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ENDURANCE TESTS OF ROBOVALVES

WASH FIELD REPORT NO. 102

SEPTEMBER 1983

for security review copy

Prepared for:
**USAID Mission to the Republic of Ecuador
and the Office of Health
Bureau for Science and Technology
U.S. Agency for International Development
Order of Technical Direction No. 71**

The WASH Project is managed by Camp Dresser & McKee Incorporated. Principal Cooperating Institutions and subcontractors are: International Science and Technology Institute; Research Triangle Institute; University of North Carolina at Chapel Hill; Georgia Institute of Technology—Engineering Experiment Station.

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**WATER AND SANITATION
FOR HEALTH PROJECT**



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September 14, 1983

Mr. Victor W.R. Wehman, Jr., P.E., R.S.
AID WASH Project Manager
S&T/H/WS
USAID
Washington, D.C. 20523

Dear Mr. Wehman:

On behalf of the WASH Project I am pleased to provide you with ten copies of a report on Endurance Tests of Robovalves.

This is the final report by Yaron Sternberg and Robert Knight and is based on laboratory tests which they conducted at the University of Maryland in 1982 and 1983.

The work was undertaken by the WASH Project on November 19, 1981 by means of Order of Technical Direction No. 71, authorized by the USAID Office of Health in Washington.

If you have any questions or comments regarding the findings or recommendations contained in this report we will be happy to discuss them.

Sincerely,

Dennis B. Warner

Dennis B. Warner, Ph.D., P.E.
Director
WASH Project

DBW:PFH:pwr

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Prepared for the USAID Mission to the Republic of Ecuador and the
Office of Health, Bureau for Science and Technology,
U.S. Agency for International Development
Under Order of Technical Direction No. 71

Prepared by

Yaron M. Sternberg
and
Robert Knight

September 1983

KD 4588

Supply

ISM 984

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Chapter 1

INTRODUCTION

A "robovalve" is an automatically-closing plastic faucet/valve. The initial development and testing of robovalves was conducted in 1978 under an AID contract (AID/ta-c-1461). The objectives of the above project were to develop and test a low-cost, locally manufacturable, essentially leak-proof faucet for both public and private hydrants. Three different types of robovalves were developed (public hydrant or standpost, house or yard connection, and water container). The principle of operation of the robovalve is identical in all three types. The valve consists of two major components: a PVC casting which houses a valve seat and a float valve. The PVC float valve is a hollow PVC cone mounted on a length of PVC rod which travels in a guide, provided in the casing.

In 1978 eight valves were placed in a testing machine and tested for leakage and wear. After approximately 200,000 cycles with line pressure of 3 psi to 25 psi, the maximum wear was 0.003 inches. Additional tests were conducted with turbid water containing 1,200 ppm of clay and fine sand. After 350,000 cycles the tested valves did not leak. In view of the absence of leakage and minimum signs of wear, it was concluded that a PVC float valve and seat assembly (sharp edged or bevelled) functioned very satisfactorily.

Chapter 2

EXPERIMENTAL WORK

2.1 Background

In November 1981, Order of Technical Direction (OTD) No. 71 was issued (Appendix A) for testing 70 individual household type robovalves manufactured in Ecuador by IEPESA Plastic Manufacturing Company. Seven groups, each consisting of ten representative pre-checked (non-leaking) robovalves were to be tested around the clock under pressures of 2, 10, 20, 40, 60, 80, and 100 psi. Testing was to continue for a period of three months for the purpose of evaluating flaws in the design, material, and/or fabrication quality.

2.2 Initial Testing

The first shipment of robovalves manufactured by IEPESA in Quito was subjected to a static leak test under a pressure of 60 psi. Each valve was mounted on a simple device which contained a threaded pipe. The water was then turned on and the valve was operated a number of times to check the action of the float. The valve was then left in the closed position and leakage was monitored for a period of five minutes. Any valve that leaked 1 ml or more during that time period was rejected. Approximately 50 percent of the first batch of about 100 valves were rejected. Since these valves were apparently tested in Ecuador and judged to be "non-leaky," a number of the valves were cut open in an attempt to determine the cause of the apparent high failure rate. Upon dismantling, it was observed that a white paste was used as a lapping compound between the valve and the valve seat. This paste hardened with time and prevented proper seating of the valve. In addition, some of the valves contained a few thin strands of plastic ("plastic hair") resulting from the valve and valve-seat machining operations. Improper sealing may result when such hair is imbedded between the above two components.

The second shipment of valves (approximately 100) received from IEPESA was of better quality; only about 10 percent of this shipment failed the static leakage test described above. Upon examination of some of the valves that failed the second test it was noted that no lapping compound was used and that failure was mainly due to improper machining and/or presence of plastic hair imbedded between the float valve and the valve seat.

2.3 High Pressure Static Test

Prior to initiating the long-term endurance tests at the various prescribed pressures, a high pressure static test was conducted. In 1979, a number of robovalves were installed at a rural site in the Philippines where the static pressure was reportedly about 80 psi. The operation of the valves was monitored by Peace Corp volunteers who indicated that some of the valves malfunctioned due to failure of the float valve. Information received suggested that at high pressures the solvent cement used to glue the bottom of the float valve failed, resulting in buckling and ultimate failure of the float valve. Therefore, it was decided to submit ten valves to a high pressure

static test to determine the behavior of the solvent cement used in Ecuador. Ten valves were randomly selected from the valves that passed the leakage test and installed in a water manifold under a pressure of 80 psi. Approximately three or four times a day the valves were activated for a few minutes and leakage after closure was monitored. During a period of two weeks no leakage was detected and all the valves functioned properly at the termination of this test. Based on the above it was concluded that the solvent cement used was of good quality and failure due to buckling during the endurance test is unlikely.

2.4 Long Term Endurance Test Apparatus

In accordance with the specifications outlined in OTD 71, a testing apparatus was constructed and tested prior to the installation of the robovalves and initiation of the long term testing.

The test rig shown in Figure 1 (Appendix C)* consisted of an aluminum frame structure which housed seven banks of ten robovalves, a one-cubic-meter reservoir, and a two-stage, 3 H.P. centrifugal pump. Each bank of ten valves was supplied with water through a common distribution header and individually controlled by its own water pressure regulator. Each bank also had a water pressure gauge as shown in Figure 2.

