PROGRESS REPORT

PR 91565-430-7

For The Period of January 11, 1963 - February 15, 1963

DEVELOPMENT OF AUXILIARY ELECTRIC POWER SUPPLY SYSTEM

NASA Contract NAS 3-2550

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INTRODUCTION

This report describes the work accomplished on the program conducted by Vickers Incorporated under NASA Contract NAS 3-2550 from January 11, 1963 to February 15, 1963. The objectives of this program are to conduct an engineering study culminating in the design of an electrical power generation system operating on hydrogen and oxygen in a space environment, and to conduct preliminary testing on critical system components.

PROGRAM SCHEDULE

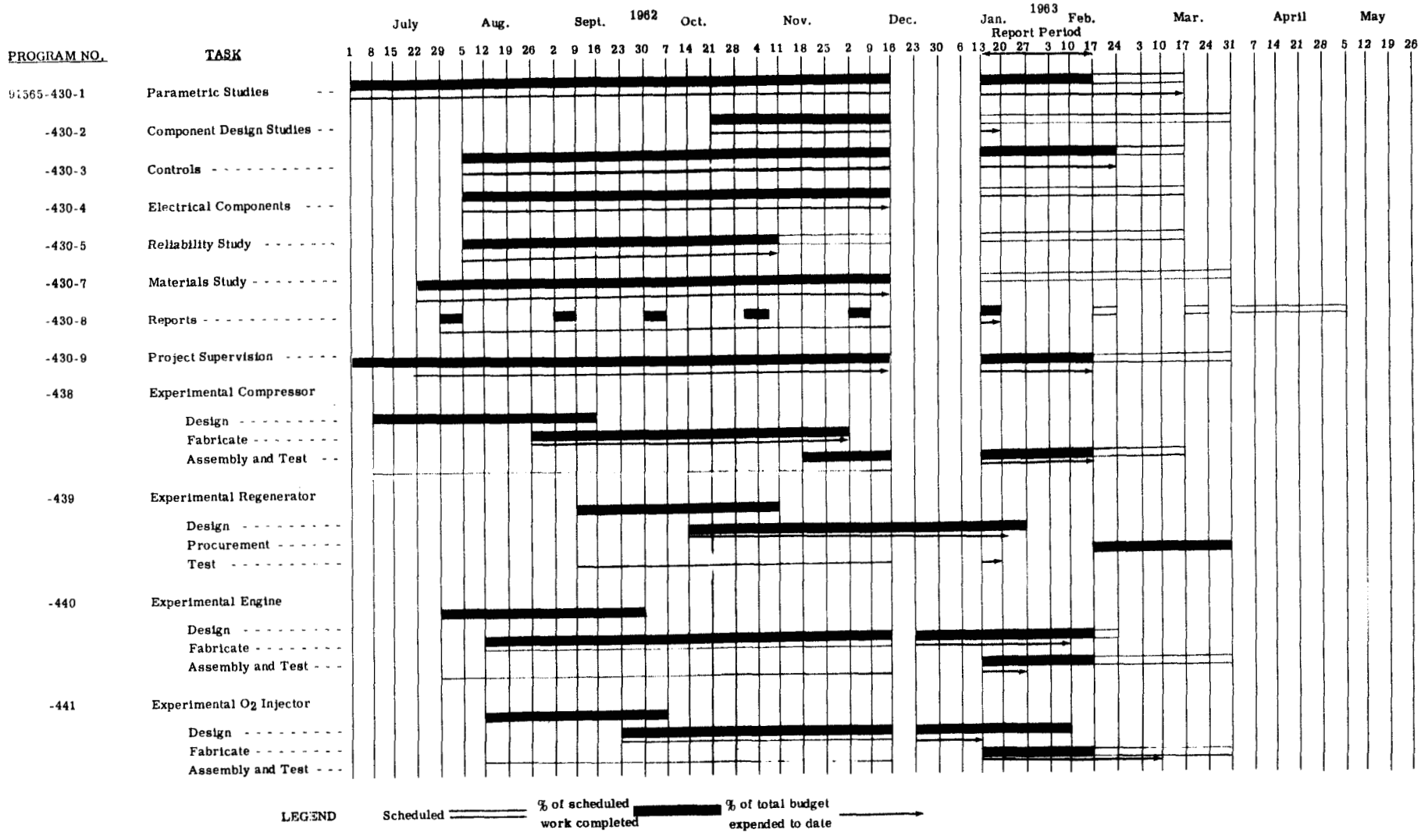
The program schedule is shown in Figure 1. After a 4 weeks' delay engineering work was resumed January 11, 1963, when a contract change provided the additional funds required to continue the program. The schedule has been revised to account for this delay and also has been extended to take advantage of a 30 day extension which was agreed to by NASA and Vickers personnel January 17, 1963. Slippage of the original test schedule has occurred due to an unanticipated amount of rework required during assembly of the compressor, engine and injector. It is expected that completion of the program can be accomplished in accordance with the revised schedule shown in Figure 1.

PARAMETRIC STUDIES

An analysis of a variable admission cycle using the dual poppet hydrogen valve was undertaken during this report period. The results are shown in Figures 2 and 3. The assumptions used and some sample calculations are given in Appendix 1. This cycle presents a considerable improvement in performance over the comparable cycle using a single variable phase valve. This improvement is due to the elimination of compression loss which occurred on early opening of the single valve.

A 40° valve duration was chosen since this will give from full throttling (no admission) to full power by phasing only one valve. Valves would be sized so that no appreciable pressure drop occurred between 1%

