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Pioneer Venus Mechanical Roots Pump Test and Evaluation

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Pioneer Venus Mechanical Roots Pump Test and Evaluation

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for

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September 1973

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Systems Division

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SECTION 1

SUMMARY

This is the final report of a follow-on task to "A Study of the Feasibility of Mechanical Pumps for Use with the Pioneer-Venus Probe Mass Spectrometer Inlet System," Contract NAS2-7384. The objective of this effort was to obtain a small Roots blower from the Arthur Pfeiffer Company of Wetzlar, Germany and to evaluate its performance characteristics.

The pump was obtained, and a limited performance testing program, including ultimate/compression ratio tests and throughput tests at three different pump speeds, was performed. Considerable operating experience with the pump was obtained over approximately 200 hours of running. The test results show general agreement with the pump specifications as established by the Arthur Pfeiffer Company. The pump was also disassembled and reassembled, in our presence by a representative of the Arthur Pfeiffer Company, so that we could perform this operation and so that we might view the design details of the pump.

The report presents a description of the pump design and construction, the overall test plan, procedures, test results, and conclusions. Raw data obtained during the testing is contained in Appendix A.

SECTION 2

INTRODUCTION

This report contains the results of a mechanical Roots pump test program, conducted as a follow-on task to the study effort reported in NASA CR 114581. The specific tasks undertaken in this program are:

- Obtain an improved model of the Roots pump produced by the Arthur Pfeiffer Company of Germany, consistent with the specifications contained in NASA CR 114581.

  Obtain engineering assistance from the Arthur Pfeiffer Company for operational instruction.

- Prepare a test plan and experimentally determine the following characteristics of the Roots pump over its operational range:

  - Compression ratio as a function of backing pressure.
  - Pumping speed as a function of backing pressure.
  - Temperature rise during operational performance testing.
  - Effect of cooling on pumping characteristics.
  - Power requirements as related to pumping characteristics.

- Analyze the test results and, from the raw data, calculate the information necessary to prepare a graphical representation of the pump characteristics.

- Prepare a detailed engineering report containing these results, the raw test data, the conclusions, and the recommendations.

SECTION 3

PUMP DESIGN AND CONSTRUCTION

The Roots pump is a small, three-stage pump produced by Arthur Pfeiffer Vakuumtechnik GmbH of Wetzlar, Germany. Figure 3-1 shows the external configuration of the pump. The pump is a cylinder approximately 11 cm in diameter by 14.7 cm high weighing 3.4 kg. This pump is a second generation feasibility demonstration model of the pump. Further flight unit design refinements would result in a weight reduction of from 0.5 to 1.0 kg and materials changes required to make the pump compatible with the expected flight environment. Details of the pump construction and assembly are shown in Figure 3-2.

Figure 3-2(a) shows the pump main shaft. From left to right, the components are a nut, a washer, a spring, a ball bearing, the first (suction) piston, a spacer ring, the second piston, a spacer ring, the third piston, a grooved spacer ring, a self-aligning bearing, gear hexagonal nut, and the rotor (permanent magnet) of the drive motor. Figure 3-2(b) is the housing of the first stage viewed from the top and Figure 3-2(c) is the housing viewed from below. Figure 3-2(d) shows the first stage assembly complete. Figure 3-2(e) shows the partitions between the first and second stage and the second and third stage. Figure 3-2(f) shows the completely assembled second stage with the partition and the pistons and spacer rings of the third stage. Figure 3-2(g) shows the housing of the third stage, with the self-aligning bearings in place. Figure 3-2(h) shows the completed assembly of the stages, with the rotor of the drive motor in place.

Figure 3-3 is a schematic diagram of the drive circuit. Table 3-1 lists the component values. The electronics unit and the pump are interconnected through a cable and a 19-pin connector. Figure 3-4 shows the top and bottom of the circuit board contained within the package. The board interconnections and cable color-coding are given in Table 3-2.

To adjust the electronics for proper motor operation, the switch points of operational amplifiers OP 1 through OP 4 are adjusted by potentiometers P 1 through P 4 so that square-wave signals of equal width appear on the outputs of resistors R 21 through R 24. Clockwise adjustment of the potentiometers results in shortening the switching time of transistors T 5 through T 8. Speed control is provided by adjustment of potentiometer P 5. Clockwise adjustment reduces the speed.

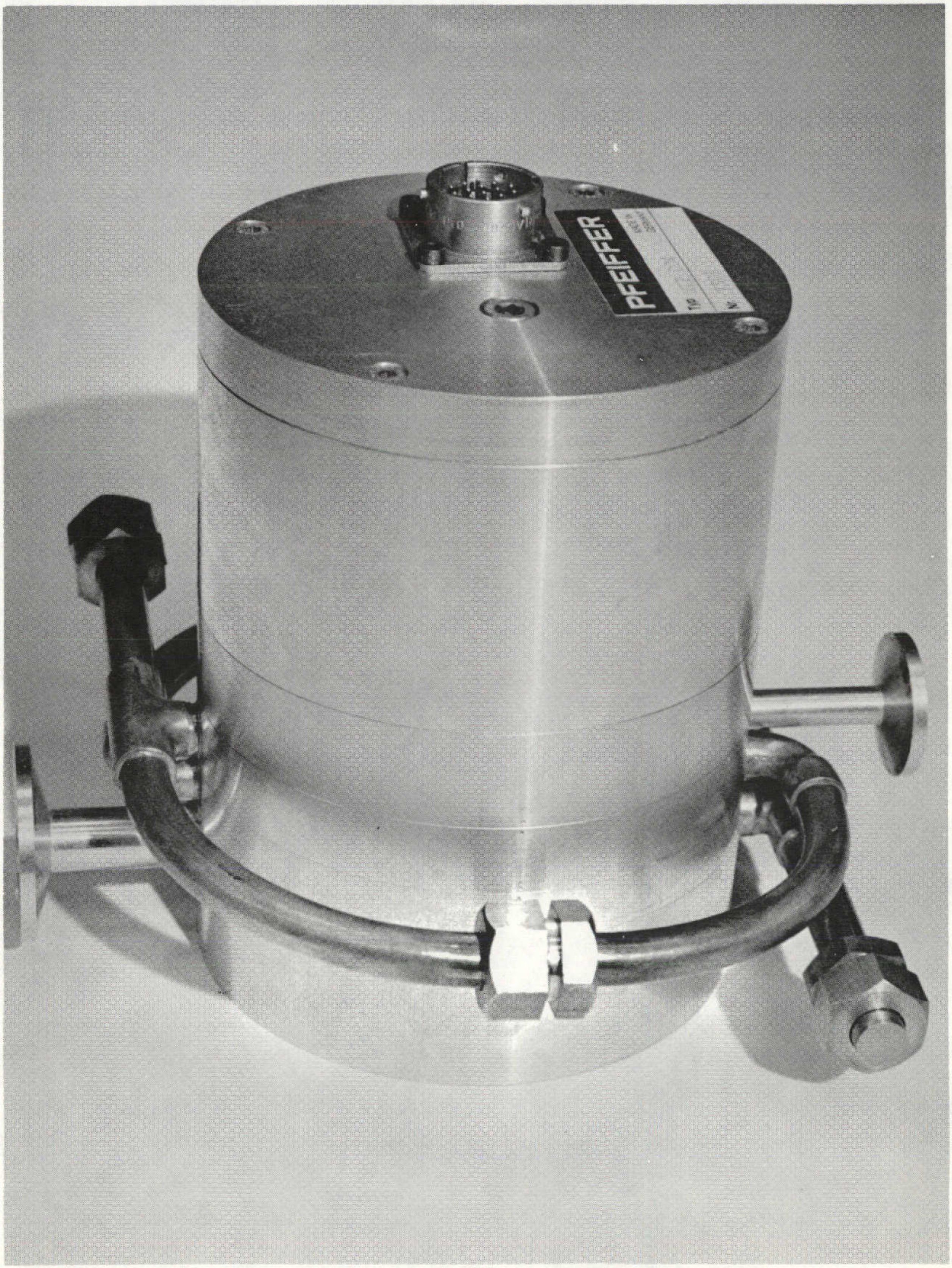

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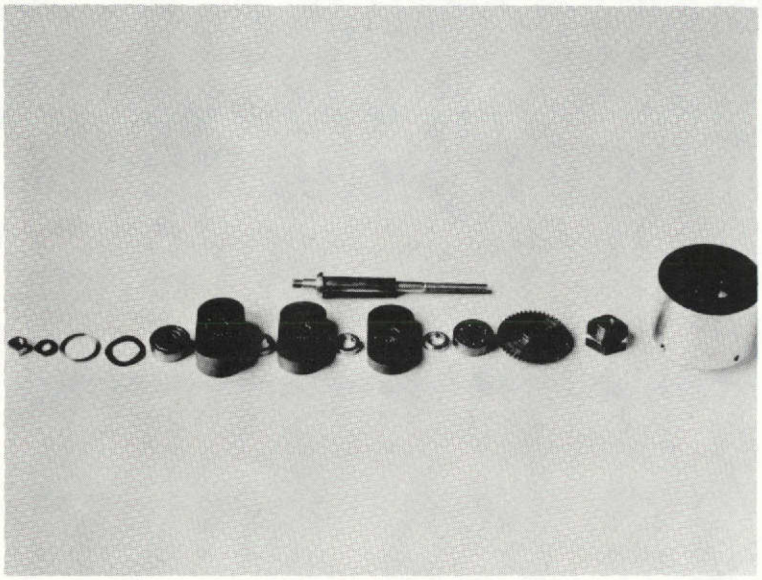
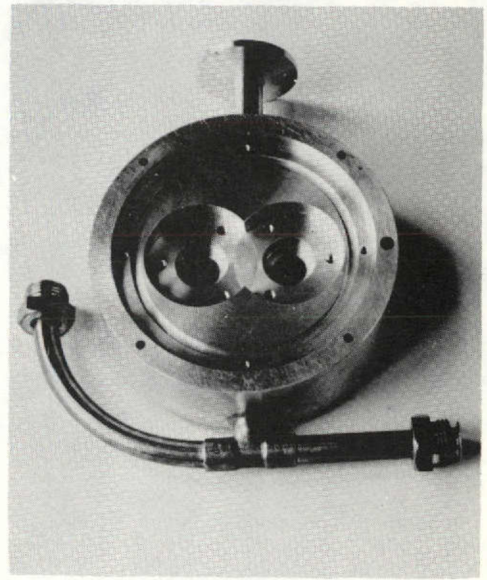
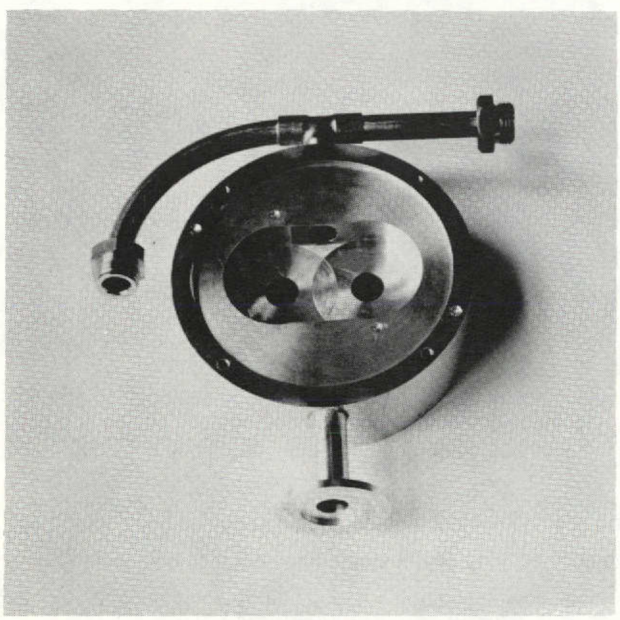
Figure 3-1 Mechanical Roots Pump



