



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA PROGRAM APOLLO WORKING PAPER NO. 1327

6

EVALUATION OF CRYOGENIC THERMAL
DESTRATIFICATION MOTOR

(11, 7, 1, 1)

1

N70-75808

(ACCESSION NUMBER)

17

(PAGES)

TMX-65189

(NASA CR OR TMX OR AD NUMBER)

(THRU)

None

(CODE)

(CATEGORY)



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

July 27, 1967

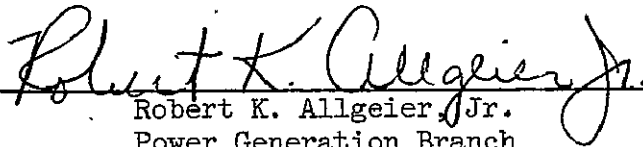
REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

17

NASA PROGRAM APOLLO WORKING PAPER NO. 1327

EVALUATION OF CRYOGENIC THERMAL
DESTRATIFICATION MOTOR

PREPARED BY


Robert K. Allgeier, Jr.
Power Generation Branch

AUTHORIZED FOR DISTRIBUTION


for Maxime A. Faget
Director of Engineering and Development

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
July 27, 1967

CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	2
DESCRIPTION OF APPARATUS	2
PROCEDURE	2
RESULTS	3
DISCUSSION	4
APPENDIX	6

Preceding page blank

FIGURES

Figure		Page
1	Assembled test equipment schematic	7
2	Oscilloscope photographs; phase-to-neutral: 50 volts	
	(a) Current trace	8
	(b) Lissajous pattern	8
3	Oscilloscope photographs; phase-to-neutral: 74 volts	
	(a) Current trace	9
	(b) Lissajous pattern	9
4	Oscilloscope photographs; phase-to-neutral: 90 volts	
	(a) Current trace	10
	(b) Lissajous pattern	10
5	Oscilloscope photographs; phase-to-neutral: 120 volts (normal operational)	
	(a) Current trace	11
	(b) Lissajous pattern	11
6	Oxygen unit speed characteristic at 1 atmosphere	12
7	Hydrogen unit speed characteristic at 1 atmosphere . . .	13

EVALUATION OF CRYOGENIC THERMAL

DESTRATIFICATION MOTOR

By Robert K. Allgeier, Jr.

SUMMARY

Alternating current electrical motors have been developed for the Apollo program as equilibration devices for cryogenic oxygen and hydrogen. This report presents the results of laboratory tests of one equilibration unit design.

The purpose of this test was to determine performance characteristics of Apollo cryogenic storage system equilibration units during continuous and cyclic operation. This evaluation included determination of power input, at various speeds in air and liquid nitrogen, associated with an Apollo-sized tank and heater mockup. Phase-to-phase and phase-to-neutral parameters were measured and recorded at several phase-to-neutral voltages in both oxygen and hydrogen. Photographs of the associated oscilloscope traces were also made. The test units were cycled with on-off timers and were subjected to duration testing in liquid nitrogen and liquid oxygen.

The testing consisted of submerged running in liquid nitrogen, liquid oxygen, liquid hydrogen, and water. One unit was restarted 1160 times and was run for a total of 1009 hours.

The motor was also analyzed for efficiency and slip. Stall, magnetic characteristics and motor speeds were determined at various phase-to-neutral voltages.

The motor fan units exhibited no degradation throughout the test program when run in cryogenic fluids. This testing provided a needed degree of confidence in this method of destratification. The Apollo cryogenic gas storage system has since been qualified for manned space flight.

INTRODUCTION

The storage of cryogenic fluids requires careful consideration of thermal control and protection. One characteristic of stored cryogenic fluids is termed thermal stratification. This phenomenon is caused by nonuniform heat transfer to the fluid, coupled with convective forces in a gravity field. The heat source may be the environment or a heater located within the storage vessel. A thermally stratified system is not in equilibrium and an unstable pressure occurs which is established by the vapor pressure of the highest temperature fluid zone. Equilibration, or mixing of thermally stratified system, results in a new equilibrium storage pressure. In a spacecraft, thermal stratification can result in a loss of system pressure control. This occurred on Gemini-Titan V and was duplicated during testing by EP6 at NASA-MSC. This effort is reported in Internal Notes MSC-IN-65-EP-13 and MSC-IN-65-EP-6.