PROGRAM SCHEDULE NASA CONTRACT NAS 3-2550



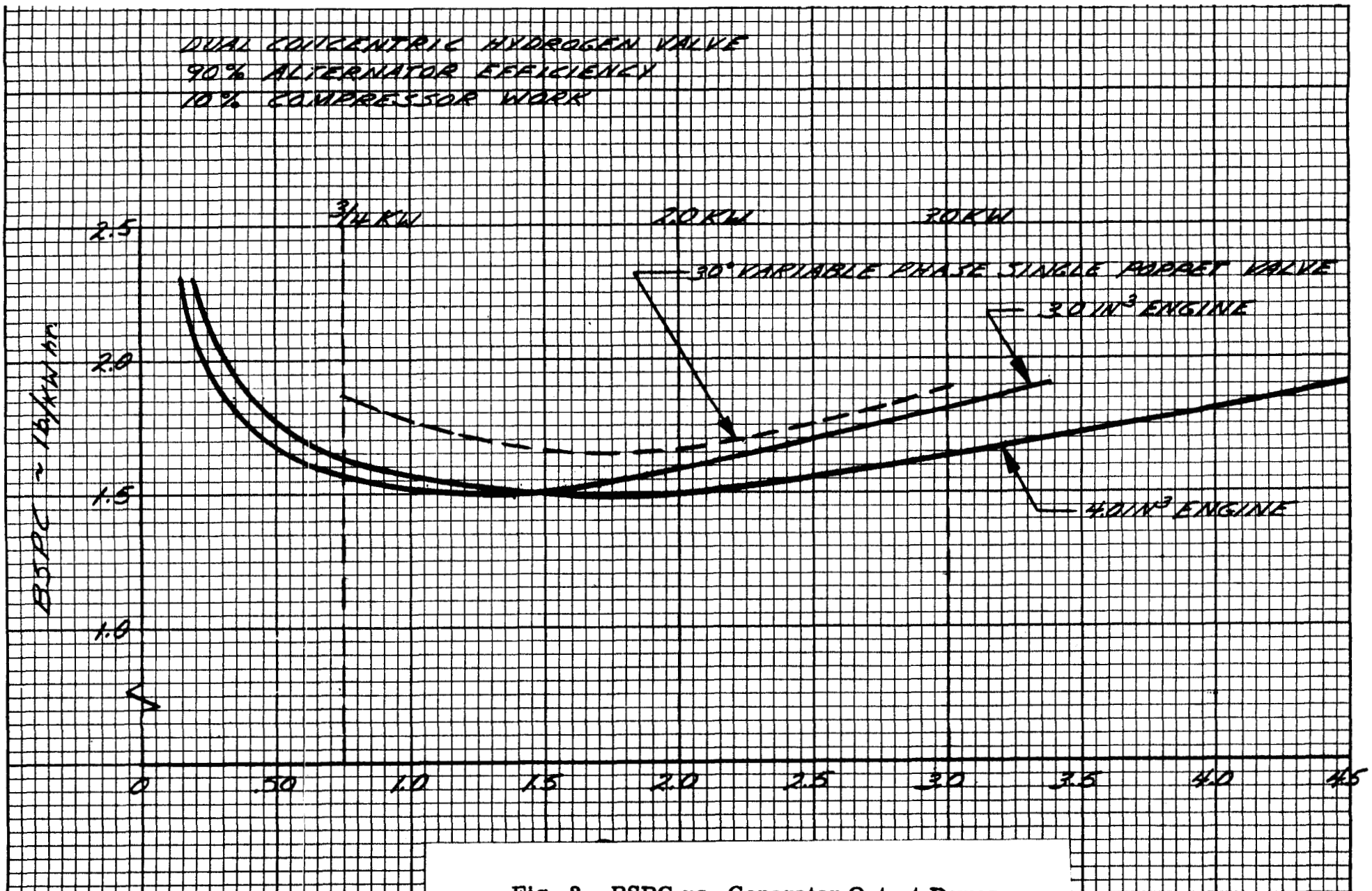


Fig. 2 - BSPC vs. Generator Output Power

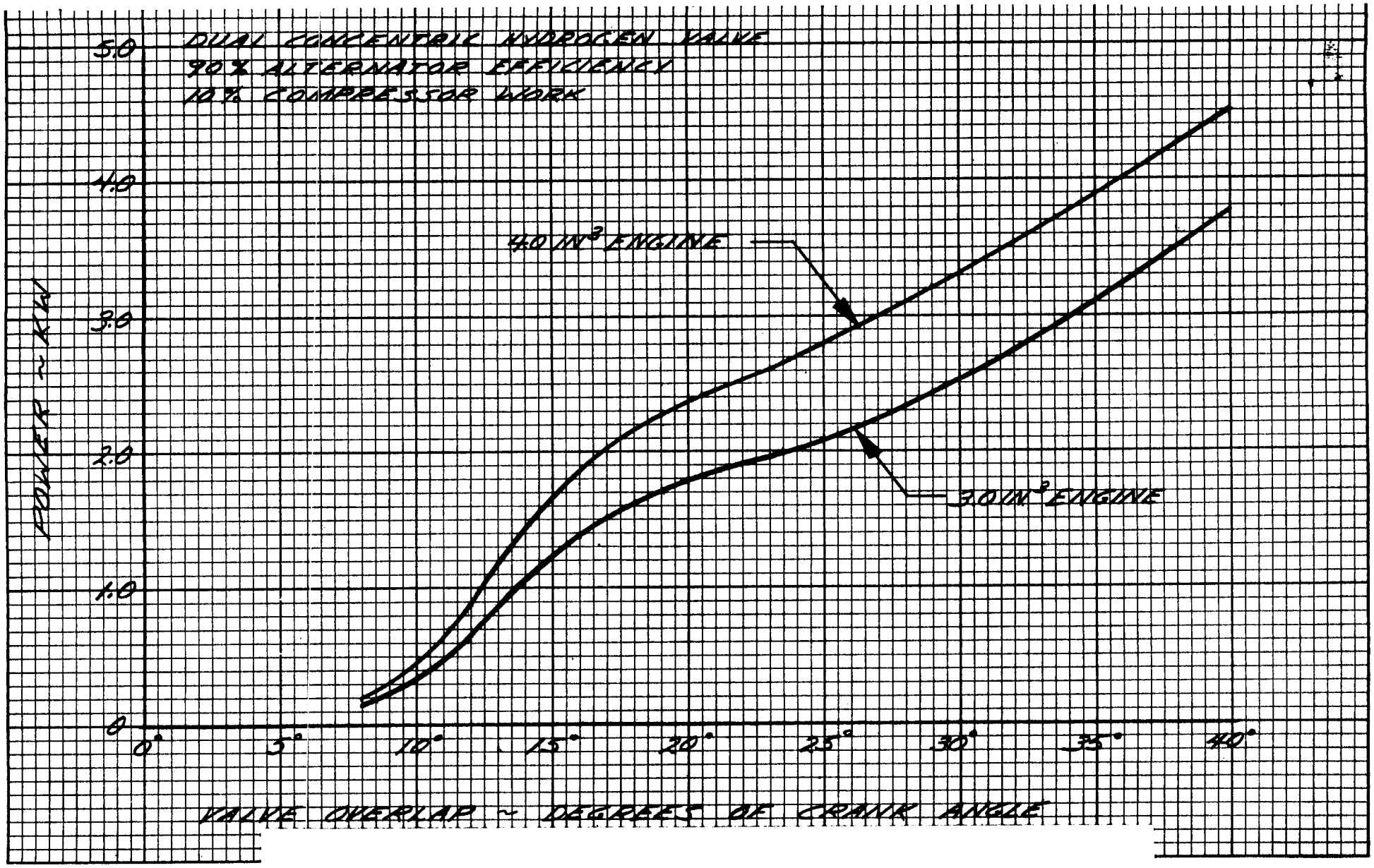


Fig. 3 - Generator Output Power vs. Hydrogen Valve Overlap

and 10% admission. This would give 17° of cam angle to phase down to full throttling. While a sinusoidal valve lift curve was assumed, in practice a very gradual opening curve and a sharp cut-off would probably be used for more linear valve control. This system has great inherent flexibility.

Engine displacements of 3.0 in^3 and 4.0 in^3 are shown. The 3.0 in^3 engine is more directly comparable to the 2.77 in^3 engine using a single poppet valve, shown as dashed lines in Figure 2. For the mission profile under consideration, the 4.0 in^3 engine will probably yield a lower system weight.

