FINAL REPORT

NASA RESEARCH GRANT
NGR 45-003-041

"OPTIMIZATION OF HYDRAULIC COMPOUND VORTEX AMPLIFIERS"

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FROM:
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TO:
OFFICE OF UNIVERSITY AFFAIRS
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INTRODUCTION

The present investigation stems from the research work carried out by the principal investigator at Marshall Space Flight Center under an ASEE/NASA Summer Faculty Fellowship in the summer of 1966. This work is described in the following report:

"Hydraulic Compound Vortex Valves with High Pressure Gain," F. R. Goldschmied, NASA TM X-53539, November 14, 1966.

Also a patent application, "Shear Modulated Fluid Amplifier," has been filed by NASA, Case No. 10412, in December 1967.

It was found that the most important problem outstanding was that of hydraulic instability, i.e. strong pressure fluctuations in the output of the fluidic amplifier. Such fluctuations could not be tolerated in an aerospace control circuit. Thus, it was decided to concentrate first on the problems of time-dependent viscous flow as against the classical inviscid acoustic treatment with the assumption of zero mean flow. At the same time hydraulic test facilities were to be assembled, to provide some 15 gpm at 3000 psi for future experimental work on new and improved amplifiers.

Some previous work was done by the principal investigator and his associates on this subject under NASA Contract NAS 8-11236 (1964) and also NAS 8-20102 (1965). These earlier results are also to be used in the present investigation as applicable and they are described in the following contractor's reports:

"Analytical Investigation of Fluid Amplifiers Dynamic Characteristics," NASA CR-244 and NASA CR-245. July 1965.

"Study of Pure Fluid Phenomena," NASA CR-69627. December 15, 1965.

RESEARCH APPROACH

It is impossible to predict theoretically the dynamic performance of a complete control amplifier or component. This is unfortunate but not disastrous if the theory will point out the correct parameters to scale experimental results from model to prototype. If such scaling is not properly understood, then truly the cost of engineering developments will be prohibitive in terms of time and money. One must be particularly careful in scaling dynamic results (amplitude-response and phase-angle) in the strongly non-linear domain of transient viscous flow.

Two apparently simple problems have been selected for analytical and experimental study:

a. Pulsating viscous incompressible flow in a long rigid tube in the intermediate damping range. Relationship between instantaneous pressure gradient and instantaneous flow for arbitrary pulse shapes, frequencies, and mean flow rates.

b. Oscillating (harmonic) viscous compressible flow in rigid tubes with volume termination. Amplitude-response and phase-angle between imposed pressure and volume termination pressure as a function of frequency, geometric, fluid, and thermodynamic parameters.

RESEARCH RESULTS

1. The problem (a) above was the first to be handled since much experimental work had already been done as part of a master's thesis at the University of Utah, Mechanical Engineering Department. The

project was completed in the 1967 fall quarter and the manuscript was submitted for publication in January 1968 to Marshall Space Flight Center, Astrionics Laboratory. It was issued in NASA format as follows:

NASA TM X-53719, March 25, 1968

AN EXPERIMENTAL STUDY OF PULSATING FLOW OF INCOMPRESSIBLE VISCOUS FLUIDS IN RIGID PIPES IN THE INTERMEDIATE DAMPING RANGE

F. R. Goldschmied

ABSTRACT

This report presents an experimental verification of Womersley's method for the calculation of instantaneous flow rate in a pulsating incompressible flow from the measured instantaneous longitudinal pressure gradient in rigid pipes. The method of computation is applicable to any complex flow pulse. The experimental flow generation was based on fluidic and peristaltic pumps producing a variety of pulsatile and oscillatory flows having finite mean flow rates. Digital computer calculations of instantaneous flow rates were in good agreement with measured data. The instantaneous phase angle between pressure and flow was also investigated and was found to be a function of the pipe Stokes Number.

2. The problem (b) above was handled next. The dimensional analysis of the problem was performed by the principal investigator under NASA Contract NAS 8-11236 and is given in NASA CR-244 (1965); the experimental data used were obtained by the principal investigator and his associates under NASA Contract NAS 8-20102 (1965). Other

test data have been obtained from the technical literature as additional verification. Having accepted the analytical theory as valid, extensive numerical computations have been performed to allow convenient application to engineering problems and also to give a good physical insight on the dimensionless parameters governing these fluid processes. The manuscript is herewith submitted to Marshall Space Flight Center, Astrionics Laboratory, for publication in NASA format. The title, author, and summary are given below:

ON THE DYNAMIC RESPONSE OF VISCOUS COMPRESSIBLE FLUIDS IN RIGID TUBES WITH VOLUME TERMINATION AS A FUNCTION OF THE STOKES NUMBER.

