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Light Water Reactor Pressure Isolation Valve Performance Testing

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Energy Technology Engineering Testing

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U.S. Nuclear Regulatory Commission

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Abstract

The Light Water Reactor Valve Performance Testing Program was initiated by the NRC to evaluate leakage as an indication of valve condition, provide input to Section XI of the ASME Code, evaluate emission monitoring for condition and degradation and in-service inspection techniques. Six typical check and gate valves were purchased for testing at typical plant conditions (550F at 2250 psig) for an assumed number of cycles for a 40-year plant lifetime. Tests revealed that there were variances between the test results and the present statement of the Code; however, the testing was not conclusive. The lifecycle tests showed that high tech acoustic emission can be utilized to trend small leaks, that specific motor signature measurement on gate valves can trend and indicate potential failure, and that in-service inspection techniques for check valves was shown to be both feasible and an excellent preventive maintenance indicator. Lifecycle testing performed here did not cause large valve leakage typical of some plant operation. Other testing is required to fully understand the implication of these results and the required program to fully implement them.

TABLE OF CONTENTS

APPENDICES

TABLES

TABLES

Page

FIGURES

FIGURES

FIGURES

EXECUTIVE SUMMARY

The NRC requires nuclear power plant owners to periodically verify pressure barriers in systems adjacent to the Reactor Coolant System. This is usually accomplished through leak testing of two valves at each interface. These in-service tests are intended to demonstrate the pressure retaining capability of the valves, and to identify leakage caused by valve degradation before it reaches hazardous levels.

It was found that the extrapolation of leakage data from previous reduced pressure tests is potentially in error. Accordingly, recommendations were made for revisions to existing leak acceptance criteria and for performance of actual confirmatory valve leak test rates. With this in mind, the objectives of this program were to:

1) Validate the theoretical work performed to upgrade leakage criteria,

2) Evaluate the effectiveness of valve leakage as an indication of valve degradation, and

3) Examine other valve parameters and their effects on valve operability.

Test articles used for this program included:

- Three Swing Check Valves
  - 4-inch disk
  - 6-inch disk
  - 12-inch disk
- Three Gate Valves
  - 4-inch double disk
  - 4-inch flexible wedge
  - 10-inch flexible wedge.

The test program consisted of:

1) Life-cycle aging at typical temperatures and pressures to assess leak degradation,

2) Acoustic emission evaluations and motor signature monitoring to assess leakage and degradation, and

3) Loosened internals testing to correlate degradation with typical valve failures.

Test results indicated the following:

Validation of Theoretical Work

- ASME Code correlations were not acceptable for predicting leak rates. In general, they underestimated flow rates.

Indication of Valve Degradation

- Visual ISI (e.g., video probe) is effective for establishing check valve internal conditions.
- Valve seating surfaces were not damaged from wear as a result of repeated cycling.
- Standard acoustic emission systems could not be used reliably for predicting leak rates less than 0.3 gpm; however, high-sensitivity AE systems were successfully used.

Parameters Effecting Valve Operability

- Neither leak rate testing or acoustic monitoring is effective for indicating check valve loosened internals and impending failure.
- Leak rate testing is an effective method for determining the immediate status of the pressure barrier.
- Motor signature monitoring was useful for indicating operator malfunctions--a major cause of MOV failure.

Although the results of the testing did not substantiate ASME Code correlations, the cause for deviation was never established. Therefore, the validity of Code correlations could not be confirmed. The tests demonstrated that the current methodologies and equipment employed in this program could not adequately measure or predict imminent valve failure. Further investigations are needed to fully understand the degradation mechanisms so that new, successful techniques can be developed. The test program was performed during the period from FY85 to late 1987.

1.0 INTRODUCTION

1.1 Background

Nuclear power plants typically determine isolation valve inter-system integrity by monitoring leak rates. To examine the validity of this practice, the Nuclear Regulatory Commission (NRC) sponsored a survey of nine utilities to examine their leak rate testing methods and to find how such tests were used to infer the extent of valve degradation. The results, documented in Reference 1, indicated that current utility practice is to leak test at reduced differential pressures and extrapolate to nominal operating conditions using a correlation given in Section XI of the ASME Code. This correlation is theoretically correct for turbulent flow if temperature effects are ignored, however, analysis of the survey data indicated that the correlation is potentially in error for laminar leakage flow across valve seating surfaces. Accordingly, a test program was recommended to validate the analytical work performed and to evaluate the leak test methods.

In November of 1983, NRC requested proposals for a Valve Performance Test Program to "validate the theoretical work performed during the survey of the nine utilities, to evaluate the effectiveness of valve leakage as an indicator of valve degradation, and to examine other valve parameters and their effects on valve operability." The Energy Technology Engineering Center (ETEC) was awarded the Valve Performance Test Program in fiscal year 1984. Check valve performance testing started in April 1985, followed by gate valve testing which terminated in August 1987.

The Valve Performance Test Program incorporates leak rate testing of valves typical of those used for pressure isolation of the primary coolant system in a light water reactor plant. Pressure isolation valves (PIVs) isolate the high pressure primary reactor coolant system from connected lower pressure systems. Commercial nuclear power plants are required to periodically leak test PIVs in accordance with Section XI of the ASME Boiler & Pressure Vessel Code. The acceptable leak rate across the PIVs is defined in the technical specifications for each plant and, therefore, the acceptable PIV leak rate can vary among plants. However, in general the NRC allows a leakage rate of one-half gpm (0.052 lb/sec at 2250 psia and 550F) per inch of nominal valve diameter, but no more than five gpm (0.52 lb/sec at 2250 psia and 550F) on any valve.

Leakage through the PIVs is monitored and limited for three safety reasons. First, leak rates are monitored to determine whether the pressure barrier exists, that is whether the valve is fully seated. Second, leak rate monitoring is used to detect imminent failure of the valves' ability to serve as a pressure barrier. And third, the overall leak rate from the high pressure system to the low pressure system must not exceed the low pressure system's pressure relief and radiological processing capabilities. Therefore, the leak rate monitoring is intended to identify leakage caused by valve degradation before it reaches a hazardous level.

1.2 Objectives

The objectives of the Valve Performance Test Program were modified during the course of the program as the initial test results were evaluated and the program redirected to address these results. Specifically, the scope of objective 4 was enlarged to encompass evaluation of acoustic emission monitoring as a means of detecting loose check valve internals and objective 5 was added. The ultimate objectives were defined as:

1. Evaluate the use of valve leakage as an indicator of valve condition.

2. Provide the technical basis for NRC recommendations regarding the ASME Code Section XI method for correlating leak rates at test and operating pressure differentials.

3. Evaluate the use of motor signature monitoring as a measure of gate valve operability.

4. Evaluate the use of acoustic emission monitoring for quantifying valve leakage and as an indicator of valve condition.

5. Evaluate the use of visual in-service inspection techniques to detect check valve degradation.

1.3 Technical Approach

1.3.1 Valve Degradation

A key element of this program is the method by which seat leakage paths that are representative of those developed by power plant PIVs are created in the test valves. ETEC's extensive experience with large valves and consultation with valve suppliers and nuclear utilities led to the Valve Performance Program test plan which is based upon life cycling of new valves. Although artificial wear aging of valves does not fully reproduce actual plant aging, the life cycling approach does impose a plant valve operational history on the test valves which simulates some of the wear that an average PIV undergoes during its life.

PIVs typically have hard faced metal to metal seat and disk mating surfaces. The leak rate for new valves of this type is usually limited to 10 cc/Hr (4.4 x 10^{-5} gpm at 550F and 2250 psig) per inch of nominal pipe size. At the other extreme, seat leakage rates of 1 to 5 gpm for 4-inch to 12-inch gate and swing check valves are indicative of valve damage resulting from wear, maintenance, careless handling, entrapment of construction debris, defective manufacturing and occasionally from unusual piping reaction loads distorting the valve. Leakage this great would indicate the valve is already degraded to the point where it must soon be repaired or removed from service.

Leak rates between these two ranges indicate the sealing surfaces of a valve are being deteriorated. The leak rates in this range are monitored to determine the rate of deterioration and to predict when maintenance will be required.

A survey of nine nuclear power plants was made to identify how many cycles a PIV would see in an average plant application. Ten dry cycles (in air) and 200 wet cycles at plant operating conditions were determined to be reasonable.

The check valves were dry cycled by pushing the disk open with pressurized nitrogen. The check valve wet cycles were made by opening an upstream valve which allowed pressurized water to push the disk open rapidly. The valve closed as the pressure across the valve equalized. There was no period of stable or unstable, such as a disk fluttering, flow through the valve. The percent open obtained by cycling the valve by these methods could not be accurately determined.

The gate valves were cycled from their fully closed position to 100% open and returned to the fully closed position by the valves' motor operators. For the wet cycles, one side of the gate valves was pressurized to 2250 psig while the other side was held at 50 psig prior to valve opening. The pressure rapidly equalized once the valves began to open. As with the check valves, there was no sustained flow through the valves. During the dry cycles, the gate valves were in air atmosphere at ambient pressure.

1.3.2 Leak Rate Testing & Code Correlation

To gain information on the effectiveness of valve leakage as an indicator of valve degradation (objective 1), a series of leak tests were conducted. The leak rate data also were used to evaluate the Section XI correlation for extrapolating leak rates at test conditions to leak rates at nominal plant operating conditions (objective 2). The leak rates were measured prior to the start of the test program, following the completion of the dry cycles, after the first 50 wet cycles, and following completion of the wet cycling. The leak tests were conducted at a variety of temperature and pressure conditions ranging from normal plant operating pressure, 2250 psig, down to pressures less than those typically used during power plant in-service testing, 150 psig. Temperatures ranged from typical operating temperatures, 550F, to ambient.

1.3.3 Motor Signatures

In addition to reported PIV intersystem failures (i.e. excessive leak rate), other failure modes also are common. Recent events in the Light Water Reactor (LWR) community illustrate the importance of valve motor operator and valve internal integrity. Reference 2 presents the operating experience with valves in LWR safety systems. Among the findings were the following:

> There was strong evidence that valve operating characteristics change with time as a result of maintenance activity.

The selection of equipment, such as motor operators and valves, and settings did not appear to address variations in such operational characteristics as increases in differential pressure or temperature, or variations in process conditions.

The motor-operator signature portion of the Valve Performance Program addresses these two issues. A common valve maintenance activity is the adjustment of the packing nut torque. Plant operators frequently increase the torque to prevent or stop leakage through the packing. Increased packing tightness can increase the friction during valve stem movement and thereby increase the operator torque requirement. It was recommended in Reference 2 that motor signature tracing techniques be developed which would indicate changes in operability characteristics and predict the remaining margin to failure.

To address objective 3, evaluating the use of motor signature monitoring as a measure of gate valve operability, the actuators' performance parameters were measured during the life cycles. Upon completion of these tests, the packing gland nuts were set at 50%, 200%, and 300% of the torque specified by the valve manufacturer. At each torque level, additional cycles were made while the valve position, stem force, velocity, motor vibration, motor temperature, motor current, torque shaft rotation, and valve limit switches were monitored. The valves were cycled at various differential pressure conditions and temperatures. There was no sustained flow through the valves either before or after the valve cycling so that only wear due to the stroking itself was reproduced.

1.3.4 Acoustic Emission

Both the check and the gate valves were used to address objective 4, evaluate the use of acoustic emission (AE) techniques for quantifying valve leakage and as an indicator of valve condition. AE data were recorded during the leak rate testing of both the gate and the check valves. For the check valves, the AE techniques also were employed to determine whether AE was a reliable means of detecting loosened internals. Four different AE monitoring systems were installed during the check valve testing. The systems were supplied by ETEC, Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), and the Naval Ship Research & Development Center. Four systems were used because this program was a unique opportunity to obtain AE test data which could be used in a number of NRC programs at minimal costs. The data were given to each of the AE equipment suppliers for their analysis and incorporation into their NRC-funded work. In response to the check valve results, an additional narrow-band AE system was procured by ETEC and installed prior to gate valve testing.

Check valve disk separation from the clapper is a potentially serious mode of failure which leaves the valve inoperable with its disk, and other parts such as nuts and washers, free to move through the piping system. It has been identified as a major cause of check valve failure. Per reference 3, disk separation accounted for 16.5% of the Licensee Event Reports (LERs) associated with valve failure, including the failure of five check valves at San Onofre Unit 1 which led to a loss of power and water hammer event in November of 1985. Disk separation can result because of the stud impacting the valve body during cycling or improper valve assembly causes the nut which secures the valve disk to the clapper to become loose, see Figure 1. During the Valve Performance Program, the disk assembly nuts, which hold the disk to the clapper arm, of each of the three check valves were loosened, described in detail in Appendix B. The 12-inch valve had a second nut, the clevis assembly nut, which suspends the clapper assembly. This nut also was loosened during testing of the 12-inch check valve. Leak rate measurements were made with the valve internals loosened to determine the suitability of leakage measurements as a means of detecting this impending check valve failure mode (objective 1). AE traces were recorded during loosened internals cycles, as well as during the leak rate tests to evaluate whether the loosened internals could be detected with typical AE instrumentation.

1.3.5 Visual Inspection

The fifth objective was identified after the initial check valve life cycling and loosened internals testing were completed. Visual inspection using a rigid borescope and a videoprobe were evaluated as methods of detecting check valve degradation, particularly loosened internals and disk stud damage. A hole was drilled in the valves' bonnet to provide access for the borescope and videoprobe.

2.0 TEST DESCRIPTION

The individual tests which comprise the Valve Performance Program were formulated to satisfy the program objectives. Since the program was stretched out over two years, information from previous tests could be digested and subsequent testing modified to satisfy the program objectives.

This section discusses the test articles; describes each of the tests; and discusses the development and logic of the test matrices. The test results are presented in Appendix B.

2.1 Test Valves

The procurement of the six test valves was a major early effort. The preferred approach was to obtain new valves. The use of new valves which had no prior service history eliminated uncertainty about the types of wear or degradation mechanisms to which the valves were exposed. Numerous utilities or their representatives as well as valve manufacturer's were contacted to obtain the test valves. The test valves, described in the following paragraphs, were obtained from cancelled LWR plants.

It was more difficult to locate gate valves of the correct size which were typical of PIVs currently used by nuclear power plants. A number of gate valves were available from the cancelled Washington Public Power Service plants, but these gate valves were of a parallel double disk design which was infrequently installed in early LWRs, although they were often included in newer LWRs.

Eventually two flexible wedge disk gate valves, a 4-inch and a 10-inch, were located and procured. The flexible disk type of gate valve is widely installed in LWRs.

To compare a flexible disk and a parallel double disk gate valve of the same nominal size in terms of valve degradation versus wear, a four-inch parallel double disk gate valve also was procured.

All six of the test valves were purchased from utilities who had obtained them from nuclear units which were cancelled subsequent to valve fabrication or from units which had surplus valves. The majority of the valves are ASME Section III, Class 1 valves although one is a Class 2 valve. Class 2 valves are of the same design as the Class 1 valves and thus are equally representative of LWR PIVs. However, Class 2 valves do not have the same quality assurance/verification documentation as Class 1 valves. The test article descriptions are as follows:

1. 4-inch, 1512 lb, swing check valve, buttweld ends, 316 stainless steel body, Stellite hard facing on the seating surfaces, ASME Section III, Class 1, manufactured by the Nuclear Valve Division, Borg-Warner Corporation.

2. 6-inch, 1500 lb, swing check valve, buttweld ends, 304 stainless steel body, Stellite hard facing on the seating surfaces, ASME Section III, Class 2, manufactured by Atwood & Morrill Company.

3. 12-inch, 1512 lb, swing check valve, buttweld ends, 316 stainless steel body, Stellite hard facing on the seating surfaces, ASME Section III, Class 1, manufactured by the Nuclear Valve Division, Borg-Warner Corporation.

4. 4-inch, 1600 lb, gate valve, buttweld ends, 316 stainless steel body, double disk-parallel seat, hardfaced seating surfaces, electric motor operated (Limitorque), ASME Section III, Class 1, manufactured by ACF Industries, W-K-M Valve Division, Model M-I-OPG POW-R-SEAL.

5. 4-inch, 1525 lb, gate valve, buttweld ends, 316 stainless steel body, flexible wedge disk, Stellite hard facing on the seating surfaces, electric motor operated (Limitorque). ASME Section III, Class 1, manufactured by Westinghouse (W-EMD).

6. 10-inch, 1525 lb, gate valve, buttweld ends, 316 stainless steel body, flexible wedge disk, Stellite hard facing on the seating surfaces, electric motor operated (Limitorque). ASME Section III, Class 1, manufactured by Westinghouse (W-EMD).

All valves were unused and stored, packaged, and shipped in accordance with ANSI/ASME N45.2.2 requirements. Although some of the utilities did not have complete operating/maintenance documentation, all drawings, manuals, and quality records available to the utilities for each valve were included as part of the valve order. The Limitorque operators, supplied with the valves, are described in Tables 1 through 3. The characteristics of the valve and operator are given for analytical calculations of the Motor Operated Valve (MOV) operability.

Table 1. Description of Westinghouse 4-in. Gate Valve with Limitorque SBD-00 *Motor Operator

Pressure class:	1525
Design pressure:	2500 psig @ 650F
Pressure rating:	3600 psig @ 100F
Differential pressure:	850 close, 2750 open
Order number:	3A5101E
Serial number:	288202
Stem thrust:	10900 lb.
Stem diameter:	1.25 inch
Stem threads:	L-1/3 P-1/3
Motor torque:	15 ft-lb starting, 3 ft-lb running
Motor speed:	3400 rpm
Motor horsepower:	1.9 hp
Power requirements:	3 phase, 60 Hz
Motor current:	3 1/2 A (460 v)
Insulation class:	B
Duty cycle:	15 min
Packing material:	John Crane 187 I
Recommended packing gland bolt torque:	27 to 33 ft-lb
Gear teeth:	Motor pinion 40T Worm shaft gear 25T Work gear 45T
Overall gear ratio:	28.2 to 1

*Operator has double compensating spring which does not allow this stem to float in either direction of travel.

Table 2. Description of the Westinghouse 10-in. Gate Valve with Limitorque SBD-3 *Motor Operator

Pressure class:	1525 lb
Design pressure:	2500 psi @ 650F
Pressure rating:	3812 psi @ 100F
Differential pressure (max):	2700 psid
Order number:	3A2956F
Serial number:	262957
Stem diameter:	2.5 inch
Motor torque:	150 ft-lb start, 30 t-lb run
Motor speed:	3365RPM
Motor horsepower:	19.2 hp
Power requirements:	3 Phase 60 Hz
Motor current:	460V, 25.7a
Insulation class:	B
Duty cycle:	15 min.
Packing material:	John Crane 187 I
Recommended packing gland bolt torque:	95 to 105 ft-lb.

*Operator has double compensating spring which does not allow the stem to float in either direction of travel.

Table 3. Description of W-K-M 4-IN Gate Valve with Limitorque SB-00S Motor Operator

Pressure class:	1600
Design pressure:	2500 psig @ 650F
Pressure rating:	3480 psi
Order number:	3B0671A
Serial number:	259239
Model:	M-1 OPG Pow-R-Seal
Stem diameter:	1.5 inch
Motor torque:	1.5 ft-lb start, run 3 ft-lb
Motor speed:	3400 RPM
Motor horsepower:	1.33 hp
Power requirements:	460 VAC, 3 phase, 60 Hz
Motor current:	3.5 amps running, 26 amps starting
Insulation class:	RH
Duty cycle:	15 min.
Packing material: Internal	1625GF Ext. Rings, Grafiol Gin
Recommended packing gland bolt torque:	30 ft-lb

2.2 Test Program Logic and Description

The test logic for a typical valve is shown in Figure 2 for both check and gate valves. The overall approach for both types of PIVs is similar. The only difference is that loosened internals tests are applicable only to the check valves and motor signature tests were applicable only for gate valves. A description of each test is given below; the test numbers correspond with those shown in Figure 2.

The basic program of life cycling consisted of (a) establishing the leak rates for the valves in an as-received condition at test conditions ranging from normal LWR plant operating conditions down to less than normal inspection test conditions and (b) repeating this series of leak tests after three periods of valve cycling. This program was geared to provide data for correlating the leakage versus differential pressure and temperature to evaluate the ASME Code correlation and to evaluate valve degradation over a typical plant service life via artificial accelerated wear aging.

1. Pre-Test Inspection and Installation - Following receipt of the valves, each was visually inspected. The smaller valves, four-in. and six-inch, were leak tested with nitrogen to verify their integrity before installation. The larger valves, ten-inch and twelve-inch, were not leak tested due to the excessive expense of the leak test for large valves as balanced against the low probability that the valves would be unacceptable for installation.

2. Baseline Leak Tests - Following installation, the baseline leak tests were conducted to verify the start-of-life condition of the test valves. Table 4 is a typical test matrix, at selected test conditions specified for each valve. The resulting data was compared to the post-cycle leak rate tests, at the same temperature and differential pressure conditions, to provide a measure of the relationship between valve degradation and leak rate. If extremely low leak rates or no leak rate were measured during the lower temperature leak test, the elevated temperature tests were deleted.

   Temperature, pressure and leak rate were measured during each test. Leakage flow was measured by collection/displacement in a downstream vessel.

   Acoustic emission (AE) monitoring was conducted during leak rate testing to evaluate whether AE is an effective means of quantitatively measuring leak rates. Four AE systems were installed on the check valves. The systems were supplied by ETEC, Argonne National Lab (ANL), Oak Ridge National Lab (ORNL), and the Naval Ship Research & Development Center. The Naval Ship Research & Development Center system was a portable manually operated system and therefore was used less frequently than the other systems. The ETEC, ANL, and ORNL systems each had a transducer installed on the valve and another transducer installed on the valve inlet pipe.

3. Dry Cycling, n = 10 - The valves were stroked 10 times in a dry, gas environment to simulate valve operation during vendor checkout, plant construction and start-up. The check valves were dry cycled by pushing the disk open with pressurized nitrogen. The motor operators were used to dry stroke the gate valves.

4. Leak Tests - This series of leak tests duplicated the baseline leak tests. If significant leak rates were observed, leak tests at various higher temperatures were conducted. The objective of varying the leak rate test temperature was to determine whether the temperature dependent variables such as density or viscosity should be included in the ASME Code correlation. A typical test matrix is given in Table 4.

5. Wet Cycling, n = 50 - The test valves were wet stroked 50 times in borated water. For the gate valves, full reactor coolant system pressure was applied to the high pressure side of the valve with 50 psig on the low pressure side. Stroking was done with the motor operator. The gate valve was stroked from a fully closed position (0% open) to a fully open position (100% open) and returned to the fully closed position.

   To cycle the check valves, fluid pressure was applied to the valve on the upstream side forcing the valve open. The check valves closed as the pressure across the valve equalized. The percent open obtained by stroking the check valves with this method could not be accurately measured. There was no sustained flow across either the gate or check valves.

   This test was modified for the six-inch and twelve-inch check valves. The six-inch valve was wet cycled 85 times. The twelve inch valve was wet cycled 20 times. In addition, test 7, wet cycling n = 150, and test 8 leak tests, were deleted for these two valves. The cycling of the six-inch and twelve-inch check valves was abbreviated so that the loosened internals portion of the program could be expanded to include these two valves without cost impact. The change to the test plan was made based on (1) the results of the four-inch check valve testing which indicated that completion of the planned wet cycles would have nominal impact on the valve leak rate and (2) the belief that it would be important to examine the leak rate response of different check valve designs to the loosened internals testing. It was decided that the program objectives would be better met by expanding the loosened internals portion of the test program and abbreviating the check valve life cycle testing.

Table 4. Typical Leak Test Matrix

Test ID. No.	Temperature (F)	Inlet Pressure (psig)	Outlet Pressure (psig)	Differential Pressure (psid)
1.	250	50	0	50
2.	250	150	0	150
3.	250	250	0	250
4.	250	350	0	350
5.	250	700	0	700
6.	250	1100	0	1100
7.	250	2250	0	2250
8.	350	2250	2200	50
9.	350	2250	1550	700
10.	350	2250	1150	1100
11.	550	2250	2200	50
12.	550	2250	1550	700
13.	550	2250	1150	1100

6. Leak Tests - This series of leak tests were similar to those described in test 4.

7. Wet Cycling, n = 150 - The test valves were stroked an additional 150 times in the manner described previously in Test 5. The 150 cycles represents the completion of a typical PIV service life. It should be noted that some PIVs are stroked significantly more than 150 times during their service life. As previously discussed, this test and test 8 were deleted for the 6-inch and 12-inch check valves.

8. Leak Tests - This series of leak tests was similar to that described in test 4.

9. Post Test Examination - Following the sequences of cycling and leak rate testing, the check valves were examined in place for any damage to the seating surfaces and the valve internals, particularly the disk stud nut attachment. All flaws or changes were characterized and documented.

10. Loosened Internals Test - This test applied only to the check valves. Per the original program plan, only one check valve was to undergo loosened internals testing. However, as the program progressed, the test plan was modified in response to

the life cycle test results and incidents in the LWR community to include all three check valves.

The first phase of loosened internals testing was conducted and involved all three check valves. The loosened internals testing consisted of breaking the weld between the nut and the stud on the back of the valve disk, Figure 1. The nut was loosened a specified number of rotations and locked in place with a backing nut. The valve then was cycled five times and the leak tests as specified in Table 5 were conducted. The leak tests were to determine whether leak tests were effective for identifying loosened check valve internals. The process of cycling and leak testing was repeated twice. The goal of the additional cycles and leak tests was to determine whether a check valve with loosened internals seated in a reproducible manner.

The sequence of tests described above was done for two different loosened conditions for each check valve.

Prior to starting the loosened internals testing, it was recognized that check valves used as PIVs are often self-centering and therefore the valve's leak rate may not significantly increase even with the integrity of the valve internals compromised. Therefore, the acoustic emission equipment was monitored during the valve cycling as well as during the leak tests. The AE equipment supplied by ETEC was readjusted to monitor the signal frequencies which occur during valve cycling. This enabled evaluation of the feasibility of using a technique, other than valve leak rate monitoring, to detect valve degradation.

11. Loosened Internals, Phase 2 - During the Valve Performance Test Program, the decision was made to conduct additional testing with check valve loosened internals to determine whether AE or visual in-service inspection techniques were effective in identifying loosened internals. The four-inch check valve was installed in the Hydraulic Test Facility (HTF), a low-temperature, low-pressure, flowing water loop. AE traces were made with the valve internals in the as-received condition at a range of flow velocities from 3 to 15 ft/sec. The valve internals then were loosened and the flow tests repeated. The objective was to evaluate whether the AE could "hear" the loosened internals with water flowing through the valve. The flow tests were of short duration, a few minutes, therefore the objective of the test did not include imposing any additional wear mechanisms on the check valves. Instead, the test focused on trying to determine whether the artificially induced loosened internals condition could be identified with AE monitoring.

Table 5. Loosened Internals Leak Test Matrix

Test ID. No.	Temperature (F)	Inlet Pressure (psig)	Outlet Pressure (psig)	Differential Pressure (psid)
1.	250	200	50	150
2.	250	300	50	250
3.	250	400	50	350
4.	250	750	50	700
5.	250	1150	50	1100
6.	250	2250	50	2200

The second portion of this task was to examine visual in-service inspection techniques. A rigid borescope and a flexible video probe were obtained. The four-inch valve was inspected while it was installed in the HTF; a small hole was machined into the bonnet to accommodate the probe. The six-inch check valve was not installed in the HTF for the in-service examination, therefore a wooden plate with a small hole was substituted for the bonnet. This approach allowed the in-service inspection to be conducted to develop the inspection procedure without altering the actual bonnet.

12. Motor Actuator Signature Tests - These tests were conducted on two of the gate valves; the 4-inch and 10-inch flexible wedge disk valves.

    As part of their work on nuclear power plant aging, ORNL made a study of motor-operated valve failures. This study showed that the primary reported failure mode, a failure of the valve to change position, was caused by problems with the motor operator. The motor actuator signature tests were designed to identify methods of surveillance effective in detecting significant aging and deterioration of valve operability prior to loss of safety function. The following parameters, which form the valve's motor actuator signature, were monitored for this purpose.

    Valve position,
    Stem force,
    Velocity,
    Motor vibration,
    Motor temperature,
    Motor current,
    Torque shaft rotation,
    Position,(both standard switches and fiber optic)

Torque (limit switches)
Acoustic emission

Prior to the life cycling, the packing nuts were adjusted per manufacturer's specifications. The motor signature was recorded throughout the life cycling to identify any significant changes in the signature or the packing leak tightness due to normal wear. After the life cycling was completed, the gland nuts were adjusted to 50%, 200%, and 300% of the manufacturer's recommended torque. The packing torque was varied because plant operators often tighten the packing torque to prevent or stop leakage through the valve stem. After the torque was adjusted, the valves were cycled at 250F, 400F, and 550F. Again, the motor signature was evaluated for indications of reduced valve operability while the valves were examined for leakage through the stem packing.

13. Removal and Final Exam - After all tests were completed on a given valve, the valve was removed from the facility and examined for degradation or damage.

2.3 Leak Rate Test Matrices

During the life cycling and the phase 1 loosened internals tests, valve leak tests were conducted at the pressure and temperature conditions shown in Tables 4 and 5. These matrices generated data for a number of independent variables; pressure drop across the valve, temperature, downstream pressure (which determines the phase of the fluid leaking through the valve at a given temperature), and the number of wet or dry valve aging cycles.

The pressure and temperature variations were specified for evaluation of the ASME Code correlation given below. Sufficient variation in differential pressures and temperatures were specified to cover the desired range of operating-to-test conditions.

$$L_o = L_t \sqrt{\frac{P_o}{P_t}}$$

where L_o = leak rate at operating conditions

L_t = leak rate at test conditions

P_o = differential pressure at operating conditions

P_t = differential pressure at test conditions

The leak tests were interspersed in the life cycle and loosened internals program to determine the relationship between valve degradation and leak rate. The check valve loosened internals matrix was formulated to determine whether the correlation between leak rate and differential pressure was the same for valves with loosened internals as it was for valves without their internals compromised.

The leak rate test matrices also were designed to minimize the test costs without sacrificing the Valve Performance Test Program objectives. Therefore, as with the other Valve Performance Program elements, these matrices were continually evaluated and tests which would not yield useful data were eliminated. For instance, if there was no measurable leak rate or an extremely low leak rate during the 250F tests, the leak tests at higher temperature were eliminated since experience had shown that the variation of extremely small leaks with temperature was minimal.

The tests in the matrices specified at isothermal conditions provide a direct correlation of leakage versus ΔP. The tests at elevated temperatures are conducted at the same ΔP as the lower temperature tests to obtain data on the effect on temperature on measured leak.

3.0 TEST RESULTS

The test data, discussed in Appendix B and References 4 and 5, were analyzed to address the objectives of the Valve Performance Program. The results are discussed in this Section as they relate to each of the five Valve Performance Program objectives.

3.1 Leakage as an Indicator of Valve Condition

For the check valves, leak rate as an indicator of valve condition was investigated for three types of valve degradation, valve wear due to cycling, erosion, and loosening of certain internals. For the gate valves, wear due to cycling was the only degradation mechanism examined.

Figures 3 and 4 are plots of valve leak rate versus the number of combined wet and dry cycles for the check valves. As Figures 3 and 4 show, leak rate does tend to increase as a function of normal wear caused by valve cycling for both gate and check valves. However, the leak rates measured at the end of the life cycling program were all well within the generally allowable leak rate of 0.5 gallons (0.052 lb/sec) per nominal inch of valve diameter (at 2250 psia and 550F).

The check valve test results indicate that erosion of the seating surfaces, caused by the presence of flashing conditions across the valve, does not cause rapid degradation of the sealing surfaces. However, the check valve leak rate generally did increase somewhat during flashing tests.

It is important to note that the results obtained during the Valve Performance Program show that dry cycling of valves is not an important area of concern, since limited dry cycling of gate and check valves had little effect on the seating surfaces. In fact, dry cycling of the check valves resulted in decreased leak rates. During the initial research that was done to develop the Valve Performance Program test plan, a number of valve manufacturers were contacted. Without exception, these manufacturers were very concerned about dry cycling of valves and felt that dry cycling would cause severe degradation of the seating surfaces.

There is concern that check valve failure can be caused by the internal components working loose and becoming incapable of performing their design function. These types of failure occurred at San Onofre, Unit 1, a water hammer event which contributed to the loss of power that occurred on November 21, 1985. At San Onofre, see Reference 3, deformation of the stud was observed in two check valves. The clapper had separated from the hinge arm in both these check valves.

During the life-cycling of check valves for the Valve Performance Program, only the four-inch check valve suffered significant damage to the clapper assembly or the valve body. The 4-inch check valve is believed to have suffered more damage than the 6-inch and 12-inch check valves because it was cycled more often than the latter two valves and because the cycling method, described in Section 2, caused the 4-inch valve to open more fully and with more force than the 6-inch or 12-inch valves. As previously discussed, life cycling of the 6-inch and 12-inch check valves was abbreviated in order to expand the loosened internals portion of the Valve Performance Program. Despite damage to the clapper assembly, separation of the clapper and the hinge arm did not occur during life cycling of the four-inch check valve in the Valve Performance Program.

The results of the Valve Performance Program loosened internals test indicate that the current utility practice of leak testing of PIVs is ineffective in detecting some types of loosened internals in check valves. Specifically, leak rate tests did not indicate that the clevis assembly nut or the clapper stud nut were loosened. In no case did leak rate exceed permissible levels. See Appendix B for details.

At San Onofre, three other check valves were found in which the nut which locks the clapper into place had worked loose. The clappers of these valves were found to be caught inside the seat ring. During the Valve Performance Program, none of the three check valves were damaged in this way. In fact, due to the stud deformation, the nut could not be removed from the four-inch check valve without cutting the stud. The design of all three check valves specified a seal weld between the nut and the stud which probably prevented the nut from working loose.

Only one check valve failure, a failure of the four-inch check valve to close, occurred during the Valve Performance Program. The failure occurred before the valve was disassembled for loosened internals testing. The leak rate monitoring did not indicate that this valve was going to fail to close. That is the leak rates were very low during all leak rate tests, less than 0.01 lb/sec (0.10 gpm at 550F and 2250 psia), prior to the failure of the valve to close. If this occurred in a LWR, the operators would not have warning that valve maintenance was required in advance of the valve failure. However, it is important to note that leak rate testing did identify that the failure had occurred.