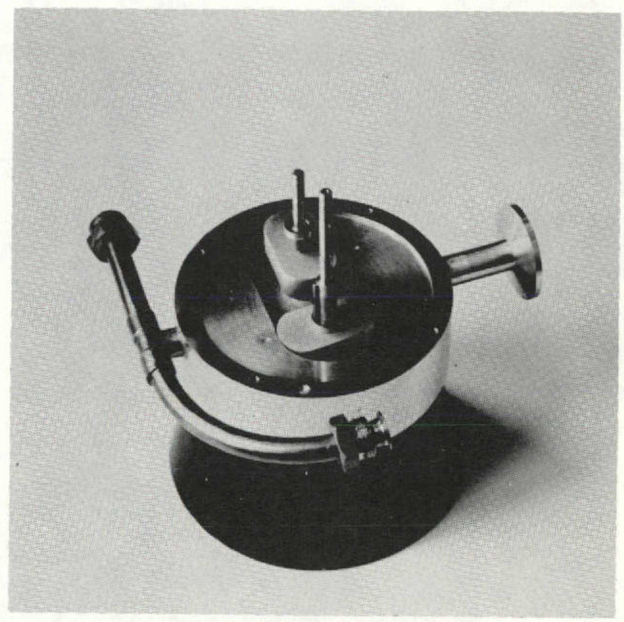
(a) Pump Main Shaft



(b) First Stage Housing; Top



(c) First Stage Housing; Bottom



(d) Completed First Stage

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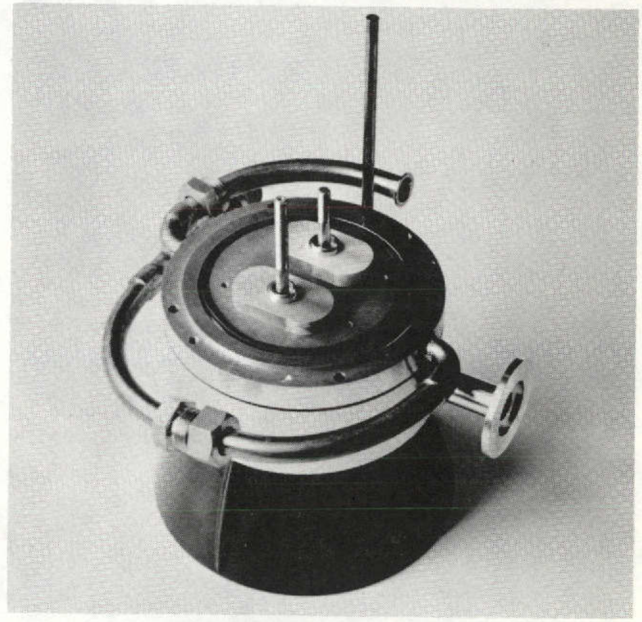
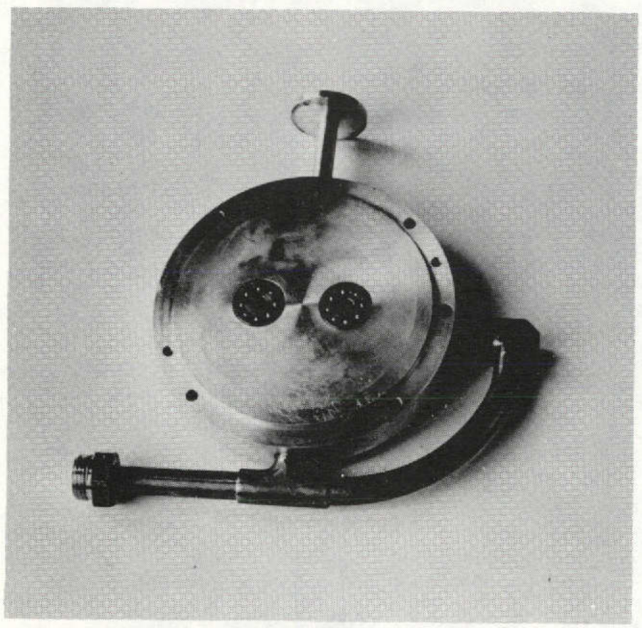
Figure 3-2 Roots Pump Construction and Assembly

(e) Stage Partitions



(f) Completed Second Stage



(g) Third Stage Housing

(h) Completed Assembly with Drive Motor Rotor

Figure 3-2 Roots Pump Construction and Assembly (Cont.)

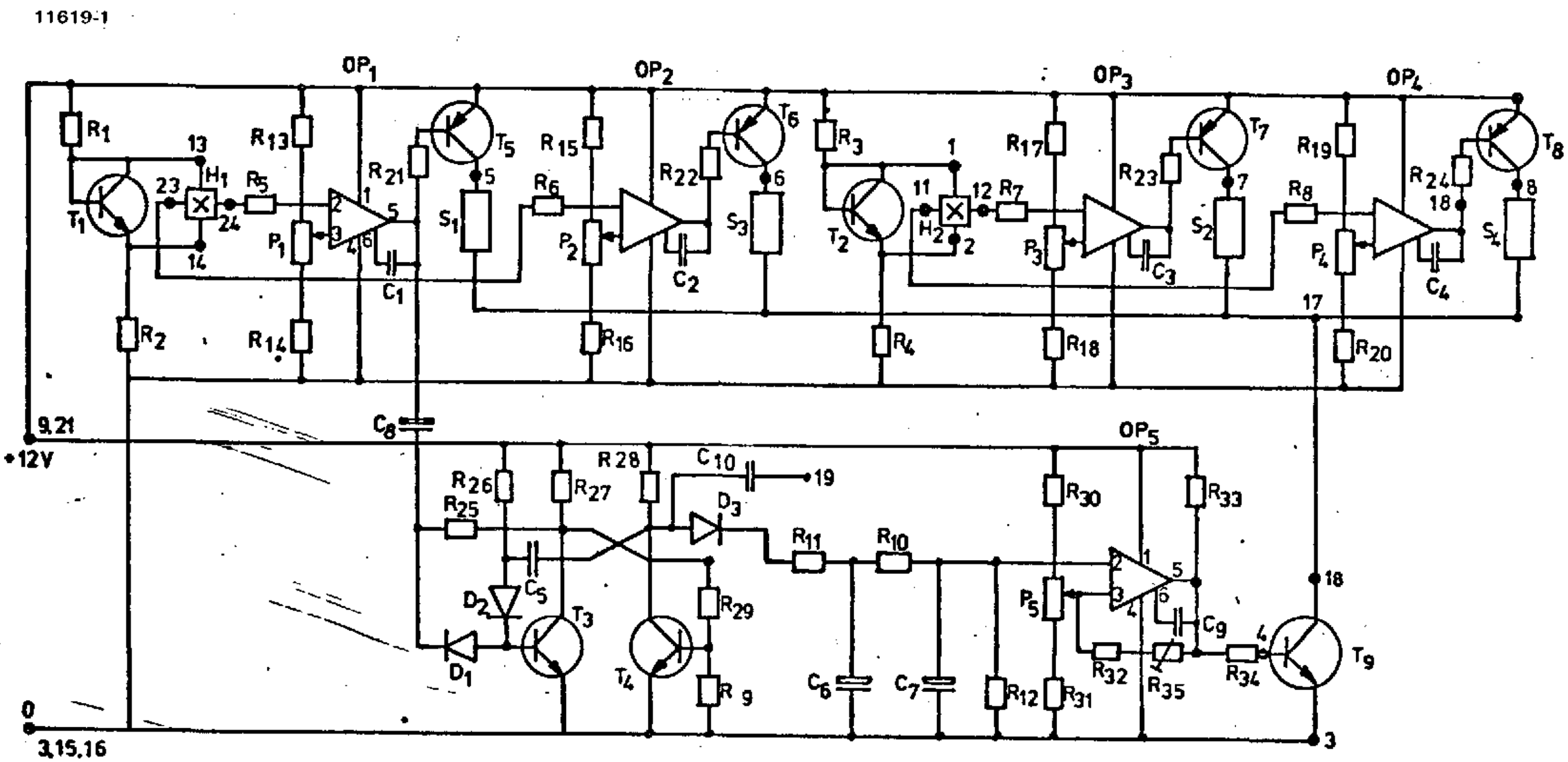
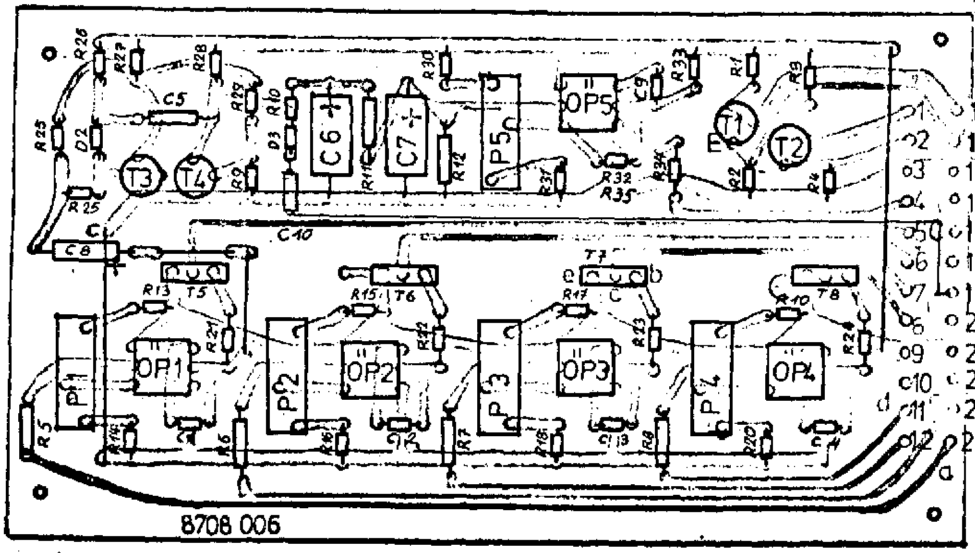