F. R. Goldschmied

SUMMARY

Air, carbon dioxide, and helium test data are presented for the experimental verification of Iberall's analysis of the dynamic response of viscous compressible fluids in rigid tubes with deadended volume termination. Additional air test data by Watts are also shown so as to complete the verification.

A graphical display is given of numerical computer solutions of Iberall's theory over a large range of parameters. The pressure amplitude ratio is shown against dimensionless frequency, Stokes number, volume ratio, and specific heats ratio. The resonance points are given in terms of maximum amplitude ratio and corresponding phase angle against dimensionless frequency, Stokes number, volume ratio, and specific heats ratio. It is seen that the Stokes number is the strongest functional parameter and that the

volume ratio has a very weak effect. Then the points where the phase angle reaches $\frac{\pi}{2}$ are given in terms of Stokes number, dimensionless frequency, volume ratio and specific heats ratio. Finally the dimensionless frequency is given at which the amplitude-ratio reaches $\pm$ 10%.

A FORTRAN V computer program for Iberall's general solution is also appended.

PUBLICATION ACTIVITY

Two NASA reports have resulted from this research grant, as follows:

"An Experimental Study of Pulsating Flow of Incompressible Viscous Fluids in Rigid Pipes in the Intermediate Damping Range" F. R. Goldschmied, NASA TM X-53719, March 25, 1968.

"On the Dynamic Response of Viscous Compressible Fluids in Rigid Tubes with Volume Termination as a Function of the Stokes Number," F. R. Goldschmied, NASA TM (to be published) October 1968.

Also of interest may be the publication in the April 1968 issue of the AIAA Journal of Hydronautics (pp. 102-107) of the following paper:

"Underwater Hovering Control with Fluid Amplifier," F. R. Goldschmied, (previously presented as AIAA Paper 67-433.)

The amplifier used in the work reported in this paper was that developed with NASA funding and described in the following publication:

"Hydraulic Axisymmetrical Focussed-Jet Diverters with Pneumatic Control," F. R. Goldschmied and M. A. Kalange, NASA TM X-53554, December 15, 1966.

The work itself was performed as a part of the University of Utah graduate research activity.

In addition, a paper has been prepared for submission to the 1969 Joint Automatic Control Conference. This paper is a revision and amplification of NASA TM X-53539, November 14, 1966, "Hydraulic Compound Vortex-Valves with High Pressure Gain," by F. R. Goldschmied. The title, author, and summary are given below:

PRELIMINARY DEVELOPMENT OF COMPOUND VORTEX AMPLIFIERS FOR HYDRAULIC HIGH-PRESSURE APPLICATION

F. R. Goldschmied

SUMMARY

A compound vortex amplifier has been developed in the field of fluidic hydraulic devices at the 700 to 2000 N/cm^2 (1000 to 3000 psi) pressure level. Unlike present vortex control valves where the control pressure must exceed the supply pressure throughout the flow turndown range, the new amplifier demands an input from 0 to 100 N/cm^2 to yield a proportional output from 0 to 620 N/cm^2 at blocked load, with a supply pressure of 965 N/cm^2.

The compound amplifier comprises a pilot stage based on vortex-shear jet modulation, suitably matched to a conventional vortex control valve as the power stage. Complete steady-state data are presented for the new configuration. Dynamic response will be presented in a future paper.

THE HIGH PRESSURE HYDRAULIC TEST FACILITY

The Fluid Control Systems Laboratory
University of Utah
March 15, 1968

The High-Pressure Hydraulic Test Facility is intended to provide versatile experimental means for the test of fluidic components and systems at pressure levels from 3000 psi to 100 psi. The erection of this facility has been made possible by NASA Research Grant NGR 45-003-041, by surplus equipment from NASA MSFC and by the donation of much hydraulic equipment from Hydraulic Research and Manufacturing Company of Burbank, California.

The test facility comprises a high-pressure (3000 psi) supply loop, a medium-pressure (500 psi) supply loop, and a low-pressure (100 psi) return-flow loop.

The test bed is serviced by three high-pressure supplies, two medium-pressure supplies, and by nine low-pressure returns.

Physically the facility comprises the following main assemblies:

a. Hydraulic power section with pumps, motors, motor starters, oil reservoir, oil filter, oil cooler, and high-pressure supply panel.

b. Test bed and return-flow manifolding.

c. High-pressure regulation panel (mounted over test bed).

d. Medium-pressure supply panel (mounted over test bed).