Leak rate testing was useful in verifying the condition of the check valves following valve maintenance. After the four-inch check valve clapper assembly was replaced following the loosening of the valve internals, the post-assembly leak rate test identified that the valve assembly was incorrect. The valve did not fail to close due to the loosening of the internals, but because of reassembling the valve, an out-dated procedures was used. This resulted in the clapper getting hung up on the valve seat. When a revised assembly procedure was obtained and followed, the valve seated without excessive leak rate, even though the internals were still loose. Post-maintenance leak tests appear to be a valuable tool for plant applications.

The leak rate during the program often varied following a single valve stroke or cleaning of the valve seating surfaces. This indicates that impurities trapped on the seating surfaces are responsible for some variation in the measured leak rate. Data reported by LWR plants, Reference 2, verify this observation.

3.2 ASME Correlation

The correlation given in Section XI of the ASME Boiler and Pressure Vessel Code is used by commercial nuclear power plants to extrapolate valve leak rates measured at low differential pressures to leak rates at larger differential pressures. The correlation was developed to allow utilities to conduct the required valve leak rate tests at low differential pressures during plant shutdowns rather than requiring them to match the differential pressure conditions which exist during normal plant operation. The correlation is based on the square root ratio of the differential pressure during operation (ΔP_o) to the differential pressure during leak rate testing (ΔP_t) as shown below. The correlation does not include temperature affected parameters such as viscosity or density. L_o is he leak rate at operating conditions, L_t is the leak rate measured at test conditions.

$$L_o = L_t \sqrt{\frac{\Delta P_o}{\Delta P_t}}$$

To evaluate the accuracy of this correlation, the check and gate valve leak rates were measured over a range of differential pressures. Leak rate measurements also were made at various temperatures to determine whether fluid temperature affects the correlation. The effects of the various parameters on this correlation are discussed separately in the following paragraphs.

3.2.1 Pressure Effects

Because the leak rates measured during this test program were typically very low, in the range of 10^{-4} to 10^{-2} lb/sec, it may be difficult to extrapolate the results of these tests to meaningful leak rates in the range of one to five gpm. The higher leak rates are of special interest to plants because leak rates in this range indicate that valve repair is, or will soon be, required.

However, the results obtained illustrate the importance of applying an adequate differential pressure across the face of swing check valves during leak rate testing. Seating force for swing check valves is supplied by the differential pressure across the valve face. If the applied differential pressure is too low, the valve may not seat properly and overly conservative results would be obtained. In general, the data show that the leak rate measured at low differential pressures exceeds the leak rate measured at higher differential pressures. It can be implied that when the leak rate increases with increasing pressures, a true leak path exists and that the valve's leak rate should be closely monitored so that valve maintenance occurs before the leak rate exceeds acceptable limits.

For the gate valves, a different pattern of leak rate versus differential pressure emerged at the lower differential pressures. The highest leak rates typically occurred with the highest differential pressures.

These results emphasize the fact that differential pressure can have two opposing effects on leak rate. It provides seating force which tends to decrease leak rate. At the same time, increased differential pressure provides a larger driving force for leakage flow which tends to increase the leak rate. For the check valves, differential pressure is the primary seating force, therefore, at low differential pressures insufficient seating force was the dominant effect resulting in higher leak rates. Whereas for wedge type gate valves, differential pressure is a secondary seating force. The primary seating force is provided by the motor operator. Therefore, the second factor was dominant and increasing the differential pressure increased leak rates.

Figures 5 to 10 are log-log plots of the leak rate versus the differential pressure for the check and gate valves. The ASME Code correlation predicts that all the points on a log-log graph would be fitted by a straight line with a slope of 0.5. If the leakage flow is laminar, then the points would be fitted by a straight line with a slope of 1.0. However, as shown on the figures, the slope of the straight line fitted to the data for the six test valves varied from 0.13 for the 12-inch check valve to 2.7 for the 4-inch W-K-M valve. For the check valves, data points at low differential pressures, less than 350 psig, were eliminated if the leak rate was abnormally high. As previously discussed, abnormally high leak rates at low differential pressures indicates that the check valve seating force is not large enough to seal the valve properly. The code correlation would not apply under these circumstances. Therefore, the data indicates that a correlation can not be proposed for leak rates in the range of those measured during the Valve Performance Program, 0 lb/sec to 3 x 10^{-2} lb/sec (0.27 gpm at 550F and 2250 psig). For higher leak rates, and thus larger leak paths, the ASME Code correlation might be more accurate. An LWR would be most concerned with leak rates in the range of one to five gpm as leak rates of these magnitudes would require valve repair.

3.2.2 Temperature Effects

There was a general pattern of decreasing leak rate with increasing temperature, see Figures 11 and 12. The sharp drop in the leak rate of the 4-in. check valve at 350F, see Figure 11, indicates that the leak rate may be due partially to impurities trapped on the seating surface which may have been swept off during the cycling between the measurements made at 250F and the 350F test. (No elevated temperature leak rate tests were conducted on the 6-inch or 12-inch check valves because the leak rates across these valve seats were consistently very low. As previously discussed, if extremely low leak rates were measured, the elevated temperature tests were deleted.)

The general trend of decreasing leak rate with increasing temperature would be theoretically expected for turbulent flow. However, the magnitude of the variation in leak rate versus temperature was greater than expected. The leak rate at constant differential pressure theoretically should vary as a square root function of the ratio of the densities. A log-log plot of leak rate versus density was made for the four-inch Westinghouse valve, see Figure 13. As this figure shows, the measured leak rates decreased more than would be predicted by this function as the slope is much greater than 0.50. The general trend of decreasing leak rate with increasing temperature did not hold for all of the test valves. The four-inch W-K-M valve leak rate increased with temperature. This general trend would be expected for laminar flow. But again, the magnitude of the change is greater than expected.

In terms of the existing code correlation, ignoring temperature effects is conservative. That is, if the correlation is corrected for temperature, then the predicted leak rate would be less.

3.3 Acoustic Emission Monitoring

Acoustic emission monitoring by the standard acoustic emission devices originally used in this program was shown not to be viable instrumentation to measure the leak rates produced by life cycling of the valves. The ETEC high sensitivity AE equipment was shown to measure water leak rates from 0.001 lb/sec (0.01 gpm at 550F and 2250 psia). Indication was that much more testing would be required to generate certifiable AE instrumentation for plant utilization. See Appendix A.1.2.

3.3.1 Leak Rate Monitoring

The leak rates measured during the check valve testing were very small, less than 3×10^{-3} lb/sec (0.03 gpm at 550F and 2250 psia). These small leak rates are below the range of reliable measurement for acoustic emission systems. Therefore, the data could not be used to evaluate acoustic emission monitoring as method for quantitative leak rate measurement.

The acoustic emission data was shared with ANL, ORNL, and the Naval Ship Research & Development Center. In addition, a representative from Leak Dynamics Company visited ETEC during the long term flashing program and monitored the acoustic emission traces of the four-inch check valve. Leak Dynamics is under contract to the NRC. These organizations will make independent evaluations of the data for the NRC programs in which they participate.

As with the check valves, a number of different acoustic emission systems were used to monitor the gate valve leak rate tests. In addition to the ANL, ETEC, ORNL, and Naval Ship Research & Development Center devices, ETEC fabricated and installed a new high sensitivity narrow-band system which monitored frequencies of 180 $\pm$ 30 kHz. The additional AE system was conceived by ETEC in response to the low leak rates that resulted from life-cycling of the check valves. ETEC believes that the new system has the potential of installed, i.e., 10^{-4} lb/sec region. As shown in Figures 14 and 15, the ETEC narrow-band system was the only system which showed promise for measuring the low leak rates obtained during the Valve Performance Program. The AE data was analyzed as a function of frequency versus amplitude.

3.3.2 Check Valve Loosened Internals Monitoring

The original purpose of the acoustic emission systems was to evaluate the effectiveness of acoustic emission techniques for detecting, quantifying, and examining trends in valve leakage. However, during the course of the program, one of the AE systems was adjusted to obtain acoustic traces of valve cycling during the loosened internals testing. The objective was to evaluate whether loosened internals could be detected with acoustic emission monitoring during valve cycling. Since the ETEC and ORNL systems were very similar, the ETEC transducers were chosen to be readjusted to monitor the acoustic frequencies produced during valve cycling.

The ability of acoustic emission monitoring to detect loosened check valve internals could not be clearly judged based on the cycling tests conducted at LLTR. There were indications that the loosened valve clapper produced a different AE trace, however, the noise from the valve opening and closing dominated the AE trace. Since this potential failure mode has proven to be important in operating LWRs, and since leak rate tests do not seem to identify this condition, a new phase of loosened internals testing was developed. These tests were conducted at the Hydraulic Test Facility (HTF).

The tests conducted at the HTF consisted of flowing water through the test valve at velocities from 3 to 15 ft/sec for each of three valve internal conditions: (1) the valve clapper nut tightened to specifications, (2) the valve clapper nut loosened two turns, and (3) the valve clapper nut loosened an additional four turns. The purpose was to determine if the acoustic sensors could detect the loosened internals during typical flow velocities.

Fourier analysis of the data was performed and is shown in Figures 16 through 18. This was accomplished to determine whether the data would show a particular frequency level that indicated loosened check valve internals. Figure 19 is a comparison of the results. This analysis confirms that AE monitoring does not produce a detectable pattern that identified loosened internals for this testing.

3.4 Gate Valve Motor Signature Monitoring

The motor signature of the Westinghouse flexible disc 4-inch and 10-inch gate valves were monitored with the packing torque set at values less than and exceeding the manufacturer's recommended torque. The fluid pressure also was varied during the testing.

The motor signature monitoring showed that closing current and dynamic stem force are both functions of packing torque. In addition, closing current is also a function of fluid pressure. The results show that the valve operational characteristics are dependent upon maintenance activities, such as tightness of the packing gland nuts to prevent leakage through the packing, and the system conditions at the time of valve operation, such as the fluid pressure and flow. The dependence of closing current on system conditions verifies LWR plant experience which shows that MOVs that operate acceptably during ISI are not necessarily functional at emergency system conditions.

The Valve Performance Program tests indicate that motor signature instrumentation can be used in LWRs to monitor valve performance and to assist in periodic readjustment of the valve to ensure operability under normal plant operating conditions as well as emergency conditions. These motor signature tests identified motor operator instrumentation to ascertain performance that is relatively easy to install and maintain that will give practical information for plant operation.

3.5 Check Valve Visual In-Service Inspection (ISI)

A rigid borescope and a flexible videoprobe were used to evaluate whether visual ISI could identify loosened and deformed check valve internals. The four-inch check valve was inspected while installed in the HTF for AE testing. The six-inch check valve bench tested to develop the ISI procedure. The 12-inch check valve was not included in these tests. The results for the four-inch and six-inch valve were conclusive and the same. Refer to Appendix B for additional details.

The rigid borescope proved to be an adequate tool for ISI when video recording of the inspection was not necessary as it was adequate to detect the loose internals. However the flexible probe was preferred because it could access more area, and was articulatable in four directions, and had video viewing and recording.

A video tape of the four-inch and six-inch ISI with the flexible videoprobe demonstrated that the check valves internals can be clearly inspected, and that a loosened nut, bent stud, bolt, or clapper seating could be readily seen with the flexible probe. In some instances, even portions of the upstream side of the check valve clapper assembly (with the clapper in the closed position) can be inspected. The visual ISI methodology developed in the Valve Performance Program can be adapted to facility PIVs. However, this requires that an access port on the order of 3/4-inch diameter be drilled into the bonnet to access to the valve internals. Although this method would accomplish the objectives of an ISI, other problems, such as breaking the primary pressure boundary, must be resolved before such methods would be acceptable for plant use.

4.0 CONCLUSIONS AND REFERENCES

4.1 Conclusions

1. Life-cycling and long term flashing of the fluid in the check valves and life-cycling of the gate valves did not cause severe degradation of the valve seating surfaces during this test program. However, plant conditions must be more severe to include flow effects and additional aging mechanisms to cause seating surface degradation as reported.

2. During the Valve Performance Program tests, leak rate testing did not identify whether the integrity of a check valve clapper or clevis assembly had been compromised, even when the clapper restraining nut was almost detached from the stud.

3. Acoustic emission monitoring did not identify when the integrity of a check valve clapper assembly had been compromised either during valve life-cycling or when the valve was subjected to varying flow rates at operating pressure and ambient temperature with no upstream flow restrictions.

4. Based on these check valve performance tests, leak rate monitoring was not effective in predicting impending failure of the four-inch check valve to close. However, the leak rate tests did detect the failure after it had occurred, therefore, post-maintenance leak tests appear to be a valuable tool for plant applications.

5. Life-cycling of the check valves can damage the clapper assembly. Although this type of damage did not result in a valve failure during the Valve Performance Program tests, the damage to the clapper stud on the four-inch check valve indicates that clapper assembly degradation could occur during abnormal plant operation. A possible scenario could include failure of the clapper stud.

6. Based on these leak performance tests, no conclusion could be drawn concerning the ASME Code correlation for extrapolating leak rates based on the results of the Valve Performance Test Program. The ASME Code correlation was not accurate for very low leak rates obtained during the Valve Performance Program (less than 0.3 gpm at 550F and 2250 psig). Nor did the correlation always give conservative results at these low leak rates, i.e. predict higher than actual leak rates at higher differential pressure which was not the case here.

   Although the results of this test program do not agree with the ASME Code correlation, the aging methods used during this program did not cause sufficient wear/degradation of the valve sealing surfaces to simulate long term plant leakage which could be a combination of wear and/or crud on the seats.

Therefore, data to validate, or invalidate, the Code correlation for leak rates greater than 0.5 gpm are unavailable and from the present program conclusions about the existing correlation can not be made.

7. There was no discernable pattern between leak rate and temperature.

8. For the low leak rates measured during the Valve Performance Program, most of the acoustic emission systems tested were not effective in quantitatively measuring the leak rate. However, the high sensitivity, narrow-band-width system did show promise for this application.

9. The motor signature monitoring showed that closing current is a function of fluid pressure and packing torque and that dynamic stem force differential also is a function of packing torque. These results verify that the valve operational characteristics are dependent upon maintenance activities and that motor signature instrumentation can be used in LWRs to assist in periodic readjustment of the valve to ensure operability. The motor signature tests identified motor/operator instrumentation that is relatively easy to install and maintain which would give practical information for plant operator.

10. Visual in-service inspection is a highly effective method of detecting loosened check valve internals and degradation. However, this method of inspection requires penetration of the primary system pressure boundary by drilling a port in the valve bonnet. The acceptance of this method would require additional effort to obtain ASME Code approval.

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APPENDIX A: TEST FACILITIES AND INSTRUMENTATION

The Valve Performance Test Program was conducted at two ETEC facilities, the Large Leak Test Rig (LLTR) and the Hydraulic Test Facility (HTF). The majority of the check valve testing, the basic in-service inspection (ISI) required for check valve inspection, and all of the gate valve tests were conducted at the LLTR. Phase 2 of the check valve loosened internals tests and ISI prototype testing were conducted at the HTF.

A.1 Large Leak Test Rig

The LLTR was selected for the bulk of the Valve Performance Test Program because of its high pressure water, steam and nitrogen supplies. The modified LLTR for the VPP is shown schematically in Figure 20. The schematic shown is for gate valve testing. For check valve testing the piping was modified to allow for flapper pressurization from the back side. It contains high pressure water storage vessels suitably sized and designed (Table 6) to permit all necessary water test operations. Extensive instrumentation are located on the piping and tanks.

The high-pressure nitrogen supply, valves, pipe/valve preheaters and heater controls were existing. Thus the only facility preparation was the relocation of some piping and valves that tied the test articles into the facility. Points of connection of the test article to existing piping were downstream of valves PCV-218 and V-204B, Figure 20. The test installation was located at grade level immediately inside the LLTR high bay door, and the piping was routed down to the existing high pressure water tanks in the LLTR vault. This arrangement facilitated test article handling and installation.

A view of the three check valves installed in the LLTR is shown in Figure 21.

The LLTR digital data acquisition system (DDAS) was capable of acquiring data at up to 250 samples per second. In addition, analog data could be analyzed at 0.1 m sec or digitized at 10,000 samples per second. Existing automated features for synchronizing tests were used for the Valve Performance Program so that the valve cycling often were run on off-shifts with minimal facility surveillance.

The LLTR control room and DAS are shown in Figures 22 and 23. The test facility design parameters that were used are listed in Table 6.

Table 6. Test Facility Design Parameters

Design Code	ANSI B31.1
Water Pressure	2250 psig
Water Quality	Grade B
System Water Supply	75 ft^3
Plant Water Supply	7,000 gal
Heat-up and Cool-down Rates	50F/hr
Nitrogen Supply Pressure	3100 psig

A.1.1 System Operation

Cycling of the test valves was by computer control using algorithms developed explicitly for life cycle valve tests as required for the Valve Performance Program. Shown in Figure 20 is the gate valve installation; the check valves were installed to open when pressurizing from V-240B. The pressure drop across the valves for cycling was created by venting the downstream side of the test valve prior to test. For check valve cycling, the system was vented down from V-240B, in order to bang the valve open. Test pressures were achieved by pressurizing the water tanks with nitrogen through valve V-217D. The water supply tanks T1, T2, and T3 were valved in parallel for these tests. For wet cycling, the tanks, piping, and test valves were heated to test conditions using existing electrical trace heaters. For leak testing the check valves, the water supply to pressurize the clapper, was from V-244B; while the leak rate measurement instrumentation was moved to the other side. For the elevated temperature leakage tests, the supply tanks were maintained at cycling temperature and only the valves and the valve inlet piping were heated to the leak test temperature. This minimized the test preparation time.

The cycling sequence algorithms for the computer are given in Tables 7 and 8 for check and gate valves, respectively. The center valve test position is described. The sequence for the other two positions were identical but had different valve numbers. The valve cycling software certified the supply water level (DP-502), the supply system temperature, various tank and line thermocouples, system pressure (P-554), proper valve positions (V-240B) and the test article.

The program was designed to cycle the test valve every two minutes. During a cycling, V-204B opened first; then, the test article was opened after the cavity was filled. Post cycle, V-4D was opened to vent the system after V-240A had been closed; then, V-218 was opened to supply a purge gas at 150 psig. The purge gas was shut off then the V-4D valve was closed to prepare for the next cycle.

A.1.2 Instrumentation

The control and data acquisition instrumentation used for the Valve Performance Test Program were calibrated by the ETEC Instruments and Standards Laboratory. This lab maintains primary and secondary standards traceable to the National Bureau of Standards for all instrument calibration. Rigorous procedures referred to as Measurement System Calibration Procedures were developed and implemented in accordance with ETEC policies to produce data of certifiable accuracy for each measurement system as it was installed in the test facility.

Three parallel systems were used to cover the complete range of interest for leak rate. For ultra-low leak rates (less than 0.1 gpm) leakage was measured by volumetric displacement versus time in a specially designed vessel. This is the standard method used extensively at ETEC in valve bench tests. A low range (0.1 to 1 gpm) and a higher range (1 to 5 gpm) turbine flow meter were installed to measure larger leak rates, F-242 and F-243 respectively, Figure 20. By dividing the measurement range among three instruments a high accuracy measurement was assured.

Table 7. Computer Valve Sequencing for Check Valves

Valve	Start	Cycle Open (sec)	Cycle Close (sec)	End
V-217D	O			C
V-204 A&B	O			O
V-240A-241A or 204H	C	8	16	C
V-240B-241B or 204J	C	11	30	C
V-4D	C	19	310	C
V-218*	C	25	280	C

*Backed by 200 psig nitrogen
Legend: O-Open, C-Closed

Table 8. Computer Valve Sequencing for Gate Valves

Valve	Start (verify)	Cycle* Open (sec)	Cycle* Close (sec)	End Program
V-217D	O			C
V-204 A&B	O			C
V-204H, V-240A, V-241A	O			O
Test Article	C	2	27	C
V-4D	C	65	120	O
V-218**	C	75	100	C

*At 50 sec. into the cycle-stem position, stem force test article temperature and water supply was certified and printed out prior to the next cycle.
**Backed by 200 psig nitrogen.
Legend: O-Open, C-Closed

Both the check and the gate valves were used to address one of the program objectives to evaluate the use of acoustic emission (AE) techniques for quantifying valve leakage and as an indicator of valve condition. AE data were recorded during the leak rate testing of both the gate and the check valves. For the check valves, the AE techniques also were employed to determine whether AE was a reliable means of detecting loosened internals. Four different AE monitoring systems were installed during the check valve testing. The systems were supplied by ETEC, Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), and the Naval Ship Research & Development Center. Four systems were used because this program was a unique opportunity to obtain AE test data which could be used in a number of NRC programs at minimal costs. In response to the low leak rates of the check valves and no effective AE measurement, an additional narrow-band AE system was conceived and procured by ETEC from Rockwell International and installed prior to gate valve testing.

The ETEC, ANL and ORNL systems each had a transducer installed on the valve and another transducer installed on the valve inlet pipe. The AE sensors were mounted on a waveguide, one-eighth inch diameter, that was capacitance-discharge welded to the valve, for maximum coupling. A soft cable connected the transducer to a locally mounted automatic gain control (AGC) amplifier. The output of the AGC amplifier provided an analog signal which was wired to the Digital Data Acquisition System (DDAS). This has been a standard technique for transducer mounting to the Liquid Metal Reactor (LMR) Development Steam Generator shells for leak detection measurement.

The ORNL device monitored at frequencies of 3.0 kHz to 8.5 kHz, the ANL system at much higher frequencies of 100 kHz to 450 kHz, and the ETEC system monitored at 0.4 kHz to 20 kHz. For gate valve testing, ETEC installed another AE system which monitored over a narrow band of 180 $\pm$ 30 kHz. The two ETEC sensor systems were also used for phase II of the check valve loosened internals testings as well as gate valve testing.

Temperature and pressure measurements of the valve inlet conditions were used for the water density computations. All temperature measurements were calibrated to an accuracy within $\pm$10F to 600F and all pressure data was certified to $\pm$2% of full scale.

A minicomputer based DDAS was used for acquiring and recording data for on-line data reduction and display. The basic software was existing and required only minor modification to accommodate the Valve Performance Program. The on-line data reduction was used for rapid assessment of test results to verify that the test objectives were being met.

Valve stem position was measured by an linear variable displacement transducer (LVDT) directly from the stem through the top of the Limitorque operator. ~~The~~ Stem velocity was a direct calculation from position data versus elapsed time. The LVDT system was calibrated to assure accuracy.

The stem force was measured from three three-element strain gages at 120 degrees on the stem and angled at 45 degrees. One of the gages mounted on the 10-inch valve is shown in Figure 24. The circumferential and longitudinal elements in each gage were measured in a bridge circuit that provided for temperature compensation. This configuration also increased the sensitivity by 1.3 since the elongation and the compression were both measured. The valve stem loading was based on the stem diameter and average material properties correlated to strain. There was no actual calibration of the force. The stem temperature was measured and used as an indication of gage sensitivity and gage bonding integrity. The stem force from each gage was available to ascertain bending moments, but typically, the average of the three gages were used in the MOV performance tests.

The motor current was measured by a current transformer on one leg of the 440 VAC line feeding the motor. This transformer was changed depending on the valve being tested to increase the sensitivity. The total system, transformer to the computer, was calibrated prior to test.

The Limitorque operator is controlled by a mechanical torque switch from the gear drive. An electronic indicator was attached to the torque shaft for measurement of its rotation in degrees as a function of torque in the system; it was system calibrated in degrees. During the opening cycle the torque switch was overridden during the first 30% of travel. This was done here to simulate plant operation such that the torque switch cannot terminate opening in an emergency situation if the gate wedge has been forced in and/or stuck for a long period of time. In that case the motor is allowed to drive to its limit.

The position limit switches are mechanical. The torque and closed limit switches were set to activate at 30% of closed.

Fiber optic open and close position sensors were installed on the 10-inch Westinghouse valve during the life cycling of the 4-inch gate valve. The basis for this instrumentation and tests were to 1) perform prototypic testing of fiber optic systems and 2) to perform life cycling and motor signature testing with state-of-the-art instrumentation for LWRs as well as other nuclear plants. The open limit detector used an EOTec Model ETR-105 - TTL level detector with a bifurcated fiber optic cable and probe, see Figure 25. The close limit detector, Figure 26, used an EOTec model ETR-103S analog module with a bifurcated fiber optic cable and probe. These two devices were selected as typical reflective devices for the open and close positions, respectively.

The open position reflective device was used as a make unit, switch, indicating that the shaft guide had passed the position. An analog reflective instrument was selected for the close position to obtain measurements of the seating position of the gate plug as a function of cycling and stem force. The characteristics for this close position device are shown in Figure 27 where the analog device could measure about 125 mil with good sensitivity.

Initially a microbending approach was used for the closed position to provide high sensitivity because we thought that the seating position variation with cycling and stem force would be small. But, during the first test sequence, the microbending mechanism was crushed and was replaced with the reflective analog device. The analog reflective device provided a larger seat position measurement range, but not with the same accuracy.

A.2 Hydraulic Test Facility (HTF)

The Borg-Warner four-inch check valve was installed in the HTF to evaluate acoustic leak rate monitoring and in-service inspection techniques of valve condition. Figure 28 shows how the check valve was installed in the water loop.

The HTF is a closed demineralized water circulation loop with remotely operated centrifugal pumps and flow control valves that direct and vary the flow through designated test areas. A deaeration tank connected to the pump suction header removes entrained gases from the water and acts as a surge tank for the circulation system. Heat input to the water from operation of the system pumps is removed by air-cooled heat exchangers.

Circulating water was provided to the four-inch check valve from the facility pump P-1, rated at 750 gpm and 900 ft of head (390 psig). Water flowed from the pump discharge through the test article, a turbine flow meter, a flow control valve and returned to the pump suction manifold.

A computer-operated DDAS recorded the flow, temperature and acoustic emissions data on disc for on-line processing and on tape for off-line processing. An analog tape recorder was used for recording the acoustic emission signals for Fourier analysis of the data.

The in-service inspection procedure was performed using two types of probes. One type was a rigid borescope with 90 or 30 viewing, standard to most utilities. The second one was a commercially available, Welch Allyn Video Probe 2000, flexible videoprobe capable of being articulated in four directions. The six-inch check valve was bench examined to develop the in-service inspection methodology.

A.2.1 System Operation

Testing of four-inch check valve was accomplished by manually setting the pump speed and a throttling valve was utilized for test flow adjustments. Data was taken throughout the throttling process. The flow was held constant at even increments between 3 and 15 ft/sec.

A.2.2 Instrumentation

All instrumentation measurements were calibrated by written procedures using standards traceable to the National Bureau of Standards on a calibration schedule commensurate with the characteristics of the measurement system. These calibrations included the measurement transducer, all signal conditioning equipment, and the measurement recording system. End-to-end system calibrations in the field were utilized to the maximum extent possible to ensure that the off-site individual component calibration were compatible and consistent, and to verify that the accuracy of the reported data was within acceptable limits. Table 9 shows a list of instrumentation used during these tests.

Table 9. Instrumentation - Loosened Internals

ID	Range	Nomenclature
AE-HSV	180 ± 30 kHz	Valve High Freq. Sensor - Acoustic
AE-HSP	180 ± 30 kHz	Line High Freq. Sensor - Acoustic
AE-HTFV	20 kHz	Valve - accelerometer (acoustic)
AE-HTFP	20 kHz	Line - accelerometer (acoustic)
AE-HSC	Calculated	Delta - High Freq. (Valve - Line)
AE-HTFC	Calculated	Delta - High Freq. (Valve - Line)
FT-110	50 - 500 gpm	Water Flow
TE-107-1	40-200F	Water temperature

APPENDIX B: TEST DATA

B.1 Check Valve Leak Rate Tests

B.1.1 Four-Inch Check Valve

B.1.1.1 Life-Cycle Tests

The four-inch check valve was subjected to 10 dry cycles, 50 wet cycles, and 150 additional wet cycles (at 250F and 2250 psid). Leak tests at various temperature and pressure conditions were conducted with the valve in the as-received condition and following each period of valve cycling.

The baseline leak tests showed very small leak rates, approximately 4×10^{-5} lb/sec (3.8×10^{-4} gpm) at 250F and 2250 psia. Following the dry cycles the valve exhibited no measurable leak rate, perhaps indicating that the seating surfaces had "worn in." After the first 50 wet cycles the valve leak rate was again in the measurable region, but was still very low, on the order of 1×10^{-5} lb/sec (1×10^{-4} gpm) at 250F and 2250 psia. The next 150 wet cycles had minimal impact on measured leak rate, marginally increasing the average leak rate to 2×10^{-5} lb/sec (1.9×10^{-4} gpm) at 250F and 2250 psia.

As discussed further in Section 3.2, at these very low leak rates, less than 1×10^{-4} lb/sec (1.0×10^{-3} gpm) at 550F and 2250 psia, there was no meaningful correlation between leak rate and either differential pressure or temperature. The only discernible effect of differential pressure was seen at low differential pressures, less than 350 psid where the leak rate was highest, indicating that seating (sealing) is somewhat dependant upon pressure actuation forces.

The seating force for a swing check valve is provided by the pressure difference across the valve; therefore, a minimum differential pressure is required for proper seating.

The life cycle testing of the four-inch check valve indicated that wear due to dry and wet cycling does not cause significant damage to check valve seating surfaces. Although this was an interesting result, it was decided that the test program objectives could be better met by investigating the effect of other check valve degradation mechanisms. Therefore ETEC recommended, and the NRC approved, a decision to modify the plan for check valve testing.

A long-term flashing test was developed to evaluate the effect of erosion on check valve leak rates. ETEC set-up the long term flashing program so that it required only periodic operator attendance. This approach allowed exploration of the erosion mechanism with little impact on program cost and schedule.

Several utilities were contacted and they indicated that some PIVs are installed in locations where the pressure and temperature conditions would result in flashing across the valve for extended periods of time. Average conditions for these valves was determined to be approximately 550F and 1500 psid. Therefore, the check valve test conditions were set at 550F and 1500 psi water on the high pressure side of the check valves while the low pressure side was at atmospheric pressure. These conditions resulted in flashing of the pressurized water as it flowed through any leakage paths to the low pressure side of the valves.

The leak rate across the four-inch check valve at the end of the flashing test had increased only slightly to approximately 1 x 10^{-4} lb/sec (1.0 x 10^{-3} gpm) at 550F and 2250 psia. A power loss was experienced at the facility during this time which resulted in a loss of pressure differential across the valves. After the pressure differential was re-established, the leak rate across the four-inch valve was noted to have suddenly increased, to approximately 1 x 10^{-3} lb/sec (0.01 gpm) at 550F and 2250 psia. Although this leak rate was two orders of magnitude greater than the previously measured leak rates, it was still much lower than the two gpm (0.21 lb/sec) at 2250 psia and 550F currently allowed for most four-inch PIVs. Because the leak rate increased suddenly after the loss of differential pressure, and decreased following subsequent cycling of the valve, the leak rate variations probably were due to impurities which were temporarily lodged between the seating surfaces rather than any permanent damage to the seating surfaces.

B.1.1.2 <u>Loosened Internals Test--Phase 1</u>

Following the completion of life cycling and then the long term flashing test completed, loosened internals testing of the four-inch check valve was initiated.

The four-inch check valve was wet cycled 10 times prior to loosened internals testing to obtain baseline acoustic emissions traces. When leak rate tests were attempted, a differential pressure could not be established across the valve indicating that the valve clapper was not seating. A borescope was used for in-situ inspection of the valve internals.

The inspection was made from a port welded into the line just downstream of the valve weld which was some distance from the clapper and in the center of the pipe which was not at optimum location. Therefore, the immediate cause of failure of the clapper to seat could not be positively identified. However, the inspections made here propagated to an excellent inspection methodology discussed later in this report. It will be shown that the methodology developed here could have easily allowed a rapid-positive ISI inspection showing the valve clapper hung up.

It is important to note that the standard leak rate inspection of PIVs would identify malfunctions of this type once a failure occurred which is one of the primary objectives of leak rate monitoring. However, the leak rate monitoring did not indicate impending valve failure therefore, if this had occurred in a LWR, there would have been no indication that the valve required, or would soon require, maintenance.

Since, the next scheduled activity was the removal of the bonnet to loosen the clapper assembly stud, the valve was disassembled for further examination. Problems were encountered during disassembly. The bonnet nuts had galled to the studs and some of the studs broke while they were being removed. New bolts were fabricated. In addition, the valve bonnet had galled to the valve body despite the anti-seizure lubricant that was applied during valve manufacture. Special tools, including a spanner wrench, had to be fabricated to remove the bonnet. Similar tools were fabricated to remove the twelve-inch check valve bonnet. The valve disassembly was videotaped which prooved to be a handy training guide for the remaining valves.

The valve body, bonnet and clapper assembly were examined with the clapper assembly removed. The clapper stud was deformed by impact with the valve bonnet during cycling, see Figure 29. The four-inch check valve had been subjected to over two hundred cycles during the life cycle phase of testing. The valve bonnet was damaged at the point of contact with the stud, see Figure 30.

Although the stud was damaged mainly on the outside of the nut, it was all deformed to some extent below the nut and prior to the clapper. It was not clear that this was the problem of not seating, i.e. the clapper hung up in the valve seat. However, considering the problem listed below where the clapper assembly was installed too low, the deformation (and considering that it never rotated) would have allowed it to be in a proper direction to hang up. Also, after the long term flashing tests and considering that they were run at temperature with borated water, the mechanism probably had crude on it not allowing it to operate freely. This phenomenon did not happen again, and therefore the failure to seat is attributed to or a combination of the above.

For the loosened internals tests, the deformed stud was replaced, and the nut backed off two full turns, approximately 0.16 inches (Figure 1). The maintenance manual for the four-inch check valve was not available (although valve purchase order included all valve documentation, the utility from which the valve was purchased did not have, or had not retained, complete operational/maintenance information for the valve). Therefore, the manufacturer was contacted to obtain the proper procedure for reassembly of the valve. A manufacturer's representative verbally described the procedure. However, after reassembly a pressure differential could not be established across the valve, indicating that the valve was not seating. A borescope and an X-ray examination were made. The borescope inspection "backed by X-ray" showed that the clapper was too low and was hung up on the seat. The manufacturer was contacted and visited the facility. It was discovered that the manufacturer had revised the reassembly procedure. The bonnet was removed and the clapper assembly readjusted allowing the valve to seat properly.