Equilibration of Apollo spacecraft cryogenic tankage is accomplished by mechanically stirring the stored fluid with an electrical impeller device. Testing of this device has been performed at NASA-MSC. The results of this test are presented.

DESCRIPTION OF APPARATUS

The apparatus is represented schematically in figure 1. The test setup consisted of an insulated lucite hemisphere with an evacuated double-wall window and supports for the dummy heater and attached motor fan unit. The peripheral equipment consisted of an ammeter, voltmeter, strobe light, electronic frequency changer, and an oscilloscope. Additional equipment such as transfer lines and an electrical harness were also used. The motor fan test units were placed in an evacuated bell jar after each run to prevent corrosion due to condensed moisture from the atmosphere.

PROCEDURE

- I Position the hemispherical tank and tank supports
- II Attach motor fan test unit to dummy heater and attach the assembly to the vertical support
- III Record phase resistances at ambient temperature
- IV Set timer at zero

- V Fill hemispherical tank with liquid nitrogen
- VI Connect electrical leads
- VII Activate motor fan unit
- VIII Record all phase-to-phase and phase-to-neutral voltages and amperages
- IX Vary voltages and record voltages and motor power
- X Switch to on-off cyclic mode of operation
- XI Review Lissajous patterns for all phase-to-phase combinations
- XII Slowly decrease voltage and record stall voltage and amperage
- XIII At close of run, record phase resistances
- XIV Detach motor fan unit and place in bell jar
- XV Evacuate bell jar

RESULTS

Operation of the motor fan units was verified in liquid oxygen, liquid nitrogen, and liquid hydrogen. These units demonstrated no problems concerning restart or endurance when run submerged in the cryogenic fluids.

The electrical analysis indicated that the full current (also known as flux capacity or magnetic saturation) of these units was reached at approximately 74 volts phase-to-neutral which is considerably less than the nominal voltage of 120 volts. The efficiency and slip for these voltages are

Voltage	Slip, percent	Efficiency, percent
74	55	44
120	52.7	47.2

The Lissajous (phase voltage) patterns and current traces for several phase-to-neutral voltages are shown in figures 2 to 5. These traces are identical for each phase and show the deformities encountered at magnetic saturation. The Appendix shows a general method for calculation of the power factor utilizing the Lissajous pattern. Phase-to-neutral voltage as a function of motor speed is presented in figures 6 and 7. These figures show that the design speed at no-load is reached at relatively low phase-to-neutral voltages and remains constant with increasing voltage. When loaded, the motor fan units exhibit irregular increases in speed with increasing voltage. It is evident from these figures that speed control is poor.

As expected, the phase-to-phase resistance of the fan units was very low at cryogenic temperatures compared to the same measurement at ambient temperature.

DISCUSSION

In general, the results of the testing at NASA-MSC have shown the Apollo cryogenic equilibration units to be capable of long life. A single unit was tested for 1160 on-off cycles over a period of 50 hours and for continuous running for a period of 1009 hours.

The motors were designed for operation in a pure environment of liquid hydrogen or liquid oxygen. During testing, water vapor condensed upon the unit following a run in a cryogenic environment. This unforeseen contaminant did not degrade subsequent performance.

The manufacturer recommended that the motor fan units not be run in ordinary tap water. Therefore, distilled water was used for the water immersion tests. One hydrogen and one oxygen motor unit were run in distilled water and rapidly degraded in approximately 30 seconds. This degradation was attributed to oxidation of the rotor which caused the airgap to clog. Disassembly and analysis of the oxygen motor was performed by ES41/Structures and Mechanics Division which resulted in this failure analysis. The oxidation of the rotor was attributed to the corrosive hydroxyl ion present in water. This ion is not present in a pure cryogen and no correlation between oxidation in water and failures in a cryogen would be correct.

Oscilloscope plots of separate phase voltages on the vertical and horizontal axes were used extensively. This technique ideally results in an ellipse called a Lissajous pattern. At approximately 74 volts phase-to-neutral, the ideal ellipse began to deform. This deformity became more pronounced as the voltage increased to the operating voltage of 120, phase-to-neutral. This deformity indicates that the motor

windings were magnetically saturated; that is, they had reached maximum flux capacity at or near 74 volts phase-to-neutral, which is well below the operating voltage.