Two high-pressure pumps provide 14 gpm at 3000 psi and two medium-pressure pumps provide 22 gpm at 500 psi with a total of 50 HP installed for electric motors. The detailed list of items is given below; the item number corresponds to the circled number in the layout (Figure 1).

List of Items

1. Denison Hydraulic Pump, Series 600 Axial Piston Type, PA 072-560B, 3000 psi, 11 gpm, 30 HP at 1800 rpm, Serial No. 2190, 5000 psi maximum pressure.

   Electric motor: Louis Allis Model COGX, Serial No. 2723277, 30 HP at 1770 rpm, 220/440 volt.

2. Kline Hydraulic Pump, Model BJA00484 CCW, Series 1205, Serial No. 1676, 3 gpm at 1740 rpm, 3000 psi.

   Electric motor: Reuland Electric Type ML, Serial No. 274910, 7.5 HP at 1800 rpm, 220/400 volt.

3. Denison Hydraulic Pump Series T1D Vane Type, Model T1D28 FAR 4, Serial No. 9300, 20 gpm at 1150 rpm, 500 psi, 10 HP.

   Electric motor: U.S. Motors Uni closed, 10 HP, 1200 rpm, Serial No. 3250223.

4. Viking Hydraulic Pump, Model 26PH2, Gear Type, Serial No. JK355B, 2gpm at 1200 rpm, 500 psi.

   Electric motor: U.S. Motors Uni closed, 1 HP, 1200 rpm, Serial No. 2643208.

5. High-pressure (3000 psi) HR&M Filter.

6. High-pressure HR&M Nitrogen Accumulator.

7. Relief valve 0-5000 psi, Denison.

8. Pressure-reducing valve, 0-3000 psi.

9. Relief valve, 0-500 psi, Denison.

10. Neddle valve.

11. Load valve.

12. Pressure gauge, 0-5000 psi.

13. Pressure gauge, 0-3000 psi.

14. Pressure gauge, 0-500 psi.

15. Low-pressure (150 psi) Sprague Filter.

16. Service low-pressure valve, 1 1/4".

17. High-pressure 1/4 turn shut-off valve, Jamesbury.

18. Check-valve, 3/4" Kepner.

19. Check-valve, 1/4" Kepner.

20. Check-valve, 1/2" Kepner.

21. Check-valve, 1" Kepner

22. Check-valve, 1 1/2".

Assembly (a) is detailed in Figure 2, "Hydraulic Power Section," and in Figure 3, "High-Pressure Supply Panel."

Assembly (b) is detailed in Figure 4, "Test Bed and Return Manifold Layout."

Assembly (c) is detailed in Figure 5, "High Pressure Regulation," comprising the regulation section and the regulation panel.

Assembly (d) is detailed in Figure 6, "Medium Pressure Supply," comprising the supply section and the supply panel.

In regard to instrumentation, in addition to conventional pressure gages, the following dynamic pressure transducers have been made available to the Hydraulic Test Facility:

