JUL 28 1965

LA-RC-7169

CONF-650802-2

MASTER

PRELIMINARY MANUSCRIPT

PROJECT ROVER
CRYOGENIC EVALUATION LABORATORY

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APPROVED FOR PUBLIC RELEASE

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ABSTRACT

This paper is presented to publicize the capabilities and the accomplishments of the Project Rover Cryogenic Evaluation Laboratory.

Project Rover is a NASA-AEC program to develop a nuclear rocket engine for space applications. The Cryogenic Evaluation Laboratory supports this program by testing cryogenic components related to the program test effort and by supplying data pertinent to cryogenic test facility operations.

Many of the laboratory features are unusual and its operation provides a source of information which may be useful to other facility designers and operators.

A complete description of the laboratory is presented and is supported by facility photographs.

A description of the liquid hydrogen test program is included which presents the results of the laboratory activities. They include flowrate element calibration, frequency and step response measurements, cryogenic valve tests, line chilldown studies, dynamic dewar pressurization studies, dynamic LH_2 consumption studies, and cryogenic flange chilldown studies.

INTRODUCTION

The Cryogenic Evaluation Laboratory is a part of the reactor test facility designed to test nuclear reactors for space applications.

(Figure 1.) The facility, Test Cell "C", is located at the Nuclear Rocket Development Station, Jackass Flats, Nevada. The Test Cell "C" complex, including the Cryogenic Evaluation Laboratory, is operated by the Los Alamos Scientific Laboratory.

Since December, 1963, the laboratory has supported the nuclear reactor testing program in two general ways: (1) by testing cryogenic system components and (2) by providing data pertaining to facility operations.

The laboratory consists essentially of a liquid hydrogen storage system with a capacity of 100,000 gallons and a pumping system capable of pressures to 1100 psig and flowrates to 87 lbs/sec. The interconnecting plumbing allows several LH_2 circulation schemes.

THE CRYOGENIC SYSTEM

The laboratory flow diagram is shown in Figure 2. LH_2 is circulated from one or both dewars, through the pump and into the Cryogenic Evaluation Laboratory. Here it is circulated through two vacuum insulated test vessels. (Figure 3.) The test vessels allow access to the cryogenic line where the test components are installed. Figure four shows a four inch turbine flowmeter installed for calibration. After passing through the laboratory, the LH_2 is either returned to the dewars or is discharged to a flare stack and burned depending upon the test requirements. The system is operated remotely from a control room located approximately 500 feet from the laboratory and dewar system. (Figure 5.)

The dewar shut-off valves allow flow to or from either dewar. A control valve downstream of the laboratory loop provides system impedance

to maintain the desired flows and pressures. A system bypass valve protects the LH₂ pump by compensating for erratic pump discharge pressures and flows. The chilldown valves allow proper cooling of the cryogenic piping prior to a test.

The cryogenic piping for the most part consists of eight inch inner line and a ten inch vacuum jacket. The vacuum is maintained warm at 5×10^{-4} Torr by a manifold system and several vacuum pumping stations.

Primary system flow measurements are obtained from two modified Herschel Venturis. One is located upstream of the LH₂ pump, the other downstream of the pump.

The storage system consists of two 50,000 gallon spherical dewars. (Figure 6.) These dewars are a part of the reactor test facility but can be spooled into the laboratory piping when the reactor program permits. The dewars are insulated with evacuated perlite. Both are instrumented with capacitance liquid level gauges and both are mounted on load cells for continuous liquid weight indication. In addition each dewar contains a temperature rake with twenty-four platinum resistance sensors mounted vertically every foot to monitor liquid or ullage gas temperatures in the dewar. Also included on the rake are four carbon resistor liquid level sensors for point calibration of the capacitance level gauges. One or both of the dewars may be pressurized to provide liquid to the LH₂ pump. Pressure during flow is maintained at 70 psig by means of a closed loop gaseous hydrogen pressurization system. Gaseous hydrogen is supplied from a high pressure gas tank farm.

The flow diagram allows several methods of LH₂ circulation. Three schemes have been utilized. The first and most commonly used scheme is dewar to dewar circulation. One dewar is used to supply LH₂ to the pump and the other dewar acts as a catch tank receiving the LH₂ after it has been circulated through the laboratory. The LH₂ pressure is increased

by the LH₂ pump from 70 psig at the pump inlet to a maximum of 1100 psig at the pump outlet. This pressure is reduced again across the control valve downstream of the laboratory piping loop and is discharged into the LH₂ dewars at a maximum pressure of 300 psig. The next scheme allows flow from one or both of the dewars through the cryogenic piping and then discharged to a flare vent for burning. Another method which has been successfully used establishes flow from both dewars simultaneously. The LH₂ passes through the laboratory piping and is discharged back into both dewars simultaneously. This method allows full utilization of the liquid storage capacity.

Several safety aspects are worth mentioning. In general all enclosed areas which contain high pressure cryogenic piping are inerted with gaseous nitrogen during all LH₂ circulation activities. The purpose is to minimize the possibility of fires by controlling the formation of combustible gas mixtures should a hydrogen leak occur. The rooms are sealed and nitrogen is introduced through a manifold near the floor. The oxygen content in the room is monitored by remote oxygen analyzers until it is less than three percent at which time the nitrogen supply is shut off. Room pressure is maintained at approximately two inches of water differential.