Calculation of motor efficiency at magnetic saturation indicates a theoretical efficiency of 44 percent. This efficiency is low for an electrical motor, but high efficiency is not a requirement for this application.

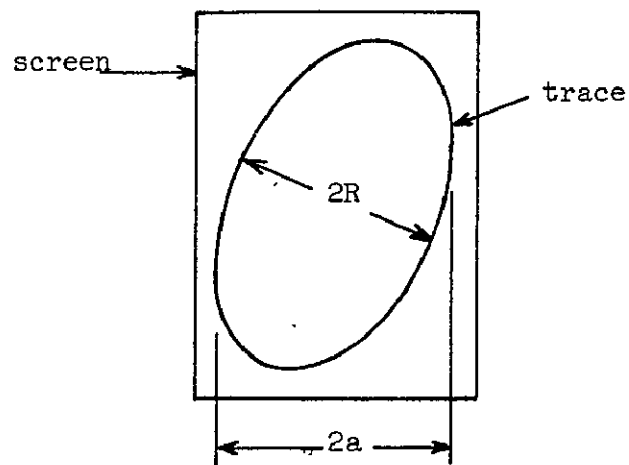
Both motor fan units reached nominal running speed at approximately 36 volts phase-to-neutral, which is well below operational voltages. No increase in motor speed occurred as voltage increased. Speed control was therefore impossible to achieve, but was not a design requirement.

APPENDIX

To determine the power factor from the Lissajous pattern, utilize the following equation

$$\text{Cosine of the phase angle (power factor)} = 1 - R^2/a^2$$

where R and a are determined from the oscilloscope trace as follows:



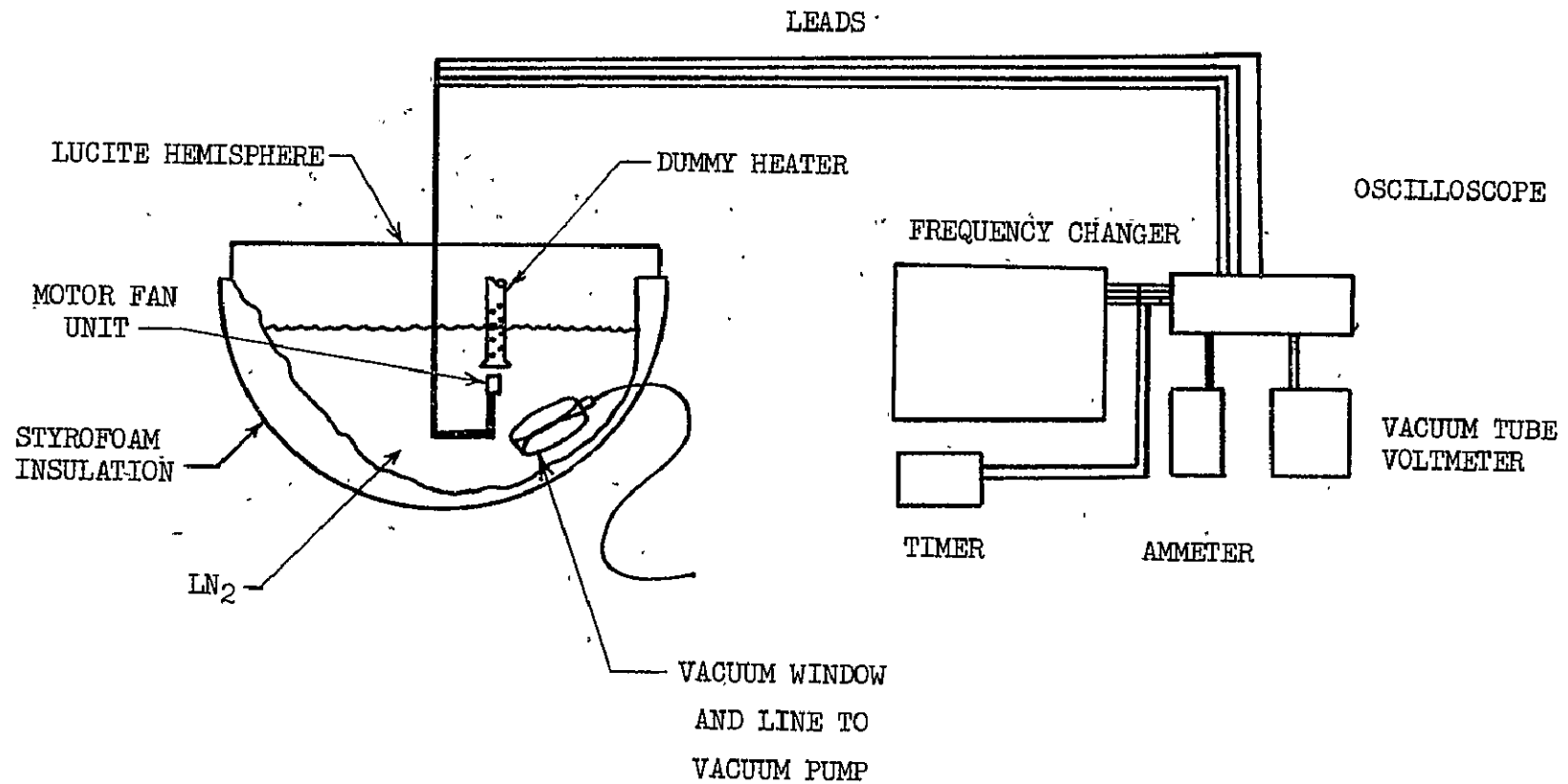
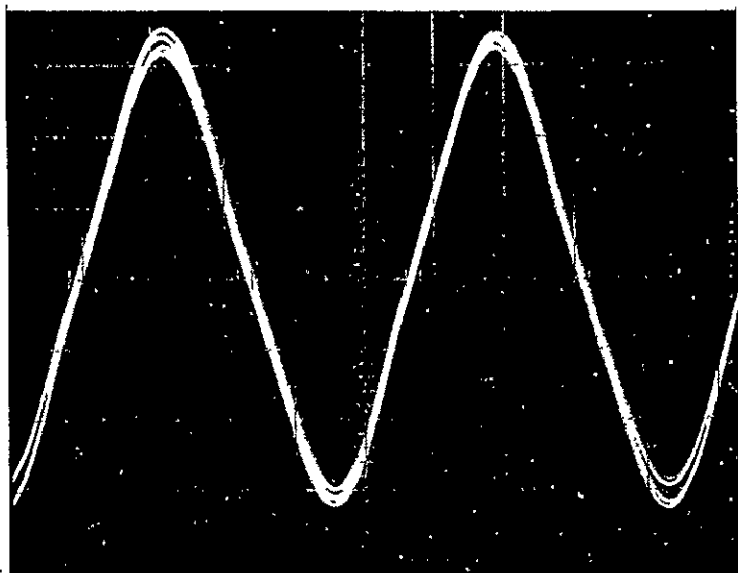
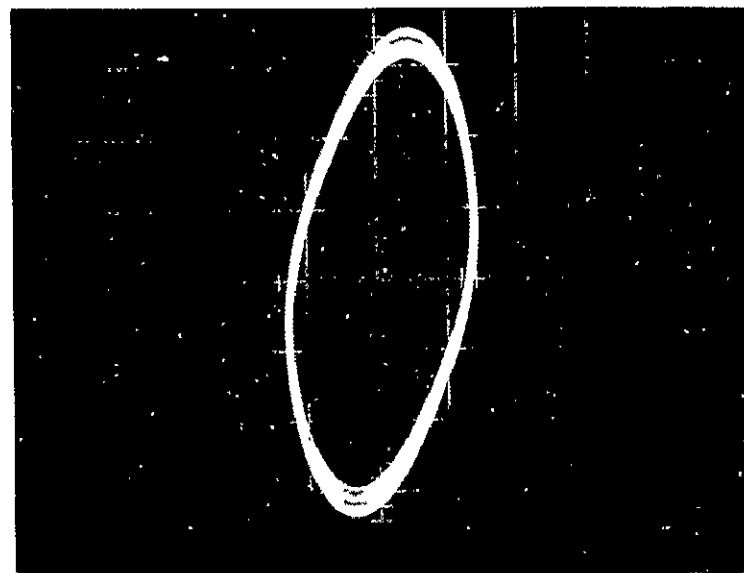


Figure 1.- Assembled test equipment schematic.



(a) Current trace.