3 Statham Model UR5 Analog Readout

3 Statham Model UC3 Compression Transducing Cell

3 Statham Model UGP4 Pressure Accessory

3 Statham Model UGPU-L Diaphragm Kit

0-1 psig
0-2 psig
0-5 psig
0-10 psig
0-20 psig
0-50 psig

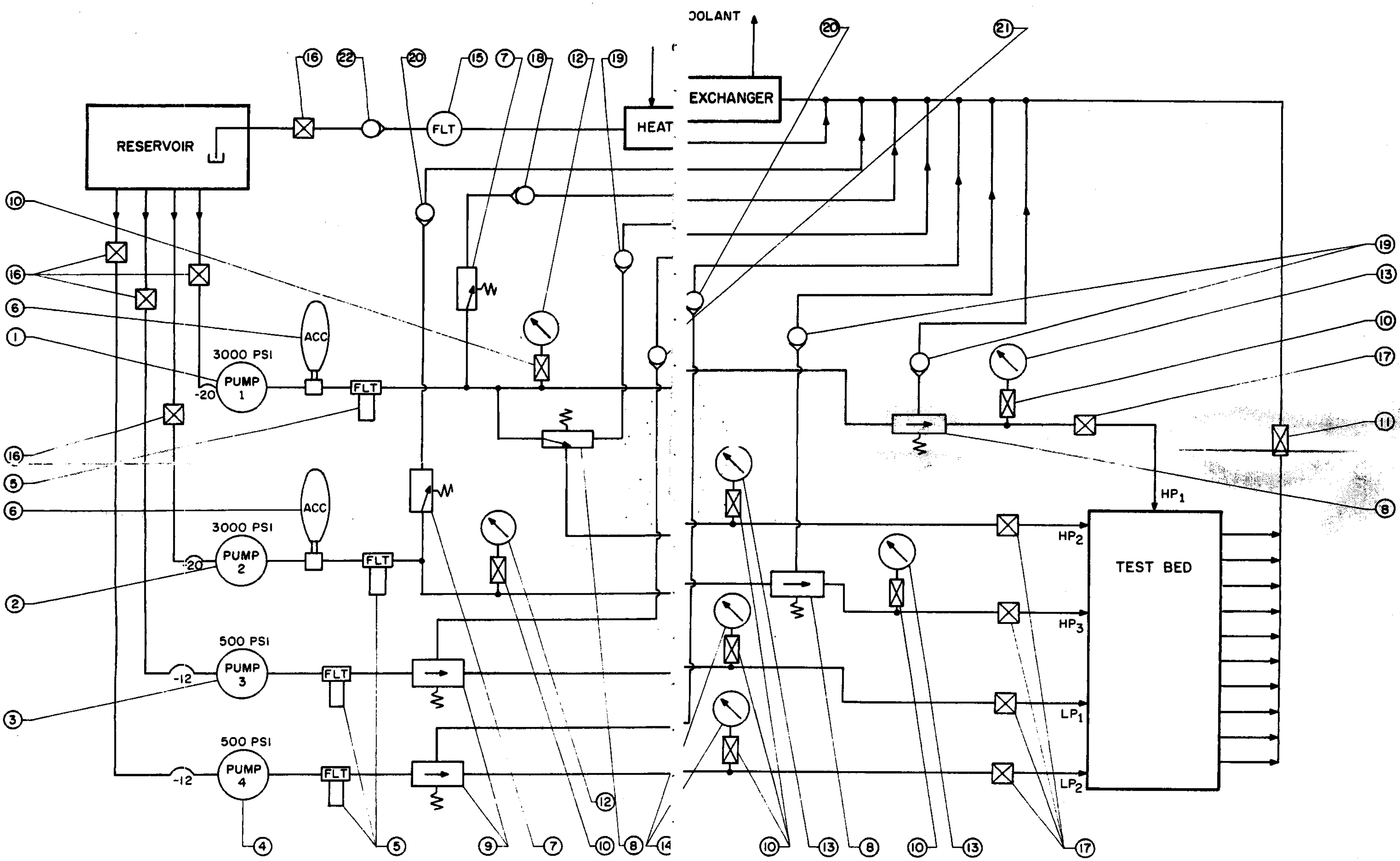
3 Statham Model UGP4-H Diaphragm Kit

0-100 psig
0-200 psig
0-500 psig
0-1000 psig
0-2000 psig
0-5000 psig

Thus, three complete channels of pressure instruments are available from 0-1 to 0-5000 psig range.

