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"The Liquid Metal Linear Generator", by E. S. Sowa

by

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DISCLAIMER

The utilization of nuclear heat energy in the production of electricity for specialized purposes such as satellite power supplies suggest the application of liquid metals to this task. Conceivably, our technology will be capable of producing, in the near future, reactor cores operating at temperatures in the range 1000 - 1100°C. With such temperatures the physical properties of liquid metals lend themselves to the operation of vapor cycles. If the vapor cycle is applied to producing motion in a liquid metal stream, the moving liquid metal can be passed directly through a magnetic field where electrical energy can be extracted.

For example, in Figure 1 the vapor pressure of sodium is plotted as a function of absolute temperature.(1) At 1100°C the vapor pressure for sodium is equal to 6 atmospheres (88.2 psia). For potassium the corresponding pressure is estimated to be about 140 psia. From this it is apparent that one can apply a heat source of this type to produce a supply of moderate pressure vapor. This vapor can now be expanded through a nozzle to convert a portion of the enthalpy of the vapor into kinetic energy. Conventionally, the high speed vapor could be used to drive the blades of a turbine to supply motive power to a generator. On the other hand, the vapor expanded through the nozzle can be used to directly propel a column of liquid metal. Such a scheme is shown diagrammatically in Figure 2. Here we can see the heat source used to produce the vapor which is led to an expanding nozzle in a jet pump or injector. In this device, the vapor impinges upon and condenses in a liquid metal stream in a constricted region where the fluid velocity achieves a relatively high value. In this region, if a proper condensing shock is formed, advantage can be taken of the high fluid velocity to extract electrical energy by allowing the liquid to pass through the generator. Following this, the fluid enters a diffuser where its velocity drops to moderate values. The fluid is then passed at some velocity through a heat rejection unit after which it re-enters the jet pump region. The details of the jet pump are shown in section in Figure 3. In this figure, one can see the annular arrangement surrounding the periphery of the vapor nozzle portion. This region acts as the place where the liquid velocity is increased before its entry into the combining section. It can be seen that a portion of the fluid is drawn off after the jet pump and returned to the heat source as makeup for the vapor introduced into the circuit.

Although it is recognized that the traditional efficiency of an injector has always been low, the recirculating system is being studied with the objective in mind that if reasonably good liquid velocity can be attained it may be possible to increase the efficiency. The possibility for this is suggested from an examination of turbine efficiency curves as a function of bucket to steam velocity ratio.(2) From this it can be seen that the efficiency of a turbine rises as this ratio is increased and reaches a maximum in the vicinity of 0.5. That is when the bucket is moving at half the speed of the impinging steam. It is apparent, of course, that for this type of a ratio, the hydraulic losses would become very important and the design of the system would have to take this into account.

The experimental effort to study this configuration has been started and equipment constructed to operate initially with steam and water as the operating medium. The apparatus is shown in Figure 4. The jet pump is located at the top with the heat exchanger mounted below. The equipment was designed to permit flexibility in changing relative positions of components and positioning of the loop. A turbine flowmeter is located in the system to measure the flowrate of water and thermocouples are positioned throughout to provide proper heat balances. In addition, a throttling valve has been incorporated in the line to simulate the effect of the generator.

If one considers the operation of a circuit of the type described during operation at equilibrium. A force balance taken over the system yields the function shown in Figure 5. Here, the term on the left is equal to the driving pressure of the impinging steam. The first term on the right is the total electrical load while the second is the loss load in the two sections of changing cross section. The final term is simply the hydraulic loss in the remainder of the circuit. If this equation is applied to the simple pumping circuit, the term for electrical force can be dropped and comparison of experimental data can be made. At the time of writing a preliminary run was made. The measured velocity of fluid showed that the liquid attained a velocity of 70 ft/sec in the constriction of the test section. The corresponding vapor velocity for this is equal to 420 ft/sec. It appears that this velocity is lower than one would expect. Estimates indicate that this velocity should be at least 914 ft/sec. On this basis, the conversion of steam kinetic energy to liquid kinetic energy is of the order of 20%. Further tests of this unit will continue before conversion to liquid metal operation.