The opening and closing of the valves for the tests were achieved through an arrangement of cams and pushrods, as shown in Figure 3. The camshafts were driven by two electric motors (1/3 H.P.) and a series of V-belts and pulleys. The recirculating water supply was provided by the two-stage pump.

2.5 Long Term Endurance Tests

Continuous testing started on January 2, 1983 and was terminated on March 25, 1983. In order to prevent damage to the pump, two shut-off pressure switches were incorporated into the pump control box. When the pressure in either the 60 or 20 psi lines dropped by more than 20 percent of their respective pressures, the pump was turned off. On three occasions the shut-off pressure switches were activated due to low volume of water in the reservoir caused by a break in the piping system. In each case testing was suspended for less than a day.

The testing equipment was monitored daily. Monitoring included inspection of the operation of the valves, pump, and pressure gauges. Once a week the pump, cam, and push rod springs were lubricated. Only one valve (#10 on the 60 psi line) had to be replaced. The valve failed because the push rod adjustment screw became loose and damaged the activating button of the valve. The valve was replaced with a spare one.

Approximately every seven to ten days a leak test was conducted. The testing procedure followed is outlined below:

* See Appendix C for all figures.

1. Stop the operation of the line (turn-off the motor which rotates the cam).
2. Activate each valve and note the operation of the activation mechanism.
3. Observe the behavior of the closed valve. If valve is not sealing properly, collect leakage for a period of two minutes. Measure and record leakage and repeat leakage measurement. Record the average leakage for the two tests.
4. Repeat the above for all the valves. Testing was suspended on March 25, 1983 after 341,000 cycles. The testing equipment functioned well, and only minor repairs and adjustments were required during the eight weeks of almost continuous operation.

2.6 Leakage Tests

Leakage test data are given in Appendix B. Prior to testing it was presumed that, if failure occurred, it should be more pronounced in the high pressure lines. Analysis of the data, however, does not indicate any relationships between failure and line pressure. In fact, there are inconsistencies in the data which are difficult to explain.

During the initial testing period random leakage was noted in a number of the valves. Some valves that leaked at one time functioned properly at subsequent testing and vice versa. After 6,000 cycles (Table 1) leakage was noted in 19 valves (see Table 1, Appendix B).^{*} Although most of the leakage was in small amounts, it was exhibited throughout the range of testing pressures. It is believed that the leakage noted was possibly due to either fine plastic hair or remnants of the lapping compound used in the original batch of robovalves produced in Ecuador.

After 28,000 cycles (Table 2) performance of the valves improved. Examples of such improvement are valves #6 (100 psi), #3 (40 psi) and #2 and #6 (2 psi) which were dry while leakage from the other valves was reduced. In total only 12 valves were leaking, seven in the 80 psi line.

Performance of the valves apparently improved with use. After 62,000 cycles (Table 3) only seven valves were leaking. No leakage was detected in the 2 and 10 psi lines. Some valves that previously did not leak exhibited leakage (valves #5 and #8--20 psi) whereas previously leaking valves exhibited good sealing characteristics (valves #2, 3 and 9--80 psi).

Little change in the leakage characteristics of the valves was noted after 129,000 cycles. Small continuous leakage was noted from valves #8 (100 psi), #5 (80 psi), #4 (20 psi). Maximum leakage after 98,000 cycles was from valve #9 (10 psi) (49 ml/2 min = 35 liters per day). However, the valve did not leak after 129,000 cycles and functioned well until the end of the testing

* Tables containing testing data are in Appendix B.

period. The noted leakage was likely caused by plastic hair or other small debris. Leakage from the non-sealing valves was in the range of 1-10 liters per day.

After 194,000 cycles (Table 6), significant leakage was noted in valves #1-4 (20 psi) while no leakage was detected in the 2 and 10 psi lines. A total of 10 valves were leaking. A similar pattern was detected after 220,000 cycles.

Serious leaks developed after 310,000 cycles (Table 8). Nineteen valves were leaking, some (#1, 4, 5--80 psi) quite significantly. The noted increase in leakage occurred primarily in the high pressure lines, i.e., 80 and 100 psi. Deterioration of the float valve and valve seat was suspected but could not be confirmed without dismantling the leakage valves. At the termination of the test (341,000 cycles) a total of 16 valves were leaking, six in the 80 psi line.

During the aforementioned leakage tests it was noted that, by manually rotating the activating button and thereby the float valve, a leaky valve on occasion stopped leaking or its leakage rate was reduced. The noted improved sealing characteristic was initially attributed to matching the presumed uneven wear of the float valve and valve seat. Since no operating valve was cut open during the tests, no information on the wear characteristics of the valve was available.

2.7 Post Endurance Test Data Analysis

Initially it was intended to compare the wear characteristics of the tested valves with untested ones. To obtain data for the valves under "no test conditions," a number of valves were cut open and various measurements were taken. It became apparent that the float valves were not uniform and no base line data could be obtained. For example, the location of the mating surface between the float valve and the valve seat varied by 0.25 in. for the ten untested valves. Likewise, the length of the float valve was variable. Therefore, it was decided that comparison of the pre- and post-testing conditions should be conducted on each individual valve as outlined below.

Four valves from each bank were selected for detailed examination. The long term leakage test data were used to select two leaking and two nonleaking specimens. Each valve was cut open and was carefully inspected with a magnifying lens. Subsequently, each float valve was inspected with a low power microscope specifically calibrated to measure wear. The original sloping surface of the cone was taken as the unworn surface, and the depth of the worn ring, i.e., depression, was measured. The cone was rotated so that the maximum and minimum wear was noted as well as the limits of the width of the ring. The surface condition of the ring, i.e., finish, was also noted as well as other features. Examples of a worn float valve and valve seats are shown in Figures 4-9. A summary of the wear data is given in Table 10. Analysis of the data did not indicate any discernable wear pattern. For example, it was expected that the magnitude of the depression in the valves subjected to high pressure would be more pronounced than that in the valves subjected to lower pressures. However, the data indicate that the maximum depression occurred at a pressure of 20 psi (0.010 in. at valve #3). A depression of 0.009 in. was noted at the 2 psi line (valve #3).

