	88.1	107.1	155.4	198.0	187.0	335.4	335.8	334.9
12	83.9	83.9	98.0	136.2	176.6	171.8	331.9	321.8	321.5
⊿T	4.2	4.2	9.1	19.2	21.4	15.2	13.5	14	13.4
Re-mark		Heat up	Heat up	Heat up	Heat up	Heat up	Rx Power:100x Flow(PZR->Hotleg)		



1. 배관상부 : 3, 5, 7, 9, 11
2. 배관하부 : 4, 6, 8, 10, 12
3. 배관좌우 : 1, 2

Figure 4. The sensor location of surge line

Table 2. ECCS thermal difference data ⊿T:T1-T2, ° C

NO / Time	1996.05.30 13:41:24	1996.06.27 14:31:22	1996.10.14 17:37:19	Remark
TE 203A	162	119	149	
TE 203B	212	173	201	
⊿T	-50	-54	-52	
TE 205A	115	70	91	
TE 205A	163	120	139	
⊿T	-47	-50	-48	
TE 103A	176	131	161	
TE 103B	226	184	212	
⊿T	-50	-53	-51	
TE 104A	204	165	207	
TE 104B	255	218	260	
⊿T	-50	-53	-53	
TE 109A	193	154	185	
TE 109B	244	206	236	
⊿T	-50	-52	-51	
TE 101A	102	56	99	
TE 101B	148	105	147	
⊿T	-46	-49	-53	
TE105A	57	9	52	
TE105A	103	58	99	
⊿T	-46	-49	-47	
TE 108A	173	132	165	
TE 108A	225	187	217	
⊿T	-52	-55	-52	
TE 102A	200	160	191	
TE 102A	251	214	243	
⊿T	-51	-54	-49	
TE 106A	156	112	131	
TE 106A	204	164	180	
⊿T	-49	-52	-49	
TE 107A	190	148	180	
TE 107A	241	201	232	
⊿T	-51	-53	-52	

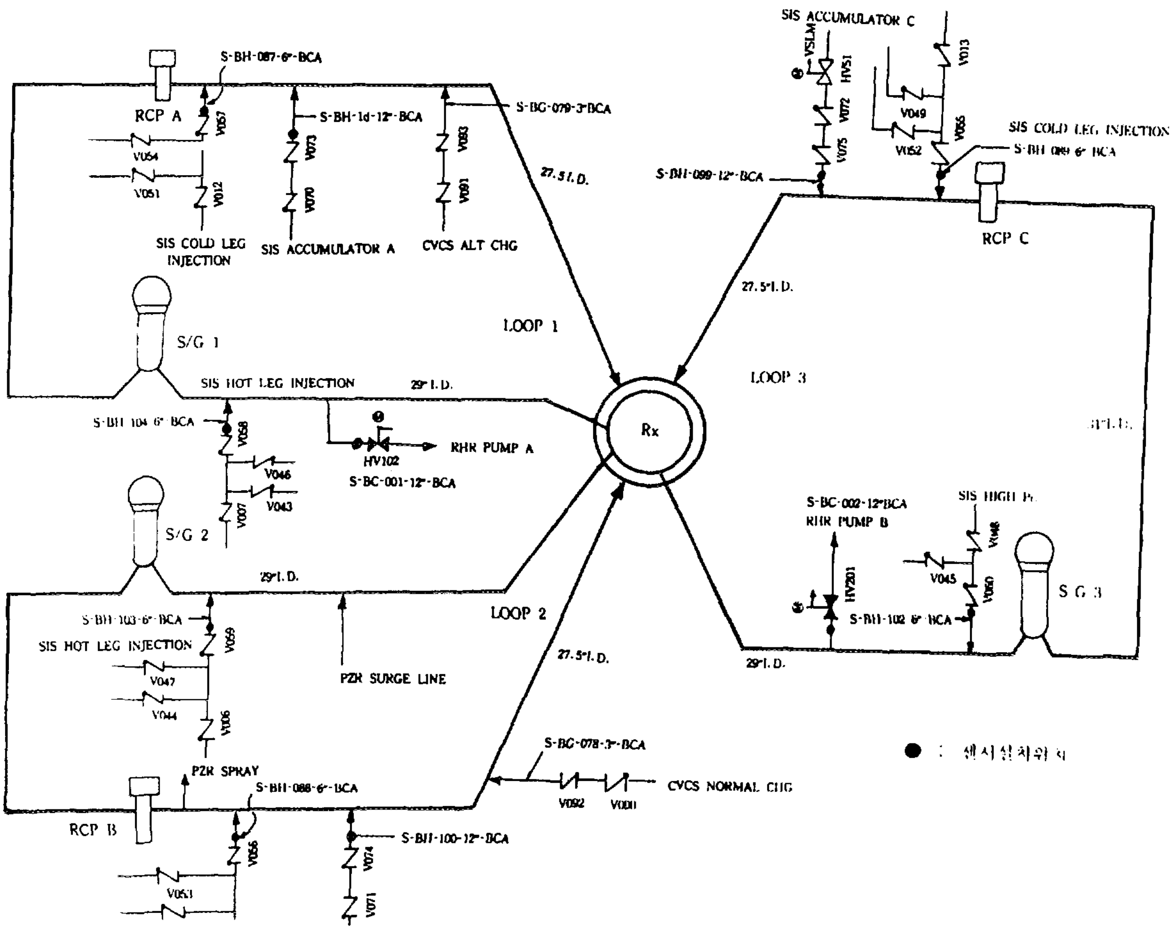


Figure 5. ECCS sensor location

2.3. Special UT exam area

In according to NRC bulletin 88-08,88-11, a special UT which can be categorized as IGSCC detection technique should be performed on the highly thermal stratification area. For this purpose, the examination table is needed. In compliance with the KAERI ISI exam-table of Younggwang1, 2, Kori 1, 2, 3, 4, Uchin 1 and 2, the point of a special UT area is lited as below

Table 3. The area of special UT of KORI 1&2

Line	Exam area		VALVE NO	
	Weldment	Base metal		
12-SIS-A-1401	3	1	8948A	
12-SIS-B-1402	3	1	8948B	
6-SIS-A-1405	3	1	8909A	
6-SIS-A-1406	3	1	8909B	
Total	12	4		

It is appropriate not to apply a special UT to PZR- surge line and CVC line since thermal stratification is not more severer than the acceptance criterion suggested by TASCS'result. The unit of Younggawng 1, 2 and Kori 3, 4 is supposed to have 46 points in regard to a special UT. The unit of Ulchin 1, 2 and Kori 1, 2 has been 42 points and 16 respectively based on an exam table of ISI. It is adviseable to determine to the cycle of exam in according to the result of TSMS. [6,7]

