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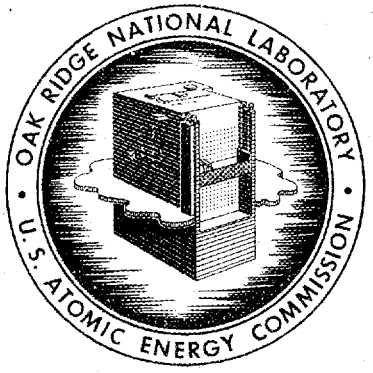

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DEVELOPMENT OF AN AIR-OPERATED, METAL-DIAPHRAGM PUMP FOR THE TRANSURANIUM PROCESSING FACILITY

T. S. Mackey

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T. S. Mackey

ABSTRACT

The TRU sampler and process pump was tested under similated operating conditions. The results demonstrate the feasibility of the design and the requirements that must be met for successful operation and maintenance. Information was determined and reported on the pump design, diaphragm seal configuration, diaphragm life, and operating procedures.

---

1. INTRODUCTION

The problems of transferring radioactive process solutions are complicated further in the TRU process by: (1) the generation of radiolytic gas in the pipe lines, (2) the viscous nature of the solutions, (3) some solutions must be handled at elevated temperatures, (4) high suction lifts, (5) material of construction requirements, and (6) remote operation and maintenance problems. The diaphragm type pump was chosen after consideration was given to several other types of pumps. The problems associated with pulsing hydraulic fluid as the diaphragm operator were eliminated by electrically timing the application of vacuum and air pressure to the pump diaphragm. The timer controls the number of cycles per minute and thus the discharge rate.

2. PUMP DESIGN

The criteria for the pump design dictated (1) high lift head, (2) all metal construction, (3) long diaphragm life, (4) compact construction and capability for remote operation and maintenance.

The high lift capability of the pump was accomplished by minimizing the ratio of the volume of the pump passages between the check valves and the diaphragm cavity to the volumetric capacity of the diaphragm cavity (see Fig. 1).

The contour for the diaphragm cavity was designed according to Eq. (1), Fig. 2. This equation describes what is known as the free deflection contour.[1] The volumetric displacement of the pump may be calculated from Eq. (2). The actual cavity contour for the TRU pump is shown in Fig. 3.

A maximum stress of approximately 30,000 lb/sq in. for metals with properties similar to stainless steel were obtained using Eqs. (3) and (4). Thus an almost infinite diaphragm life could be expected as far as fatigue failure is concerned.

Diaphragm Seal. Three diaphragm seal designs were investigated. These included the tongue and groove seal which was accepted, the tantalum gasket seal, and a design in which a rectangular tongue 0.015 in. wide and 0.003 in. high was tested. The tongue and groove seal gives excellent sealing qualities and can be remotely maintained.

The tongue and groove seal (Fig. 4A) functions similarly to the Chemical Technology quick disconnect. The seal is made on the inclined

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[1] E. C. Hise, Design, Development and Operation of Metal Diaphragm Reactor Service Pumps, ORNL-2841 (April 26, 1960).