The laboratory building was not originally designed for inerting and was constructed of bare galvanized corrugated sheet metal. The room was sealed by spraying the internal surfaces with polyurethane foam. (Figure 7.) This method allows the laboratory building, which has a volume of 50,000 cubic feet, to be inerted with 105,000 standard cubic feet of gaseous nitrogen or approximately two volumes of nitrogen per room volume. Initial inerting time is approximately twenty-five minutes.

The atmosphere in the rooms is monitored continuously both by the oxygen analyzers and by combustible gas detectors. The detectors are a part of a facility wide hydrogen warning system which is maintained operable whenever there is hydrogen liquid or gas at the test cell. This

system consists of thirty-seven combustible gas detectors located at strategic points throughout the test cell. Any one will activate a siren alarm should a combustible mixture occur.

As an added safety factor and as an operational aid, all test operations are monitored on closed circuit remotely operated television.

The liquid hydrogen pump is a seven stage axial flow pump manufactured by Rocketdyne Division of North American Aviation, Inc. (Figure 8.) It is driven by two D.C. motors which combined can deliver 5000 horsepower. (Figure 9.) The common shaft passes through an induction gear assembly which increases the shaft speed by a ratio of 70:1 to a maximum of 26,000 RPM. Figure ten presents a pump map and outlines the operating parameters for the laboratory.

Normal pump operation is at a specific speed¹ of 950 which produces a maximum flow of 70 lbs/sec. at a discharge pressure of 880 psig. The pump has been operated at a specific speed of 850 which boosts the discharge pressure to 1100 psig at 70 lbs/sec. The pump has also been operated at a specific speed of 1300 which allows flow rates of 87 lbs/sec. at a discharge pressure of 740 psig.

The pump can be controlled by one of three modes. Manual RPM control, closed loop RPM control and closed loop flowrate control. Flow ramps or steps are manually controlled.

THE GAS SYSTEM

Three gases are used at the facility; helium is used for cryogenic line purging and line warmup, nitrogen is used for room inerting and purging, hydrogen is used for dewar pressurization. All gases are stored

¹Specific Speed, N_s , is a dimension less quantity which describes the critical parameters of a particular pump system.

$$N_s = K \frac{N Q^{1/2}}{\Delta P^{3/4}} \quad \text{Where } K = \text{constant, } \Delta P = \text{Head change across pump and } Q = \text{flowrate.}$$

at 3000 psig in the high pressure tank farm shown in figure six. The normal use for the tank farm is reactor testing, however, common piping allows useage by the laboratory when the reactor program permits. The tank farm consists of twelve cylindrical steel bottles, each of which holds 370,000 standard cubic feet of gas at 3000 psig for a total storage capacity of 4,400,000 standard cubic feet. Hydrogen and nitrogen are received at the test cell as liquids and are vaporized and pumped to 3000 psig.

THE DATA COLLECTION SYSTEM

The data collection instrumentation is located in the control room adjacent to the facility control consoles. (Figure 11.) Ninety-four channels are available for recording measured parameters from strain gauges, pressure transducers, thermocouples, resistance thermometers, and linear displacement transducers. This number includes sixty-four channels on eight, eight channel Sanborn recording oscillographs, twenty-five channels on a digital scan system, and five channels on separate potentiometric recorders. These systems, including the transducers and signal conditioners, are subject to $\pm 1\%$ full scale errors. The data collection system for the reactor test program includes a multiplex system which allows data recording on magnetic tape and subsequent digital computer data reduction. The normal system error from the transducer to the reduced data is $\pm 0.5\%$ full scale. This system is available to the laboratory when the reactor program permits.

All recorders are synchronized by means of a time code generator which prints a binary time code in the margin of all strip charts.

TEST PROGRAM

In addition to the component test program the laboratory has pro-

vided data pertaining to facility operation. Some of this information may be of general interest and is presented in the following paragraphs along with a description of the component testing that has been done.

FLOWRATE ELEMENT CALIBRATION

Three basic flow measurements have been made to determine the accuracy with which LH₂ flowrates can be measured. The dewar capacitance gauges have been used as flow measuring devices by timing large changes in level and calculating the volume flowed per unit of time. The capacitance gauge flowrate has been compared to the LH₂ pump inlet venturi flowrate and pump discharge venturi flowrate.

These flowrate measuring devices have been used to calibrate a four inch turbine flowmeter at a maximum flowrate of 70 lbs/sec. and 950 psig. (Figure 4.)

FREQUENCY AND STEP RESPONSE

The LH₂ flow system has been used to measure frequency and step response within the limits imposed by the motor drive system on the LH₂ pump. This system has a break frequency response of 0.5 CPS. However, the flow system may be perturbed by introduction of a 10% flow step for step response measurements. This is accomplished by rapidly changing the stem position of the system impedance valve downstream of the laboratory loop. This valve has a break frequency response of 15 CPS.