Table 4. The area of special UT of KORI 3,4, YG 1,2

Line	Exam area		Valve NO	Remark
	Weldment	Base metal		
12-RC-A-1111	3	1	HV102	
12-RC-C-1112	3	1	HV201	
12-SIS-A-1401	3	1	V073	
12-SIS-B-1402	3	1	V074	
12-SIS-C-1403	3	1	V075	
6-SIS-A-1404	3	1	V058	
6-SIS-A-1405	3	1	V059	
6-SIS-A-1406	3	1	V060	
6-SIS-A-1407	3	1	V057	
6-SIS-B-1408	3	1	V056	
6-SIS-C-1409	3	1	V055	
12-RHR-A-1301	1		HV102	
12-RHR-B-1302	1		HV201	
Total	35	11		

Table 5. The area of special UT of Ulchin 1&2

Line	Exam area		Valve NO	Remark
	Weldment	Base metal		
6-RC-A-1150	3	1	120VP	
6-RC-A-1151	9	5	122VP	
6-RC-B-1152	5	2	220VP	
6-RC-B-1153	6	3	222VP	
6-RC-C-1154	3	1	320VP	
6-RC-C-1155	3	1	322VP	
Total	29	13		

III. The non-intrusive test of check valve using acoustics and magnetics

3.1 Background

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 that in some cases can 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, 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 acoustics and magnetics with a digital signal analysis allows in the evaluate check valve performance without a disassembly and trends that may help the user detect degraded valve conditions.[8] 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. Figure.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 50mm and 762 mm. Typical problems found in these valves included missing disks, 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 disk.

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.[9] 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. As the flow velocity decreases, the diskassembly moves to a new equilibrium position.

The tilting disk check valves in power plants are swing check types,about 75%. Approximately 15% are tilt dics and all other types remain 10%.[10]

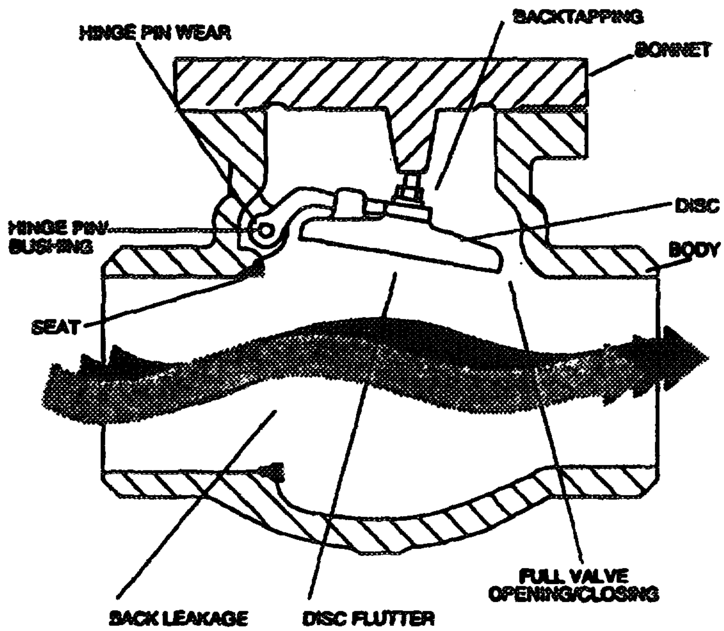


Figure 6. Swing check valve

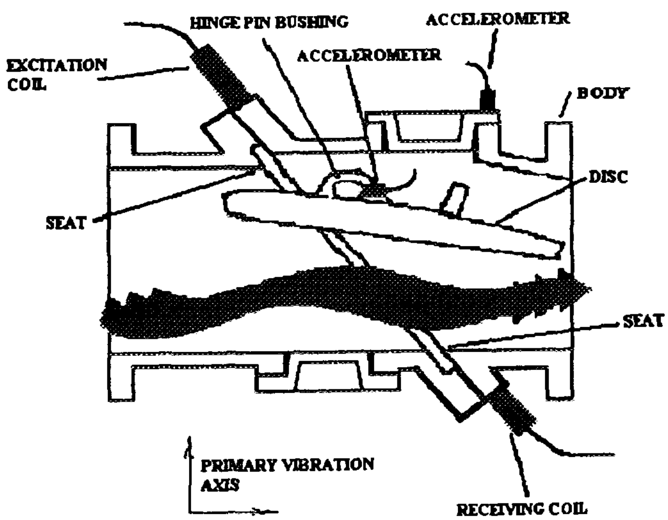


Figure 7. Tilt Disk setup

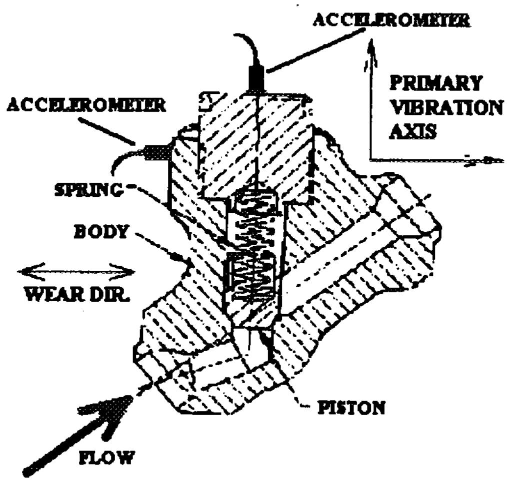


Figure 8. Piston check valve

3.2 Non-intrusive method of check valve test

3.2.1 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. The latter 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. These waves can exist only in solids where the dimensions in all directions are much greater than the wavelength. 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 (3-1) and sense point (3-2) can be defined as the equation.[13]

$$A_r = A_{max} r^{-J} \tag{3.1}$$

$$A_r = A_{max} e r^{-J} \tag{3.2}$$

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.

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 current 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 current in the valve. Namely, the disk opening/closing in the check valve produces the eddy current between the induction coil sensors [14]

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

$$\Phi_E \propto N_E I_E \tag{3.3}$$

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

$$V_{S1} = -N_E \frac{d\Phi_E}{dt} \tag{3.4}$$

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,

$$\Phi_E = \Phi_o \sin \omega t \tag{3.5}$$

where Φ_o is the magnetic flux corresponding to I_o. The induced voltage as described by equation (3.4) results in

$$V_{s1} = -N_E \omega \Phi_o \cos \omega t \tag{3.6}$$

which also varies periodically with time. If sensor coils are located to detect a disk motion, Ohm's law states that there is a inducing voltages V_{s1} and the disk' impedance is Z_{s1} , current I_{s1} will detect.

$$I_{s1} = \frac{V_{s1}}{Z_{s1}} \tag{3.7}$$

$$\Phi_{s1} \propto -Is_1 \tag{3.8}$$

$$Z_{s1} \propto \Phi_{s1} \tag{3.9}$$

When the disk moves back and forth, disk impedance will change from Z_{s1} to Z_{s2}. Consequently, current change I_{s2} results in voltage V_{s2}. These induced currents are known as eddy currents because of their circulatory.

$$\Phi_{s2} \propto -I_{s2} \tag{3.10}$$

$$Z_{\ell} \propto \Phi_{\ell} \quad (3.11)$$

$$V_{\ell} = Z_{\ell} I_{\ell} \quad (3.12)$$

3.2.2 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 check valve condition. This section will explain the recommended placement of accelerometers and ac magnetics 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 properly set accelerometer ranges.[12]

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. One accelerometer should be placed on the bonnet the check valve in the vertical direction(Fig. 9) since accelerometers 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 (Fig. 9).