FOLDOUT FRAME 1

FOLDOUT FRAME 2



FOLD-OUT #3

FOLD-OUT #4

LAYOUT OF HYDRAULIC FACILITIES

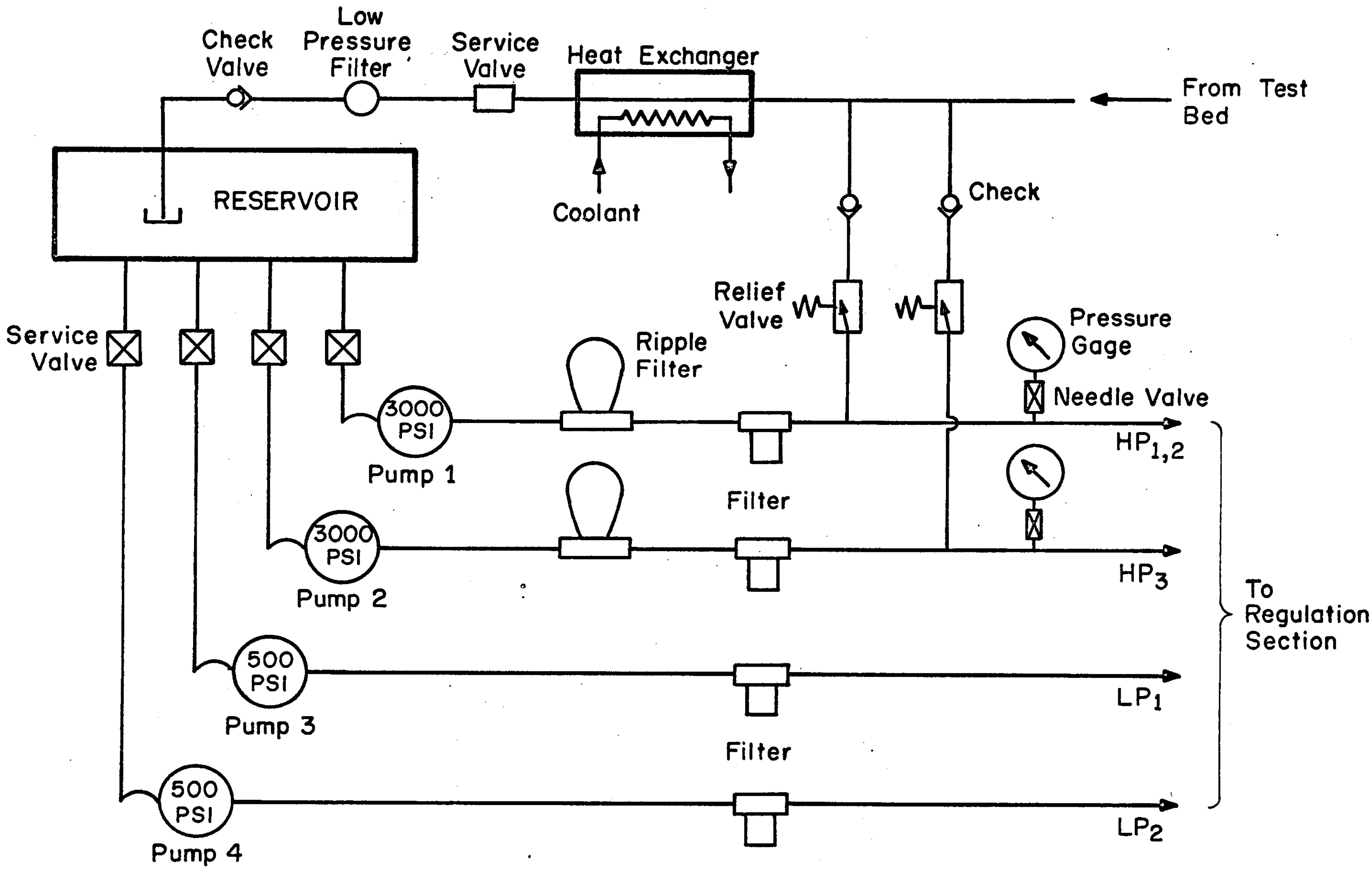


Figure 2. Hydraulic Power Section

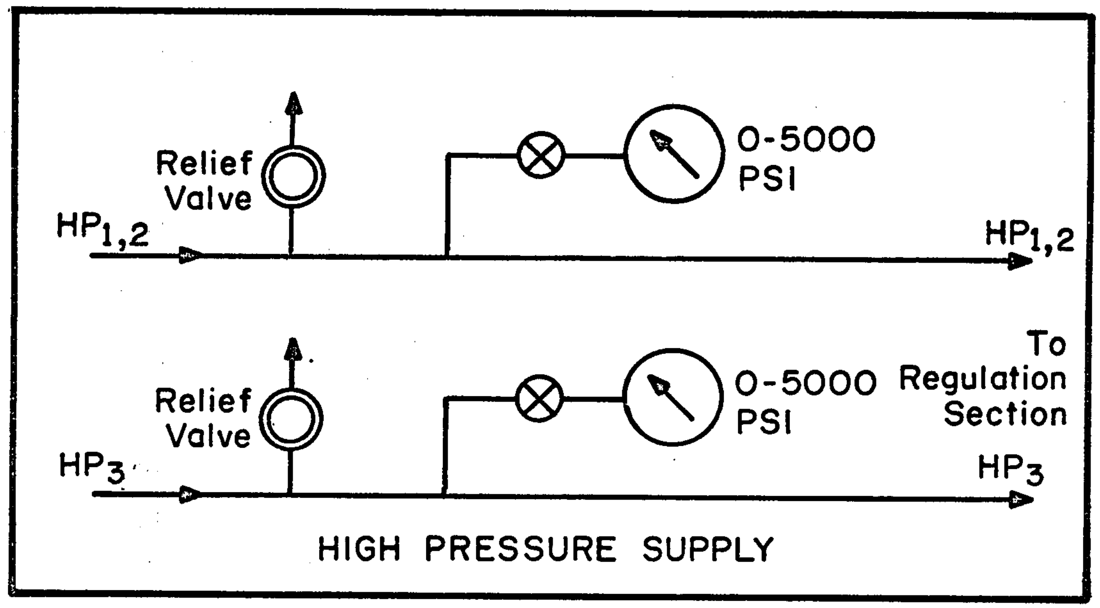