Likewise, the difference between the maximum and minimum depression cannot be correlated with leakage. For example, a maximum difference of 0.007 in. was measured for a non-leaky valve (#3, 2 psi line) while valves with a 0.001 difference exhibited leakage.

The float valves were mounted in a lathe to check their concentricity. Only two non-leaking valves exhibited poor concentricity. Thus, concentricity is not a contributor to the noted leakage.

The only measurement, albeit qualitative, that can be correlated with leakage is the finish of the ring. Valves with a smooth finish, in general, did not leak while those with a rough finish exhibited leakage of varying magnitudes.

Comparison of the wear data from this study with the results of the initial tests performed in 1978 indicates that the present valves experienced more severe wear. The maximum wear to the sharp-edged seat and valve assembly in the 1978 study was 0.003 in. after 350,000 cycles; the wear was even resulting in a thin uniform ring around the float valve and no leakage was noted.

It is believed that the reason for the severe wear noted in this test is due to the fact that the valves were constructed from ABS (Acrylonitrile Butadiene Styrene) and not from PVC. ABS plastic contains styrene which is a non-crystalline material which lacks the toughness and impact strength needed for the robovalve. Although ABS is manufactured at various degrees of hardness, the chemical composition used for the valves tested is unknown. It is likely that the ABS used was "softer" than the pvc used in the original valves, resulting in the significant wear noted.

The valve manufacturer, IEPESA, also produced ABS Roboscreens. Initial attempts to slot the screen resulted in uneven gummy slots which were attributed to the "softness" of the material. The addition of hardeners to subsequent screen production resulted in screen that had better slotting characteristics. It is not known whether hardeners were added to the resin used for the production of the robovalves.

2.8 Acceptability by Users

Another aspect of "testing" robovalves is related to user acceptability. In some instances around the world where the robovalve has been used or tested it has met with less than an enthusiastic reception among users because it requires continuous pressure on the valve to keep it open. If the water container is large this can be rather tedious and time consuming. In Tunisia in one instance it was obvious that a heavy object, probably a rock, had been used to hold the valve open and thus the button was worn away. In one Latin American country a local engineer said that the robovalve would probably not be popular with users because it would deprive them of the use of their hands while talking with fellow water gatherers at what is in many parts of the world a social occasion.

FOR COUNTRY WATER SUPPLY

Chapter 3

CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

Robovalves manufactured by IEPESA, Quito, Ecuador were subjected to long term endurance tests. The valves were apparently made from an ABS resin in contrast to previously tested valves made of PVC.

Up to approximately 200,000 cycles the performance of the valves was marginal; about 10 out of 70 valves were leaking. After about 340,000 cycles almost 20 of the valves were leaking. Inspection of the valves indicates that serious wear occurred and this wear is attributed to the fact the ABS resin used was apparently much softer than PVC. No correlation was evident between wear, leakage, and line pressure. The quality of the valves was generally good but care was not exercised in assembling the valves. Plastic hair not removed prevented the proper seating of a number of valves. The concentricity of the float valve/stem was good in almost all of the valves tested and did not affect the sealing characteristics of the valves.

3.2 Recommendations

1. Previously tested PVC valves had considerably less wear than the currently tested ABS valves. Future robovalves should not be manufactured from ABS unless the ABS resin has hardness and abrasion resistance characteristics similar to those of the PVC used for manufacturing Schedule 40 pipes.
2. Robovalves manufactured from ABS are suitable for field installation. However, before the present batch (approximately 400 valves) is installed, they should be subjected to field testing.
3. Field testing should include short-term intensive use and long-term moderate to low use. Intensive use tests can be conducted in migrant labor camps where a large number of users per robovalve can be expected. Careful monitoring of 25-50 robovalves for 2-3 months will provide the necessary data for comparing the behavior of the robovalves under field and laboratory conditions. Long term monitoring of robovalves in yard installations are essential for evaluating the behavior of the valve under various climatic conditions, i.e., subfreezing temperatures, direct sunlight, etc. The protocol for field tests (long term) should detail proper monitoring for the effect of dirt and grit in the water, climatic conditions, and other aspects that could affect manufacturing techniques and materials.
4. Monitoring should be planned and executed to insure that proper and timely data are collected and transmitted for analysis and evaluation.

5. It is recommended that along with testing the technical feasibility of the robovalve, its acceptability among users also be tested and other behavioral aspects of its use surveyed.
6. If future large scale production of robovalves is planned, they should be manufactured from PVC. Prior to executing a production run, a small sample of 25-50 robovalves should be subjected to intensive laboratory testing similar to the one reported herein.
7. Considerable thought was given to various design modifications of the robovalve. It is concluded that the present configuration of the outlet port is adequate and should not be modified for a garden hose connection. Likewise, a locking device on the activating button is not recommended.

If local country needs are such as to require a hose bib and a provision to lock open the valve, a separate and independent device would be recommended. Such an auxiliary clamp-on device could be designed, in cooperation with a manufacturer, at such time as its need is identified. Holding the basic design intact retains the concept and reason for an automatic shut-off valve.

APPENDIX A

WATER AND SANITATION FOR HEALTH (WASH) PROJECT
ORDER OF TECHNICAL DIRECTION (OTD) NO. 71

November 19, 1981

TO: Dr. Dennis Warner, Ph.D., P.E.
WASH Contract Project Director

FROM: Victor W.R. Wehman, Jr., P.E., R.S. *VWR*
S&T/HEA/CWSS
AID WASH Project Manager

SUBJECT: Provision of Technical Assistance Under WASH Project Scope of Work
for S&T/HEA and USAID/Quito

REFS: A) Wehman/Farr telcon 10/81
B) Wehman/Knight discussion 10/81

1. WASH contractor requested to provide technical assistance to S&T/HEA and USAID/Ecuador as described below in conjunction with OTD Number 50.
2. WASH contractor/subcontractor/sub-subcontractor and consultants authorized to expend up to 20 person days over a 5 month period to accomplish this technical assistance effort.
3. Contractor to coordinate with S&T/HEA (Wehman) and USAID/Quito (Farr) project officers and should provide copies of this OTD to them as well as to health engineering and desk officers for LAC Bureau.
4. Contractor authorized no, repeat no, domestic or international travel or per diem in connection with this OTD.
- 5.A. Contractor requested to time-stress test approximately 70 Ecuadorian made Robovalves (individual family) for a continuous day-in and day-out period of 3 months to determine design flaws, material flaws and fabrication quality control flaws.

