Computer Controlled Long-Term Cyclic Fatigue Testing of Pressure Vessels

Charles B. Brenn
Andrew M. Clark

Harbor Branch Foundation, Inc.
R.R. 1, Box 196
Ft. Pierce, FL 33450

ABSTRACT

Described is a computer-controlled hydrostatic test facility capable of high pressure, cyclic fatigue testing. Harbor Branch Foundation located in Ft. Pierce, Florida, has recently completed construction of their Deep Ocean Simulation Facility for the study of hydrodynamically loaded vessels. The facility is equipped with four pressure test chambers with capabilities to 10,000 fsw. The chambers are interfaced with micro-processors and signal conditioning instrumentation, enabling programmable pressure cycling and data acquisition for strain, temperature, volumetric displacement or other parameters of interest. Included is sufficient information in the form of hydraulic and electronic schematics to serve as a guide for the development of an automated, cyclic pressure test system. The test facility, in combination with Harbor Branch Foundation's mainframe computer and expertise in ocean engineering provides a powerful facility for the design and testing of pressure vessels, available to the oceanographic community.

INTRODUCTION

Since the beginning of modern oceanography, with the voyages of H.M.S. CHALLENGER, scientists have continued to observe and sample the oceans depths, to the limits of technology. Recognized as a leader in submersible technology, Harbor Branch Foundation (HBF) currently operates two, four-manned deep-diving submersibles (JOHNSON-SEA-LINK I and II) which have certified operational depths of 2,640 fsw. The JOHNSON-SEA-LINK employs two independent pressure hulls, a two-man pilot/observer sphere constructed of acrylic plastic and a welded aluminum diver lock-out compartment equipped with viewports. The sphere provides its occupants with a near panoramic view of hydrospace and is maintained at one atmosphere (1).

In an effort to remain at the leading edge of oceanographic research, the Ocean Engineering Division at HBF, in conjunction with Stachiw Associates, is currently engaged in the preliminary design stages for the development of a third submersible. The JOHNSON-SEA-LINK III design will incorporate an acrylic plastic pressure hull with a design operational depth of 8,000 fsw (2). In order to validate the sphere design for this unprecidented application of acrylic plastic, extensive long-term cyclic pressure testing of scale model spheres is required, with capabilities to monitor and record critical parameters such as temperature, duration of hydrostatic loading and stress magnitude.

DISCUSSION

Given the broad scope of the test requirements for the JOHNSON-SEA-LINK III project and the need to monitor the process closely, HBF has constructed a Deep Ocean Simulation Facility (DOSF). The facility is comprised of four pressure test chambers, two of which are computer-controlled to pressurize and vent automatically, enabling long-term, unattended cyclic pressure testing. In addition to automated chamber control functions, remote analog inputs from strain gage, temperature and pressure sensors are monitored and recorded at programmed intervals, stored on disk and printed out in hard copy form. The two remaining test chambers are operated manually, independent of their computer-controlled counterparts.

The facility is physically separated into two sections. The control room is a 165 square feet air-conditioned laboratory containing the hydraulic control console, all electronic, data acquisition and computer equipment (Figure 1), as well as a pneumatic work station (Figure 2). The chamber containment pit is installed adjacent to the control room in an outside, covered work bay (Figure 3). High pressure hydraulic lines and ducted instrumentation cables connect the console and data acquisition electronics through bulkhead penetrators in the control room wall.

PRESSURE CHAMBERS

The four pressure test chambers operated by HBF are listed in Table 1.

Chamber A is an ASME code certified pressure vessel (Figure 4). The shell and closure forgings are fabricated from SA-105 steel and the head from SA-516 GR. 70 steel. The shell has four 3/4 inch nozzles. The four radial, threaded tubing connections are for general service, two of which are used for pressurizing the chamber and adapting to a pressure relief valve. The remaining two radial connections are typically not used but are available for additional sensors or hydraulic ports as needed. The head has a single 3/4 inch threaded tubing connector which is used as a chamber fill and drain port. The chamber closure plug contains an intermediate 6 inch plug and bolted retaining ring which can be configured to serve a variety of electrical or hydraulic pressure boundary penetration requirements. The closure plug also has two 3/4 inch threaded tubing connections available for use as instrumentation and/or hydraulic ports.