Figure 3-3 Pump Drive Circuit

Table 3-1

Drive Circuit Components

Reference Designation	Part	Value
C1 - C4	Capacitor	33 pF (20 V)
C5	Capacitor	100 nF (20 V)
C6, C7	Capacitor, Electrolytic	4.7 μF (20 V)
C8	Capacitor, Electrolytic	0.1 μF (20 V)
C9	Capacitor	56 pF (20 V)
C10	Capacitor	22 nF (20 V)
D1 - D3	Diode, Silicon	BAY 19
H1, H2	Hall Probe	SBV 556
OP1-OP5	Operational Amplifier	TAA 861A
P1 - P4	Potentiometer	1 kohm (0.3 W)
P5	Potentiometer	500 ohms (0.3 W)
R1 - R4	Resistor	240 ohms (0.3 W)
R5 - R10	Resistor	12 kohms (0.3 W)
R11	Resistor	2 kohms (0.3 W)
R12	Resistor	5.6 kohms (0.3 W)
R13 - R20	Resistor	2.2 kohms (0.3 W)
R21 - R24	Resistor	470 ohms (0.3 W)
R25, R26	Resistor	33 kohms (0.3 W)
R27, R28	Resistor	2.7 kohms (0.3 W)
R29	Resistor	20 kohms (0.3 W)
R30	Resistor	4.7 kohms (0.3 W)
R31	Resistor	1.2 kohms (0.3 W)
R32	Resistor	13 kohms (0.3 W)
R33	Resistor	390 ohms (0.3 W)
R34	Resistor	270 ohms (0.3 W)
R35	Resistor, Adjustable	250 kohms (0.3 W)
T1 - T4	Transistor, NPN	BC 107B
T5 - T8	Transistor, PNP	BD 136-10
T9	Transistor, NPN	2 N 3055
S1 - S4	Motor Coil	



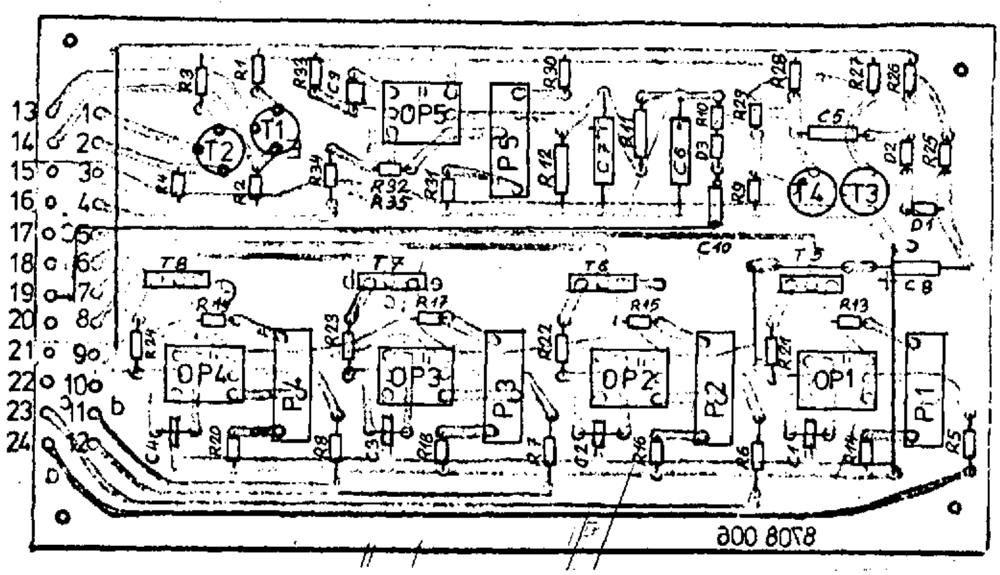


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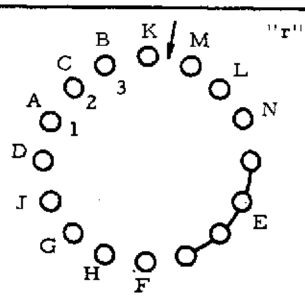
Figure 3-4 Circuit Board Layout

Table 3-2

Board Interconnections and Cable Color Code

Soldering Lug Strip	Connection	Cable Color	Plug Pin
1	H2 control current	green	F
2	H2 control current	green	G
3	T9 emitter (connected with 15)		
4	T9 base	yellow	
5	T5 collector	red	A
6	T6 collector	red	B
7	T7 collector	red	C
8	T8 collector	red	D
9	+ 12 V power supply (connected with 21)		
10	Not used		
11	H2 signal	green	H
12	H2 signal	green	J
13	H1 control current	yellow	K
14	H1 control current	yellow	L
15	Power supply ground	black socket on front panel	
16	Power supply ground (connected with 15)		
17	Star point of motor coils	black	E
18	T9 collector (connected with 17)		
19	Output for rpm indicator	yellow socket on front panel	
20	Not used		
21	+12 V power supply	red socket on front panel	
22	Not used		
23	H1 signal	yellow	M
24	H1 signal	yellow	N



"r" figure stamp on stator laminations

Motor Socket

SECTION 4

TEST PLAN

This section of the report contains the test plan for the Pfeiffer Roots pump. Three types of tests are performed: (1) compression ratio-ultimate pressure, (2) throughput, and (3) effects of temperature and power characteristics.

4.1 COMPRESSION RATIO — ULTIMATE PRESSURE

4.1.1 General Description

A series of tests under "no flow" conditions are performed to determine the ultimate obtainable pressure and compression ratio as a function of the backing pressure. Pump power and temperature are monitored during the tests. Figure 4-1 shows, schematically, the test manifold that is used for this purpose. It is constructed from 3/8 in. stainless-steel tubing and Teflon-sealed brass Swagelok fittings and valves. The combination of a mechanical pump, throttle valve, and air leak on the output side of the pump are used to maintain a desired output pressure. Beryllium copper and molecular sieve traps are used to minimize mechanical pump oil backstreaming. The test dome is actually nothing more than a 3/8 in. Swagelok cross.

4.1.2 Test Procedure

4.1.2.1 Preparation

With the throttle valve open, the entire system is evacuated and purged with dry nitrogen (LN_2 boil off) to ensure a controlled atmosphere.

4.1.2.2 Setup

Once purged, P_2 is set to 10^3 pascals (Pa), the first test pressure, and allowed to stabilize. A combination of valve throttling and N_2 flow is used to establish the test condition. It is not essential that the pressure be accurately set.

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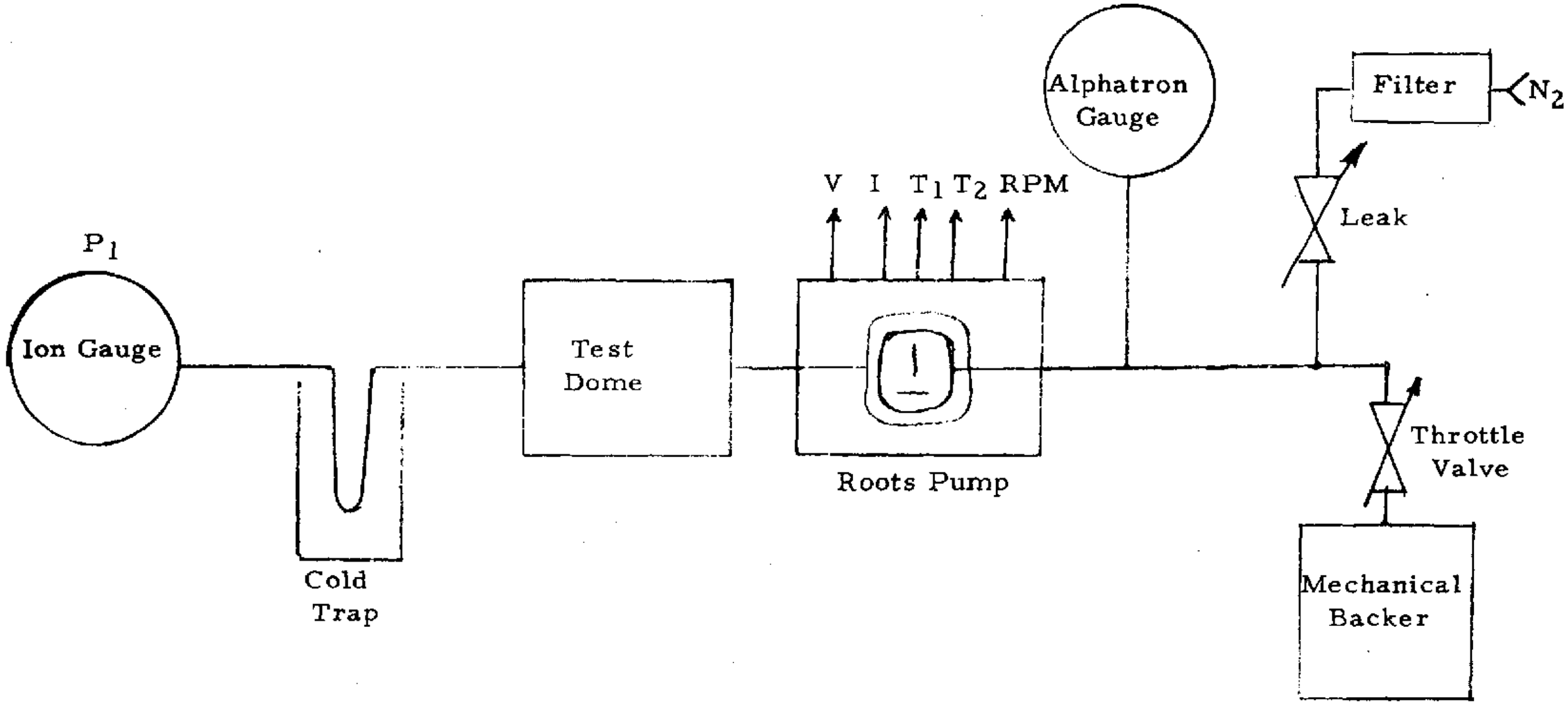

Figure 4-1 Compression Ratio - Ultimate Pressure Test Setup

4.1.2.3 Pump Performance

Once stabilized, the pump is turned on and set at the lowest test speed. This causes a transient change in P_2, and time must be allowed for conditions to restabilize. Pressure (in and out), temperature, and power are recorded.