Ten representative pre-checked Robovalves each will be subjected to continuous opening and closing with at least 5 second closed period and at least 5 second open period at each of the following line pressures: 2 PSIG, 10 PSIG, 20 PSIG, 40 PSIG, 60 PSIG, 80 PSIG and 100 PSIG.

B. Measurements on leakage, breakage, deformation, and failure will be documented on a weekly basis with appropriate data maintained on each Robovalve tested.

C. Contractor requested to investigate, design and prototype changes that become apparent in test for subsequent testing and later feedback to the manufacturer in Ecuador. Contractor should at least consider Robovalve prototype modifications leading to:

- (1) larger effective operating line pressures (1-110 PSIG)
- (2) possibility of designing button locking mechanism to hold Robovalve open for use in houses over sinks

(3) possibility of placing hose connection type nozzle on outlet of Robovalve for garden connections

(4) other possibilities as authorized by AID project manager

6. Contractor authorized to expend up to \$6,200 for testing equipment (pumps, guages, jig fixtures, measuring and stressing equipment, etc.).

7. Contractor report on progress of activity to be made orally in briefing by IWRDL personnel to WASH CIC and AID project manager each 10 person days of effort. Final report will be considered, but at this time is not mandatory unless requested by AID project manager.

8. Contractor authorized up to \$700 for miscellaneous expenses relating to coordination of information on findings made in this study with USAID/Quito and local manufacturer personnel in Ecuador.

9. Contractor should be contacted immediately and technical assistance initiated as soon as possible but before 10 December 81.

10. Appreciate your prompt attention to this matter. Good Luck.

VWW:ja

WATER AND SANITATION FOR HEALTH (WASH) PROJECT
ORDER OF TECHNICAL DIRECTION (OTD) NUMBER 71
Amendment No. 1
June 8, 1982

TO: Dennis Warner, Ph.D., P.E.
WASH Contract Project Director

FROM: Victor W.R. Wehman, Jr., P.E., R.S.
A.I.D. WASH Project Manager
A.I.D./S&T/H/WS

VWR

Stamp: JUN 10 1982

SUBJECT: Provision of Technical Assistance Under WASH Project Scope of Work
for S&T/H and U.S. A.I.D./Quito

1. Paragraph 2 of subject OTD #71 (Ref A) is cancelled. New paragraph 2 of OTD #71 is to read as follows:

"WASH contractor/subcontractor/consultants authorized to expend up to 90 (ninety) person days of effort over a 10 (ten) month period to accomplish this technical assistance effort."

2. Paragraph 5.B. of subject OTD #71 (Ref A) is cancelled. New paragraph 5.B of OTD #71 is to read as follows:

"Measurements on leakage, breakage, deformation, and failure will be documented on a biweekly basis with appropriate data maintained on each Robovalve tested."

3. Nothing follows.

DEC 01 1982

WATER AND SANITATION FOR HEALTH (WASH) PROJECT
ORDER OF TECHNICAL DIRECTION (OTD) NUMBER 71
AMENDMENT No. 2
November 29, 1982

TO: Dennis Warner, Ph.D., P.E.
WASH Contract Project Director

FROM: Victor W.R. Wehman, Jr., P.E., R.S. *VWW*
AID WASH Project Manager
AID/S&T/H/WS

SUBJECT: Provision of Technical Assistance Under WASH Project Scope of
Work for S&T/H and USAID/Quito

REFERENCE: A) OTD #71, dated 19 Nov 1981

1. Paragraph 2 of subject OTD #71 (Ref. A) is cancelled. New para. 2 of OTD #71 is to now read as follows:

"2. WASH contractor/subcontractor/consultants authorized to expend up to 110 person days of effort over a 16 month period to accomplish this technical assistance effort."

2. Para. 6 of subject OTD #71 (Ref. A) is cancelled. New para. 6 of OTD #71 is now to read as follows:

"6. Contractor authorized to expend up to \$8,400 for testing equipment (pumps, gauges, jig fixtures, measuring and stressing equipment, etc.)."

3. Nothing follows.

WATER AND SANITATION FOR HEALTH (WASH) PROJECT
ORDER OF TECHNICAL DIRECTION (OTD) NUMBER 71
AMENDMENT NUMBER 3
April 12, 1983

TO: Dr. Dennis Warner, P.E.
WASH Contract Project Director

FROM: Victor W.R. Wehman, Jr., P.E., R.S. *JWW*
AID WASH Project Manager
AID/ST/H/WS

SUBJECT: Provision of Technical Assistance Under WASH Project Scope of
Work for S&T/H and USAID/Quito

REFERENCE: A) OTD #71, dated 19 Nov 1981

1. Paragraph 2 of subject OTD #71 (Ref A) is cancelled. New para. 2 of OTD #71 is to now read as follows:

"2. WASH contractor/subcontractor/consultants authorized to expend up to 140 person days of effort over a 20 month period to accomplish this technical assistance effort."

2. Nothing follows.

CHW/ddc

JUL 11 1983

WATER AND SANITATION FOR HEALTH (WASH) PROJECT
ORDER OF TECHNICAL DIRECTION (OTD) NUMBER 71
AMENDMENT NO. 4
10 July 1983

TO: Dr. Dennis Warner, Ph.D., P.E.
WASH Contract Project Director

FROM: Mr. Victor W.R. Wehman Jr., P.E., R.S. *VW*
AID WASH Project Manager
AID/S&T/H/WS

SUBJECT: Provision of Technical Assistance Under WASH Project
Scope of Work for S&T/H and USAID/Quito

REFERENCES: A) OTD # 71, dated 19 Nov 1981

1. Para 2 of subject OTD # 71 (Ref A) is cancelled. New para 2 to subject OTD # 71 (Ref A) is now to read as follows:

"2. WASH contractor/subcontractor/consultants authorized to expend up to 140 person days of effort over a 22 month period to accomplish this technical assistance effort."