This experience emphasizes the importance of having up-to-date maintenance procedures for the particular piece of equipment.

Following valve reassembly, leak rate measurements were made. The leak rate was measured at 250F and at a range of differential pressures from 150 psi to 2,200 psi. The leak rate varied from 1.4×10^{-4} lb/sec (1.3×10^{-3} gpm) at low differential pressures to 7×10^{-5} lb/sec (6.7×10^{-4} gpm) at higher differential pressures. The average was approximately

1.2 x 10^{-4} lb/sec (1.1 x 10^{-3} gpm). This rate was roughly the same as the leak rate measured after completion of the long-term flashing test, and was well within the range of acceptable PIV leak rates. The valve then was cycled five times and the leak rate measurements were repeated. The average leak rate from the second set of leak rates was equal to that of the first, 1.2 x 10^{-4} lb/sec (1.1 x 10^{-3} gpm).

The purpose of the sequence of leak tests and cycling was twofold: first, to determine if the valve reseated in a reproducible manner, as determined by leak rate, with its internals loosened; secondly, to obtain AE traces of the valve cycle to evaluate whether the degraded condition of the valves could be identified using AE data. The results of the leak rate tests indicated that the valve did seat in a reproducible manner. The AE data is discussed in Section 5.

The clapper assembly nut then was backed off an additional four rotations. This resulted in a free length of 0.5 inches between the front of the nut and the back of the clapper. The sequence of leak tests, five wet cycles, leak tests, five wet cycles, and leak tests was repeated. The leak rate was consistently very low during all the leak tests, 2.0 x 10^{-4} lb/sec (1.9 x 10^{-3} gpm) at 550F and 2250 psia before cycling, 1.0 x 10^{-4} lb/sec (1.0 x 10^{-3} gpm) at 550F and 2250 psia after five cycles, and 2.6 x 10^{-4} lb/sec (2.5 x 10^{-3} gpm at 550F and 2250 psia) after ten cycles. The leak rate with the internals loosened was not significantly different from the leak rate with the internals in the as-received condition, therefore, leak rate does not appear to be a good diagnostic technique for loosened check valve internals.

B.1.1.3 Loosened Internals Test--Phase 2

This task was the second portion of the Loosened Internals Test Phase performed at the HTF. The objective of this portion of testing was to examine how well loosened and deformed valve internals could be observed using visual in-service inspection techniques. The AE tests conducted at the HTF consisted of flowing water through the test valves at velocities from 3 to 15 ft/sec for each of three internal conditions: (1) the valve internals tightened to specifications, (2) the valve clapper nut loosened two turns, and (3) the valve clapper nut loosened an additional four turns. The purpose was to determine if the acoustic sensors could detect the loosened internals during typical flow velocities.

Figures 31 through 39 show the data obtained at various velocities for each setting of the valve internals. Comparison of these figures demonstrates how the acoustic emission monitoring equipment was not capable of detecting the loosened internals. No useful pattern of AE noise level versus check valve condition can be observed.

For ISI, access to the four-inch valve internals was obtained by drilling and tapping a 1/2 inch NPT through the bonnet. A four inch pipe extension and cap were added to prevent leakage during testing and simulate an access port on an insulated valve.

Two videoprobes were used during the in-service inspection: one rigid and one flexible. The rigid probe, standard to most utilities, is available at 30, 60,and 90 degree angles.

The flexible probe is a Videoprobe 2000 from Welch Allyn and it is capable of recording the complete inspection on VHS tape. It has the capability to freeze a particular frame. Insert titles to identify the inspection being performed and instant print of the stopped frame. The flexible probes come in different sizes; the one used for this inspection was 0.375 inch in diameter and twenty feet long.

Figure 40 shows the inspection of the four-inch check valve with the Welch Allyn flexible videoprobe. Figures 41 and 42 show the inside of the four-inch check valve as seen through the flexible videoprobe.

A video tape (VHS) was made of the flexible videoprobe inspection of the valve. As with all test data, the tape has been placed in storage at ETEC for two years. A copy of the tape has been issued to NRC as a portion of the test results. The tape demonstrates that a boroscope is a very effective tool in ISI for determining the condition of the check valve internals.

B.1.2 Six-Inch Check Valve

B.1.2.1 Life Cycle Tests

The results of the life-cycling of the six-inch check valve were very similar to those obtained with the four-inch check valve. The baseline leak rates were very low, approximately 8×10^{-5} lb/sec (7.6×10^{-4} gpm) at 550F and 2250 psia and there was no measurable leak rate following the dry cycles.

The 6-inch and 12-inch check valves were subjected to long-term flashing concurrently with the four-inch check valve. At that time the six-inch check had been dry cycled but had not been wet cycled. Its leak rate before the flashing test was not measurable. At the end of the long-term flashing test, the leak rate had increased slightly to an average of 4.4×10^{-4} lb/sec (4.2×10^{-3} gpm) at 550F and 2250 psia. The minor increase in leak rate indicated that the ability of the six-inch check valve to function as a pressure barrier was not impaired by erosion damage to its seating surfaces.

The leak rate also was measured at intervals during the long-term flashing test. It varied but was always small. Changes in the leak rate often occurred after the valves were cycled; probably due to particulate matter either being swept off or deposited on the seating surfaces during the cycling.

When wet cycling of the six-inch valve was initiated, a water hammer problem was encountered and the cycling was interrupted after ten cycles had been completed. The facility was modified by adding a standpipe to the inlet line to subdue the water hammer problem. The six-inch check then was subjected to seventy five additional wet cycles (eighty five total wet cycles). Leak tests conducted after the cycling indicated that the seating surfaces had suffered only minor damage during the life cycling, the average leak rate was 1.9×10^{-3} lb/sec (1.8×10^{-2} gpm) at 550F and 2250 psia.

B.1.2.2 Loosened Internals Testing--Phase 1

After completion of the wet cycling program, the valve was disassembled for loosened internals testing and the clapper assembly and valve body were examined after completion of the wet cycling program. Although the six-inch check valve leak rates after life cycling and the long term flashing were well within the allowable leak rate for PIVs, they were higher than the leak rates across either the 4-inch or 12-inch check valves. Examination of the valve seating surfaces did not show any damage to account for the higher leak rates. Differences in valve design may account for the higher leak rates.

Unlike the four-inch valve, the six-inch check valve did not sustain damage to the clapper assembly, bonnet or valve body during the cycling. However, the four-inch check valve was cycled more than the six-inch check valve, approximately two hundred cycles versus one hundred cycles, respectively, which may explain the difference in stud deformation. An alternative explanation might be that the check valve wet cycling method, described in Section 2, did not result in the six-inch valve reaching the full open position.

The internals of the six-inch valve, shown in Figure 43, were loosened by grinding off the bolt to clevis assembly weld and loosening the bolt 0.27 inches. After the internals were compromised the valve was cycled five times, leak tests were conducted, the valve was cycled five additional times and the leak tests were repeated. The average leak rate after the first set of cycles was almost the same as the leak rates measured before the loosened internals test, 1.5×10^{-3} lb/sec (1.4×10^{-2} gpm) at 550F and 2250 psia. After the second set of cycles, the leak rate decreased by an order of magnitude to 1.9×10^{-4} lb/sec (1.8×10^{-3} gpm) at 550F and 2250 psia.

The decrease may indicate some inconsistency in seating of the six-inch check valve with loosened internals or may be due to particulate matter dislodging from the seat thereby producing a better seal.

The six-inch valve internals were loosened a second time with the bolt being loosened a total of 0.5 inches. After five wet cycles, the leak rate was 1.9×10^{-4} lb/sec (1.8×10^{-3} gpm) at 550F and 2250 psia, the same as before the additional loosening. Following five additional cycles, the average leak rate was measured as 1.1×10^{-3} lb/sec (1.0×10^{-2} gpm) at 550F and 2250 psia. Thus the inconsistency in leak rate was repeated. The valve was apparently reseating differently after being cycled. However, the leak rates were so small that it would be impractical to expect utilities to detect similar variations.

B.1.2.3 Loosened Internals Testing--Phase 2

Unlike the four-inch check valve, the six-inch Atwood-Morrill check valve was not installed in the HTF for AE monitoring for the second phase of loosened internals testing, since there was no funding for flow tests--only ISI setup. A wooden bonnet was fabricated and an in-service inspection (ISI) port was drilled through the wooden bonnet. This avoided altering the actual bonnet. ISI was conducted on the six-inch valve to develop an inspection procedure and to demonstrate ISI with a check valve that is of a different design than the four-inch Borg-Warner check valve.

The rigid borescope and the flexible videoprobe described previously in Appendix B.1.1.3 for the ISI of the four-inch check valve also were used for ISI of the six-inch check valve. Figures 44 and 45 show the inside of the six-inch check valve as seen through the flexible videoprobe.

A video tape (VHS) was made of the Welch-Allyn videoprobe inspection of the valve. As with all test data, the tape has been placed in storage at ETEC for two years. A copy of the tape has been issued to NRC as a portion of the test results. During this testing it was demonstrated that a boroscope is a good tool to use in determining the condition of a valve during ISI.

B.1.3 Twelve-Inch Check Valve

B.1.3.1 Life Cycle Tests

The twelve-inch check valve was subjected to the long-term flashing conditions and then wet cycled twenty times at 250F and 2,250 psid, the number of cycles which could be made with one full load of supply water. The life cycling of the twelve-inch valve was abbreviated because life cycling did not significantly damage the seating surfaces of the four-inch and six-inch check valves. As previously discussed, loosened internals testing was done instead of the complete life cycling program.

As for the smaller diameter check valves, the twelve-inch valve baseline leak rate was very small, the average was 4.0×10^{-6} lb/sec (3.8×10^{-4} gpm) at 550F and 2250 psia. The erosion produced by flashing across the valve resulted in a small increase in leak rate to an average leak rate of 7.7×10^{-4} lb/sec (7.3×10^{-3} gpm) at 550F and 2250 psia. Likewise, the wet cycling had minimal impact on leak rate as the average leak rate actually decreased slightly to 3.6×10^{-4} lb/sec (3.4×10^{-3} gpm) at 550F and 2250 psia. But as later examination would show, neither the cycling nor flashing caused significant damage to the twelve-inch check valve seating surfaces.

B.1.3.2 Loosened Internals Tests--Phase 1

The valve was disassembled for loosened internals testing and the clapper assembly, valve body, and seating surfaces were examined. No significant damage was found. The seating surfaces were cleaned before reassembly.

The twelve-inch valve is similar in design to the four-inch check valve. However, there are two nuts in the twelve-inch valve clapper assembly, the stud nut which holds the disk to the clapper arm and the clevis assembly nut which supports the entire clapper assembly, as shown in Figure 46. For the first loosened internals test, the stud nut on the back of the clapper assembly was loosened. The weld between the nut and the stud was cut and the nut was loosened 1.12 inches. If the nut were loosened more than 1.12 inches, the clapper arm would completely slide off the ball bushing. This would probably cause the clapper arm to hang up on the outer edge of the bushing preventing the clapper from seating. By loosening the nut 1.12 inches, the test program evaluated whether the valve could seatwith the integrity of its internal assembly compromised, rather than illustrating that it was possible to loosen the internals to a degree that would ensure that the clapper did not seat. The ability of leak rate testing to identify impending valve failure also was examined.

The valve was cycled six times and the leak rate was measured. The leak rate was lower than it was prior to the loosening, 7×10^{-6} lb/sec (6.7×10^{-5} gpm) at 550F and 2250 psia versus 3.6×10^{-4} lb/sec (3.4×10^{-3} gpm) at 550F and 2250 psia. Cleaning of the seating surfaces was probably the cause for the decreased leak rate. After five additional cycles, the measured leak rate was somewhat larger, 1.2×10^{-5} lb/sec (1.1×10^{-4} gpm) at 550F and 2250 psia.

For the second part of the loosened internals testing, the stud nut on the back of the clapper was tightened to its manufacturer's recommended torque. The clevis assembly nut was loosened 2 rotations (0.15 inches) allowing the clapper assembly to rotate freely. In order to loosen the clevis assembly, it was necessary to cut two welds: one between the bolt and the clevis; and the second between the clevis and the bonnet. After the valve was cycled five times, the average measured leak rate was 4.5×10^{-4} lb/sec (4.3×10^{-3} gpm) at 550F and 2250 psia. The leak rate following an additional five cycles was 3.8×10^{-5} lb/sec (3.6×10^{-4} gpm) at 550F and 2250 psia. Although these results show some inconsistency in leak rate following cycling, the leak rates are consistently low, well within allowable PIV limits. It would be difficult to accurately measure leak rates of this magnitude in operating plants.

B.1.3.3 Loosened Internals Testing--Phase 2

The program scope and funding allowed for conducting the phase 2 loosened internals tests on two of the three check valves. The 12-inch check valve was not used for these tests because it was fabricated by the same supplier, to the same basic design, as the 4-inch check valve. It was decided that more information could be obtained by using check valves with different basic designs.

B.2 Gate Valve Leak Rate Tests

The life cycle tests of the gate valves were very similar to the check valves. The valves were (1) leak tested in their as-received condition to obtain baseline leak rates, (2) they were dry cycled 10 times and leak tested to determine the degradation which could result for vendor and plant check-out, and (3) they were wet cycled 50 times and then an additional 150 times with leak tests after each set of cycles to evaluate leak rate versus valve wear.

The leak tests were conducted at a range of differential pressures ranging from 150 psid to 2200 psid. The baseline leak tests and the leak tests after the first set of wet cycles were conducted at 250F. The tests conducted after the dry cycles and after the last set of wet cycles were conducted at 250F and then some were repeated at approximately 400F and 550F if a significant leak rate was measured at 250F. The leak tests were conducted at a range of differential pressures to provide data for evaluation of the ASME Code correlation. The leak tests were repeated at higher temperatures to determine if temperature had any effect on the leak rate correlation.

B.2.1 Four-Inch Parallel Disk Gate Valve

Prior to initiating the life cycling of the W-K-M four-inch parallel disk gate valve, the packing gland nut torque was set to 30 ft-lb per manufacturer's recommendation. The limit and torque switches were set.

The four-inch parallel disk gate valve had no measurable leak rate during the baseline tests. Following the 10 dry cycles, there was still no measurable leak rate.

After the first 50 wet cycles, the leak rate was still extremely low. The average was 2.2×10^{-4} lb/sec (2.1×10^{-3} gpm) at 250F and 2250 psia but no leak rate was measured at the lower differential pressures. The first time a leak rate was measured was at a differential pressure of approximately 1160 psi.

After the final set of 150 wet cycles, the leak rate had significantly increased. At approximately 250F, the average leak rate was 1.4×10^{-3} lb/sec (1.3×10^{-2} gpm) at 2250 psia. Since the leak rate was relatively high compared to previously measured leak rates, additional leak rate tests were conducted at approximately 400F and 500F. At 400F the average leak rate was 1.0×10^{-3} lb/sec (9.5×10^{-3} gpm) at 2250 psia and at 500F the average was 2.6×10^{-3} lb/sec (2.5×10^{-2} gpm) at 2250 psia. For these tests, the leak rate again was highest at the higher differential pressures.

A small amount of leakage through the packing was observed after the 150 wet cycles. This type of leakage is common in PIVs and a usual maintenance procedure is to tighten down the packing gland nuts. During the motor signature tests conducted on the 4-inch and 10-inch flexible disk gate valves, the packing gland nuts were adjusted to various torque settings to evaluate the effect of this common maintenance activity on MOV operability.

B.2.2 Four-Inch Flexible Disk Gate Valve

Before the start of the life cycle tests of the W flexible disk gate valve, the packing gland nuts were torqued to 30 lb-ft and the valve switches were set. The valve also was instrumented with the motor signature monitoring instrumentation, detailed description in Appendix A. The baseline motor signature was recorded and used for comparison with the signatures recorded during the motor signature portion of the testing.

The baseline leak rate at 250F for the four-inch flexible disk gate valve was very small, averaging 7.8 x 10^{-5} lb/sec (7.4 x 10^{-4} gpm) at 550F and 2250 psia. The average leak rate at 250F after ten dry cycles was virtually unchanged 7.7 x 10^{-5} lb/sec (7.3 x 10^{-4} gpm) at 550F and 2250 psia. The leak rate showed no dependency on pressure. Since the leak rate after the dry cycles was very low, leak tests were not conducted at higher temperatures.

After the first 50 wet cycles, the average leak rate had increased somewhat to 1 x 10^{-4} lb/sec (9.5 x 10^{-4} gpm) at 250F add 2250 psia. Again, the leak rate did not vary significantly with differential pressure.

Following completion of the additional 150 wet cycles, the leak rate had increased an order of magnitude to an average of 1.5 x 10^{-3} lb/sec (1.4 x 10^{-2} gpm) at 250F and 2250 psia at 250F. However at higher temperatures the measured leak rate was lower; 4.5 x 10^{-4} lb/sec (4.3 x 10^{-3} gpm) at 400F and 2250 psia and 4.1 x 10^{-4} lb/sec (3.9 x 10^{-3} gpm) at 550F and 2250 psia. Theoretically, the mass leak rate should decrease with the temperature for turbulent flow based on the square root ratio of the density at the higher temperature divided by the density at the lower temperature. For laminar flow, mass leak rate is proportional to density over the cube root of viscosity; therefore, leakage should increase slightly with temperature. In either case, between 250F and 550F the leak rate should not decrease by an order of magnitude.

For all leak tests, the downstream pressure was held above the saturation pressure; this prevented flashing of the water across the valve. If flashing had occurred across the leak path, a large drop in the mass leak rate would be expected as the water flashed into water vapor. No leakage through the packing was observed during the life cycle program.

B.2.3 W Ten-Inch Flexible Disk Gate Valve

With the packing gland torque set at 100 ft-lb., the valve switches were set and the motor signature instrumentation described in Appendix A was installed. Check out was then completed. Baseline leak rate tests were conducted with the average leak rate being only 4 x 10^{-6} lb/sec (3.8 x 10^{-5} gpm) at 250F and 2250 psia. After the 10 dry cycles, the leak rate at 250F had increased to 2.8 x 10^{-4} lb/sec (2.7 x 10^{-3} gpm) at 2250 psia. As opposed to most of the other gate valve leak tests, the leak rate was higher at the lower differential pressures by an approximate factor of three. However when additional tests were conducted at approximately 350F, no leak rate was measured. After the first 50 wet cycles the average measured leak rate was only 1.4 x 10^{-5} lb/sec (1.3 x 10^{-4} gpm) at 250F and

2250 psia. These results indicate that perhaps the valve was not completely sealed (seated in) during the first series of tests after the dry cycles. However, the leak rates always were extremely low. It would be very difficult, and not vital, for plants to measure leak rates in this low range because these low leak rates do not significantly impair the ability of the valve to act as a pressure barrier.

After the next 150 wet cycles, the leak rate substantially increased to 1.3×10^{-2} lb/sec (0.12 gpm) at 250F and 2250 psia. The leak rate was higher at higher differential pressures. At approximately 350F, the average leak rate was 1.1×10^{-2} lb/sec (0.10 gpm) at 2250 psia. At approximately 550F, the average leak rate was 7.4×10^{-3} lb/sec (0.07 gpm) at 550F and 2250 psia. The trend seen with the four-inch flexible disk was repeated; the leak rate significantly increased following the last 150 wet cycles, the leak rate increased with differential pressure, and decreased with temperature.

B.3 Gate Valve Motor Signature Testing

The motor signature tests were performed to study the basic operating characteristics of LWR MOVs and instrumentation required to allow MOV operational characteristics. The tests simulated LWR plant conditions, such as temperature and fluid, to provide sensor sensitivity and applicability to determine operational readiness of the MOVs. The parameters selected to trend monitor will identify suitable plant instrumentation that can easily be monitored to assure continuing gate valve operability. Today, there are many instances where valves can be certified operational by the ASME Code, i.e., stroke and leak rate, but these certifications do not assure operability. The motor signature tests may identify problem areas and indicators to detect impending MOV malfunction.

Motor signature monitoring was performed during and after the life cycle aging tests. The parameters monitored are given in Section 2.2.11 and shown in Figures 20 and 47. Only the 4-inch and 10-inch Westinghouse gate valves were fully instrumented for motor signature testing. The 4-inch W-K-M valve was instrumented for stem position, velocity, torque-switch-shaft rotation, limit switches, and motor current (see Appendix A.1.2).

During the life cycle aging tests, data was plotted to trend the MOV operating parameters. The post life cycle testing MOV signature tests are given in Table 10; these tests were run from zero to the worst case differential pressure across the seat, 2200 psi. With no differential pressure across the valve seat, the effects of hydraulic loading on the stem could be ascertained. In the case of the 4-inch W valve, a special set of MOV signature tests were run prior to the life cycle aging tests and are given in Table 11. They were run at various temperatures and differential pressures from 0 to 2250 psi and various packing bolt torque values to test the MOV for opening force characteristics.

The data taken during these tests was typically recorded at 3 per second on disc and at 1 per second on tape. Predominantly, the test data was plotted on-line from the disc and the tape was only used for general back up. This allowed the test results to be viewed for validity prior to proceeding.

For all of the cycle testing, as well as the motor signature testing, the torque switch was overridden during the first 30% of travel. This was done in these tests to represent similar plant operations. In a safety system hypothesis is that the plant would prefer the motor to be the limiting factor rather than other equipment for the valve to open in an emergency situation.

B.3.1 Preliminary Motor Signature Test on the 4-Inch Westinghouse

The first set of motor signature testing was performed on the 4-inch flexible wedge disc gate. The tests and characteristics are given in Table 11. Tests 4, 8 and 13 were used as reference tests in that they were randomly interjected as a standard and also is typical plant operating conditions for PIV's.

The first eight tests were ran in the as-received condition and had a torque setting of only 15 ft/lb on the packing gland bolts after test 8 had been run. The factory specified torque was 30 ft/lb. However, for test 9 the torque was checked and increased to 30 ft/lb, 100%. Tests 10 through 12, as required, were run at overtorque conditions. The data plotted were motor current, average stem force, torque switch rotation, stem velocity, calculated position and motor vibration. A reference test (4, 8 and 13) was interjected during the test as a comparison to base conditions. In tests 13 through 16 the torque was backed off to 30 ft/lb but the data indicated that the loading of the packing was still excessive. This problem will be discussed later in detail.

Table 10. Post Life Cycling Motor Signature Tests

Test	Packing Bolt Torque (%)	Upstream Fluid Pressure (psi)	Downstream Fluid Pressure (psi)	No. of Cycles	Temperature (°F)
1.	50	2250	0	5	250
2.	200	2250	0	5	250
3.	300	2250	0	5	250
4.	50	2250	0	5	400
5.	200	2250	0	5	400
6.	300	2250	0	5	400
7.	50	2250	0	5	550
8.	200	2250	0	5	550
9.	300	2250	0	5	550

Other tests were run as required

Figures 48 through 52 are the data from Test 4 that was run at 550F and 2250 psig fluid pressure which is a reference test and is typical of the data characteristics investigated for MOV operating characteristics. This test was run then with 2250 psid fluid pressure across the seat at the start of the cycle sequence.

Figure 48 is the current as measured in one of the 440 VAC legs of the 1.9 hp motor operator. The cycling was about once every 10 seconds and run in a manual mode. The close to open current is shown to be about 3 A while the open to close current is about 4 A. These data were taken at about 300 msec, therefore, some of the faster transient data at the leading edge of the close to open cycle is missing in some cases.

On the first part of the opening cycle of the gate valve the gate was pulled out of seating surfaces after being wedged in by the operator, Figure 51 and 52. It was shown that during the opening operation the disc loads then pops out in a few milliseconds to level off for the remainder of opening as a function of the dynamic forces. In the open to close cycles the current is higher and a transient pulse (motor start) is noted in some cases. The higher running current during closure was due to the hydraulic forces exerted on the stem by the water pressure. These transients are related to the motor starting and to excessive stem force being allowed by the torque switch in some cases, (see Figure 50).

Table 11. Motor Signature Tests 4-inch Westinghouse Gate Valve

Test	Internal Fluid Pressure (psig)	Initial Pressure Drop (psid) (close to open)	Fluid Temp. (°F)	Packing Bolt Torque (ft-lb)	No. of Cycles
1	0	0	250	15	3
2	2250	850	300	15	3
3	0 (ambient)	0	550	15	4.5
4[1]	2250	0	550	15	4.5
5	2250	400 & 0	550	15	6
6	2250	800 & 0	550	15	4
7	1100	0	550	15	4
8[1]	2250	0	550	15	4
9[2]	2250	0	550	30[2]	4
10	2250	0	550	60	3
11	2250	0	550	90	2.5
12	2250	0	550	75	2.5
13[1]	2250	0	550	30[3]	4.5
14	0 (ambient)	0	550	30[3]	4
15	2250	800 & 0	550	30[2]	5.5
16	2250	400 & 0	550	30[2]	5

[1]Reference tests
[2]Retorqued to specification
[3]Questionable; see text for details

Figure 49 shows the average stem force on the W-4-inch valve for a fluid pressure of 2200 psid. Just prior to cycling, the downstream pressure was 50 psig; however, upon opening, the cavity filled very fast and exerted a compression force (pressure assist) on the stem in the direction of opening. Pulling the gate from its ways, which is shown as a spike on the leading edge of the open cycle and was as high as 4,000 lbs in some cases, which is additive to the dynamic opening force. The opening force on the stem is the packing friction minus the dynamic hydraulic force, which was very near the open zero value of -3500 lb in this case. Upon closing, the dynamic stem force is the packing friction plus the hydraulic force, since in these tests the fluid was not blown down prior to closing. In Test 4 the dynamic force (during travel) was about 2,000 lb. while the total force on seating was about 10,900 lb. averaged over the four cycles. The data from Test 5 indicated about this same seating load.

Test 3, shown in Figures 53 to 55, was similar to Test 4 (550F) but the fluid pressure was reduced to 0 psig. Test 3 data, in comparison with Test 4, Figure 49, should eliminate the hydraulic stem forces and leave only the packing coefficient on stem force. The full average stem seating force was about 16,200 lb. for Test 3, or about 5,300 lbs. higher than for Test 4. However, the actual dynamic driving force was only 800 lbs. Considering this and the dynamic force at higher pressures, the differential is 1200 lbs. which does not sum to the 5,300 lb. differential between the two tests. This anomaly is attributed to the mechanical torque switch which governs the Limitorque force on the stem and allows for greater seating with no internal pressure. Therefore, the seating force is a function of internal pressure and in this case, greater by 5,300 lb with zero internal pressure.

The dynamic torque switch rotation at 2250 psig was 5.8 to 7.2 degrees as compared to 1.9 degrees at ambient pressure, Figures 50 and 54, respectively. However, the total rotation upon seating was about the same at 15 degrees. Looking at the difference in the dynamic torque value one might expect that the seating force should be increasing with increased stem velocity. This is shown not to be the fact since the closing velocity is about the same in both cases, Figures 51 and 55, Test 4 and 3 respectively. The velocity seems to be governed solely by the motor and its gear reduction. The sudden jump of the gate out of the seat due to wedging, is clearly indicated at the leading edge of the opening cycle (positive). The motor current was a constant 3.5 A while the motor vibration did not change from Test 4.

MOV signature tests were run at the operating conditions of 550F and 2250 psig fluid pressure during all cycling sequences; the motor current versus packing bolt torque data are presented in Figure 56. The first segment of the signature tests was run with a packing bolt torque of 15 ft.-lb. which is 50% of specification; therefore, the packing bolt torque was increased to 100, 200, 250 and 300% of specification. Three cycles were typically run for each test. Indications are that the motor power was terminated early on the last cycle of the 250% and 300%.

The dynamic closing force of the MOV signature tests at 2250, 1100 and 0 psid are plotted in Figure 57. These data indicate about the same trend as the motor current, Figure 56, for different packing bolt torques. These data show a very good correlation for current to packing torque and condition. The current could prove to be a viable in-plant parameter to trend and ascertain MOV operability.

The Figure 58 triangle data (dynamic closing force) and the three high current data points at 100% packing torque were taken after the 300% packing bolt torque test. The high data was attributed to residual loading from the packing even though the bolts had been backed off. The packing used in both Westinghouse valves is John Crane 187I a graphite impregnated braided asbestos with a fine braid of Inconel wire. It was shown that this type of packing does not have resilience adequate to recover, at least, in the short time utilized here. From these data it is not clear that the packing would release slowly or not at all if the valve packing was over-torqued and then released since in this set of tests it was cycled to break it loose. In the plant case, the packing could seize to the stem after long periods of time at high temperature and not allow appropriate operation at the next required actuation although the inconel braid in the packing is supposed to obviate this problem area.

Realizing that the motor current should be a function of MOV degradation, that is, increased packing load, etc., the closing motor current versus the dynamic closing force was plotted for this set of tests and is shown in Figure 59. The dynamic closing force is defined as the difference from the open valve to the dynamic loading just prior to seating. The odd point in these data is the 0 delta P at about 3000 lb. That data point was taken after the valve stem hung up during a 300% packing test and therefore had not released at the time the next set of cycles and measurement were run.

The operator motor current as a function of the dynamic stem force was shown to be a linear increasing function of all the cycle tests performed in this set of tests. The data taken after the 300% packing bolt torquings, where the packing friction was excessive, fit the general data trend. Therefore, motor current seems to respond the same as the stem force to give informative information on operability.

The data shows a direct relationship between the two parameters. These data are indication that MOV motor current could be used in the plant as an indicator to assess packing problems and operability.

B.3.2 4-In. W Motor Signature Tests - Second Set

After the first set of motor signature tests was performed on the 4-in. W gate valve, the testing was terminated until the next fiscal year. At that time, the life cycle tests were performed for valve degradation, then the second set of motor signature tests was run per Table 10. Therefore, after the first set of tests, the packing was left torqued and the system dry.

The data obtained during these tests are given in Table 12 and include life cycle testing. The data from the test sequence was very scattered due to packing friction problems; therefore, data listed in the table are the motor current, differential stem force, and vibration.

The currents and differential stem loads ranged from 3.5 to 5.7 amps and 2,700 to 12,200 lbs, respectively. The larger stem loading due to the excessive packing friction was such that the torque switch would terminate closure prior to total gate travel. The vibration of the motor is included as an indication of excessive motor work. Results indicate that the valve packing can become over packed during a long period of time and, even if the bolt packing torque was backed off, the stem to packing frictions may still exhibit loading that is excessive for operation.

Table 12. 4-in W Motor Signature Tests

Test	Current (amps) Open	Current (amps) Close	Differential Load (lb x 10^3)	Motor Vibration (G's)	Comments
Dry cycle	3.8	4	N.O.	6	0 psig
Life cycle	3.5	4	2.1 - 3.5	4.5	
550F:					
15 ft-lb	3.5	4.0	2.8	4 - 6	
60 ft-lb	4.8	5.0	5.9	5 - 6	
90 ft-lb	5.5	5.7	10 - 12.2	5 - 6	Hung up
250F:					
15 ft-lb	4.5	5.1* - 4.5	8.3 6.98*	4 - 6	No closure
60 ft-lb	4.6	5.0	7.9	5.5	
450F:					
90 ft-lb	-	-	-	-	Would not cycle
15 ft-lb	4.1	4.5	5.7	4.8	
60 ft-lb	4.2	5.1	7.6	-	
90 ft-lb	4.2	5.7	>12.2	4 - 6	No full closure
75 ft-lb	4.1	5	10	4 - 5.7	0 psig
75 ft-lb	4.2	5.7	10	4.5 - 6	No full closure
30 ft-lb	3.5	4.2	4.5	3.9	

*Current high due to excess friction.

B.3.3 10-Inch W Motor Signature Testing

The Westinghouse 10-in. flex-wedge disc gate valve was instrumented much the same as the 4-in. to perform motor signature testing, Figure 47 and Section A.1.2. The differences were that the current transformer and LVDT were changed to maximize the measurements. Fiber optics, Section A.1.2, was also added to ascertain seating characteristics in the life cycling and specific motor signature testing. The life cycling test results of various sections of the life cycling program are discussed in this section. Then, the motor signature test results, as required by Table 10, are included which required tests at various bolt packing torque and temperature at typical plant operating conditions. All of the life cycling and motor signature tests were performed with the same gate valve computer algorithm, Table 8. Typically, all of the tests were run at 250F and 200 psid across the gate at valve actuation, except the first ten dry cycle tests that were run with zero differential pressure at 650 and 250F.

Plots from the dry cycle test for motor current and average stem force versus time are shown in Figures 60 and 61 for zero differential pressure. Shown are cycles four through ten run at 250F. The data plotted for these tests was at one per second. The opening and closing currents were very near the same and averaged 28.8 amps. Figure 61 shows the average stem force during this segment of the test; these data indicate a dynamic differential stem force of from 5.8 to 8.8 x 10^3 lbs during the dry cycling. However, the dynamic differential stem force was increasing as the number of cycles increased indicating the dry packing giving a problem. This dynamic differential stem force data at zero differential pressure is directly related to the packing forces.

During this set of cycles the current did not change appreciably, but the motor vibration, Figure 62, increased in about the same manner as the differential stem force. This is a clear indication of the gate wedging into the seat. A typical unwedging characteristic is shown at the leading edge of the opening cycle, at about 5 min., and the total vibration during opening. The remaining unwedging pulses were not recorded due to the data frequency used here.

The next set of life cycles were in a group of 50 all run at typical operating conditions of 250F to result in flashing during the opening. These cycles were run with 2250 psid across the seat just prior to opening, then closure with 2250 psi fluid pressure on the stem/gate assembly.

Valve operator data of the initial 24 wet cycles for motor current, fiber optics close and valve stem loading, are shown in Figures 63, 64, and 65, respectively. The motor current, Figure 63, was fairly consistent during the first and last of this data. The average opening current during the first half was averaged at about 27 amps and 24 for the last. The closing current was about 40 amps and 37 to 38 amps, respectively. The first portion of the data shows large leading edge spikes (~120 amps) that represent the gate being pulled from the seat. The fiber optics data, Figure 64, shows a decreasing trend and also a lessening of the envelope. This is assumed to indicate the gate seating in a lower portion of the seat assembly.