COMPONENT DESIGN STUDIES

Little work was done on component design studies during this time period due to the unavailability of the design staff personnel. Present plans are to design an engine using the dual poppet hydrogen valve concept operating on the cycle discussed above under parametric studies. A single stage hydrogen compressor and a double stage oxygen compressor (similar in design concept to the hydrogen compressor now being tested) will be incorporated into the system.

Some preliminary analysis has been done on engine balancing and vibration isolation, compressor sizing, and engine-hydrogen compressor heat transfer. It appears possible from a thermal insulation standpoint to incorporate the hydrogen compressor as an integral part of the engine, using the compressor piston as a balance piston. This configuration will be investigated as an alternate design concept. Most of the design effort will be concentrated on a conventional engine using a counterweighted crankshaft and tuned mounts.

CONTROLS

Work is continuing on pilot control and override methods and a final control schematic.

ELECTRICAL

No further effort has been expended on the electrical system during this report period.

RELIABILITY

No work has been done on reliability during this report period.

COMPONENT TESTING

Experimental Compressor

I Design

A. Initial Design - Complete

B. Re-design

Grooves for all Teflon coated metal "O"-ring seals have been changed from a "V" to a rectangular cross-section. This will provide proper "crush" on the metal "O"-ring seals.

A floating pin with Teflon filled bronze bearing pin joint has been designed as a back-up to the Bendix flex pivot (see Figure 4). New endurance life data received from this flex pivot vendor indicates inadequate life capacity in the present design. The present configuration does not allow room for a larger flex pivot.

II Detailing - Complete except for future changes.

III Fabrication - Complete

IV Assembly and Bench Checkout - Complete

Figure 5 is a photograph of the compressor component parts and sub-assemblies. The compressor was assembled (except for metal "O"-rings) and was bench mounted during the week ending 1-20-63 (see Figure 6). Assembly with metal "O"-rings was completed during the week ending 2-17-63.

