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SENSITIVITY OF ROCKET ENGINE STABILITY TO PROPELLANT FEED SYSTEM DYNAMICS

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ABSTRACT

Because of the increased reliability required of rocket systems in their more recently assigned missions, previously acceptable design features must be reappraised and refined. In the region of rocket engine system stability, the problem is centered in two areas, the combustor and the propellant feed system. The principal interest of this paper lies in the coupling that occurs between the feed system and combustion dynamics, often termed a "buzzing" instability when the dynamics are characterized by periodic pressure oscillations in the range of 200 to 1000 cps appearing in the combustion chamber and the feed system.

The volume and refinement of the analytical work performed in more-recent years on this topic have generally supported the existence of this "buzz"-type phenomena. However, information regarding full-scale large rocket engine testing in this respect is not as readily available. And, in going from laboratory experimental engines to full-scale large engines, it can be recognized that the scale effect in rocket engines is especially significant due to, for example, the highly complex geometry of the injector. Herein lies the point of this paper. Test data was obtained in quantity from large engine test hardware instrumented with reliable transducers. In all, 37 heavily instrumented, large scale tests were conducted to

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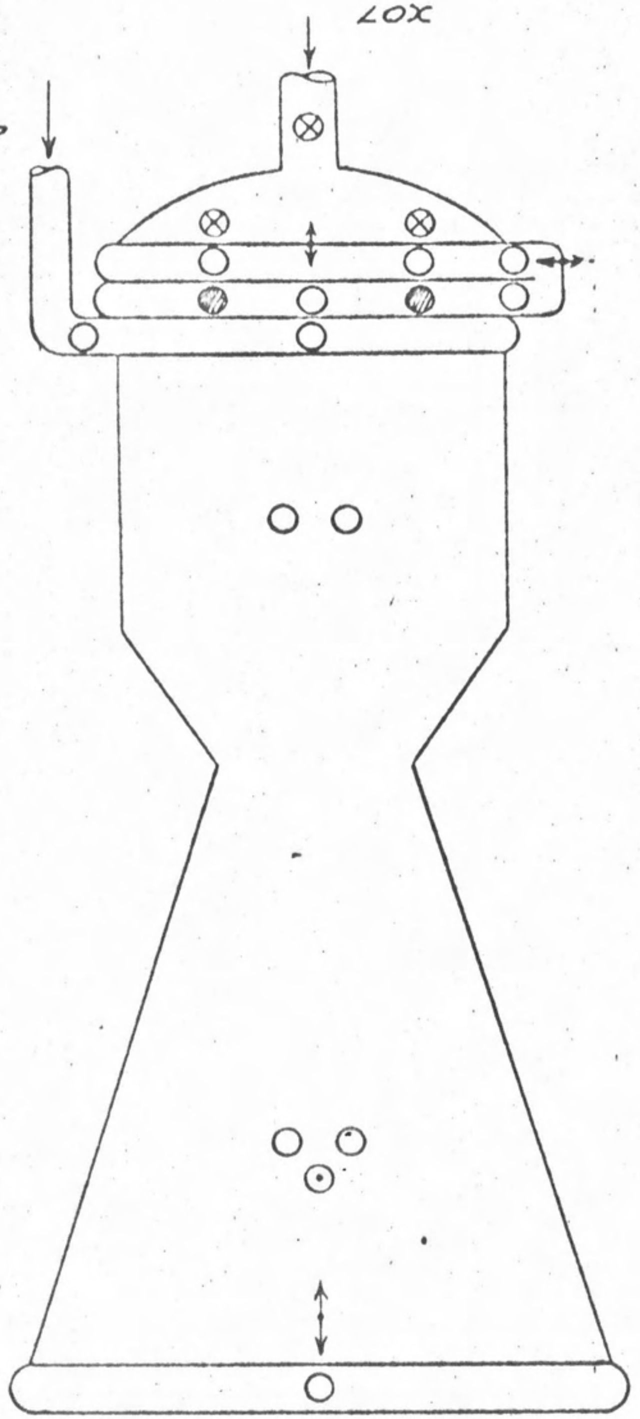
The approach taken to attain the objective, the determination of the sensitivity of rocket engine stability to propellant feed system dynamics, was threefold, including: (1) analog and digital computer studies of distributed hydraulic systems, (2) laboratory hydraulic system studies, and (3) full-scale thrust chamber testing. The analog computer studies were conducted to investigate the effect of the hydraulic inertance, capacitance, and resistance parameters on the output of a mechanized computer model of a simple hydraulic feed system. The system which was a pressurized tank-fed duct terminated by an orifice, was excited by a hydraulic siren to supply the variable frequency input signal to the system. The orifice and input signal hold some analogy to the injector and oscillating combustion chamber pressure in a rocket engine. Following extensive analog computer work to verify that the model was external to the input, that the computer input corresponded to the anticipated laboratory model input, and that the frequency characteristics of the lumped parameter computer model matched those of a distributed system to at least the third harmonic within a close tolerance, a laboratory experimental prototype of this feed system was fabricated and tested using a hydraulic siren, continuously increasing frequency input. Transducer traces of the dynamic test pressures and flows (the latter measured with an electromagnetic high-response flowmeter) closely matched traces produced by the analog computer model. At this phase it was felt the computer model could faithfully reproduce the characteristics of the physical system, and, to evaluate the effect of one type of hydraulic component on feed system dynamics, a hydraulic capacitor was designed for incorporation into the laboratory model. Again, with the computer model modified to simulate the hydraulic capacitor added to the system, computer and test results showed good agreement. This preliminary analysis lead to the design of a hydraulic capacitor for a large rocket engine to be installed at the inlet to the fuel injector manifold of a specially fabricated triple manifold thrust chamber which permitted locating the capacitor very close to the discharge end of the fuel feed system where it would be the most effective, as indicated by the computer studies. It was demonstrated that this capacitor significantly reduced feed system pressure oscillation amplitudes by a factor of 5:1 as the capacitor was pressurized, and that the initial oscillations reappeared after the capacitor was depressurized, during the course of the same run.