Next, the pump power is changed to increase the rotation rate to the next test level. Again, time must be allowed for pressure stabilization before the data are recorded. A third pump speed is desirable and is used, subject to the recommendations of the Pfeiffer Company.

After the above-described test is completed, the throttle valve is slowly opened and power to the pump is reduced for slow rotation operation. P_2 is set at the second value, and the performance test is repeated as above. Figure 4-2 is, essentially, a conversion chart of torr to pascals, but the various settings of P_2 anticipated for this test are also shown. Figure 4-3 is an example of the type of data sheet used.

4.2 THROUGHPUT

4.2.1 General Description

The test manifold used for ultimate pressure testing includes plumbing which permits a controlled flow of nitrogen to be added at the input of the pump for throughput measurements, as shown in Figure 4-4. Because of the throughput condition, the backing pressure, P_2, can be adjusted by the throttle valve alone.

4.2.2 Test Procedure

4.2.2.1 Preparation

No additional preparation steps are necessary if the throughput tests directly follow the ultimate tests. However, if the pump or manifold were re-exposed to the atmosphere, the procedure described in Section 4.1.2.1 should be repeated.

4.2.2.2 Setup

First, a throughput of 2.5×10^{-3} torr l/s (the lowest measurable quantity in this manifold) is established. Next, pressure P_2 is set to 10^{-3} P_a and allowed to stabilize. As noted, this can be accomplished through the use of the throttle valve alone.

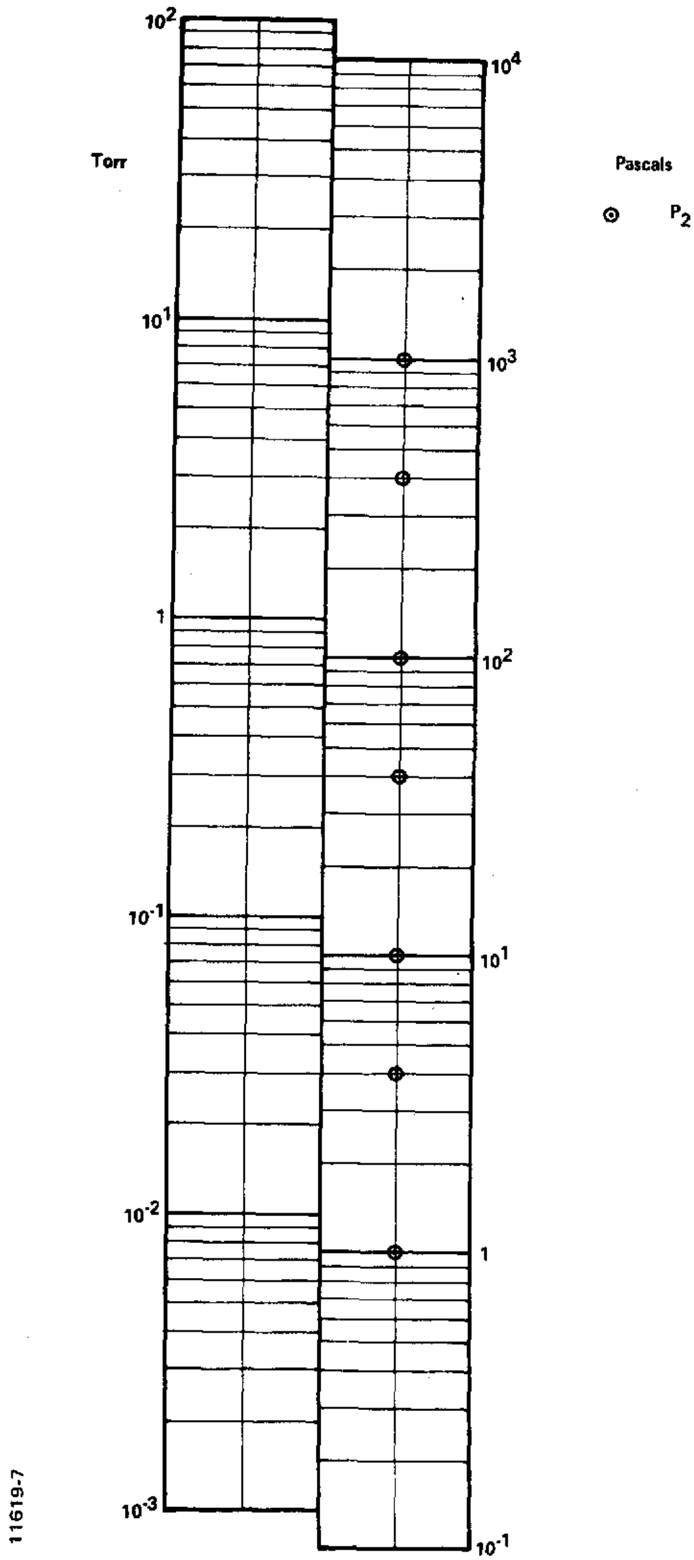

Figure 4-2 Torr - Pascal Conversion Chart

Test: Compression/Ultimate   Date:______________

P_2 (Set)		P_1	P_1 (Read)				
Pa	Torr	Actual	Torr	Pa	I	V	T
______	rpm						
1	7.4×10^{-3}						
4	3×10^{-2}						
1×10^{1}	7.4×10^{-2}						
4×10^{1}	3×10^{-1}						
1×10^{2}	7.4×10^{-1}						
4×10^{2}	3						
1×10^{3}	7.4						
______	rpm						
1	7.4×10^{-3}						
4	3×10^{-2}						
1×10	7.4×10^{-2}						
4×10	3×10^{-1}						
1×10^{2}	7.4×10^{-1}						
4×10^{2}	3						
1×10^{3}	7.4						
______	rpm						
1	7.4×10^{-3}						
4	3×10^{-2}						
1×10	7.4×10^{-2}						
4×10	3×10^{-1}						
1×10^{2}	7.4×10^{-1}						
4×10^{2}	3						
1×10^{3}	7.4						

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Figure 4-3 Compression Test Data Sheet

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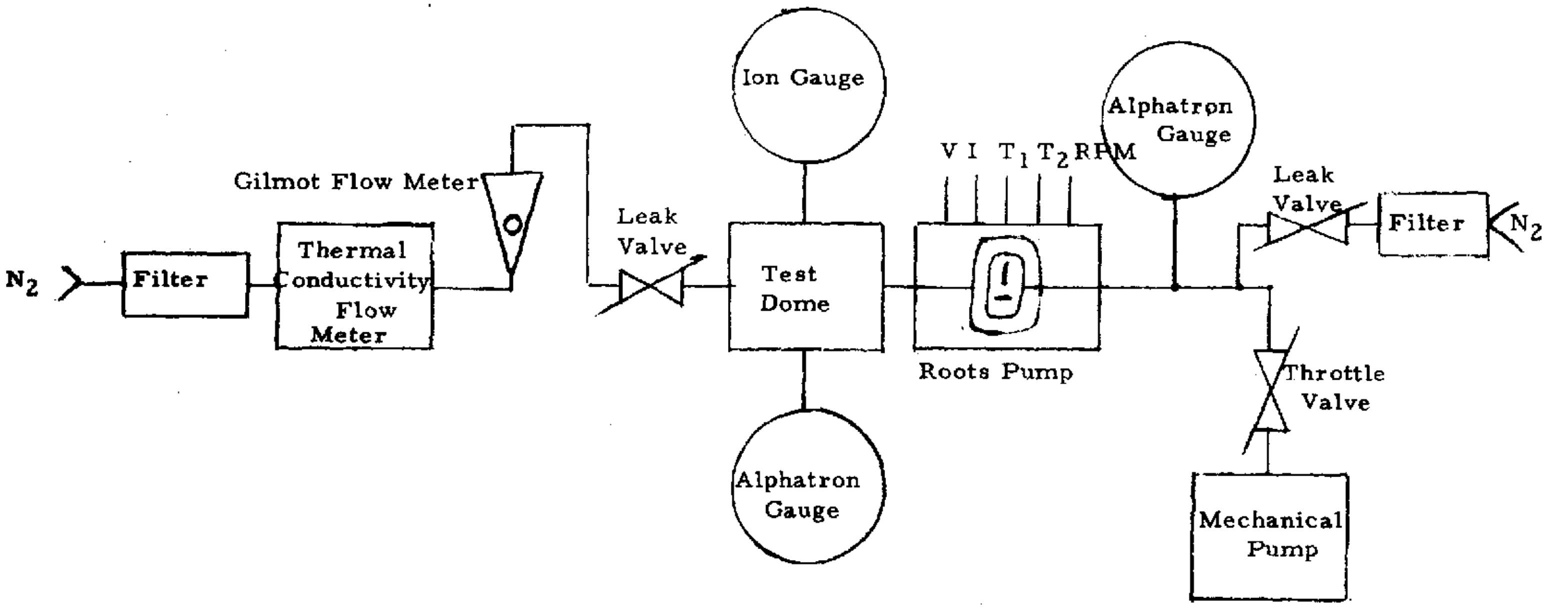

Figure 4-4 Throughput Test Setup

4.2.2.3 Pump Performance

Once stabilized, the pump is turned on at the lowest test speed. This will cause a transient change in P_2, and time must be allowed for conditions to restabilize. Pressure (in and out), temperature, and power is then recorded.

Next, the pump power is changed to increase the rotation rate to the next test level. Time must be allowed for pressure stabilization before the data are recorded. If possible, a third rotation rate is used.

Having completed tests using one flow rate, the pump power is reduced and the flow rate is increased to the next test level. Figure 4-5 shows the data sheets used in this test.

4.3 EFFECTS OF TEMPERATURE

4.3.1 General Description

The Roots pump performance is affected by temperature, especially where the heat of compression becomes a major factor. Some selected tests are performed to determine the extent of the problem.

From the previous tests, two conditions can be chosen; one where temperature rise was a minimum (zero throughput most likely) and the other where the temperature rise of the pump was significant. These tests are rerun with an attempt to increase and/or decrease the temperature of the first test.

4.3.2 Test Procedure

4.3.2.1 From the previous data, a test of approximately two hours duration is selected in which there was a minimum temperature rise. Duplicating conditions are set up and the test is rerun. During the test, thermal insulation is added and the test is rerun.

