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SUMMARY

The electrical analog study of the diaphragm feed pump system resulted in changes to the system which have improved the overall operation and reliability of the pumps. Specifically, the study showed that if the release of the high pressure oil from the pulsator through the valve on the Scott and Williams pump could be made to take place over a longer period of time, pressure oscillations could be substantially reduced. Also, pressure surges could be reduced by placing an accumulator in the pump discharge line near the check valve. Both of these ideas have been incorporated into the experimental test equipment which has resulted in a quieter and smoother operation of the pumping system.

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INTRODUCTION

The experimental studies of the diaphragm feed pump have shown that extreme pressure oscillations occur in many parts of the system during a pumping cycle. It is considered that these pressure oscillations are directly associated with high fatigue stresses and lead to the failure of diaphragms and check valves. The solution of the problem of how to reduce the amplitude and frequency of the oscillations would then result in a more stable and efficient pulsafeeder pump system.

The analytical and/or graphical solution of the pressures (or pressure changes) during a pumping cycle is a very difficult and tedious problem. The solution is a function of the interaction between three separate, yet, dependent systems, i.e., the oil system, the intermediate water system, and the fuel system. Each of these have unique flow and pressure characteristics which complicates an analysis. If a change in velocity (or pressure) occurs in any one of the components, the change is observed or reflected to other parts. These reflections are functions of the fluids and configuration of the entire pumping system.

Rather than attempt to determine the effects of modifications to the pulsafeeder system by directly changing components or by making a numerical analysis, it was decided to make a study on a "mock-up" electrical system. If an electrical analog could be made of the existing pump, a device would then be available which could easily simulate changes made to the original mechanical system. Thus, it was the purpose of this investigation to analog electrically the mechanical system and then to determine by the analogy what changes could be made that would reduce pressure surges and vibrations in the original system.

PROCEDURE

The transformation of hydraulic parameters into their electrical analogs is accomplished by first constructing a mathematical model of a typical element of the pump system. The diagram of Figure I shows a typical cell.

Let V_i = initial volume of the cell

M_i = initial mass in cell

$\rho_i = M_i/V_i$ = initial density

P_i = initial pressure in cell

ΔM = change in mass in cell

ΔV = change in volume of cell

The relationship between the changes of pressure, mass and volume within the cell can be determined from the bulk modulus equation

$$E = - \frac{1}{\rho} \frac{dp}{d(1/\rho)} = - \frac{V}{M} \frac{dp}{d\left(\frac{V}{M}\right)} = \frac{MV dP}{VdM - MdV}$$

$$\text{or } dp = E \left(\frac{dM}{M} - \frac{dV}{V} \right)$$

Then

$$\Delta p = E \left[\ln \frac{M}{M_i} - \ln \frac{V}{V_i} \right]$$

$$\text{or } \Delta p = E \left[\ln \left(1 + \frac{\Delta M}{M_i} \right) - \ln \left(1 + \frac{\Delta V}{V_i} \right) \right]$$

The logarithmic terms may be expanded in series form as:

$$\ln \left(1 + \frac{\Delta X}{X} \right) = \frac{\Delta X}{X} - \frac{1}{2} \left(\frac{\Delta X}{X} \right)^2 + \frac{1}{3} \left(\frac{\Delta X}{X} \right)^3 - \frac{1}{4} \left(\frac{\Delta X}{X} \right)^4 + \dots$$

For the purposes of simulation only, the first term of the series is used. Since the true value is somewhat less than the first term, the approximation is made that

$$\ln \left(1 + \frac{\Delta X}{X} \right) \approx 0.9 \frac{\Delta X}{X}$$

Therefore

$$\Delta p = 0.9 E \left(\frac{\Delta M}{M_i} - \frac{\Delta V}{V_i} \right) \dots \dots \dots (1)$$

This is the pressure change associated with a change in mass and volume of a region.