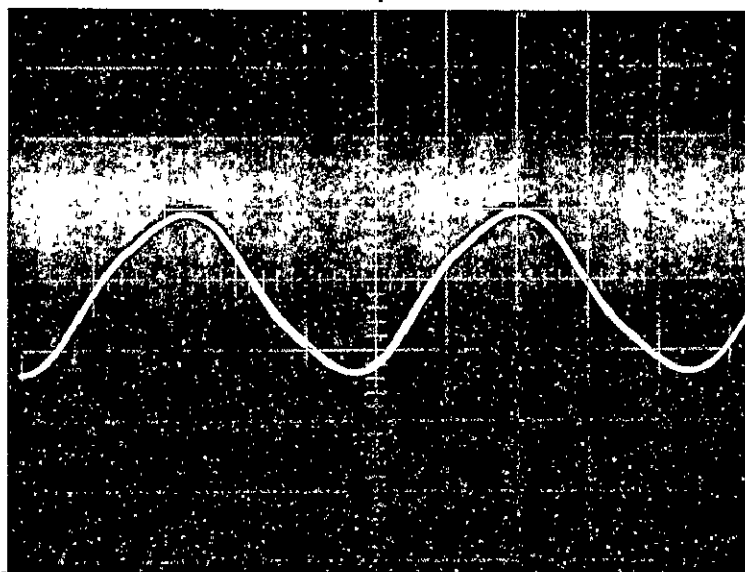
(b) Lissajous pattern.

Horizontal and vertical sensitivity: 20 full CCW (uncalibrated)
Sweep: 0.5 μ sec

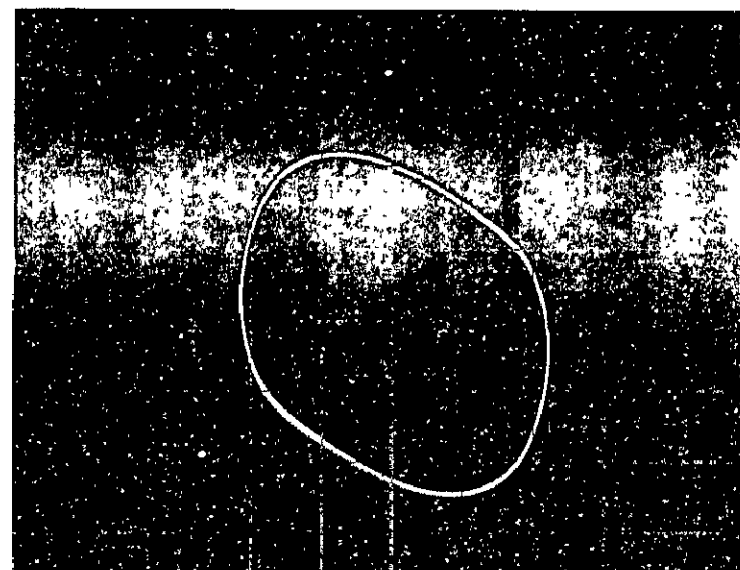
Lens: F-8
Shutter: 1/50 sec

Data is typical of all photographs unless noted

Figure 2.- Oscilloscope photographs; phase-to-neutral: 50 volts.

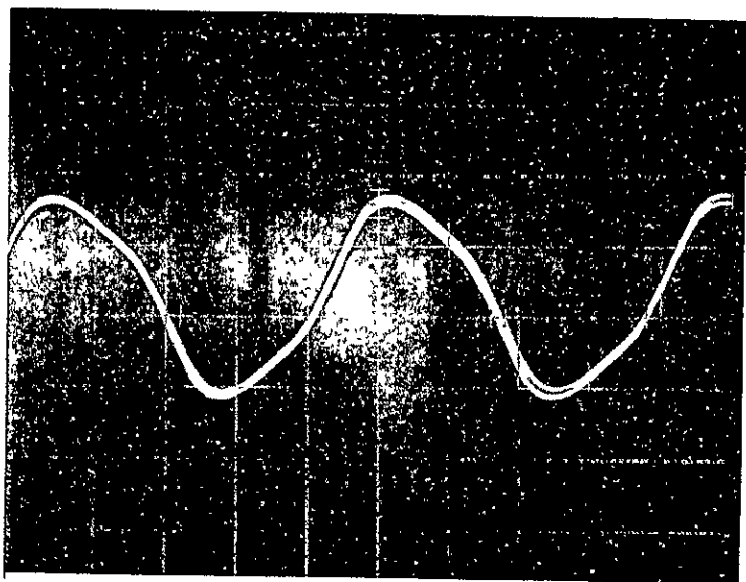


(a) Current trace, vertical
sensitivity: 0.1.

