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RESEARCH REPORT 2-61

EVALUATION OF A NEW, POSITIVE DISPLACEMENT MECHANICAL RESPIRATOR FOR USE IN THE TESTING OF BREATHING APPARATUS

PROJECT NS 185-005 SUBTASK 4 TEST 1

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29 AUGUST 1960

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ABSTRACT

A "positive displacement" mechanical respirator, designed by the Experimental Diving Unit is described. Its operating characteristics were determined and compared with those of a bellows-type respirator previously used for testing breathing equipment. Recommendations for minor modifications and for the use of the new respirator are made.

SUMMARY

PROBLEM:

To describe the new Experimental Diving Unit mechanical respirator, its characteristics and operation procedures and to determine its suitability for testing breathing equipment.

FINDINGS:

(1) The respirator design is essentially satisfactory.
(2) Modification of the orginal relief valves is necessary.
(3) The respirator is essentially a positive displacement pump.
(4) The results obtained with the new respirator can be compared with results previously obtained with old respirator.

RECOMMENDATIONS: It is recommended that:

(1) The Experimental Diving Unit mechanical respirator replace the old mechanical respirator for future tests and evaluation of breathing equipment.
(2) The flow patterns actually obtained with the cams be measured.
(3) An attempt be made to locate small, reliable, non-leaking, relief valves to replace the mercury switch assembly.

ADMINISTRATIVE INFORMATION

Ref: (a) Telcon of 1 March 1958 between M.J. Foran, (BuShips Code 638) and W. F. Searle, (EDU)

Reference (a) assigned project number NS 185-005 Subtask 4 Test 47 to this project.

A positive displacement mechanical respirator was designed and fabricated by the Naval Weapons Plant in accordance with specifications furnished by the Experimental Diving Unit. The mechanical respirator is to be used to test diving equipment and will replace a bellows type mechanical respirator previously reported under the same project number.

R. L. Gwinn, MM1(DV), USN and R. J. Avila, GM1(DV), USN were assigned as assistant project engineers and G. M. Janney, LTJG, USNR as cognizant project officer. Work began on 9 November 1959 and was completed on 18 July 1960.

The following manhours were expended for this study:

DESCRIPTION	MANHOURS
Design and fabrication of switch	50
Calibration	200
Comparison tests	100
Report preparation	6
Clerical	4
TOTAL	360

This report is issued in the Experimental Diving Unit Research Report series. It is the second report written under this project number.

Costs incurred in the execution of this project were lodged against allotment 16102/59 and 70102/60.

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1. INTRODUCTION

1.1 Background

1.1.1 A bellows type mechanical respirator, manufactured by the Mine Safety Appliance Company, Pittsburg, Pennsylvania, has been used at the Experimental Diving Unit for many years to aid in the evaluation of diving equipment. This instrument and the procedures for its use are described in Experimental Diving Unit Research Report 6-58 "Mechanical Respirator Techniques in the Evaluation of Scuba" dated 30 June 1958.

1.1.2 As described in the report mentioned above, tidal volume (volume of gas per cycle) of the old mechanical respirator varied as the breathing pressure (pressure differential between the mouthpiece or mask attached to the mechanical respirator and the ambient atmosphere) varied. The only flow pattern which can be obtained from the old mechanical respirator is a roughly sinusoidal of variation in flow rate.

1.1.3 A new mechanical respirator was designed and fabricated at the Naval Weapons Plant in accordance with specifications furnished by the Experimental Diving Unit. The new mechanical respirator (here after referred to as the EDU respirator) was designed to have a tidal volume independent of breathing pressure and provides for a variety of flow patterns. A wide range of tidal volumes and respiratory rates is easily achieved.

1.2 Objective

1.2.1 The objective of this report is to describe the Experimental Diving Unit mechanical respirator; its characteristics and operating procedures.

1.3 Scope

1.3.1 The tests conducted on the Experimental Diving Unit respirator were all done with the sinusoidal flow pattern arm. No tests have been conducted with the positive motion cams.