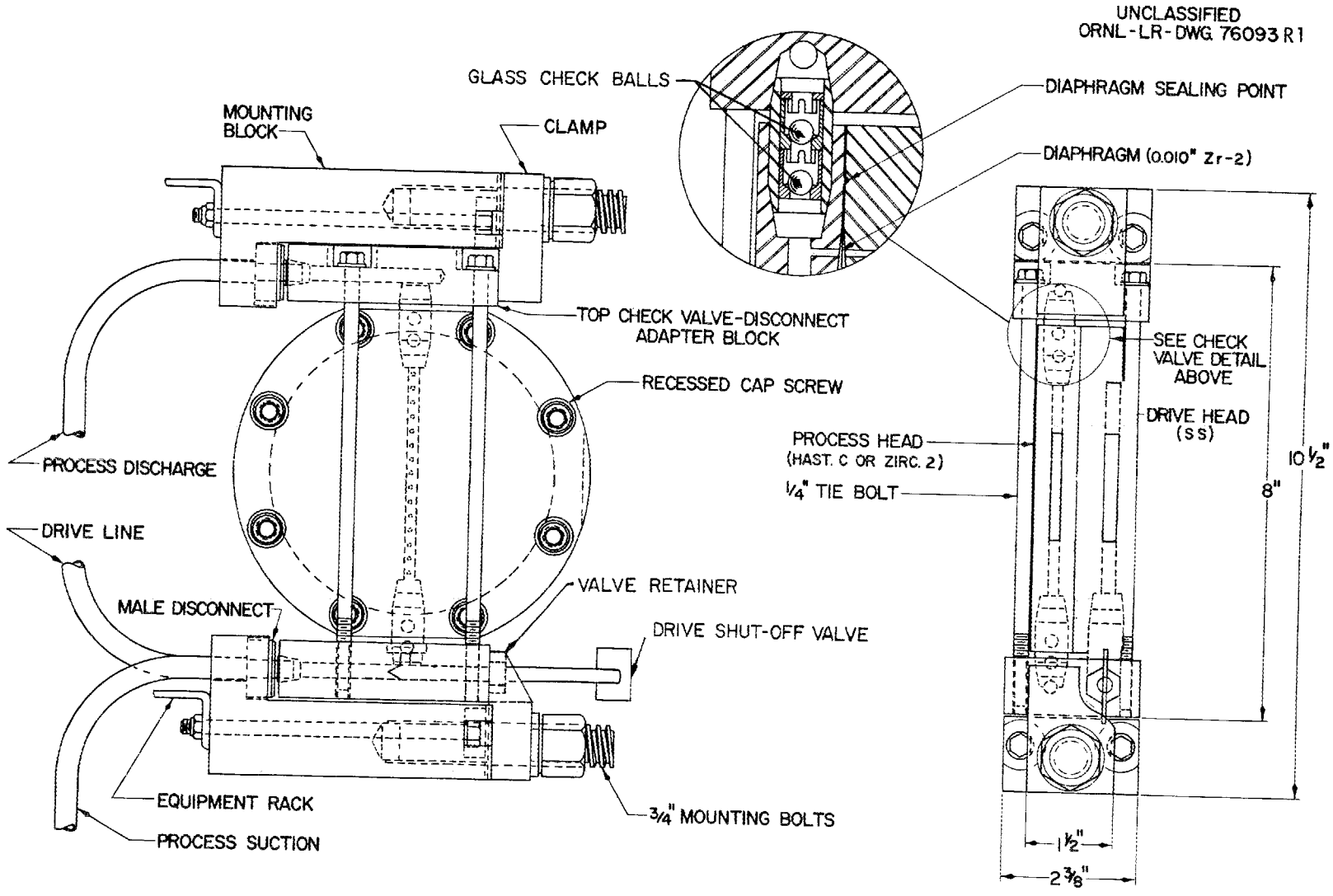

Fig. 1. TRU Process Pump.

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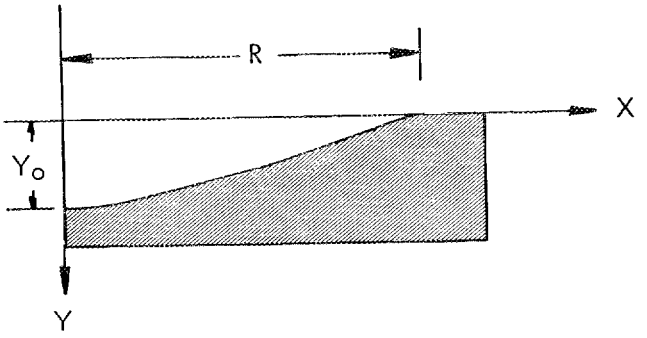


EQUATION NO. 1.

$$Y = \frac{Y_o}{R^4} (R^2 - X^2)^2$$

R = Cavity Radius

Y_o = Maximum Cavity Depth

EQUATION NO. 2.

VOLUME $-Y_o$ TO $+ Y_o$ $\quad$ VOL. $= \frac{2\pi Y_o R^2}{3}$

EQUATION NO. 3. RADIAL MEMBRANE STRESS γ_m

$$\gamma_m = E\left(\frac{Y_o}{R}\right)^2 \left[\frac{2}{3}\left(\frac{X}{R}\right)^4 - \left(\frac{X}{R}\right)^2 - \frac{1}{6}\left(\frac{X}{R}\right)^6 + 0.9762\right]$$