To study the effect of the capacitor on thrust chamber "buzzing", it obviously first had to be demonstrated that the chamber was buzzing. During one of the test series, a suspected buzzing chamber assembly would not buzz prior to an attempted capacitor evaluation test. The only known feed system configuration hardware change made after the chamber had buzzed in a previous test series was the addition of a short length of fuel ducting to the approach to the fuel injector inlet manifold. When the fuel feed system ducting was again shortened by this same length, the buzzing clearly reappeared, demonstrating the significant effect of this relatively small inertance and capacitance associated with the short length of ducting, considering its insignificant size in relation to the remainder of the long and large-diameter fuel duct which lead from the fuel tank to the thrust chamber. Of course, its strategic location also was a factor.

Indeed, rocket engine stability <u>is</u> sensitive to propellant feed system hydraulic inertance and capacitance.



THRUST CHAMBER SCHEMATIC

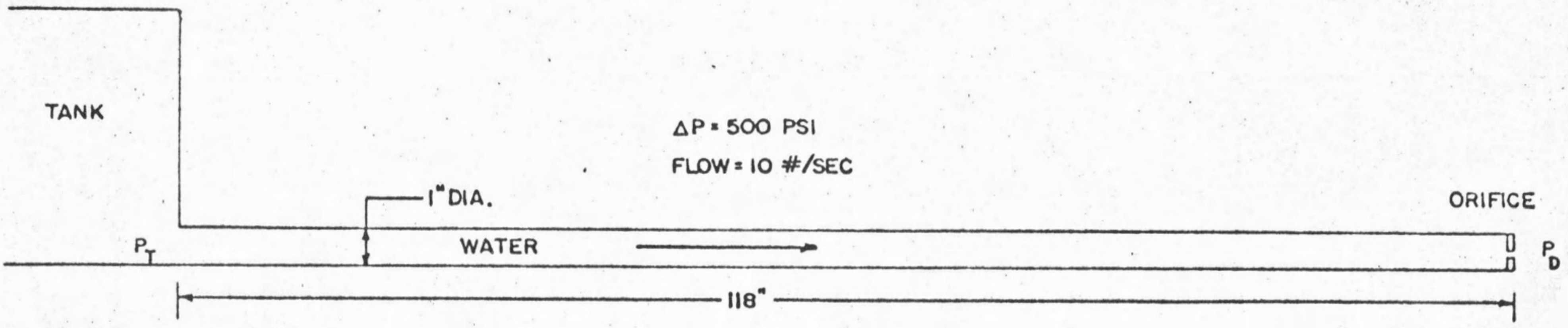
○ FUEL FEED SYSTEM PHOTOCONS

⊗ LOX FEED SYSTEM PHOTOCONS