Chamber B is fabricated from SCH. 160, Type A234, 10 inch pipe (Figure 4). The bolted closure for Chamber B is comprised of two components, a 2,500 PSI class weld neck, ring-joint flange mated with a blind flange, each forged from type A105, Grade II carbon steel. The closure is secured with twelve, 2 1/2 inch diameter bolts. A spiral wound gasket is used to effect the pressure seal. The shell has one 3/4 inch pipe coupling installed in the end cap, used for filling and draining the chamber. A second 3/4 inch coupling is installed on the radius of the shell for pressurizing the chamber. The blind flange has two 3/4 inch threaded tubing connections for a pressure relief valve and a vent valve.

Chamber C, similar in construction to Chamber B, is fabricated from 12 inch SCH (Figure 4). 80 pipe and a 600 psi class weld neck flange. The closure is constructed with a pipe cap welded to a ring flange. The closure is secured with twenty 1 1/4 inch diameter bolts.

Double o-rings on the face of the weld neck flange constitute the seal. The nozzle schedule for Chamber C provides for a 3/4 inch IPS fill and drain port in the end cap and two 3/4 inch IPS ports on the radius of the shell are used for pressurizing the chamber and providing a pressure relief valve. A removable 2 inch diameter acrylic plastic viewport is located on the radius of the chamber. This port is also used for a variety of electrical/instrumentation penetration requirements. A single 3/4 inch IPS fitting on the closure serves as a vent valve port.

Chamber D is a comparatively small, portable, general purpose vessel used primarily for testing electrical penetrators, transducers and pressure switches (Figure 2). The vessel is machined from 6 inch SCH. 120, 316L stainless steel pipe. The closure is a 2 1/2 inch thick acrylic plastic viewport, reinforced with a stainless steel wedge ring. The viewport has a single radial o-ring seal and is secured in the vessel with a bayonet type retaining ring. Two 7/16-20 UNF tubing connectors at the lower radius of the chamber serve as hydraulic ports. A 3/4-16 UNF tubing connector port located at the center of the bottom plate is used for electrical penetrations. The viewport may be replaced with machined metal plugs, as needed, to meet special test requirements.

Chambers A and B are currently dedicated to the JOHNSON-SEA-LINK III model test which is anticipated to continue until late 1986, at which time the test chambers will be available for other purposes. Currently, Chambers C and D are routinely available for general purpose testing, to support the operating submersibles needs and other project interests.

CHAMBER CONTAINMENT PIT

The pressure chamber containment pit is located directly outside of the control room (Figure 5). Chambers A, B and C reside in a 12' L x 5' W x 4' D precast concrete bunker which is set approximately 4 feet in the ground. The pit is constructed of steel reinforced concrete with 6 inch thick walls and has a drain hole which is

TABLE ONE
PRESSURE VESSEL CAPABILITY

	CHAMBER			
	A	B	C	D
Max. I.D. of Vessel (inches)	24	8.5	11.75	5.5
Inside Length Sealed (inches)	60	79	64	5.5
Operating Pressure (psi)	4500	4500	1400	3000
Pressure Medium	Water	Water	Water	Water
Elect. Penetrators	Yes	Possible	Yes	Yes
Closure Type	Breech	Bolted Flange	Bolted Flange	Bayonet
Seal type	O-ring	Compression Gasket	O-ring	O-ring

plumbed out to a nearby canal to dispose of discharged water. A 5 1/2 ft. insulated, concrete block wall encompasses the open pit area and is covered with four insulated aluminum panels. In combination with the insulating construction, an air-conditioning unit is installed in the block wall to provide nominal cooling for temperature sensitive test procedures. An elevated work platform surrounds the pit area on three sides to permit easy access to the pressure vessels. An overhead, electric, chain hoist, with a capacity of 2 1/2 tons, is positioned on a steel I-beam and is free to travel along the center line of the pit to remove and engage each of the pressure vessel closures. The entire work area surrounding the containment pit is under-roof with open sides and is easily accessible by truck or crane.

SYSTEM HYDRAULICS

Chamber A and Chamber B, with their respective fluid control components, each comprise a parallel leg of a complete hydraulic circuit that is pressurized by a central, air driven hydrostatic pump (Figure 6). Chamber C and its associated components constitute a similar but independent hydraulic circuit pressurized by a second air driven pump (Figure 6). This arrangement permits the use of Chamber C (or D) for general purpose testing while Chamber A and/or Chamber B is engaged in long-term, automatic cyclic tests.

Three-way solenoid valves (L1-L6) provide the fundamental control parameters, enabling manual or computer controlled pressure testing. All hydraulic functions may be directed from the control console by engaging switches (S1-S6) to select the desired valve operation (Figure 7). Solenoid valves associated with Chambers A and B (L1, L3-L5) may also be addressed with binary input signals from the computer work station for automated test procedures.