EQUATION NO. 4. RADIAL BENDING STRESS γ_B

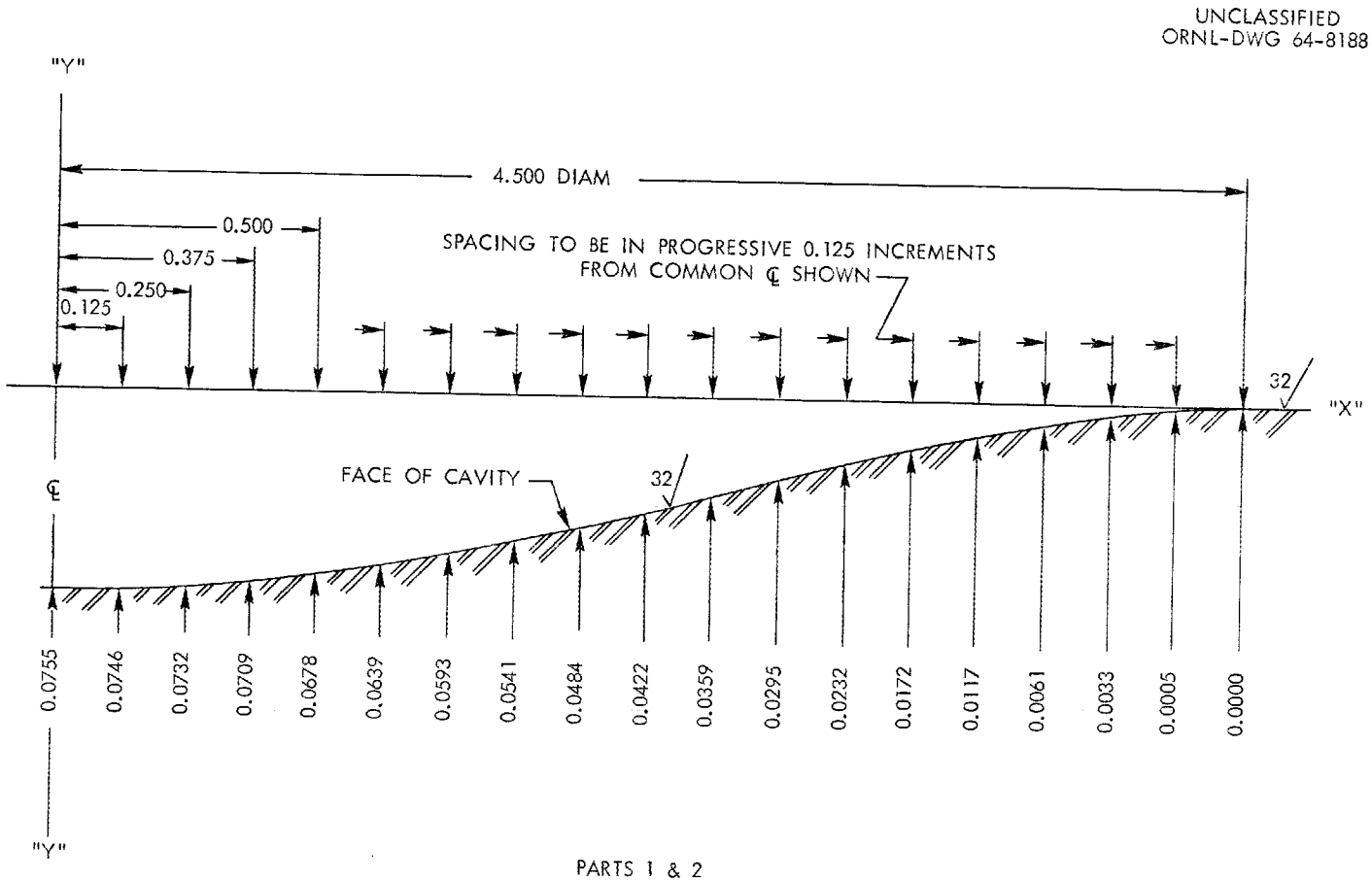
$$\gamma_B = \frac{2 E h Y_o}{(1-\nu^2)XR}\left[3.3\left(\frac{X}{R}\right)^3 - 1.3\,\frac{X}{R}\right]$$

ν = Poisson's Ratio

E = Modulus of Elasticity

h = Diaphragm Thickness

Fig. 2. Free Deflection Contour.



PARTS 1 & 2

SCALE: "X-X" AXIS 4"-1"
"Y-Y" AXIS 20" = 1"

TOLERANCE: "X-X" AXIS ±0.002
"Y-Y" AXIS ±0.001

NOTE: CONNECT ALL POINTS SMOOTHLY TO PRODUCE A CONTINUOUS, SMOOTH CAVITY FACE.

Fig. 3. Typical Cavity Development.