The inefficiency encountered in a system of this type can come from several sources. Primarily, the major losses may be as follows.

1. Decrease in steam enthalpy due to heat loss.
2. Turbulence in nozzle and impact area.
3. Slip between vapor and liquid.

This is in addition to the hydraulic losses. The first step in the program, consequently, is aimed at optimizing the conditions to produce the flow.

Finally, when the experiments are converted to liquid metal operation it appears that a number of techniques can be used in an effort to decrease hydraulic losses. Primarily, these are:

1. Boundary layer injection of vapor to reduce wall friction.
2. Ultrasonic cavitation produced at the boundary in an effort to induce the liquid to supply its own lubricating vapor.(3)
3. Reduction of flow turbulence loss by magnetic fields parallel to the flow direction.(4,5)

Acknowledgements

I would like to express my appreciation to the people who have been instrumental in the execution of the various phases of this project. In particular, Messrs. D. Raridon and C. Divona of the Argonne National Laboratory.

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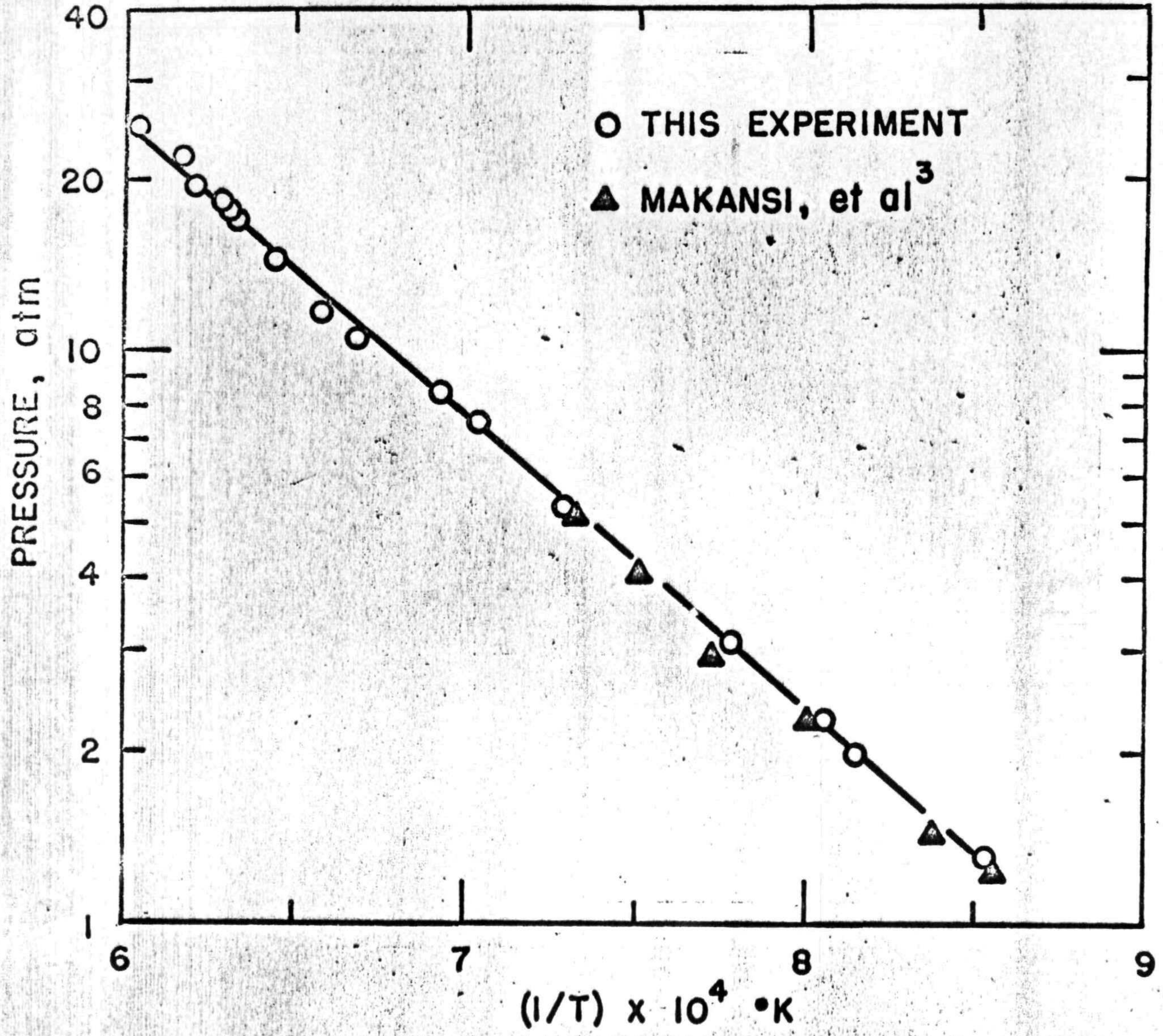