The pumps develop high output pressure by applying the principal of differential areas. The pump has a large area piston, air-driven at low pressures. The air piston drives a small area liquid piston that in turn pumps liquid at high pressure. The liquid output pressure is determined by the piston ratio and the inlet air pressure. An air control unit (F-R-L) on each pump, filters out moisture, regulates inlet pressure and lubricates the pump air supply. Regulation of the inlet air supply permits infinitely adjustable output pressures throughout the pumps pressure range. Only 100 psi air pressure is required to obtain a maximum output pressure of 10,000 psi.

The inlet water supply to each pump and pressure chamber is filtered to inhibit particulate contamination of the high pressure valve seats. A 100 micron sediment filter is installed on the main water line to the control room and chamber containment pit. An additional 10 micron filter element is used at the inlet water line to each pump. Past experience has proven this preventative maintenance item to be invaluable, as an oversight in this regard, resulted in premature failure of several valves during the early stages of the facilities' development.

Due to the inherent nature of the piston pumps, pulsatile flow (water hammer) is a serious consideration with regard to the more sensitive components of the hydraulic circuits. Pressure snubbers are incorporated in association with all pressure sensing devices such as analog gages and pressure transducers to protect gage movements and transducer diaphrams.

Each pressure chamber is equipped with an adjustable pressure relief valve attached directly to the chamber wall. In addition to a solenoid actuated vent valve for each chamber at the control console, a manual vent valve for purging entrained air, is located at the top of each vessels' closure.

The normally closed (vent) port of each charge/vent solenoid valve is equipped with a variable flow valve which can be adjusted to achieve desired discharge flow rates during depressurization.

SYSTEM ELECTRONICS

All of the solenoid valves, switches, relays, power distribution terminals and pressure transducers are located in the hydraulic control console (Figure 8). Cable harnesses connect the console to the chain hoist, data acquisition instrumentation and binary input module. A 115 VAC buss distributes power to the chain hoist, solenoid valves, solid state relays and an internal 12 VDC power supply (Figure 7).

Switches S1-S6 are used to select desired hydraulic functions manually. In their normally open position, relays K1-K6 energize the "OFF STATE" (OFF/CHARGE) indicators through normally closed contacts. When a selected switch is closed, the relay coil is energized and the contact opens, extinguishing the "OFF STATE" indicator, while power is applied to the "ON STATE" (ON/VENT) indicator. Concurrently, the 12 VDC signal is applied to the input of the associated solid state relay which energizes the coil of the solenoid valve. The solid state relay is a hot-line switching device that utilizes an optically isolated triac driver to control the A.C. load with a low level D.C. signal.

When operating in the computer-controlled mode, a 12 VDC signal from the binary input module emulates the manual switch function to energize the valve solenoid at programmed intervals.

Transient suppression diodes are used to prevent voltage spikes originating at the relay coils and switch contacts from disrupting the binary input signals or triggering the solid state relays.

INSTRUMENTATION

The critical test parameters of interest in the JOHNSON-SEA-LINK III project are pressure, temperature and magnitude of strain. The system is presently dedicated to these specific variables, however, capabilities to monitor other parameters of interest for future projects, are inherent to the overall system design.

Three pressure transducers, located in the control console, are used to monitor pressure levels at the pump output, Chamber A and Chamber B. The chamber transducers send information to the data acquisition system for feedback control and recording purposes (Figure 9).

Each of the 15 inch model spheres is instrumented with five, two-element 90° "Tee" stacked rosette strain gages for recording hoop and meridional strain concentrations.

A total of 22 channels of strain and temperature information is provided to the data acquisition system with a twenty-four channel strain gage conditioner and amplifier system. In conjunction with the strain gages, each 15 inch model is equipped with a resistance-temperature-detector (RTD). The temperature sensors are constructed much like wide-temperature-range strain gages. Standard strain gage instrumentation is ideal for use with these RTD's. Digital displays in the strain gage instrument rack are also used to monitor temperature data.

The 15 inch models are also provided with water intrusion alarms. In the event excessive moisture should collect on the interior of a model, a normally open, waterproof switch is closed by an expandable cartridge which in turn triggers a visual indicator in the control room.

DATA ACQUISITION AND CONTROL SYSTEM

The system, in general, consists of a personal computer with dual disk drives and a color graphics monitor. The computer terminal is interfaced with a multi-function data acquisition and control work station and a printer capable of high quality text and graphics. All devices essential to data storage and retrieval are powered by an uninterruptable power supply (UPS) so data is not lost in the event of a power outage (Figure 9).