4.3.2.2 From the data of the tests described in Sections 4.1 or 4.2 where a significant temperature rise was observed, a test is selected. Duplicating conditions are set up and the test is rerun. Forced air cooling is added and the test is rerun.

4.3.2.3 The test described in Section 4.3.2.2 is rerun but with insulation added (no cooling).

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_______________ rpm   Date_______________

_______________ Torr Backing Pressure______ Pa

Flowmeter		P_1 (Torr)	P_1 (Pa)	Flow (Pa liters/sec)	Pump Speed (liter/sec)	Temper-ature	Voltage	Current	
Reading	Std ml/min								

Figure 4-5 Throughput Test Data Sheet

SECTION 5

TEST RESULTS

This section of the report contains the test results as reduced from the raw data contained in Appendix A.

5.1 COMPRESSION RATIO ULTIMATE TESTS

Tests were performed for 8,000, 7,000, and 6,000 rpm rotation. The results are plotted in Figure 5-1. The results show a maximum compression ratio of 6,500 at 400 pascals. The Pfeiffer Company data presented in CR 114581 shows a compression ratio of about 2200. Pfeiffer subtracts the background pressure from the pressure reading before computing the compression ratio. Our data was computed directly from the pressure readings. When the Pfeiffer data is computed in this manner, good agreement is obtained. As a result of this test, it was found that an ultimate pressure of 6.1×10^{-2} pascals (5×10^{-4} torr) could be obtained at 400 pascals (3 torr) backing pressure and an ultimate pressure of 2.5×10^{-1} pascals (1.9×10^{-3} torr) could be obtained at 1,333 pascals (10 torr) backing pressure. However, it should be clearly noted that complete bakeout and sealing of the test setup was not accomplished prior to the test.

During the tests, difficulties were experienced in attempting to achieve a leak-tight test setup. The difficulties were primarily experienced in the test article (pump) itself. It was found to leak around the inlet and outlet joints, where an epoxy cement had been used to join the tubing to the pump body, and around the interstage structure, where O-rings are used for sealing. These difficulties were overcome through the use of vacuum sealing compound and it was possible to proceed with the tests.

Maximum temperature rise experienced during the tests was 3.9°C. Figure 5-2 shows the thermocouple calibration curve used. Thermocouples were mounted on the top and bottom of the pump. The thermocouples were nearly in agreement (within 2.5°C), indicating nearly uniform temperature throughout the pump. Power level was found to remain constant up to a backing pressure of 40 pascals (0.3 torr), where it began to rise. Maximum power input at 1,333 pascals (10 torr) backing pressure and an 8,000 rpm rotation rate was found to be 11.25 watts. The input power required is summarized in Table 5-1.

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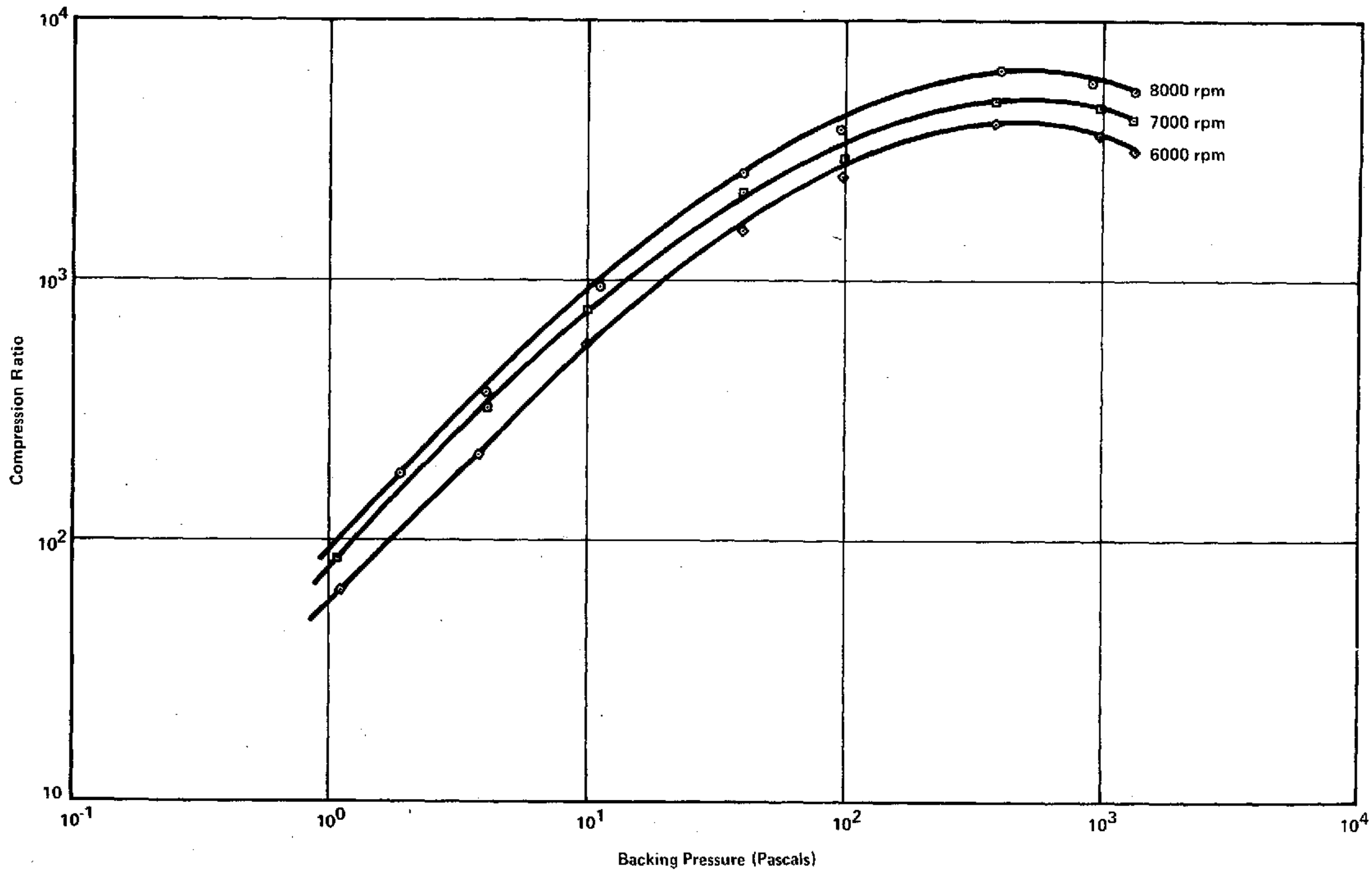

Figure 5-1 Compression Ratio as a Function of Backing Pressure

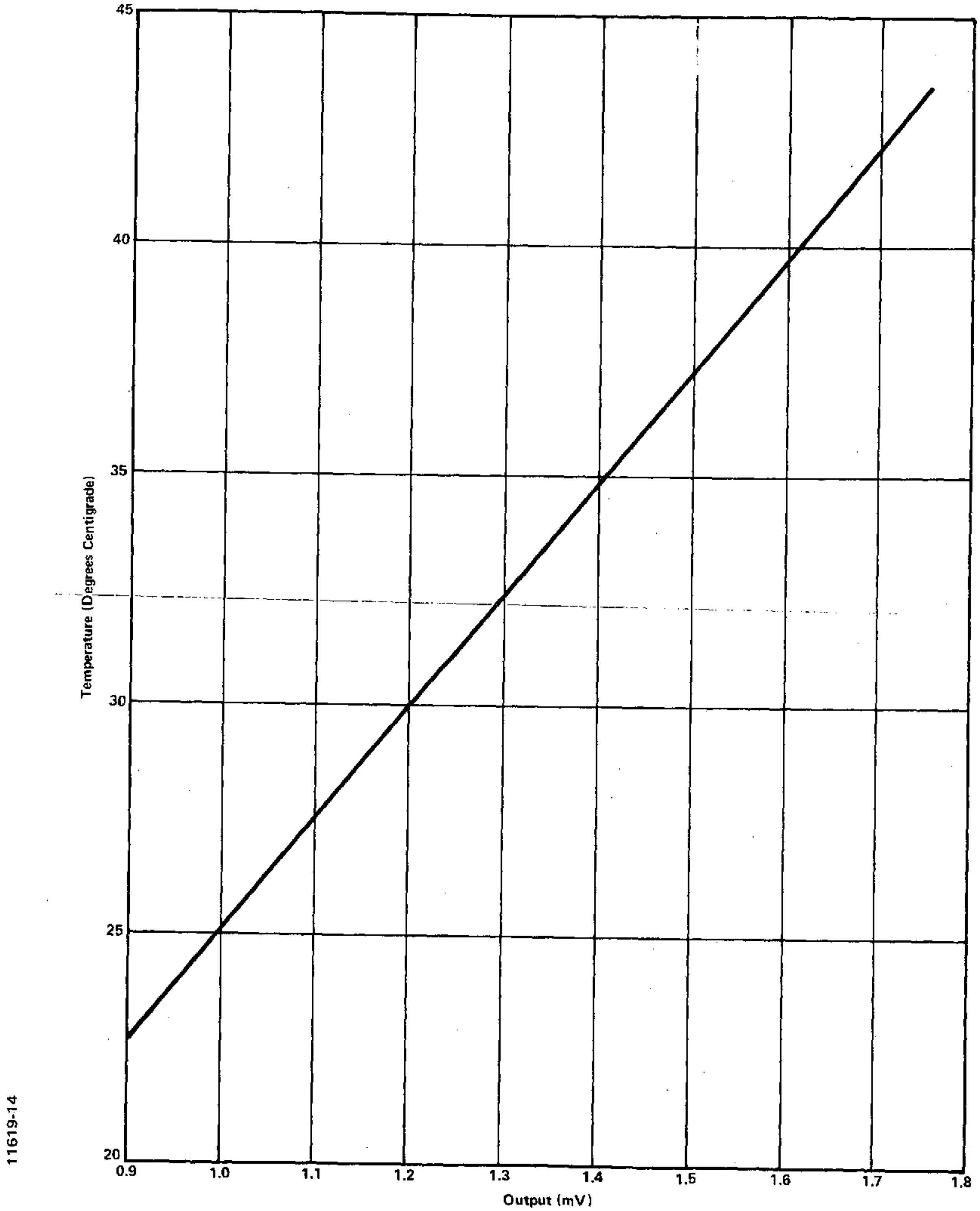

Figure 5-2 Thermocouple Calibration Curve

Table 5-1

Pump Input Power

Speed (rpm)	Backing Pressure (pascal)	Compression Ratio	Input Power (watts)
8,000	1.933	181	9.4
	3.999	375	9.4
	10.131	950	9.4
	39.99	2,609	9.4
	98.64	3,895	9.6
	399.9	6,521	10.0
	926.4	5,792	11.1
	1,333.0	5,263	11.2
7,000	1.08	85.3	9.2
	4.07	321	9.2
	9.998	789	9.2
	39.99	2,143	9.2
	99.31	2,980	9.3
	386.6	4,874	9.7
	979.8	4,742	10.5
	1,333.0	4,167	11.3
6,000	1.12	65	8.8
	3.73	215	8.8
	10.0	556	8.8
	41.3	1,550	8.8
	98.6	2,508	9.1
	386.6	4,028	9.3
	973.1	3,560	10.2
	1,333.0	3,175	10.5

5.2 THROUGHPUT

As a result of initial testing, it was found to be much simpler to set a specific backing pressure and make measurements at various flow levels than to set the flow level and vary the backing pressure. Therefore, the data were taken in this manner. Figure 5-3 is a plot of pump speed versus inlet pressure for speeds of 8,000, 7,000, and 6,000 rpm and a backing pressure of 1,333 pascals (10 torr). Figure 5-4 is the data obtained at 666.5 pascals (5 torr). Maximum temperature rise during these tests was about 2°C. Maximum power input at 8,000 rpm and 1,333 pascals (10 torr) backing pressure was 16.4 watts. At 667 pascals (5 torr) and 8,000 rpm, the power input was 12.5 watts.