The stem forces are directly related to the motor current in that, when the gate is being wedged into the seat appreciably; the gate will tend to hang up on removal causing a high motor current pulse. However, if the packing friction coefficient increased during cycling, since the cycle is terminated on the torque switch, the opening and closing currents would also change proportionately. Also, a packing friction increase would cause the actual seating to be decreased by the same additional force required for the extra packing drag. Thus, when the packing forces are released, both the opening and closing motor currents should decrease. Therefore, assuming the above argument, the gate should not be wedged as hard into the seat. This is shown to be the case in the second half of Figures 63, 64, and 65, and also in Figure 66 which is the rotation of the torque switch during the same test time. This data indicates that the gate, seat, and packing are being worn in initially. The torque switch rotation in Figure 66 indicates that for greater stem forces, as shown in Figure 65, the rotation is less and does show an inverse trend. But, it should be remembered that this is a mechanical device and may have some initial settling. This subject will be discussed at greater length later in this section.

After the 50 wet cycle leak rate measurements were made, the facility was reloaded with water and the temperature stabilized for the 150 wet cycle test. The cycling tests were run in the typical manner. Figure 67 shows the valve stem and motor temperature (top and bottom curves respectively) increase as a function of cycling. The test valve cycling temperature was 250F and the valve stem temperature was measured to give an indication of the strain gage bonding integrity as well as an indication of the temperature of the operator, and, to some extent, the fiber optics signal conditioners. The temperature started out at 80F then increased to about 185F near the end of the cycling program. Considering the valve body temperature and that the stem was cycling, this was about the limit expected.

The motor temperature is also shown in Figure 67 and depicts the motor temperature increase during the cycle test. The maximum temperature was about 135F. This temperature increase is at least partially due to the fact that this motor has a 15 minute duty cycle, but considering the specifications, it is still in the operating range.

Figures 68, 69, and 70 show the motor current, average stem force, and fiber optic closed data during a major portion of the 150 wet cycle tests. The data indicates the trend of the parameters as a function of each other and as cycling progressed. These data, plotted over a long period of time shows a general trend, but does not have appreciable definition. Areas of interest will be expanded for discussion later in the text. The areas of no cycling depicts those areas where required facility parameters were not met for the computer program, therefore the computer waited until all the parameters were met prior to the next cycle.

The motor current data starts with current pulses in the 120 amp range for the opening cycle and closing current of about 35 amps. But, the data through the cycling is not constant and shows the opening pulse and the closing current running in cycles, which indicates that there was a change probably due to the packing friction.

Figure 68 shows the valve stem force as a function of cycling. The data are fairly constant for the closing force except in the region of about 130 and 200 minutes where there are sudden slips in the closing load. These same variations are shown in the fiber optic data, Figure 70. An important region of the stem force data is in the initial portion of the opening when the gate is pulled from the seat; the indication is a negative force. The darkened negative pulses are the regions where the gate was forced into the seat which is identical and typically to the high motor current region. The closed fiber optic data, Figure 70, indicates some trend of general decrease but the closed position decreases from -5100 Mv to a -5400 Mv through the cycle program. This is an indication that the gate was seating at a lower position as it was worn in.

The region of 200 minutes was expanded for a more detailed investigation of the step in fiber optics and stem loading. Valve stem loading in that region, Figure 71, is shown at 15 minutes with about six cycles before and after it closed. The stress decreased by about 20,000 psi then recovered by about >10,000 psi, much the same trend as the fiber optic data. However, the open stem force is less negative in that region, but does not show the step function. The temperature, torque switch rotation and motor vibration do not indicate any abnormalities in this region. The explanation for this data shift and the one at about 120 minutes remain unexplained except that it could have been a shift in the torque switch operation.

When looking at the motor current data in the 190 minute region, Figure 68, there is one of the general increases and then a diminishment by 200 minutes. The motor current and vibration in this region were expanded, Figures 72 and 73, to look at the general current excursion and the step function. None of these data show indication of a step function at 200 minutes. These data are good general data for cycling. The first two cycles show the large current spikes of up to 140 amps on valve opening with a typical open running current of about 25 amps. The open to close current dropped from 40 plus amps down to about 36 amps in the dip region. From this low level there was a general increase in both the open and close current starting at about 240 minutes Figure 72 data. These expanded data indicate that the opening pulse current averaged about 75 amps as compared to 40 amps in the general plot, Figure 68; these expanded data are at a higher frequency and therefore have greater sensitivity. The motor vibration is fairly constant through this region of cycling, indicating no sensitivity to the step function phenomenon.

In summary, the life cycling data indicates that the wedge tends to settle-in to some extent during cycling and that the closed fiber optic data tend to verify this. The current indicated a tendency to cycle, e.g., increase then drop back to normal. This resulted in exceptionally large opening pulses of the order of 120 amps. This was attributed to sticking friction of the gate to the seat. The total increased cycling load was attributed to packing friction. The standard position indication was not able to detect the trend and minor changes in seating as did the analog fiber optic device which gave indication proportional to the stem loading and wedging of the gate into the seat.

The motor signature testing, Table 10, was performed after the life cycling tests and leak checks were completed. This set of tests was run only to ascertain characteristics of the motor operator, Table 2, for non-typical stem packing torques with an internal fluid pressure of 2250 psig.

The motor signature tests were run at 250F, 400F, and 550F. The 250F tests were run for ten cycles for each torque setting to ascertain if extended cycling was required. The remaining tests were run at the required five cycles for each torque setting. The cycles were typically run in two minute intervals and the various torque setting cycles are grouped in the figures.

The operator motor current for the motor signature tests is summarized in Figure 74 where the motor current is plotted against a percent of the required packing torque. The specified packing bolt torque was 100 ft-lb. for this valve. The data plotted for 100% was all at 250F and taken during the life cycle testing. No cycles were run at 100% in this motor signature phase. Typically, the motor current increased as the temperature increased except in the 300%-400F test where the current increased to about 51 amps when the excess packing friction stopped the cycle.

Effectively, the close to open stroke running current was fairly constant at about 25.7 amps for the 250F tests and increased slightly with temperature. The only anomaly was in the 0 psid test which was run dry and at the first of life cycling. It showed open and closed currents of 30.5 and 31.8 respectively; the low opening current is directly proportional to the internal fluid pressure. However, each was higher than the other minimum currents because the internal pressure, i.e., driving force, was removed and it was the first dry cycle. This wearing-in characteristic was shown to continue into the first 50 wet cycle tests, Figure 74, which showed the initial closing and opening currents at about 42 and 30 amps, respectively, prior to decreasing after some number of cycles.

The closing current during these tests tended to be around 41 amps. The trend was to increase slightly with the temperature of the tests, except in the 400F-300% case at 51.5 amps. There was some indication that the packing tests at 50% could have been effectively over-torqued, (indication was that the packing did not release even though the packing bolt torque was released), from the previous tests, even the 100%. The set ran at 250F for ten cycles and did show some settling and decrease in current in the first portion of the cycles and, therefore, may be a little high.

In the case of the motor signature tests at 400F, there was no indication in the general data that there was a packing friction problem. The motor current, stem force, closed fiber optic, and torque switch are shown in Figures 75 through 78. The three data segments are of the 50, 200, and 300% packing torque. The irregular spacing in the cycling is due to facility parameters being out of specification, therefore the computer holds until the parameter specification is met.

The motor current starts off in a reasonable range in the 50% packing tests while the fiber optics show that it was not seating as well during the cycling. The stem forces agree with the seating characteristics while there was some decrease in the mechanical torque switch setting which, to some extent, which could have been contributed to the low current and stem loading. However, during the 200% test, the open and close pulse currents increase appreciably and are in agreement with the gate seating while the stem loading stayed about the same. Then, during the last test at 300% the pulse currents are not as high but close running current increase to about 52 amps. During this time, the stem force and close fiber optics indicate the gate not seating to some extent while the torque switch shows some increase and indicates excess stem load during gate travel. This is an indication that these parameters trend the actual operating characteristics quite well.

The dynamic differential stem force versus the packing bolt torque is summarized in Figure 79. The data of the 100% packing bolt torque was taken during the cycle tests. These differential stem force data are shown to increase with the number of cycles. Of course when referencing (Figure 69) the long term cycling data, it is appreciated that we used discretion in selecting these data, the data plotted was selected prior to the creation of Figure 69 and only included as a general indicator. The cycling data are shown to increase with temperature and packing bolt torque in a fairly linear fashion. These data indicate that at the higher temperatures, one could expect greater differential stem forces which should be proportional to the motor current, of which these data are (see Figure 80).

B.4 Acoustic Emission Monitoring

Four acoustic emission measurement systems were installed on both the check and gate valves for leak rate monitoring. The systems were supplied by ETEC, ANL, ORNL, and the Naval Ship Research & Development Center. For the gate valve testing, a fifth acoustic emission system was developed and installed by ETEC. This device was to hopefully allow the measurement of water leakage through the valve seats at lower levels than the other systems. The Naval Ship Research & Development Center equipment is portable equipment which must be manually operated, therefore it was not used as extensively as the other equipment. The ANL, ETEC, and ORNL sensors were read automatically by the facility DAS. Each of the systems had a transducer installed on the valve and on the valve inlet pipe, Figures 81 and 82, respectively.

The acoustic emission measurement with the various systems was to ascertain 1) a level of detection and, 2) the ability to correlate AE to leak rate. Unfortunately, the leak rates obtained in the valves as a function of life cycling was only in the low 0.01 lb/sec (0.10 gpm at 550F and 2250 psia) region.

Addressing the AE leak rate measurement problem, ETEC had the high sensitivity acoustic emission (HSAE) equipment built for the last series of life cycle testing. This equipment consists of narrow band 180 Hz transducers that use a pinger for setup calibration which enhanced the sensitivity. To reduce background system noise, the pinger was located an appreciable distance on the line away from the line transducer in order to calibrate the system plant noise transducer on the line and the valve transducer.

The HSAE device was the only device that gave effective information during these tests. The data from a series of leak tests are presented in Figure 14. Plotted is the calculated leak rate and acoustic emission as a function of test time. The initial leak rate measurement was, at 2100 and 1100 psid, 0.0025 and 0.0017 lb/sec (0.02 gpm). The acoustic emission is shown to increase as a function of leak rate. The lower AE measurement was at a leak rate of 0.0005 lb/sec (0.005 gpm). The leak rate data show positive and negative pulses around a center value. The pulses occurred at times when the differential pressure tubes filled and then blown down in order to continue leak rate measurements for an extended time.

During some of the leak rate tests, the acoustic emission spectrum was recorded on analog tape to survey for frequency content and amplitude that could be attributed to a water leak across the valve seat. It was recorded at 60-inches per second and when digitized for plotting results in 10,000 points per second. These data indicate that, at least, below 0.01 lb/sec (0.10 gpm) at 550F and 2250 psia, there was no discernable frequency or amplitude signature that could be attributed to leak rate of the standard transducers. The HSAE data was not recorded on the analog tape and, therefore, was not analyzed for frequency signature.

Acoustic emission is a good non-intrusive method to measure valve degradation, however, there is a sensitivity problem to trend the leak rate by AE. One would like to measure in a low leak rate region and increase into; a region where maintenance is required. The ETEC HSAE device would allow this measurement down to at least the .001 lb/sec (0.01 gpm) leakage region. However, this device requires additional testing prior to certification for LWR utilization.

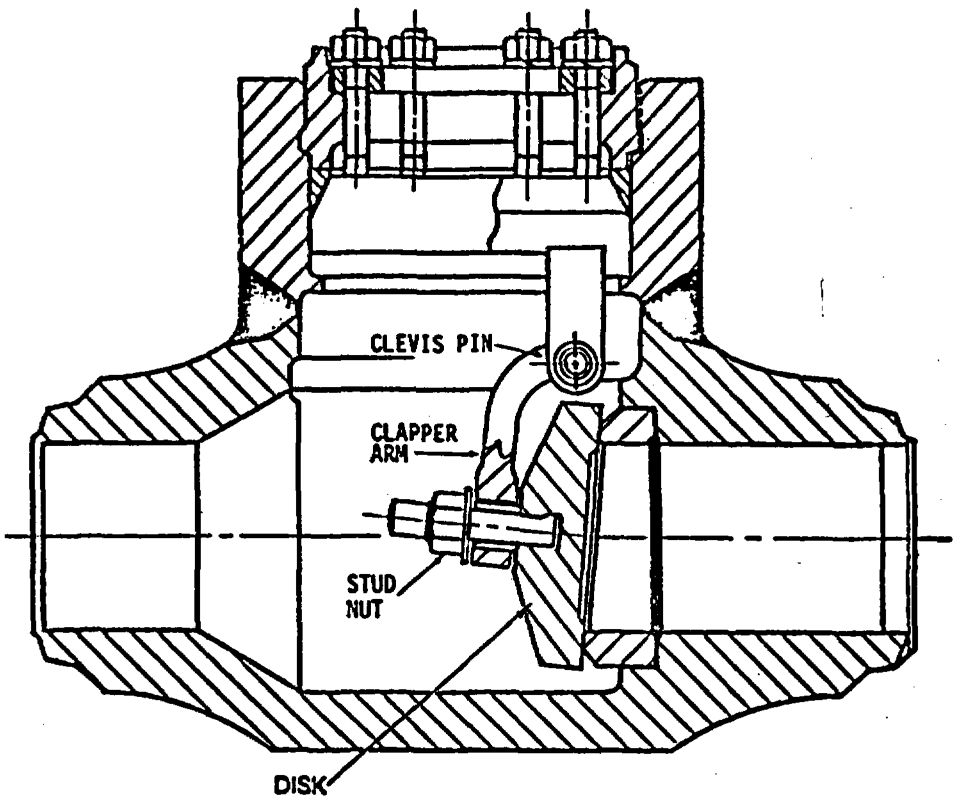


Figure 1. Four-Inch Check Valve Internals

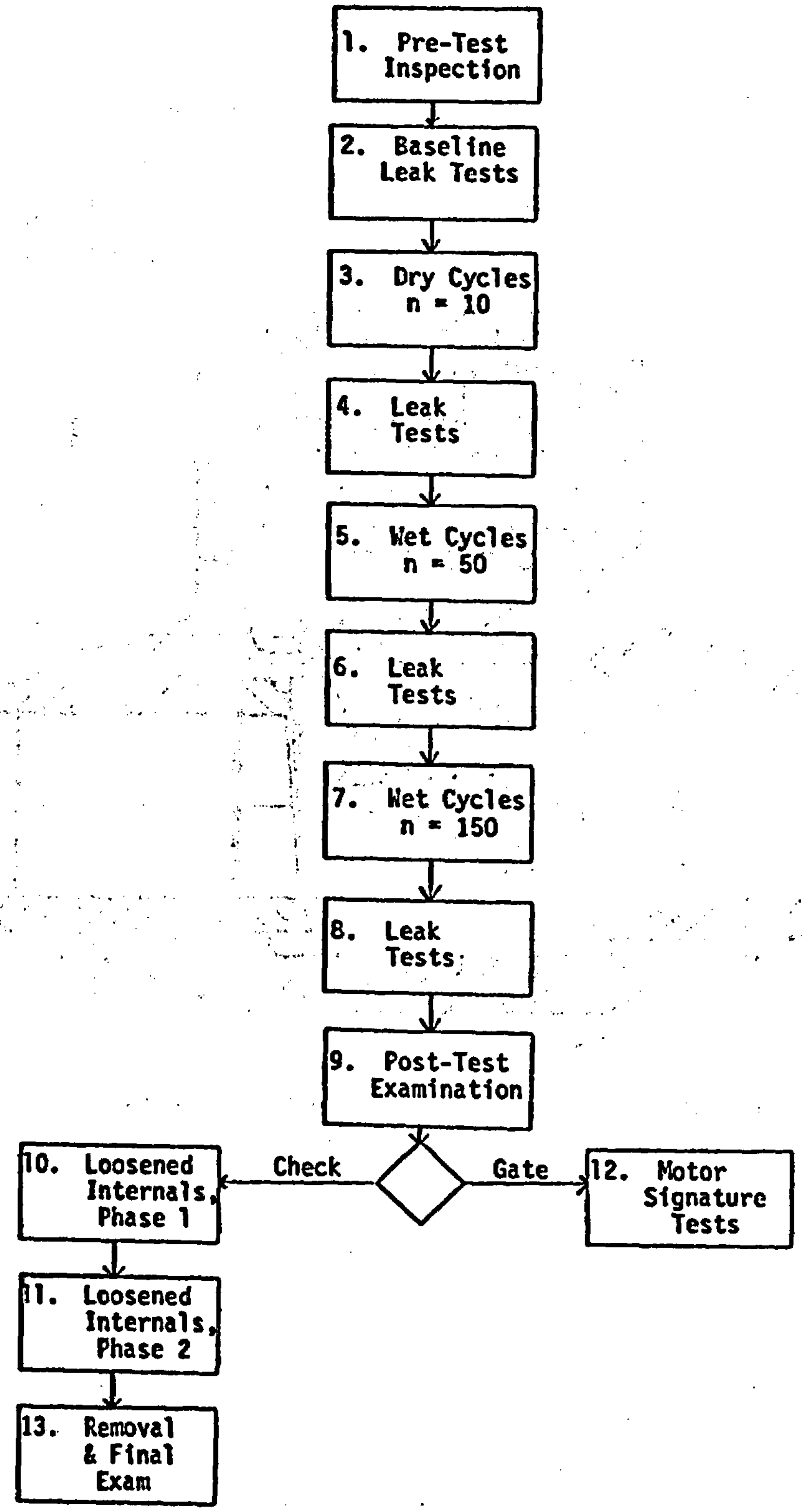


Figure 2. Test Logic

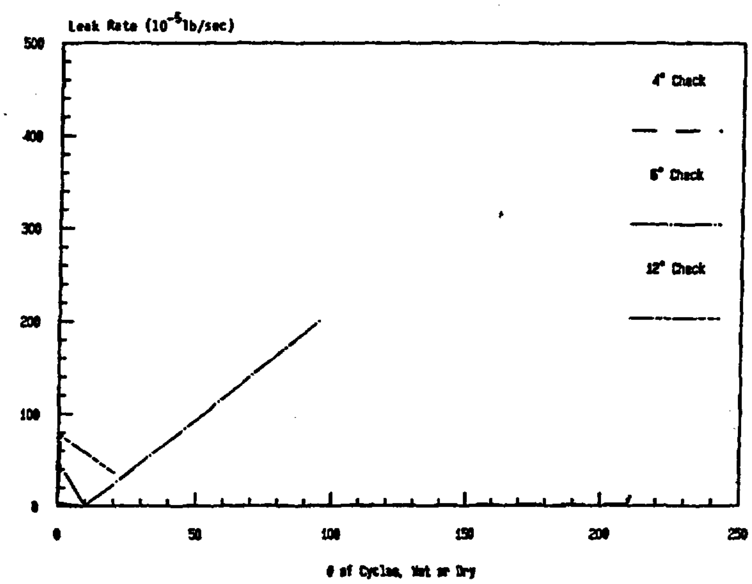


Figure 3. Check Valves--Leak Rate
Versus Life Cycling

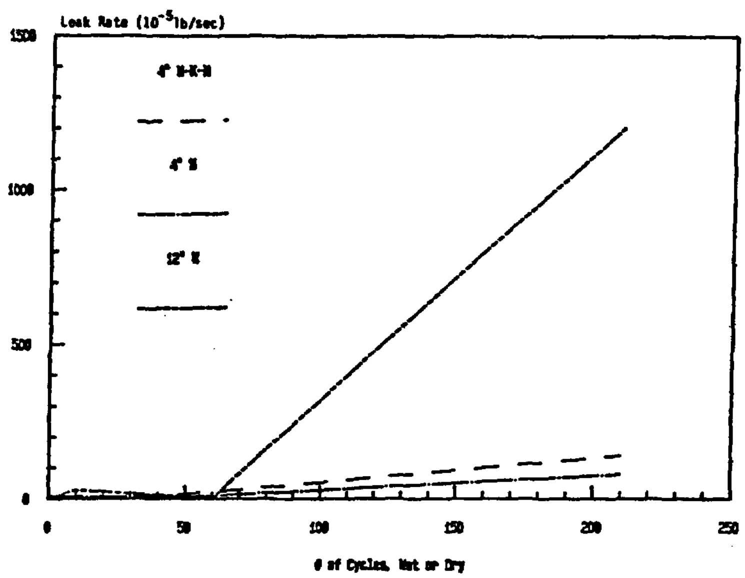


Figure 4. Gate Valves--Leak Rate
Versus Life Cycling

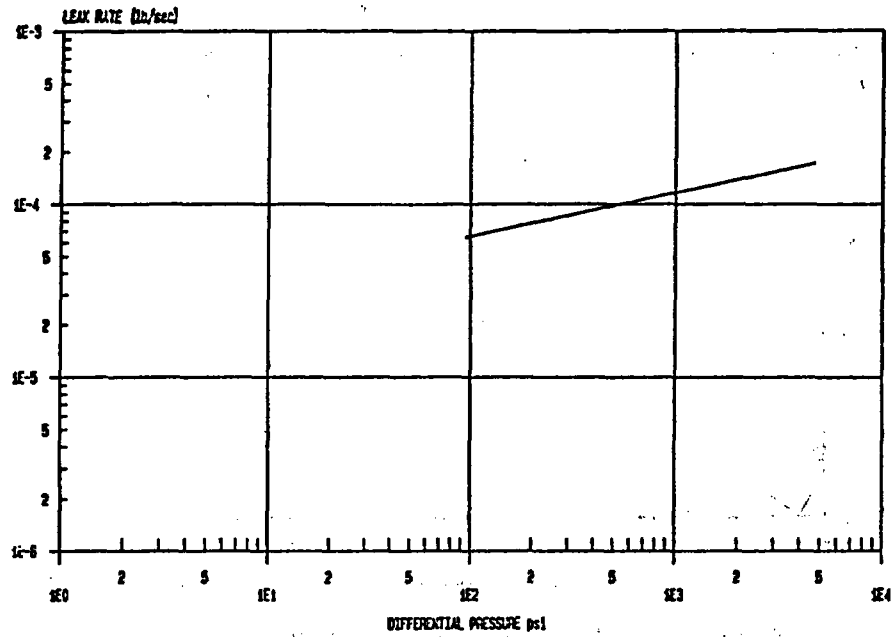


Figure 5. Four-Inch Check Valve Leak Rate Versus Differential Pressure

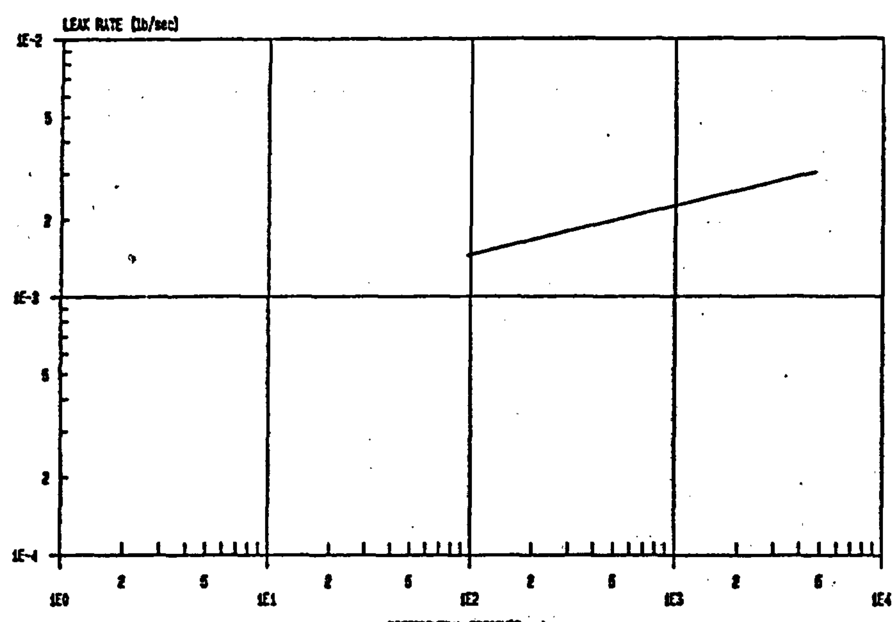


Figure 6. Six-Inch Check Valve Leak Rate Versus Differential Pressure

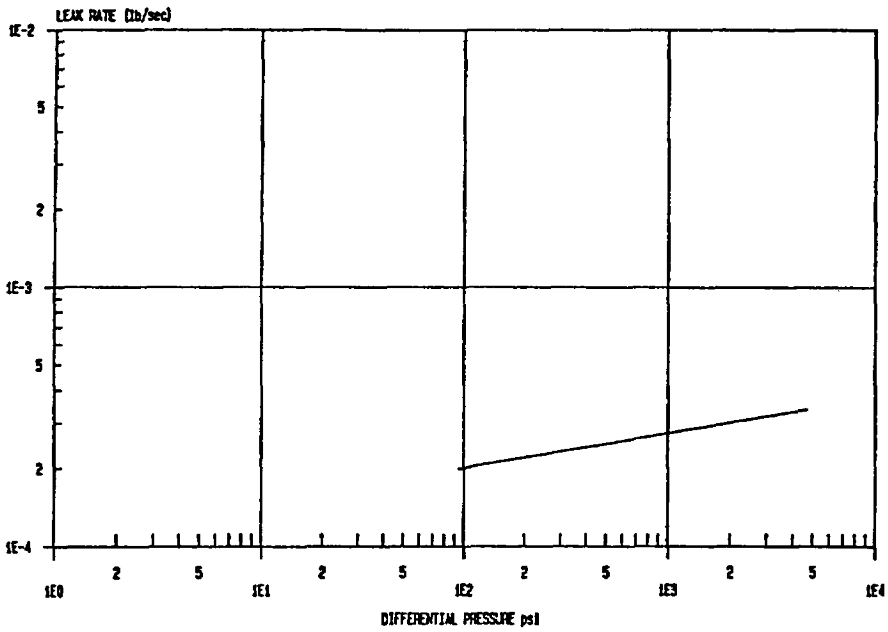


Figure 7. Twelve-Inch Check Valve Leak Rate Versus Differential Pressure

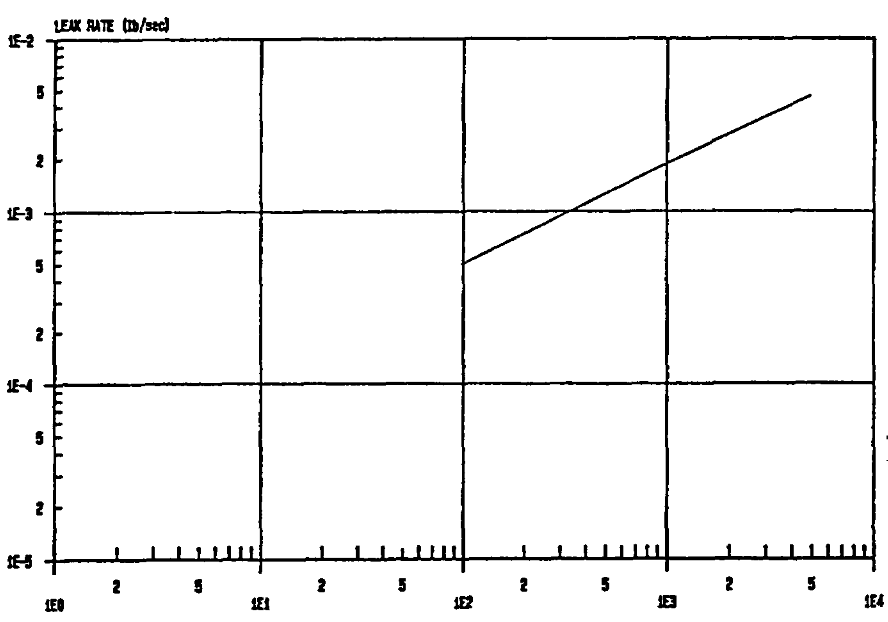


Figure 8. Four-Inch Westinghouse Gate Valve Leak Rate Versus Differential Pressure

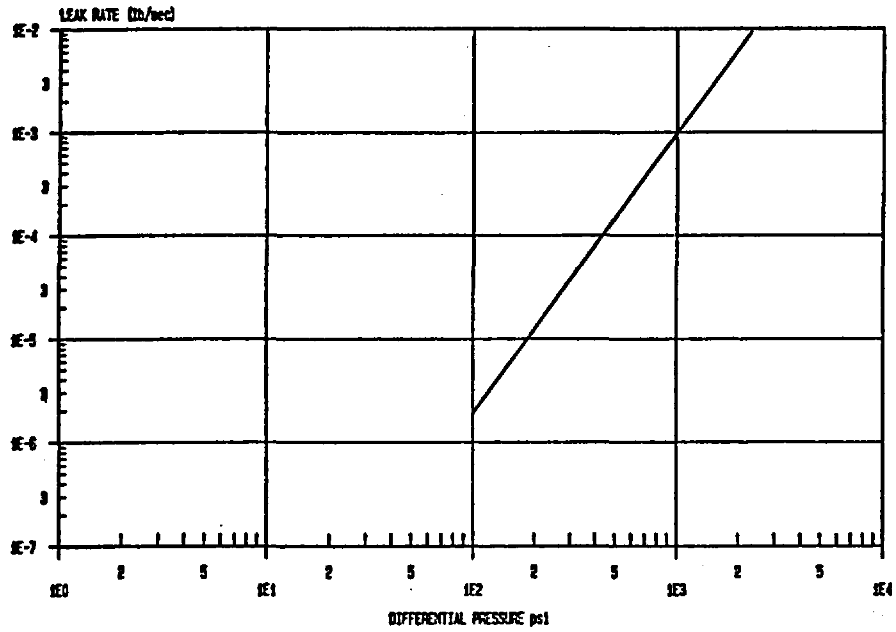


Figure 9. Four-Inch W-K-M Gate Valve
Leak Rate Versus Differential Pressure

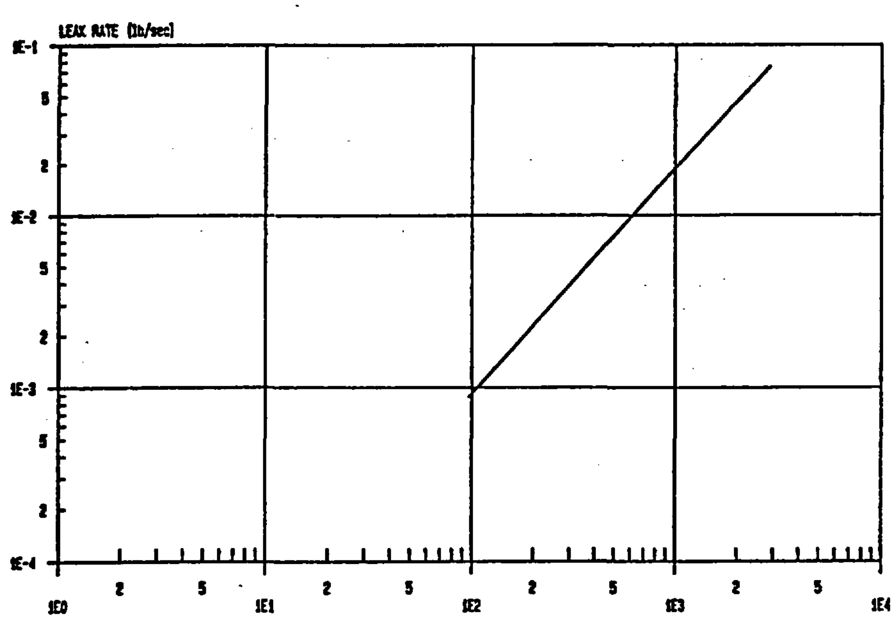


Figure 10. Ten-Inch Westinghouse Gate Valve
Leak Rate Versus Differential Pressure