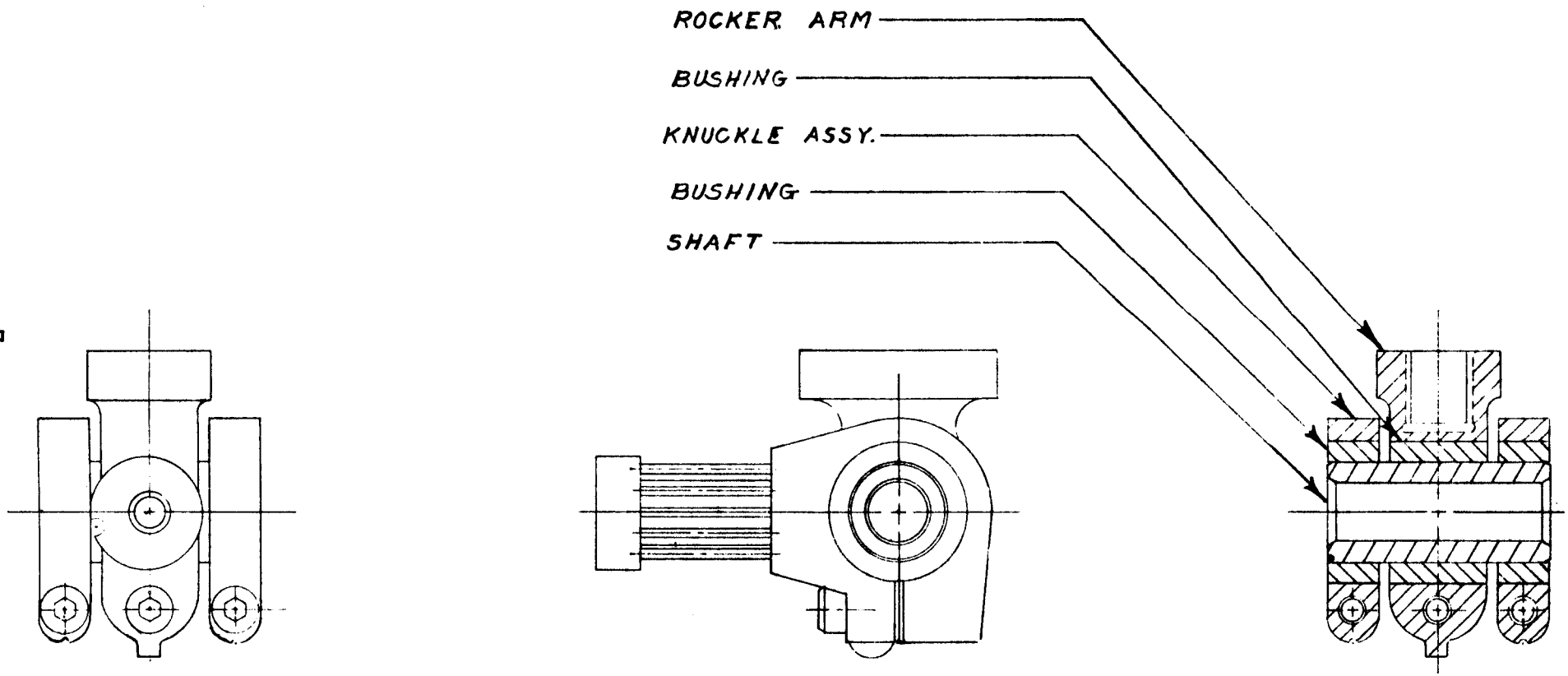


Fig. 4 - Floating Piston Pin Design

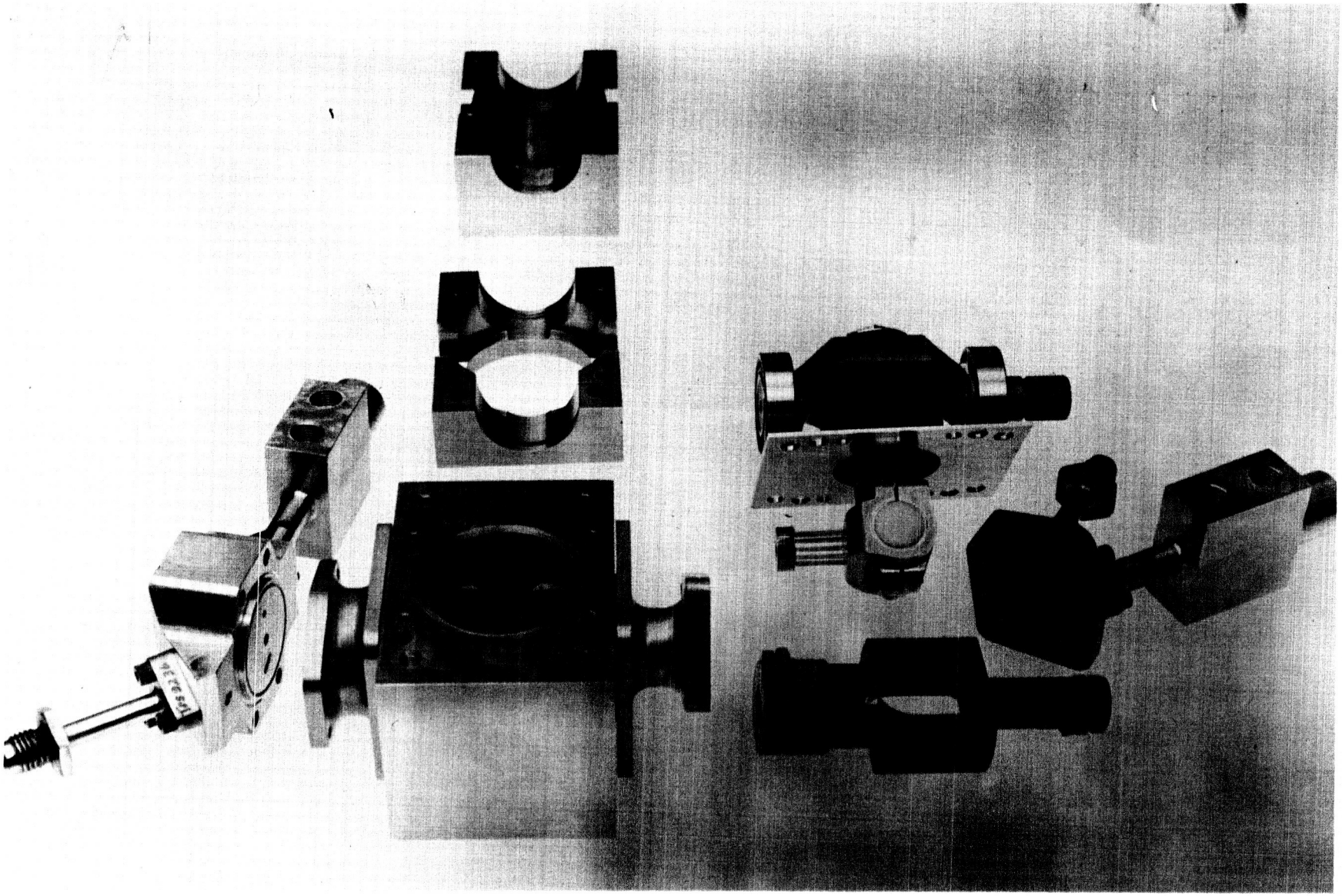


Fig. 5 - Compressor Components and Sub-Assemblies

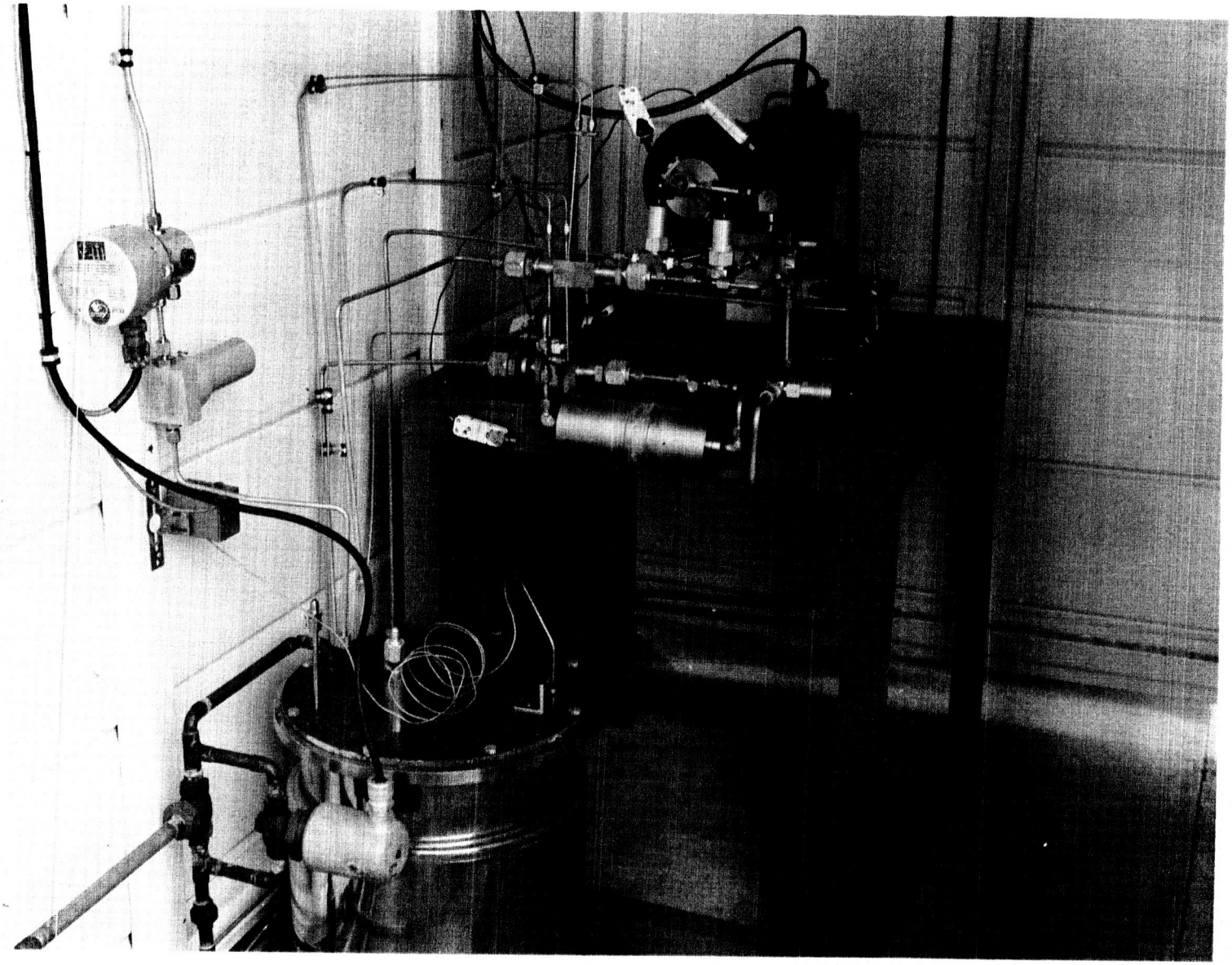


Fig. 6 - Compressor Mounted on Best Test Rig

V Test Facilities - Complete

Figure 7 is a photograph of compressor and the complete test circuit. Figure 8 is a photograph of the control panel and instrumentation inside control room. Plumbing of the test circuit and the attachment of instrumentation will be completed during the week ending 2-27-63.

VI Preliminary Tests on Nitrogen

A. Mechanical Function Checkout of Compressor and Compressor Drive Complete 1-27-63

The compressor was run without heads for approximately 10 minutes as the speed was gradually increased from 100 RPM to 750 RPM. Both the compressor and the drive functioned satisfactorily. The test caused no visible change to any of the compressor parts except that some of the rods in the drive cage had taken a slight "S" bend set. The braze assembly was a few thousandths of an inch out of line before assembly and it is not known whether this initial misalignment or compressor operation caused the rod to bend. The rods have been straightened and the assembly will be re-used and inspected. The rod cage has been re-brazed in an improved braze fixture.