2. Nothing follows.

APPENDIX B
Robovalve Testing Data

Table 1
Leakage of Valves in ml/2 min (1/4/83 - 6000 cycles)

Pressure (psi)	Valve No.										No. of Leaking Valves
	1	2	3	4	5	6	7	8	9	10	
100	0	0	0	0	0	1	0	2	0	0	2
80	1	6	93	0	45	0	0	13	0	0	5
60	0	0	0	0	0	0	0	0	2	0	1
40	0	0	1	0	0	95	0	1	0	0	3
20	19	0	0	13	0	0	1	0	0	0	3
10	0	0	0	0	1	0	0	0	1	0	2
2	1	1	0	0	0	1	0	16	0	0	3
											<u>Total:19</u>

Table 2
Leakage of Valves in ml/2 min (1/12/83 - 28,000 cycles)

100	0	0	0	0	0	0	0	1	0	0	1
80	2	4	87	0	32	1	0	11	3	0	7
60	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	88	0	0	0	0	1
20	18	0	0	2	0	0	0	0	0	0	2
10	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	10	0	0	1
											<u>Total:12</u>

Table 3
Leakage of Valves in ml/2 min (1/21/83 - 62,000 cycles)

100	0	0	0	0	12	0	0	0	0	0	1
80	16	0	0	0	6	0	0	14	0	0	3
60	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	36	4	0	0	8	0	0	3
10	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
											<u>Total: 7</u>

Table 4
Leakage of Valves in ml/2 min (1/28/83 - 98,000 cycles)

100	0	0	0	0	11	0	0	10	0	0	2
80	13	0	0	0	5	0	0	8	0	0	3
60	7	0	0	4	0	0	0	0	0	1	3
40	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	18	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	49	0	1
2	0	0	0	0	0	0	0	0	0	0	0
											<u>Total:10</u>

Table 5
Leakage of Valves in ml/2 min (2/4/83 - 129,000 cycles)

Pressure (psi)	Valve No.										No. of Leaking Valves
	1	2	3	4	5	6	7	8	9	10	
100	0	0	0	0	0	0	0	6	0	0	1
80	19	0	0	0	10	0	0	10	0	0	3
60	9	0	0	3	0	0	0	0	0	2	3
40	0	0	0	0	0	0	0	0	0	0	0
20	5	0	0	12	0	0	0	6	0	0	3
10	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
Total:											10

Table 6
Leakage of Valves in ml/2 min (2/21/83 - 194,000 cycles)

100	0	0	0	0	8	0	18	12	0	0	3
80	9	0	0	0	0	0	0	1.5	0	0	2
60	0	0	0	0	0	0	0	0	0	18	1
40	0	0	0	0	0	0	0	0	0	0	0
20	84	6	26	21	0	0	0	0	0	0	4
10	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
Total:											10

Table 7
Leakage of Valves in ml/2 min (2/25/83 - 220,000 cycles)

100	0	0	0	0	2	0	14	16	0	0	3
80	9.5	0	0	0	0	0	0	6	0	0	2
60	0	0	0	0	0	0	0	0	0	12	1
40	0	0	0	0	0	0	0	0	0	0	0
20	0.5	10	50	17	0	0	0	2	0	0	5
10	18	0	0	0	0	0	0	0	0	5	2
2	0	0	0	0	0	0	0	0	0	0	0
Total:											13

Table 8
Leakage of Valves in ml/2 min (3/14/83 - 310,000 cycles)

100	0	15	0	16	3	9	0	0	0	0	4
80	48	0	0	52	64	16	0	8	0	0	5
60	12	0	0	0	0	0	0	0	0	0	1
40	0	0	0	34	24	0	3	12	0	0	4
20	4	14	15	0	0	0	0	0	0	0	3
10	x	0	0	13	45	0	0	0	0	0	2
2	0	0	0	0	0	0	0	0	0	0	0
Total:											19

Note: X-valve jammed open

Table 9
Leakage of Valves in ml/2 min (3/25/83 - 341,000 cycles)

Pressure (psi)	Valve No.										No. of Leaking Valves
	1	2	3	4	5	6	7	8	9	10	
100	0	0	0	80	0	0	0	0	0	0	1
80	26	0	0	39	60	30	0	64	9	0	6
60	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	15	5	0	0	59	29	0	4
20	0	10	0	0	0	0	0	2.5	21	0	3
10	x	0	0	0	27	0	27	28	0	0	3
2	0	0	0	0	0	0	0	0	0	0	0
Total:											17

Note: X - Valve Jammed Open

Table 10
Float Valve Wear Data

Pressure psi	Value No.	Depression, 1/1000 in		Width of Ring*, in.		Ring condition (finish)	Concentricity Valve Stem/Cone	Leakage
		max	min	max	min			
2	3	9	2	.105	.04	SR	G	-
	7	2	1	.078	.062	S	G	-
	4	3	2	.110	.04	SR	G	-
	9	7	3	.098	.053	S	G	-
10	2	7	5	.106	.09	S	G	-
	7	4	3	.109	.058	R	G	+
	5	6	3	.114	.044	SR	G	+
	9	8	5	.120	.064	S	P	-
20	2	4	3	.106	.106	SR	G	+
	6	5	5	.075	.060	S	G	-
	7	3	2	.060	.060	S	G	-
	3	10	5	.120	.053	VR	G	+
40	4	4	3	.085	.056	S	G	+
	5	6	3	.09	.047	SR	G	+
	9	8	2	.10	.04	S	G	-
	2	5	3	.078	.045	S	G	-
60	7	4	3	.099	.068	SR	G	-
	1	4	4	.070	.049	SR	G	+
	10	4	3	.074	.045	S	G	+
	4	6	3	.095	.048	R	G	-
80	1	5	2	.108	.053	SR	G	+
	5	3	1	.102	.047	R	G	+
	9	7	2	.10	.034	S	F	-
	3	3	2	.072	.032	S	C	-

Table 10 (Cont'd)