The software for system automation and data collection is programmed in integer Basic language (Figure 10). The flow chart is used to illustrate the software, which contains approximately 800 lines of code and is not within the scope of this text. The program for the JOHNSON-SEA-LINK III project is structured to charge and vent Chambers A and B in a cyclic, alternating fashion, with specific pressurized and relaxation periods. The menu driven program contains subroutines that accept user supplied input values to select variable pressurization and de-pressurization rates for each chamber. Threshold values are set for pressure and elapsed time and are used to detect a sudden pressure drop, as would be the case if one of the model spheres were to implode. A "low pressure" output routine disables the chamber in question and a "crash" message is reported on the printer, indicating date and time of the event.

Pressure, temperature and strain data is sampled and recorded during each cycle at preset intervals. Pressure is recorded once per minute during transition periods and once every twenty minutes during steady state periods. Strain and temperature is recorded at the beginning and end of each steady-state period. The transition period constitutes the charge and vent rate (500 psi/min) and the steady-state periods are four hours each. All recorded information is printed to disk and the printer simultaneously.

The data acquisition and control device contains 32 analog input channels, 4 analog outputs and 16 binary input/output ports. Remote input capabilities include thermocouples, RTD's, strain gages and a wide range of instruments. The device is also equipped with expansion slots for additional I/O modules and has the ability to handle over 500 channels.

CONCLUSION

The creation of the DOSF has proven to be a facility vital to ocean engineering research. The results of the JOHNSON-SEA-LINK III test program will provide both information as to the feasibility of an all acrylic hull with such an unprecidented depth capability, and also serve to make a significant contribution to the literature and this technology, by determining the limits of acrylic as an oceanographic material. As opportunities become available, the test facility will support and expedite the development of other innovative, pressure sensitive designs and materials for subsea applications.

ACKNOWLEDGMENTS

The authors wish to acknowledge with appreciation the contribution of Quentin Voyles of Harbor Branch Foundation for developing the computer software so vital to the success of this project. This paper is Harbor Branch Foundation Contribution Number 501.

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FIGURE 1. DOSF CONTROL ROOM

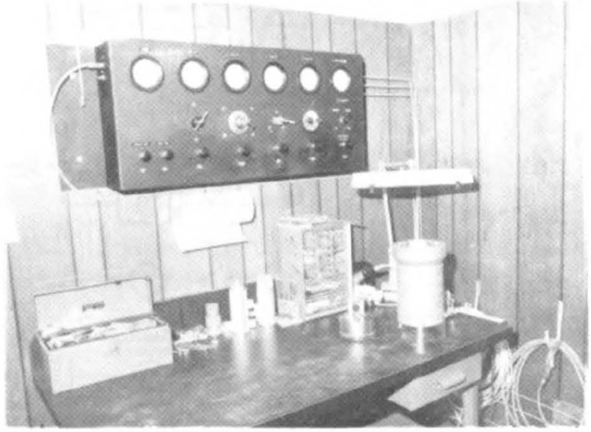

FIGURE 2. PNEUMATIC WORK STATION (CHAMBER D)