B. Facilities - Checkout and Trial Run

This phase of testing was started during the week ending 2-17-63 and is scheduled for completion during the week ending 2-24-63.

During these tests the following will be accomplished:

1. Test operation techniques will be learned and an operation procedure written.

2. The test circuit will be modified and leak-sealed if necessary.

3. The actual compression ratio will periodically be compared with the expected value to determine whether or not the rings are wearing in properly. The cylinder bore finish will be roughened, if necessary, for proper ring seating.

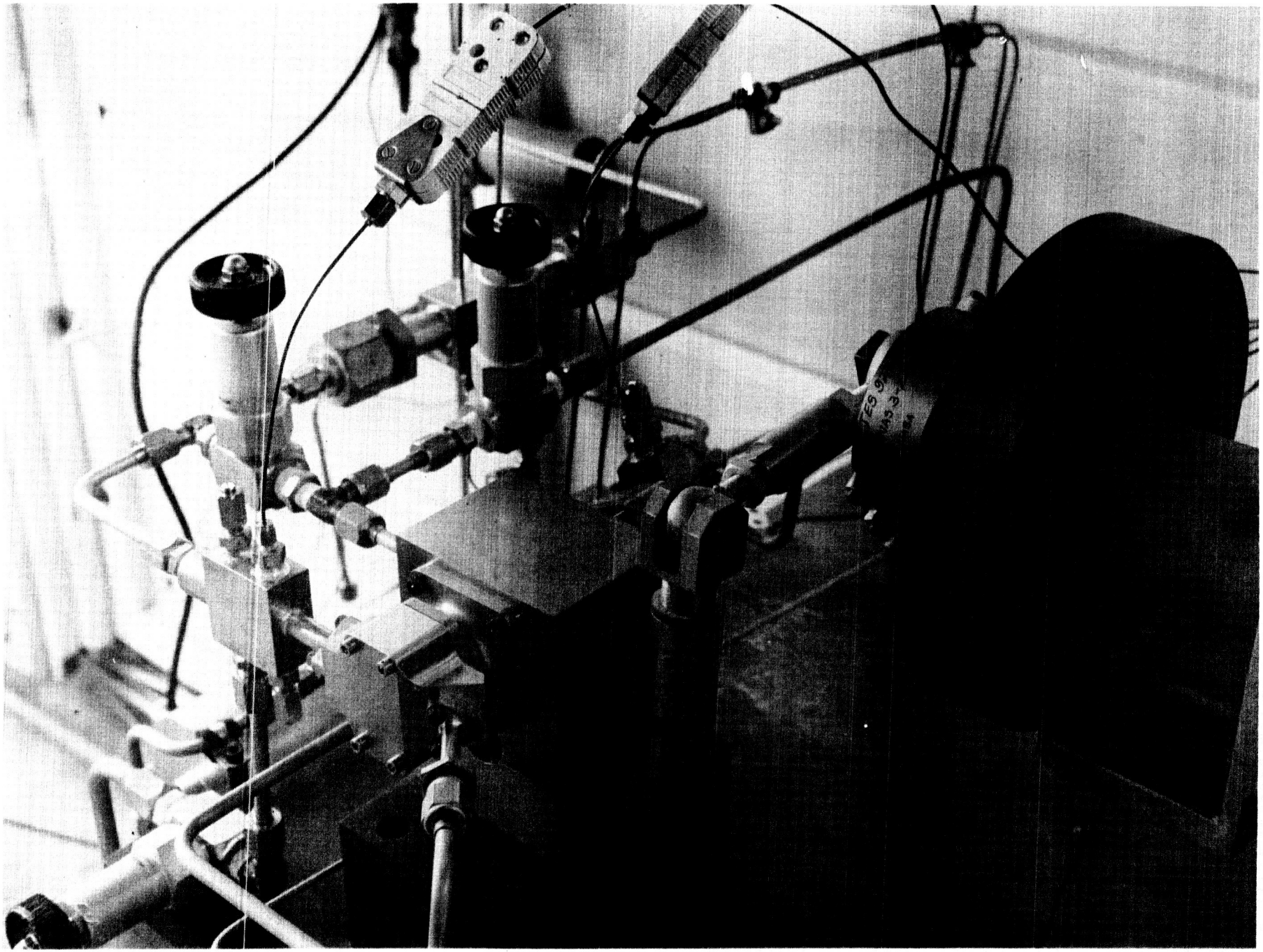


Fig. 7 - Compressor and Test Circuit

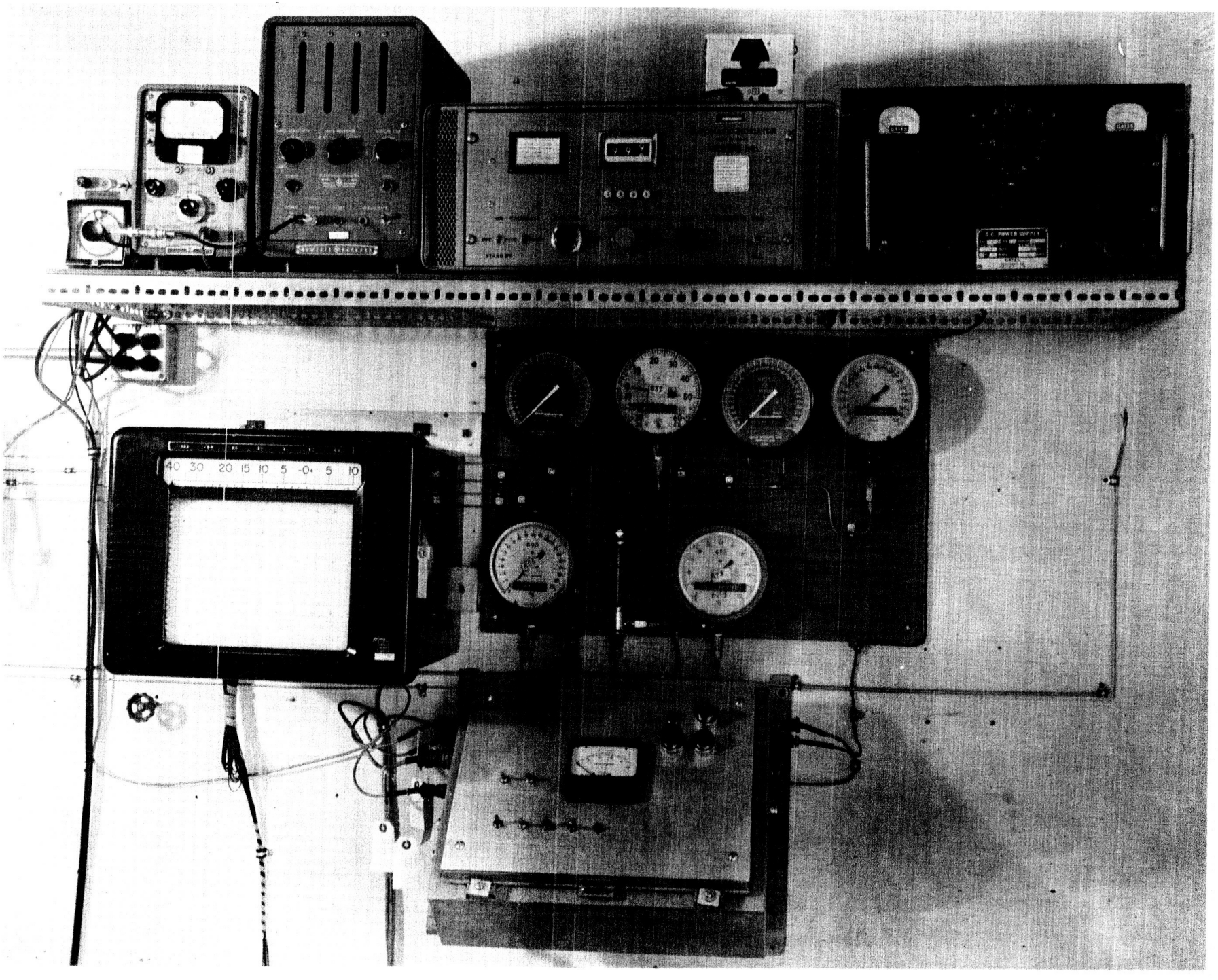


Fig. 8 - Compressor Test Circuit Control Panel

C. Inspection

The compressor will be disassembled and inspected for wear, galling, pitting, etc., and micro-photographs will be taken where deemed necessary.

VII Performance Tests with Hydrogen

Performance tests will begin during the week ending February 24, 1963. Test effort has been previously described. Performance tests are scheduled for completion on March 15, 1963.

Experimental Regenerator

I Design - Complete

II Detailing - Complete

III Fabrication and Procurement - Complete

IV Assembly and Checkout - Complete

Figure 9 is a photograph of regenerator components and the core sub-assembly.

V Test Facilities

The test facilities are being fabricated and will be completed by 2-24-63.

VI Preliminary Tests

The proof pressure test (2250 psi with solvent) and helium leak test (300 psi) of the H_2 side of the regenerator will be completed during the week ending 2-24-63.

