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A DIVISION OF AVCO CORPORATION

FINAL REPORT

ULTRA-HIGH VACUUM MATERIAL AND LUBRICANTS TEST SYSTEM

By J. C. Law

February 1970

Prepared Under Contract No. NAS 9-8312 By

Avco Electronics Division
Tulsa, Oklahoma

For

Manned Spacecraft Center
National Aeronautics and Space Administration

NASA CR 108389

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1.0 INTRODUCTION

The Ultra-High Vacuum Material and Lubricants Test System consists of a main chamber, nine auxiliary chambers, vacuum pumping subsystems, bakeout subsystem, liquid nitrogen shroud, an apparatus for tensile testing, and control consoles. Figure 1 shows the system during various stages of assembly.

The vacuum range of the system is from atmospheric pressure to the 10^{-10} torr range. Pumping to this range is accomplished by rough pumping with a 4250 liter/sec. turbomolecular pump which was supplied by NASA-MSC. High vacuum pumping is supplied by titanium sublimation pumps and a liquid nitrogen shroud. Heating blankets are used to provide bakeout capability.

Dimensions of the main chamber are 36-inch diameter by 72-inch length. The liquid nitrogen shroud fits inside the main chamber with ports opening into auxiliary chambers. Each auxiliary chamber can be valved off from the main chamber.

Six of the auxiliary chambers have the capability of holding specimens for tensile tests. These chambers may be vacuum pumped with an auxiliary pumping system. Bellows type feedthroughs attach the tensile testing apparatus, which has a capability of 10,000 pounds pull at 1.0 inch/minute velocity. Speed regulation can be maintained at ± 0.1 percent and torque control (force) at ± 1 percent.

The console provides remote control for instrumentation, power, high vacuum pumping, bakeout, tensile tester, and rough pumping subsystems.

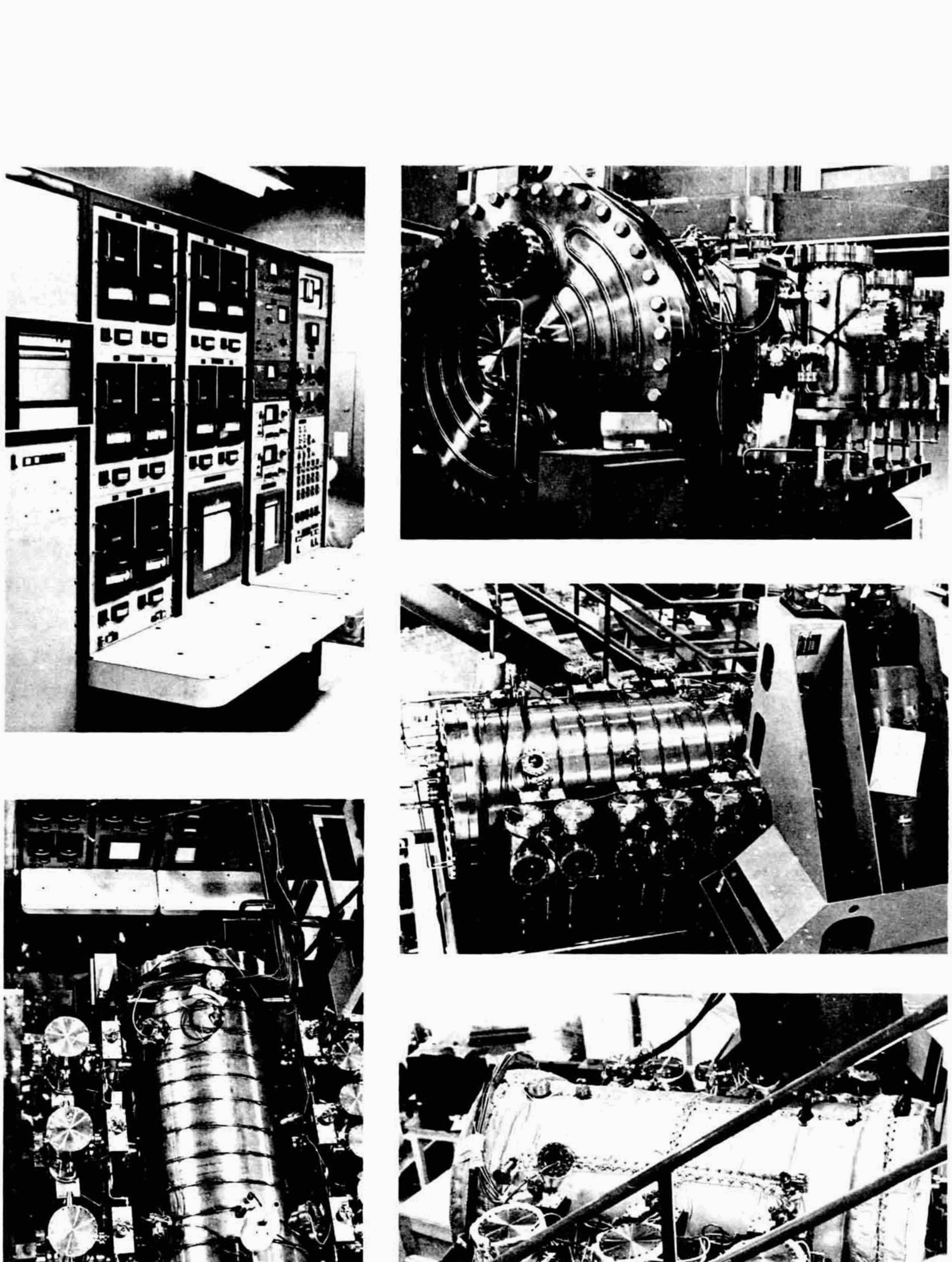


Figure 1. System During Assembly

NASA-MSC provided the final installation of the system, but the general arrangement is shown in Figure 1. The chamber is mounted on a cradle supported by a stand. The tensile testing equipment is mounted on a carriage which will move along the main chamber to the various auxiliary tensile test chambers. The three console groups are located at floor level facing the chamber. The three groups are UHV console, tensile tester console, and tensile tester power console. The turbomolecular pump is located below the main chamber and is connected by a bellows.

2.0 DESIGN

The system contract contained a group of NASA-MSC drawings which were used as general system requirements. These drawings were modified and supplemented by Avco to provide the total system design as specified in the contract requirements.

2.1 Vacuum Chamber

The vacuum chamber design used methods required for ultra-high vacuum operation. All materials selected were type 304 stainless steel except valves, feedthroughs, gauges, and viewports. These exceptions were then selected for use at the pressure and temperature requirements (10^{-10} torr range and 750°F). As a result, the six-inch gate valves are the only chamber components which contain materials not compatible to the bakeout requirements. Viton O-rings in these valves are limited to 292°F in the open position. The valves have a separate cooling water circuit to keep them below 292°F during bakeout.

All flanges in the chamber use metal gaskets. Two flanges (the main chamber heads and bellows) use metal O-rings.

2.2 Liquid Nitrogen Shroud

The main chamber was fitted with a liquid nitrogen shroud which has ports into the auxiliary chambers, vacuum gauges and pumps. The shroud is designed with a unique liquid nitrogen (LN_2) feed-through assembly which removes all mechanical connections at LN_2 temperatures from the vacuum area. This design reduces the chances of cryo-leaks. Also, the feedthrough allows the shroud to be removed by opening only one end of the chamber.

2.3 Vacuum Pumping

The vacuum pumping port is located on the bottom center of the chamber. The port is designed such that the maximum turbo-molecular pump speed is realized. The nominal 20-inch port matches the NASA-MSC supplied flange to produce a high pumping throughput.

High vacuum pumping is designed to use both cryo-pumping and titanium sublimation pumping (TSP). The LN_2 shroud provides a large pumping surface (approximately 100 sq. ft.) for water vapor and other condensable gases. The shroud also provides a cold surface for the TSP. The shroud increases the TSP rate from 30 liters/sec/in^2 to 65 liters/sec/in^2 for nitrogen.

2.4 Instrumentation

The instrumentation design provides accurate measurement of pressures and temperatures within the system.

2.4.1 A two-channel thermocouple gauge provides pressure measurement from atmosphere to one (1) micron in the vacuum chamber and rough lines. A pirani gauge is also provided for rough line pressure measurement. The rough line gauges are installed by NASA-MSC and the exact use cannot be shown here.

The chamber also contains a nude ionization gauge for pressure measurement from 1×10^{-3} torr to 2×10^{-11} torr and a Helmers ionization gauge for operation from 1×10^{-4} torr to 1×10^{-13} torr. The Helmers gauge provides for x-ray removal by electrostatically deflecting the ion beam, and it is more accurate than the ion gauge below 5×10^{-10} torr. A 100 mv, two-channel recorder is provided for recording these two gauge readings.

2.4.2 Temperatures for all heating zones on the chamber are measured by thermocouples and recorded on a 0 to 800°F recorder. The recording system is ambient temperature compensated. Accuracy is ±4°F to 530°F and ±3/4% from 530°F to 800°F.

The thermocouple wiring system is designed to operate to the recording limit of 800°F. Fiberglass insulated wire was selected.

2.5 Bakeout Subsystem

The bakeout subsystem is designed to provide a method of reducing gas load in the vacuum chamber and auxiliary chambers. Heat is applied to the outside surfaces of the chambers by a resistance heater-insulated blanket.

Design of the bakeout power controls uses a power relay operated by a temperature controller which has a variable set-point. A safety temperature switch is in series with the temperature controller. Power controls for the main chamber blankets also have a motor driven switch which alternates the power between the power relays to prevent all four (4) blankets from being "ON" at the same time. This switch was found necessary, during design review of the NASA-MSC drawing, to keep the total power requirements within the capability of the system.

2.6 Tensile Tester Subsystem

The tensile tester subsystem design consists of the integration of a force drive unit built by General Electric into a mechanical drive unit and adding the necessary controls and instrumentation.