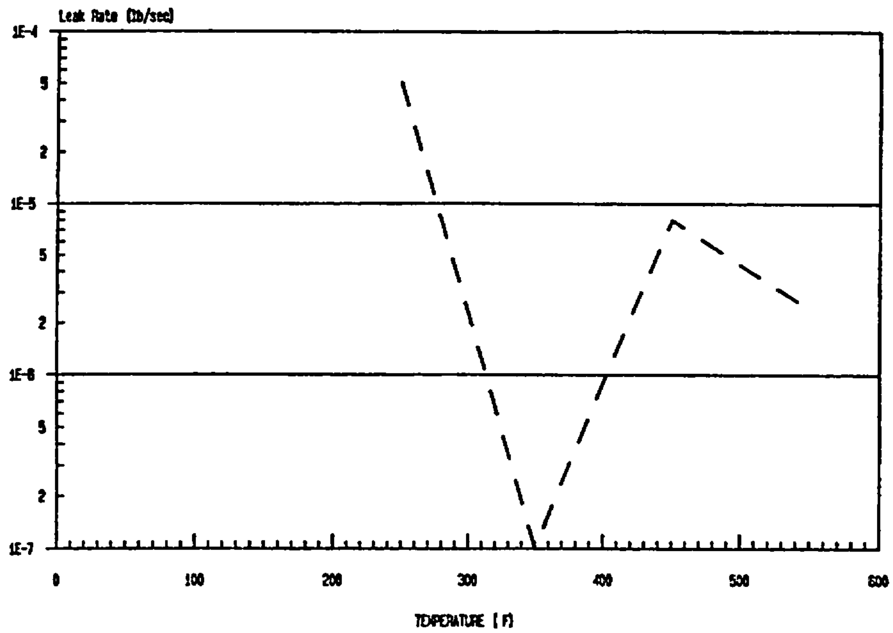


Figure 11. Four-Inch Check Valve
Leak Rate Versus Temperature

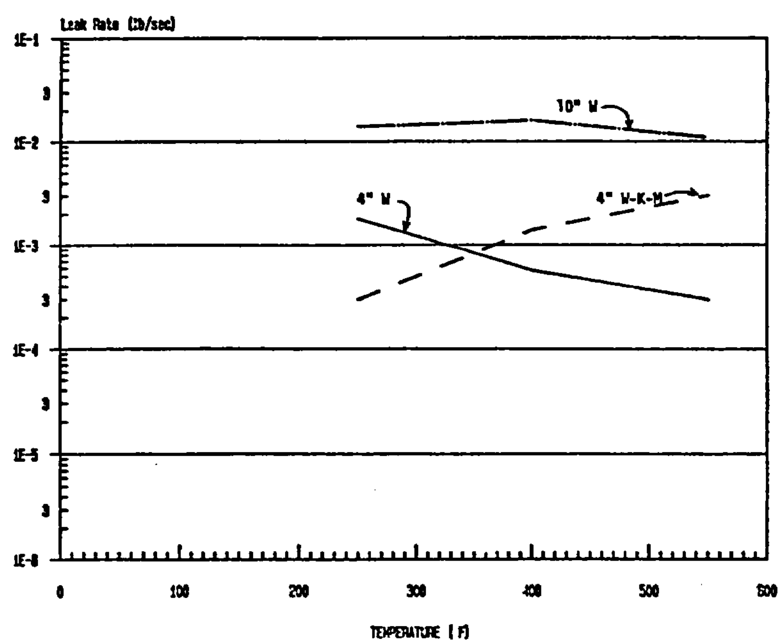


Figure 12. Gate Valves
Leak Rate Versus Temperature

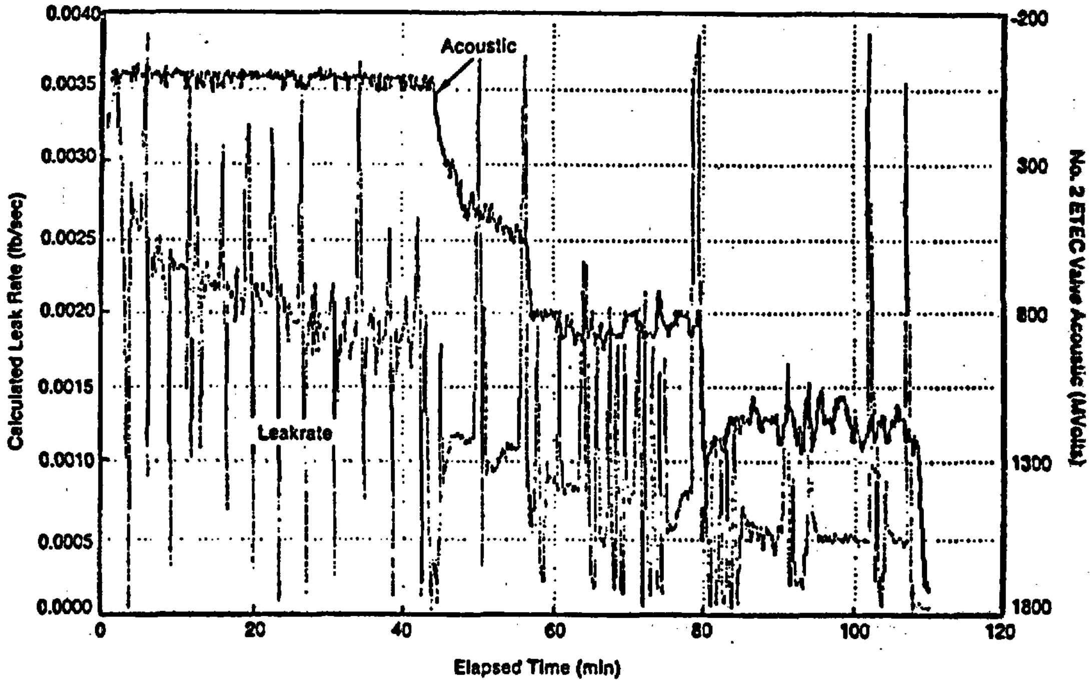


Figure 14. Four-Inch Westinghouse Gate Valve
Leak Rate Versus Density

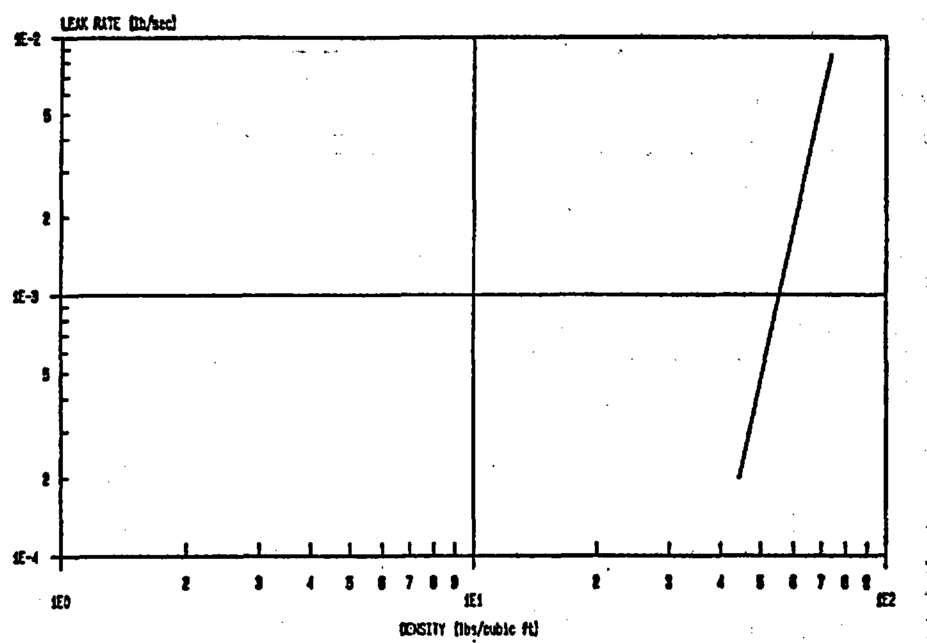


Figure 13. Acoustic Emission High Sensitivity
and Standard Leak Measurements --
Four-Inch Gate Valve Post Life Cycles

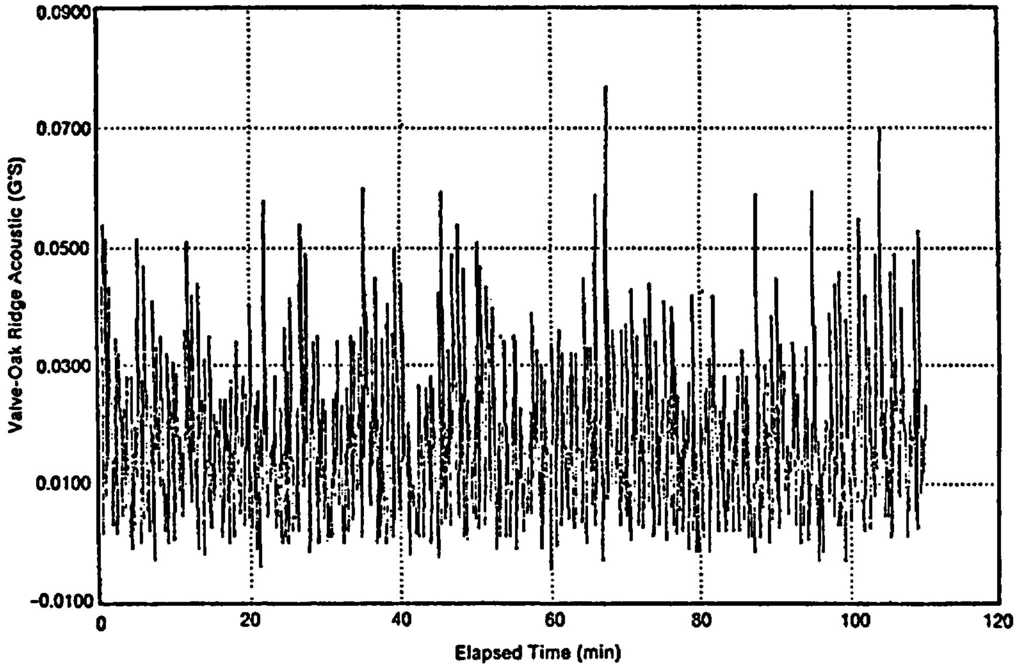
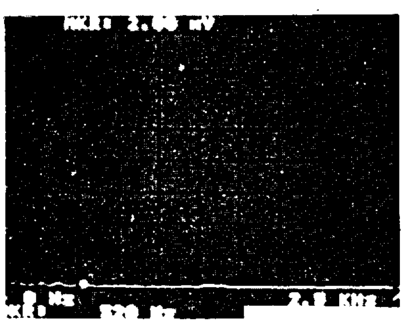
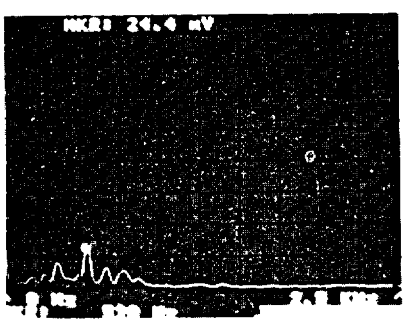


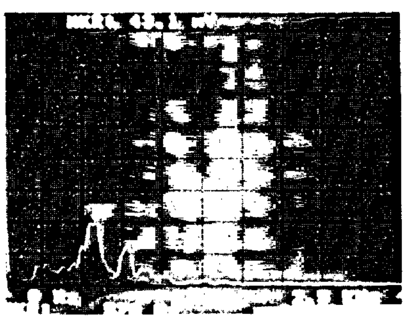
Figure 15. Standard Acoustic Emission Trace -- Four Inch Gate



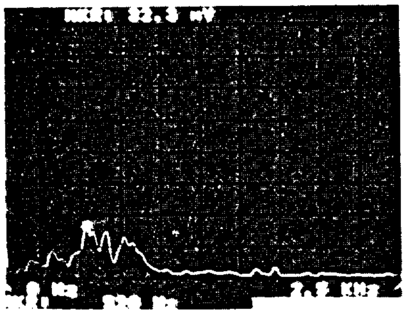
83 GPM (velocity = 3 ft/sec)



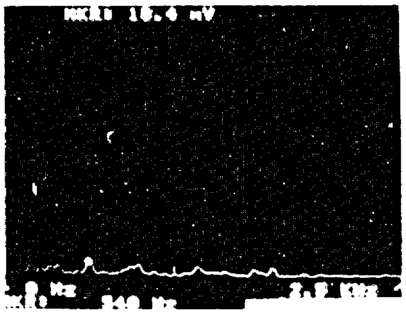
172 GPM (velocity = 6 ft/sec)



258 GPM (velocity = 9 ft/sec)

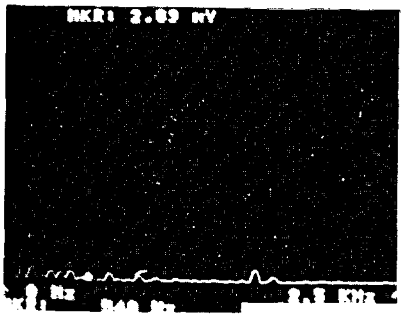


344 GPM (velocity = 12 ft/sec)

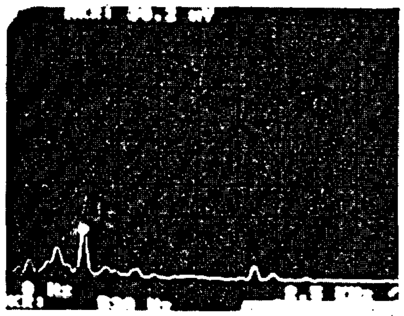


430 GPM (velocity = 15 ft/sec)

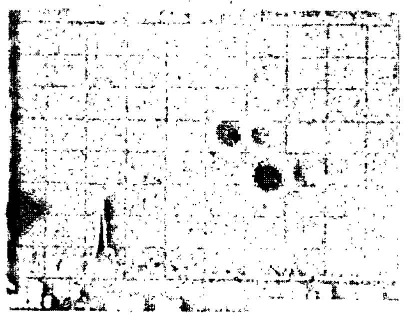
Figure 16. Fourier Analysis of Acoustic Data -- Baseline



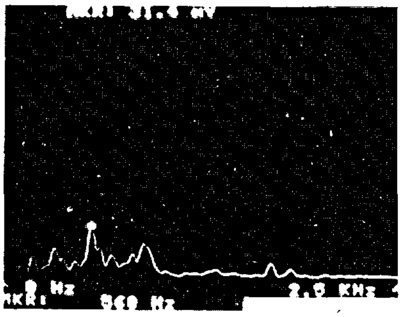
83 GPM (velocity = 3 ft/sec)



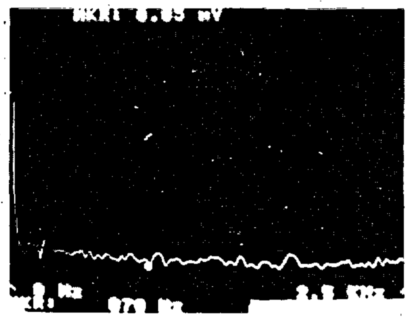
172 GPM (velocity = 6 ft/sec)



258 GPM (velocity = 9 ft/sec)

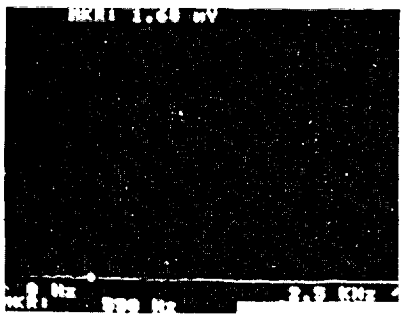


344 GPM (velocity = 12 ft/sec)

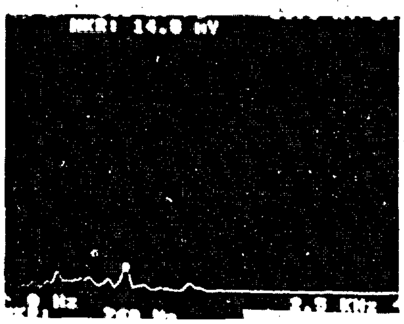


430 GPM (velocity = 15 ft/sec)

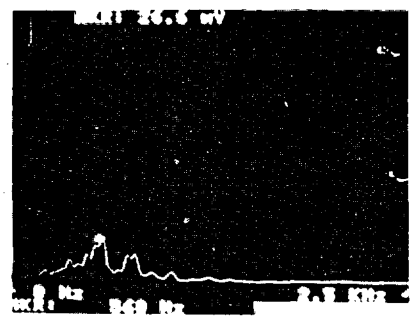
Figure 17. Fourier Analysis of Acoustic Data
Internals Loosened (2 turns)



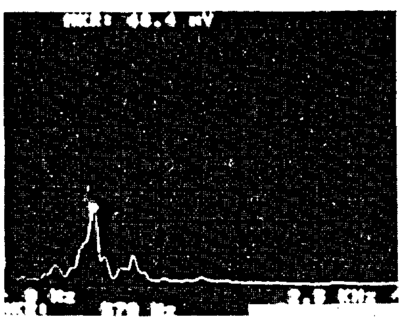
83 GPM (velocity = 3 ft/sec)



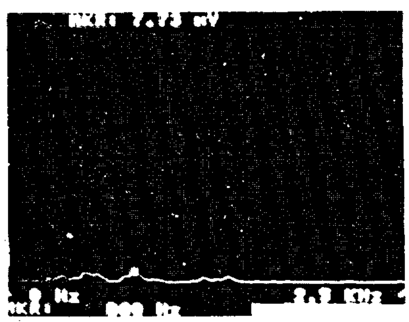
172 GPM (velocity = 6 ft/sec)



258 GPM (velocity = 9 ft/sec)



344 GPM (velocity = 12 ft/sec)



430 GPM (velocity = 15 ft/sec)

Figure 18. Fourier Analysis of Acoustic Data
Internals Loosened (4 turns)