VII Performance Tests

A. Pressure Drop

The pressure drop of the hydrogen side of the regenerator will be determined with nitrogen for different discharge pressures. Performance tests will be completed by February 24, 1963.

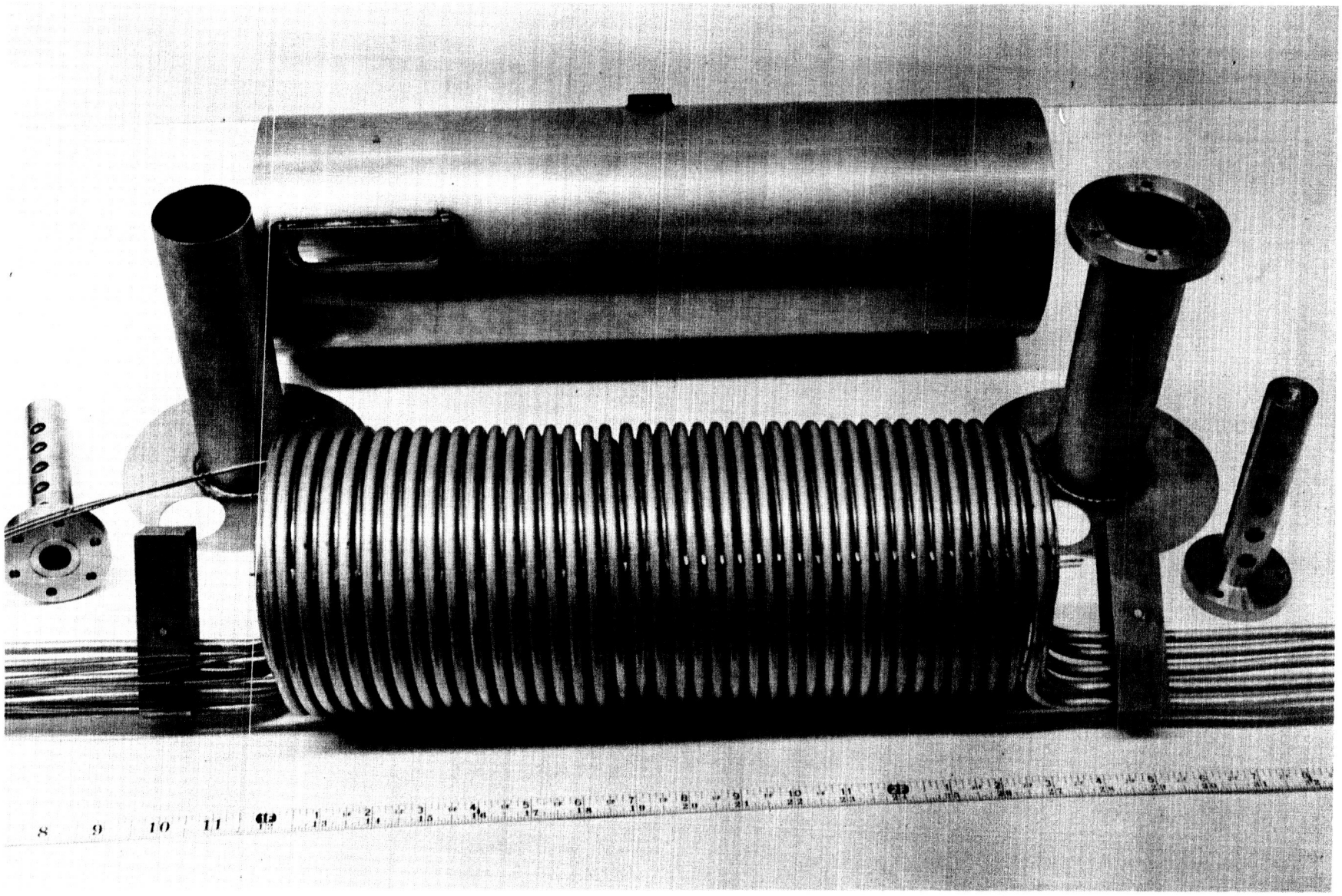


Fig. 9 - Regenerator Components

B. Calibration - Start March 15, 1963

After sufficient engine tests to determine the maximum achievable O/F ratio have been performed, the regenerator will be run in conjunction with the engine to determine film coefficients, approach temperatures, and icing characteristics, at different engine power levels.

Experimental Engine

I Design - Complete

II Detailing - Complete

III Fabrication - Complete

IV Assembly and Bench Checkout - Complete

V Test Facilities - Complete

Component parts for the balance pressure pick-up oscilloscope readout have been fabricated.

VI Preliminary Tests

The following preliminary tests are planned:

A. Run-in by motoring the engine hydraulically.
B. Preliminary engine break-in tests using an O/F ratio of 1 to check design and mechanical integrity.
C. Checkout balance pressure pick-up readout system.

Preliminary tests will be completed by February 24, 1963.

VII Performance Testing

Performance tests will start during the week ending 2-24-63. The test schedule has been described in previous reports. Tests with the regenerator will begin on 3-15-63, at which time compressor testing will be complete and the liquid nitrogen cooler will be moved to the engine test cell.