The force drive unit uses a variable speed DC motor as the force unit. The motor and control unit utilizes silicon controlled rectifiers for AC to DC voltage conversion. The drive speed and torque (force) is adjusted by controlling armature voltage and the motor field current. The design allows both the speed and force to be preset for a test run. The drive unit accelerates linearly to the preset speed and stops at the preset force.

Speed regulation can be maintained at ±0.1 percent and torque control (force) at ±1 percent from 0 to 300 RPM (0 to 26.8 in/min) and from 0 to 10,000 pounds tension at the specimen.

Instrumentation is provided by a load cell in the drive unit and a tachometer on the motor. The load cell can be selected from either a 0-1000 or a 0-10,000 pound unit. DC signals are recorded on a mv recorder for both the load cell and the tachometer. The tensile tester subsystem has various interlocks and limit switches to aid operation.

3.0 FABRICATION AND ASSEMBLY

The system was fabricated and assembled at the Avco Electronics Division/Tulsa Operation. Detail progress and problems were reported in monthly letter reports. The system was inspected during assembly by the NASA-MSC technical monitor.

There were four (4) critical areas of fabrication and assembly:

(1) The vacuum chamber and vacuum components required extreme care to provide a clean, leak-free chamber.

(2) The mechanical fit of the LN_2 shroud feedthrough and the chamber head required good dimensional control of the fabricated parts and accurate design.

(3) The supporting shafts for the tensile tester assembly also required accurate assembly to allow free movement in the transverse direction.

(4) Electrical assembly and wire routing were considered critical to prevent the power circuits from interfering with the instrumentation circuits.

All of the above items were accomplished with a minimum of problems. There were no leaks found in the main chamber during fabrication. Only two auxiliary chambers had leaks, and these were repaired. A simple filter was added to the tachometer instrumentation circuit during final testing (see Section 4.0) to prevent interference.

One problem did arise on the heating blankets. After the system had been delivered to NASA-MSC, it was found that three (3) of the auxiliary chambers had heating blankets made wrong. These blankets were sent to the manufacturer for repair and returned to NASA-MSC.

4.0 TESTING

System testing was performed at three facilities. The force drive unit was tested at the General Electric facility, Erie, Pennsylvania. The auxiliary pumping system was tested by NRC, Newton, Mass.

4.1 Auxiliary Pumping System

The auxiliary pumping system was tested by the manufacturer (NRC) to verify pumping speed and blank-off pressure.

Required pumping speed was 350 liters/sec. The test actual was 500 liters/sec. The required blank-off pressure was 1×10^{-6} torr or lower. The test actual was 1.8×10^{-7} torr. The test record summary is contained in Appendix A.

4.2 Tensile Tester Test - G.E. Facility

Performance tests on the tensile tester force drive unit were performed at the General Electric, Erie, Pennsylvania, facility on December 10, 1968. The test was witnessed by an Avco representative. Documentation of the performance is shown in Appendix B. NASA-MSC chose not to send a representative to this test.

4.3 Performance Tests

Performance tests were conducted on the system at Avco, Tulsa Operation, during two periods. The first period was September 12 and 15, 1969. Tests conducted were cold shock, shroud removed, and ail leak tests. NASA-MSC chose not to send a representative to witness these tests.

The second period of testing was October 16-22, 1969. Tests conducted were system checkout, tensile tester operation, and ultimate vacuum. Mr. J. J. Liddell represented NASA-MSC at these tests.

4.3.1 Liquid Nitrogen Shroud Removal Test

A test was conducted to verify the LN_2 shroud could be removed from the vacuum chamber. As a result of this test an additional roller was added to the chamber shell. After the roller was added, the shroud could be removed from the chamber.

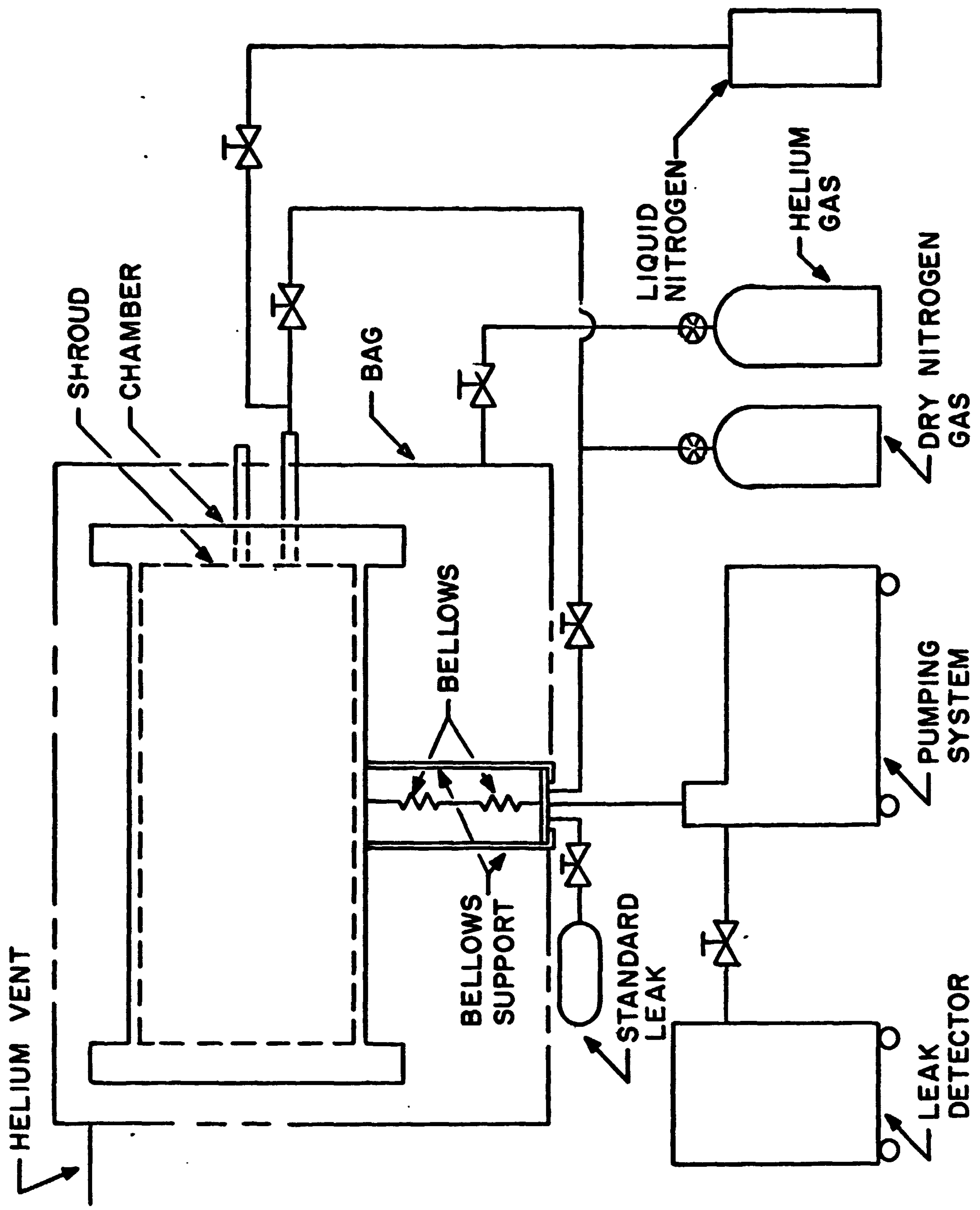
4.3.2 Cold Shock and Chamber Leak Test

The vacuum chamber was cycled from atmospheric pressure to below 100 microns pressure while the LN_2 shroud was cycled from LN_2 temperature to room temperature. Figures 2 and 3 show the test setup.

After three (3) cycles the chamber and shroud were leak checked. A helium leak detector with a sensitivity of 3.35×10^{-10} Std. cc/sec was used, and the total chamber leakage was 1.3×10^{-9} Std. cc/sec. No detectable leaks were found in the LN_2 shroud.