2. DESCRIPTION

2.1 Experimental Diving Unit Mechanical Respirator

2.1.1 The Experimental Diving Unit mechanical respirator is essentially a three cylinder, piston type air pump. It is designed to simulate human respiration. The respirator can pump tidal volumes from 0.5 liters to 4.5 liters, producing a nearly sinusoidal flow variation. The respiratory rate can be varied from 5 to 72 cycles per minute. In addition to the sinusoidal flow pattern, three positive motion cams can be used, which produce breathing patterns which more closely simulate the human respiratory flow patterns which can be anticipated during usual underwater swimming activity.[1]

1. G.J. DUFFNER, EDU Research Report 9-57 "Canister Design Criteria of Carbon Dioxide Removal from Scuba", 8 March 1957.

These flow patterns are plotted in figure 1. The three cams provide tidal volumes of 1.0, 2.0 and 3.5 liters per stroke. The respirator is designed to operate in ambient pressures up to 13 atmospheres and can be safely used in an atmosphere containg high concentrations of oxygen.

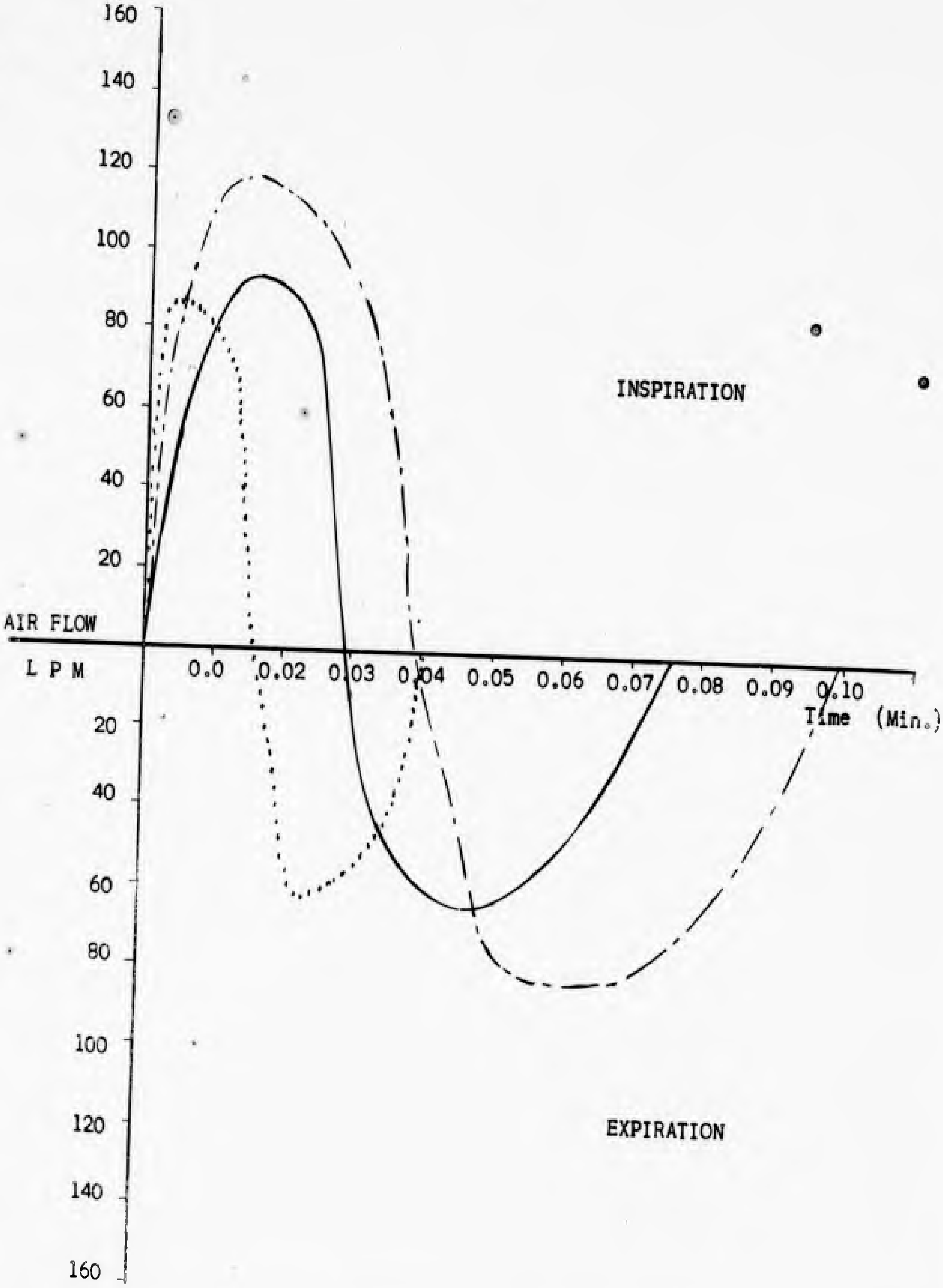
2.1.2 The Experimental Diving Unit mechanical respirator is shown, along with the cams in figures 2 and 3. The respirator consists of the following major components.