The calibration curve utilized for the Gilmont flow meter is given in Figure 5-5. The figure can be used to convert flowmeter readings to standard milliliters per minute. Milliliters per minute were then converted to pascal liters per second by multiplying by 1.685.

The data show a maximum pumping speed of 1.5 liters per second at 8,000 rpm and 1,333 and 667 pascals backing pressure. This agrees with the Pfeiffer Company data.

5.3 EFFECTS OF TEMPERATURE

Since no noticeable temperature effects were observed during the compression and throughput testing, the temperature effect test was deleted from the effort.

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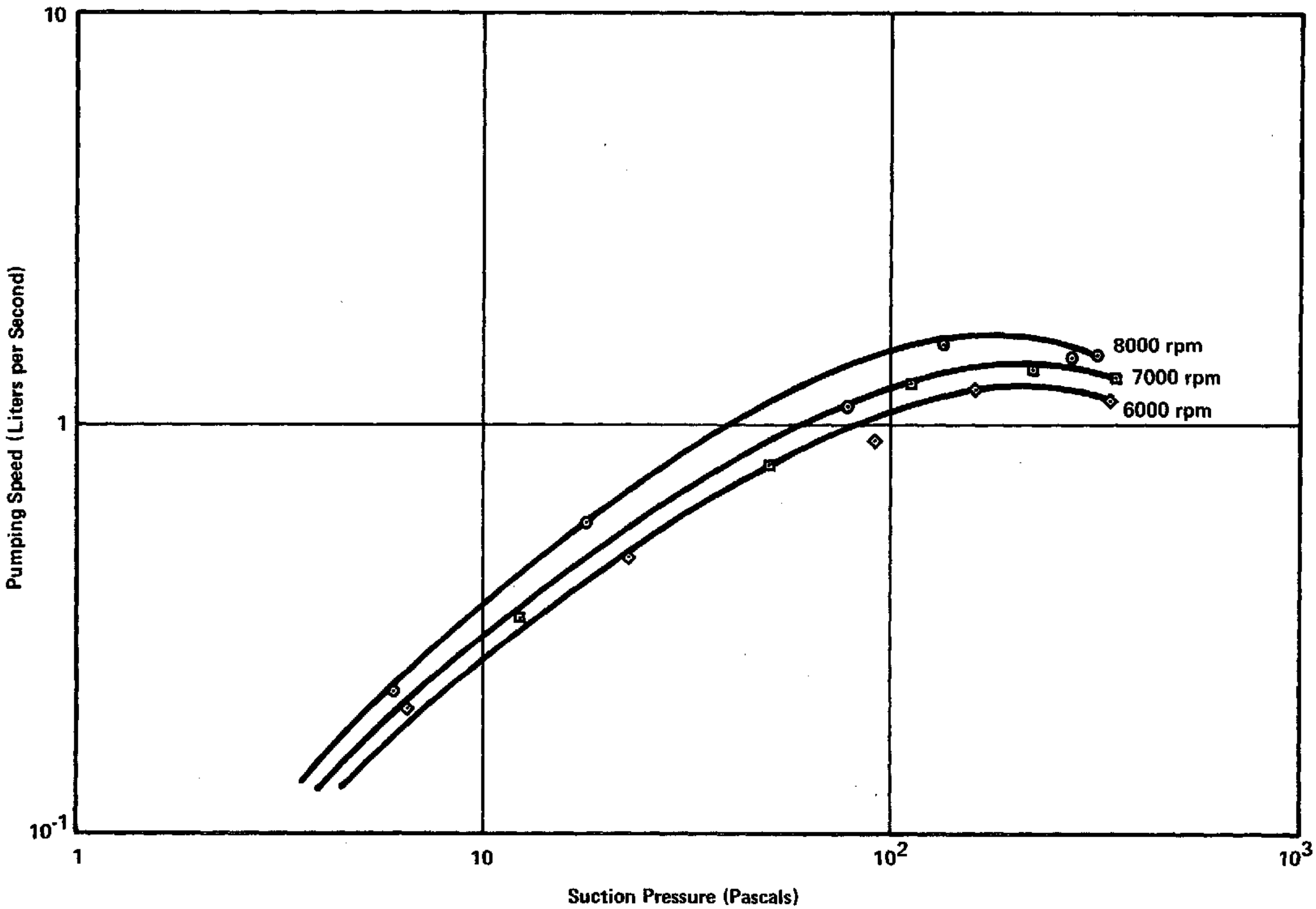

Figure 5-3 Pumping Speed versus Suction Pressure at 1,333 Pascals Backing Pressure

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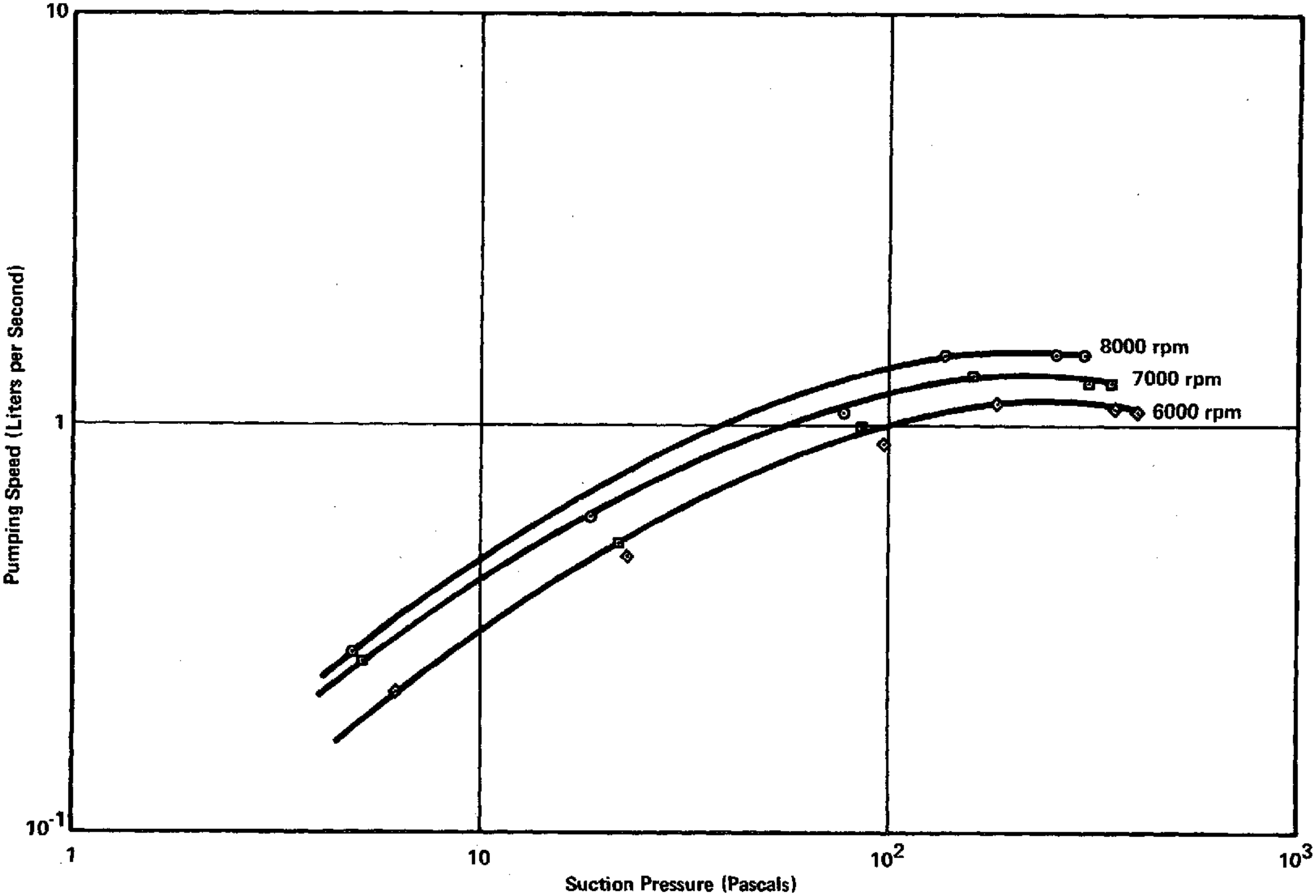