CRYOGENIC VALVE TESTS

The laboratory can be used to test cryogenic valves. A test setup is shown in figure twelve. This setup shows an eight inch butterfly valve

that was subjected to flowrates to 45 lbs/sec. at 100 psig. A static leak check was performed at 35°R and ΔP versus flowrate information was collected.

CHILLDOWN STUDIES

Two separate chillover studies have been made. Cryogenic line skin temperatures were measured at several points along the eight inch line downstream of the LH₂ pump. Temperatures were measured to determine the temperature profiles along the line at various times during chillover.

The second study was performed to determine the thermal stress distribution in an eight inch 600 ASA R.T.J. flange during the initial LH₂ chillover. This type flange is used in the LH₂ piping system to provide inner line connections and the stress distributions during chillover and at steady state were not well known. One of these flanges was instrumented with thermocouples which were imbedded in the flange at several radial distances toward the outer edge of the flange. Temperature profiles were then measured at several time increments during chillover and at steady state.

DEWAR PRESSURIZATION STUDIES

When flowing from dewar to dewar the LH₂ temperature is increased when the pressure is increased at the pump outlet. The pressure is then reduced across the control valve downstream of the laboratory piping. Flashing occurs as the pressure is decreased. This excess gas must be vented at the catch dewar or excessive pressure buildup will occur in the catch dewar. Pressure rise versus time has been closely monitored during the laboratory tests to determine the length of time flow may continue until overpressure occurs in the catch dewar. Each dewar has one 6 inch globe type vent valve with a flow coefficient, C_v , of 400.

LIQUID CONSUMPTION STUDIES

Another important consideration in dewar to dewar flow is the loss of LH_2 because of the flashing when discharging high pressure liquid through a control valve into a vented dewar. These measurements have been made in the laboratory by preparing a material balance after equilibrium has been attained in the catch dewar.

DISCUSSION

Figure thirteen presents a comparison of the three flowrate measuring devices utilized in the laboratory. Overall agreement between devices is $\pm 2\%$. The accuracy of any particular flowrate measurement may be increased to $\pm 1\%$ by selective use of the measuring devices. The pump discharge venturi is scaled for the higher flowrates and the resolution of the ΔP transducer limits its use at the lower flowrates. The inherent accuracy of the capacitance level gauge is $\pm 0.5\%$ full scale. To attain 1% accuracy or better a minimum of 25,000 gallons LH_2 must be transferred at a particular flowrate.

Temperature profiles of the cryogenic line are shown in figure fourteen. Eight measurements were taken on a section of line 116 feet long. The end of this section is 216 feet from the dewars. The chilldown time was 400 seconds and the equilibrium temperature averaged 60°R . The equilibrium flowrate was 4 lbs/sec. LH_2 . The gas flowrate prior to equilibrium was maintained above 1 lbs/sec. No appreciable line bowing was detected during chilldown.

The results of the temperature measurements taken on the eight inch flange are shown in figure fifteen.

Five temperatures were measured radially from the base of the welding neck to the outer edge of the flange. The thermocouples were imbedded half-

way through the thickness of the flange. With the exception of the flanges the chilldown was complete in 600 seconds. At this time the inside of the flange contained LH_2 . The temperature of the flange 0.4 inches from the outer edge was 505°R .

An equilibrium profile was attained 4.5 hours after the chilldown was started. The cryogenic line had contained LH_2 during the entire period. At equilibrium the temperature 0.4 inches from the outer edge was 130°R .

Catch dewar pressure rise versus time curves during dewar to dewar flow are presented in figure sixteen. Curves are shown for flowrates of 70, 60, 40 and 20 lbs/sec. LH_2 . Pump discharge pressures are shown for each flowrate. In each case the flow was initiated with the catch dewar vented to 3 psig and containing less than 10% LH_2 . The 70 lbs/sec. flowrate produces a pressure rise of 79 psig in 350 seconds. The final catch dewar level was 86%. The rate of pressure rise varied throughout the run as a result of the change in ullage volume with time and the increase in ΔP across the vent valve.

LH_2 loss rate as a function of flowrate is presented in figure seventeen. Loss rates were calculated at 10 lbs/sec. increments to 70 lbs/sec. The pump discharge pressures and LH_2 temperatures are shown at each flowrate. An increase in loss rate was experienced as the flowrate and consequently the LH_2 pressure and temperature increased. At 10 lbs/sec. the loss rate was $1\frac{1}{2}\%$; at 70 lbs/sec. the loss rate increased to 16%.

FIGURE ONE

LEGEND:

JBV - MOTOR OPERATED VALVE
 OBV - SOLENOID OPERATED VALVE
 PCV - PRESSURE CONTROL VALVE
 ACV - ANALOG CONTROL VALVE
 FE - VENTURI FLOW ELEMENT

FIGURE N° 2

CRYOGENIC EVALUATION LABORATORY
 FLOW LOOP

FIGURE THREE

FIGURE FOUR

FIGURE FIVE

FIGURE SIX

FIGURE SEVEN

FIGURE EIGHT

FIGURE NINE

FIGURE 10

FIGURE ELEVEN

FIGURE TWELVE

FIGURE 13

FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17