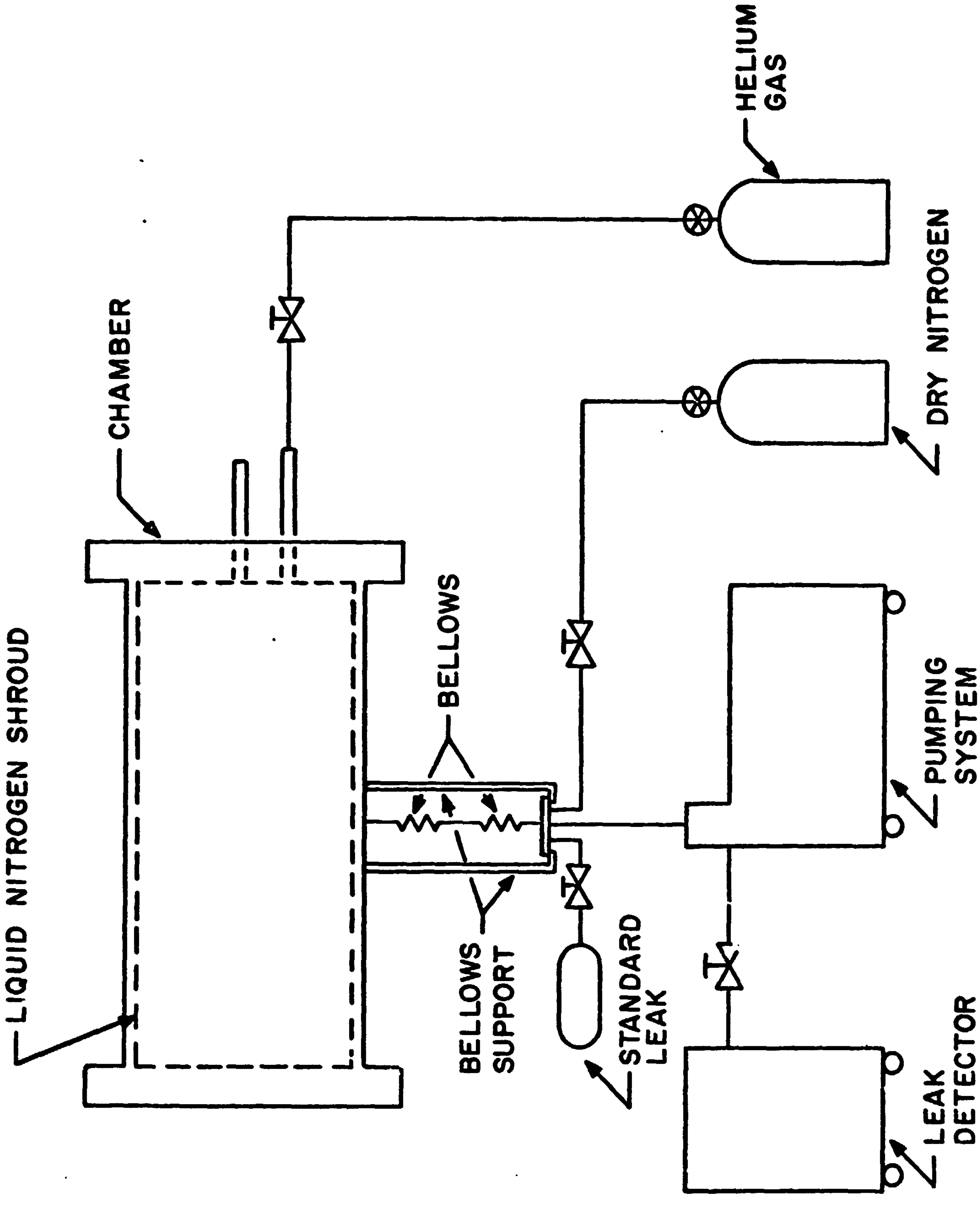
4.3.3 Flexible Tubing Leak Test

The flexible tubing assembly, which connects the auxiliary pumping system to the tensile test chambers, was leak tested. No detectable leaks were found with a detector sensitivity of 3.2×10^{-10} Std. cc/sec.



COLD SHOCK AND CHAMBER LEAK TEST SET-UP

Figure 2



LIQUID NITROGEN SHROUD LEAK TEST SET-UP

Figure 3

4.3.4 System Checkout

A checkout was performed on the console units to verify all systems were operational. The various subsystems were operated, including: power, bakeout, instrumentation, recording and control. One over-limit switch was repaired in the bakeout controls, and two loose wire connections were found in the General Electric force drive unit and repaired.

4.3.5 Tensile Tester Operation Test

Tests were performed to verify the total tensile tester subsystem was operational. The following tests were successfully performed:

4.3.5.1 The force drive unit was moved from its limits along the chamber to each tensile test chamber to verify the transverse drive unit was functional.

4.3.5.2 A specimen of 4031 steel 1.00 inch dia. x 10.50 inch long was installed in a tensile test chamber and the following test conditions were established:

Note: A filter was added to the tachometer circuit to remove electrical noise.

a. The specimen was loaded at 5850 pounds. After 10.5 hours there was no change in the load.

b. The specimen was loaded at 9900 pounds at 0.5 inches/min.

c. The specimen was loaded at 10,000+ pounds (off scale) at 1.3 inches/min.

4.3.5.3 With the specimen removed, the force drive unit was operated at 26.5 inches/min.

4.3.6 Ultimate Vacuum Test

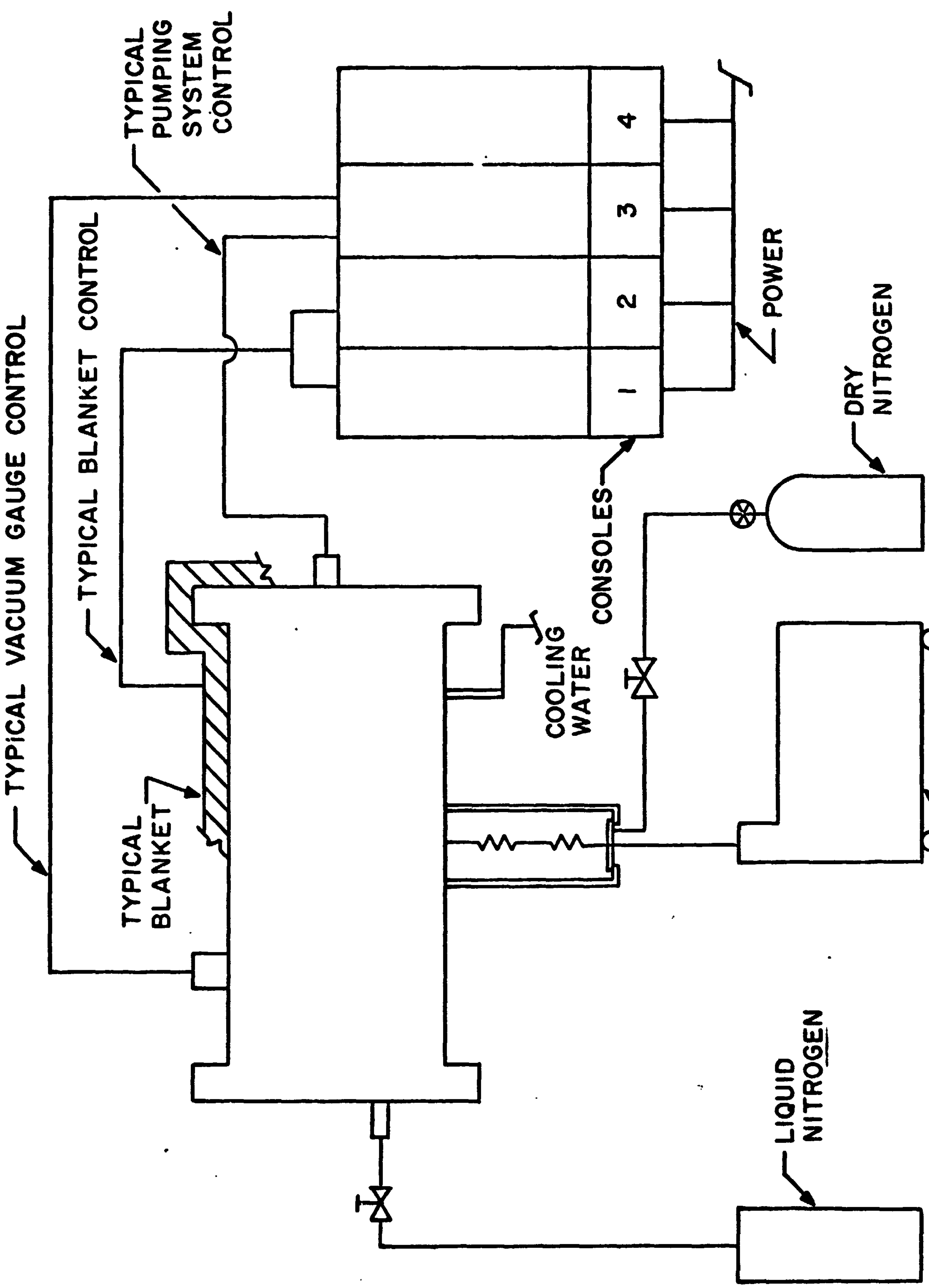
The vacuum chamber and all auxiliary chambers were opened together for the ultimate pressure test. The system was set up as shown in Figure 4 for testing.

4.3.6.1 The test started with a chamber bakeout at an average temperature of 475°F for 16 hours at an average pressure of 6×10^{-5} torr. After bakeout the chamber was cooled. Leaks were found in the main flange gaskets. The flanges were retorqued and the leaks were stopped. A leak was also found in a thermocouple feedthrough and repaired.

After all leaks were repaired, the LN_2 shroud was filled and the pressure was reduced to 4.4×10^{-8} torr. At this time the test was again stopped when a leak developed in the auxiliary pumping system.

4.3.6.2 The auxiliary pumping system was repaired and the test continued with a bakeout at a pressure of 2.2×10^{-6} torr to 1.6×10^{-6} torr for 15 hours. The chamber was cooled and the diffusion pump baffle cleaned. The pressure was then 6.65×10^{-7} torr.

Liquid nitrogen was added to the shroud and the pressure reduced to 4.5×10^{-8} torr. TSP was added and the pressure reduced to 1.6×10^{-9} torr. Figures 5 and 6 show the pumpdown data for this period of the test. After several cycle rates were tried for the TSP, the pumping systems were turned off for 10 hours.



SYSTEMS CHECKOUT AND VACUUM TEST SET-UP

Figure 4

AVCO CORPORATION

P.O. Drawer N, Admiral Station Tulsa, Oklahoma

TITLE Pumpdown Curve

Data taken 10-20-69 and 10-21-69 from log sheets 13, 14 and 15.