(1) Aluminum frame
(2) G.E. motor, size 43, type K, explosion proof CL 1, GPD, ½ HP, 1140 RPM, 60 cycl, 3 phase
(3) Zero - max, model 24 std - REVCO INC
(4) Gear assembly
(5) Sine mechanism assembly
(6) Positive action cams
(7) Tachometer
(8) Slide assembly
(9) 3 - 0 ring type aluminum pistons
(10) 3 - Aluminum cylinders
(11) Cylinder manifold
(12) Relief valve assembly

The respirator weighs 200 lbs. It is approximately 62" long, 18" wide and 24" high in overall demensions. Experimental Diving Unit drawings 1-58 through 16-58 pertain to this equipment. They are presently being revised.

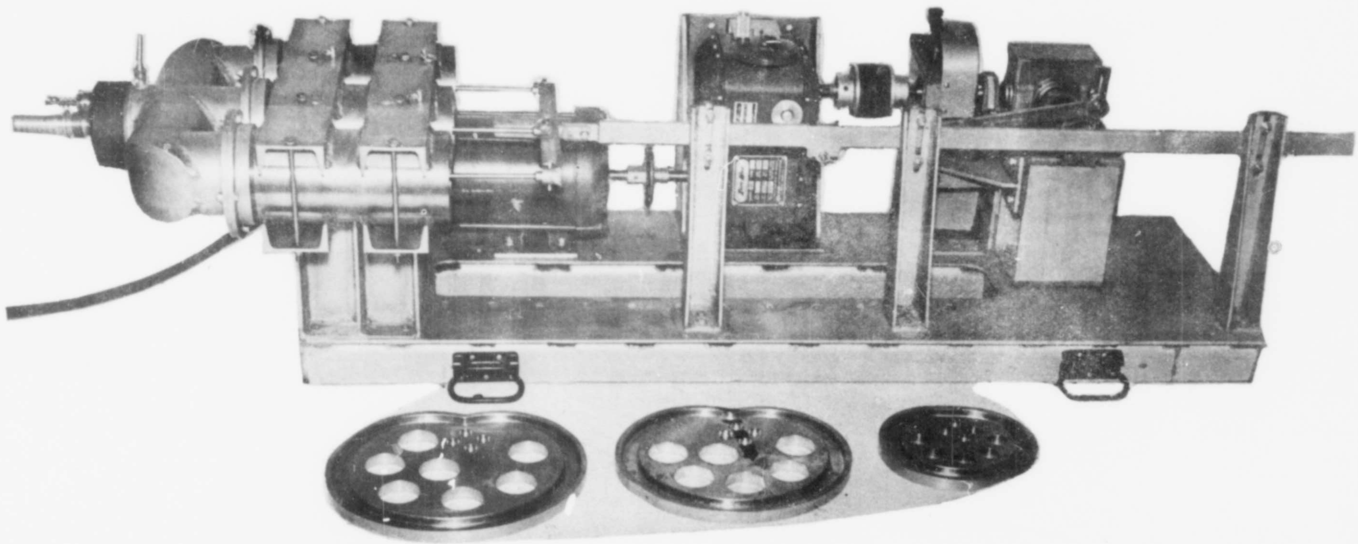
2.1.3 The electric motor drives the Zero-Max Unit which transmits a constant shaft speed independent of the load. The shaft rpm is easily varied by means of a hand crank on top of the Zero-Max Unit. The shaft revolutions are transmitted to the slide arm by means of a gear assembly and either the sine arm assembly or one of the cams. The slide arm moves with a reciprocating motion conforming either to the sine pattern or one of the cam patterns. The length of the stroke is determined by the length of the adjustable sine arm or the size of the cam being used. Either one, two or three pistons may be used. Pistons are attached to the slide assembly by easily removable pins. The pistons not being used are pinned in place within their respective cylinders. The motion of the pistons forces air in and out of the cylinders, through the manifold and through the breathing apparatus which would be attached to the manifold as described in Experimental Diving Unit Research Report 6-58. A pressure transducer can be attached to a pressure tap in the manifold or to a tap in the mask or mouthpiece of the breathing apparatus.