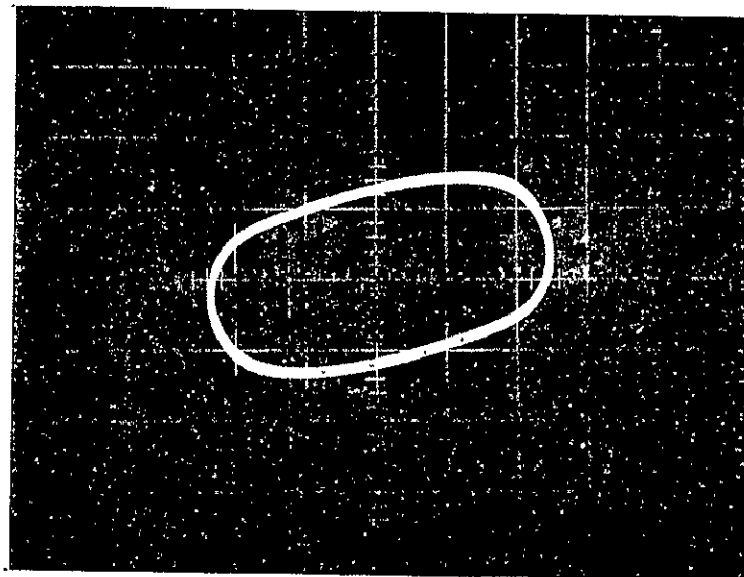


(b) Lissajous pattern, vertical
sensitivity: 50.

Figure 3.- Oscilloscope photographs; phase-to-neutral: 74 volts.



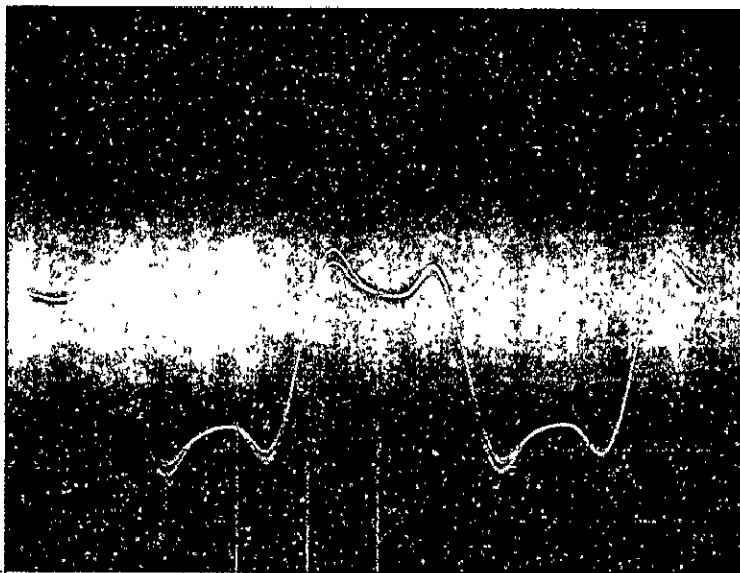
(a) Current trace.



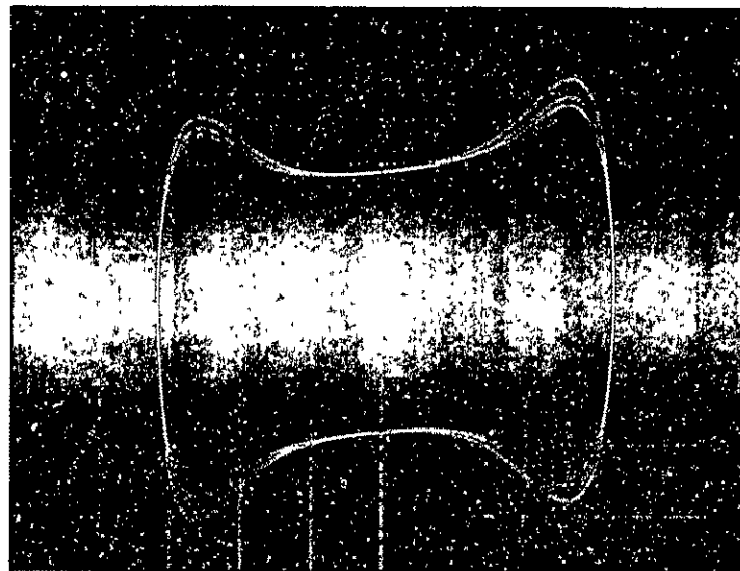
(b) Lissajous pattern.