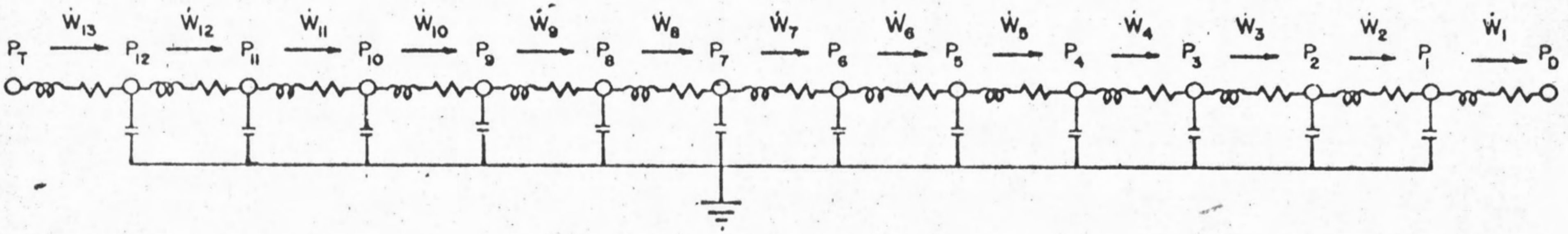
▨ CHAMBER PRESSURE PHOTOCONS

⊙ ↕ ACCELEROMETERS

ANALYTICAL HYDRAULIC SYSTEM SCHEMATIC



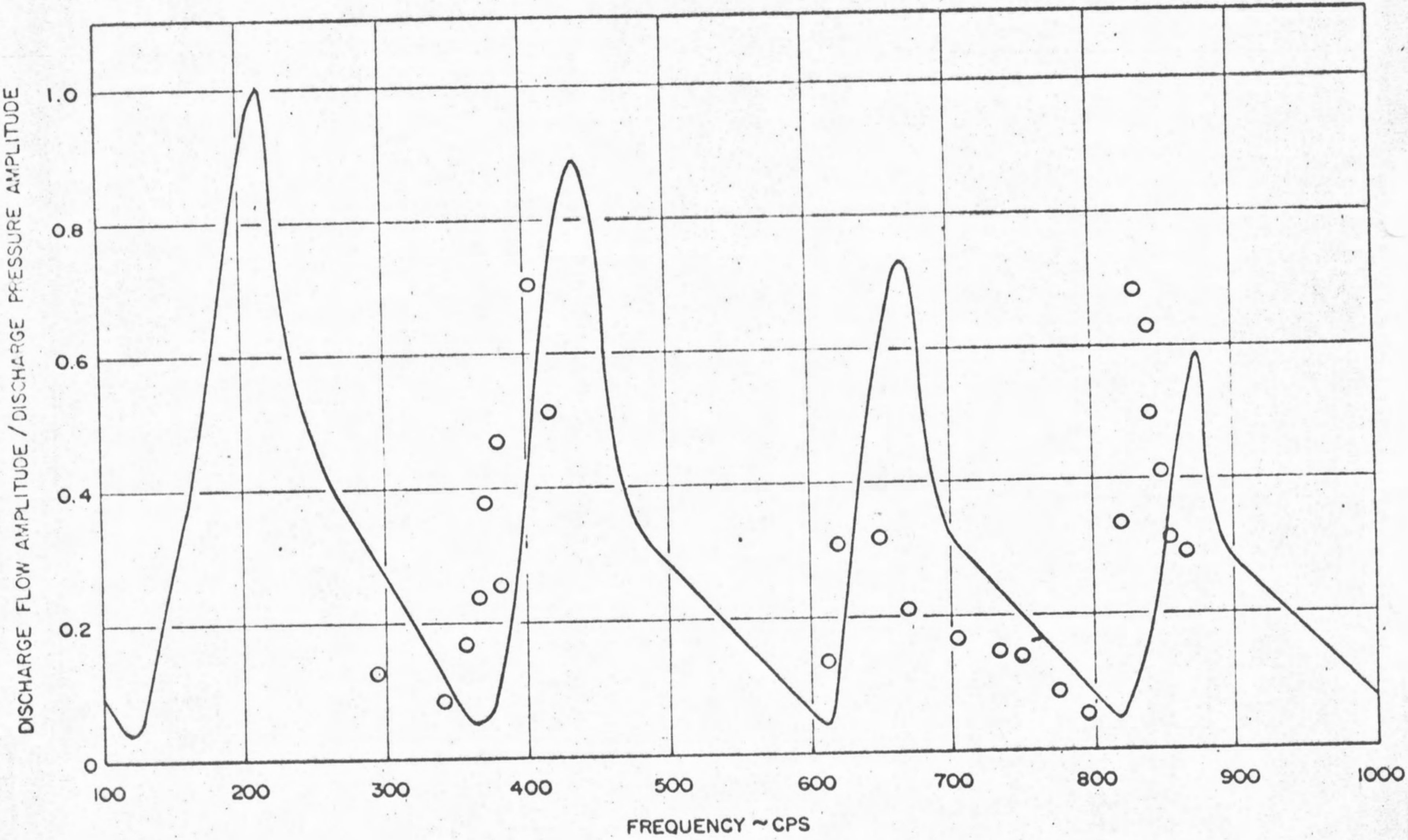
PHYSICAL SYSTEM



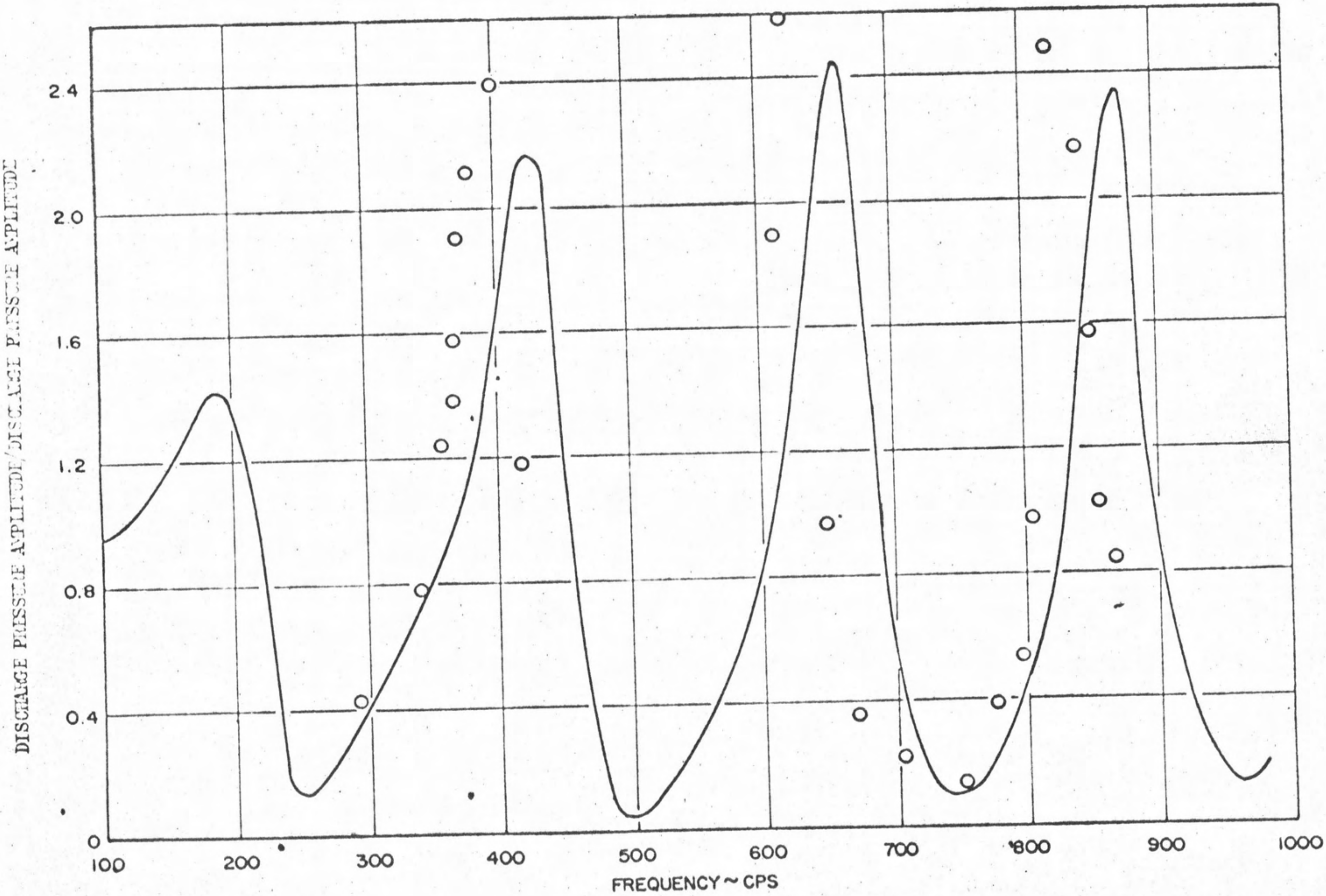
ELECTRICAL ANALOG

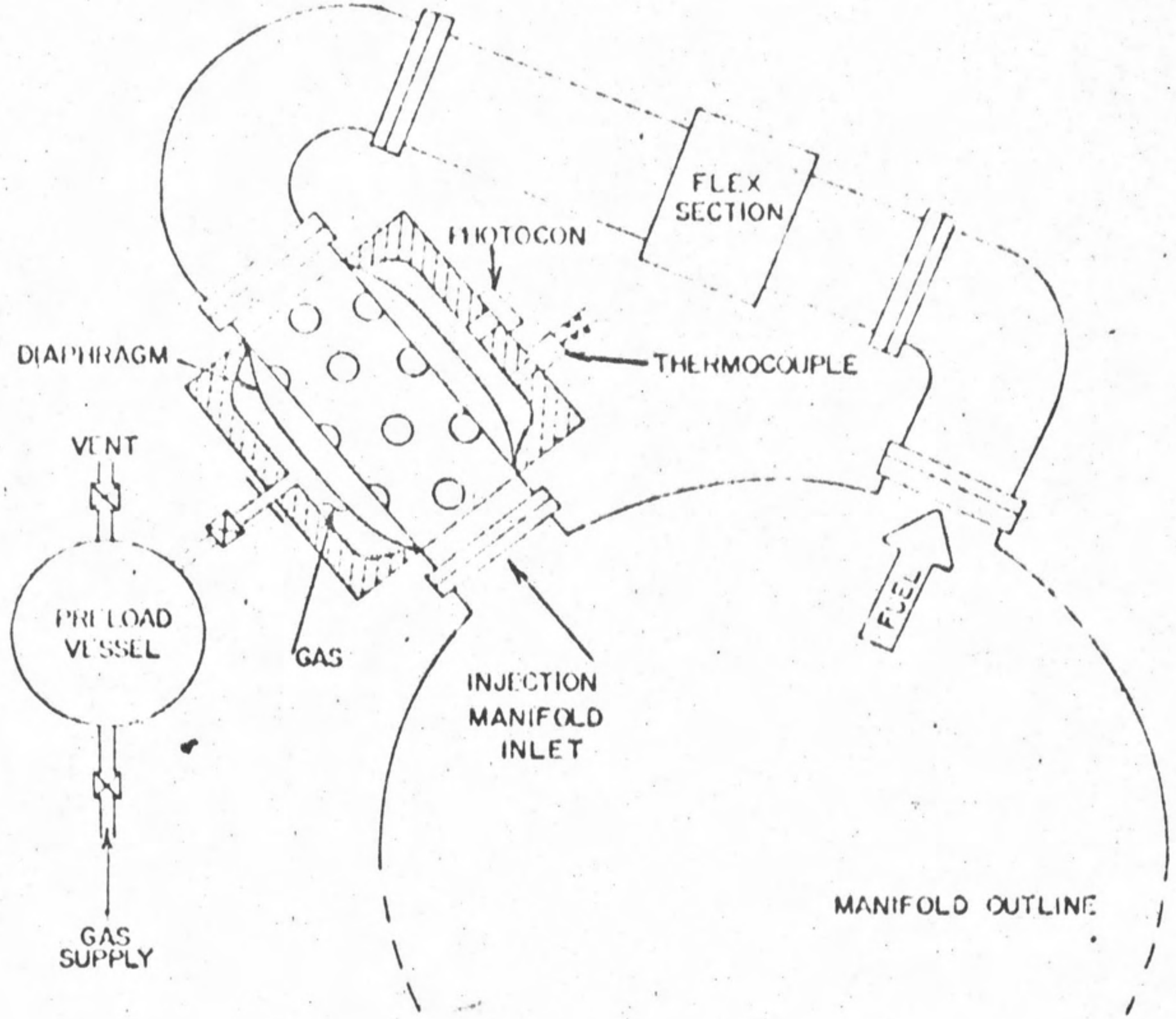
P = PRESSURE
$\dot{W}$ = FLOW RATE

CORRELATION OF TEST RESULTS WITH PREDICTED CURVE IN TERMS OF DISCHARGE FLOW (WITHOUT HYDRAULIC CAPACITOR INSTALLED IN LABORATORY SYSTEM)



CORRELATION OF TEST RESULTS WITH PREDICTED CURVE IN TERMS OF DISCHARGE PRESSURE (WITHOUT HYDRAULIC CAPACITOR INSTALLED IN THE LABORATORY SYSTEM)