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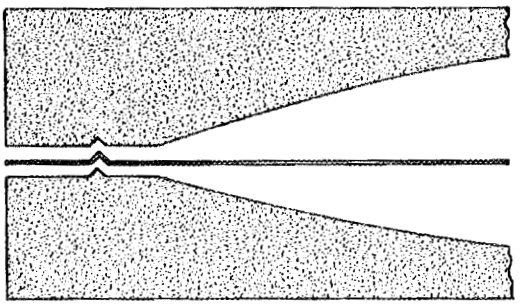
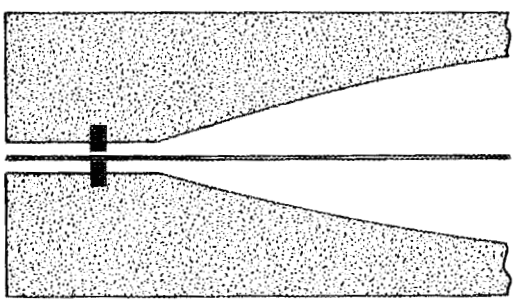
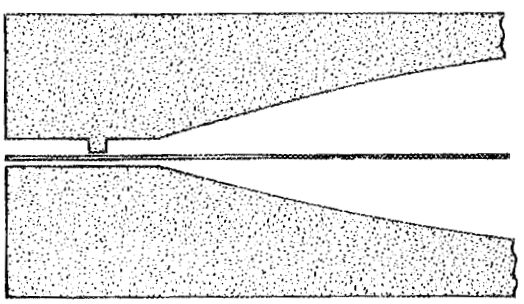


A. TONGUE AND GROOVE SEAL



B. GASKET SEAL



C. RING SEAL

Fig. 4. Seal Designs.