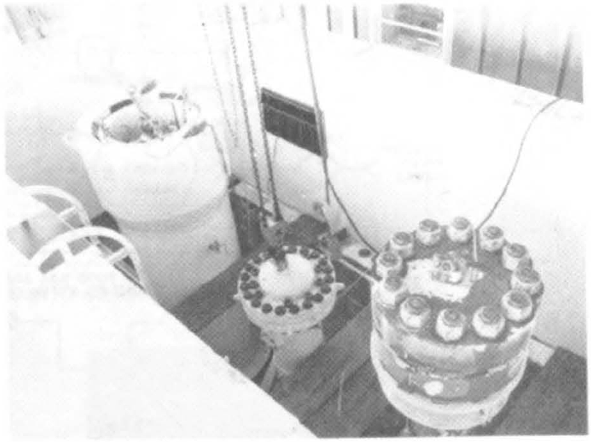

FIGURE 4. CHAMBERS A, C AND B

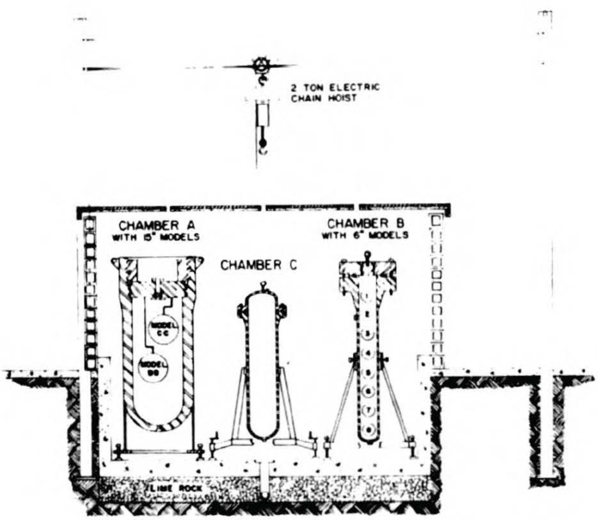

FIGURE 3. SECTION THRU CHAMBER CONTAINMENT PIT

FIGURE 5. CHAMBER CONTAINMENT PIT

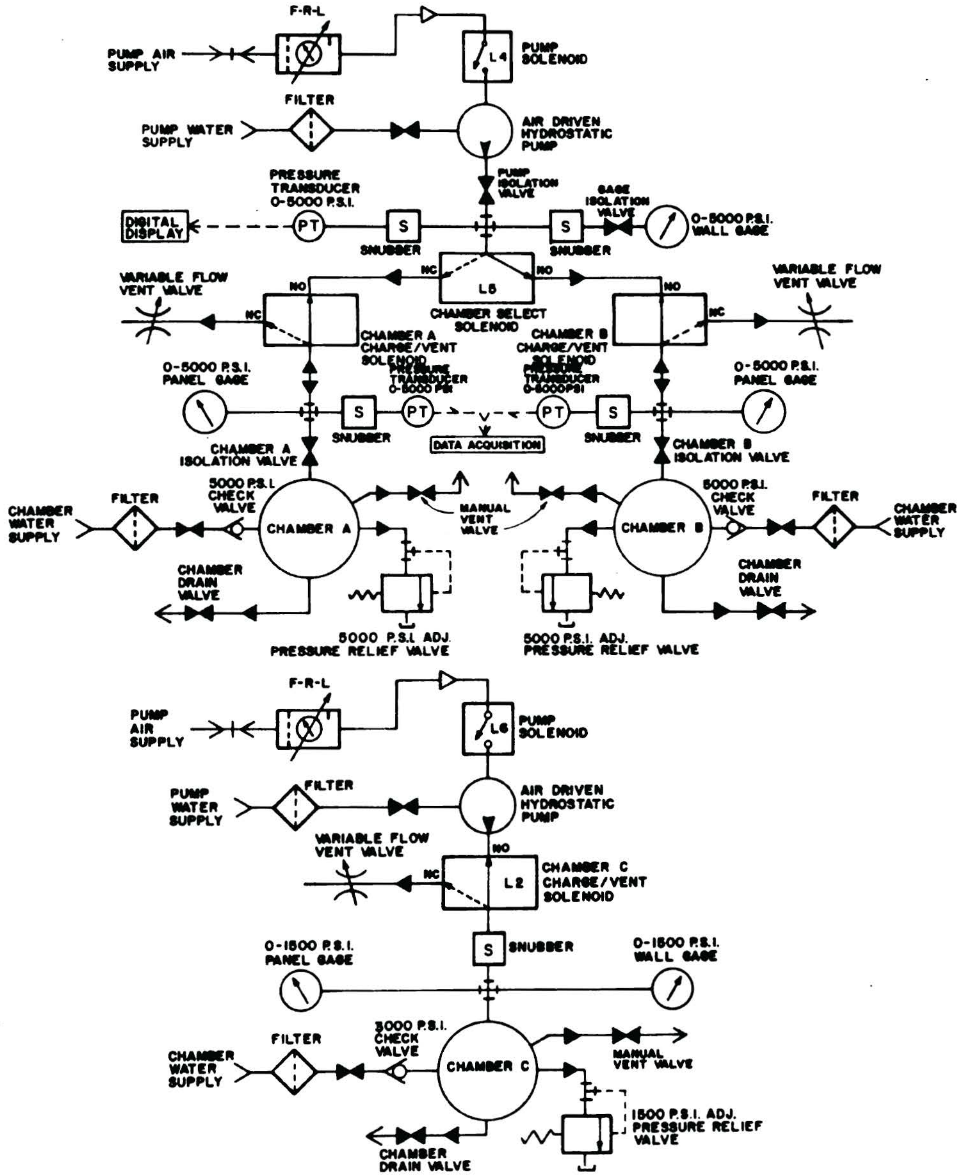