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 coil should be 180° from the excitation coil. Both coils need to be placed below the flange split as possible.

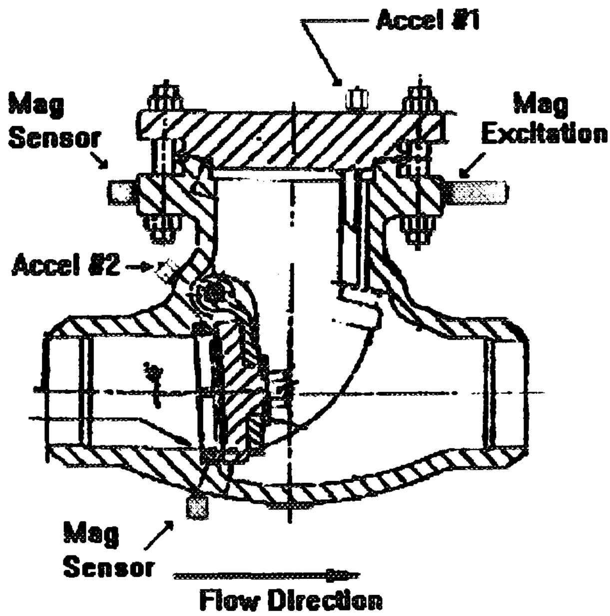


Figure 9. Sensor location of check valve

3.3.3 Experiment

The experiment mainly consist of two parts. One is acoustic channel board contains all circuit 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° C to 371° C . The other is magnetic channel board sends ac current to the excitation coil, creating a magnetic field both outside and inside 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 a amplitude and a phase are monitored, filtered, demodulated, so that information about the position of the valve's internal parts can be extracted. The magnetics sensors is 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 plant unit 1 (Fig.10,11). No. 055, 058

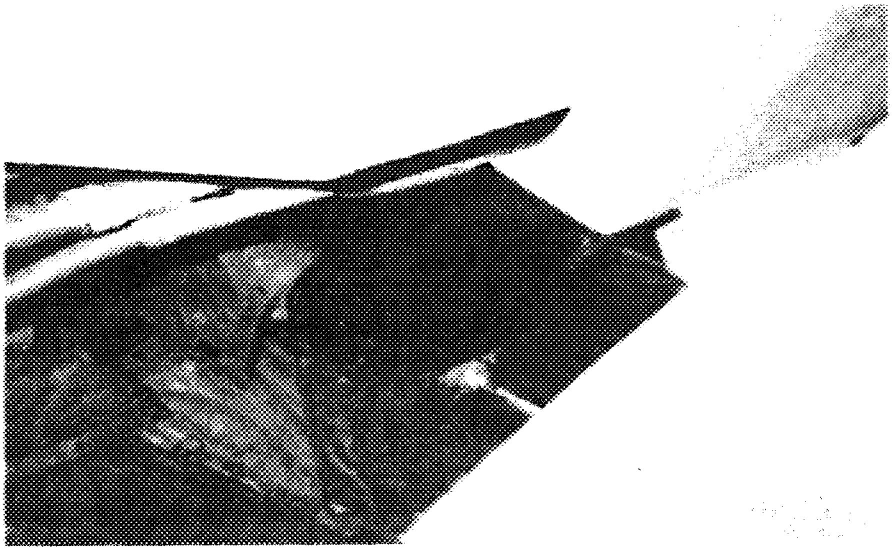


Figure 10. V055 vlave of Younggawng unit 1

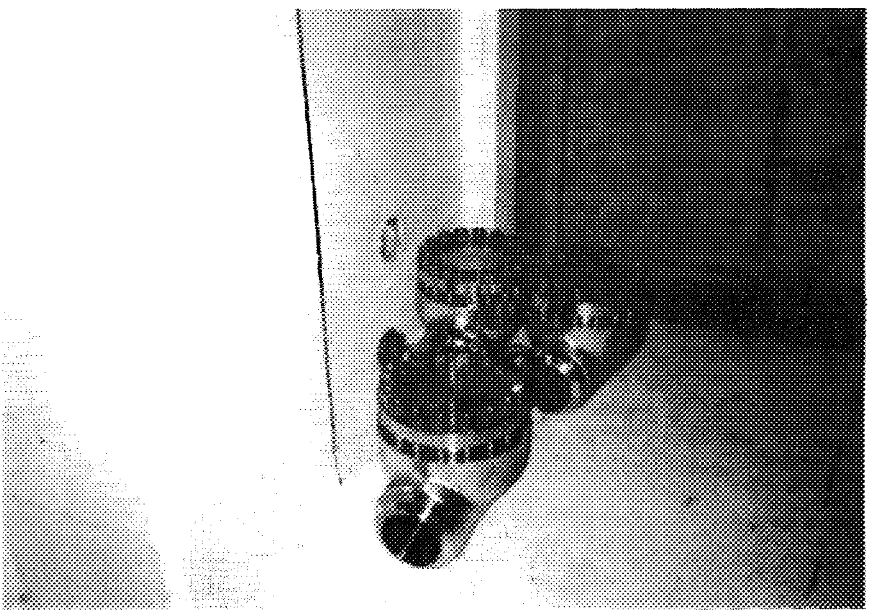


Figure 11. V055, V058 and V059 swing check valve for a replacement

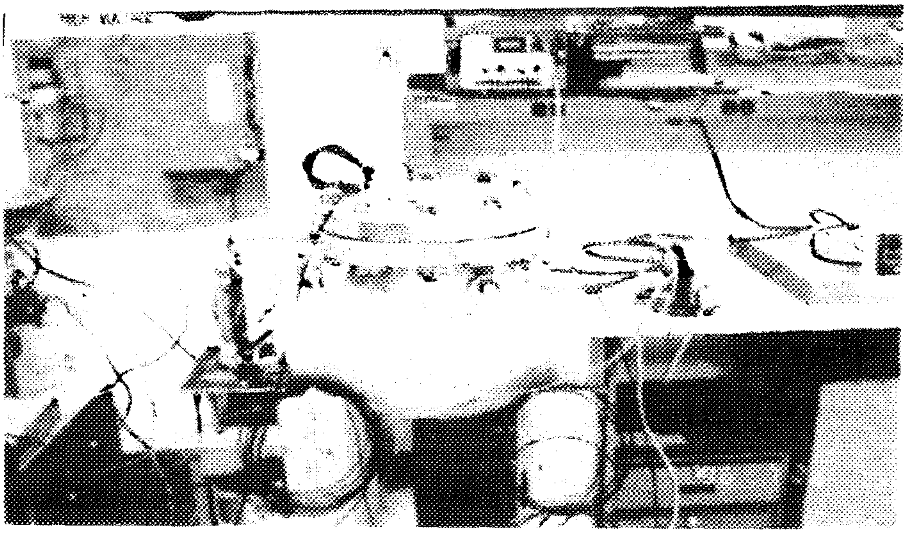


Figure 12. Swing check valve in Liberty Technologies.

and 059 of swing check valves is inspected visually. An internal corrosion is detected in hingepins and seats. Three valves is replaced by new ones. Data acquisition is performed 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 various 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 (Fig. 12).