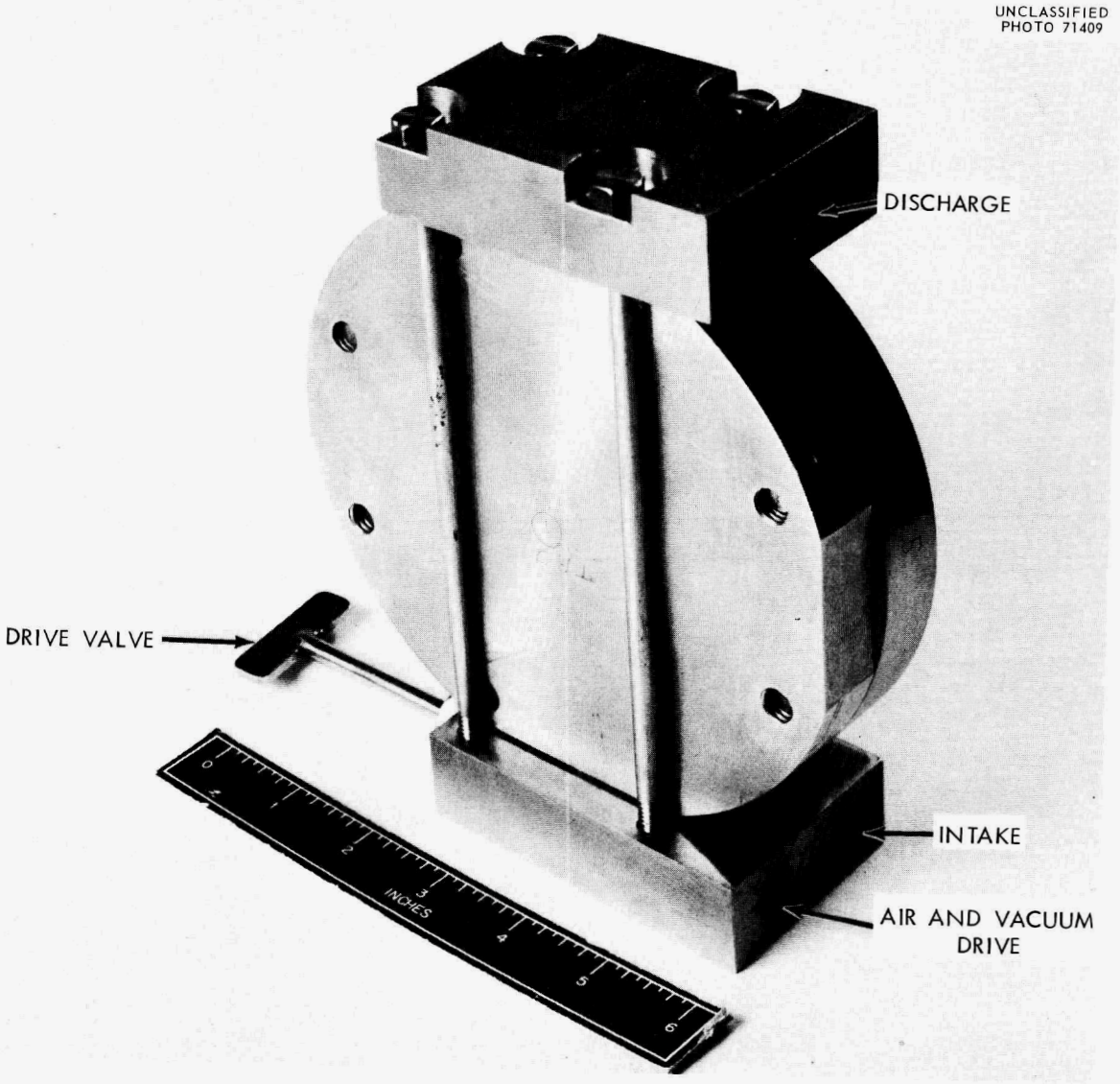


Fig. 5. Tru Process Pump

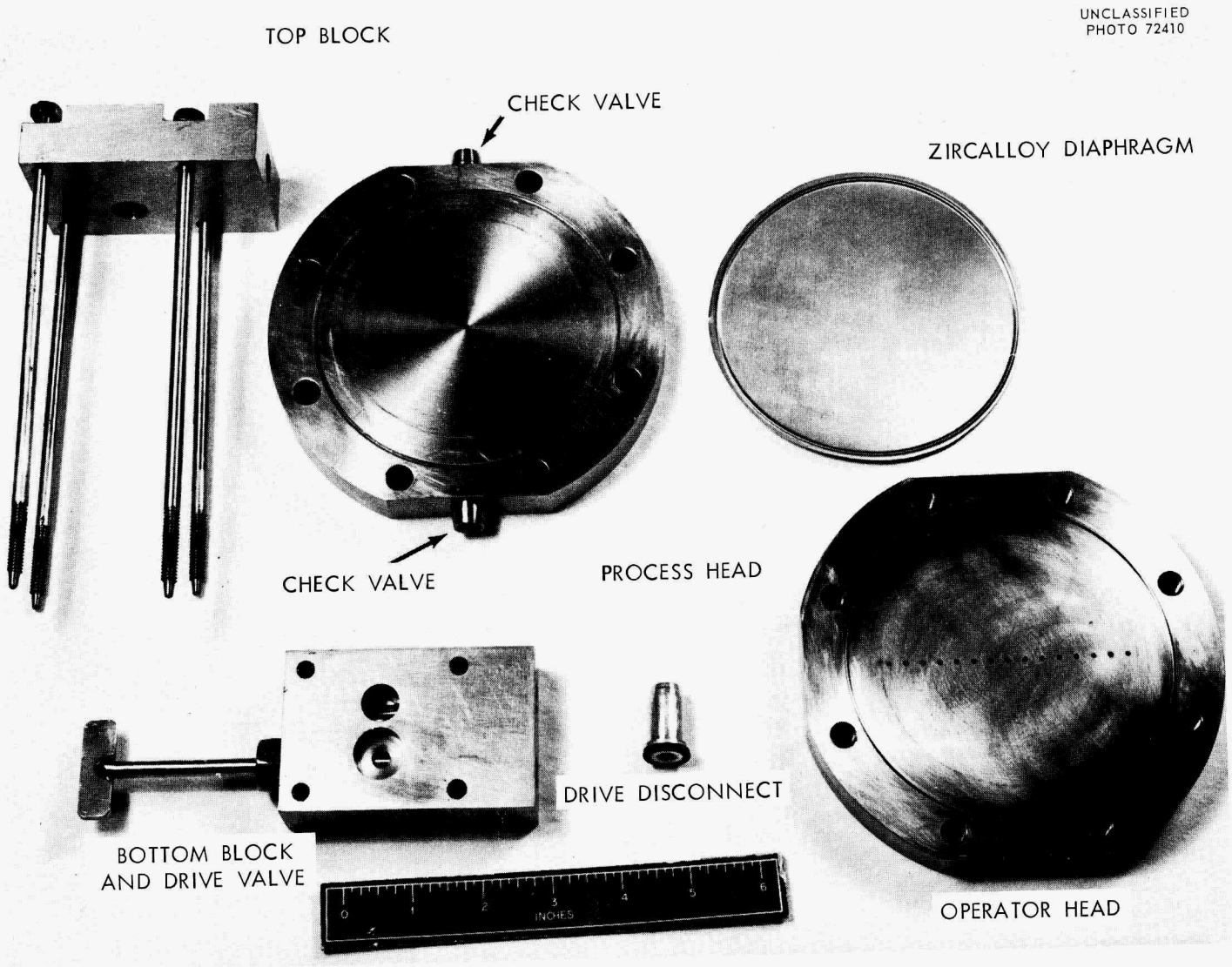


Fig. 6. Disassembled TRU Process Pump

surface of the diaphragm and pump head as the two are drawn together by the pump head bolts. The quality of the seal depends largely on the surface finish of the diaphragm material and also on the pump head surface finish at this point. Leak rate measurements of seals of this type using the helium leak detector showed a leak rate of less than 1×10^{-8} std cc of helium per sec at 0.05 micron. Hardened materials crack across the tongue and produce high leak rates. It was necessary to anneal the Zircaloy-2 stock to prevent leaks from this cause.