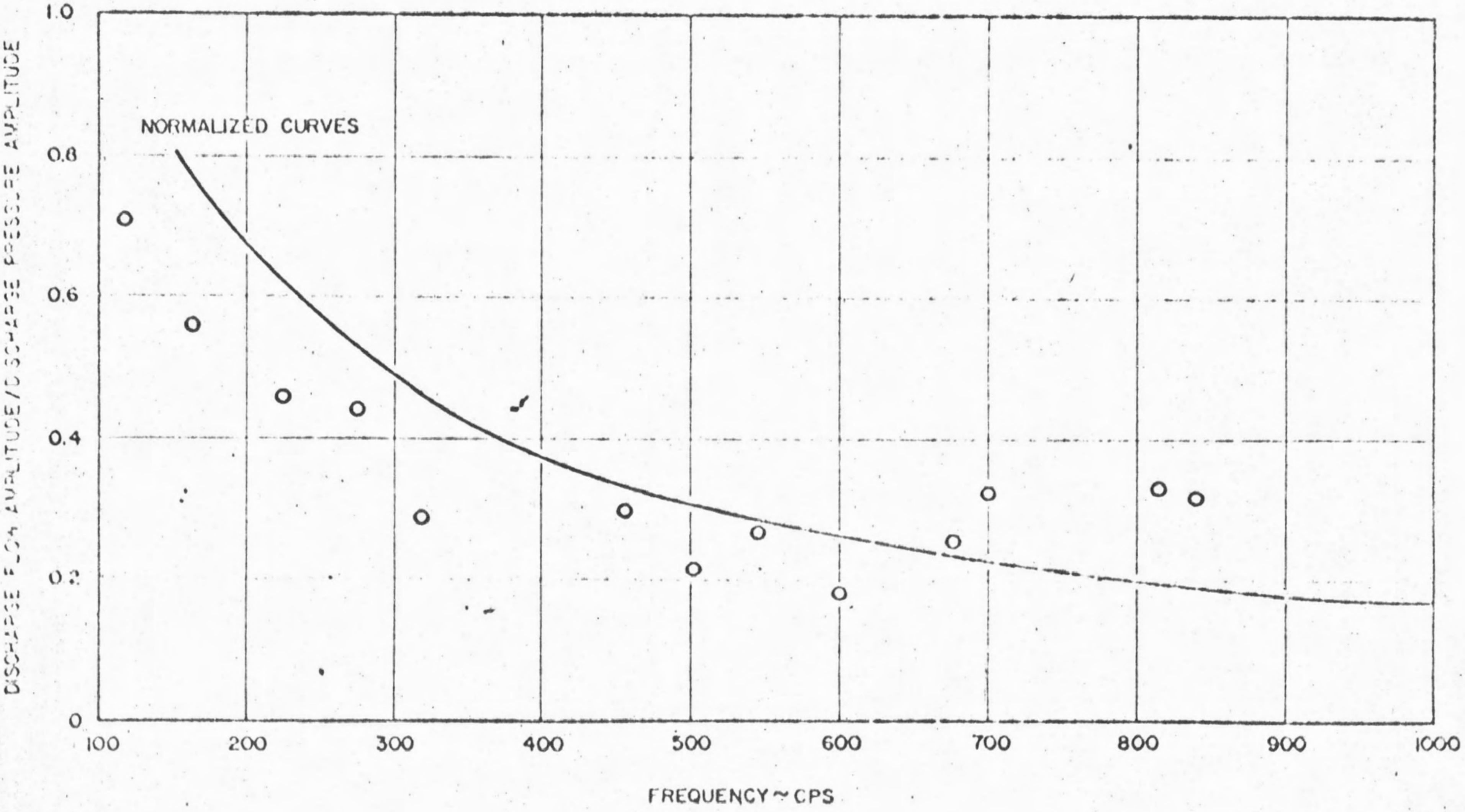




HYDRAULIC CAPACITOR AND CHARGING SYSTEM INSTALLED ON FUEL SIDE OF THRUST CHAMBER

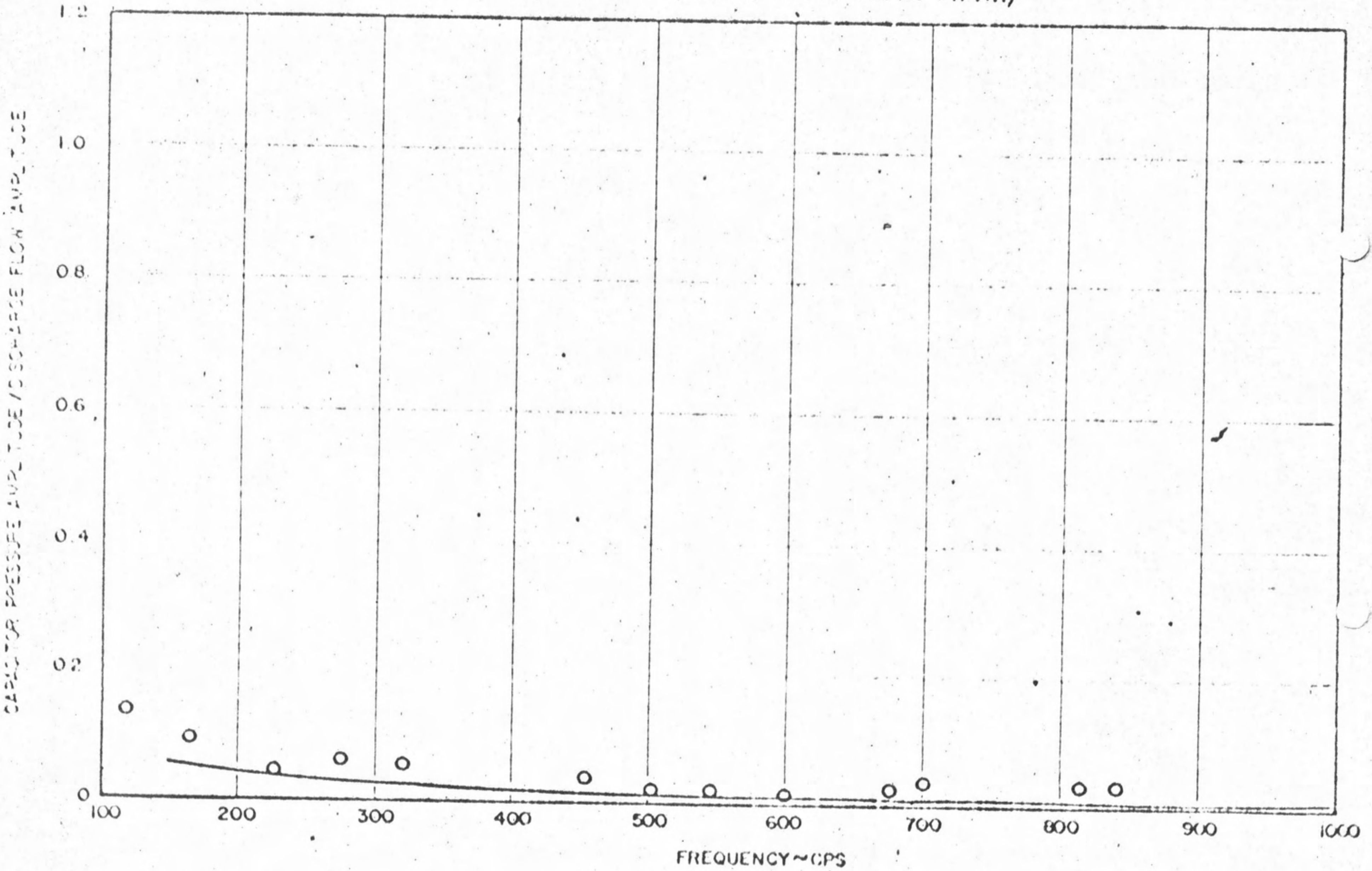
CORRELATION OF TEST RESULTS WITH PREDICTED CURVE IN TERMS OF DISCHARGE FLOW

(WITH HYDRAULIC CAPACITOR INSTALLED IN LABORATORY SYSTEM)



CORRELATION OF TEST RESULTS WITH PREDICTED CURVE IN TERMS OF CAPACITOR PRESSURE

(WITH HYDRAULIC CAPACITOR INSTALLED IN LABORATORY SYSTEM)