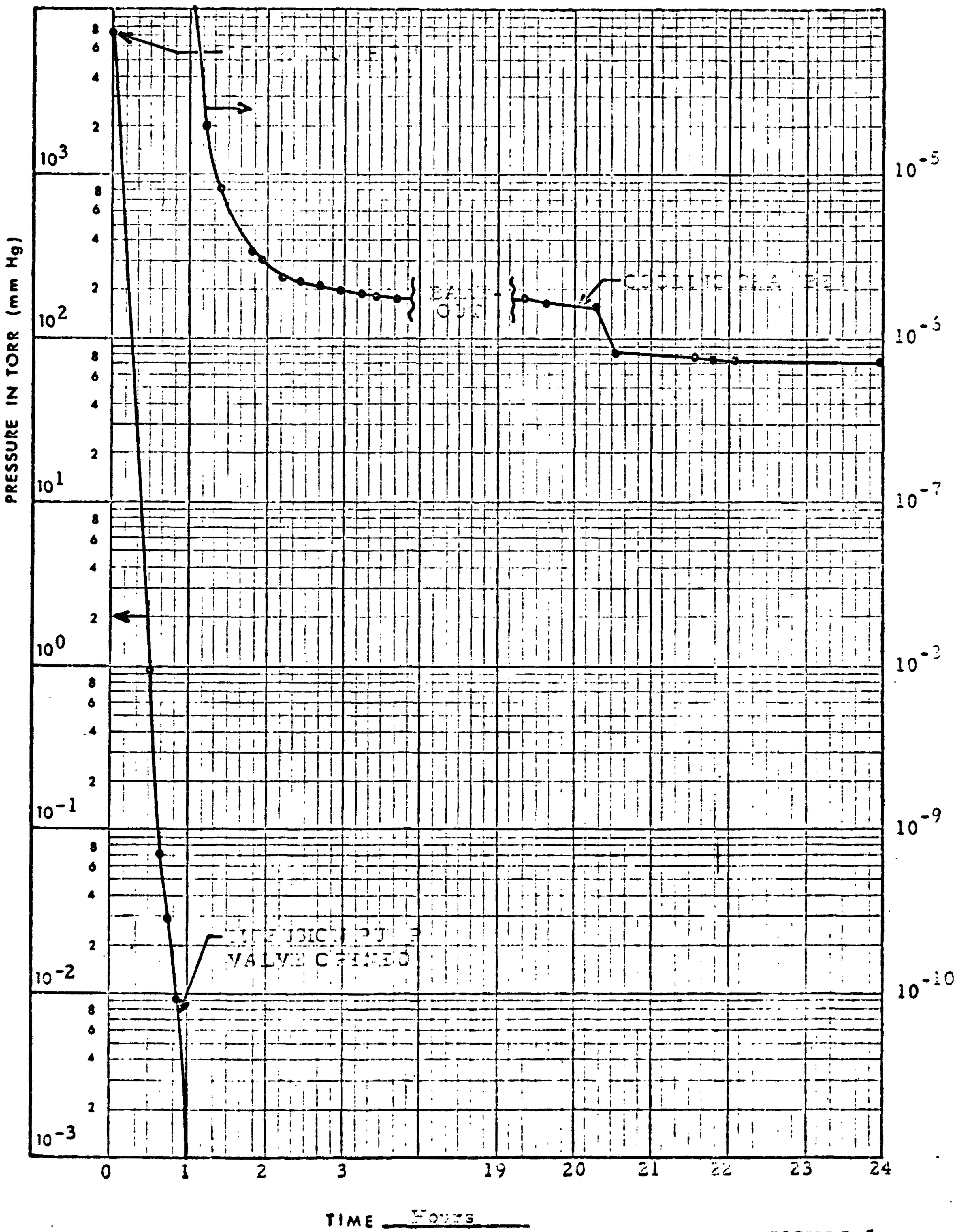


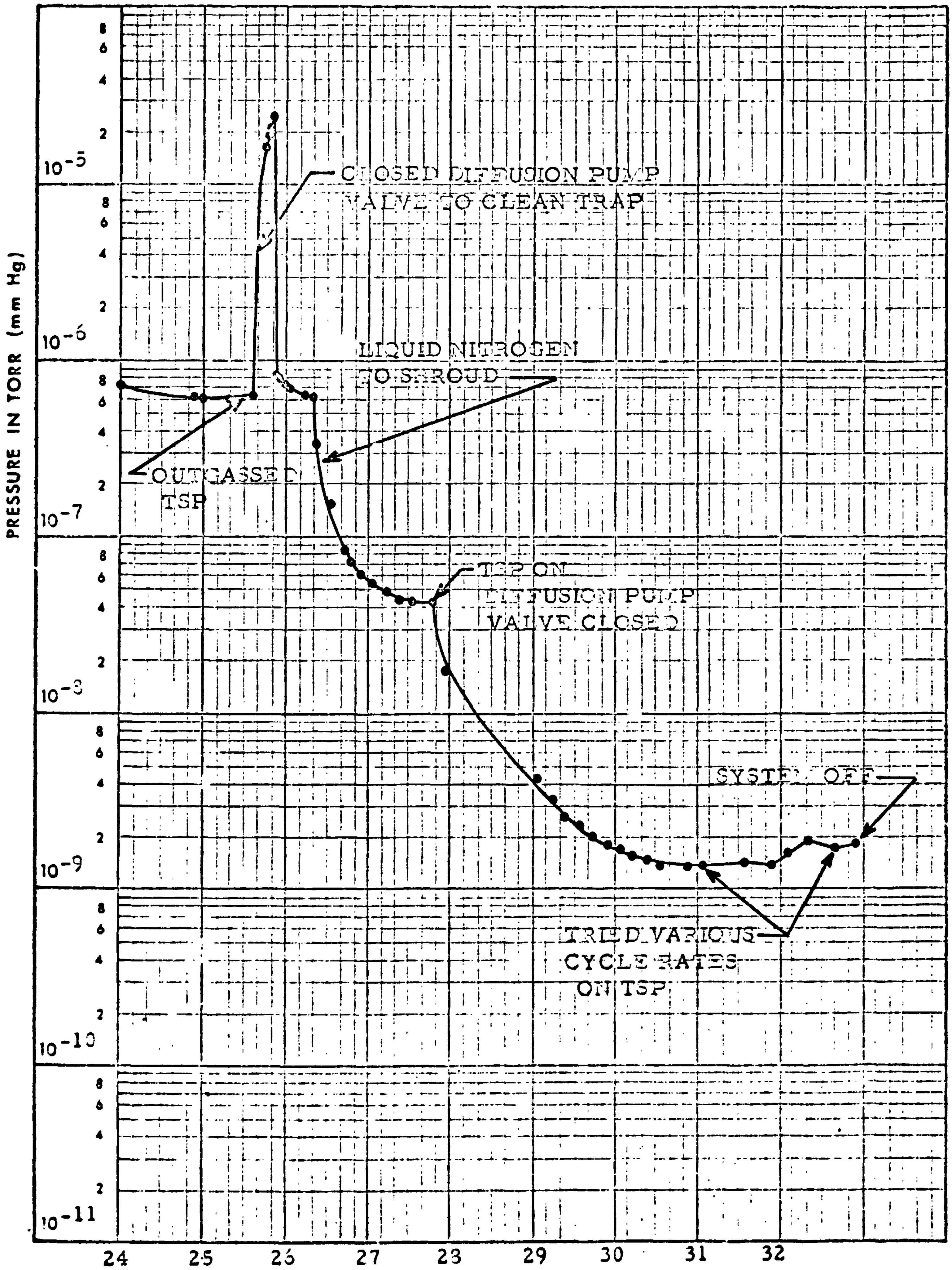
FIGURE 5

AVCO CORPORATION

P.O. Drawer N, Admiral Station Tulsa, Oklahoma

TITLE Pumpdown Curve

Data taken 10-21-69 from log sheets 15, 16 and 17



TIME Hours

FIGURE 6

4.3.6.3 The pumping system was started at a pressure of 3×10^{-5} torr by turning on the TSP followed by opening the valve to the diffusion pump. The system pumped to an indicated pressure of 3.5×10^{-10} torr as measured on the Model 971-0003 ionization gauge control unit. The Helmers gauge unit measured 2.0×10^{-10} torr. The pumpdown data for this period is shown in Figure 7.

4.3.6.4 Figure 8 shows a comparison of the two vacuum test runs (paragraphs 4.3.6.2 and 4.3.6.3). Improvement in ultimate vacuum resulted from two factors: the system had been at a high vacuum longer which decreases the outgassing load, and the diffusion pump was used in parallel with the TSP.

AVCO CORPORATION
P.O. Drawer N, Admiral Station Tulsa, Oklahoma

TITLE Pumpdown Curve

Data taken 10-21-69 and 10-22-69 from log sheets 1 , 17, 18 and 19.