FIGURE 6. SYSTEM HYDRAULIC SCHEMATIC

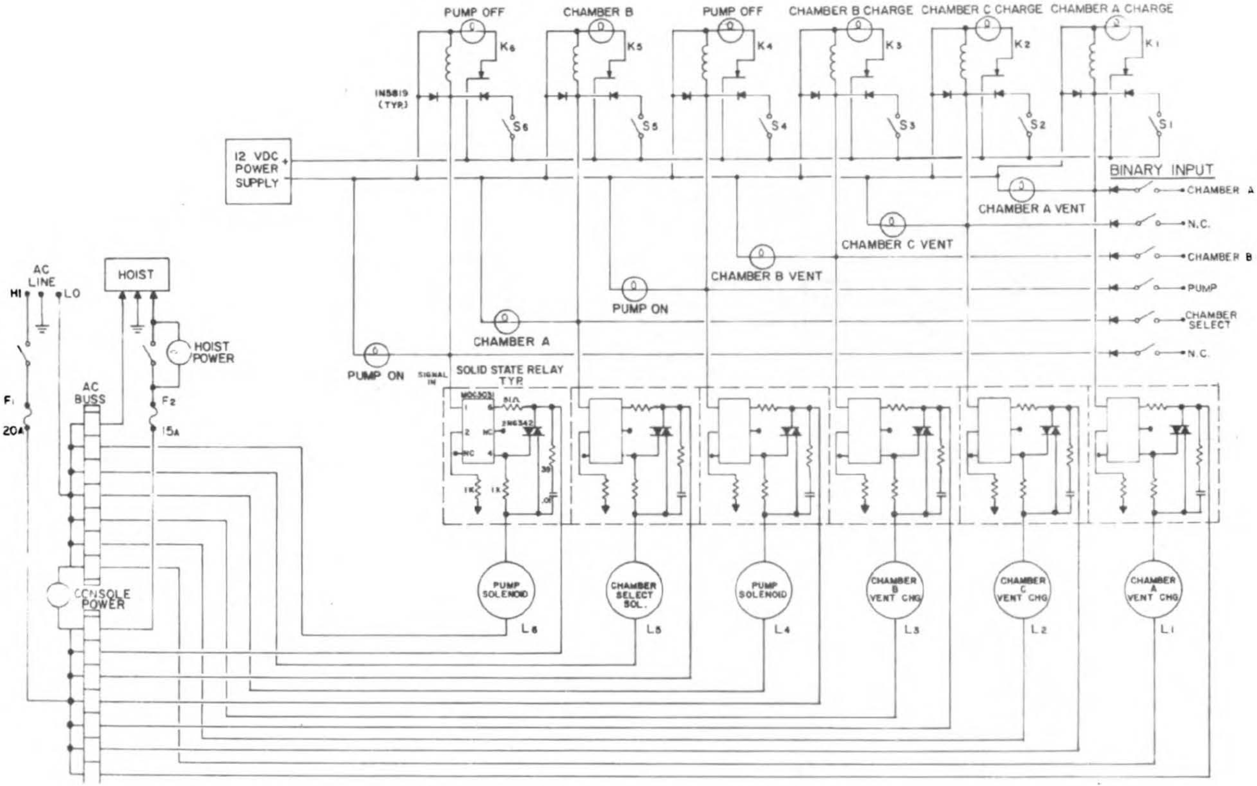

FIGURE 7. SYSTEM ELECTRONIC SCHEMATIC

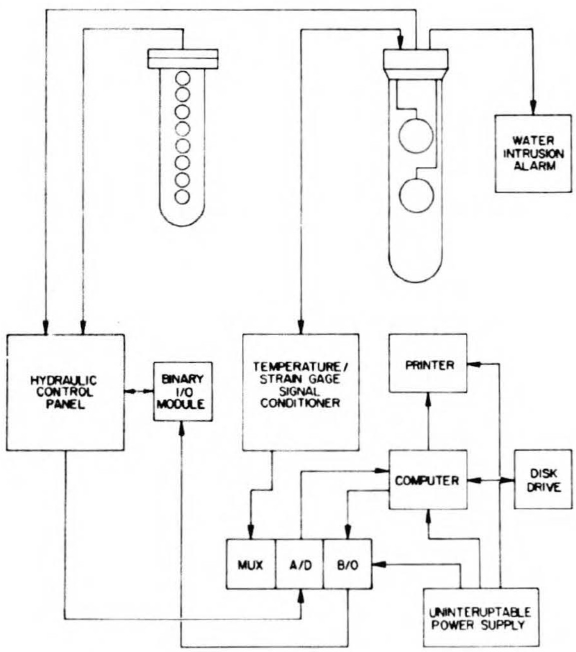

FIGURE 8. DATA ACQUISITION/CONTROL DIAGRAM

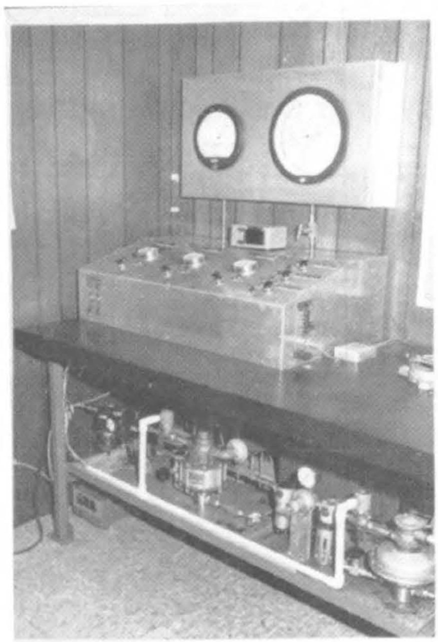

FIGURE 9. CONTROL CONSOLE.