3.4. Data Interpretation

3.4.1 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.13 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 disk 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 Fig14 is refered to as ring down. This spike reveals impact wave forms with durations of 10ms to 20ms

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.14 is a common example of a mechanical rub.

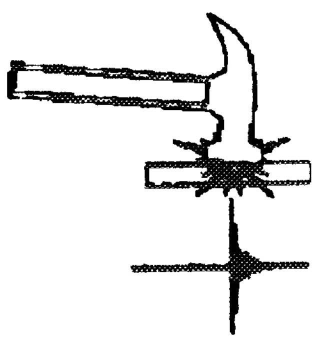


Figure 13. Metal to metal impact

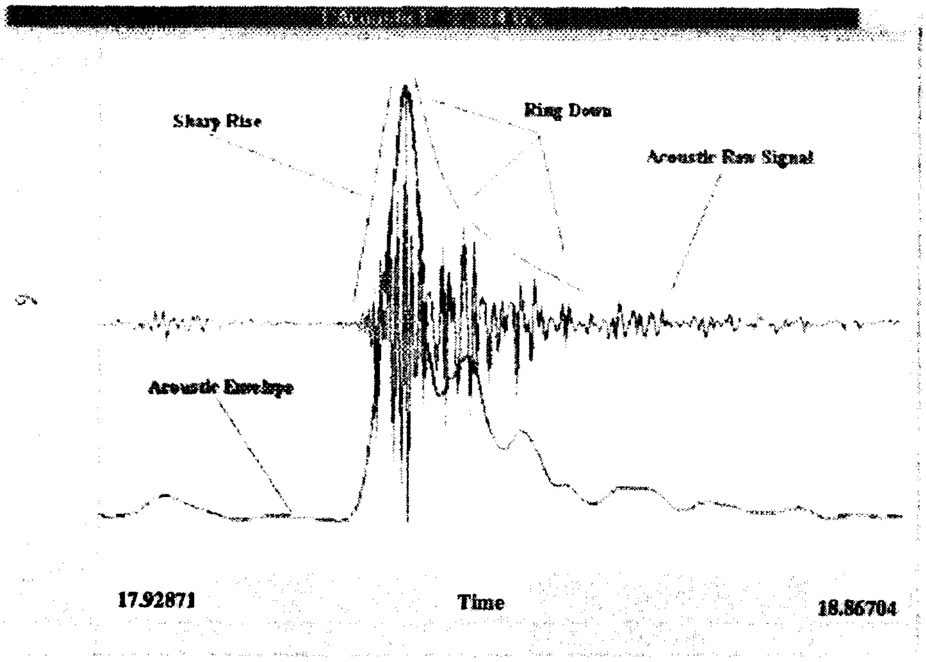


Figure 14. Opening impact from swing check valve showing metal to metal impacts

Mechanical rubs are characterized as a mechanical looseness between parts such as the hinge pin and disk 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 ports are damping the effects of the impacts(Fig 15)

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 disk stud, and their respective mounting surfaces. As this wearness increases, the parts can move more freely.

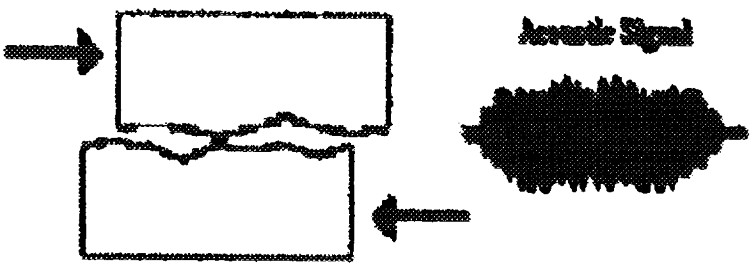


Figure 15. Signature showing metal to metal rubs

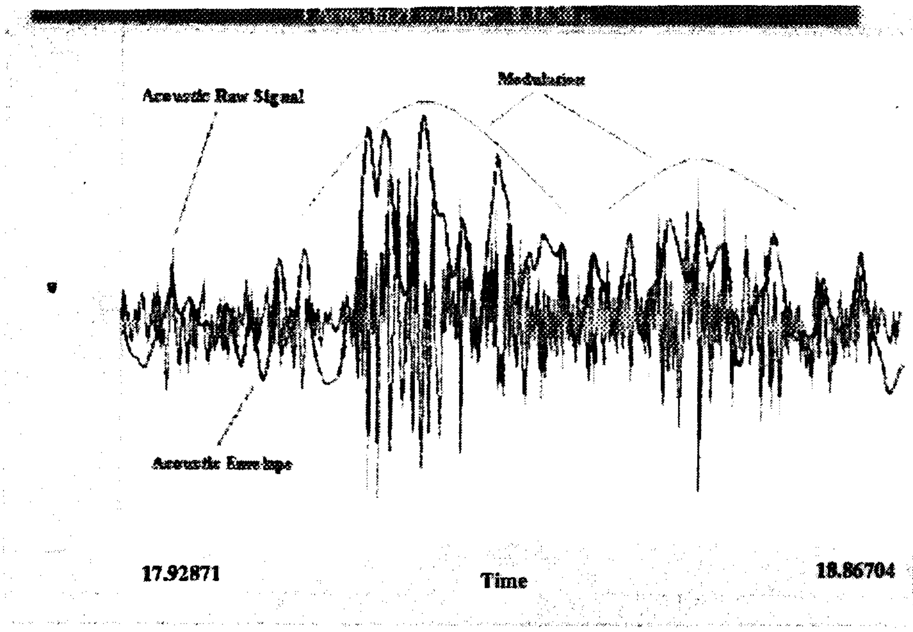


Figure 16. Signature showing metal to metal rubs

This leads to larger and more frequent impacts between these parts. An example of this condition of the V055 valve is shown in Fig.17(the V055 valve with a worn hinge pin) and Fig.18 (a new swing check valve). It is noticeable that the acoustic of Fig. 17 appears more impacts of significantly greater amplitude.