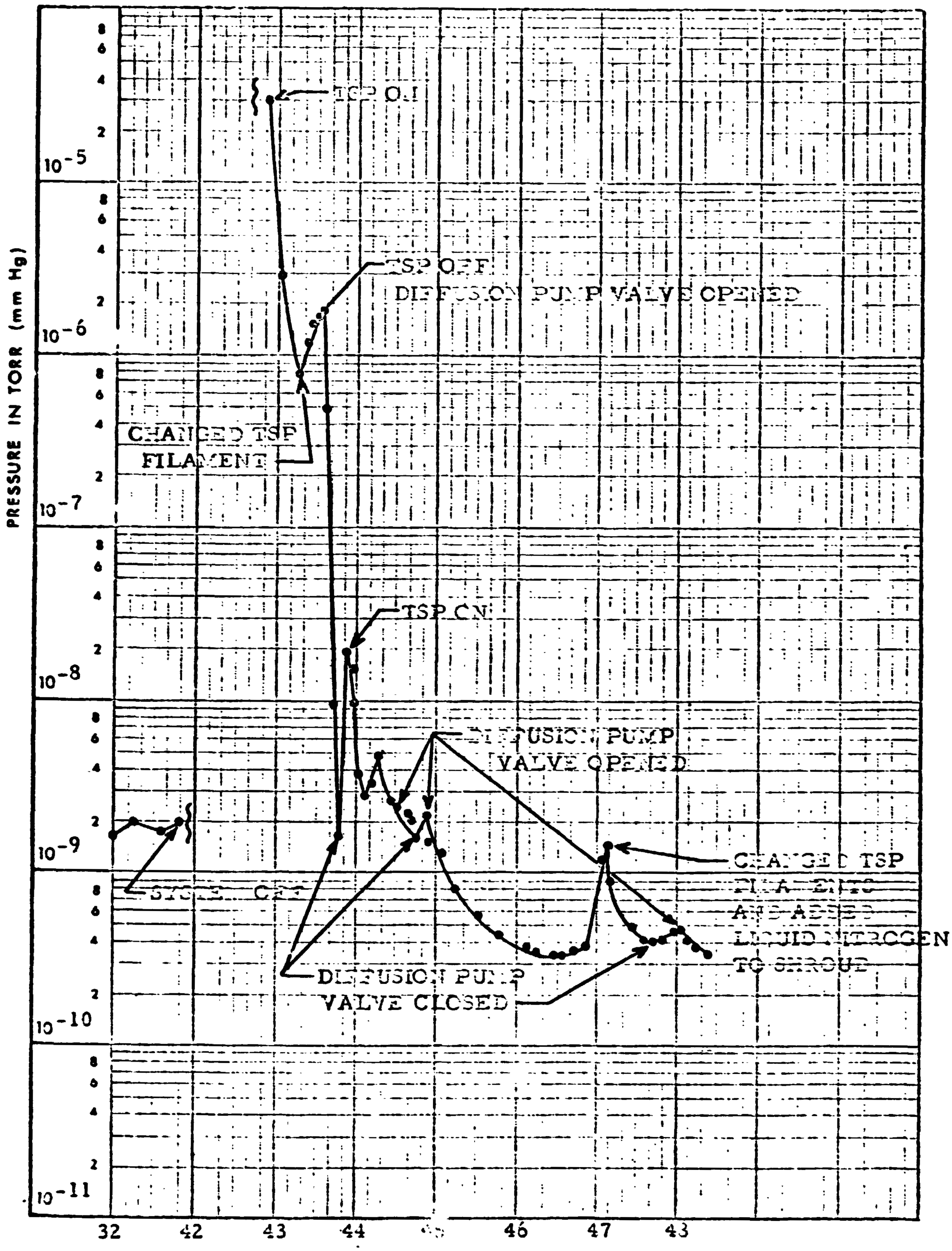


FIGURE 7

Avco CORPORATION

P.O. Drawer N, Admiral Station Tulsa, Oklahoma

TITLE Comparison of Two Pumpdown Rates

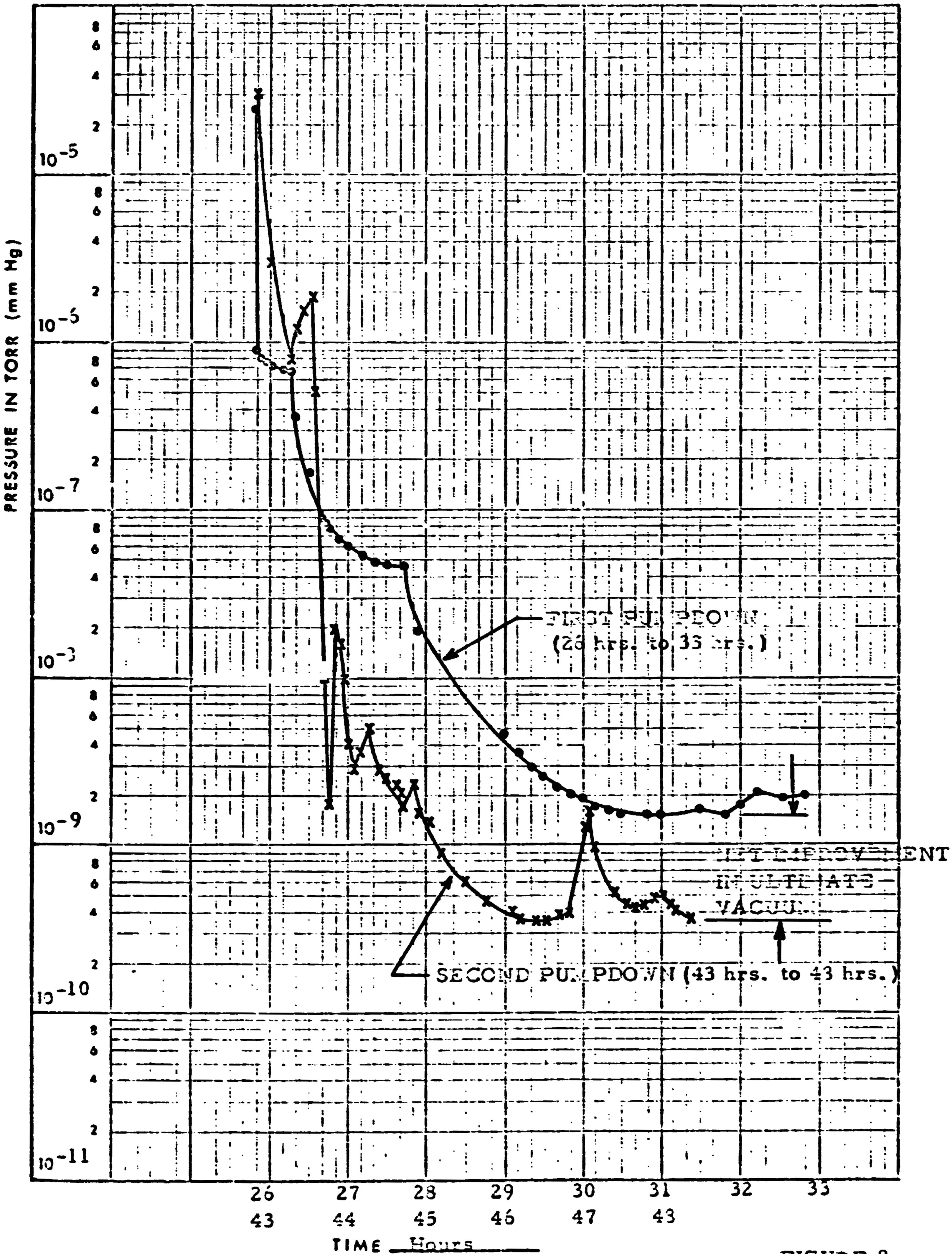


FIGURE 8

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The most important conclusion that can be drawn is the system will accomplish its purpose of providing an ultra-high vacuum environment with an accurate tensile test capability. Secondary conclusions are that the system is a safe, easy-to-operate vacuum system with adequate controls and instrumentation. The design uses straightforward and logical methods.

All vacuum test results can be improved when the NASA-MSC turbomolecular pump is added to the system. Its pumping speed of 4000 liters/sec. is much greater than the 500 liters/sec. speed of the auxiliary pump system which was used during performance tests.

5.2 Recommendations

The following recommendations of improvements or additions should make the system more functional:

5.2.1 A mechanical shield should be designed to be used between tensile test specimens and the viewport for use when photographic data is not required. The shield could prevent damage to the viewport and a sudden venting of the chamber if the specimen fractured.

5.2.2 Feedthroughs which are not used should be removed from the auxiliary chambers and replaced with blank flanges. These feedthroughs could easily be damaged during normal work and create a leak.

5.2.3 The temperature recorder has two channels which are not in use. These channels could be used to monitor the gate valve temperatures during bakeout and aid in adjustment of cooling water.

APPENDIX A

TEST RECORD SUMMARY

(For NRC Model 3307 Pumping System)

TEST RECORD SUMMARY

CUSTOMER AVCO ELECTRONICS P/O# 90258 Q#9866

Date JUNE 4&5, 1968 Tested By J.R.

Type Equipment 3307

CHAMBER: Size ____ Material S.S. SPOOL Inside Finish ____

No. Ports ____ Type Gaskets BUTYL

Type of Diffusion Pump Fluid DC705

VACUUM SYSTEM TEST

TEST	SPECIFICATION	ACTUAL	Reason for Deviation	Spec. Waivered By
Blank-Off	2×10^{-7} torr	1.8×10^{-7} torr		
Pump Down	5×10^{-7} torr in 30 min. ___ sec.	4.3×10^{-7} torr in 30 min. ___ sec.		
Rate of Rise	___ Microns/hr @ ___ Microns	___ Microns/Hr @ ___ Microns		
Leak Rate	___ Micron CFH	___ Micron CFH		

Comments:
SERIAL # M002
NET PUMPING SPEED AT SYSTEM INLET IN THE MOLECULAR FLOW RANGE: 500 LITERS PER SECOND.

WATER FLOW TEST

COMPONENT	SPECIFICATIONS	ACTUAL	Reason for Deviation	Spec. Waivered By
	___ GPM@ ___ PSIG	___ GPM@ ___ PSIG		