Vertical sensitivities: 0.1

Figure 4.- Oscilloscope photographs; phase-to-neutral: 90 volts.



(a) Current trace, vertical
sensitivity: 0.2.



(b) Lissajous pattern, vertical
sensitivity: 0.1.

Figure 5.- Oscilloscope photographs; phase-to-neutral: 120 volts (normal operational).

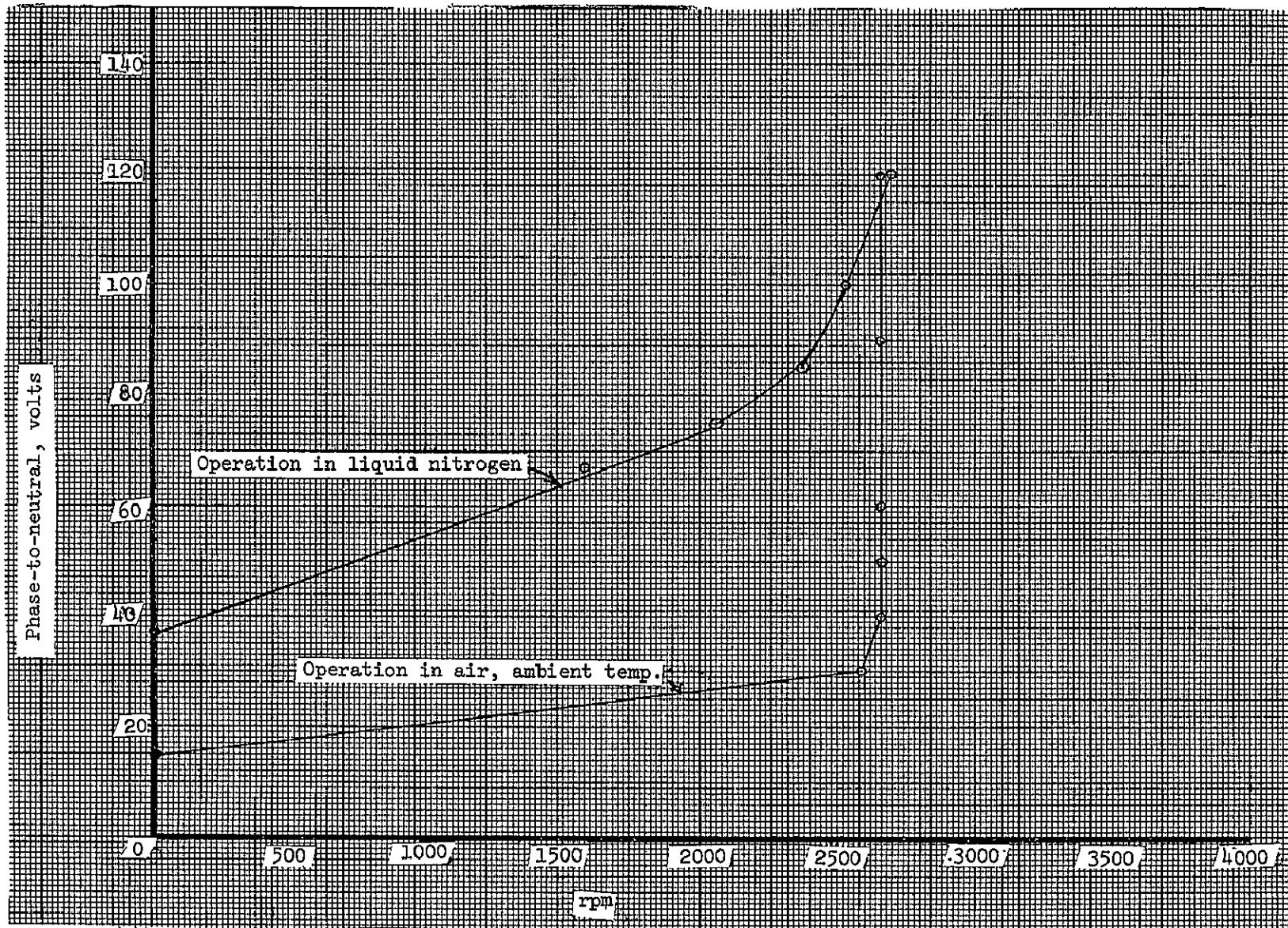


Figure 6.- Oxygen unit speed characteristic at 1 atmosphere.