In flow through pipes, there are two factors which affect the pressure drop across the pipe, i.e., friction and inertia. The frictional pressure drop is determined from the Fanning equation and the inertia drop from Newtons equation as

$$\Delta p = \frac{f L_{eff}}{2 g_c D} \frac{1}{\rho A^2} \left(\frac{dM}{dt} \right)^2 + \frac{L}{g_c A} \frac{d^2 M}{dt^2} \dots \dots \dots (2)$$

where

- L_{eff} = equivalent frictional length of pipe
- L = length of pipe
- D = diameter of pipe
- A = cross sectional area of pipe
- f = friction factor (assumed constant)

ρ = mass density (assumed constant)
 g_c = dimensional constant.

or

$$\Delta p = K_1 \left(\frac{dM}{dt} \right)^2 + K_2 \frac{d^2 M}{dt^2} \dots \dots \dots (3)$$

K_1 and K_2 are functions of the geometry and properties of the fluid in the system.

Thus, equations (1) and (3) are the basic equations for pressure changes within the hydraulic system and must be satisfied by the electrical analog system.

The simplified flow diagram of the feed pump system which was simulated is shown in Figure I, and its electrical counterpart is shown in Figure II⁽¹⁾. All of the operations of the hydraulic system are duplicated in the analogy.

DISCUSSION AND RESULTS

After the write out from the analog duplicated the pressure traces from the experimental pumping system, changes were made in the analog which corresponded to changes in the physical system. The changes amounted to varying the line diameters and line lengths in the intermediate and fuel systems, changing speed of operation and changing inlet fuel pressure. The results from these changes did not show any appreciable improvements in reducing the frequencies or amplitudes of the pressure oscillations.

It was noted in the analog that damping in the oil line of the Scott and Williams pump had a large effect on the oscillations in the rest of the system. The initial setup has the oil entering and leaving the pulsator boot with essentially a square wave which should be rounded to reduce oscillations. It was also observed that damping in the fuel discharge line would also reduce the magnitude of the pressure oscillations.

As a result of these two observations on the analog system, changes were made in the feed pump system. The slide valve on the Scott and Williams pump was modified so that the release of the high pressure oil from the pulsator boot was made to occur over a long period of time⁽²⁾. In effect this change reduced the source of one of the large pressure gradients within the system. Another source of a large pressure gradient was substantially reduced by modifying the high pressure oxygen injection system so that it acted as an accumulator in the discharge line. The original O₂ injection system was connected by a 1/2-in. Sch. 80 pipe which permitted the O₂ to expand and release its stored energy rapidly at the end of each discharge stroke thus slamming the discharge check valve balls violently against their seats. Placing an orifice in the O₂ injection line at its junction with the fuel feed line measurably eased the seating of the check valve and reduced pressure oscillations and vibrations.

Earlier studies with a diaphragm follower⁽³⁾ demonstrated that the diaphragm responded to all pressure oscillations so that it was in effect suffering many stress reversals per cycle. A diaphragm follower has not been used on the modified system but since pressure oscillations have been reduced, it is expected that the oscillations of the diaphragm have been correspondingly reduced. Although it is not possible at this time to assign a quantitative value to the life expectancy increase of the system components, a significantly demonstrable reduction in system vibration, in valve seating force, and in diaphragm cycling resulted from the modifications based on the analog study.

REFERENCES

- (1) A complete analysis of the electrical analogy was made by R. S. Stone and can be found in the files of I. Spiewak.
- (2) H. R. Payne, "Modification of Oil Control Valve in Scott and Williams P-9 Pulsator Drive," ORNL-58-1-65, January 14, 1958.
- (3) R. Blumberg, C. H. Gabbard, and E. C. Hise, "Diaphragm Feed Pump Development Program Progress Report," ORNL-56-10-114, October 29, 1956.

FIG. I. SCHEMATIC OF DIAPHRAGM
FEEDPUMP SYSTEM.

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