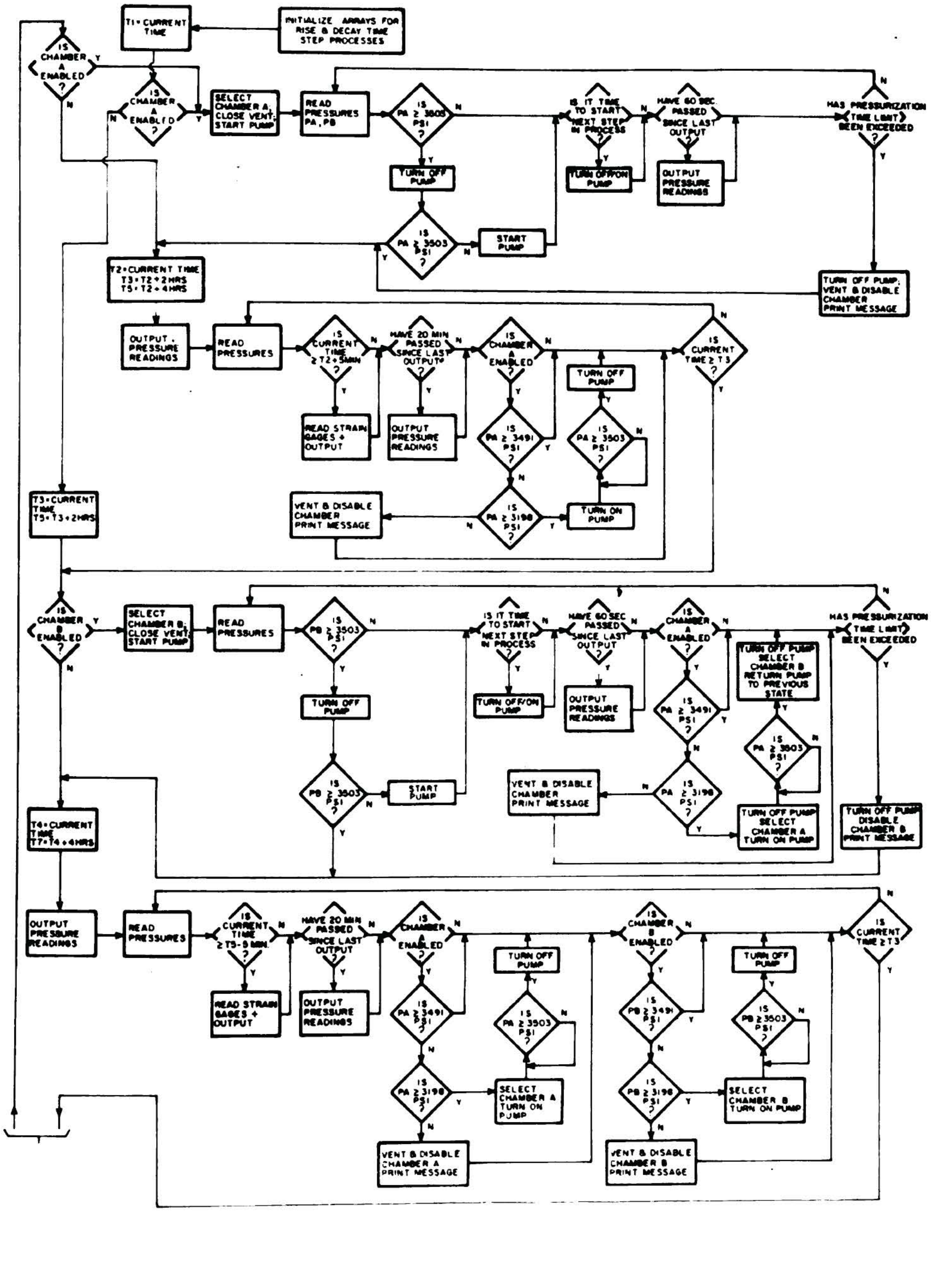

FIGURE 10. FLOW CHART