Pressure psi	Value No.	Depression, 1/1000 in		Width of Ring, in.		Ring condition (finish)	Concentricity Valve Stem/Cone	Leakage
		max	min	max	min			
100	4	7	4	.112	.055	R	G	+
	8	7	5	.128	.058	SR	G	-
	7	5	4	.114	.048	SR	G	-
	2	8	6	.107	.065	S	G	+

Notes: S - smooth G - good + - leaky
 SR - slightly rough P - poor - - nonleaky
 R - rough F - fair
 VR - very rough C - cracked

* Groove worn by contact with valve seat

APPENDIX C
Photographs of Robovalve Testing

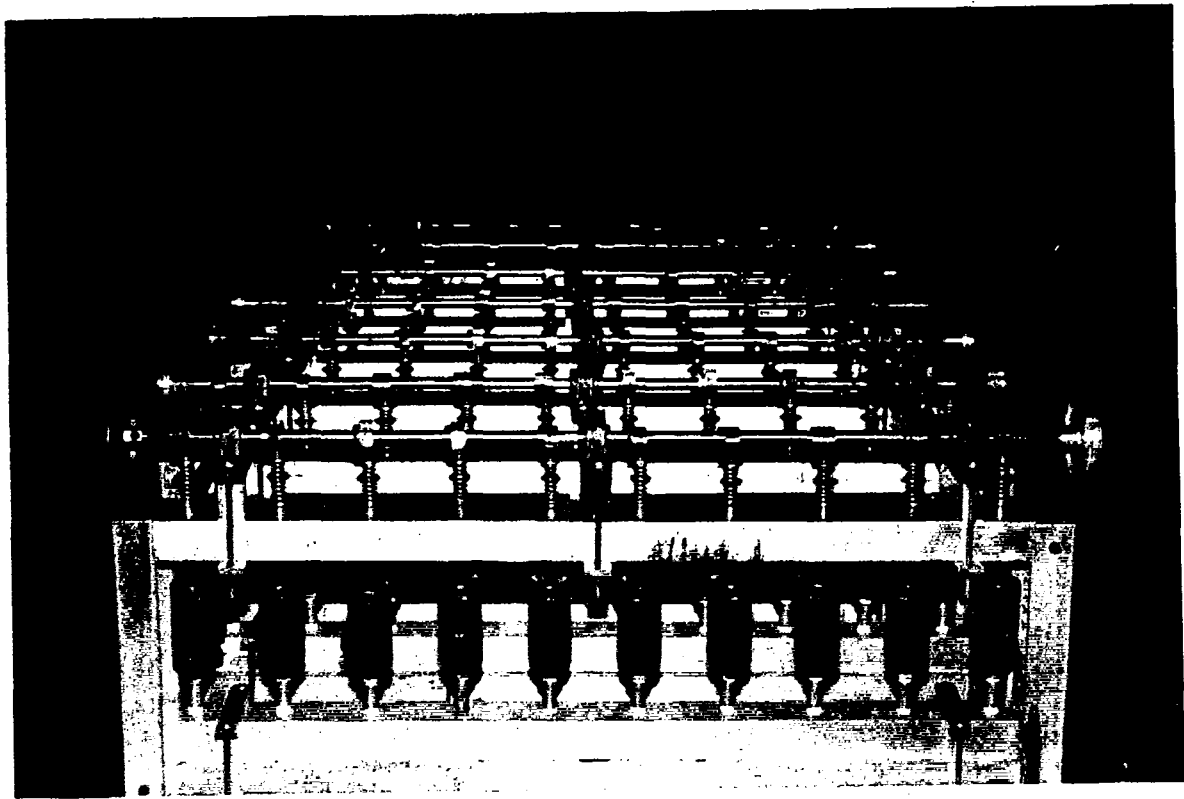
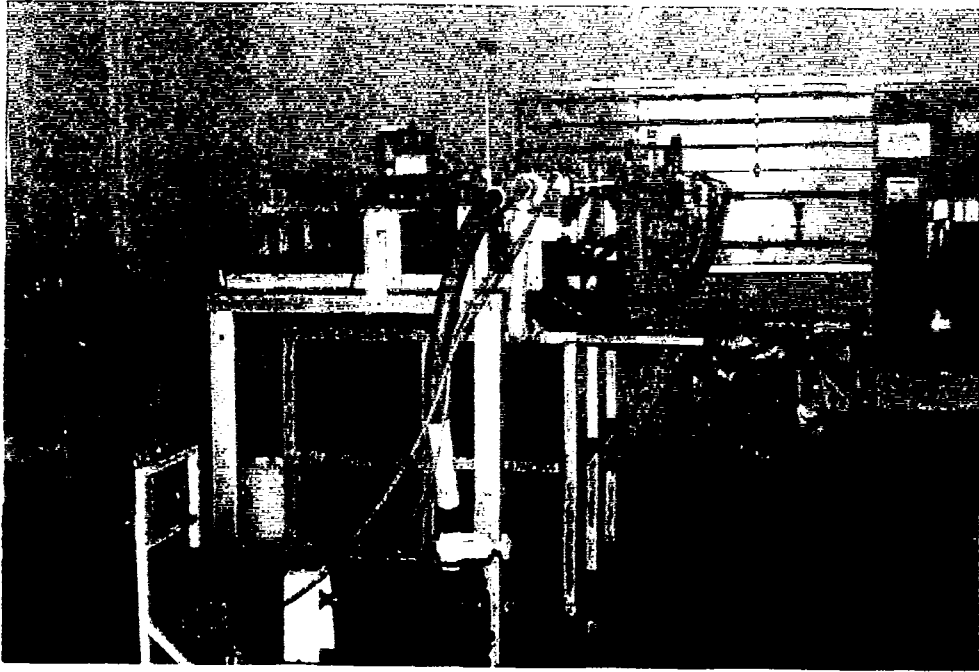