VACUUM PUMPING SYSTEM SCHEMATIC

VACUUM GAUGE: TYPE ____________ LOCATION ____________

Diffusion Pump Fluid ____________

Cold Trap: Type ____________ LN_2 to fill ____________ litres

LN_2 Consumptions ____________ litres ____________ hours

FOR FURNACE HEAT RUN: ____________

THERMOCOUPLE: TYPE ____________ No. ____________ LOCATION ____________

OPTICAL: ____________ CORRECTION ____________ TEMPERATURE ____________

PRIMARY: Voltage: ____________ Power Setting ____________ % ____________

Current: ____________

ELEMENT: Leads Voltage: 1 ______ 2 ______ 3 ______ @ Temp ____________

Current: ____________

Test Record Summary

CUSTOMER AVCO ELECTRONICS P/O# 90254 Q# 49866

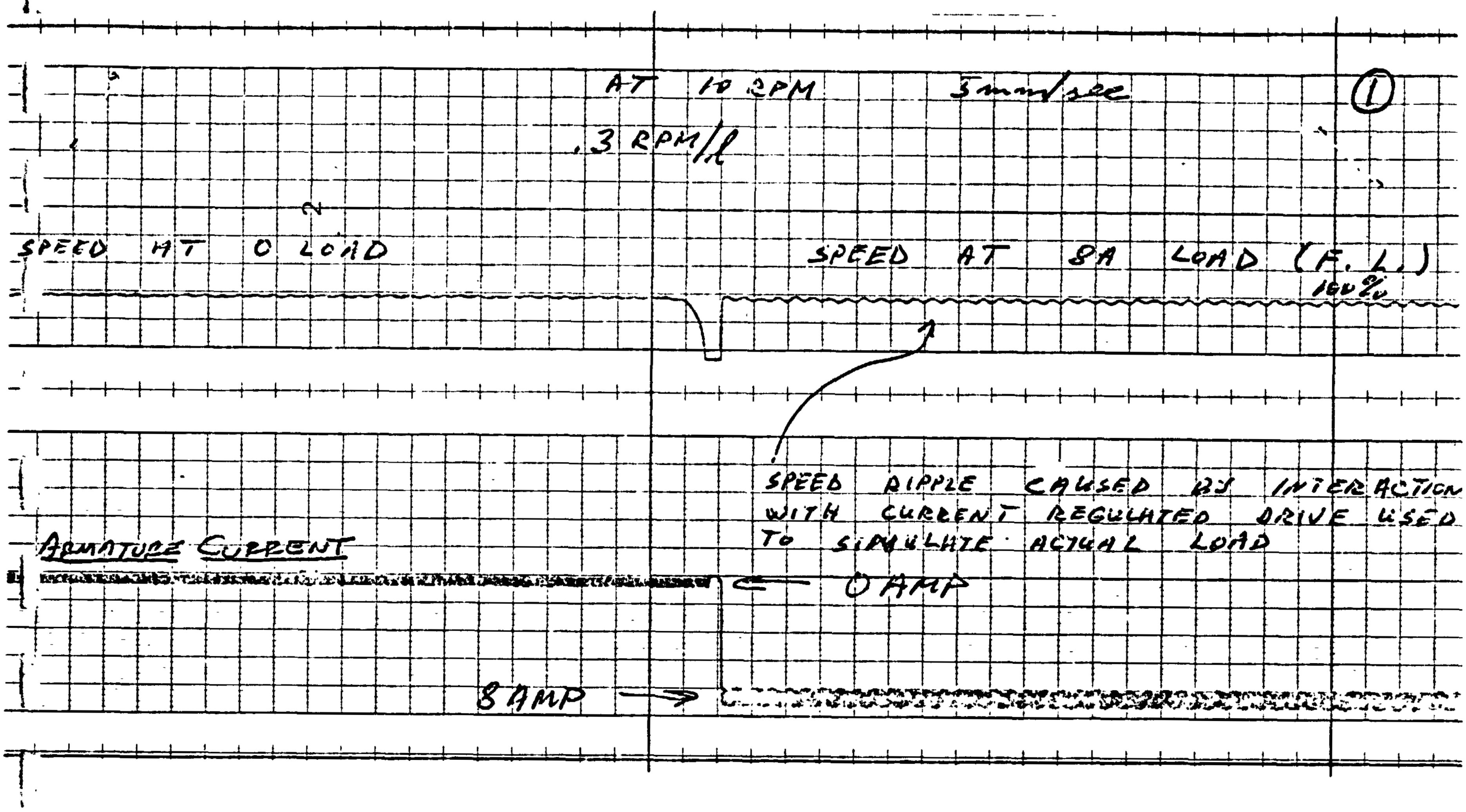
Tested By NRC 720 GUAGE CONTROL WITH NRC 507 GUAGE TUBE

DATE	TIME	PRESSURE	REMARKS
6/4	1500	$1x10^{-5}$	SNIFFED WITH HELIUM- NO LEAKS
"			ADD LIQUID NITROGEN
"	1520	$1x10^{-6}$	
"	1530	$9.6x10^{-7}$	
6/5	0718	$6.4x10^{-7}$	OUTGAS FOR 10 MIMUTES
"	0955	$5.4x10^{-7}$	ADD LIQUID NITROGEN
"	1018	$1.8x10^{-7}$	TOPPED OFF LIQUID NITROGEN
"	1042	$1.8x10^{-7}$	
"			RELEASE TO ATMOSPHERE AND BEGIN PUMPDOWN
"	25 sec	200microns	
"	33 sec	100microns	
"	45 sec	50microns	
"	2 min	$6.8x10^{-6}$	
"	3 min	$4.0x10^{-6}$	
"	4 min	$3.0x10^{-6}$	
"	5 min	$2.3x10^{-6}$	
"	6 min	$1.8x10^{-6}$	
"	7 min	$1.4x10^{-6}$	
"	8 min	$1.2x10^{-6}$	
"	9 min	$1.0x10^{-6}$	
"	10 min	$9.6x10^{-7}$	
"	15 min	$7.1x10^{-7}$	
"	20 min	$5.4x10^{-7}$	
"	30 min	$4.3x10^{-7}$	