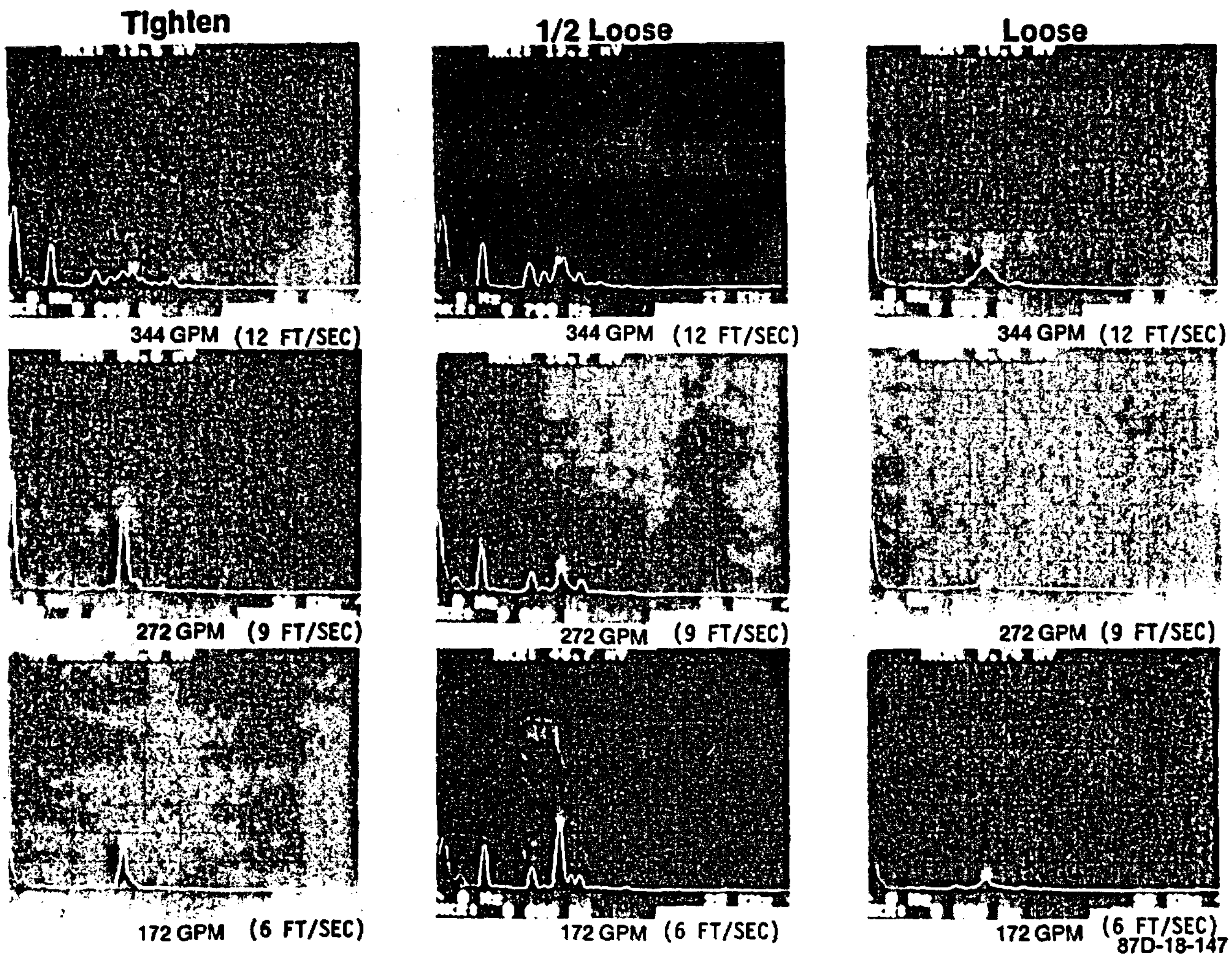


Figure 19. Fourier Analysis of Acoustic Data
Comparison of Results

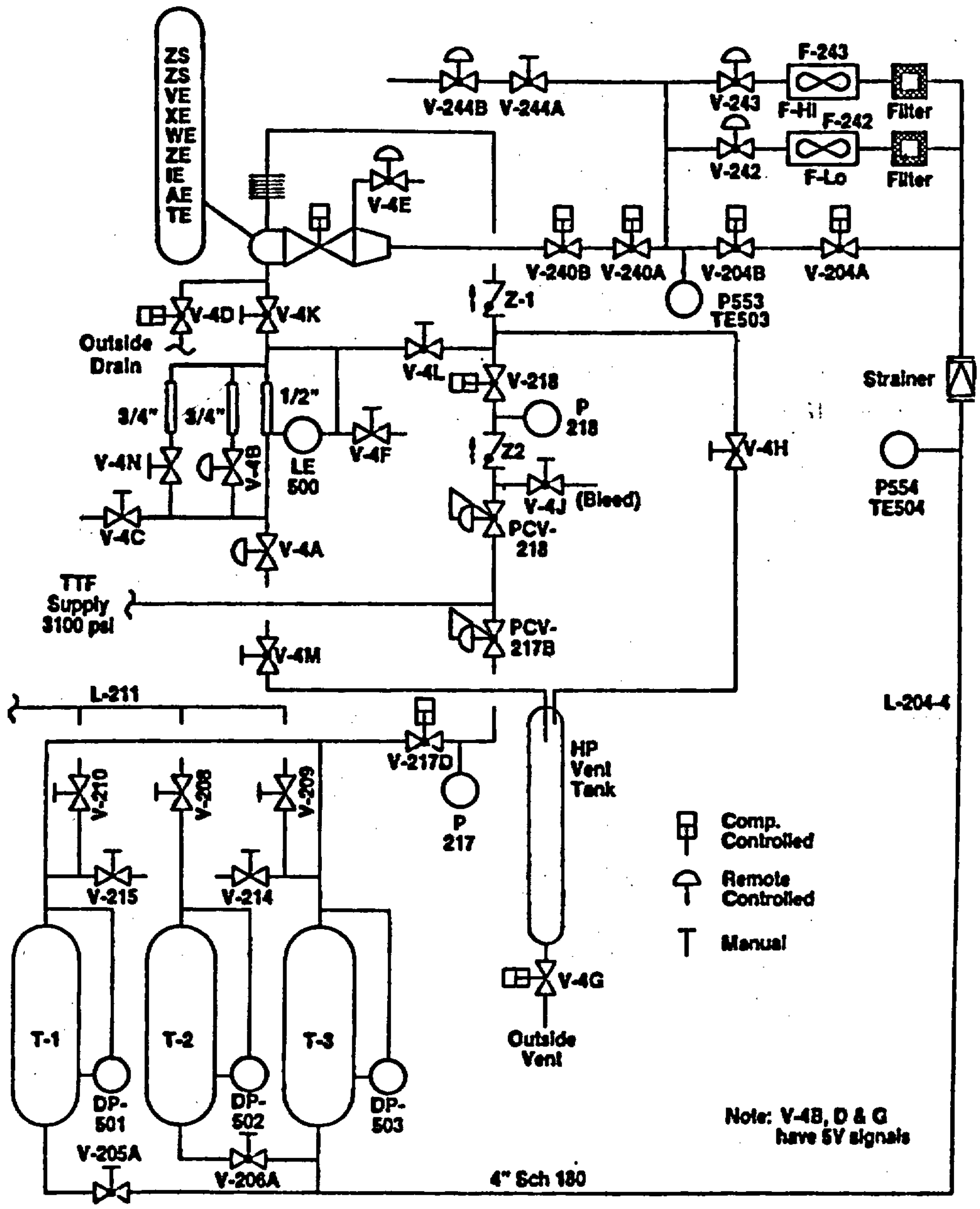


Figure 20. LLTR Schematic

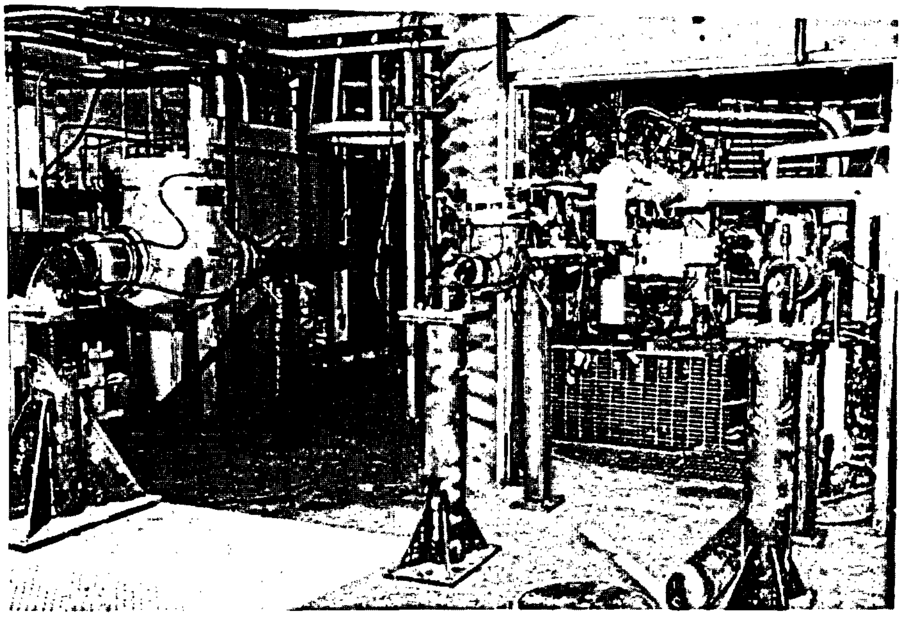


Figure 21. Check Valve Installed In LLTR

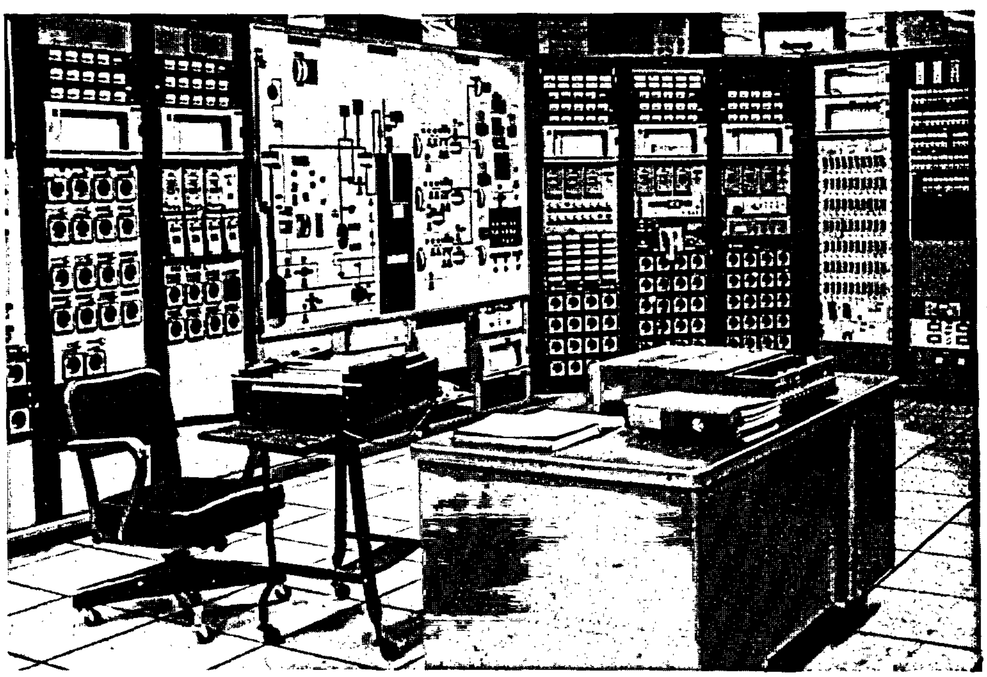


Figure 22. LLTR Control Room

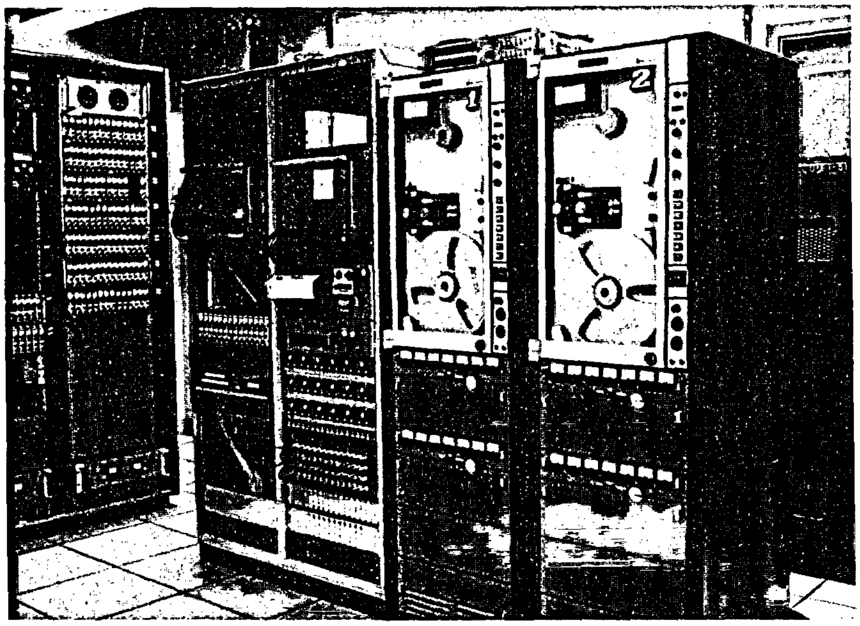


Figure 23. LLTR Data Acquisition System

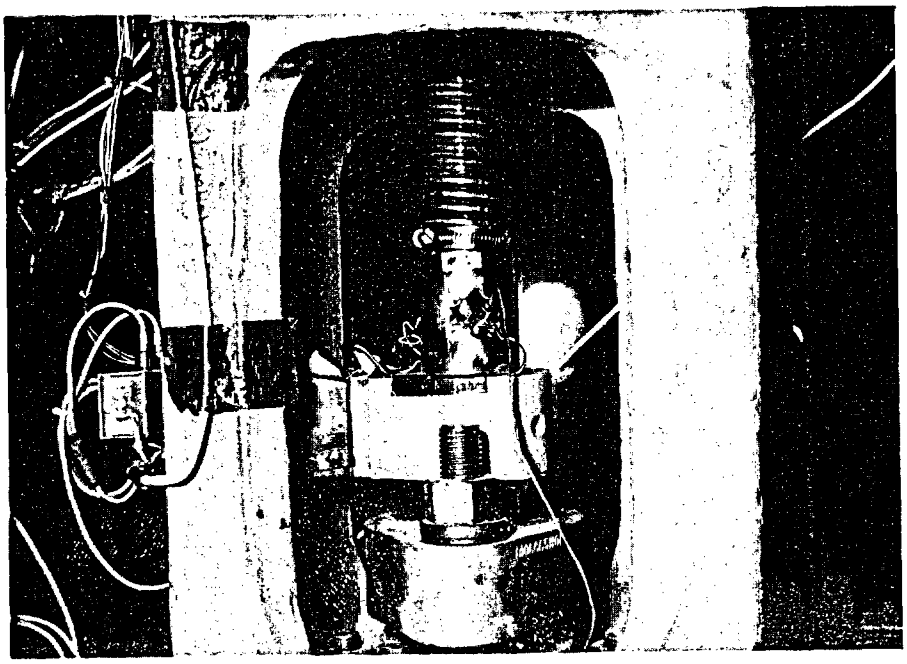


Figure 24. Three-Element Strain Gage to Measure Stem Force

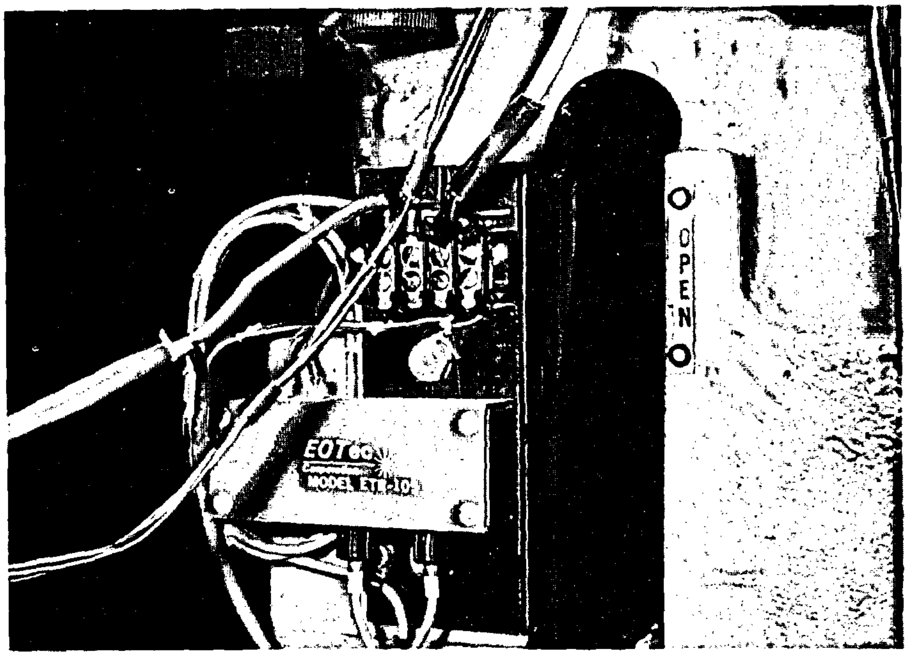


Figure 25. Open Position Bifurcated
Fiber Optic Device

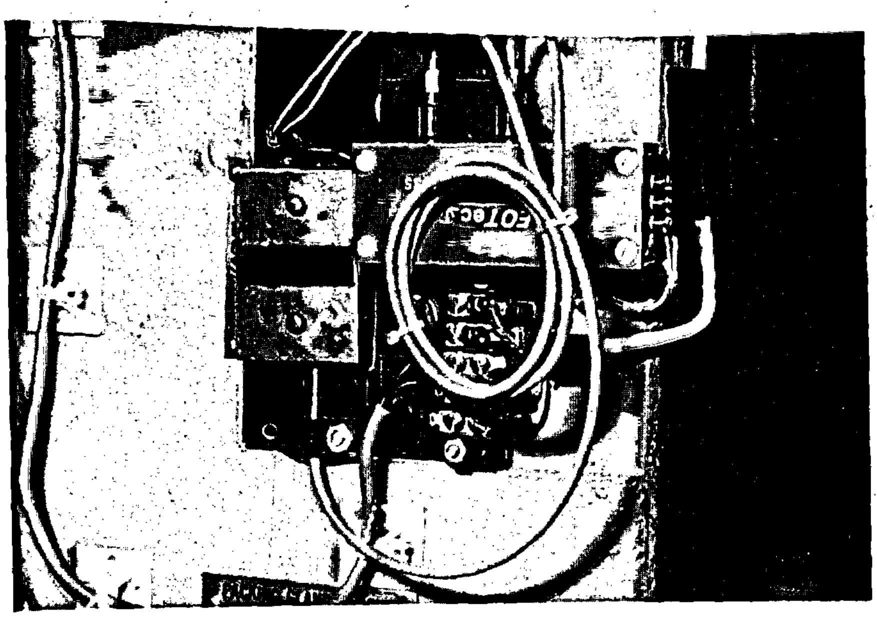


Figure 26. Close Position Bifurcated Optic Device

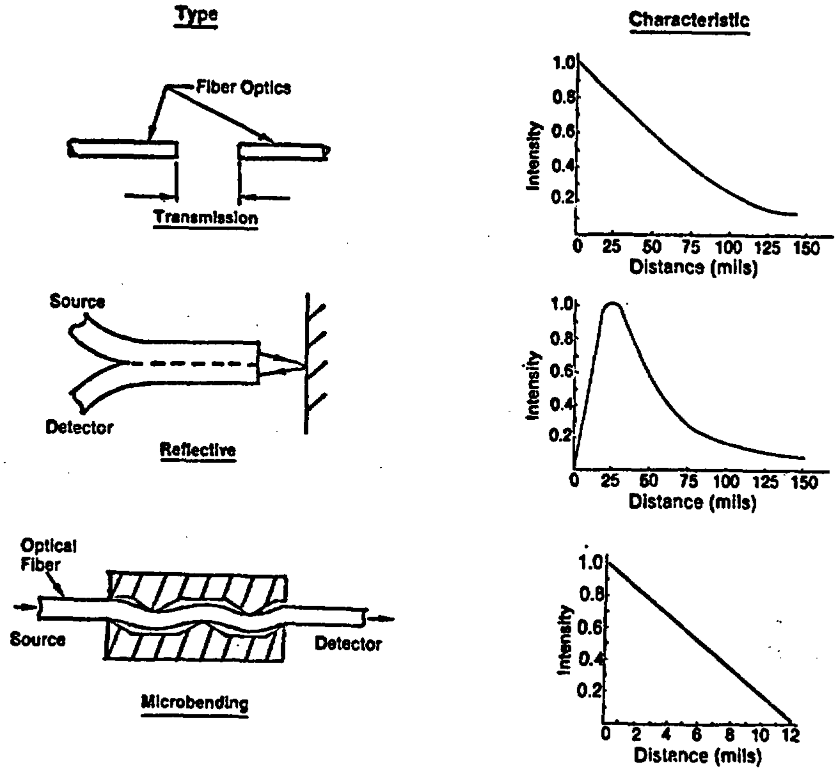


Figure 27. Characteristics of Various Fiber Optic Devices

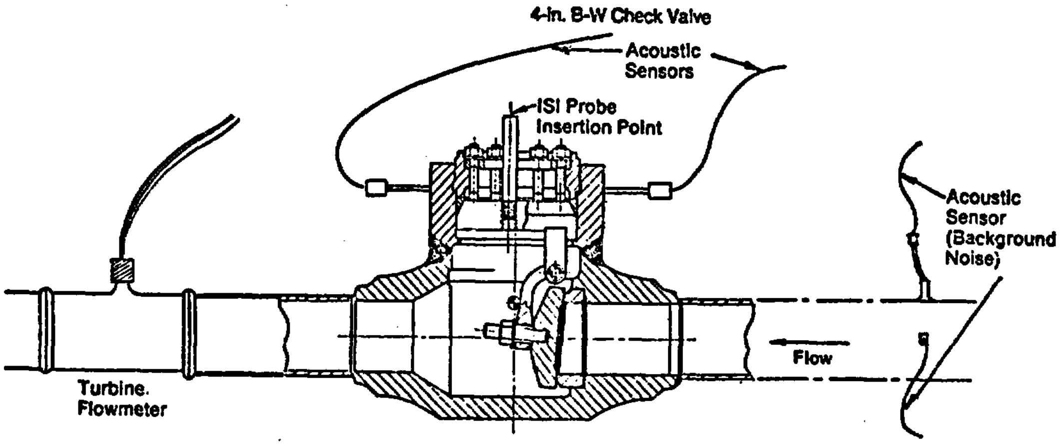


Figure 28. Four-Inch Check Valve Flow Test Setup

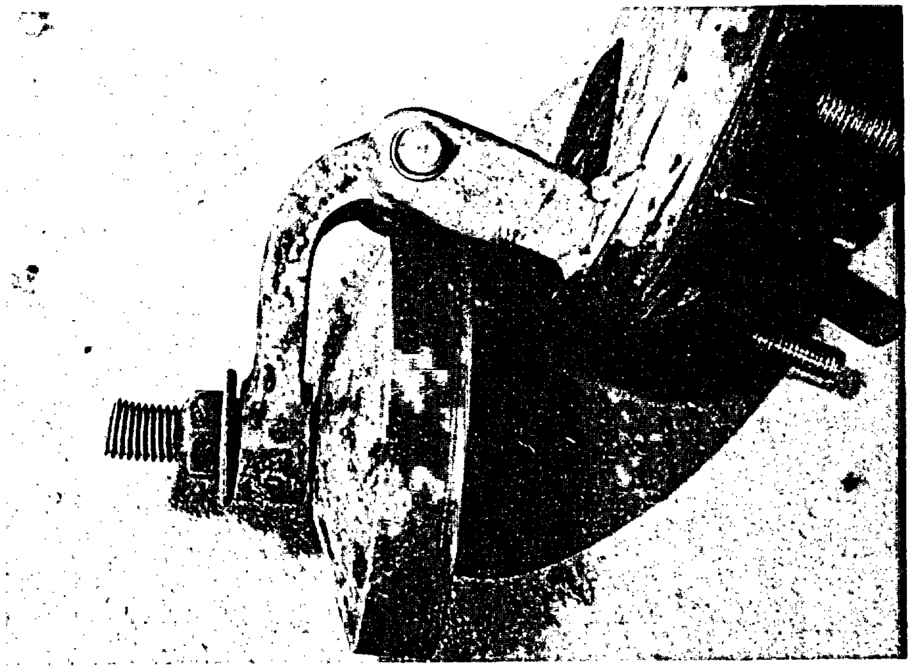


Figure 29. Four-Inch Check Valve Stud After Life-Cycling

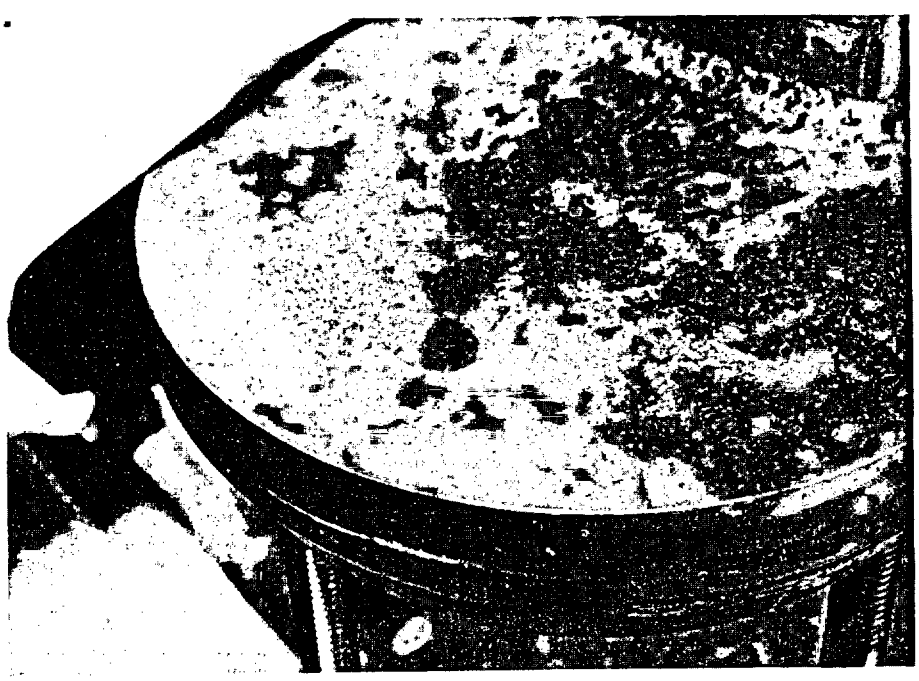


Figure 30. Four-Inch Check Valve Bonnet After Life-Cycling

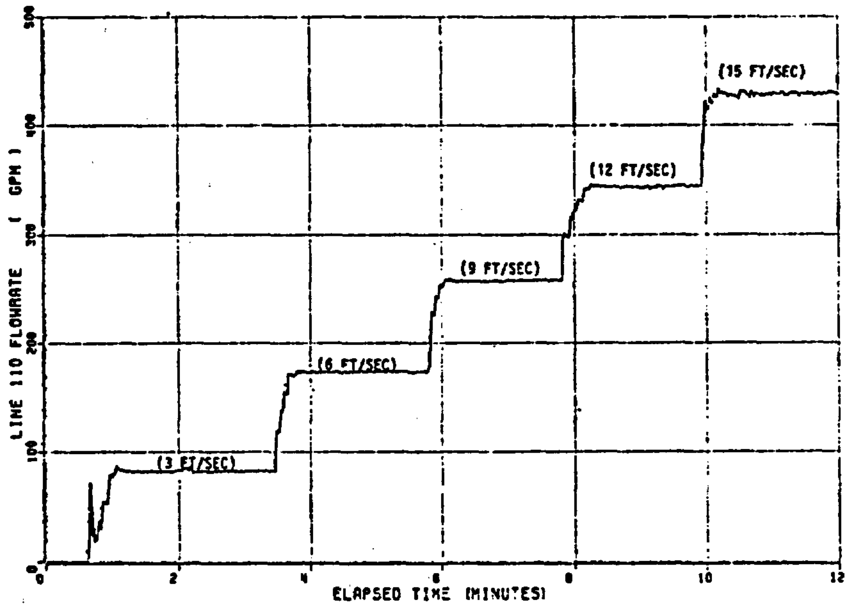


Figure 31. Flowrate Versus Time -- Internals As-Received

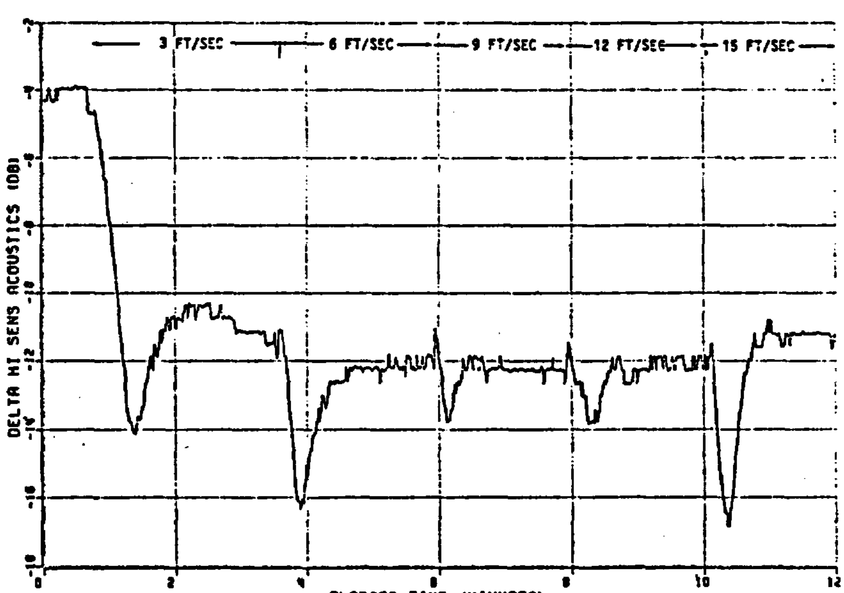


Figure 32. Narrow Band Acoustic Signal Internals As-Received

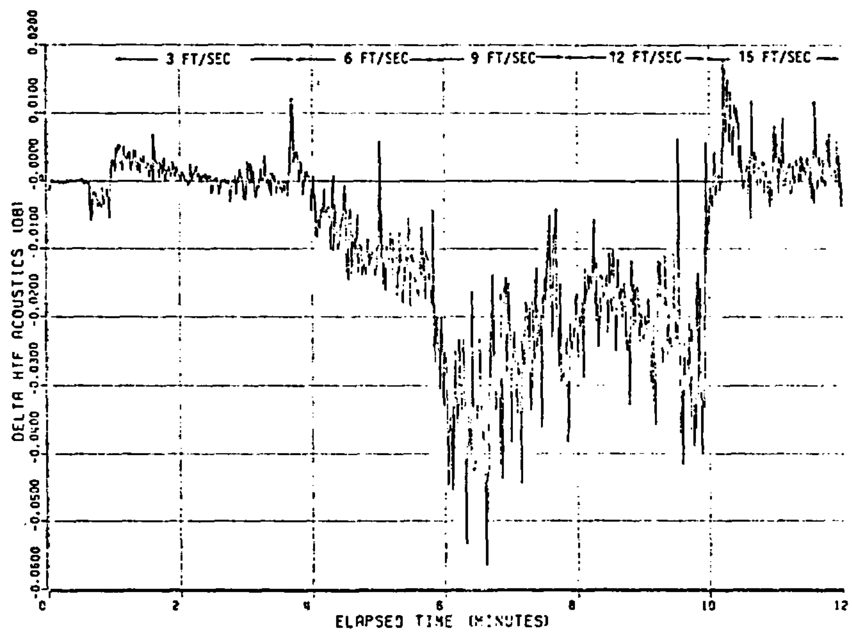


Figure 33. ETEC 10 kHz Acoustic Signal Internals As-Received

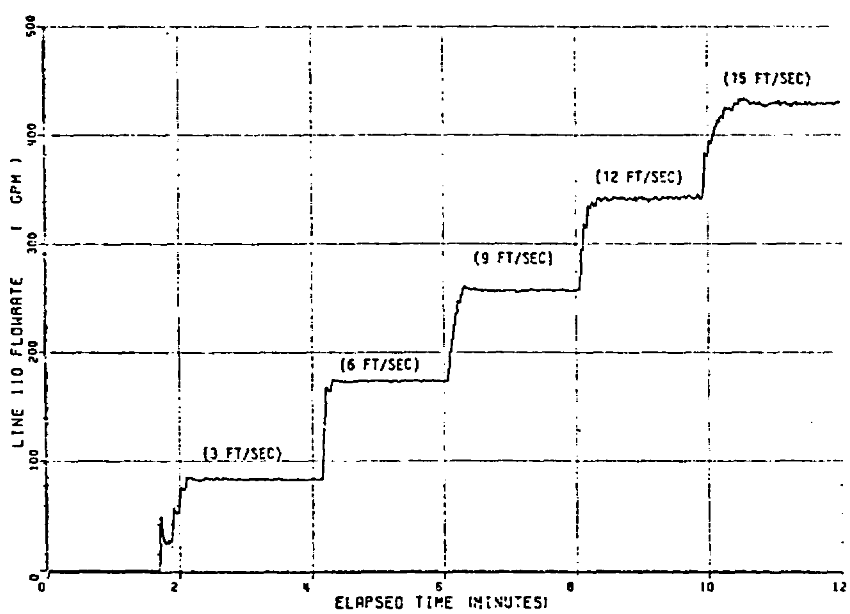


Figure 34. Flowrate Versus Time Loose Internals (2 turns)

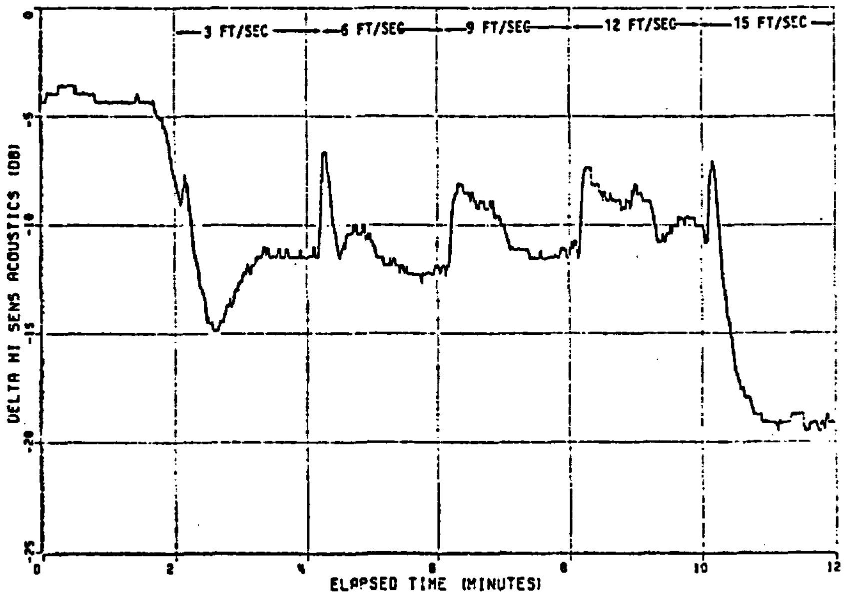


Figure 35. Narrow Band Acoustic Signal
Loose Internals (2 turns)

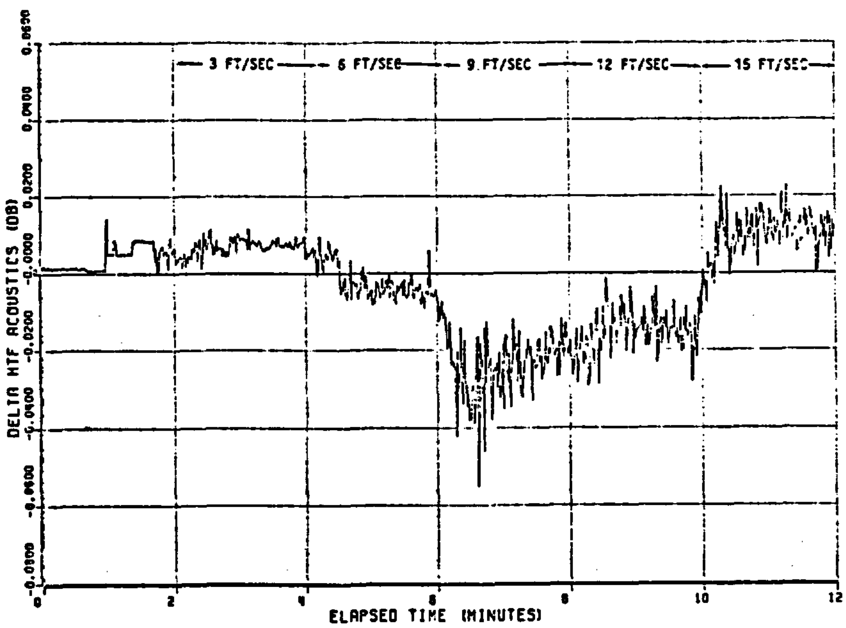


Figure 36. ETEC 20 kHz Acoustic Signal
Loose Internals (2 turns)

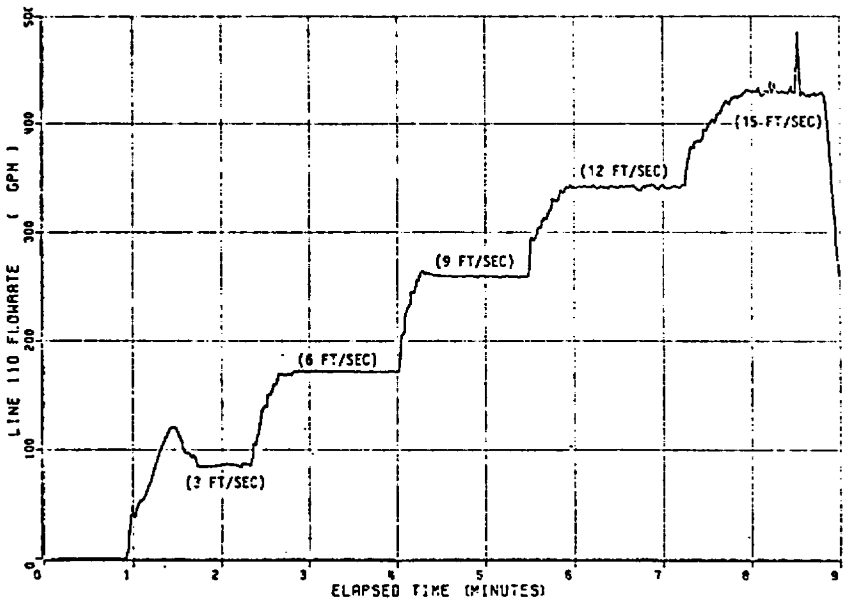


Figure 37. Flowrate Versus Time
Loose Internals (4 turns)

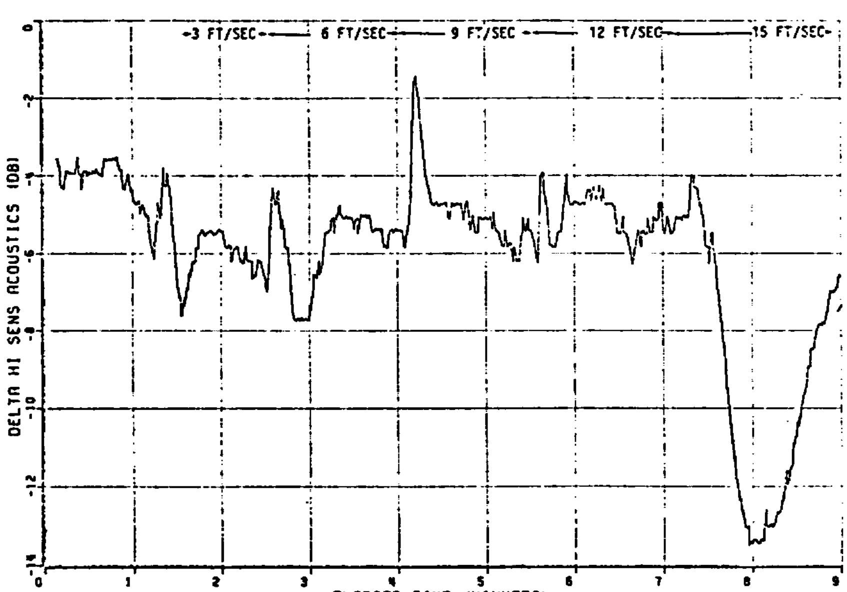


Figure 38. Narrow Band Acoustic Signal
Loose Internals (4 turns)

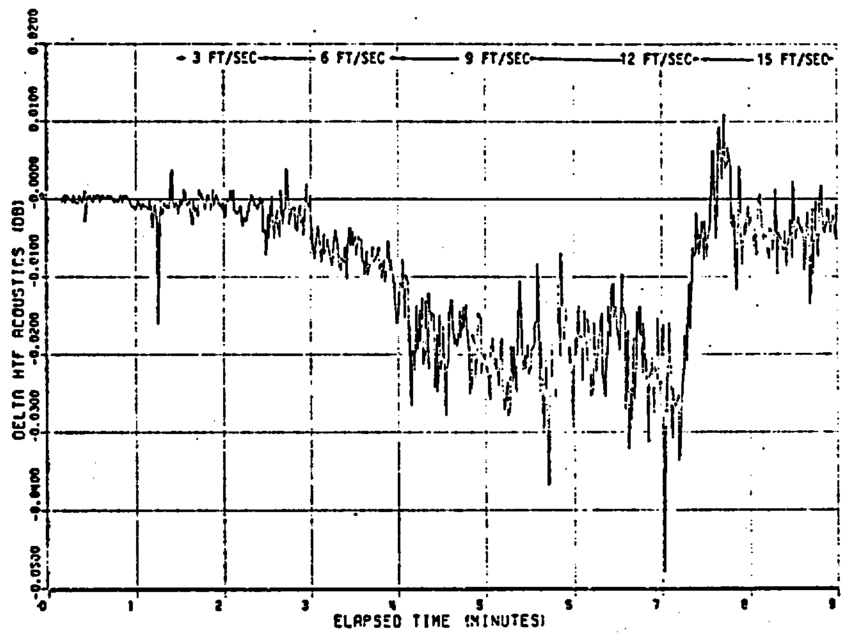


Figure 39. ETEC 20 kHz Acoustic Signal
Loose Internals (4 turns)