2.1.4 Two relief valves were provided in the manifold to prevent either positive or negative differentials in excess of 1 psi from ambient pressure. These valves were brass to brass, spring loaded check valves. They were observed to leak. The relief valves are necessary to protect the respirator and the pressure transducer from damage in case of flow restriction in a piece of breathing apparatus. Two large solenoid valves were mounted in series in place of one of the original relief valves. The other relief valve opening was plugged. A U-tube was filled approximately halfway with mercury. A glass float attached



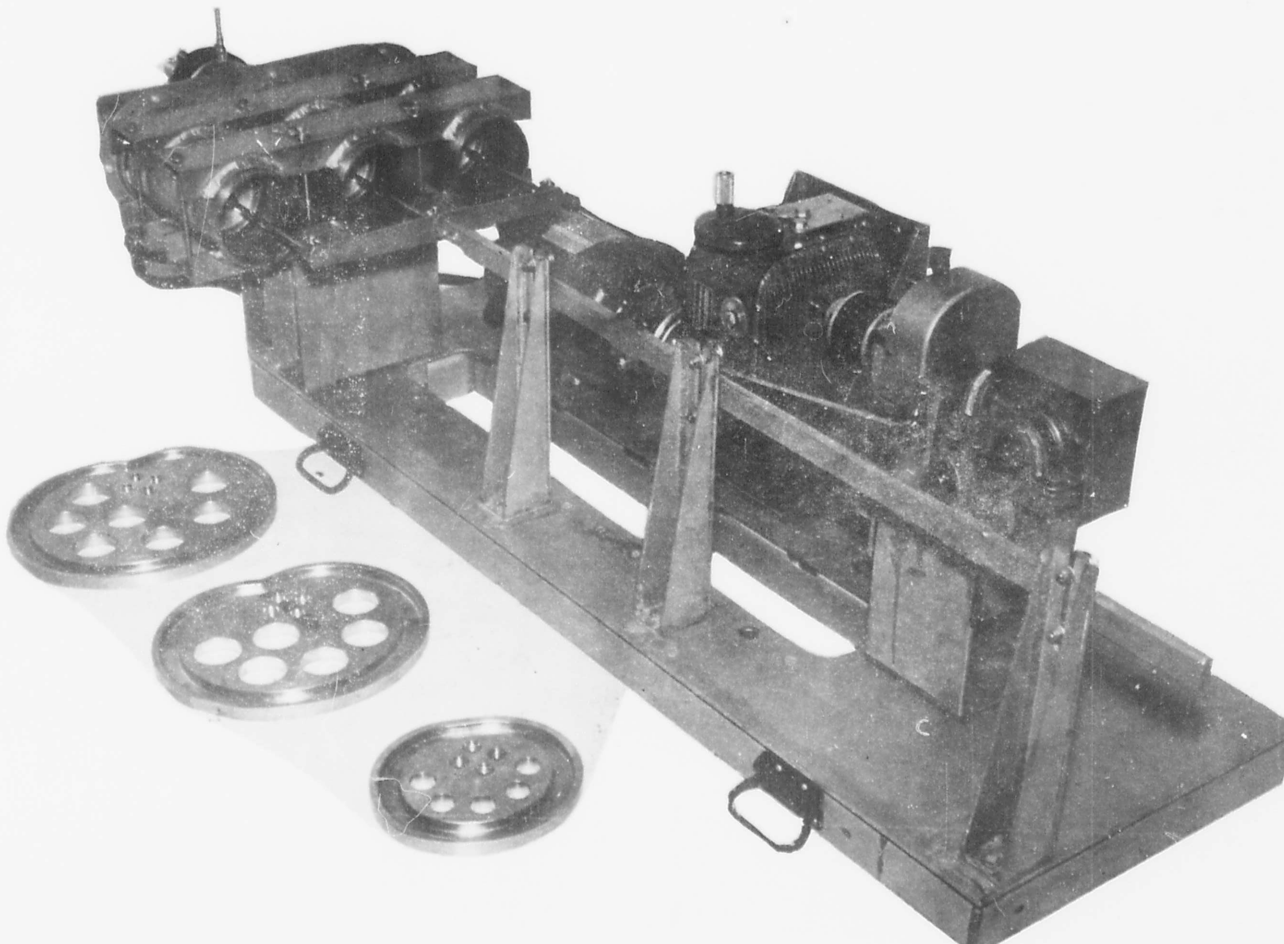
AIR FLOW CURVES WHICH CAN BE ANTICIPATED DURING USUAL UNDERWATER SWIMMING ACTIVITY.