Figure 1 Endurance Test Rig

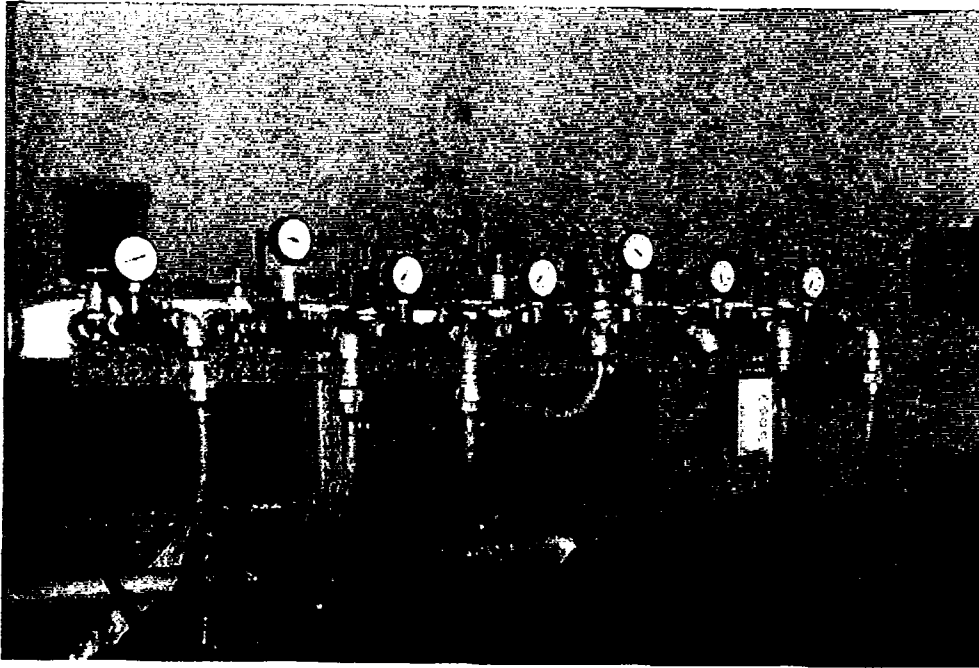


Figure 2 Pressure Gauges Included in Test Rig

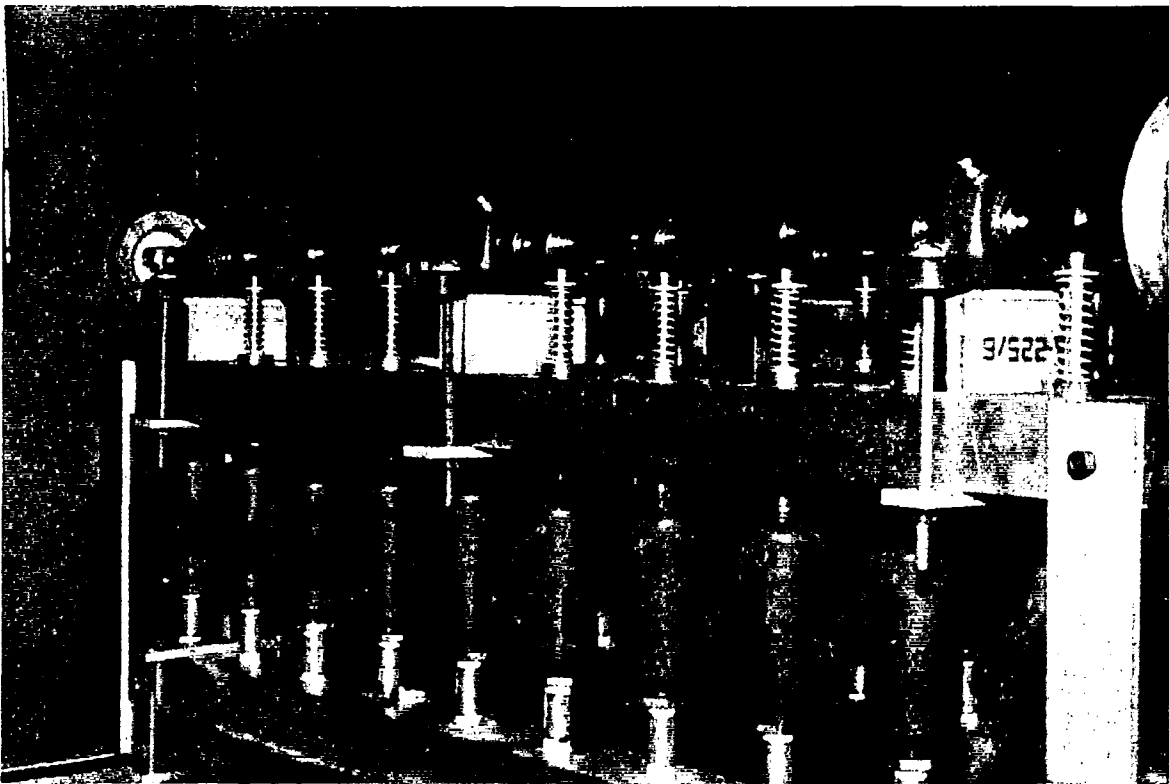


Figure 3 Camshafts and Pushrods Arrangement

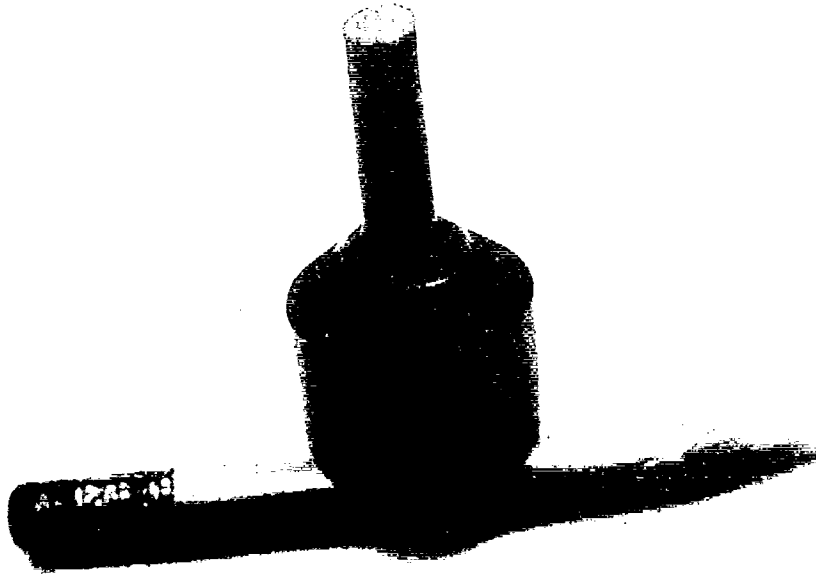


Figure 4 Severely Worn Float Valve (#3, 10 psi)