Figure 3. High Pressure Supply Panel

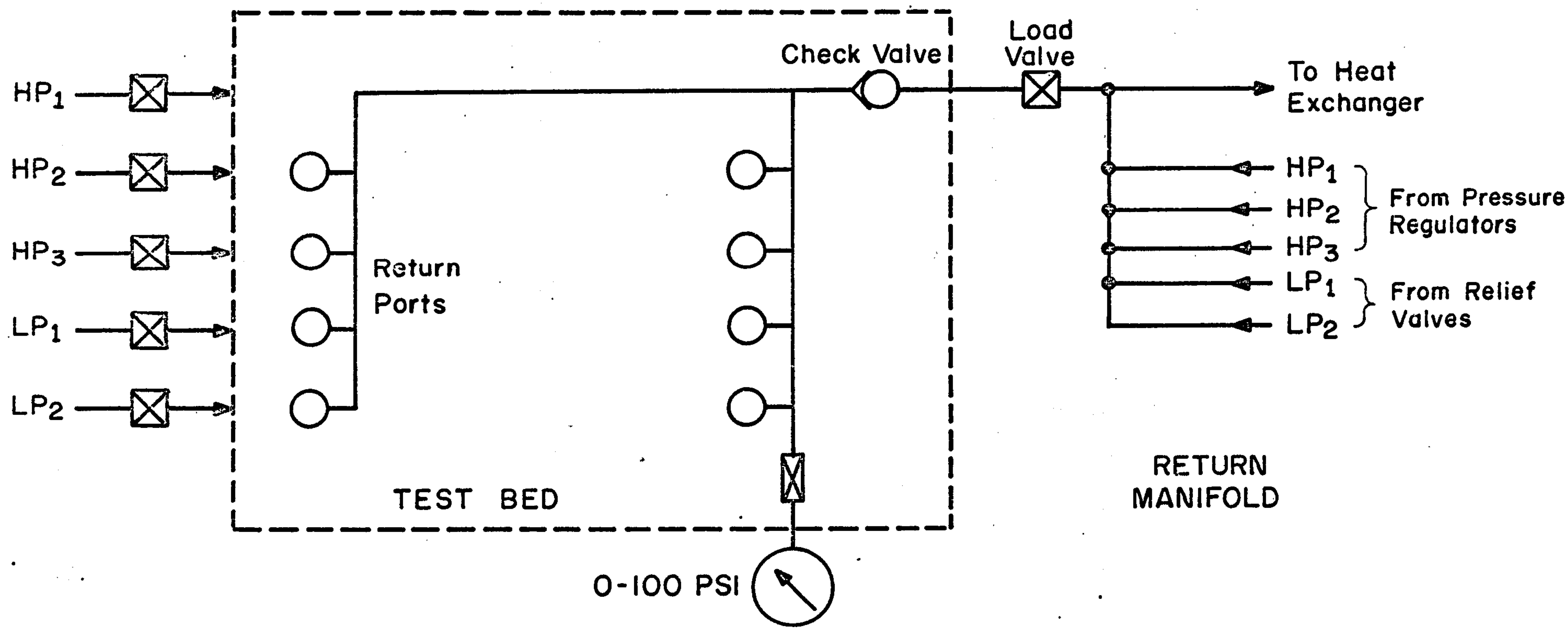
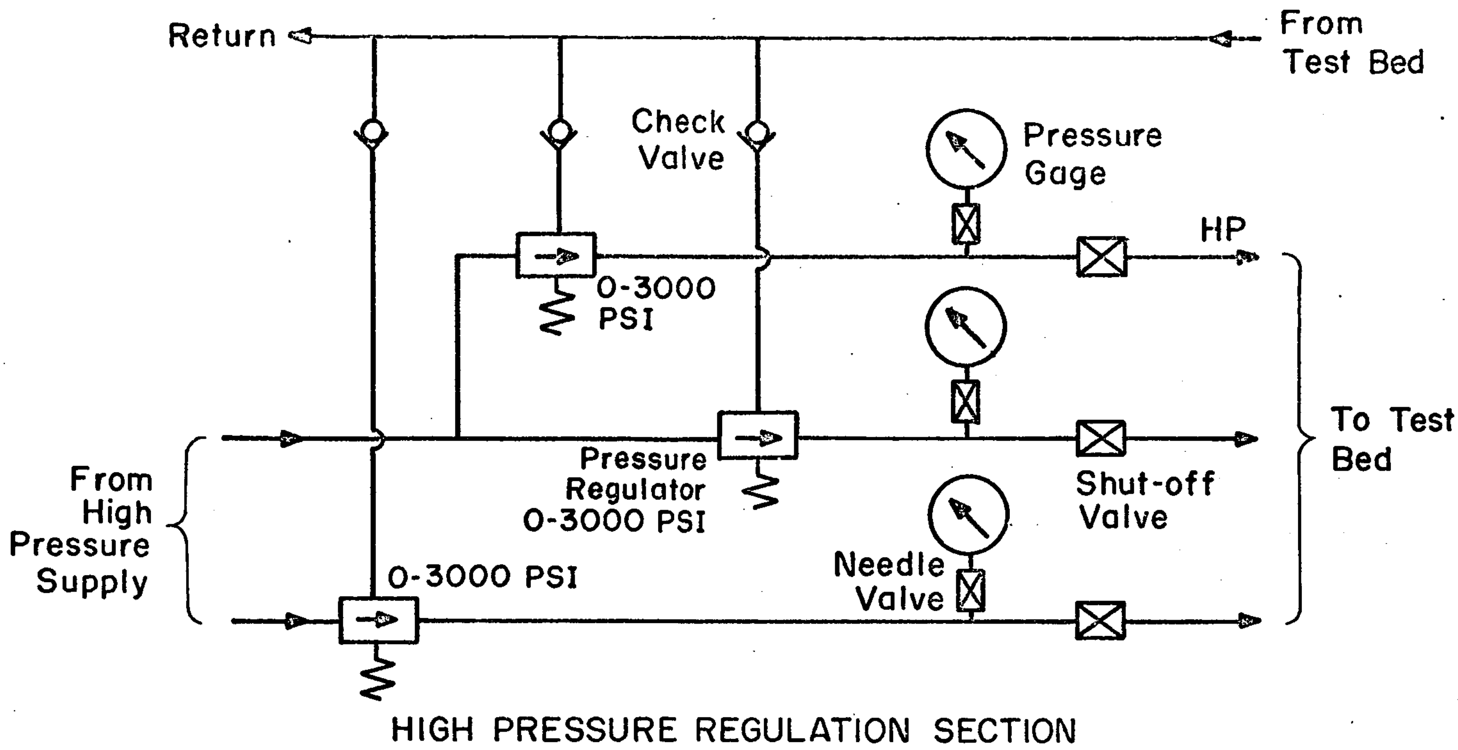