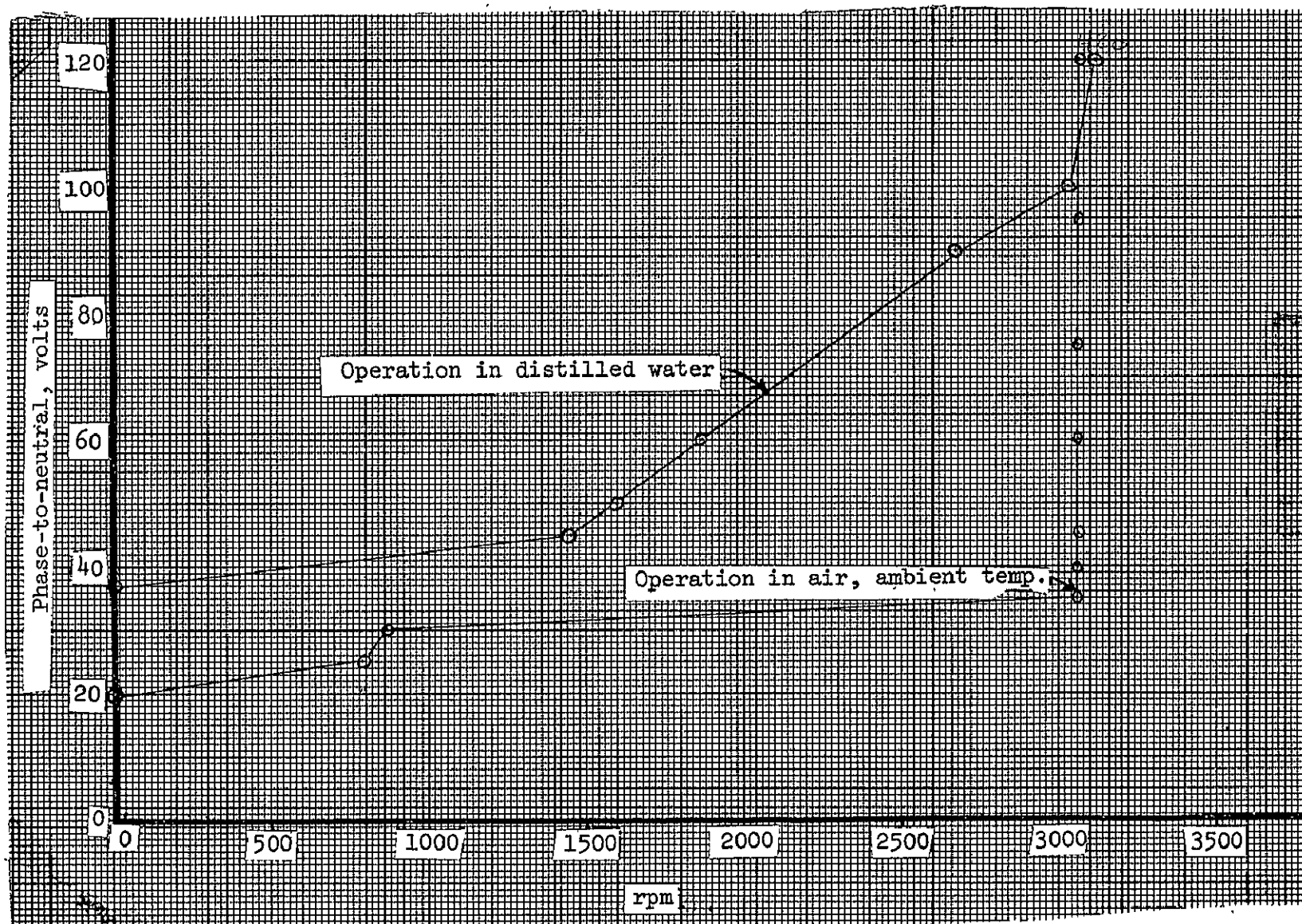


Figure 7.- Hydrogen unit speed characteristic at 1 atmosphere.