Experimental Oxygen Injector

I Design - Complete

II Detailing - Complete

III Fabrication and Procurement - Complete

IV Facilities - Complete

V Assembly and Test

Two injectors have been assembled. Figure 10 is a photo of injector parts. One injector was installed on the engine and the other one was mounted on the injector test stand. Considerable rework was necessary during assembly to make parts fit and function properly. While adjusting valve phasing on the engine an unaccounted for loss of poppet lift of approximately .003" was discovered. By analysis it was found that the lower lift was caused by an initial quill shaft deflection of approximately 0.37° due to excessive force by the poppet hold-down spring. The condition was corrected by reducing the thickness of the poppet hold-down spring. Testing of both injectors will start during the week ending 2-24-63.

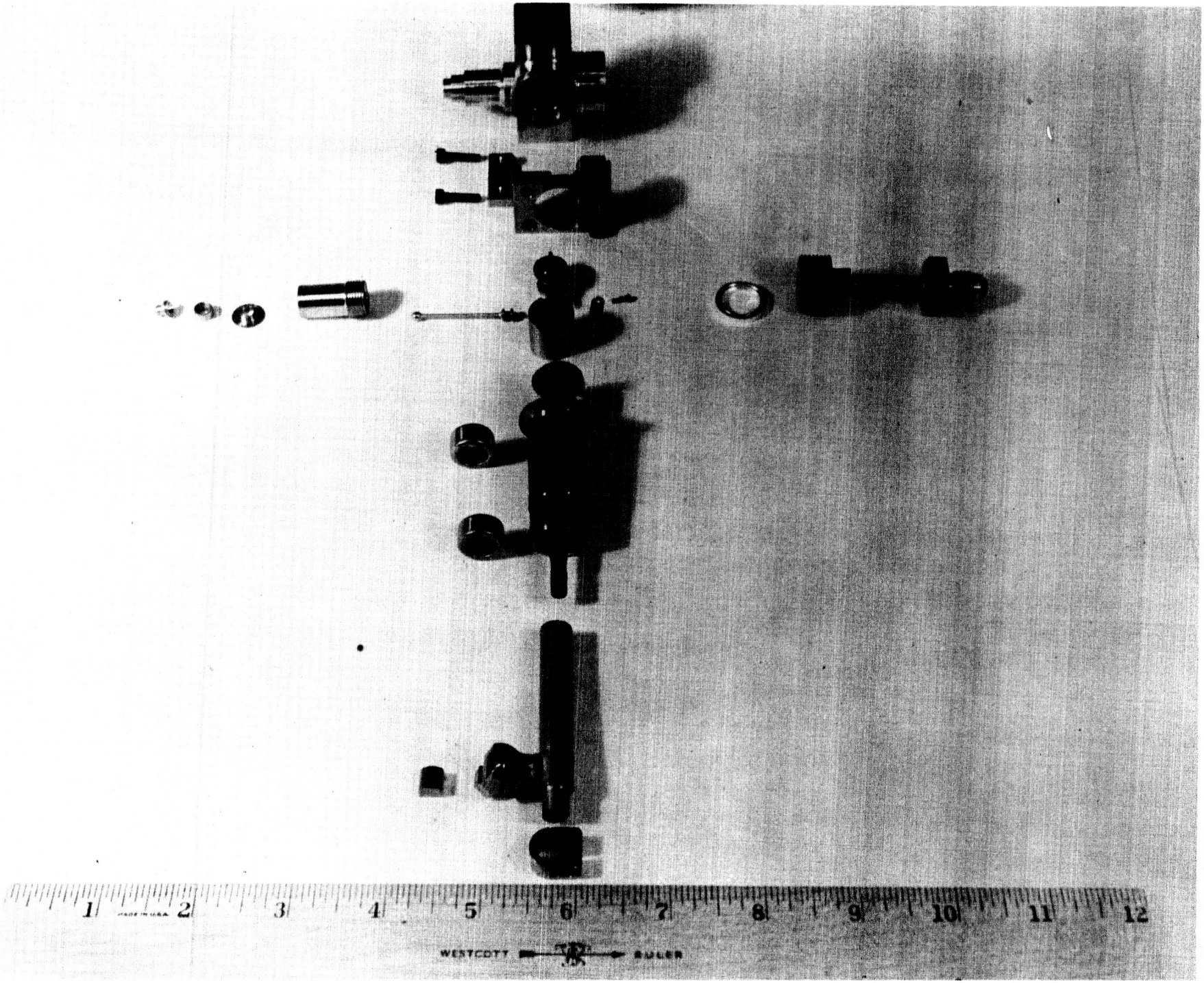


Fig. 10 - Injector Sub-Assemblies

APPENDIX "A"

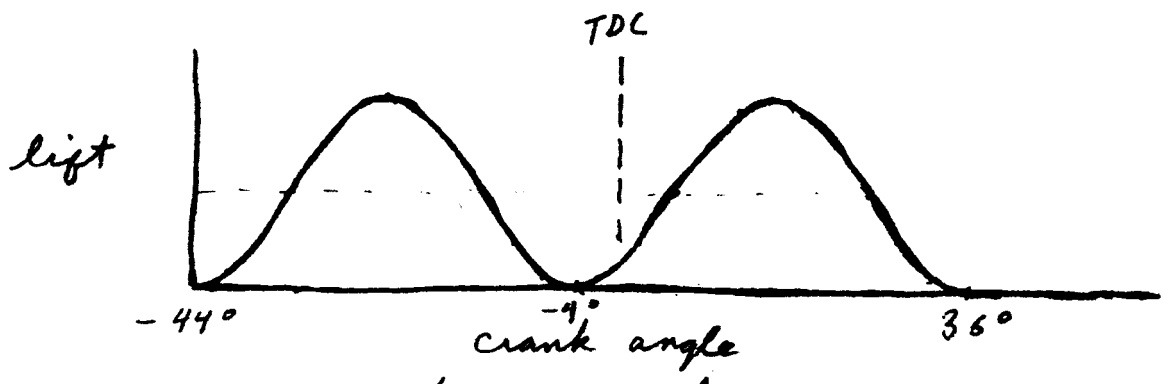
CYCLE ANALYSIS - DUAL POPPET HYDROGEN VALVE

PREPARED BY R. C. THOMAS	VICKERS INCORPORATED ENGINEERING CALCULATION FORM	PAGE 1 OF 4
CHECKED BY	SUBJECT CYCLE ANALYSIS – DUAL POPPET HYDROGEN VALVE	PROGRAM & PROJECT NO.
		DATE 2-18-63

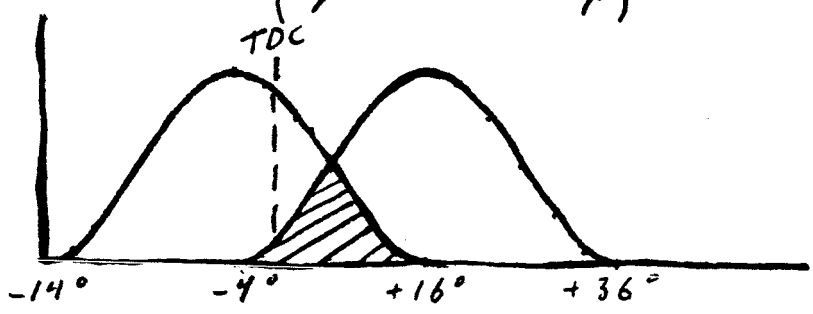
ASSUMPTIONS:

90 % alternator efficiency
10 % increase in BHP for compressor work
$O_2/H_2 = 2/1$.
speed = 4000 RPM.
Diagram Factor = 0.9
$K = 1.289$ Inlet temp = 1000°F = 1460°R.