Sodium Vapor Pressure as a Function of Temperature

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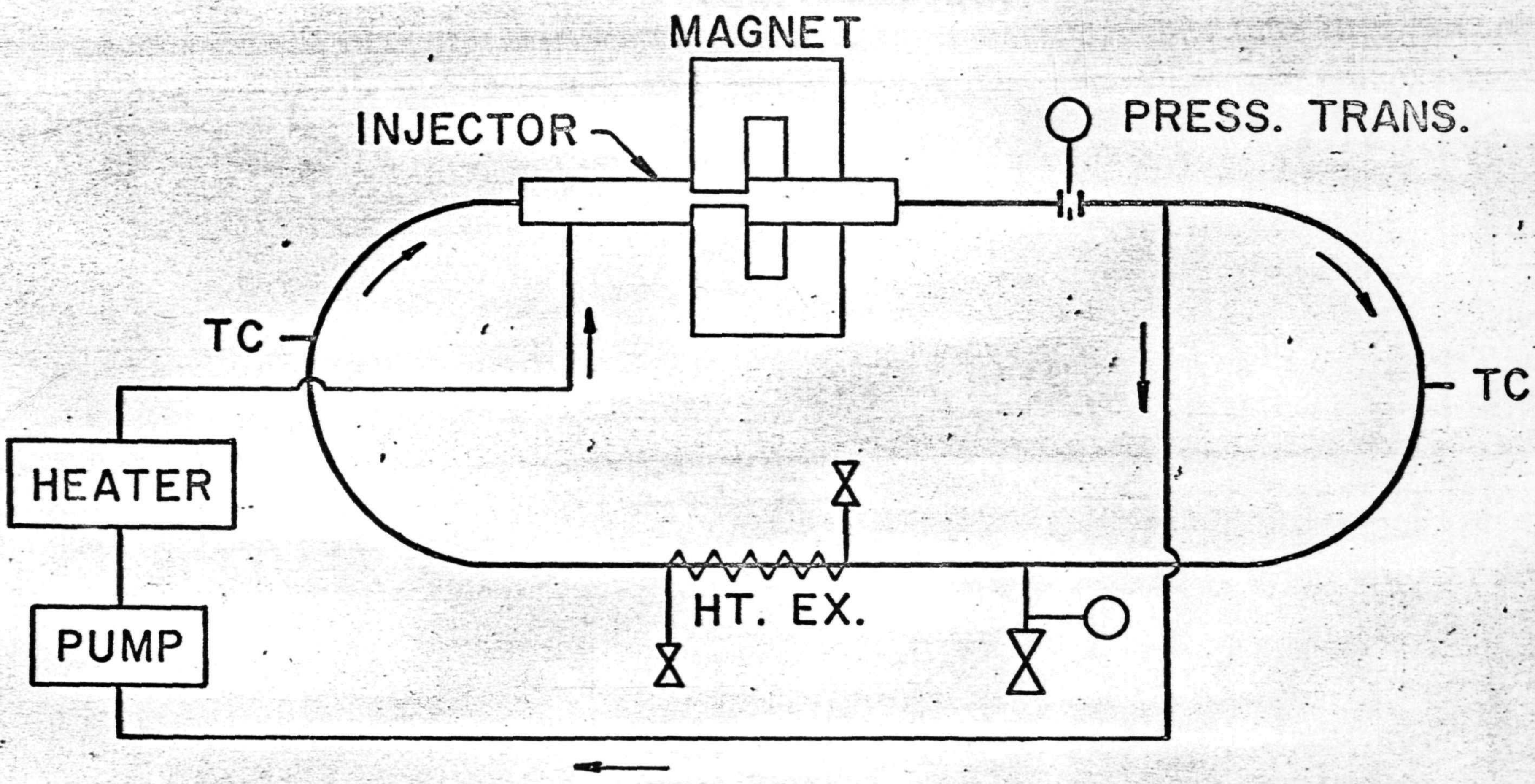
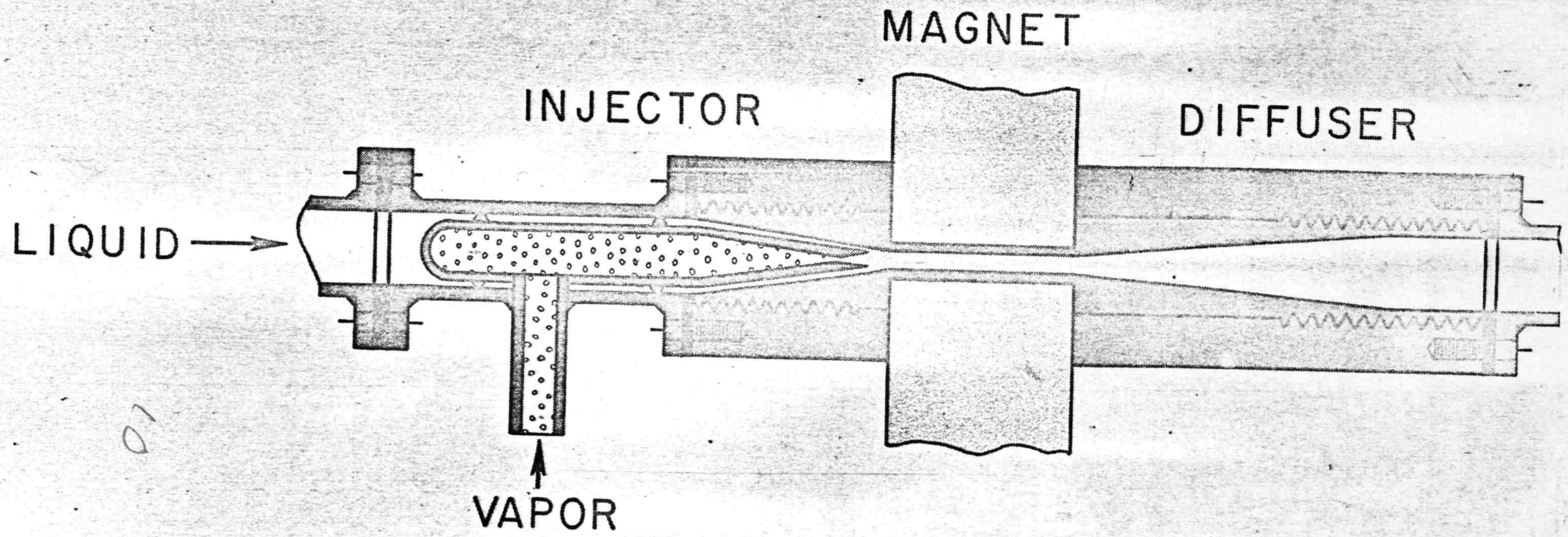