3.4.2 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 current induced in the elements perturb the inductances and therefore total impedance 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

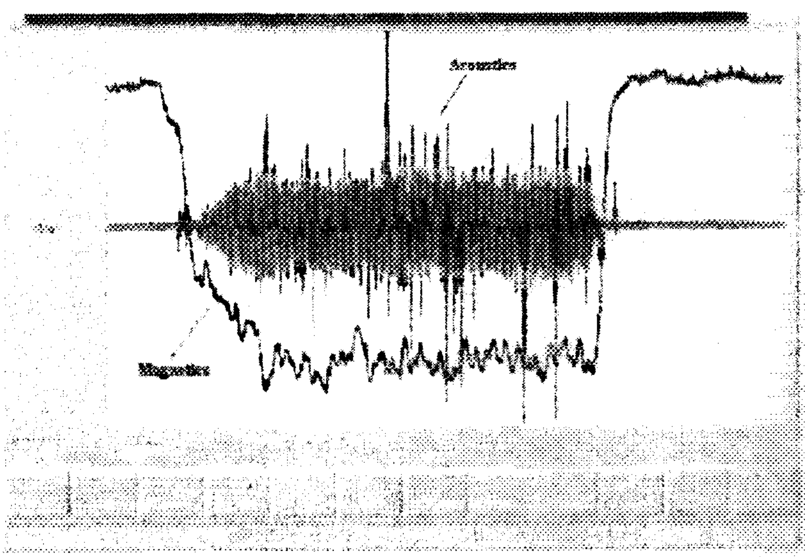


Figure 17. Swing check with worn hinge pin

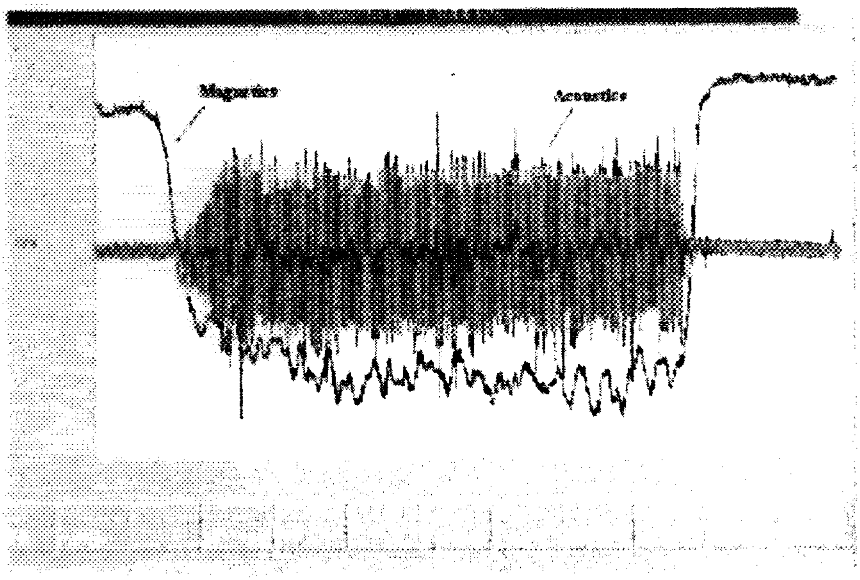


Figure 18. Swing check valve in a new condition

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.19 shows the induced current signature as a function of time as the valve disc opened, hit the backstop, stayed in the fully opened(OI1) position, then closed with a distinct seat impact(CI0).

It shows the disc fluttered at a frequency of about 2.0 Hz (FS1). However, quantitative flutter amplitude cannot be derived from the signature as the induced voltage is not a linear function of disc displacement

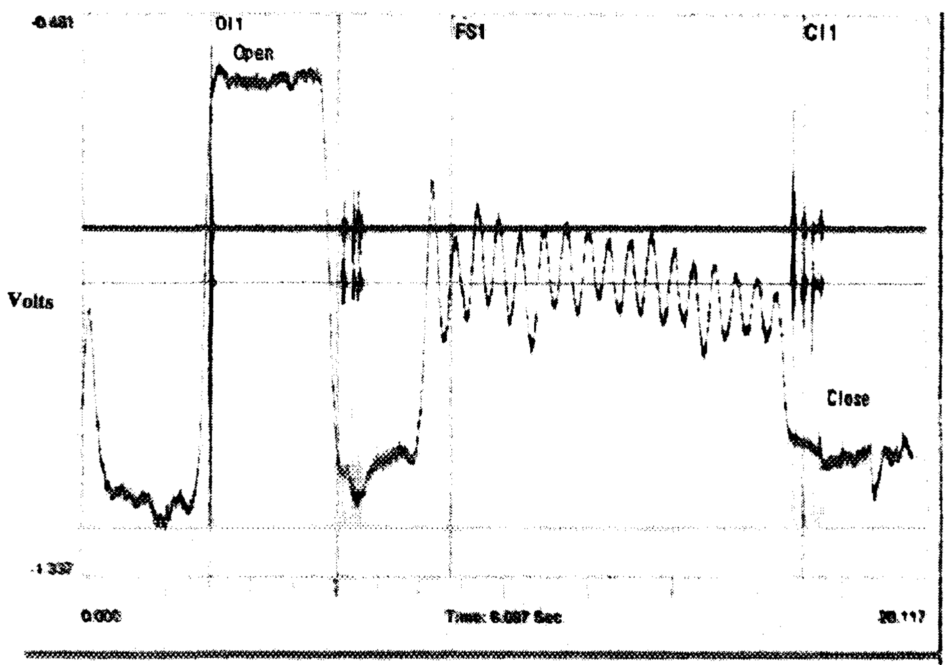


Figure 19. Magnetics time trace showing dics opened and fluttering.

3.4.4 Valve leakage study

There are three method internally in leak detection.[13] The first one is signature comparision with and without ΔP. The method is useful when testing valve can be closed by upstream or downstream and can be operated. the diagnosis of leak detection will be able to come out after comparing a signature on testing valve to pressure and a signature without pressure. The valve is leaking if the dB of a pressure signature is greater than pressure off signature(Fig.21). On the contrary, The valve is tight if both signature are equal(Fig.22). The result is unknown if background noise signature is higher than a pressure signature(Fig.23). The second one is differential signature. This method is appropriate when not only it is impossible to close upstream and downsream valve and operate vlave under test but also noise level continually changes.