The gasket type seal (Fig. 4B) possessed excellent sealing qualities but is more difficult to assemble remotely.

The seal shown in Fig. 4C exhibited excellent sealing qualities but proved to be unusable because it was not possible to pull the pump heads down to the diaphragm leaving a space for solids to accumulate and high stress concentration at the inner edge of the seal ring.

Figure 5 shows the final assembled TRU pump. Figure 6 shows the disassembled TRU pump.

Diaphragm Material. Several materials were tested for use as pump diaphragm materials. The results of the tests are as follows:

347 stainless steel	2.8×10^5 cycles to failure
Tantalum	1.5×10^5 cycles to failure
Hasteloy C	6.17×10^5 cycles to failure

The above tests were made with the pump handling water.

With the pump operated dry, Zircaloy-2 diaphragm material gave a life in excess of 3×10^6 cycles.

A longer diaphragm life would be expected when the pump is operated dry because corresponding points of the diaphragm travel at a uniform rate. When the pump is operated with liquid passing through the pumping cavity,

the lower portion of the diaphragm lags the upper section because of non-uniform pressure drops across the diaphragm. This produces failures in the lower sections of the diaphragm. This effect is much more pronounced when the pump is operated with excessive air drive pressure. For this reason the drive air pressure should be set as low as possible consistent with the pumping rate desired.

Fabrication Techniques. Several techniques were developed during the course of pump fabrication which were necessary for satisfactory pump performance.

The first consisted of forming the check valve seats using a hardened steel ball. A deformation of 0.010 in. was required to give a nonleaking check valve seat. It is not possible to lap Zircaloy-2 check valve seats properly.

The second consisted of the addition of a polishing step to the disconnect mating surfaces. Before a leak-free seal could be made with Zircaloy-2 disconnects, it was necessary to provide a high polish on the seal surface with hardened steel rollers of a burnishing tool.

Maintenance Procedure. The removal of the pump for maintenance operation is accomplished by loosening the two disconnect clamp nuts shown in Fig. 1. This also breaks the process and air operator lines. It will be necessary to use an alignment jig to ensure proper alignment of the top and bottom blocks when the pump is assembled remotely. Preformed diaphragms will also aid the remote assembly of the pump.

3. PERFORMANCE TESTS

A large number of variables affect the output of the pump in the TRU process. Among these are: (1) the length and diameter of the air drive line, (2) the air supply pressure, (3) the suction lift, and

(4) the quantity of radiolytic gas generated in the pipe lines. Tests were made to determine the effect of each. The tests were made with a constant setting of 1.0 sec on the pressure stroke with a change in the vacuum stroke time to give the variation in strokes per minute until a setting of 1.0 sec was reached for the vacuum stroke. At this point both the pressure stroke and vacuum stroke times were decreased.

Effect of Size and Length of Air Drive Line on Pump Output

a. For 0.500-in. tubing 0.049-in. wall 2 ft long

Strokes/min	Output (cc/stroke)
5	9.8
12	9.8
15	9.8
20	9.8
25	9.8
30	9.2

b. For 0.500-in. tubing 0.049-in. wall 25 ft long

Strokes/min	Output (cc/stroke)
5	8.4
7.5	8.4
10.0	7.4
12.0	6.2
13.3	5.4
15.0	0.0

c. For 0.250-in. tubing 0.049-in. wall 2 ft long

Strokes/min	Output (cc/stroke)
5	10.0
12	10.0
15	10.0
20	10.0
30	10.0
40	9.9
60	10.0
80	10.0
100	9.3
144	3.6

d. For 0.250-in. OD tubing with 0.049-in. wall 25 ft long

Strokes-min	Output (cc/stroke)
5	9.2
12	9.5
15	9.5
20	9.4
30	8.2
40	8.0
60	7.7
130	1.5

e. For 0.1875-in. OD tubing with 0.035-in. wall 25 ft long

Strokes/min	Output (cc/stroke)
5	9.4
12	9.4
15	9.4
20	9.4
30	9.0
45	8.1
60	7.7
100	3.2

f. For 0.125-in. OD tubing, 0.035-in. wall 25 ft length

Strokes/min	Output (cc/stroke)
5	8.6
12	8.6
15	8.2
20	7.4
30	3.0
60	1.3

Effect of Air Pressure Supply on Pump Output

Pressure (lb/sq in.)	Output (cc/stroke)
15	6.4
20	7.4
25	7.6
30	8.2
37.5	8.4
45	8.6

Effect of Suction Lift on Pump Output

Operating conditions were: vacuum source 23 in. Hg,
Pressure source: 45 lb/sq in.
Water temperature: 75°F
Air drive line: 25 ft of 0.187 in. OD tubing

Suction Life (ft-in.)	Strokes/min	Output (cc/stroke)
19-0	10	9.2
	25	9.0
25-8	10	7.2
	20	7.2
30-0	10	6.6
	20	6.6

Measurement of Flow Rate Variation with Time

In this test the pump was set up to discharge into a large burette. An essentially pulse-free flow was fed from the burette to a rotameter by adjusting the burette stopcock.