Schematic Diagram of MHD Circuit



Cross Section of Jet Injector

Force Balance Equation for Circuit

$$F_u = F_e + F_f$$

WHERE: F_u = VAPOR IMPACT FORCE

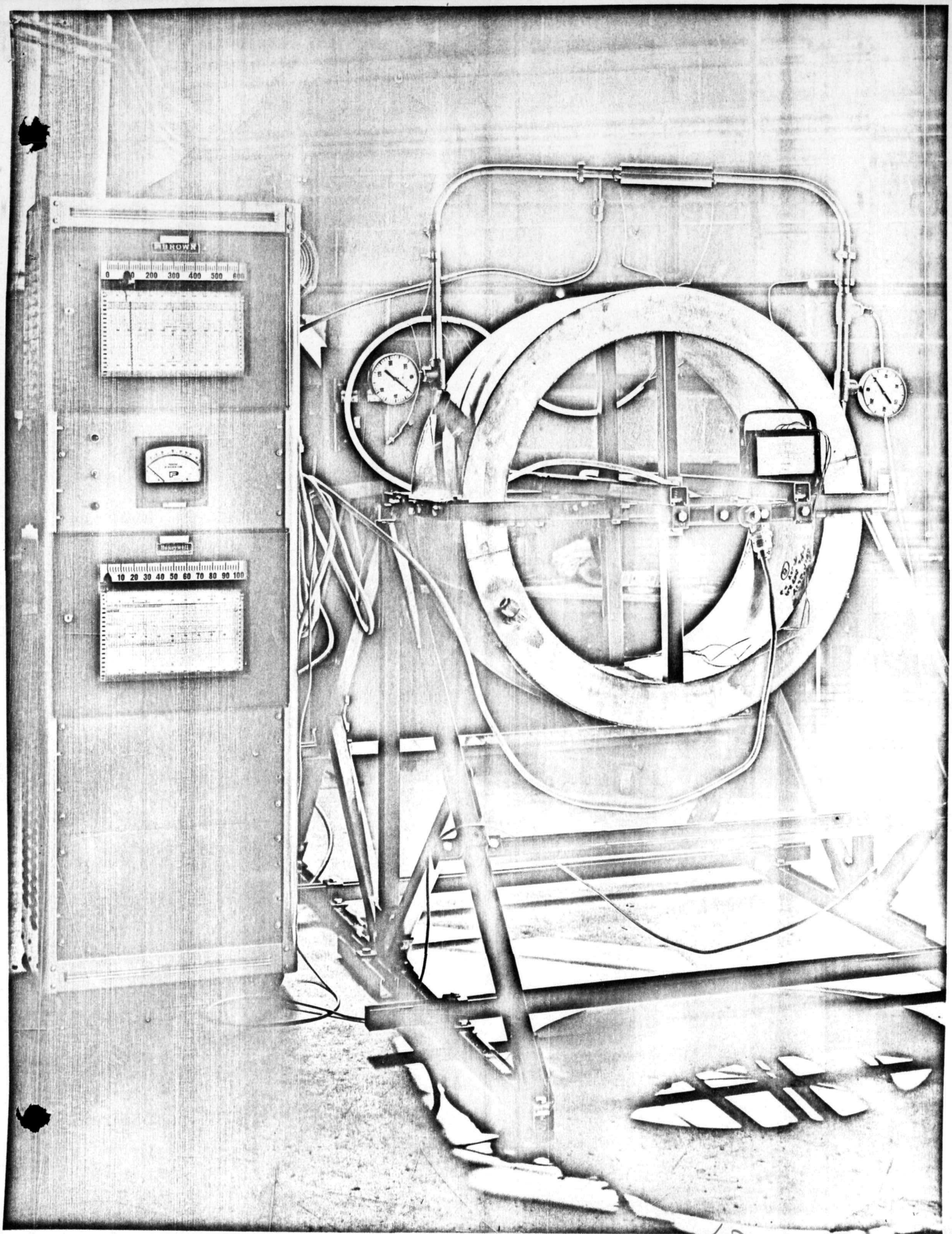
F_e = ELECTRICAL RETARDING FORCE

F_f = ADDITIVE HYDRAULIC FORCE

$$\frac{W}{g}\,\frac{u_1-u_2}{A_n} = \frac{6.357\left(10^{-11}\right)B^2\ell^2 u_2}{RA_n} + \frac{0.1\left(u_2^2-u_3^2\right)\rho}{144\,g}$$

$$+ \frac{2fLu_3^2\rho}{144\,gD}$$

WHERE: $f = 0.04\,(Re)^{-0.16}$


BROWN
0 100 200 300 400 500 600
Honeywell
10 20 30 40 50 60 70 80 90 100