FIGURE # 1



POSITIVE DISPLACEMENT MECHANICAL RESPIRATOR FOR USE IN THE TESTING OF BREATHING APPARATUS.

FIGURE 2



POSITIVE DISPLACEMENT MECHANICAL RESPIRATOR FOR USE IN THE TESTING OF BREATHING APPARATUS.

FIGURE 3

to a wire actuating arm was placed in one side of the U-tube. The other side of the U-tube is connected to a pressure tap on the manifold or the mouthpiece of the breathing apparatus being tested. The wire actuating arm trips a spring loaded mercury switch whenever the pressure differential exceeds plus or minus approximately 70 mm of mercury. The mercury switch opens the solenoid valve, providing the necessary protection. This relief valve assembly was manufactured from available equipment and works very satisfactorily. However, the same protection could be provided by two reliable, non-leaking, spring loaded relief valves, which would open at a pressure differential of 1 psi.

2.2 Maintenance

2.2.1 The following lubrication is recommended for the Experimental Diving Unit mechanical respirator:

(1) Electric motor - none
(2) Zero-Max - remove all of manufacturers lubricant, then add Halocarbon medium oil series 11-21.
(3) Pillow blocks - use Halocarbon heavy oil series 14-25.
(4) Gear housing - use Halocarbon medium oil series 11-21. Fill to depth of 0.500" to .750".
(5) Cam follower - use Halocarbon medium oil series 14-25.
(6) Cam grooves - apply Halocarbon grease series 25-10 to all groove surfaces.
(7) Variable sine mechanism - lubricate bearings thoroughly with Halocarbon heavy oil series 14-25. Relubricate periodically.
(8) Slide roller - lubricate bearings with Halocarbon heavy oil series 14-25 periodically.
(9) Air cylinder bore - prior to use remove pistons from cylinders and swab thin coating of Halocarbon heavy oil series 14-25 onto bore walls. Apply samé lubricant to outside diameters of piston and O-ring.

Note: Halocarbon oil is specified due to the explosion hazard when operating in an oxygen rich atmosphere.

The only other maintenance required is the periodic replacement of the piston O-rings when they become worn.

2.3 Operation

2.3.1 To operate the Experimental Diving Unit mechanical respirator, the desired flow pattern, tidal volume, and respiratory rate must first be selected. The appropriate cam or sine arm is then installed. The rough adjustment for the tidal volume is made by attaching one, two or three pistons to the slide assembly. Each cylinder has a maximum displacement of approximately 1.5 liters. A spirometer is then attached to the manifold and the respirator is turned through one exhalation cycle by hand. The amount of gas collected in the spirometer is the tidal volume. Repeated adjustments of the sine arm length and tidal volume measurements will result in the desired tidal volume setting. In the case of the cams, no further volume adjustment is possible once the particular cam and the number of cylinders to be used are selected.

2.3.2 To set the respiratory rate, the respirator is turned on and the revolutions per minute as indicated on the tachometer are noted. The rate may then be increased or decreased by turning the hand crank on the Zero-Max. gear box. It will be noticed that the indication on the tachometer dial oscillates slightly about a center valves. The center value may be taken as the correct one or the rate may be measured with the aid of a stop watch and a further adjustment made.

2.3.3 After the above measurements have been made, the Experimental Diving Unit mechanical respirator is used in the same manner as the old mechanical respirator, as described in Experimental Diving Unit Research Report 6-58.