Operating conditions: 15 ft suction lift head, water at 75°F, drive line, 25 ft of 3/16-in. tubing, 45 lb per sq in. drive pressure, 23 in. Hg vacuum drive, and 0.500-in. tubing with 0.049-in. wall for intake line.

Results for 10 cycles per min:

Rotameter Reading (cc/min)	Time (min)
85 to 95	0
85 to 95	2
85 to 95	4
85 to 95	6
85 to 95	8
85 to 95	10

Results for 10 cycles per min: (continued)

Rotameter Reading (cc/min)	Time (min)
85 to 95	12
85 to 95	14
85 to 95	15

Results for 25 cycles per min

210 to 220	0
200 to 210	3
210 to 215	5
210 to 215	7
210 to 215	9
210 to 215	11
210 to 215	12
210 to 215	15

Effect of Air Injection into Pump Intake line

Operating conditions same as above; 10 strokes per min and injection of 12.5 cc of air per min in intake line.

a.

Discharge Rate (cc/min)	Time (min)
60 to 62	0
60 to 62	3
60 to 62	5
60 to 62	7
60 to 62	9
60 to 62	11
60 to 62	13
60 to 62	15

b. For 10 strokes per minute and 22 cc of air per minute:

Discharge Rate (cc/min)	Time (min)
48 to 50	0
48 to 50	3
48 to 50	5
48 to 50	7
50 to 52	9
49 to 51	11
49 to 51	13
49 to 51	15

c. For 25 strokes per minute and 12.5 cc per minute of air:

Discharge Rate (cc/min)	Time (min)
185 to 190	0
190 to 195	3
190 to 195	5
195 to 200	7
190 to 195	9
190 to 195	11
190 to 195	13
190 to 195	15

d. For 25 strokes per minute and 50 cc of air per minute:

Flow Rate (cc/min)	Time (min)
127 to 132	0
120 to 125	3
120 to 125	5

For 25 strokes per minute and 50 cc of air per minute (cont'd)

Flow Rate (cc/min)	Time (min)
120 to 125	7
120 to 125	9
120 to 125	11
120 to 125	13
120 to 125	15

Effect of Gas Generation on Pump Discharge Rate.

The operating conditions were as follows: 15 ft lift head, 0.1 molar HNO_3 solution at 75°F containing 10 g/liter H_2O_2 and ferric nitrate, gas evolution rate 17 cc/min per liter of solution.

Discharge Rate (cc/min)	Strokes (per min)
110	25
50	12
35	8.6

4. PUMP OPERATION

The pump operation depends on movement of the metal diaphragm back and forth by alternate vacuum and air pressure (Fig. 1). The length of the vacuum and pressure stroke are timed by an electrical timer. The setting of the timer determines the number of cycles per minute and hence the discharge rate of the pump. The maximum output of the pump is accomplished by optimizing the time relationship of the pressure and vacuum stroke. Since more time is required to remove the air in the operator cavity with the vacuum supply than for the pressure to build up on the diaphragm from the air supply an optimum vacuum time setting

would be somewhat greater than for the pressure time setting. The test work was done with a constant setting of 1.0 sec for the pressure setting and then decreasing the vacuum time setting to control the number of pumping cycles per minute. After a certain point is reached for a given pump installation a further increase in the pump frequency decreases the output as shown in Fig. 7. Figure 7 is a plot of test 1-C- in which a 2-ft length of 0.250-in.-diam tubing was used as the drive line. The dropoff in output is caused by lack of sufficient time for the diaphragm to move the required distance for complete displacement.

The following precautions should be observed to ensure proper operation of the TRU pump.

1. Avoid handling solutions containing solids as this will produce premature diaphragm failure.
2. Do not operate the pump after the process tank has been pumped dry. If the pump is operated dry crystallization will occur in the check valves.
3. If the check valves should hang, tap the pump with a rubber faced mallet.
4. Set the time interval for the pressure stroke and vacuum stroke properly as described in the performance test procedure.
5. Observe the maintenance procedures given in the pump assembly procedure and indicated in the manufacturing drawings and specifications.[2]
6. Install only high quality diaphragm material in the pump. Diaphragm material with a scratched or dented surface will fail very quickly.