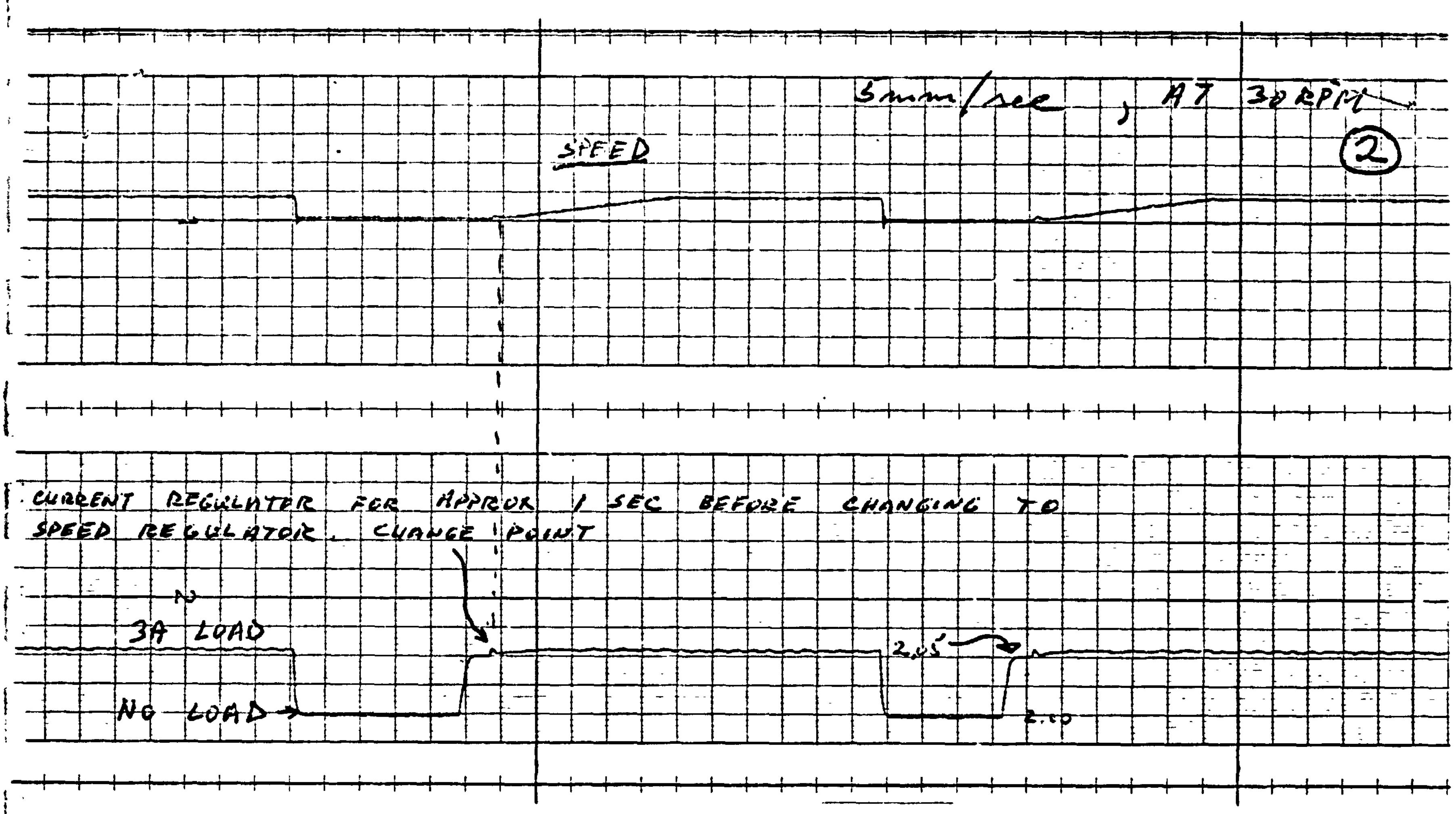
APPENDIX B

Documentation of Performance for G. E. Force Drive Unit

DOCUMENTATION OF PERFORMANCE

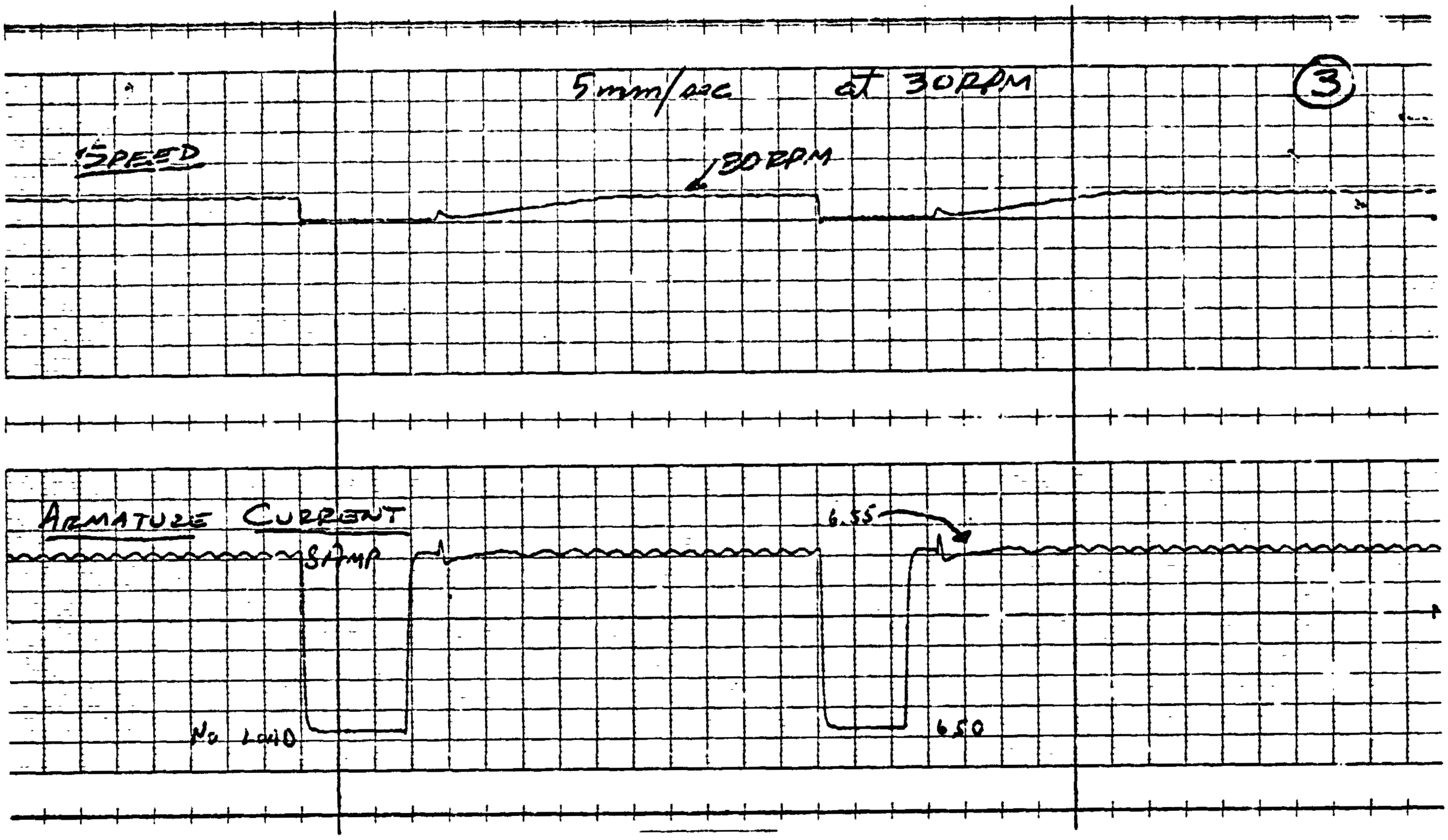


(1) This graph shows that the drive steady state speed regulation (at 10 RPM initial speed) from no load to full load is less than 0.1% of base speed. Each small horizontal line on the upper scale represents 0.3 RPM. Approximately in the middle of the graph, a 100% load (8 ampere armature current) is applied to the drive. The steady state speed (nominal) is within about 0.15 RPM of initial setting after the load change. The speed ripple is caused by interaction of the drive with the equipment used to simulate the actual load.

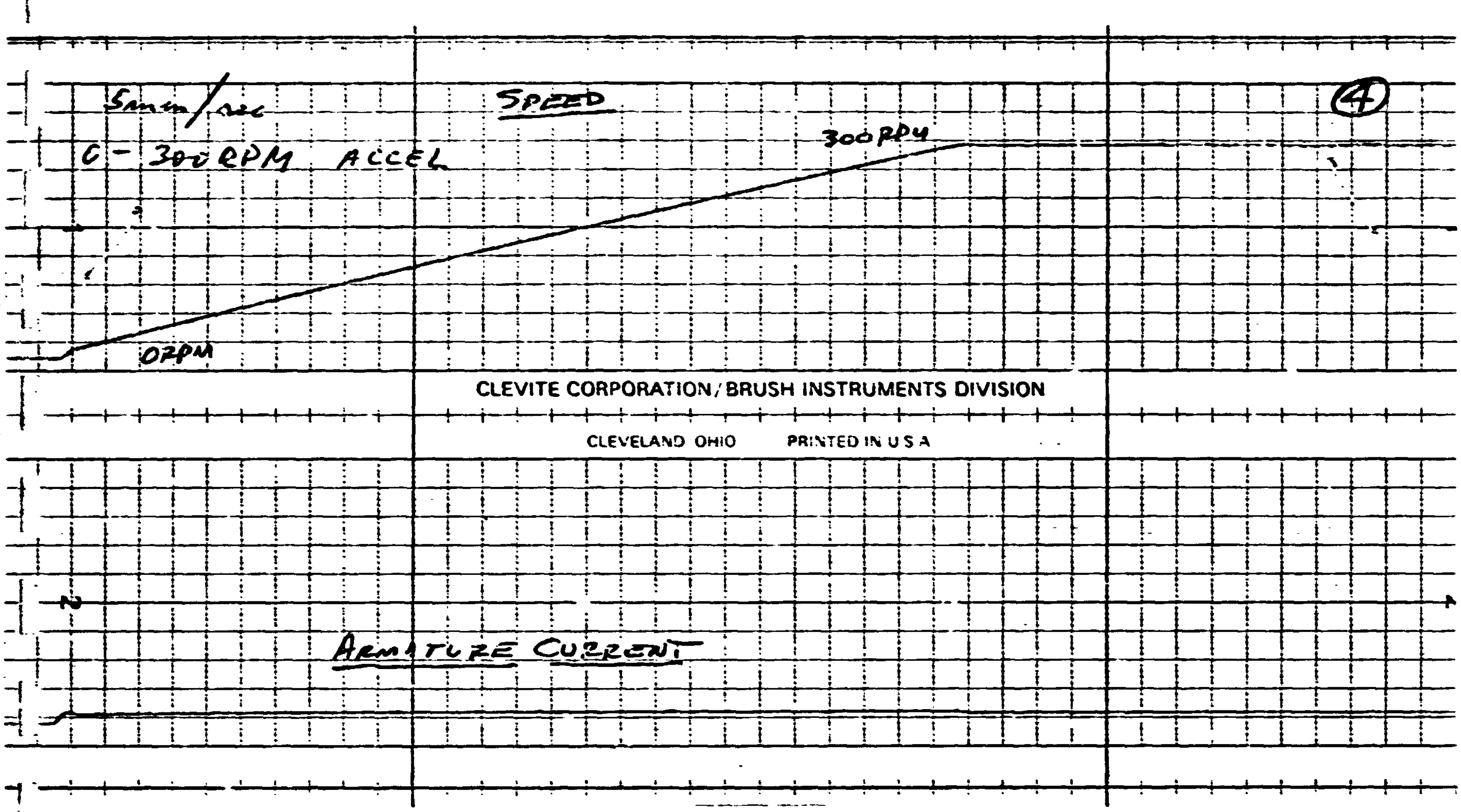


(2) This graph shows the actual operation of the drive. Starting at the extreme left hand side, speed is 30 RPM with armature current at about 3 amperes (about half load). At the first discontinuity, the brake has set and speed and current are zero because the drive has hit the preset torque value. Next the torque potentiometer was adjusted upward and the motor restarted. Notice that speed does not go negative, even though, the motor is seeing approximately half load at zero speed. The motor is actually "building up" torque to counteract this negative torque by the load before the brake releases. At the instant of "re-start", the regulator acts as a current regulator for about one second, during the current and torque "buildup" period. Next tne speed increases linearly to 30 RPM, and torque increases to the value corresponding to the 2.00 setting on the torque potentiometer, and the brake sets. The torque setting is than increased to 2.05 and the drive restarts as before.

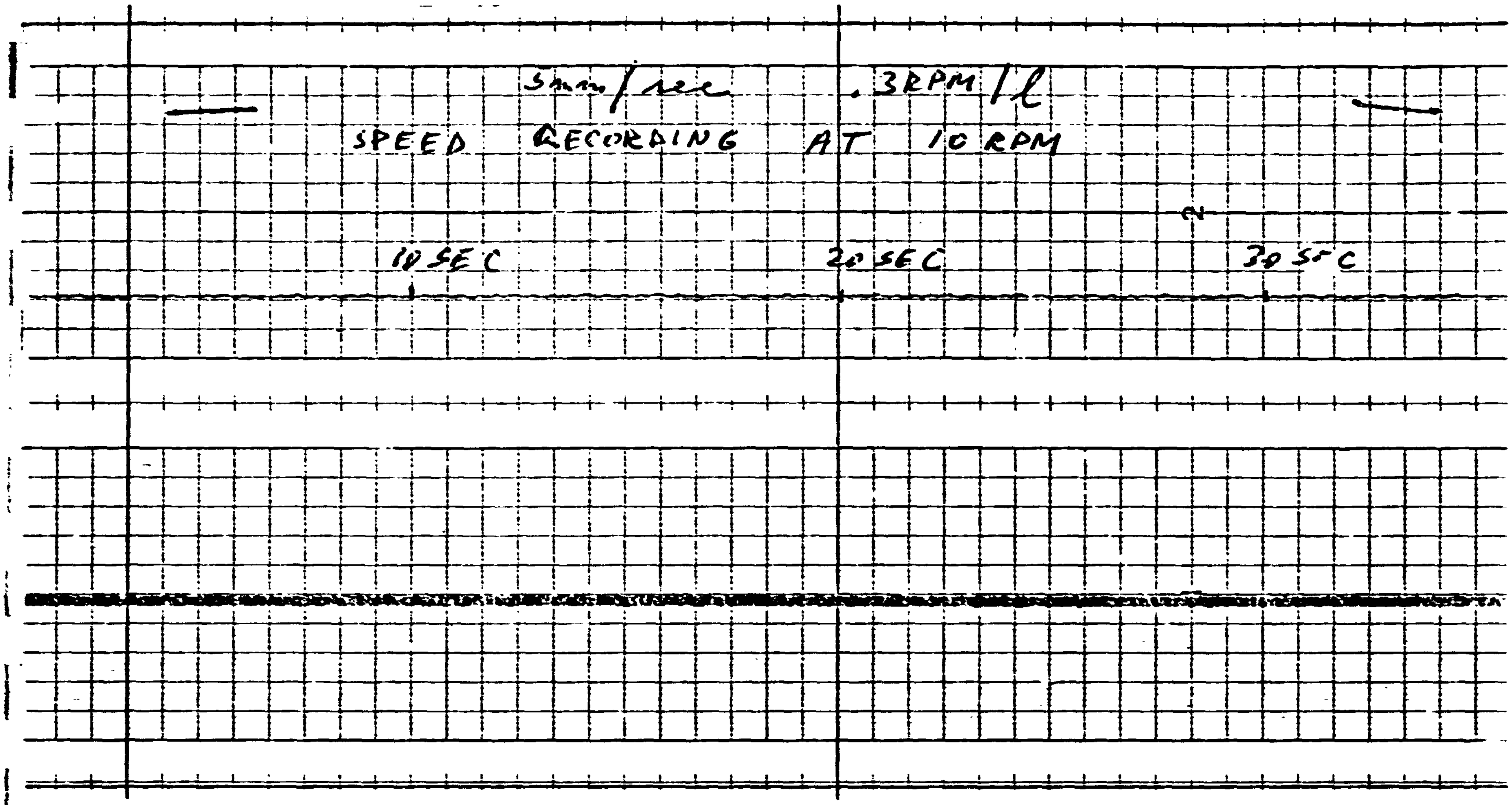
Since the torque potentiometer is a 10 turn type, the ability to preset torque to within 1% would require the drive to sense a change in setting of 1% or 1/10 turn, which is 0.10 on the scale. This curve then also shows the ability to preset torque to within 1/2% of rated.