Figure 5-4 Pumping Speed versus Suction Pressure at 667 Pascals Backing Pressure

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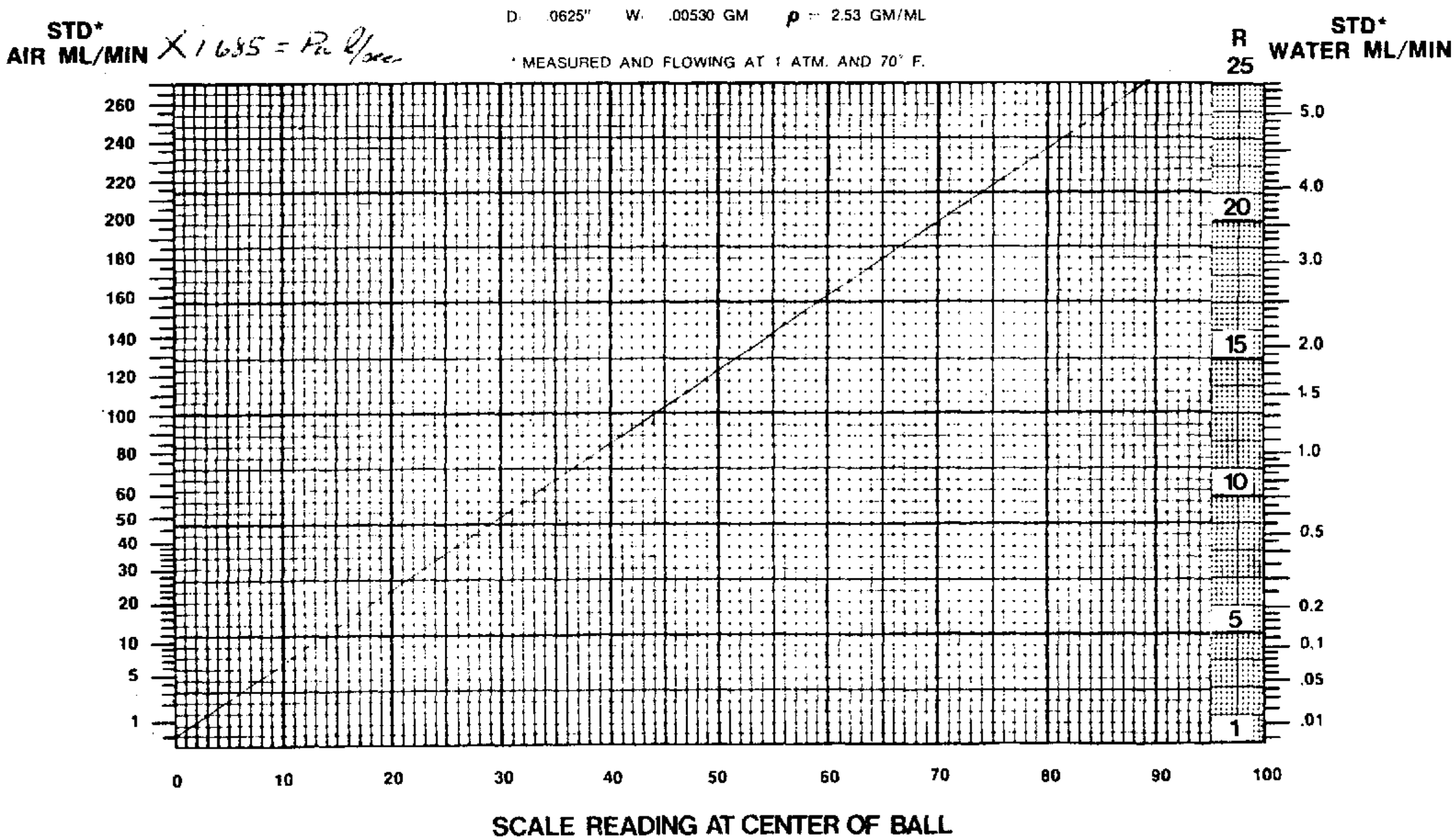

Figure 5-5 Gilmont Flowmeter Calibration Curve

SECTION 6

RECOMMENDATIONS AND CONCLUSIONS

Because of limited budget and test time restrictions, it was impossible to establish a clean, leak-free, test setup. Therefore, it is rather difficult to establish any conclusive, quantitative data regarding the Roots pump. However, the general performance from some data points has been achieved. In general, the data are in agreement with the pump specifications as established by the Arthur Pfeiffer Company, i.e., compression ratio about 5,000 at 1.33×10^3 pascals and pumping speed about 1.5 liters per second at 1.33×10^3 pascals. However, ultimate pressure measurements of 3.33×10^{-1} pascals at 1.33×10^3 pascals backing pressure or 10^{-1} pascals at 6.67×10^2 pascals backing pressure are very uncertain because of the test setup and pump leakage problems. Consequently, it is recommended that further tests be conducted to establish quantitative performance figures for the pump. To perform these tests, it is recommended that the Roots pump be completely disassembled, cleaned, and lubricated with appropriate lubricants for long-term high-vacuum operation, and that all joints and fittings be reworked to accept O-ring seals for leak-tight operation. (It is noted that the input/output plumbing and interstage plumbing was attached to the pump and sealed with epoxy. This should not be done if any handling, particularly with respect to making or breaking of joints in the lines, is required.) The interstage structure of the pump should be cleaned and properly sealed with fitted O-rings. A complete vacuum bakeout of the pump at about 100°C for at least 24 hours should then be accomplished to clean it up. Provisions should be made to test the three stages separately.

Insofar as possible, the test setup was leak-tested with a mass spectrometer leak detector and found to be leak-free. However, considerable changes were made during the testing, the most notable being the addition of the two Alphatron gauges required to accommodate the wide pressure range experienced. One of these gauges was found to be dirty and extensive bakeout was required to clean it up. A new, clean test setup should be assembled.

Finally, it is recommended that a Pioneer-Venus mass spectrometer inlet engineering breadboard model be built and tested to achieve the objective of an inlet system preliminary design. The following specific tasks are recommended:

- Build engineering breadboard model, complete with vacuum or chemical ballast, restrictors, etc.

- Test over the entire operating range with a Venus model test gas.

- Make mass spectrometer measurements to determine extent of chemical pump or lubrication problems.

- Analyze and test system for worst-case conditions and single-point failure possibilities.

- Provide an inlet system preliminary design.

As a first step in the buildup of the engineering breadboard, the present mechanical pump should be tested in combination with the available chemical pump ballast to determine if a compatible operation can be achieved and to obtain preliminary test data. More extensive inlet system breadboard tests should utilize a third generation pump which should be built more along the flight specification lines, i.e., materials should be selected for compatibility with higher temperature bakeout, construction should be lighter and in the flight configuration, and complete interstage sealing including welding should be used (this might include flanges which could be ground off if disassembly were required).

APPENDIX A

This appendix contains the raw data obtained during testing, along with the calculations performed.

TEST: Ultimate [illegible] DATE: 8-6-73

FLOW:

T_0 = Room Temp = 28.5°C
Pump Temp = 27 [illegible]

P_2 (SET)		P_2	P_1 (READ)		compression ratio		
P_A	TORR	ACTUAL	TORR	~~P_A~~ K	I	V	T
8000/133 Hz	RPM	1.45×10^{-2}	0.08×10^{-3}	181	.750	12.6	1.25 1.20
1	7.4×10^{-3}						
4	3×10^{-2}	3×10^{-2}	0.08×10^{-3}	375	.750	12.6	1.26 1.20
1×10^1	7.4×10^{-2}	7.6×10^{-2}	0.08×10^{-3}	950	.760	12.6	1.27 1.22
4×10^1	3×10^{-1}	3.0×10^{-1}	0.115×10^{-3}	2609	.760	12.6	1.30 1.25
1×10^2	7.4×10^{-1}	7.4×10^{-1}	0.19×10^{-3}	3895	.760	12.6	1.33 1.27
4×10^2	3	3	0.46×10^{-3}	6521	0.790	12.6	1.34 1.28
1×10^3	7.4	6.95	1.2×10^{-3}	5792	0.860	12.6	1.40 1.34
130 Hz		10.0	1.9×10^{-3}	5263	0.892	12.6	1.42 1.34
T_0 = 27° 7000/118 Hz	RPM						
1	7.4×10^{-3}	8.1×10^{-3}	0.095×10^{-3}	85.3	0.730	12.6	1.38/1.32
4	3×10^{-2}	3.05×10^{-2}	0.095×10^{-3}	321	0.730	12.6	1.39/1.32
1×10	7.4×10^{-2}	7.5×10^{-2}	0.095×10^{-3}	789	0.730	12.6	1.40/1.32
4×10	3×10^{-1}	3×10^{-1}	0.14×10^{-3}	2143	0.730	12.6	1.40/1.33
1×10^2	7.4×10^{-1}	7.45×10^{-1}	0.25×10^{-3}	2980	0.740	12.6	1.41/1.35
4×10^2	3	2.9	0.595×10^{-3}	4874	0.770	12.6	1.42/1.35
1×10^3	7.4	7.95	1.55×10^{-3}	4742	0.830	12.6	1.44/1.37
		10	2.4×10^{-3}	4167	0.900	12.6	1.44/1.36
T_0 = 29°C 6000	RPM						
1	7.4×10^{-3}	8.4×10^{-3}	0.13×10^{-3}	65	0.700	12.6	1.32/1.27
4	3×10^{-2}	2.8×10^{-2}	0.13×10^{-3}	215	0.700	12.6	1.33/1.27
1×10	7.4×10^{-2}	7.5×10^{-2}	0.135×10^{-3}	556	0.700	12.6	1.34/1.27
4×10	3×10^{-1}	3.1×10^{-1}	0.20×10^{-3}	1550	0.700	12.6	[illegible]/1.28
1×10^2	7.4×10^{-1}	7.4×10^{-1}	0.295×10^{-3}	2508	0.720	12.6	1.37 1.30
4×10^2	3	2.9	0.72×10^{-3}	4028	0.740	12.6	1.37 1.31
1×10^3	7.4	7.3	2.05×10^{-3}	3560	0.810	12.6	1.38 1.32
		10	3.15×10^{-3}	3175	0.835	12.6	1.38 1.32

TEST: Ultimate/Compression

DATE: 8-7-73

FLOW: ________

Room temp 27°C
Pump Temp 1.03 mv. Pressure = 9.7×10^{-3}

P_2 (SET) P_A 5000	TORR RPM	P_2 ACTUAL	P_1 (READ) TORR	K ← Compression Ratio	I	V	T 1	T 2
1	7.4×10^{-3}	8.6×10^{-3}	0.07×10^{-3}	123	0.690	12.6	1.30	1.25
4	3×10^{-2}	3.1×10^{-2}	0.07×10^{-3}	443	0.690	12.6	1.31	1.25
1×10^1	7.4×10^{-2}	7.4×10^{-2}	0.08×10^{-3}	925	0.690	12.6	1.33	1.28
4×10^1	3×10^{-1}	2.85×10^{-1}	0.155×10^{-3}	1839	0.690	12.6	1.34	1.29
1×10^2	7.4×10^{-1}	7.35×10^{-1}	0.28×10^{-3}	2625	0.690	12.6	1.35	1.30
4×10^2	3	2.9	0.79×10^{-3}	3671	0.690	12.6	1.36	1.31
1×10^3	7.4	7.3	2.65×10^{-3}	2755	0.690	12.6	1.39	1.33