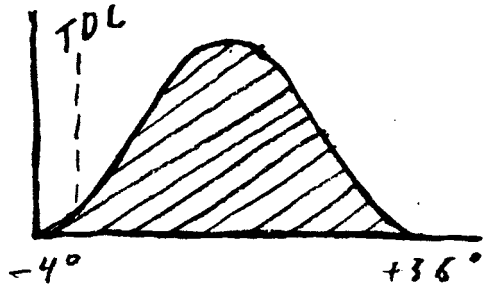
Valve opening curves:



(zero overlap)

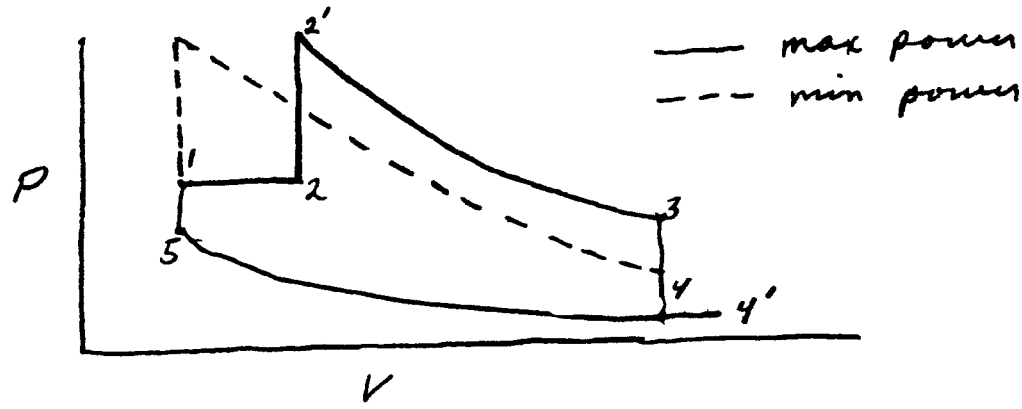


(20° overlap)



full admission.

Cycle:



let D = Displacement = $V_{4'} - V_5$

a = admission ratio = $\frac{V_2 - V_1}{D}$

b = compression ratio = $\frac{V_4 - V_5}{D}$

c = clearance volume ratio = $\frac{V_1}{D}$

(1) $$\frac{IMEP}{P_{2'}} = a + \left(\frac{a+c}{k-1}\right)\left[1 - \left(\frac{a+c}{b+c}\right)^{k-1}\right] - \frac{P_a}{P_{2'}}\left(\frac{b+c}{k-1}\right)\left[\left(\frac{b+c}{c}\right)^{k-1} - 1\right]$$

$P_{2'}$ = combustion pressure = 900 psi

(inlet pressure = 300 psi)

for $c = .05$, $a = .02$, $b = .9$, $P_a = 2$ psia,

eq. (1) yields

$$\frac{IMEP}{P_{2'}} = .02 + \frac{.07}{.289}\left[1 - \left(\frac{.07}{.95}\right)^{.289}\right] - \frac{2}{900}\left(\frac{.95}{.289}\right)\left[\left(\frac{.95}{.05}\right)^{.289} - 1\right]$$

$$\frac{IMEP}{P_{2'}} = .02 + .128 - .0094 = \underline{.1386}$$

$$\frac{IMEP}{P_{2'}}\text{ corrected} = \frac{IMEP}{P_{2'}} - H_2 \text{ admission loss}$$

$$H_2 \text{ admission loss} = \text{admission} \times \frac{900-300}{900}$$

$$= .02 \times .667 = .0134$$

$$\frac{IMEP}{P_{2'}}\text{ corrected} = .1386 - .0134 = .1252$$

$$\left[\frac{IMEP}{P_{2'}}\text{ actual} = \frac{IMEP}{P_{2'}}\text{ corrected} \times D.F. = .1252 \times .9 = .113\right]$$

$$* \quad ISPC = \frac{1.755}{\frac{IMEP}{P_{2'}}}\left[a + \frac{c}{k}\left(1 - \frac{P_5}{P_{2'}}\right)\right]$$

$$P_5 = P_e\left(\frac{b+c}{c}\right)^k = 2\left(\frac{.95}{.05}\right)^{1.289} = 2(19)^{1.289} = 88.6 \text{ psia}$$

$$ISPC = \frac{1.755}{.125}\left[.02 + \frac{.05}{1.289}\left(1 - \frac{88.6}{900}\right)\right] = 14.05\left[.02 + .0388(.901)\right]$$

$$\underline{ISPC = .77 \text{ lb/hp-hr}} \qquad FMEP = 11 \text{ psi}$$

$$\eta_m = \frac{IMEP - FMEP}{IMEP} = \frac{900 \cdot .125 - 11}{900 \times .125}$$

$$\eta_m = \frac{113-11}{113} = \frac{102}{113} = .90$$

$$BMEP = IMEP \times D.F. - FMEP = 113 \times .9 - 11 = \underline{91 \text{ psi}}$$

$$\frac{BMEP \times RPM}{2\pi \times 63025} = \frac{BHP}{Disp.} = \frac{4000}{63025 \times 2\pi} BMEP = \frac{BMEP}{98.8}$$

$$\frac{HP}{D} = \frac{91}{98.8} = .923 \text{ HP/in}^3$$

$$\left(* \quad 1.755 = \frac{1.98 \times 10^6}{RT}, \text{ where } R = \frac{1745}{2}, \; T = 1460°R.\right)$$

$$BSPC = \frac{ISPC}{DF \times \eta_m} = \frac{.77}{.90 \times .9} = \underline{.95 \text{ lb/hp hr}}$$

alternator output:

$$BSPC = 1.65 \times .95 = \underline{1.56 \text{ lb/kw HR}}.$$

(includes compressor + alternator efficiencies)

Power for 3.0 in^3: $.923 \times 3.0 = 2.77 \text{ HP} = 1.68 \text{ kw}$

4.0 in^3: $.923 \times 4.0 = 3.69 \text{ HP} = 2.24 \text{ kw}$

Allowing 2° for closing, 2% admission corresponds to 19° overlap.

In the throttled regime, $P_2' = 3 \times P_{inlet}$, $P_{inlet} \sim$ Valve area, assuming no throttling effect at 1% admission.

The relationship between inlet pressure and maximum combustion pressure has been verified in previous analysis.