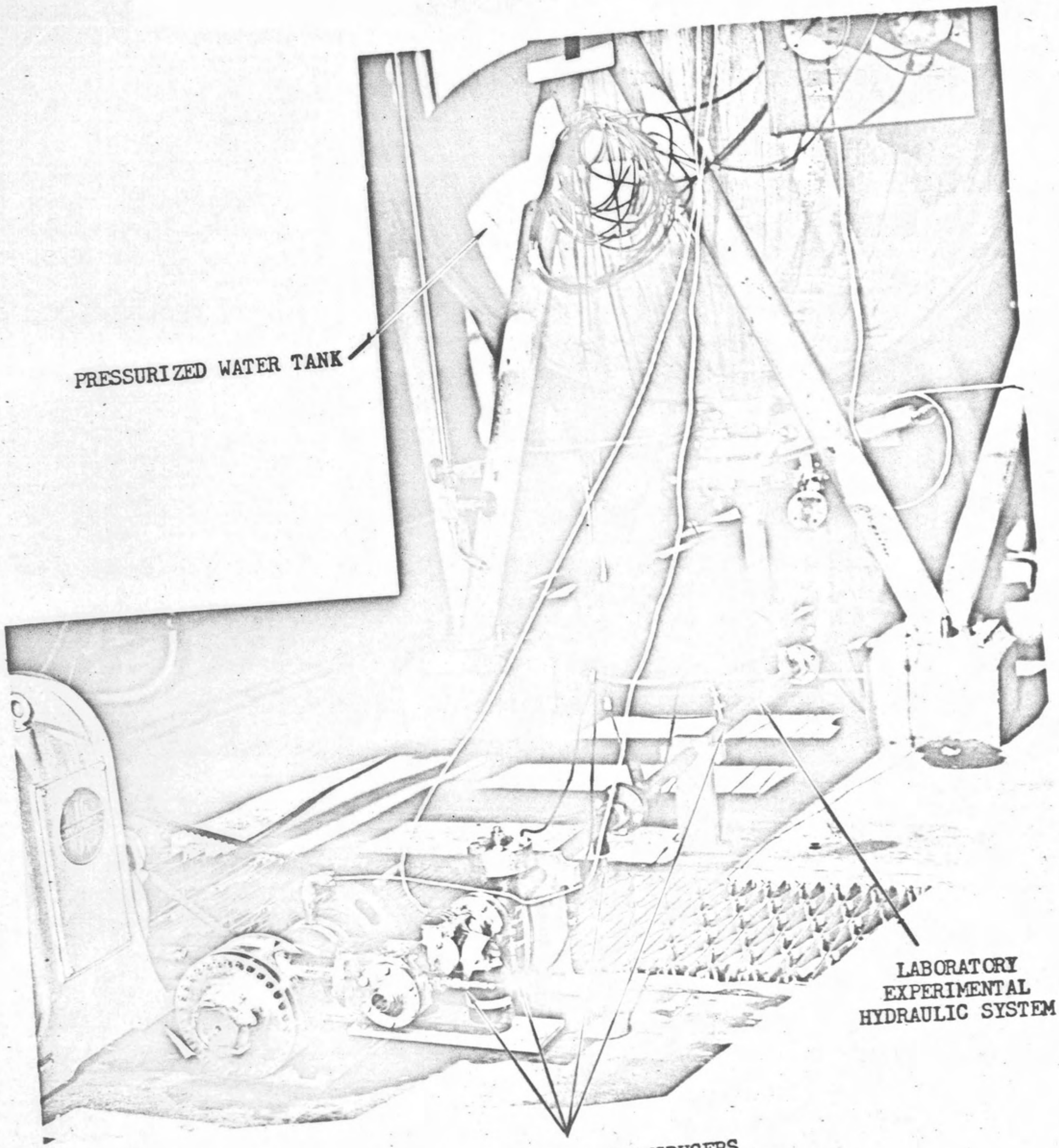


FIGURE 4: THE LABORATORY EXPERIMENTAL HYDRAULIC SYSTEM WITH PRESSURE PERTURBATION INPUT APPARATUS ATTACHED

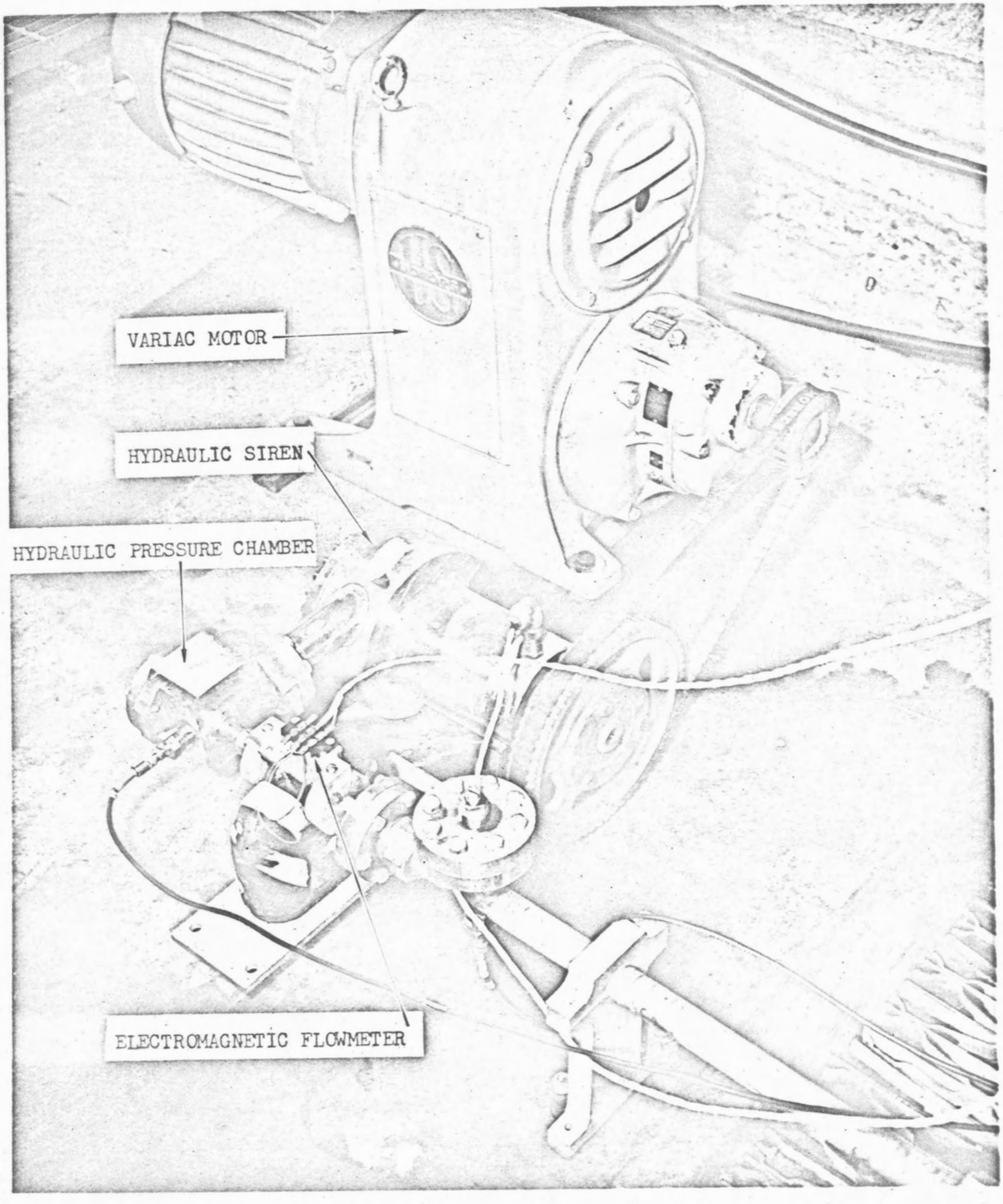


FIGURE 5: CLOSE-UP OF THE PRESSURE PERTURBATION INPUT APPARATUS