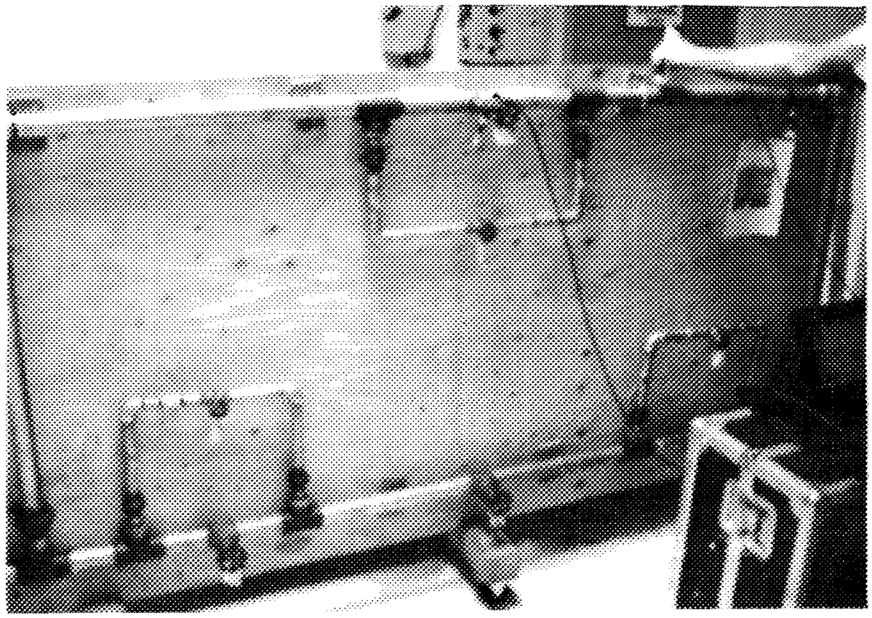


Figure 20. Test of system

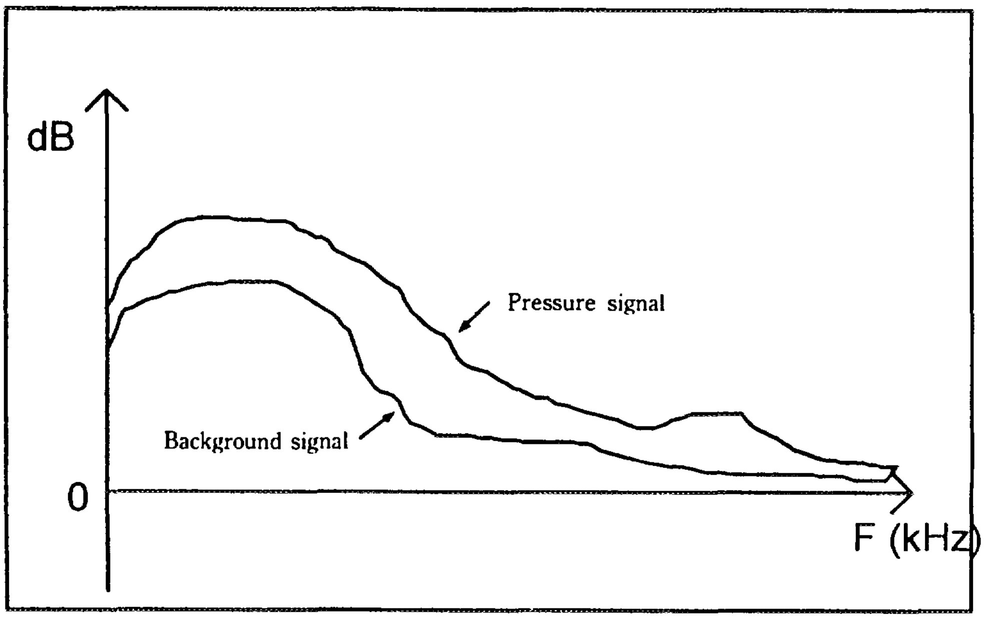


Figure 21. Leakage in valve

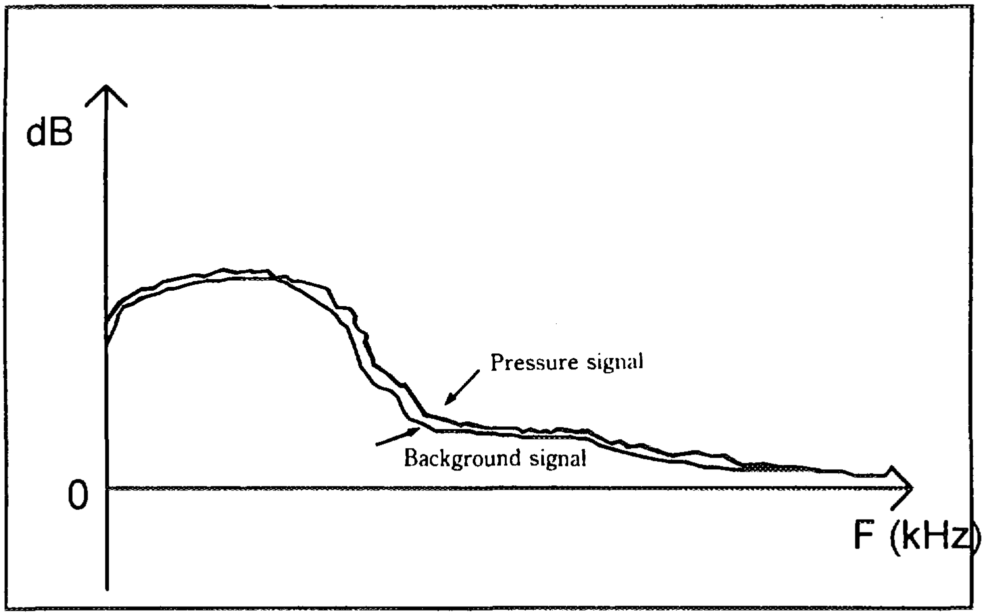


Figure 22. Tight in valve

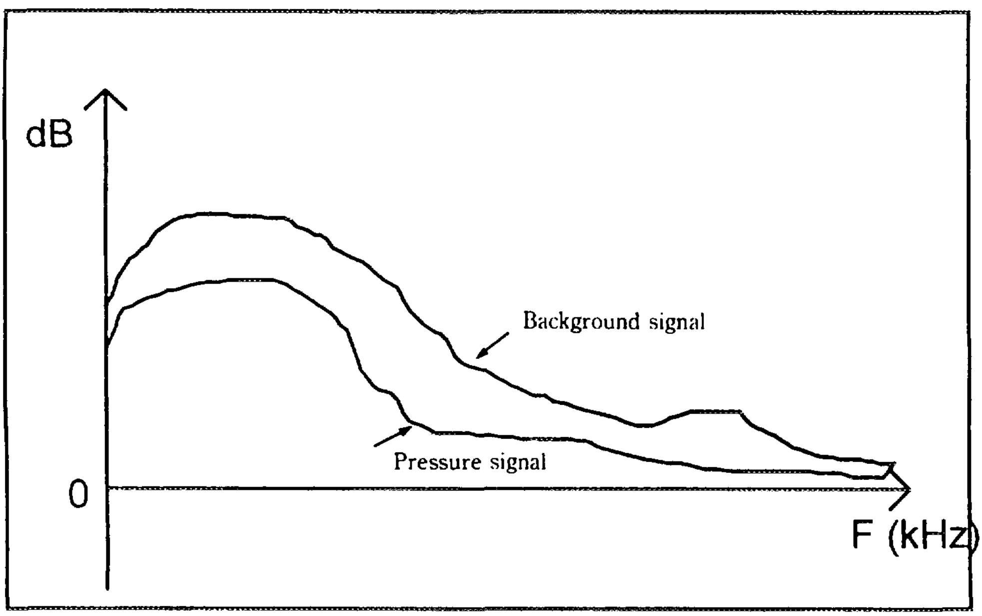


Figure 23. Unknown result

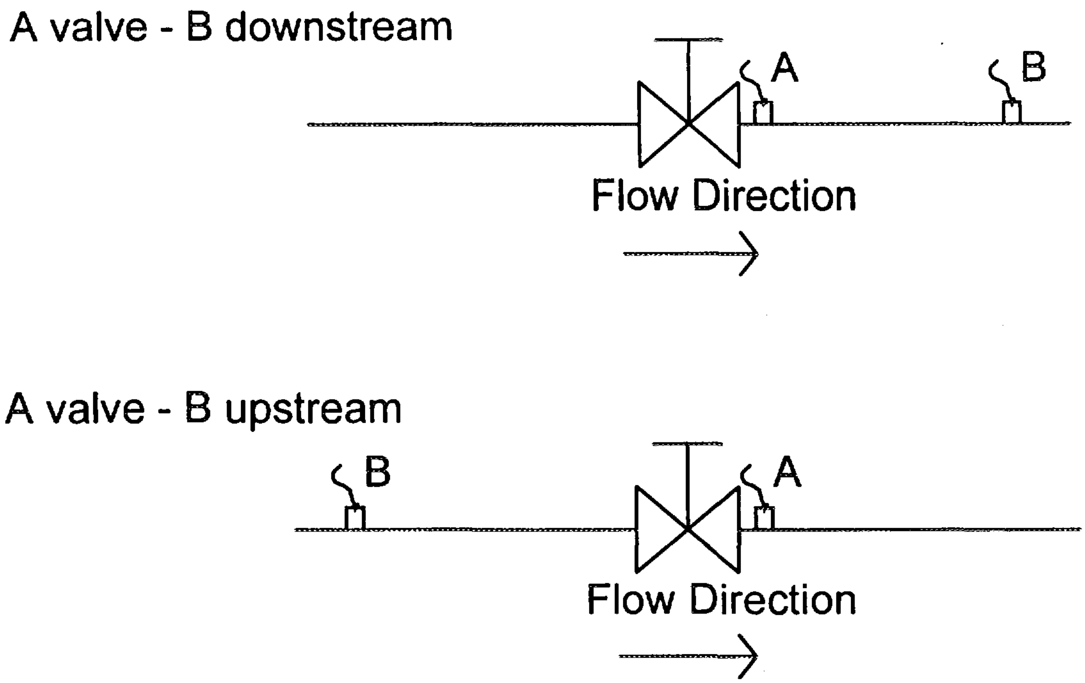


Figure 24. The method of tests in differential signature

The vlave is leaking if both signatures are positive(Fig.25). Also leaking valve if 1 of 2 is entirely positive and the other not entirely negative(Fig.26). The