3. PROCEDURE

3.1 Tests of respiratory rate

3.1.1 The Experimental Diving Unit mechanical respirator was operated using the sine mechanism. The revolutions per minute were measured with a stop watch and with the tachometer. The results of the measurements are presented in table I below:

TABLE I

Calibration of Tachometer

ACTUAL RPM (Stopwatch)	TACHOMETER RPM (1 piston)	TACHOMETER RPM (3 pistons)
10	10 - 12	9.8 - 10.5
15	14.75 - 15.25	14.75 - 15.25
20	19.9	19.9
25	24.9	24.9

Each test was conducted for 25 minutes with no changes observed. No oscillation of the tachometer needle was noted for respiratory rates above 20 rpm.

3.2 Tidal Volume vs Resistance Tests

3.2.1 A SCUBA mouthpiece with inhalation and exhalation check valves was attached to the manifold of the Experimental Diving Unit respirator. A throttle valve was installed in the inhalation hose leading to the mouthpiece and another throttle valve was installed in the exhalation hose leading from the mouthpiece. A hose from the exhalation throttle valve was connected to a large spirometer. The Experimental Diving Unit respirator was operated for one minute at each of various tidal volume settings and inhalation and exhalation throttle valve settings. The breathing pressure in the mouthpiece was measured by a Stathom pressure transducer and Brush Amplifier-recorder system as described in Experimental Diving Unit Research Report 6-58. The results of these tests are plotted in figures 4 and 5. Similar data for the old mechanical respirator is plotted for comparison.