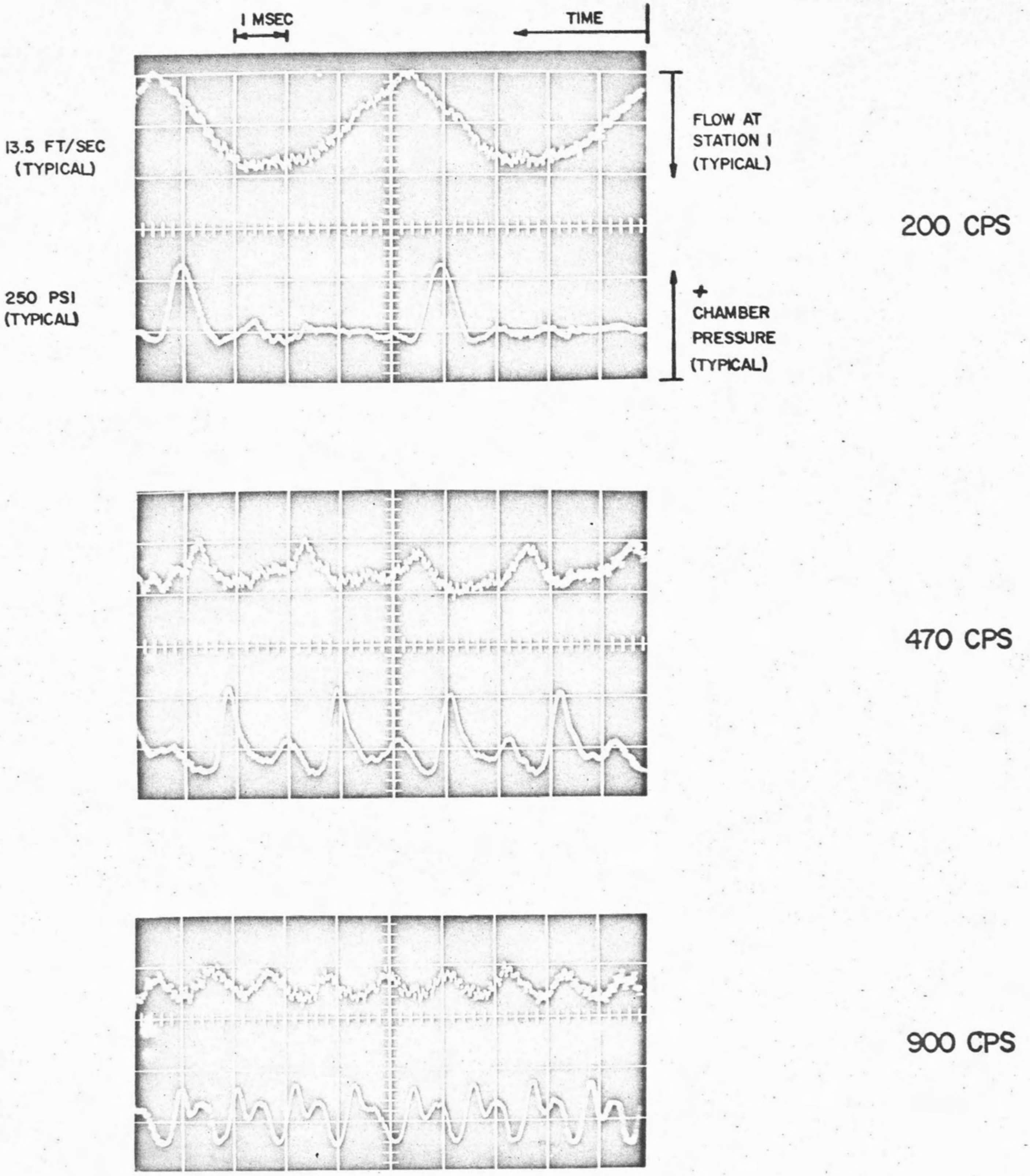


FIGURE 6: COMPLEX WAVE FORMS PRODUCED BY THE LABORATORY HYDRAULIC REFERENCE SYSTEM SUBJECTED TO A HYDRAULIC SIREN PRESSURE DISTURBANCE AT THE DISCHARGE END.