unknown result if 1 of 2 is negative when there is another noise source, higher than valve noise(Fig.27).

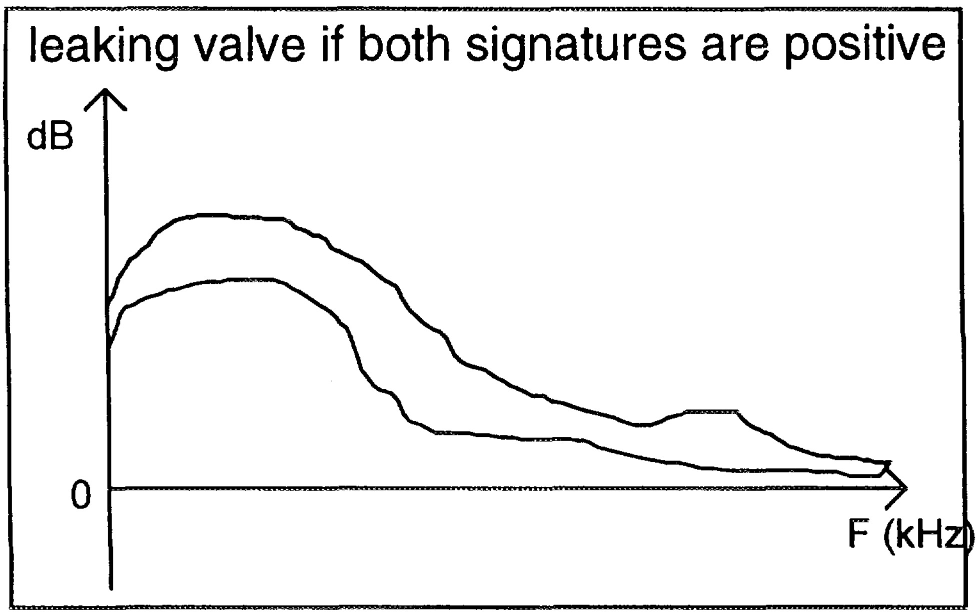


Figure 25. Leaking in differential signature

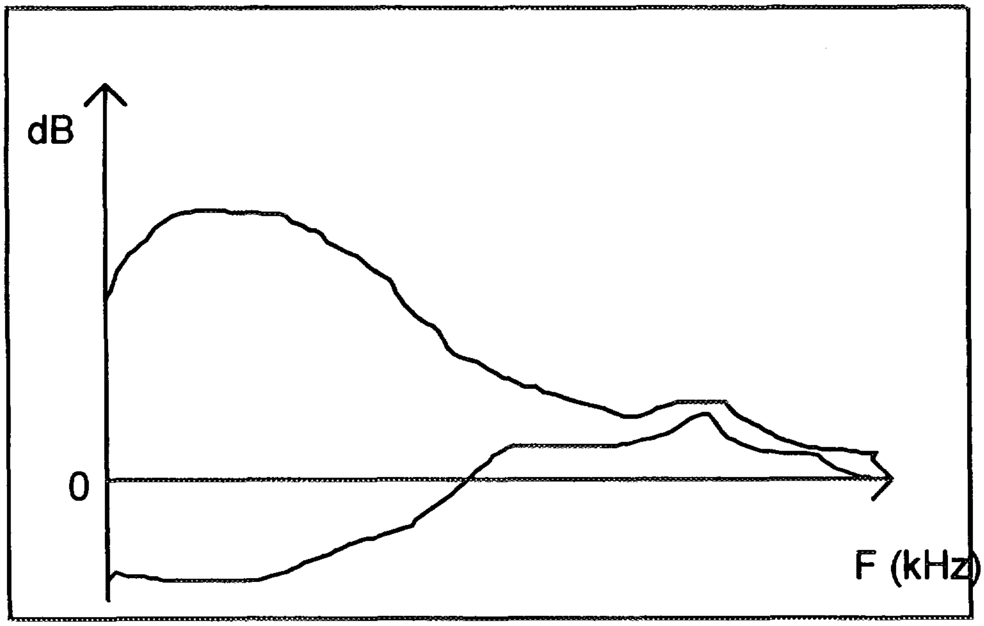


Figure 26. Leaking valve if 1 of 2 is entirely positive and the other not entirely negative

Figure 27. Unknown result if 1 of 2 is negative.

The last one is direct comparison among similiar valves. This methods is aimed at finding the most leaking vlaves in a group of simliar valves..