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[2]ORNL drawings E-52225 through E-52230 Process Equipment Specification C.T. 23.3 Specification for TRU air-operated diaphragm pump.

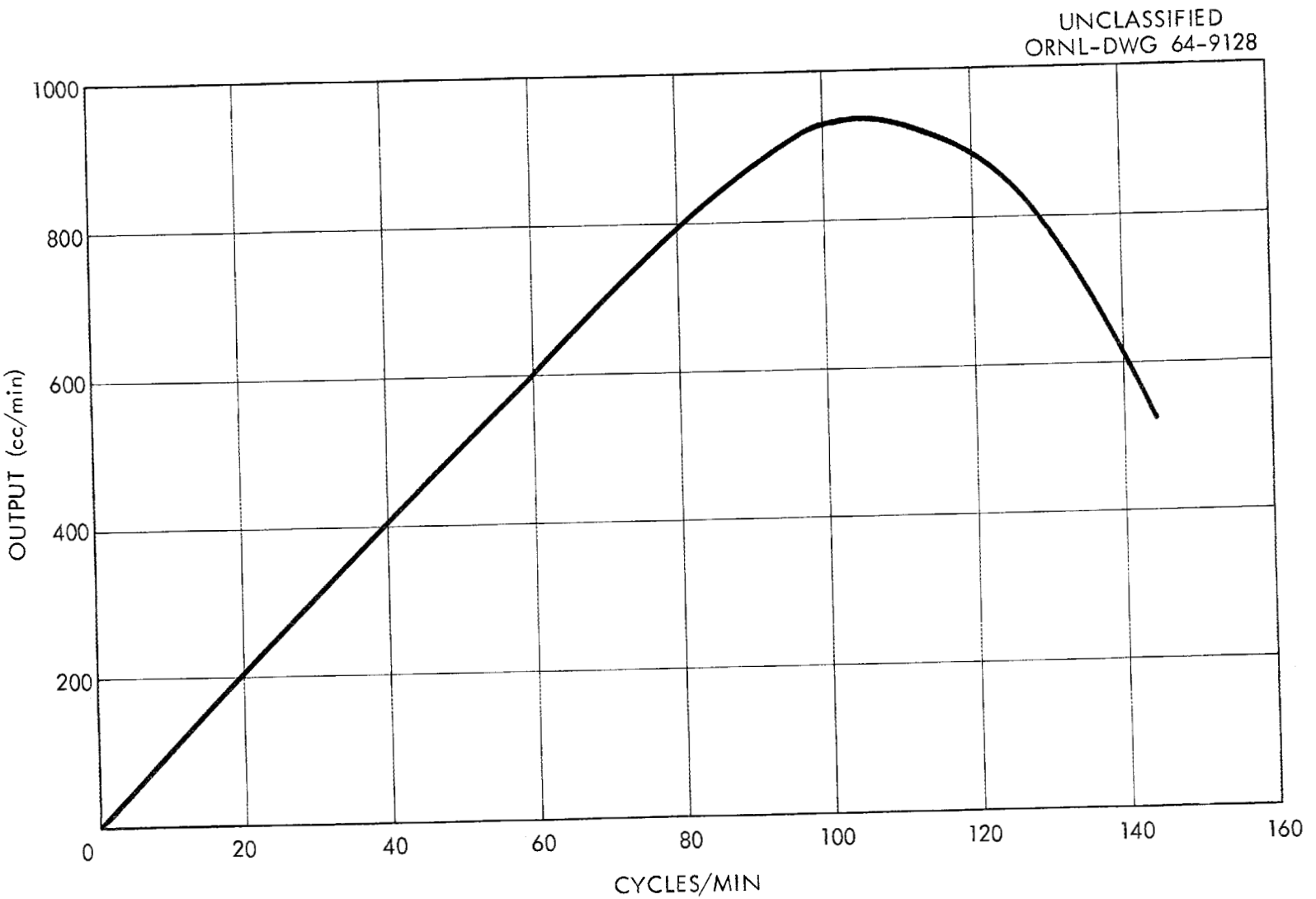

Fig. 7. Total Pump Output vs Cycles/Minute.

5. ACKNOWLEDGMENTS

Orlan O. Yarbro of the Chemical Technology Division and Berl Zimmerman of the ORGDP were responsible for the final TRU pump designs which adapted it for use in the TRU processing facility.

J. M. Turley of the Chemical Technology Division was responsible for the manufacturing specifications.

E. J. Breeding of the Reactor Division was responsible for development of the disconnect burnishing procedure.

J. N. Wheeler of the Engineering and Mechanical Division contributed the diaphragm seal design.

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