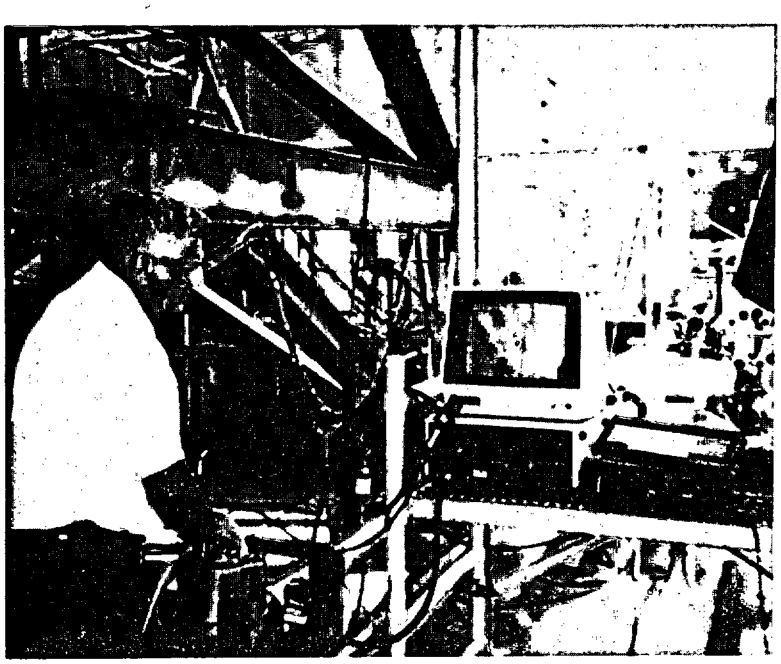


Figure 40. Four-Inch Check Valve
Videoprobe Inspection

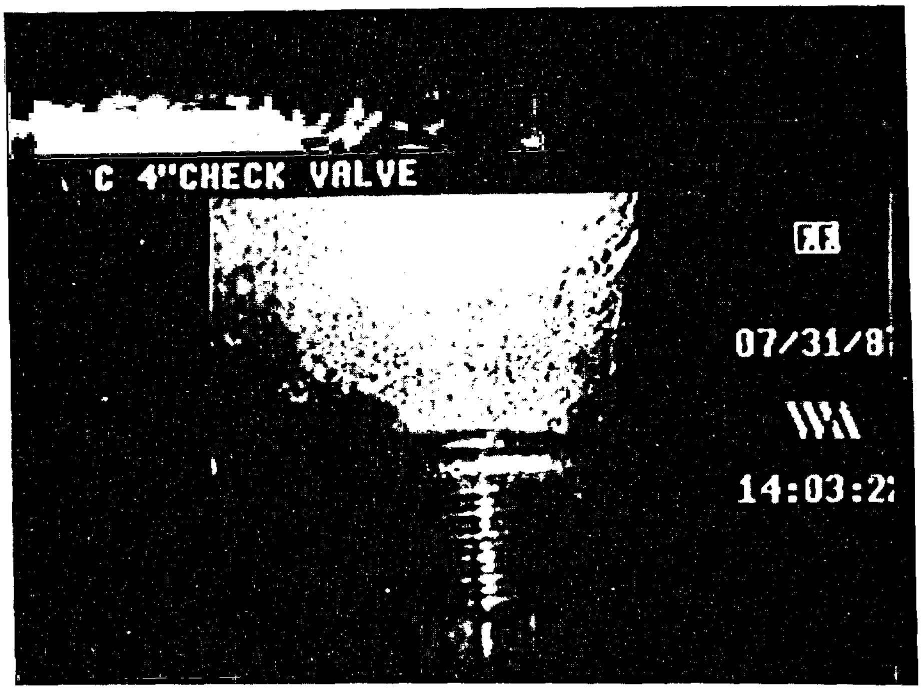


Figure 41. Four-Inch Check Valve In-Service Inspection--Clapper Stud Assembly

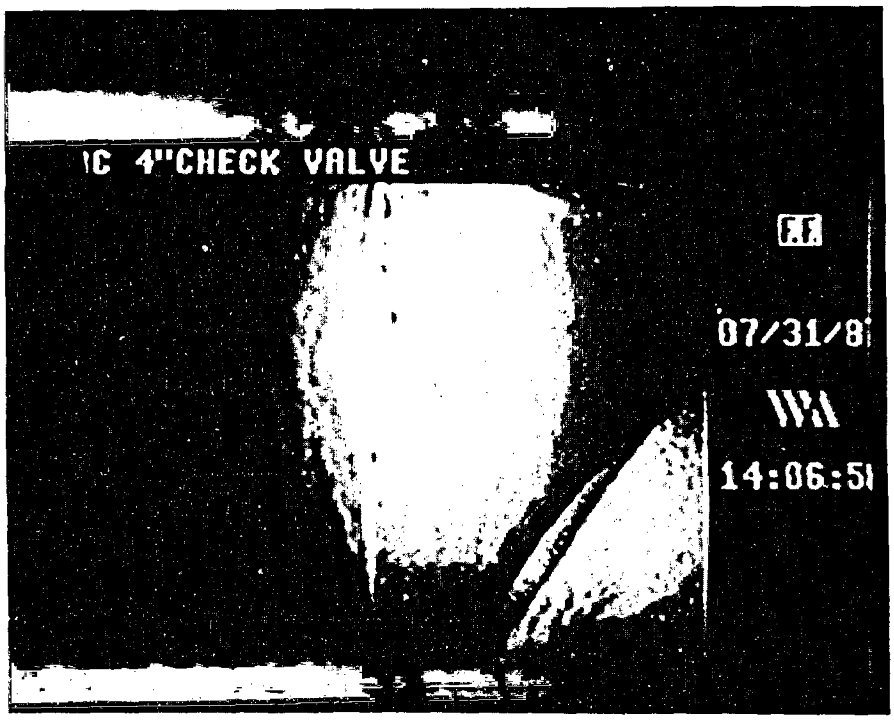


Figure 42. Four-Inch Check Valve In-Service Inspection--Clapper Pin Area

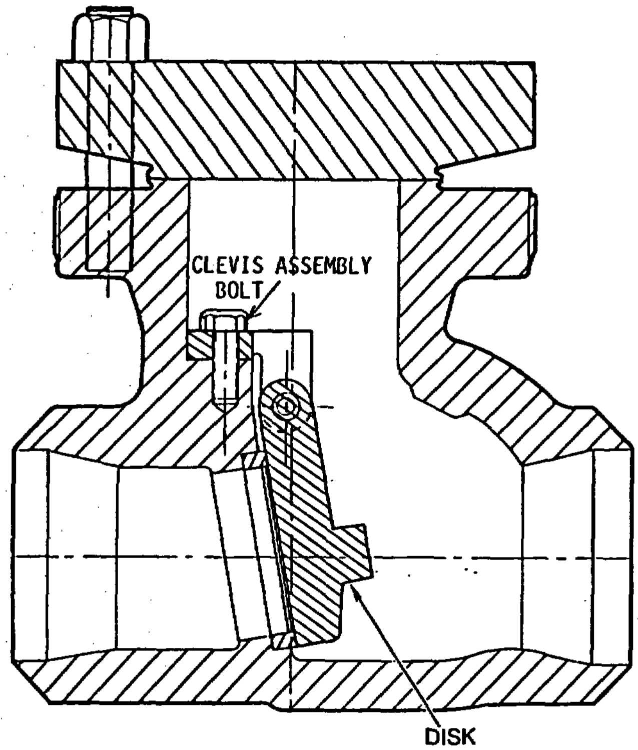


Figure 43. Six-Inch Check Valve Internals

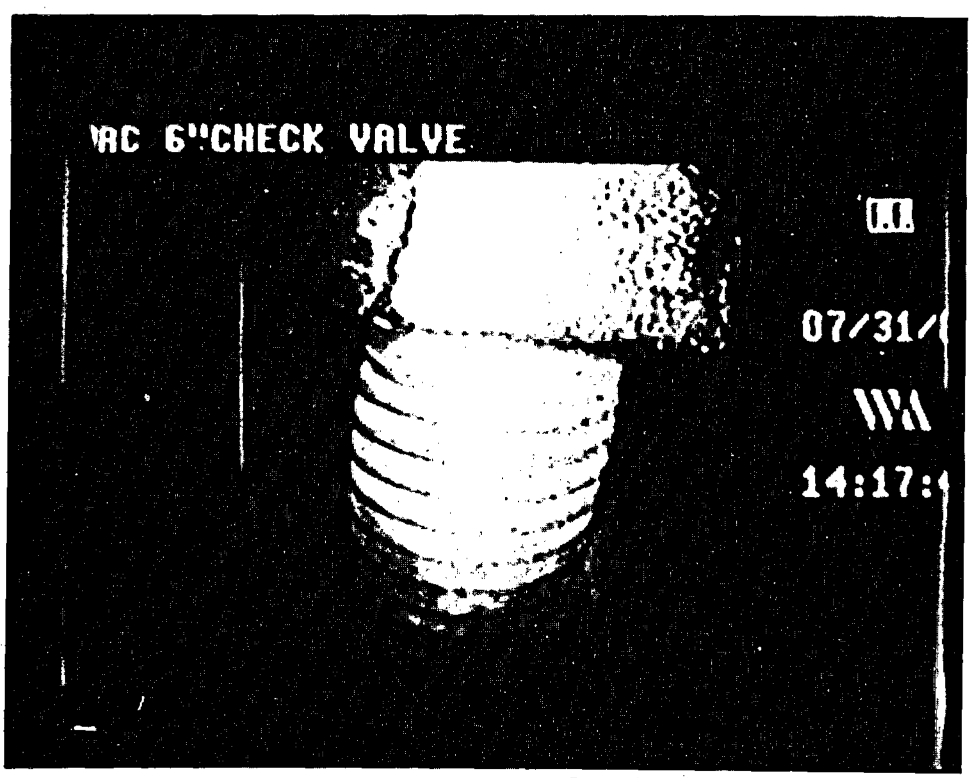


Figure 44. Six-Inch Check Valve In-Service Inspection -- Clapper Stud

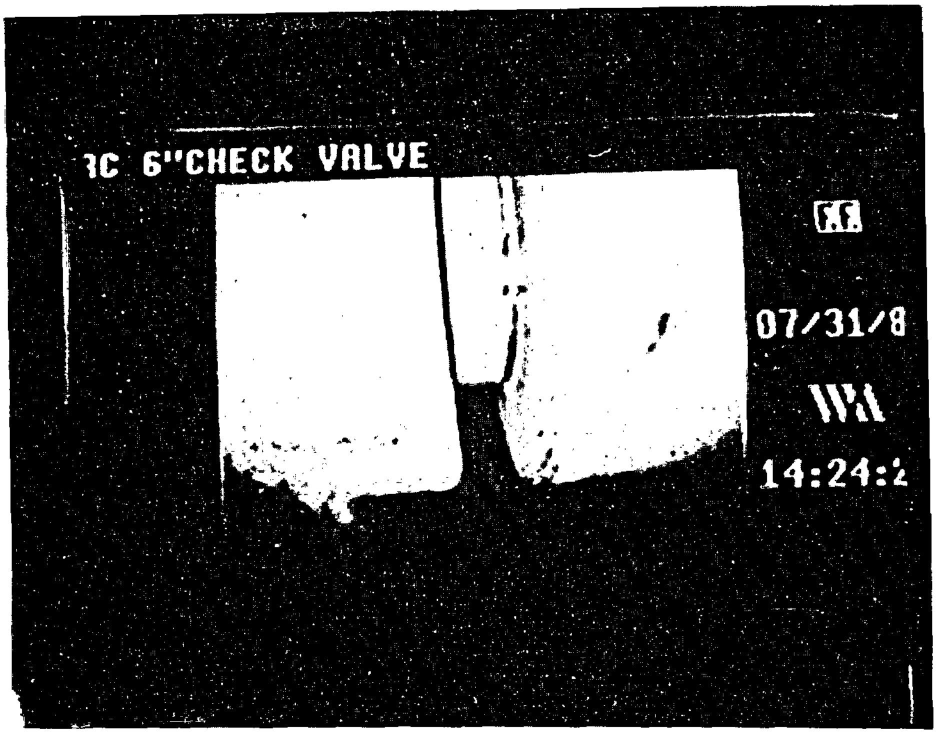


Figure 45. Six-Inch Valve In-Service Inspection Clapper Pin Area

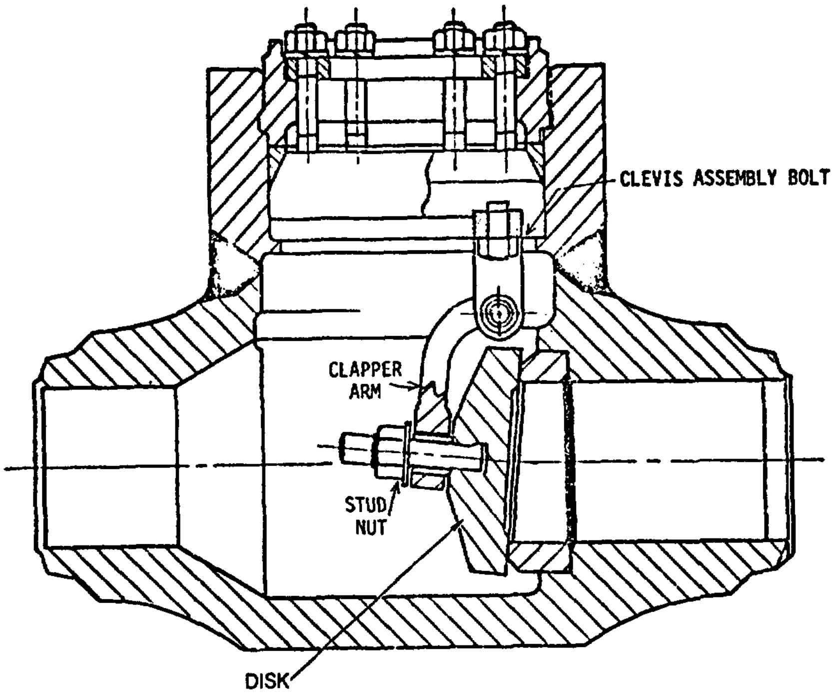


Figure 46. Twelve-Inch Check Valve Internals

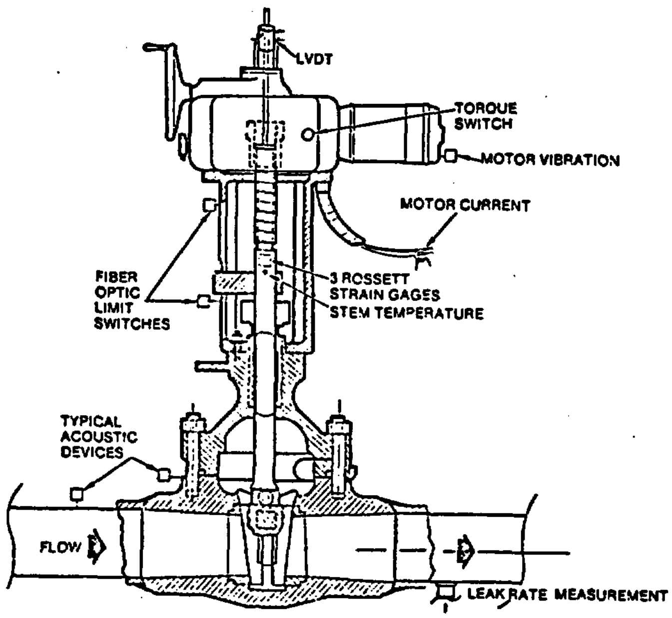


Figure 47. Ten-Inch Gate Valve With Motor Signature Instrumentation

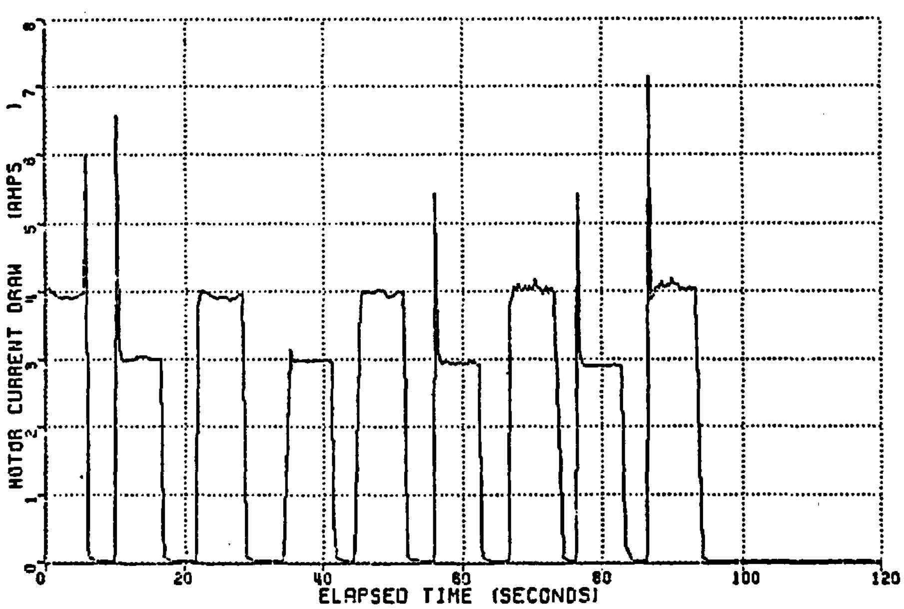


Figure 48. Motor Signature Test Four Motor Current Versus Time

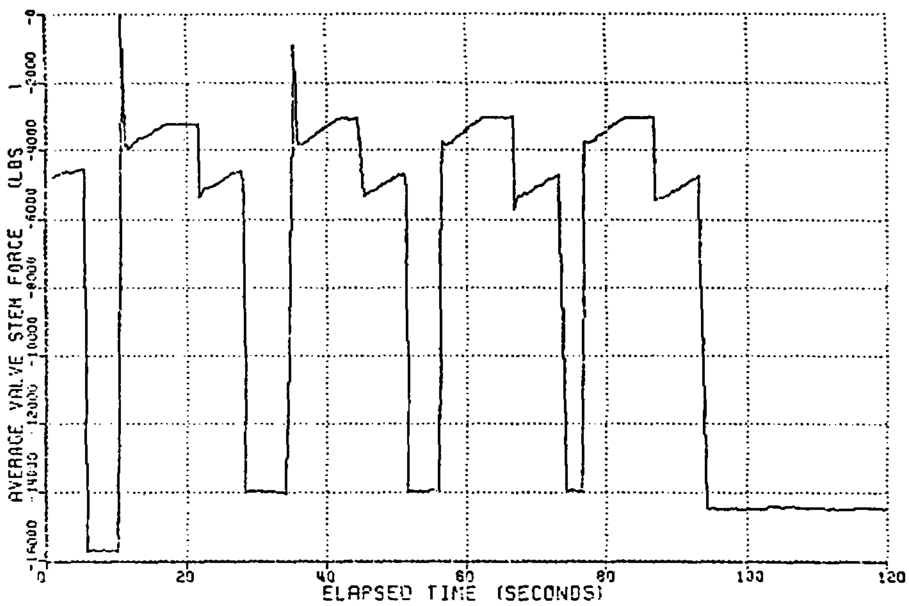


Figure 49. Motor Signature Test Four
Stem Force Versus Time

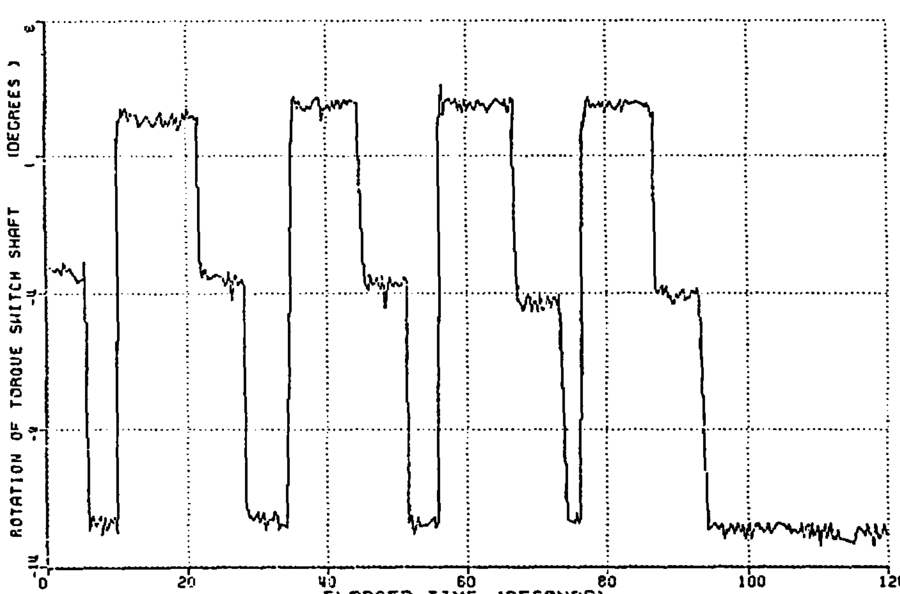


Figure 50. Motor Signature Test Four Rotation
of Torque Switch Versus Time

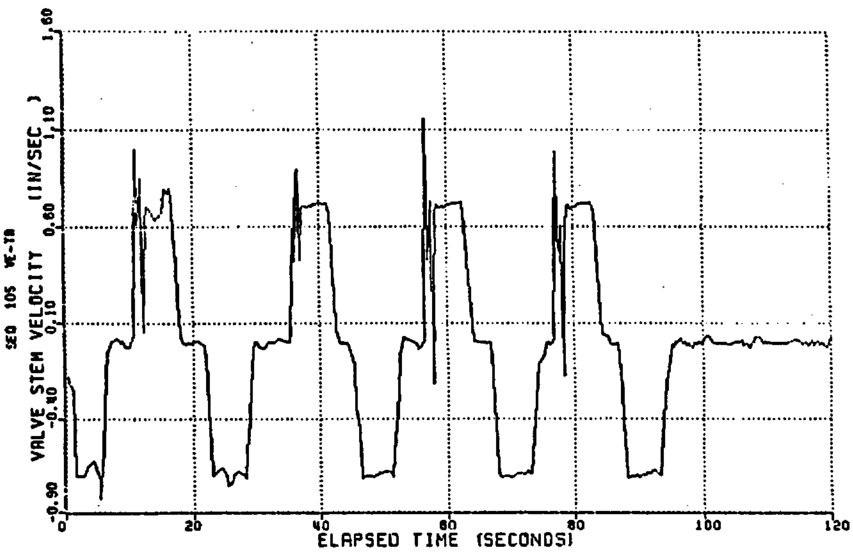


Figure 51. Motor Signature Test Four
Valve Stem Velocity Versus Time

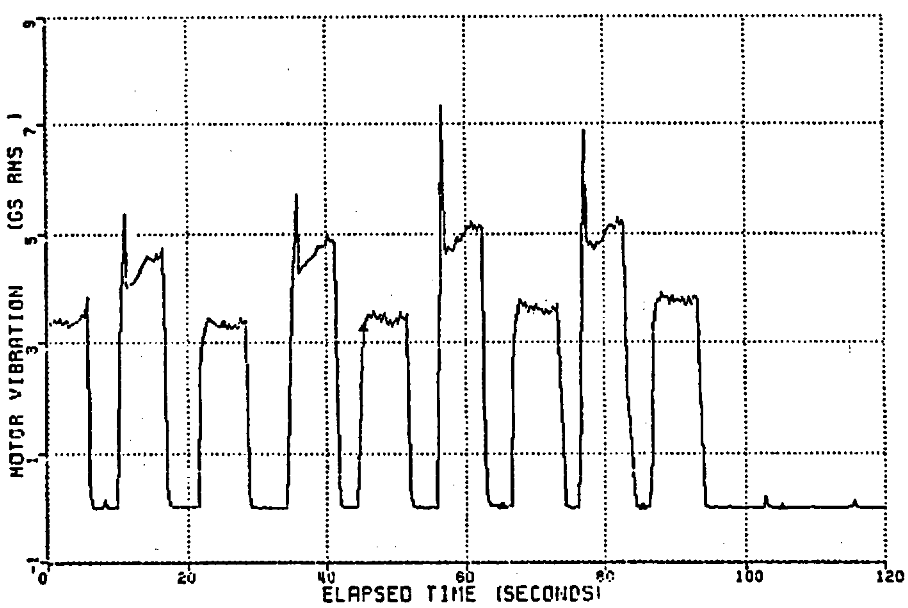


Figure 52. Motor Signature Test Four
Motor Vibration Versus Time

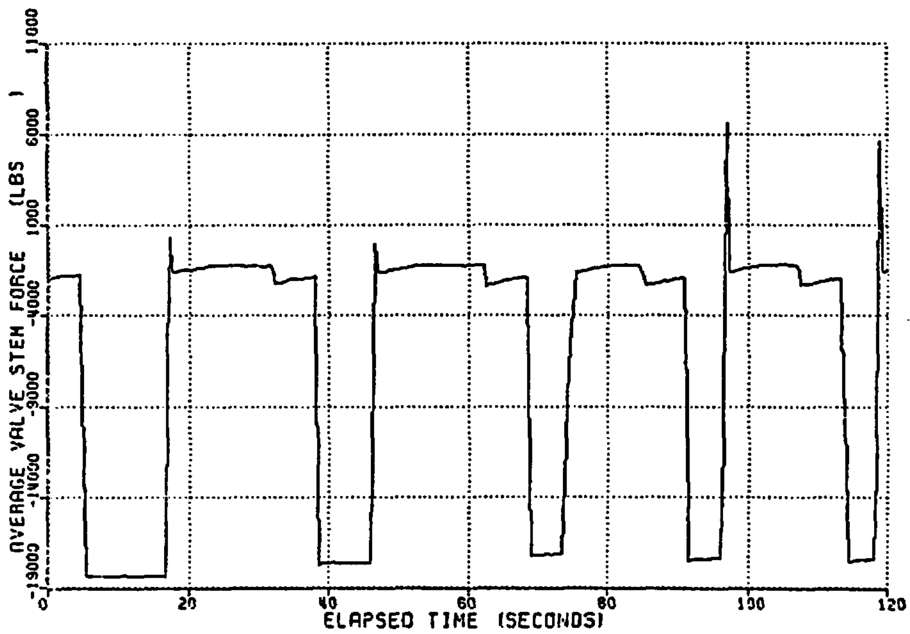


Figure 53. Motor Signature Test
Three Stem Force Versus Time

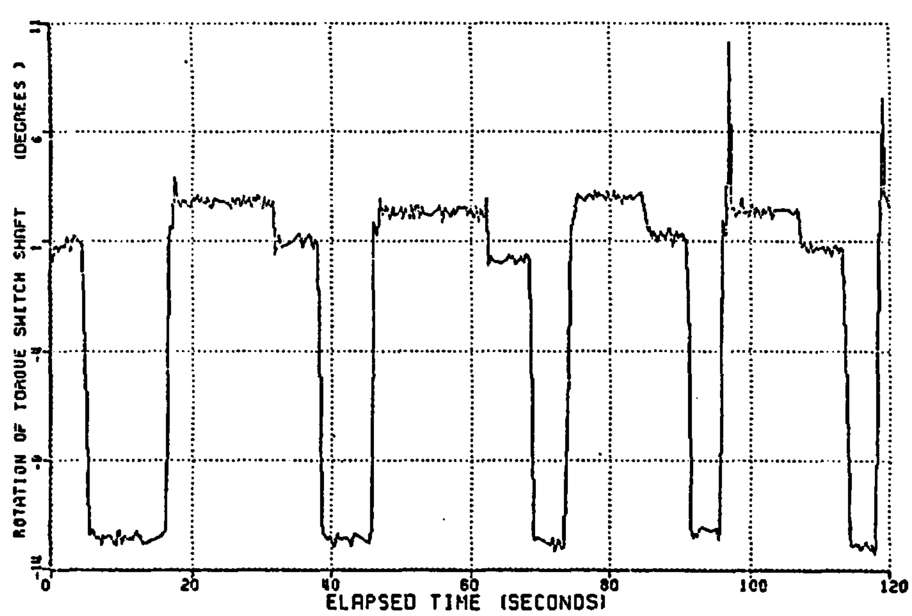


Figure 54. Motor Signature Test Three
Rotation of Torque Switch Versus Time

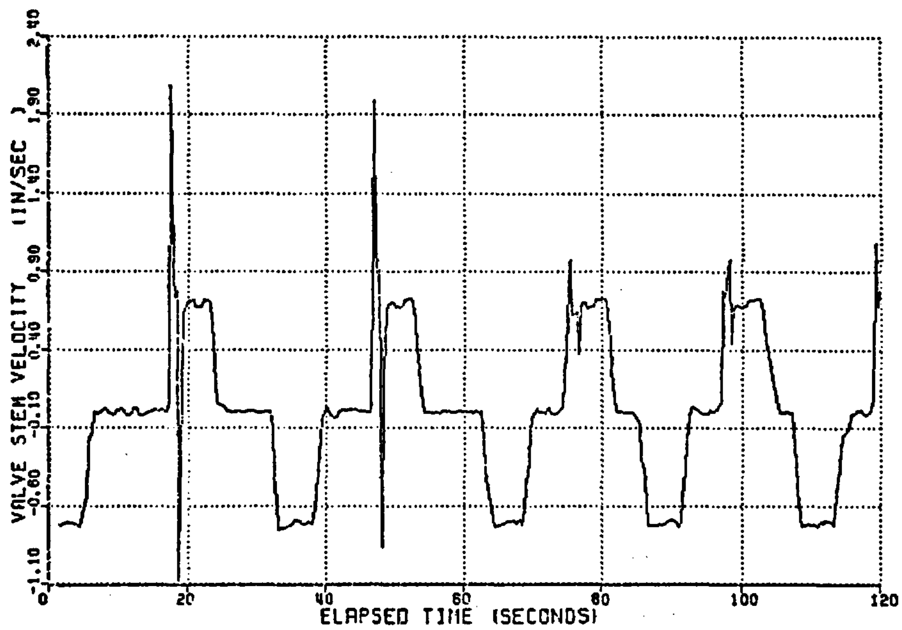


Figure 55. Motor Signature Test Three
Stem Velocity Versus Time

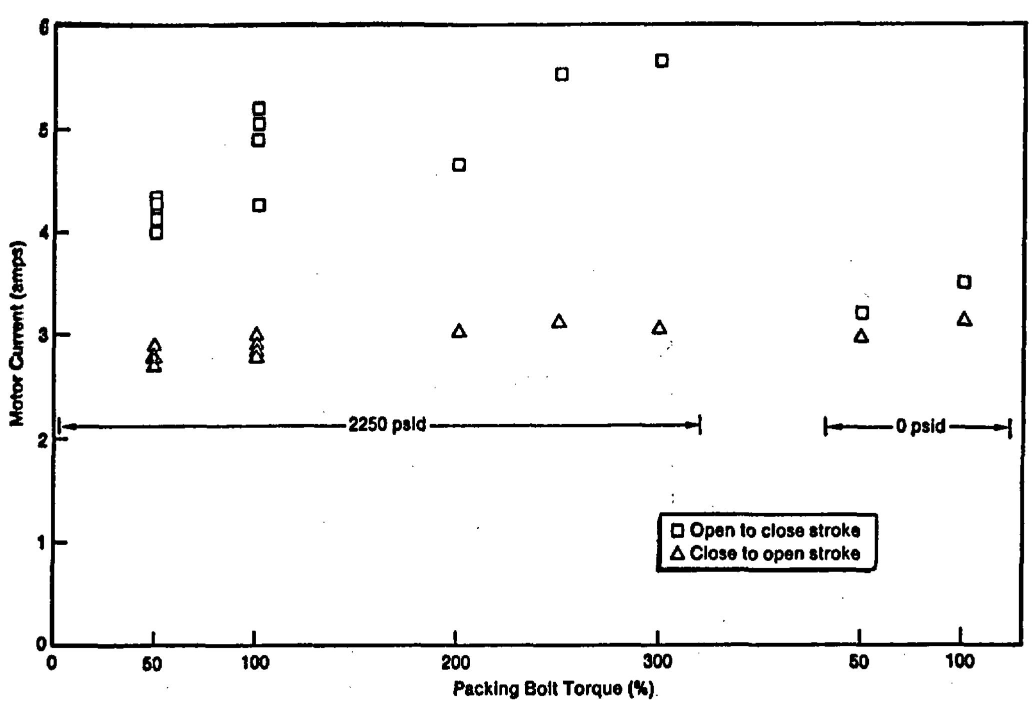


Figure 56. Four-Inch Gate Valve --
Motor Current Versus Packing
Torque, Valve Opening & Closing

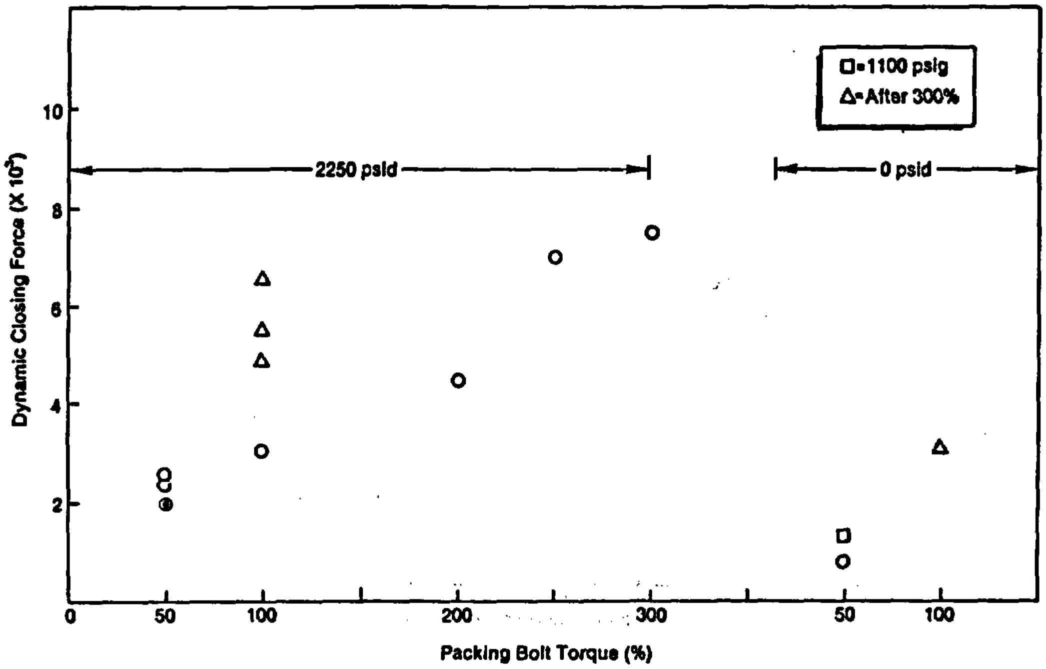


Figure 57. W Four-Inch Gate Valve -- Closing Force Versus Packing Torque, Various Pressures

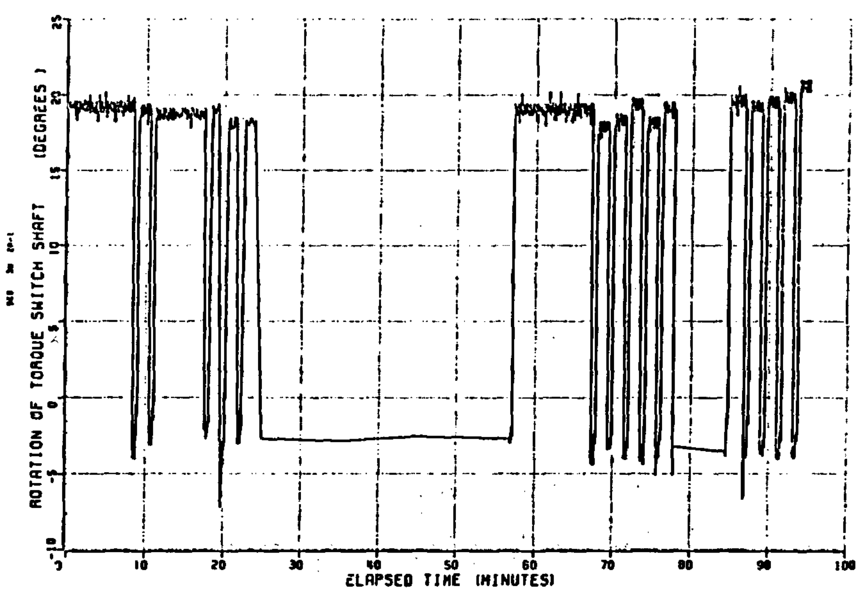


Figure 58. Ten-Inch Gate Valve -- Rotation of Torque Switch at 300% Packing Torque

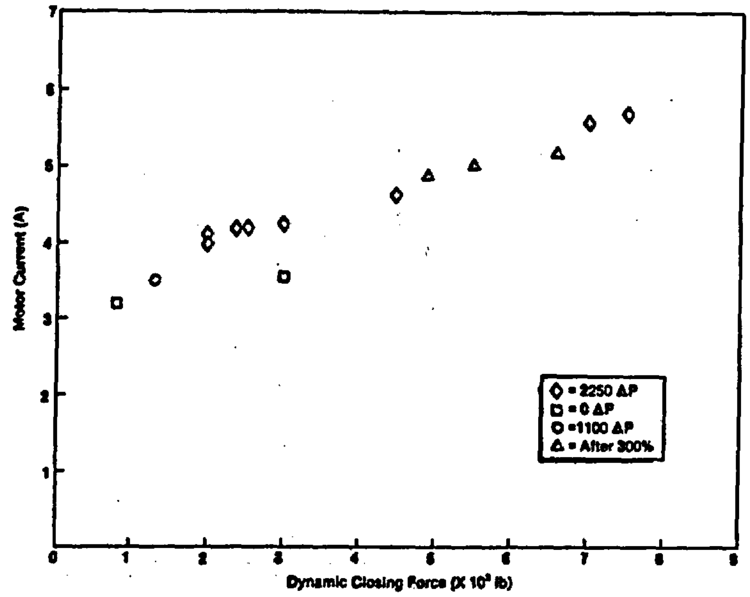


Figure 59. Four-Inch Gate Valve -- Motor Current Versus Closing Force, Various Pressures

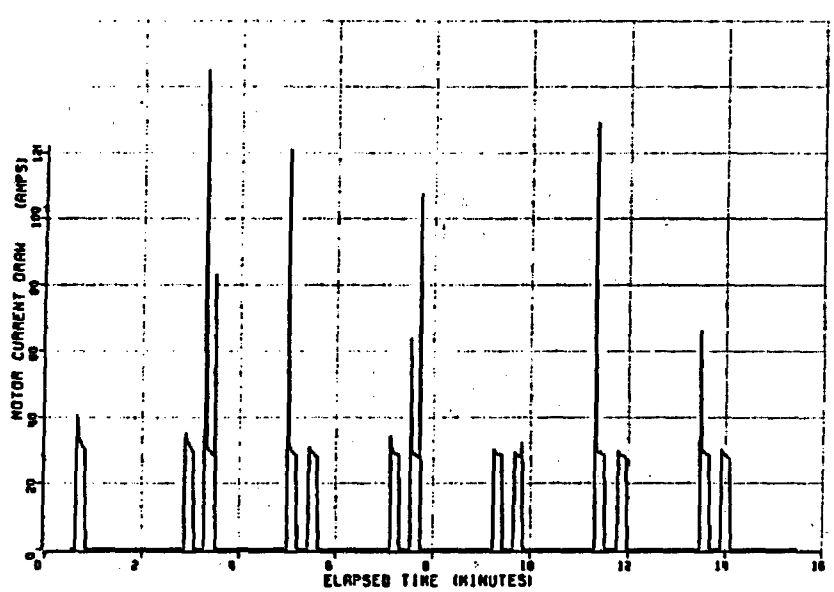


Figure 60. Ten-Inch Gate Valve Motor Current for Initial Dry Cycles

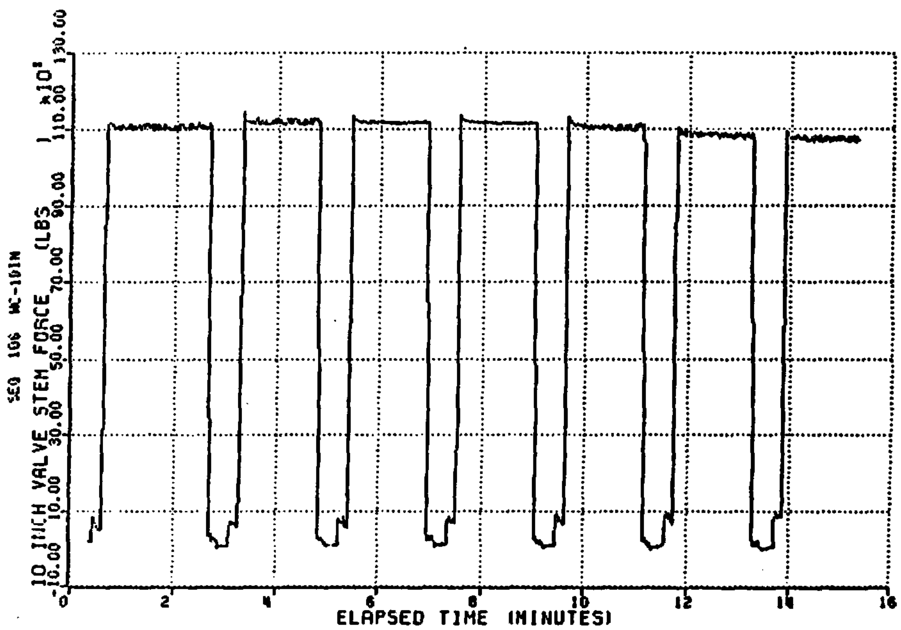


Figure 61. Ten-Inch Gate Valve Stem Force for Initial Dry Cycles

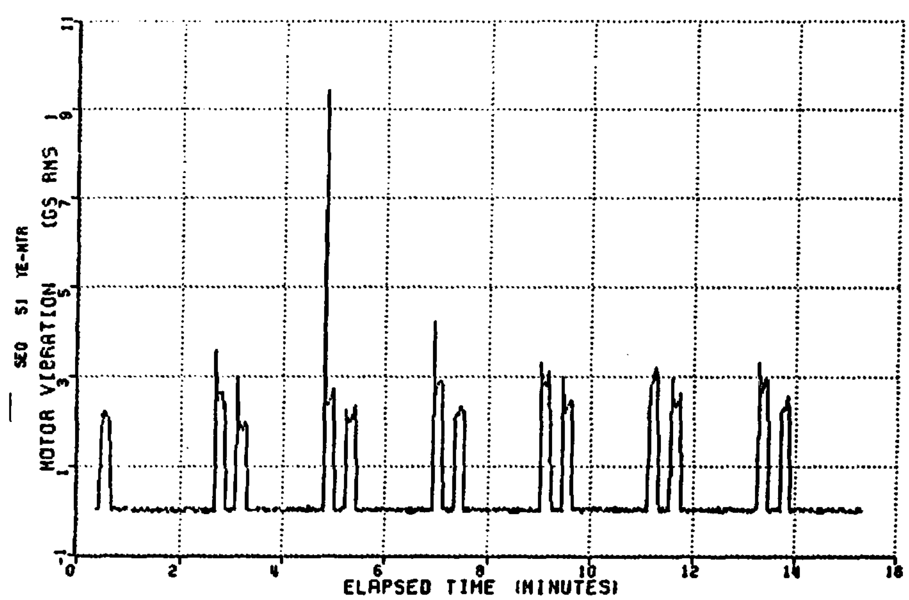


Figure 62. Ten-Inch Gate Valve -- Motor Vibration for Initial Cycles

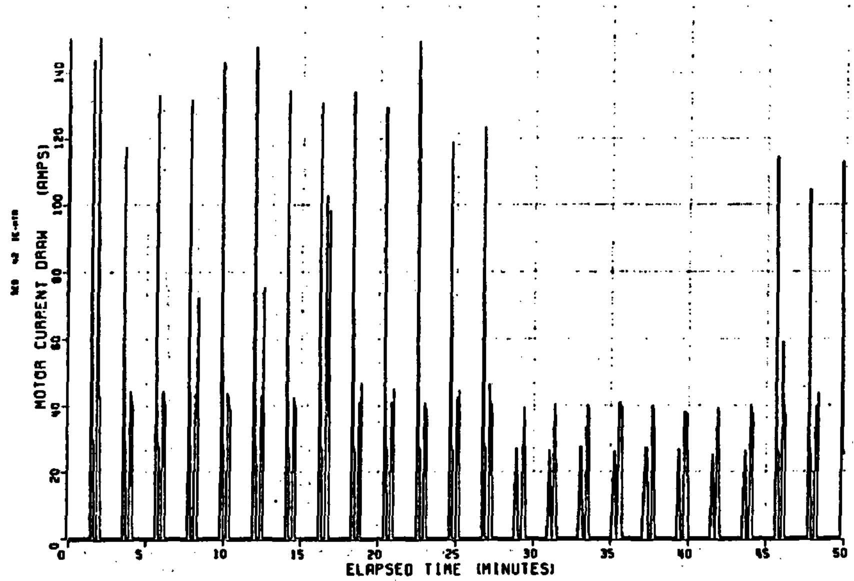


Figure 63. Ten-Inch Gate Valve Motor Current for Initial 24 Wet Cycles

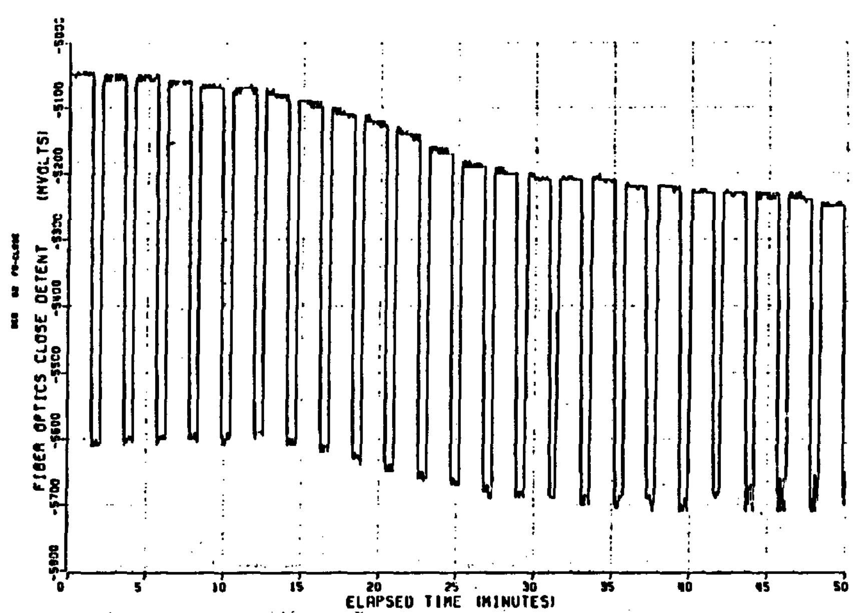


Figure 64. Ten-Inch Gate Valve Fiber Optic Close Position for Initial 24 Wet Cycles