______	RPM						
1	7.4×10^{-3}	Ultimate test after 2 hours					
4	3×10^{-2}	at 8000 RPM					
1×10	7.4×10^{-2}	0.7×10^{-4}					
4×10	3×10^{-1}	Back Pressure 7×10^{-3}					
1×10^2	7.4×10^{-1}						
4×10^2	3						
1×10^3	7.4						

______	RPM						
1	7.4×10^{-3}						
4	3×10^{-2}						
1×10	7.4×10^{-2}						
4×10	3×10^{-1}						
1×10^2	7.4×10^{-1}						
4×10^2	3						
1×10^3	7.4						

DATE 8/21/73

8000 RPM

10 TORR BACKING PRESSURE 1.33×10^3 Pa

Flowmeter Reading	Flowmeter Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa-liter/sec)	Pump Speed (liter/sec)	Temp.	Voltage	Current	
0		2.75×10^{-3}		—	—	1.28	13.0	1.1A	Initial Set.
1	0.8	4.5×10^{-2}	6.0	1.348	0.225	1.29	13.0	1.1A	
10	6.5	1.4×10^{-1}	18.66	10.952	0.587	1.31	13.0	1.1A	
30	50	5.75×10^{-1}	76.66	84.25	1.10	1.33	13.3	1.2A	
50	123	1	133.32	207.26	1.55	1.34	13.5	1.2A	
80	236	2.1	280	397.66	1.42	1.35	13.6	1.2A	
88	267	2.3	306.6	449.9	1.47	1.36	13.7	1.2A	

DATE 8/21/73

7000 RPM

10 TORR TORR BACKING PRESSURE ______ Pa

Flowmeter Reading	Flowmeter Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa-liters/sec)	Pump Speed (liters/sec)	Temp.	Voltage	Current
		-				1.29 MV	12.7V	1 AMP
1	.8	3.6×10^{-2}	4.8	1.348	.28		12.7V	1 AMP
5	2.3	8.75×10^{-2}	11.64	38.76	.333			
10	6.5	1.40×10^{-1}	18.62	109.53	.588			
20	24.0	3.80×10^{-1}	50.54	404.4	.800			
33	60.0	6.2×10^{-1}	80.06	101.1	1.25		12.7V	1.1 AMP
40	85.0	8.45×10^{-1}	112.38	143.22	1.27			
50	123	1.22×10^{0}	162.26	207.26	1.28			
65	180	1.70×10^{0}	226.10	303.3	1.34		12.6	1.0 AMP
80	236	2.35×10^{0}	312.55	397.66	1.27			
89	270	2.72×10^{0}	361.76	454.95	1.26	1.36 MV	12.6	1.1 AM

BSR 4090

DATE 8/21/73

6000 RPM

10 TORR BACKING PRESSURE 1.33×10^3 Pa

Flowmeter Reading	Flowmeter Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa liters/sec)	Pump Speed (liters/sec)	Temp.	Voltage	Current
0		3.8×10^{-3}				1.37	12.6	0.95A
1	0.8	4.9×10^{-2}	6.53	1.348	0.206	1.38	12.6	0.95A
10	6.5	1.7×10^{-1}	22.66	10.952	0.483	1.39	12.6	0.95A
30	50	6.85×10^{-1}	91.32	84.25	0.922	1.39	12.6	0.95A
50	123	1.25	166.65	207.26	1.244	1.40	12.6	0.97A
80	236	2.6	346.64	397.66	1.15	1.41	12.6	0.98A
88.5	265	2.95	393.30	449.0	1.14	1.41	12.6	0.98A

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BSR 4090

8000 RPM

5 TORR BACKING PRESSURE ______ Pa

DATE 8/21/73

Flowmeter Reading	Flowmeter Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa-liters/sec)	Pump Speed (liters/sec)	Temp.	Voltage	Current	
0		1.19×10^{-3}				1.41	12.6	0.95	
1	0.8	3.7×10^{-2}	4.93	1.348 ~~[illegible]~~	0.273	1.42	12.6	0.95	
10	6.5	1.4×10^{-1}	18.66	10.952 ~~[illegible]~~	0.587	1.43	12.6	0.95	
30	50	5.85×10^{-1}	77.99	84.25 ~~[illegible]~~	1.08	1.43	12.6	0.95	
50	123	1.05	139.99	207.26 ~~[illegible]~~	1.48	1.44	12.6	0.98	
80	236	2.0	266.64	397.66 ~~[illegible]~~	1.49	1.44	12.6	0.99	
88	267	2.25	299.97	449.9 ~~[illegible]~~	1.50	1.45	12.6	0.99	

BSR 4090

DATE 8/21/73

7000 RPM

5 TORR BACKING PRESSURE ______ Pa

Flowmeter Reading	Flowmeter Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa·liters/sec)	Pump Speed (liter/sec)	Temp.	Voltage	Current
0		1.5×10^{-3}	—	—	—	1.45	12.6	0.85
1	0.8	3.85×10^{-2}	5.13	1.348	0.263	1.45	12.6	0.85
10	6.5	1.65×10^{-1}	22.0	10.952	0.498	1.45	12.6	0.88
30	50	6.4×10^{-1}	85.32	84.25	0.987	1.46	12.6	0.90
50	123	1.2	159.99	207.26	1.295	1.46	12.6	0.90
80	236	2.35	313.30	397.66	1.27	1.46	12.6	0.90
88	267	2.65	353.3	449.9	1.27	1.47	14.2	0.95

DATE 8/21/73

6000 RPM

5 TORR BACKING PRESSURE ______ Pa

Flowmeter Reading	Flowmeter Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa-liters/sec)	Pump Speed (liters/sec)	Temp.	Voltage	Current
0	—	1.6×10^{-3}		—	—	1.47	12.5	0.80
1	6.8	4.1×10^{-2}	6.27	1.348	0.215	1.48	12.5	0.80
10	6.5	1.7×10^{-1}	22.66	10.952	0.483	1.48	12.5	0.80
30	50	7.20×10^{-1}	95.99	84.25	0.878	1.48 1.49	12.5 12.5	0.81 0.82
50	123	1.4	186.65	207.26	1.11	1.49	12.5	0.82
80	236	2.7	359.97	397.66	1.10	1.49	12.5	0.82
82.5	265	3.05	406.63	449	1.10			

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BSR 4090

TEST: 7000 RPM DATE: 8/20/73

FLOW:

P_2 (SET)		P_2	P_1 (READ)		Flow		
P_A	TORR	ACTUAL	TORR	P_A	[illegible]	V	I
	RPM	10 torr	2.5×10^{-3}		0		
1	7.4×10^{-3}	10 torr	3.85×10^{-2}	5.13	1.0	0.8-1.35	-.263
4	3×10^{-2}	10 torr	8.6×10^{-2}	11.47	5.0	3.5-5.90	-.514
1×10^1	7.4×10^{-2}	10 torr	1.5×10^{-1}	20.0	10.0	6.5-10.95	-.548
4×10^1	3×10^{-1}	10 torr	3.75×10^{-1}	50.0	20.0	24-40.4	-.808
1×10^2	7.4×10^{-1}	10 torr	5.85×10^{-1}	78.0	32.0	56-94.4	-1.21
4×10^2	3	10 torr	8.6×10^{-1}	114.7	40.0	86-144.9	-1.26
1×10^3	7.4	10 torr	1.25	166.7	50.0	123-207.3	-1.24
	RPM	10 torr	1.6	213.3	60.0	160-269.6	-1.26
1	7.4×10^{-3}	10 torr	1.95	260.	70.0	200-337	-1.30
4	3×10^{-2}	10 torr	2.35	313.3	80.0	236-397.7	-1.28
1×10	7.4×10^{-2}	10 torr	2.70	360.	88.0	267-449.9	-1.25
4×10	3×10^{-1}						
1×10^2	7.4×10^{-1}						
4×10^2	3						
1×10^3	7.4						
	RPM						
1	7.4×10^{-3}						
4	3×10^{-2}						
1×10	7.4×10^{-2}						
4×10	3×10^{-1}						
1×10^2	7.4×10^{-1}						
4×10^2	3						
1×10^3	7.4						

DATE 8/21/73

8000 RPM

10 TORR BACKING PRESSURE 1.33×10^3 Pa

(Small) Flowmeter Reading	Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa-liters/sec)	Pump Speed (liters/sec)	Temp.	Voltage	Current	
0	—	2.6×10^{-3}	—	—	—	1.44	12.8	1.0A	
0.2	0.2	1.65×10^{-2}	2.2	0.337	.153	1.44	12.8	1.0A	
0.5	0.5	2.35×10^{-2}	3.13	0.842	.269	1.45	12.8	1.0A	
4.0	4.0	0.75×10^{-1}	10.0	6.74	.674	1.46	12.8	1.0A	
10.0	10.0	1.6×10^{-1}	21.33	16.85	.790	1.46	12.8	1.0A	
20.0	20.0	2.5×10^{-1}	33.33	33.70	1.01	1.46	12.8	1.0A	
35.0	35.0	3.6×10^{-1}	48	58.98	1.23	1.47	13.4	1.0A	
50.0	50.0	4.9×10^{-1}	65.3	84.25	1.29	1.48	13.0	1.0A	
80.0	80.0	7.85×10^{-1}	104.66	134.80	1.29	1.48	13.4	1.0A	note: This data not utilized as flowmeter calibration was not obtained. Therefore cannot be correlated. WEL

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BSR 4090

DATE 8/21/73

8000 RPM

5 TORR BACKING PRESSURE 6.65×10^2 Pa

(Small) Flowmeter Reading	(Small) Flowmeter Std ml/min	P_1 (TORR)	P_1 (Pa)	Flow (Pa-liters/sec)	Pump Speed (liters/sec)	Temp.	Voltage	Current
0		1.1×10^{-3}				1.49	12.4	0.9A
0.2	0.2	1.65×10^{-2}	2.2	0.337	0.153	1.49	12.4	0.9A
0.5	0.5	2.35×10^{-2}	3.13	0.842	0.269	1.49	12.4	0.9A
4.0	4.0	6.4×10^{-2}	8.53	6.74	0.79	1.49	12.4	0.9A
10.0	10.0	1.65×10^{-1}	22	16.85	0.77	1.49	12.4	0.9
20.0	20.0	2.45×10^{-1}	32.66	33.70	1.03	1.49	12.4	0.92
35.0	35.0	3.75×10^{-1}	50.0	58.98	1.18	1.50	12.4	0.92
50.0	50.0	5.0×10^{-1}	66.66	84.25	1.26	1.50	12.4	0.95
80.0	80.0	8×10^{-1}	106.66	134.80	1.26	1.50	12.4	0.96

note: This data not utilized as flowmeter calibration was not obtained. Therefore cannot be correlated.
WLL