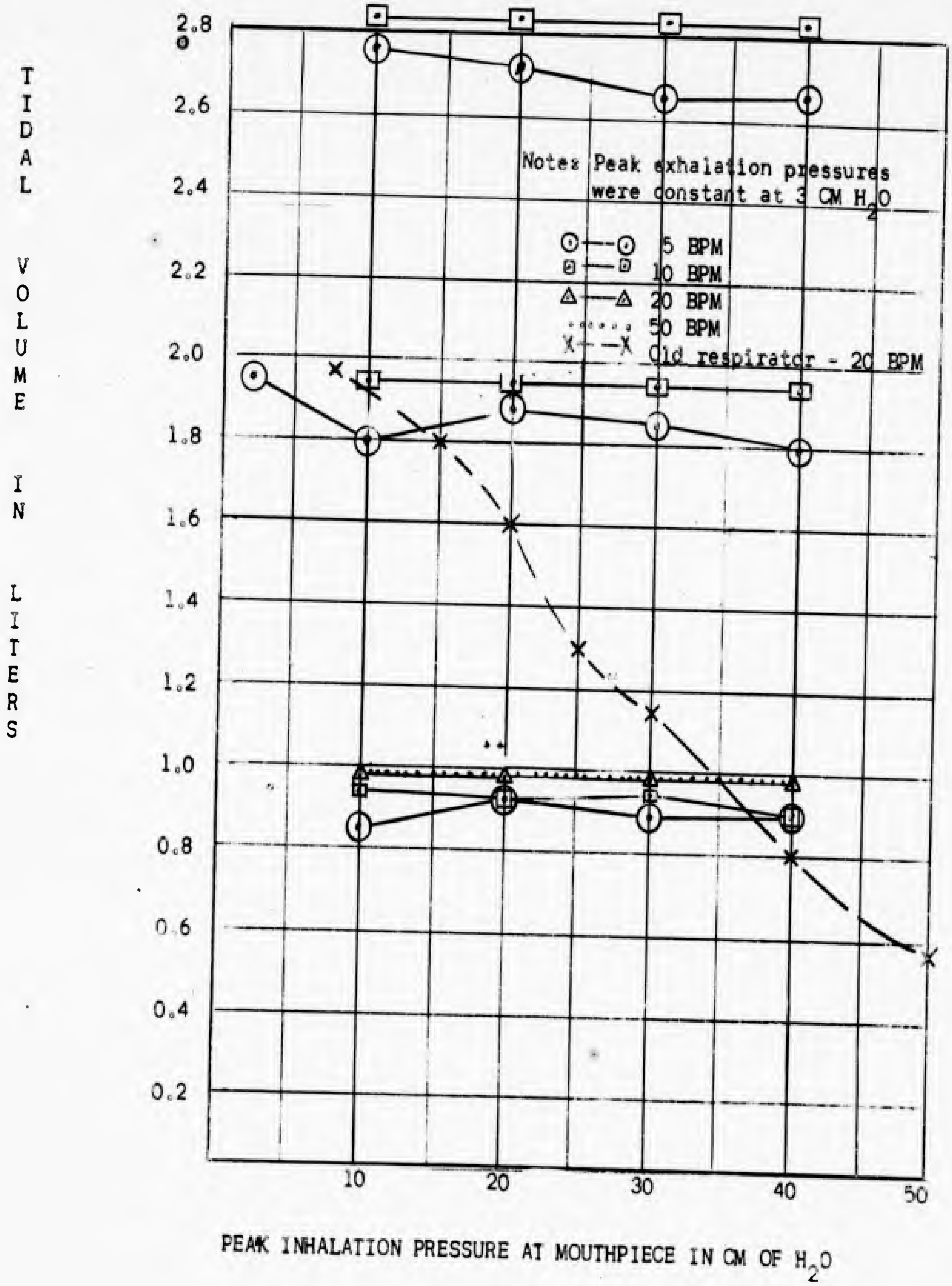


FIGURE 4: TIDAL VOLUME VS INHALATION PRESSURE.