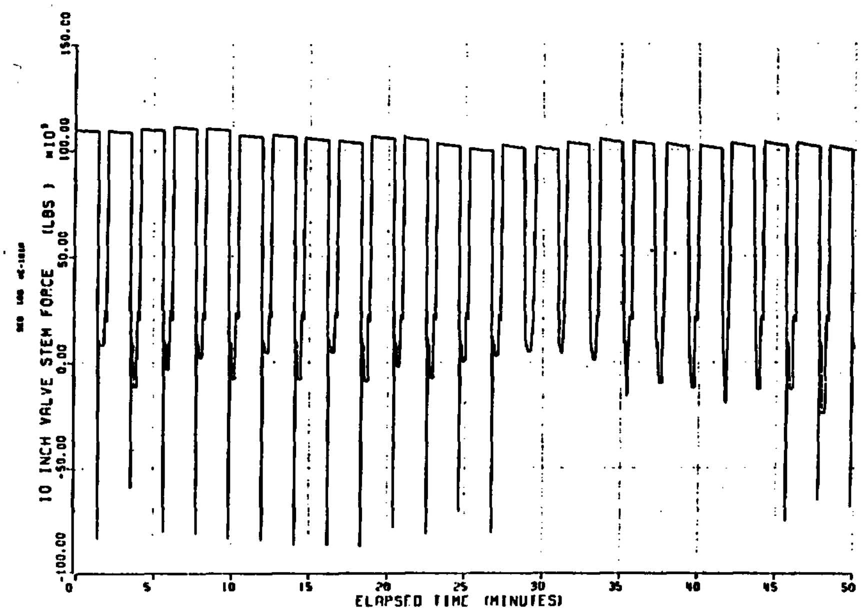


Figure 65. Ten-Inch Gate Valve Stem Force for Initial 24 Wet Cycles

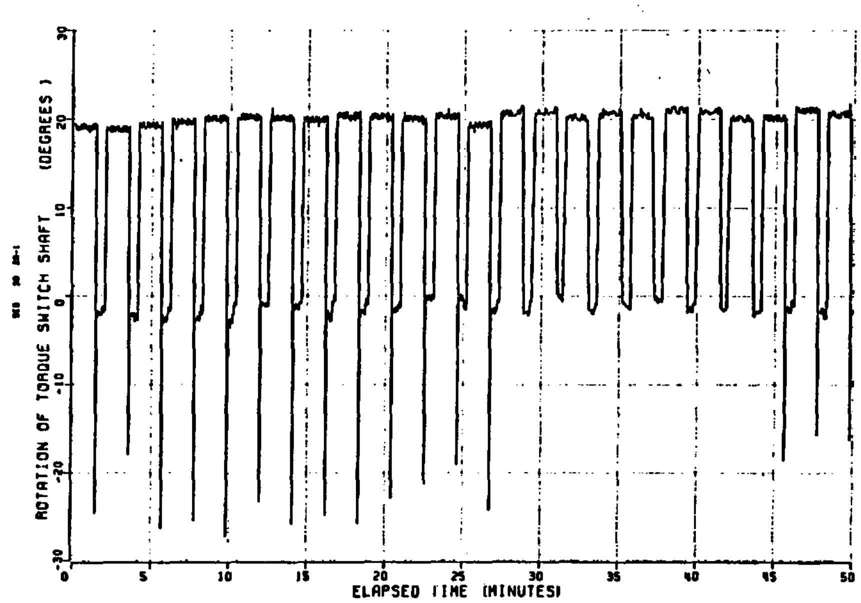


Figure 66. Ten-Inch Gate Valve Rotation of Torque Switch for Initial 24 Wet Cycles

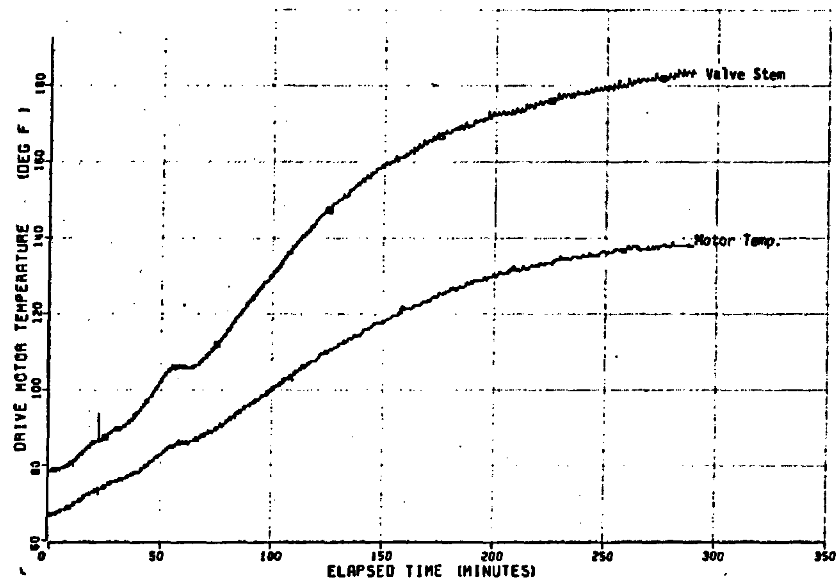


Figure 67. Ten-Inch Gate Valve -- Increasing Motor Temperature and Valve Stem Temperature During Wet Cycling

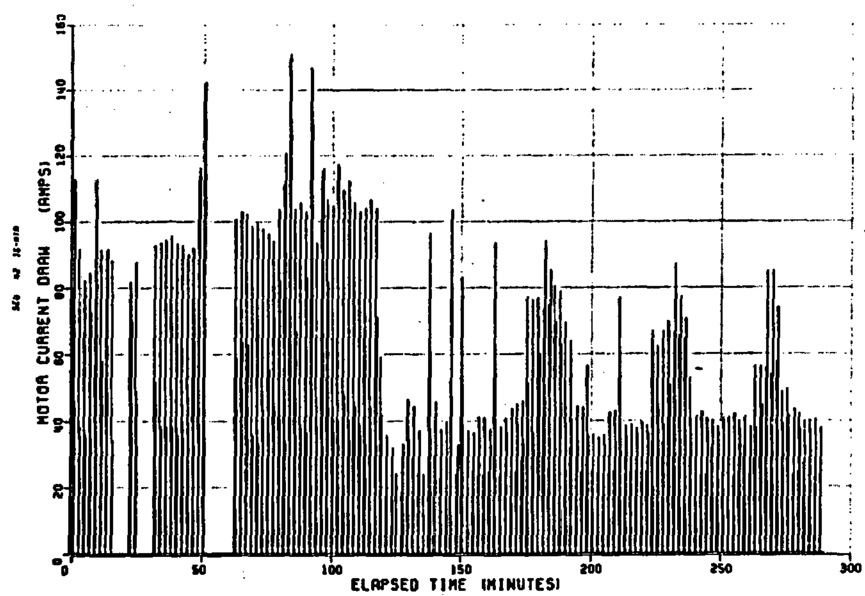


Figure 68. Ten-Inch Gate Valve Motor Current for 150 24 Wet Cycles

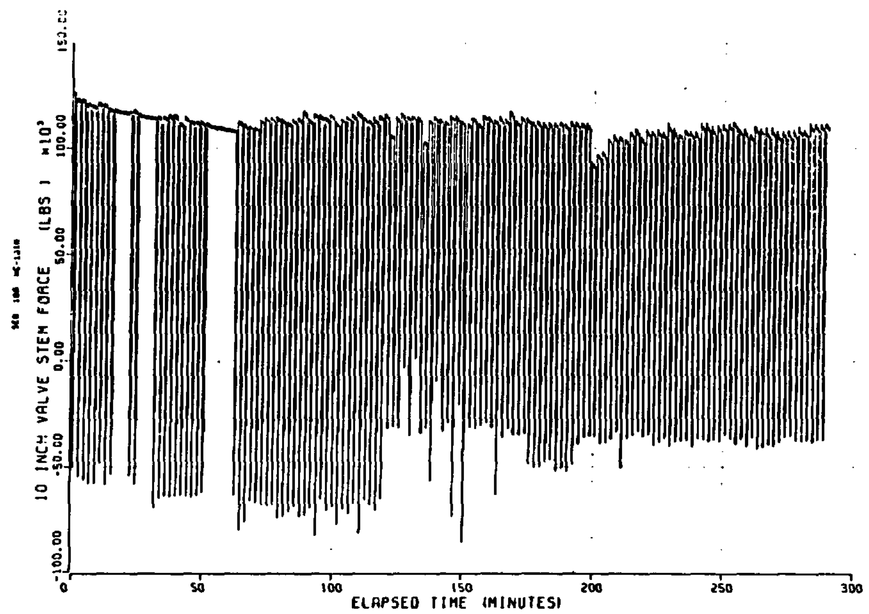


Figure 69. Ten-Inch Gate Valve Stem Force for 150 24 Wet Cycles

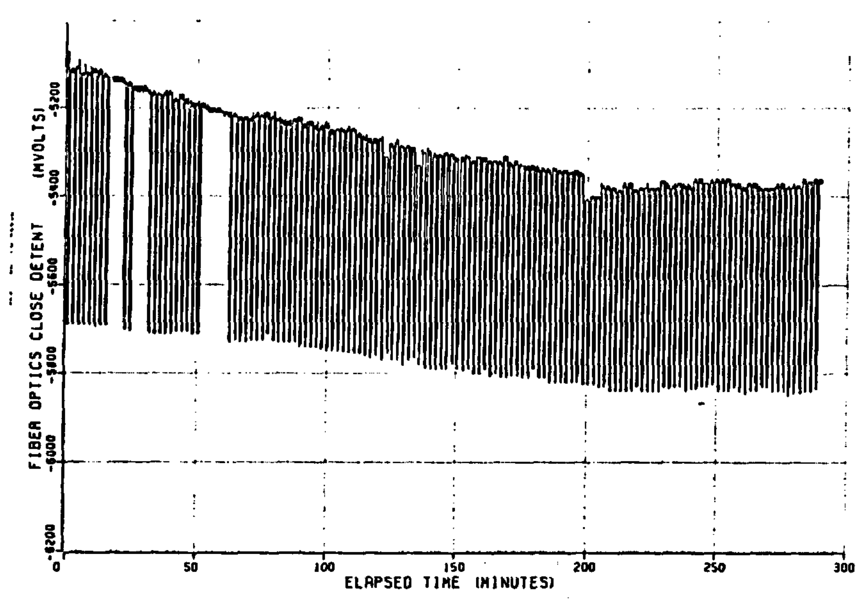


Figure 70. Ten-Inch Gate Valve Fiber Optic Close Position for 150 Wet Cycles

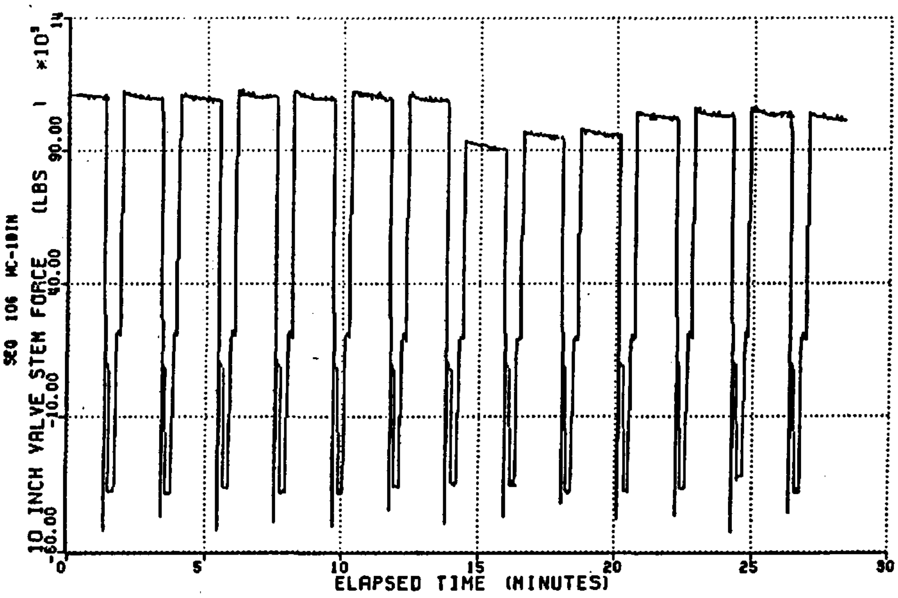


Figure 71. Ten-Inch Gate Valve
Stem Force During 13 of 150 Wet Cycles.

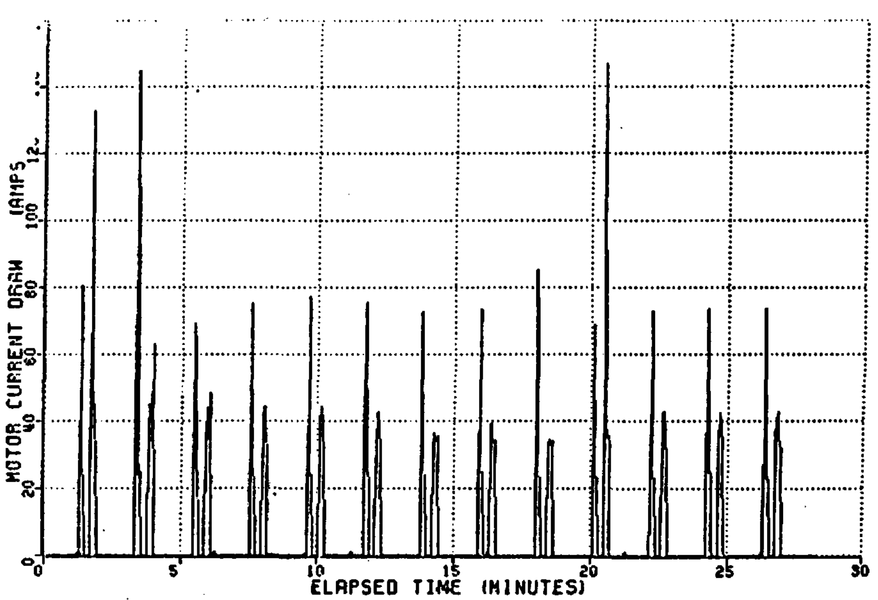


Figure 72. Ten-Inch Gate Valve
Motor Current During 13 of 150 Wet Cycles

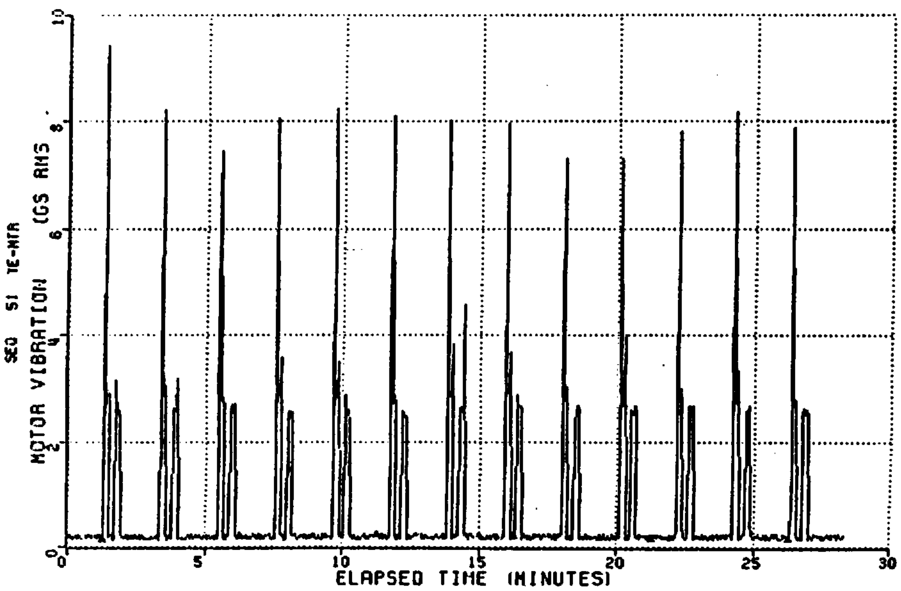


Figure 73. Ten-Inch Gate Valve Vibration During 13 of 150 Wet Cycles

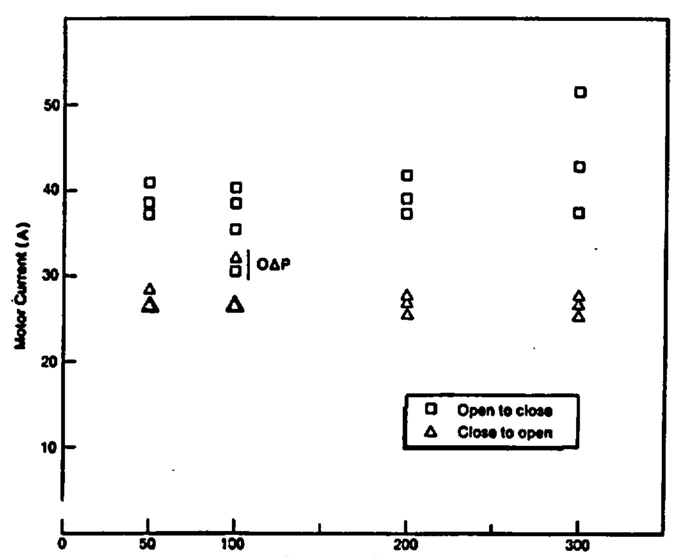


Figure 74. Ten-Inch Gate Valve Opening & Closing Motor Current Versus Packing Torque

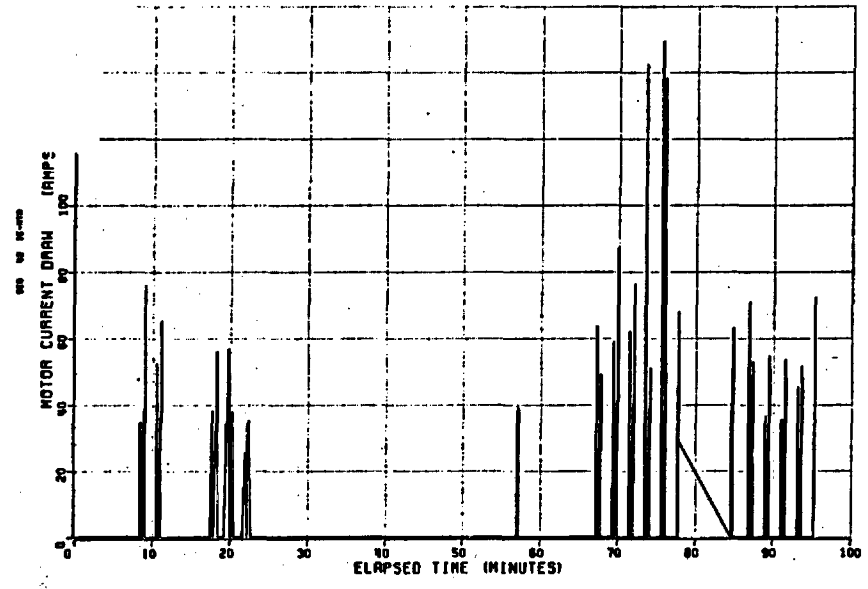


Figure 75. Ten-Inch Gate Valve Motor Current after Cycles at 400F

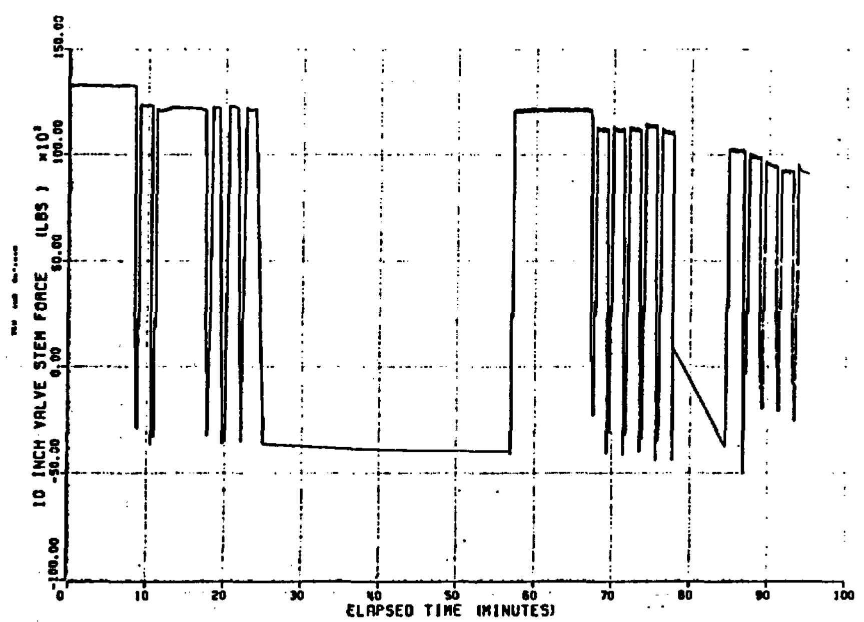


Figure 76. Ten-Inch Gate Valve Stem Force for Cycles at 400F

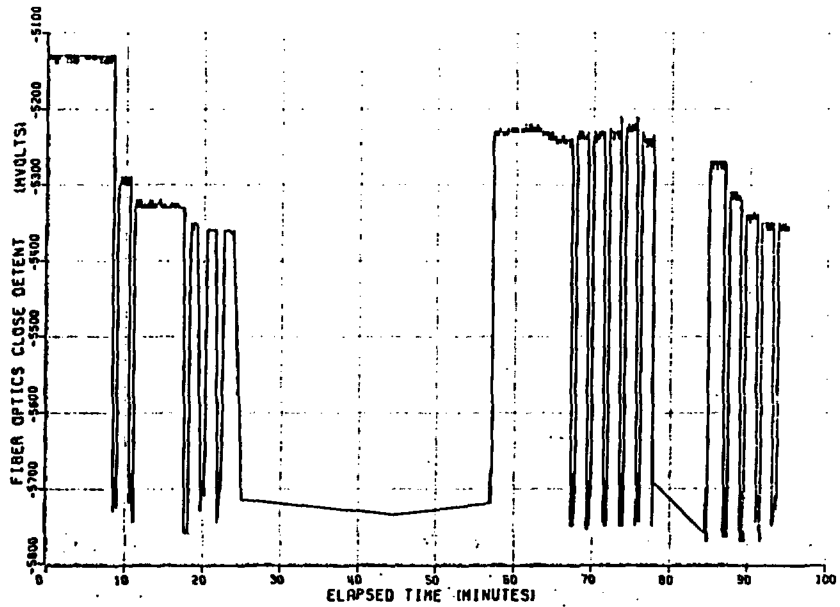


Figure 77. Ten-Inch Gate Valve
Fiber Optic Close Position for Cycles at 400F

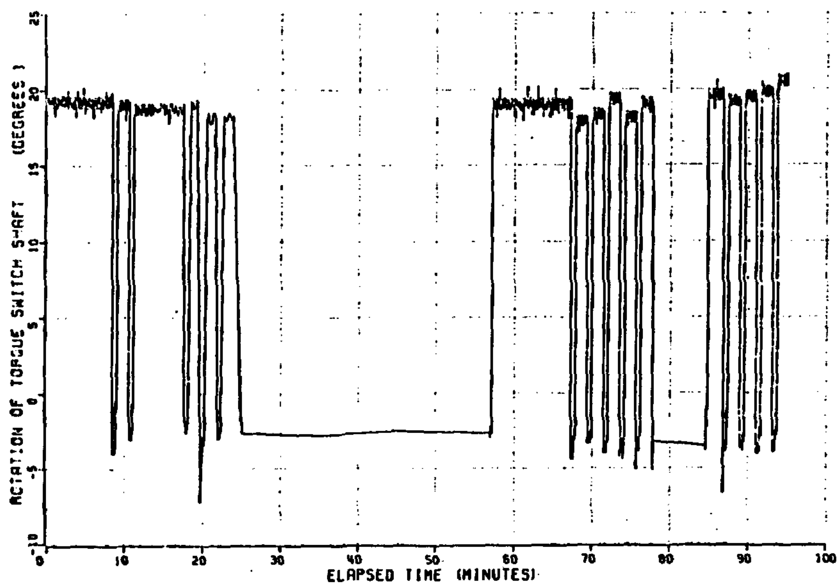


Figure 78. Ten-Inch Gate Valve
Rotation of Torque Switch for Cycles at 400F

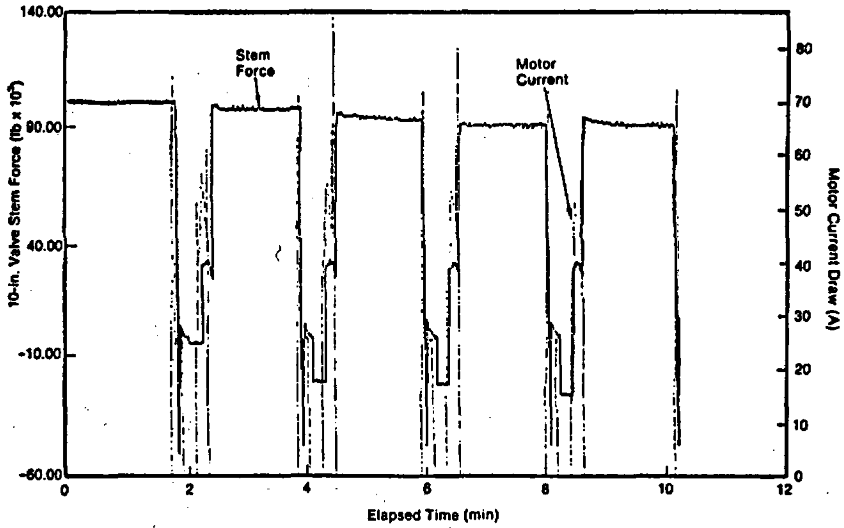


Figure 79. Ten-Inch Gate Valve
Stem Force at 400F and 300% Packing Torque

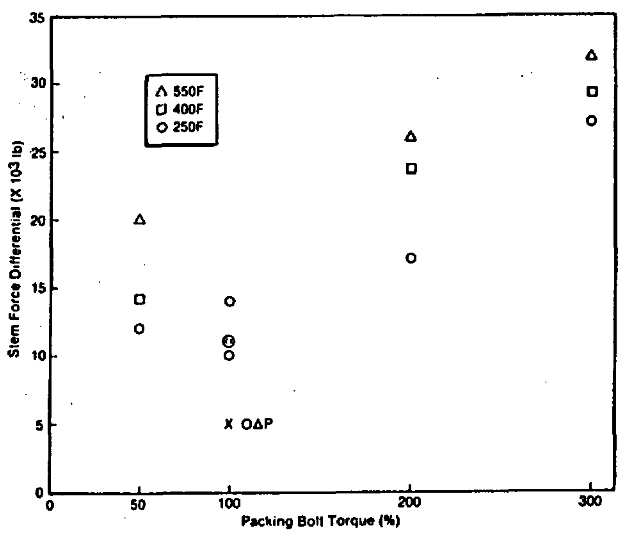


Figure 80. Ten-Inch Gate Valve
Closing Stem Force Versus Packing Torque

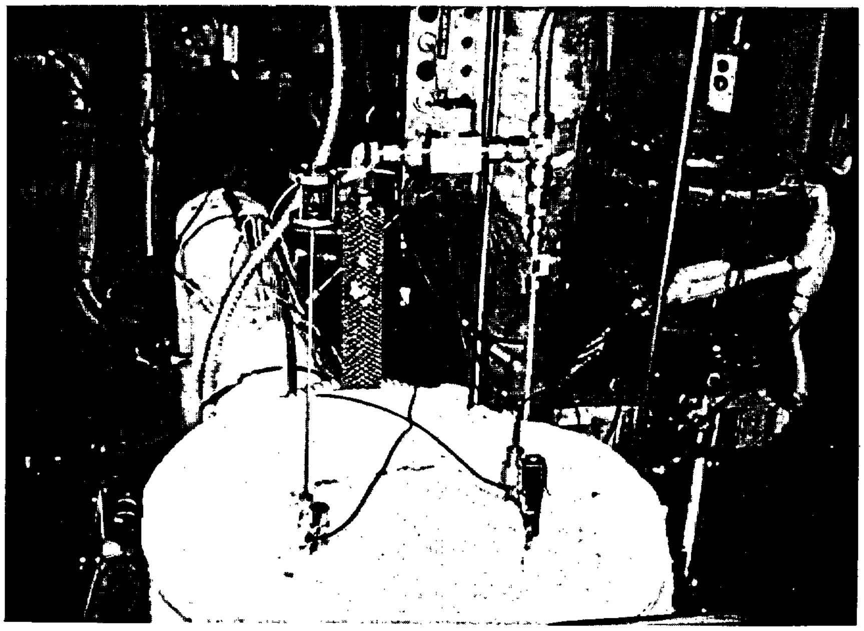


Figure 81. Acoustic Emission Sensors Installed on Bonnet of Check Valve

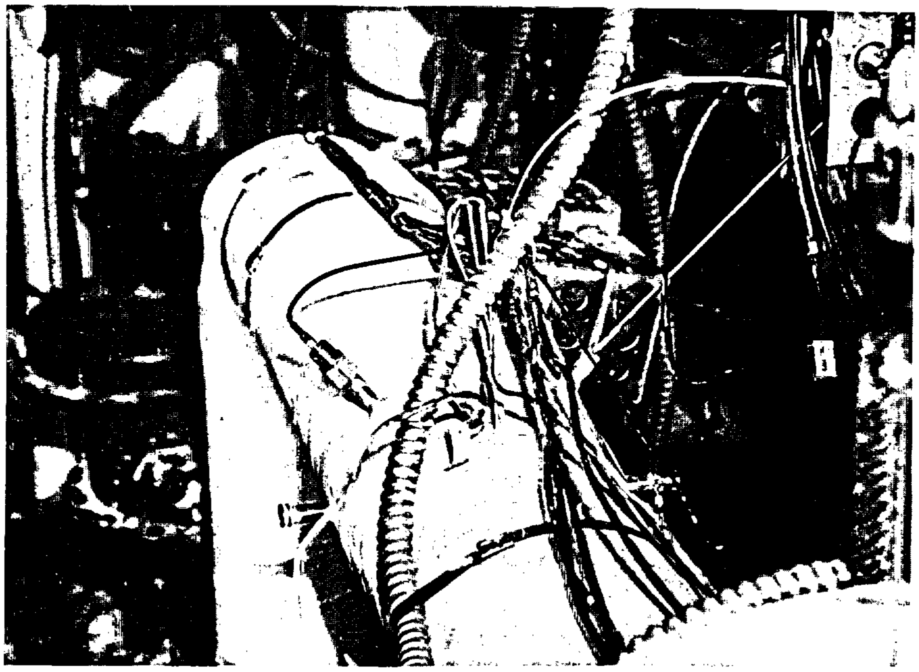


Figure 82. Acoustic Emission Sensors Installed Upstream on Pipe

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13. ABSTRACT (200 words or less)

The Light Water Reactor Valve Performance Testing Program was initiated by the NRC to evaluate leakage as an indication of valve condition, provide input to Section XI of the ASME Code, evaluate motor signature testing to measure valve operability, evaluate acoustic emission monitoring for condition and degradation and in-service inspection techniques. Six typical check and gate valves were purchased for testing at typical plant conditions (550 F at 2250 psig) for an assumed number of cycles for a 40-year plant lifetime. Tests revealed that there were variances between the test results and the present statement of the Code; however, the testing was not conclusive. The lifecycle tests showed that high tech acoustic emission can be utilized to trend small leaks, that specific motor signature measurement on gate valves can trend and indicate potential failure, and that in-service inspection techniques for check valves was shown to be both feasible and an excellent preventive maintenance indicator. Lifecycle testing performance here did not cause large valve leakage typical of some plant operation. Other testing is required to fully understand the implication of these results and the required program to fully implement them.

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Valve Performance Tests
Valve Leakage and Valve Condition
Acoustic Emission and Valve Degradation

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Check Valves	Valve Degradation
Gate Valves	Acoustic Emission

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