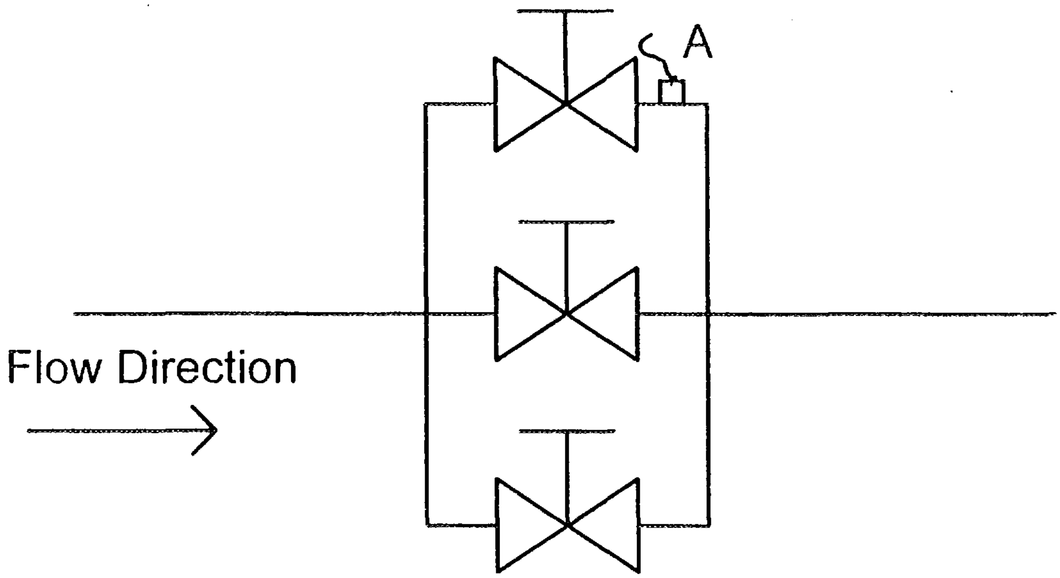


Figure 28. The method of direct signature comparison.

Above three methods are measured using the dB of power spectral density emitted from the acoustics of internal leakage. The frequency band of acceleometer is below 1 MHz. The resonant of frequency is between 100kHz and 500kHz.

IV. Conclusion

Thermal Stratification Monitoring System has been designed and installed at ECCS line permanently in Younggwang-Nulcear Power Plant 2 and at surge line temporally in Younggwang-Nulcear Power Plant 1. The data originated from TSMS is useful for the arrangement of NDT program and stress analysis. The survey has been resulting in a series of countmeasures. Accordingly, it is appropriate not to apply a special UT to PZR- surge line and CVC line since thermal stratification is not more severer than the accpetance criterion suggested by NRC. The units of Younggwang 1,2 and Kori 3,4 are supposed to have 46 points in regard to special UT, the units of Ulchin 1,2 and Kori 1,2 have been 42 points and 16 respectively based on an exam table of ISI. It is adviseable to determine to the cycle of exam in according to the result of TSMS.

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. These 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 valve 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.

Since a internal leakage brings a big trouble into the integrity of pipe, a broad study of the detection method has been performed. It is necessary to do further studies.

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서 지 정 보 양 식

수행기관보고서번호	위탁기관보고서번호	표준보고서번호	INIS주제코드
KAERI/RR-1660/96			

제목/부제 원전 배관 열성층화 감시 기술 개발

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발 행 지	대전	발행기관	한국원자력연구소			발행일	1996. 12. 15
페 이 지	52		도 표	유(X), 무( )		크 기	16절지
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비밀여부	공개(V), 대외비( ), ____ 급비밀					보고서종류	원전기술개발
연구위탁기관						계약 번호	

초록 (300 단어 내외)

현재 원자력 발전소에서는 NRC 권고에 따라 열성층화 발생 가능 배관에 대한 비파괴 검사를 수행하고 있으나 이것은 이미 열성층화의 지속으로 인한 열피로 균열을 검출하는데 적합할 뿐이며 근본적인 문제 해결 방법은 되지 못한다. 열피로 균열을 검출했을 경우 관련 배관의 결함을 제거하는 보수 작업이 뒤따라야 하므로 보수에 많은 어려움과 비용이 소요되게 된다. 따라서 본연구의 목적은 배관 열성층화 감시 장치를 개발하여 영광 1,2호기에 설치하여 한국 원전에 대한 열성층화 현상을 조기에 탐지하고 또한 관련 자료를 조사하여 기본자료로 활용하도록 하였다. 온도 감시 결과 TASCS 실험 기준치 이상으로 나타나는 것은 없으며 온도감시 장치의 타호기 적용, Special UT 검사를 위한 검사 부위표 작성을 하였다. 열성층화 현상을 유발하는 결함 역지 밸브 대하여 비해체법(Non-intrusive)중 음향 발생법 및 와전류를 이용한 자기법을 개발하였다. 상기 방법은 밸브를 해체하지않고 진단하는 방법으로 내부 누설 및 스테인레스 역지밸브의 진단에 사용할 수 있다.

주제명 키워드 (10 단어 내외)

열성층화, 열성층화감시장치, 영광2호기, 역지밸브, 배관(ECCS), 비해체법 (Non-intrusive) , 음향 발생법, 자기법, 와전류.

BIBLIOGRAPHIC INFORMATION SHEET

Perfoming Org. Report No.	Sponsoring Org. Report No.	Standard Report No.	INIS Subject Code
KAERI/RR-1660/96			

Title/Subtitle

The development of Monitoring Techniques for Thermal Stratification in Nuclear Plant Piping

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Pub. Place	Daejeon	Pub. Org.	KAERI	Pub. Date	96.12.15
Page	52	III. and Tab	Yes(X), No( )	B5 Size	
Note					
Classified	Open(o), Outside( ), ____ Class	Report Type	Research Report		
Sponsoring Org.	KAERI	Contract No.			

Abstract (about 300 Words)

The conventional nondestructive testing has been perfomed in those area which are susceptible to thermal stress in according to NRC 88-08,11. In addition to that, it is necessary to set up a monitoring system to prevent severe thermal stress to pipes in early stages and to develop the non-intrusive tecniques to diagnose the check valve because the thermal stratification has been caused by the malfuction of the check valve in ECCS pipe. Thermal Stratification Monitoring System has been designed and installed at ECCS line permanently and surge line temporally in YG nulcear power plant. The data is acceptable in according to TASCS guide line. Also, the data orginated from TSMS is useful for the arrangement of a special UT program and stress analysis. 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 show that the accelerometers can be used to measure and to differentiate the three types of impacts; metal to metal impacts mechanical rubs, and worn internal parts. The magnet sensors can be used to detect the opening/closing of stainless steel check and fluttering of disk.

Subject Keywords (about 10 Words)

Thermal Stratification Monitoring System, Check Valve, Crack, Non-Intrusive Method, ECCS pipe. Acoustics, Eddy current, Magnetics.