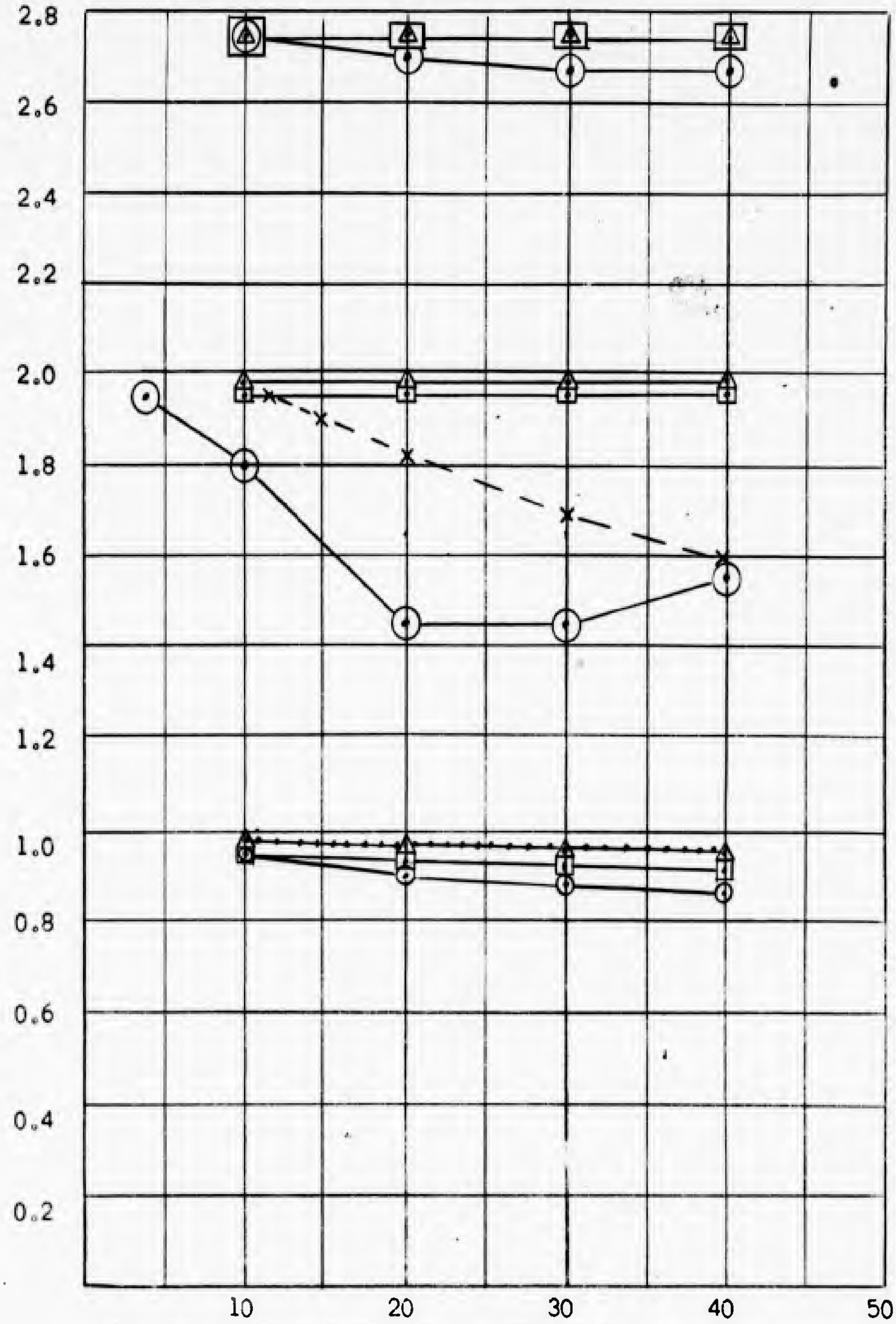


FIGURE [illegible] TIDAL VOLUME VS EXHA[illegible] PRESSURE.

3.2.2 It can be seen that the tidal volume Experimental Diving Unit respirator remains very constant with varying inhalation or exhaltion pressure, with the exception of the one test plotted in figure 5. In view of the constancy of all other tests, it is felt that the results of that particular test are spurious.

3.3 Comparative breathing pressure test of open circuit scuba with old mechanical respirator and Experimental Diving Unit respirator.

3.3.1 An open circuit regulator was connected to a tee arrangement with shut off valves in both branches of the tee. One side of the tee was connected to the manifold of the Experimental Diving Unit respirator; the other side was connected to the old mechanical respirator. A pressure tap was installed in the mouthpiece of the demand regulator and connected by tubing to a pressure transducer. The set up was placed in a recompression chamber and the regulator was given the new standard test procedure as described in Experimental Diving Unit Research Report 6-58, using first one respirator and then the other at each depth, to compare the results obtained with each respirator. The results are given in table II below:

TABLE II

RESULTS OF COMPARATIVE TESTS OF OPEN CIRCUIT SCUBA

TEST	DEPTH	EXH PRESSURE (cm of H20) OLD	EXH PRESSURE (cm of H20) NEW	INH PRESSURE (cm of H20) OLD	INH PRESSURE (cm of H20) NEW
# 1	Surface	12	10	8	8
	30	18	16	10	10
	60	22	21	11	11
	90	27	26	12	13
	120	30	30	12	14
	150	32	31	12	14
	180	33	35	14	18
# 2	Surface	12	10	7	7
	30	18	15	8	8
	60	23	20	8	9
	90	27	25	9	9
	120	26	28	9	11
	150	32	30	10	14
	180	36	30	10	16

4. DISCUSSION

4.1 Design and Construction of Experimental Diving Unit Mechanical Respirator

4.1.1 The design and construction of the new Experimental Diving Unit mechanical respirator is satisfactory except for the faulty pressure relief valves. The equipment is easy to adjust, operate and maintain and should prove to be very reliable.

4.2 Cams

4.2.1 The accuracy with which the Experimental Diving Unit respirator, with the cams installed can reproduce the flow patterns of figure 1 has not been tested. However, in view of the very good results obtained in the tidal volume vs breathing pressure tests for a wide range of operating speeds, there should be very little discrepancy between the theoretical and actual flow patterns.

4.3 Comparative Test of Open Circuit Scuba

4.3.1 The results of the comparative test made with the two respirators indicate that the results of tests made with the new Experimental Diving Unit respirator can be compared fairly closely with previous results obtained or the old mechanical respirator.

5. CONCLUSION

5.1 Conclusions

5.1.1 The following is concluded about the new Experimental Diving Unit Mechanical Respirator:

(1) The respirator design and construction is essentially satisfactory.
(2) The pressure relief valves originally installed are unsatisfactory.
(3) The Experimental Diving Unit respirator is essentially a positive displacement pump; the tidal volume vs respiratory pressure curves are nearly flat.
(4) The results obtained with the new Experimental Diving Unit respirator can be compared with results previously obtained with the old mechanical respirator.
(5) The cams should provide the desired flow patterns.

5.2 Recommendations

5.2.1 It is recommended that:

(1) The new Experimental Diving Unit mechanical respirator replace the old mechanical respirator for future tests and evaluation.
(2) The flow patterns actually obtained with the cams be measured.
(3) An attempt be made to locate small, reliable, non-leaking, relief valves to replace the mercury switch assembly.

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