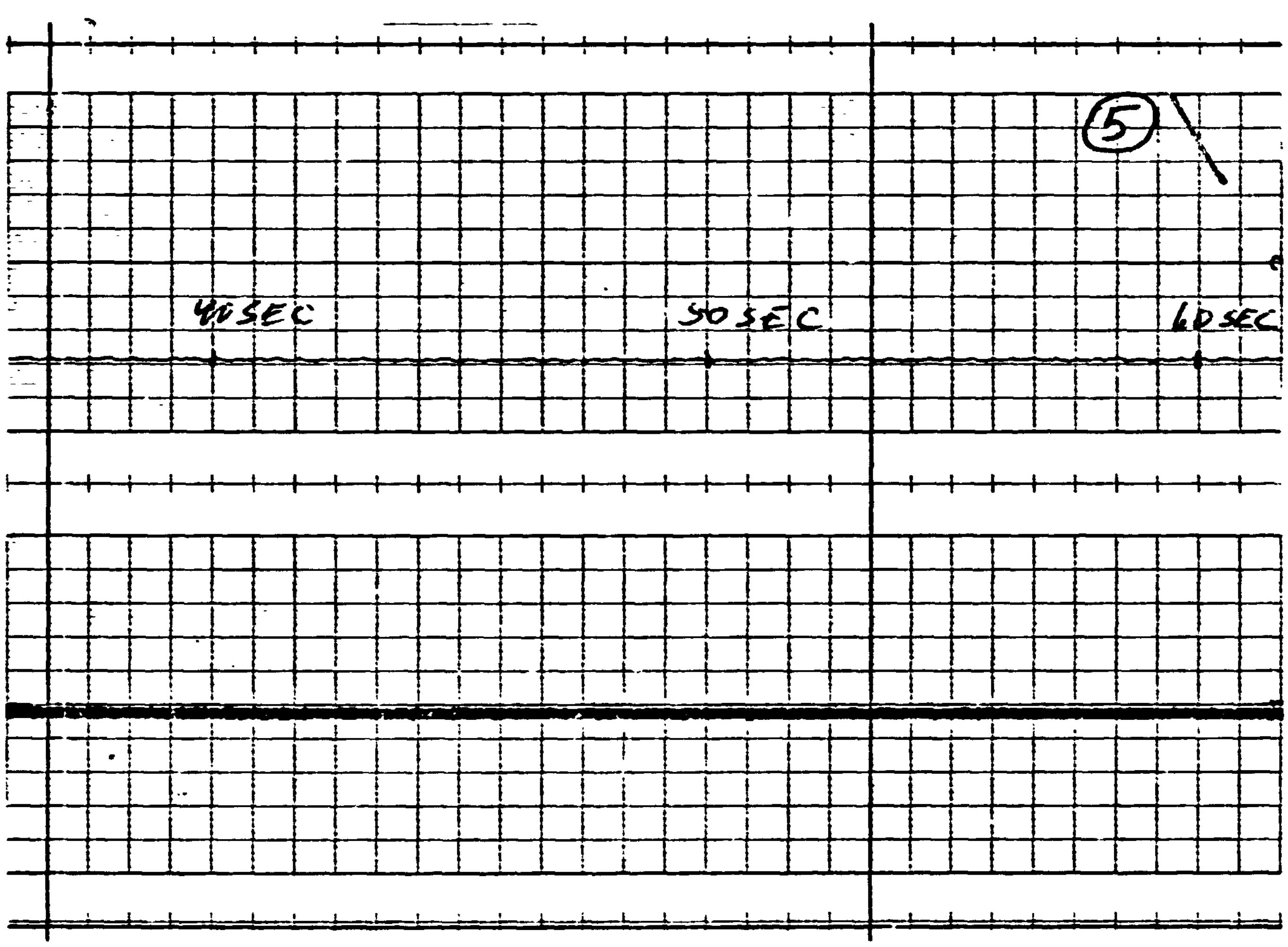


(3) This curve is the same as (2), except it is run at full load current of 8 amperes.

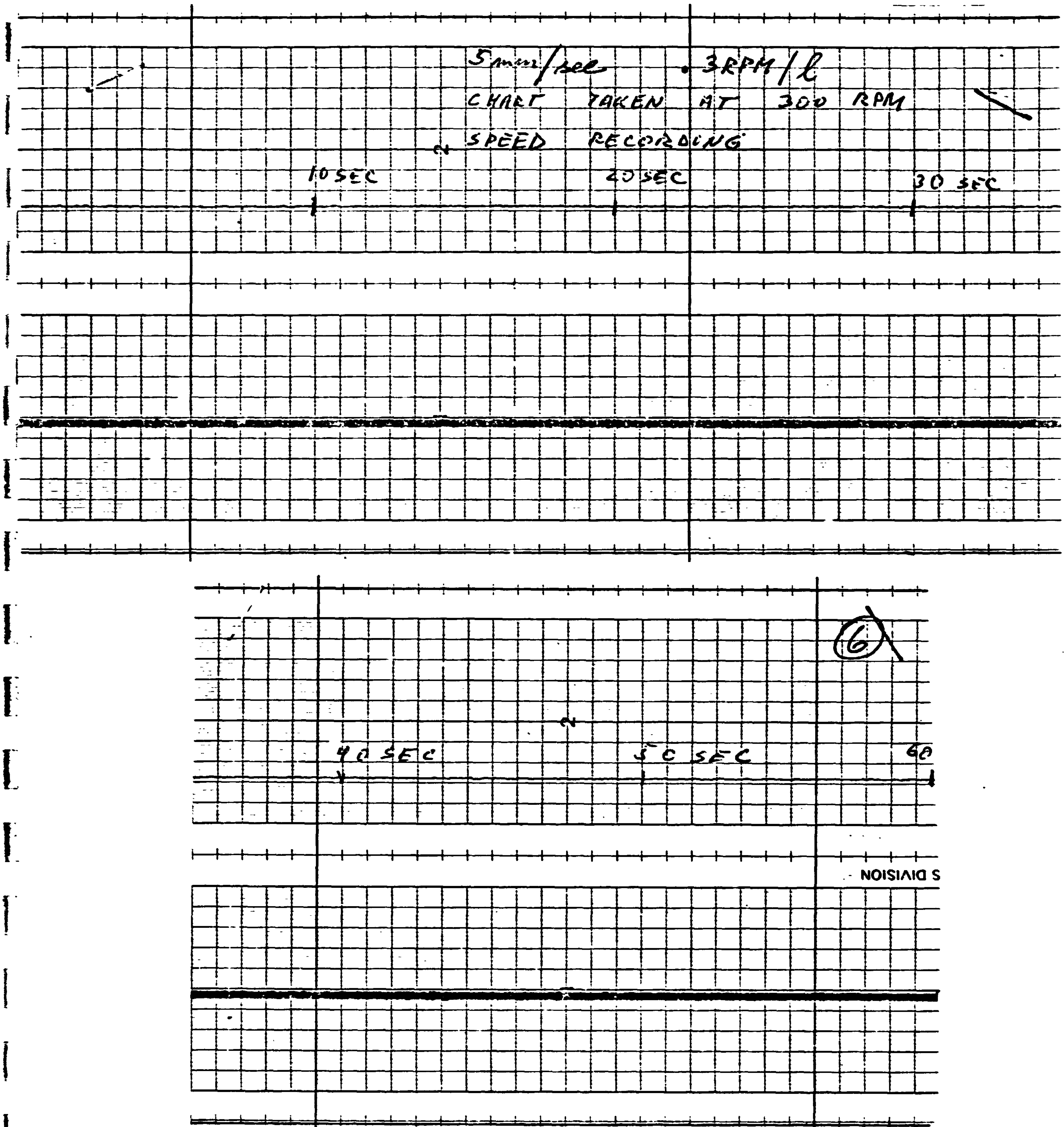


(4) This curve demonstrated the linear acceleration from 0-300 RPM, with armature current on the bottom chart. In this case the linear time function card is set at about 26 seconds.





(5) This curve demonstrates that short term (1 minute) speed drift is less than 0.15% of base speed with load being constant. Set speed is 10 RPM.



(6) Same as (5) except set speed of 300 RPM.