Figure 4. Test Bed and Return Manifold Layout



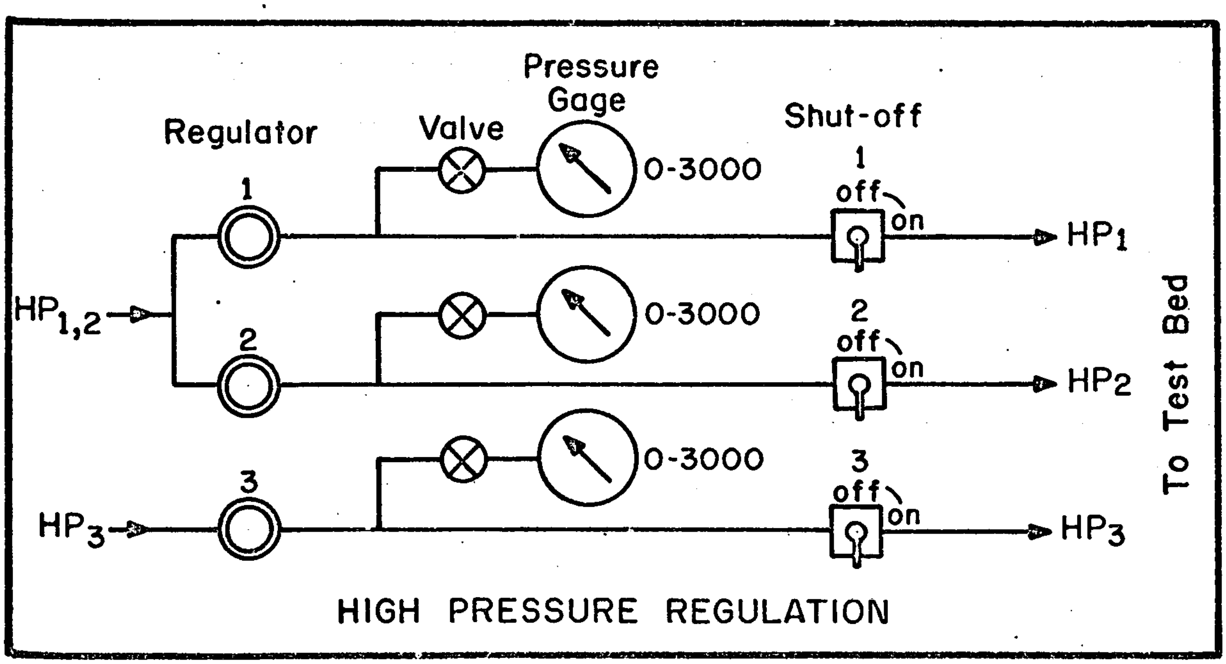
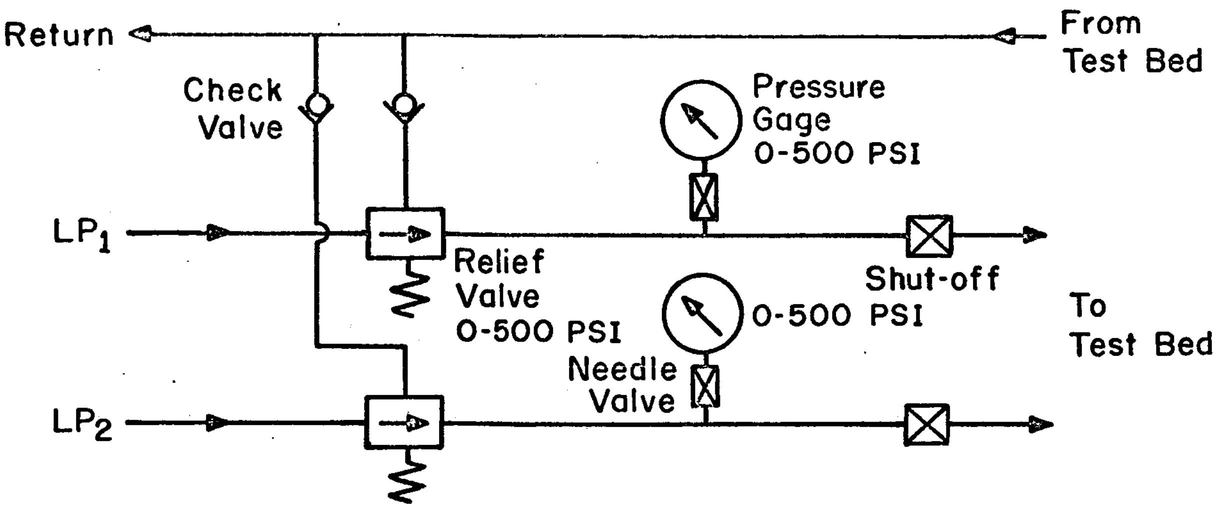
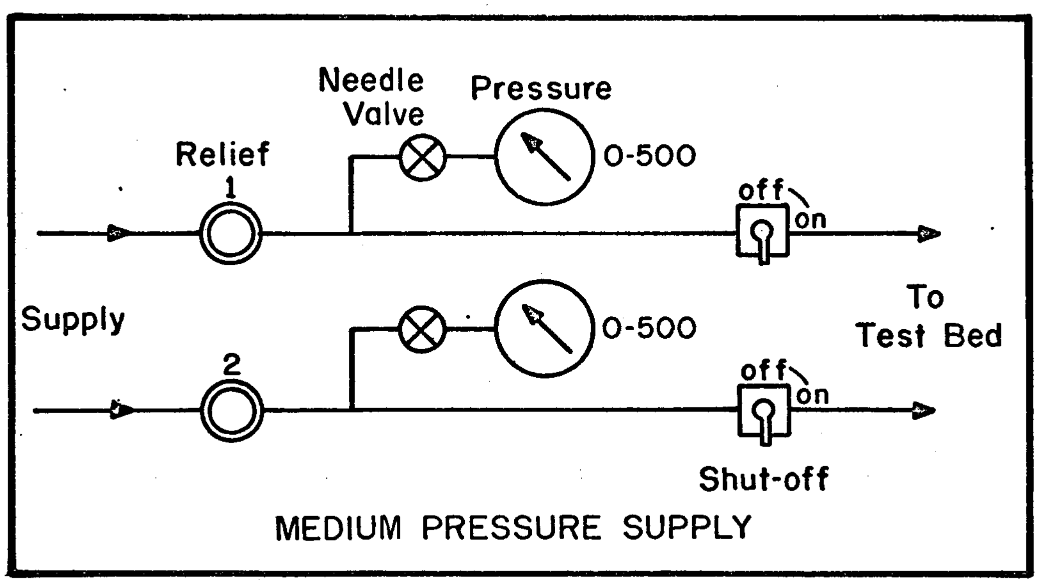


Figure 5. High Pressure Regulation



MEDIUM PRESSURE SUPPLY SECTION



MEDIUM PRESSURE SUPPLY PANEL

Figure 6. Medium Pressure Supply