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Subject: Analog Study of MSRE Component Cooling Pump Differential Pressure Controller (P_dIC-960A)

System Description

A block diagram of the system is shown in Figure 1. The two blowers are positive displacement-type "Roots-Blowers", with volume flowrate vs. ΔP characteristics as shown in Figure 2. The volume on the discharge side of the blowers was found by adding up the volumes in all piping upstream of the valves controlling air flow to the various components. The mass flow rate of air out of the discharge volume was approximated by:

\[ W = 3.80 \left( C_v(\text{load}) + C_v(960A) \right) \sqrt{\frac{P_a(\text{D.V.)}}{12.7}} \]

where \( W \) = mass flow rate, SCFM

\( P_a(\text{D.V.)} \) = pressure in discharge volume, psia

\( C_v(\text{LOAD}) \) = effective \( C_v \) of all load valves

\( C_v(960A) \) = \( C_v \) of control valve \( P_d \text{CV}-960A \)

This is a simplification of the more exact formula:

\[ W = 16.1 \ C_v \sqrt{(P_1 - P_2)} \left( \frac{P_1 + P_2}{GT} \right) \]

where \( P_1 \) = upstream pressure, psia

\( P_2 \) = downstream pressure, psia

\( G \) = fluid specific gravity relative to air (1.38 for Helium)

\( T \) = fluid temperature, °R

in which the quantity \( \sqrt{\frac{P_1 + P_2}{GT}} \) was assumed constant (≈0.236).

The effective \( C_v \) required for rated operating conditions is 85.1, so the control valve, which has a \( C_v \) of 90, can handle the full load.

Since the inlet conditions were assumed fixed at 150°F and 12.7 psia, the mass flow rate into the discharge volume is:

\[ W = (\text{Inlet flowrate, cfm})(\frac{520°F}{610°F})(\frac{12.7 \text{ psia}}{14.7 \text{ psia}}) \]
At rated operating conditions:

\[ W = (1286 \text{ cfm})(.737) = 950 \text{ scfm} \]

The blower output as a function of \( \Delta P \) was approximated by a straight-line relationship (Fig. 2), and for blower startup simulations, the flow was assumed to be directly proportional to pump speed.

The controller to be used is a Foxboro pneumatic controller with proportional, reset, and derivative actions. For the simulation, a Foxboro ECI controller was used; it is assumed that the characteristics of the two are equivalent.

**Results of Simulation**

The simulation indicated that the control system, as designed, would provide satisfactory control for the maximum expected load changes during normal operation. In order to control automatically during a blower startup, however, it was found that an interlock should be provided which keeps the by-pass valve open when the blower is off. This would prevent the pump discharge pressure from exceeding the pressure relief valve setting on the initial startup transient. The interlock assumed was a switch which opens the valve if the \( \Delta P \) is less than 2 psig and allows the controller to operate the valve for \( \Delta P > 2 \text{ psi} \). (The \( \Delta P \) for all load valves and the by-pass valve open, and the blower running at rated speed is > 3 psi).

The control valve \( F_{CV}-960A \) now has equal percentage trim, which, for a constant \( \Delta P \) across the valve, has a characteristic of \( \Delta \text{Flow/\Delta Stem position} \) which is dependent on the operating point. This has the effect of changing the control loop gain - - the gain being higher for low load flows (control valve near full open). The simulation showed that much more satisfactory control can be obtained if linear trim is used, and it is recommended that the trim be changed.

The following controller settings were found to give optimum performance with the simulated system (with full scale \( \Delta P = 15 \text{ psi} \)):

- Proportional Band = 12%
- Reset Time = 0.1 min.
- Derivative Time = 0.1 min.

Figures 3 and 4 show the predicted performance of the system for load changes during normal operation and for blower startup. It was assumed that the valve had linear trim, its operator time constant was 5 sec., and the blower startup time constant was 2 sec. The performance of the system was satisfactory for all tests with these conditions. Other tests showed that a faster valve operator (e.g. 2.5 sec. T.C.) gave slightly better performance for load changes but unsatisfactory operation for blower startup. It is felt that the 2 sec. T.C. assumed for the blower startup is conservatively fast, though it is recommended that this be checked by experiment when possible.

\[ \text{Signed: S. J. Ball} \]
FIG. 1. COMPONENT COOLING SYSTEM

FIG. 2. BLOWER CHARACTERISTICS FOR 10 X 15 RAS BLOWER, S/N 26803-4
Fig. 3. Response to Load Flowrate Changes

ΔP Across Blower, PS

Load Flowrate, % of Rated Blower Flow

Time, SEC.
Fig. 4. Response to Blower Startup

Effective Load $C_v = 8.5$ (Gives 95 scfm @ Operating Pt. = 10% Max.)
Blower Startup Time Constant = 2 sec
Interlock Kept Control Valve Open Until $\Delta P = 2$ psi.

(Note: The overshoot in $\Delta P$ is less for higher values of load $C_v$)

$\Delta P$ Across Blower, PSI

Time, Sec

Value T.C. = 2.5 sec
Value T.C. = 5 sec