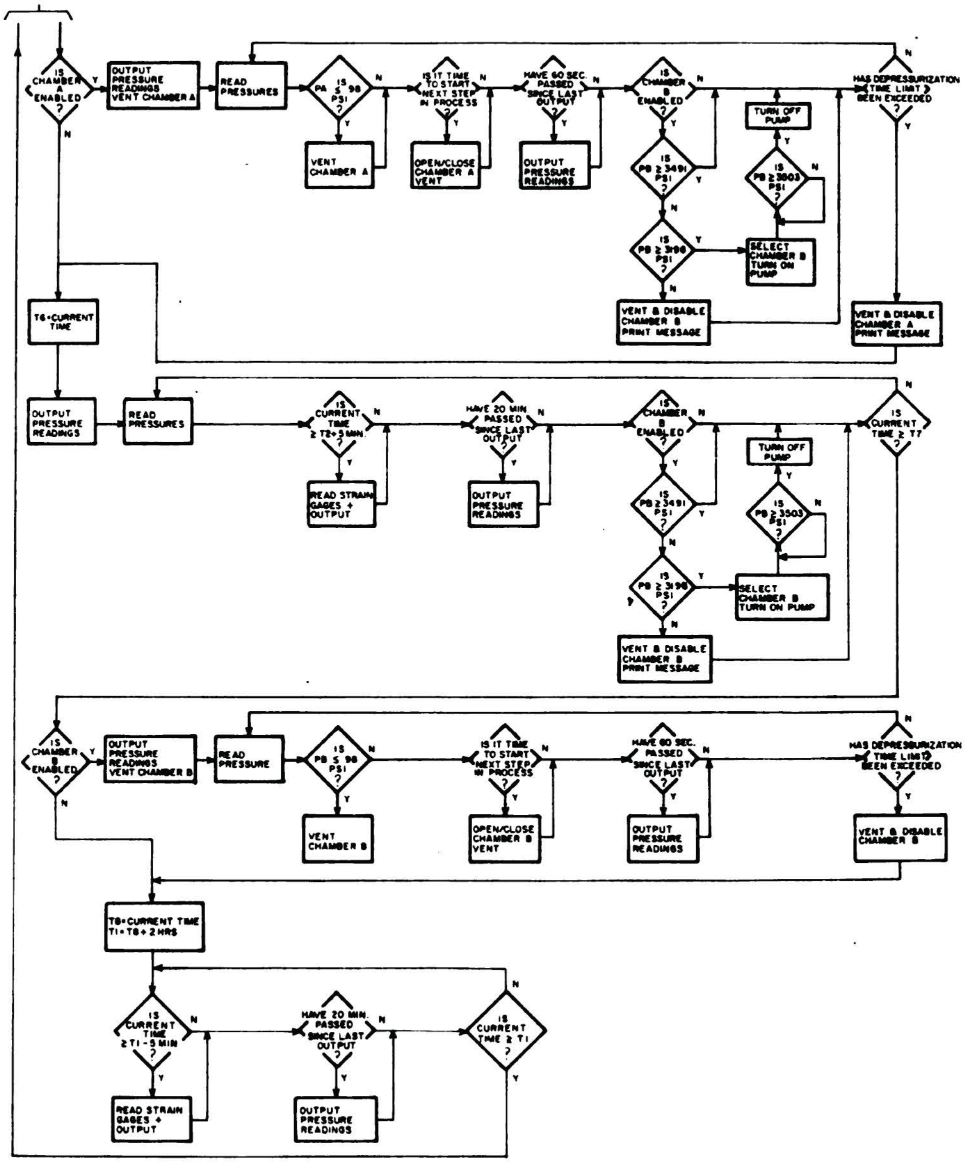

FIGURE 10. FLOW CHART (CONTINUED)