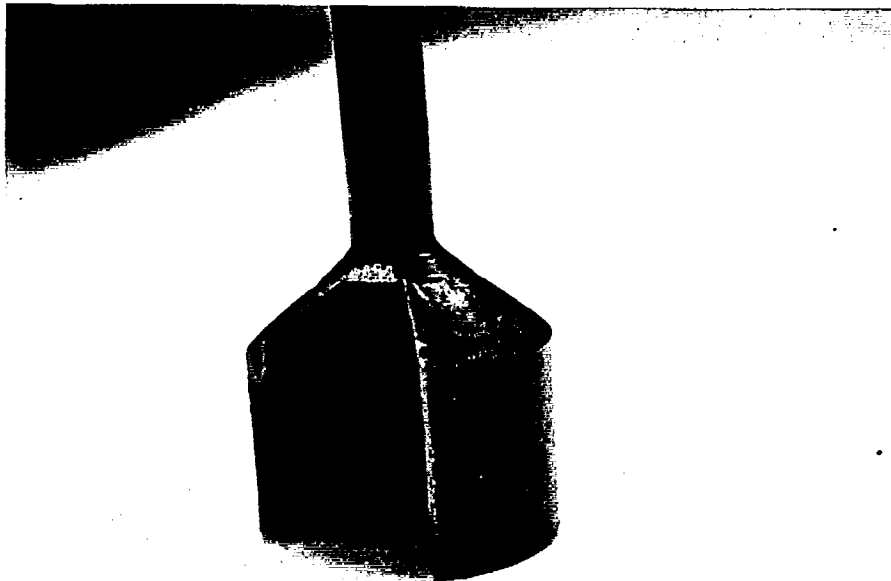


Figure 5 Cut-away of a Worn Float Valve (#3, 20 psi)



Figure 6 Float Valve and Seat Assembly-Note Wear on Valve and Deformed Seat (#7, 10 psi)

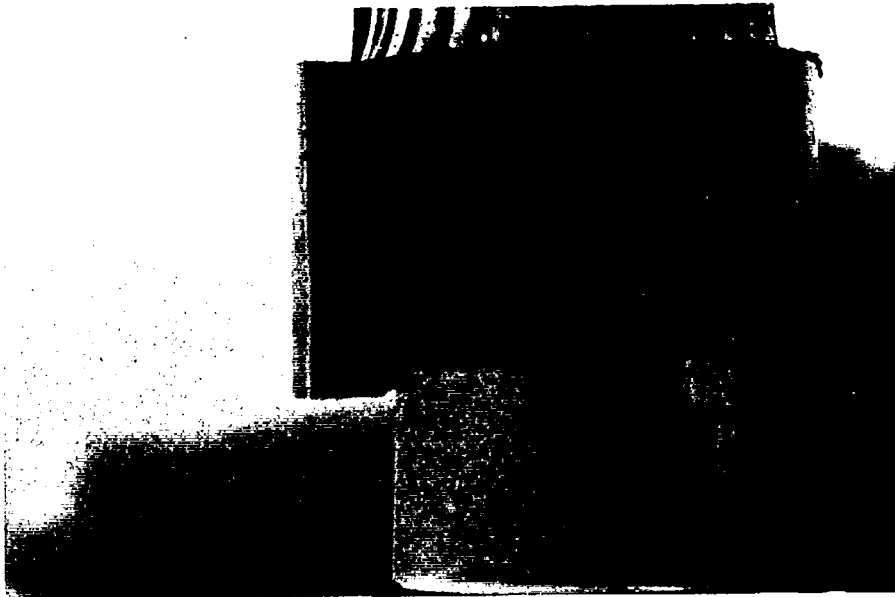


Figure 7 Wear of Float Valve and Seat Assembly (#3, 80 psi)

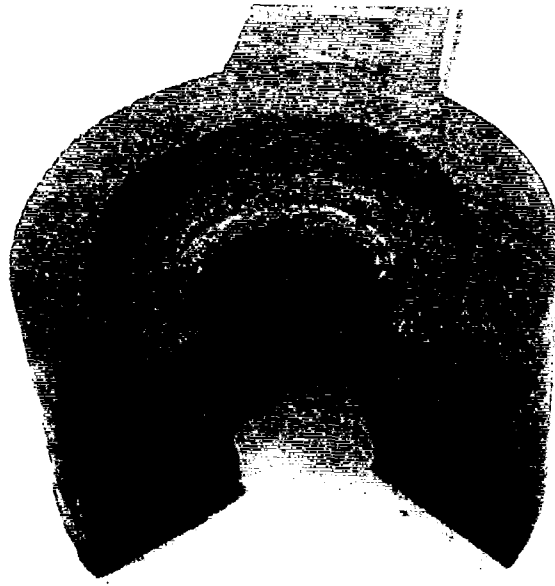


Figure 8 Deformed Valve Seat (#3, 80 psi)

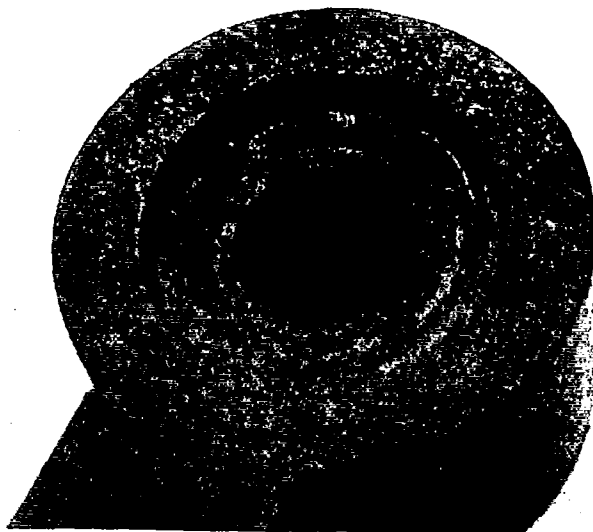


Figure 9 Irregular Wear Pattern of a Valve Seat (#3, 2 psi)