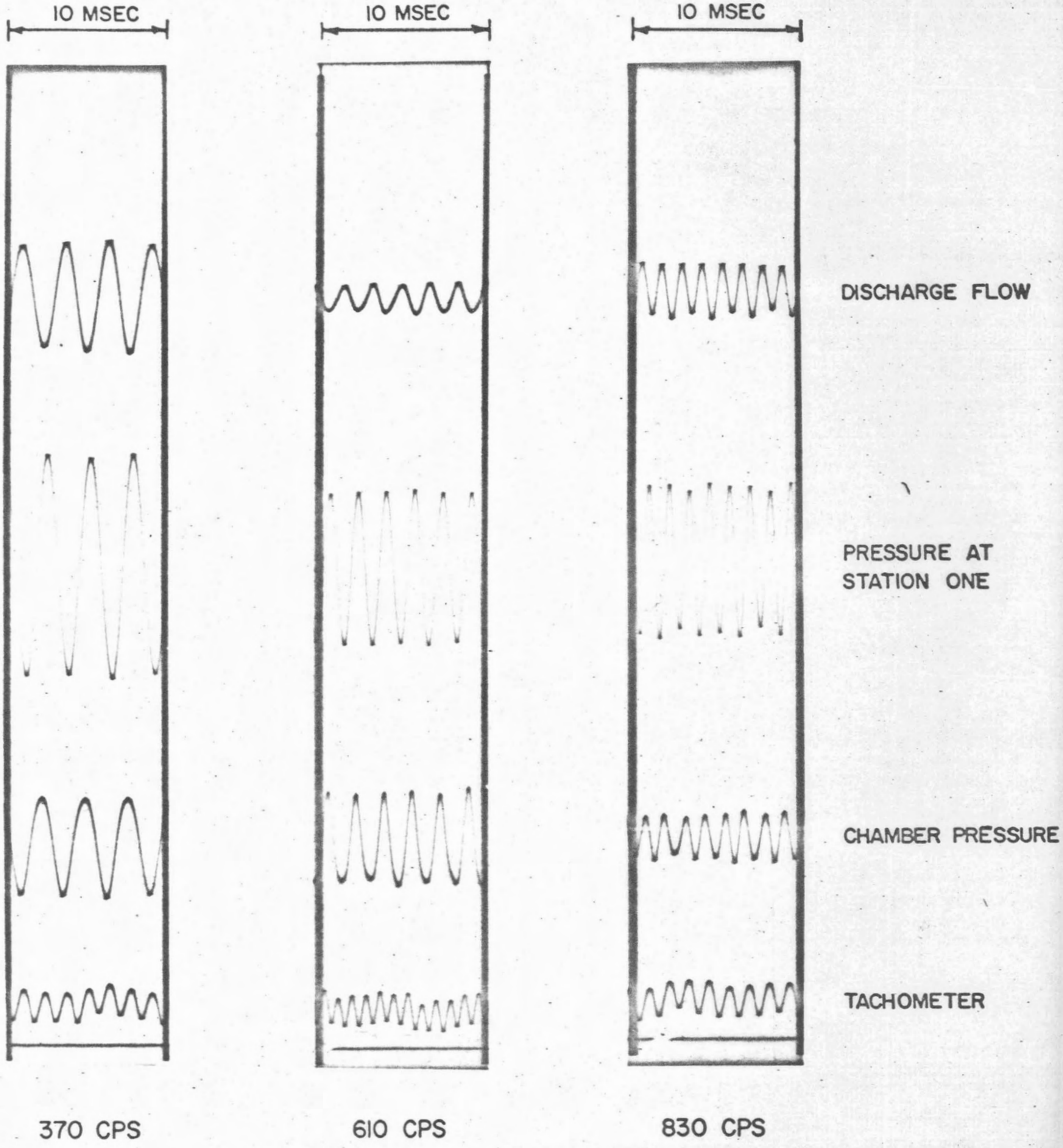


FIGURE 7: CORRELATABLE TRACES OBTAINED THROUGH FILTERING THE COMPLEX WAVES PRODUCED BY THE EXPERIMENTAL HYDRAULIC REFERENCE SYSTEM MODIFIED FOR SIREN INPUT,

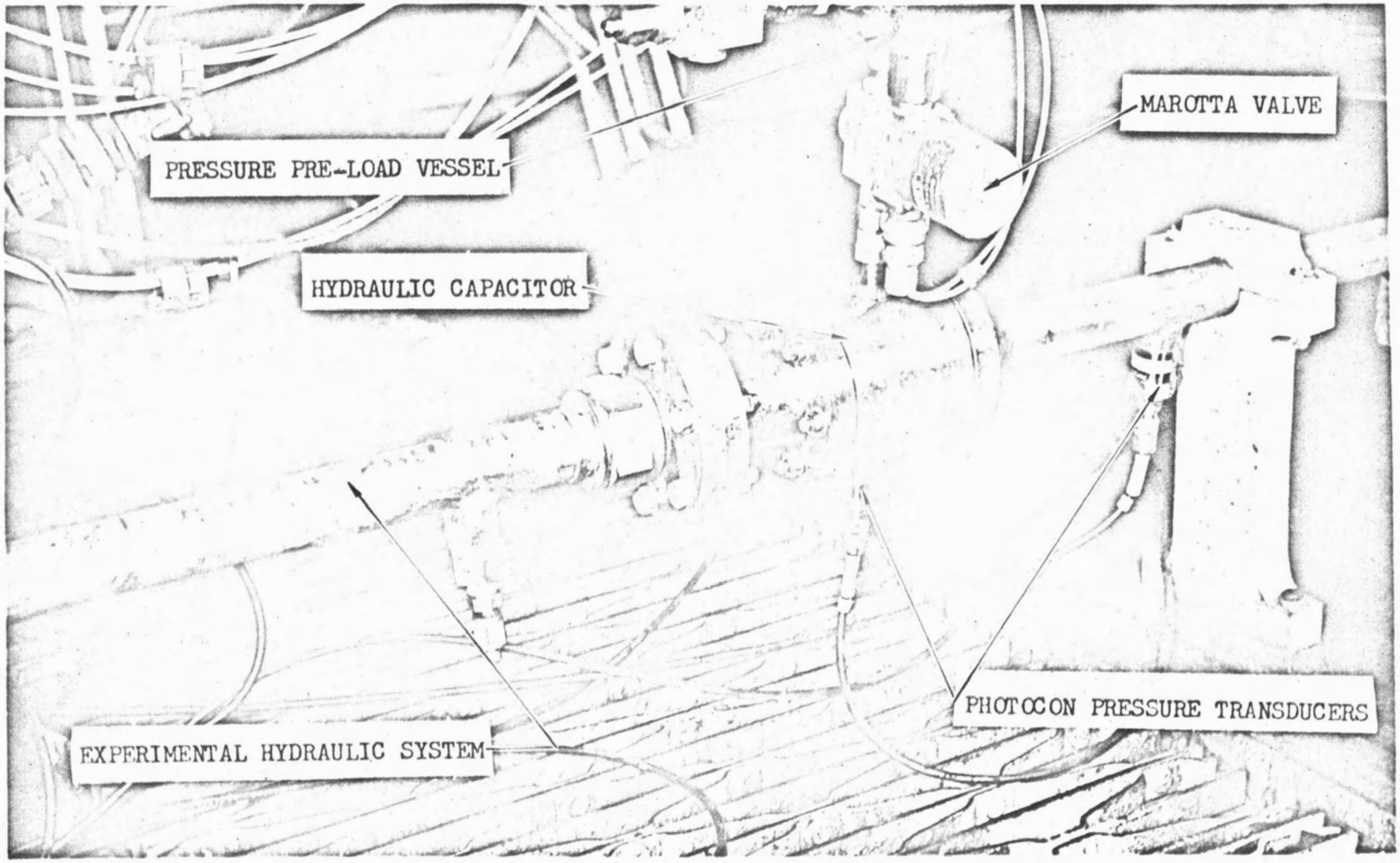


FIGURE 11: HYDRAULIC CAPACITOR AND CHARGER INSTALLED IN THE LABORATORY EXPERIMANTAL HYDRAULIC SYSTEM