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A Study of System Pressure Transients Generated by Isolation Valve Open/Closure in Orifice Manifold

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1. Introduction

In this study, we explore the effects of pressure transients on peak and minimal pressures caused by the actuation of isolation valve and control valve reacting to the combined orifice operation of orifice manifold with motor-operated valve installed in the rear of the orifice. We then use the collected data to direct our effort towards cause analysis and propose improvements to efficiency and safety of operation.

2. Methods and Results

The orifice manifold used in this experiment involves orifices arranged in 3-mesh parallel formation. This formation is used to by domestic and foreign nuclear power plants as a mean to control flow rate, producing required flow rate jointly together by combination of the orifices.

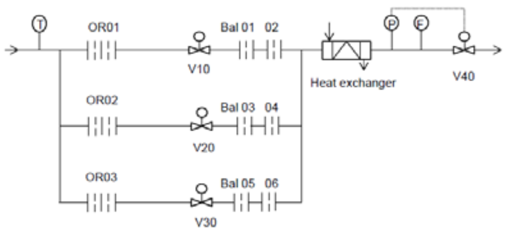

Fig. 1. Schematic drawing of orifice manifold

On a general note, when the fluids pass through the orifice nozzle, the downstream pressure of orifice can fall below vapor pressure because the pressure decreases while flow rate increases. As a result, flashing and cavitation can occur which will give rise to vibration and rupture of the downstream valve or pipe and other structures while the fluid is clearing.

2.1 Orifice manifold design

2.1.1 Decompression orifice

The design of orifice is based on the required differential pressure; error within ± 5% is acceptable. Differential pressure and inlet pressure are key variables considered into the design of the orifice; the flow rate occurring from the two variables determines the size of the orifice.

Table I. Operating condition

	Inlet pressure (kg/cm^2)	Operating temperature (℃)	Flow rate (L/m)
1	130-163	60-232	151.4
2	130-163	60-232	302.8
3	130-158.9	101.7-232	530

2.1.2 Isolation valve and Control valve

Isolation valve requires constant stroke time during the period of valve operation. The administrative controls of motor operated valve installed on each row of orifice manifold are operated by torque and limit switches and the strokes are administered in mutual-independent fashion. Air-operated valves (AOV) may exhibit error due to pressure fluctuation of instrument air and degradation of accessory; motor operated valve (MOV) shows higher reliability in comparison.

The variables of operating torque of motor-operated valve are as follows:

$$T_{qDV} = MT_{DV} \times OVR \times \eta_{Pullout} \times AF \times TDF$$

T_{qDV} : Maximum actuator torque during voltage drop (ft-lb$_f$)
MT_{DV} : Motor torque under voltage drop conditions (ft-lb$_f$)
OVR : Total actuator gear ratio
$\eta_{Pullout}$: Pullout efficiency
AF : Applied coefficient
TDF : Temperature Loss Factor

Table II Isolation valve specifications

Valve number	V10, V20, V30
Valve type (operator)	Globe (Motor)
Design Pressure (kg/cm^2)	174.7
Design Temperature (℃)	287
Differential Pressure (kg/cm^2)	174.7
Flow coefficient (Cv)	10

Pneumatic operated valve for backpressure control shows excellent dynamic performance as demonstrated by extensive use by various fields of industry. However, the stroke administrations are interdependent.

The variables for the driving force of air-operated valves are as follows:

$$F = (P\pi r^2) - S$$

F : Force generated from actuator (lbs.)
P : Air pressure applied to the diaphragm (psig)

γ : Effective radius of diaphragm (inches)
S : Spring force (lbs)

Table III Control valve specifications

Valve number	V40
Valve type (operator)	Globe (Pneumatic)
Inlet pressure (kg/cm^2)	28.1
Temperature (℃)	48.9
Flow coefficient (Cv)	9.304
Vapor pressure	0.119

2.2 Valve stroke time

Valve stroke time affects the pressure increment caused by the increase in the flow of the system. The stroke time for isolation valve is 30 seconds and 5 seconds for control valve.

2.3 Selection of operating modes

The flow output produce from manifold orifices through isolation valve are 113.6, 265 and 511 L/m. Flow rate can increase and decrease incrementally. The backpressure of manifold orifice is 28.2 kg/cm^{2}G, at fluid temperature of 50 ℃.

The following operating cases are selected for this study.

Case	flow rate mode (L/m)	Valves status
1	151.4 to 302.8	V-10/20 open
2	302.8 to 530	V-10/20/30 open
3	530 to 302.8	V-30 closed
4	302.8 to 151.4	V-20/30 closed

2.4 Results and analysis

The phenomena of excessive pressure occurring from selected operating conditions were observed. Data for peak pressure and minimum pressure were collected from said phenomena in the manner of figures 1 and 2.

a. System peak pressure
If flow rate is increased from 157L/m to 300L/m, peak pressure 39.7 kg/cm^{2}G is observed in Fig. 1.

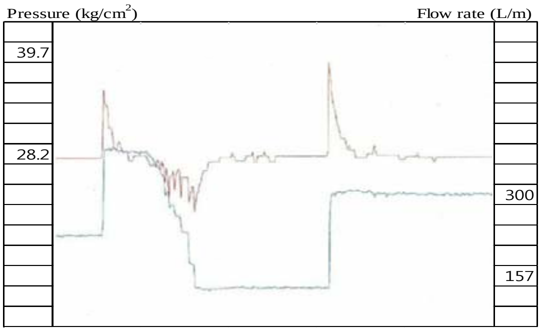

Fig. 1. Peak pressure in case 1

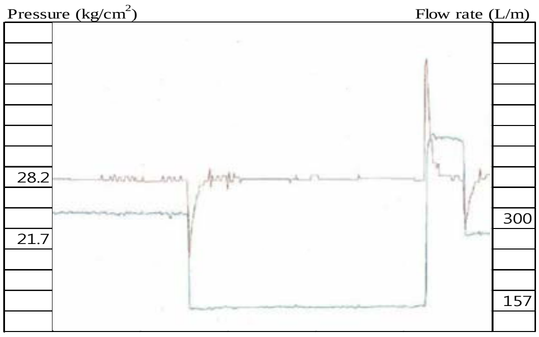

Fig. 2. Minimum pressure in Case 4

b. System minimum pressure
If flow rate is reduced from 300L/m to 157 L/m, minimum pressure of 21.7 kg/cm^{2}G is observed in Fig 2. This is higher than the vapor pressure at the downstream of orifice, therefore is deemed safe. However, in the case of control valve, the outlet pressure approaches closely to the vapor pressure as a result of differential pressure.

Cavitation index, which is used to predict the cavitation of valve is calculated using equation 1.

$$\sigma = \frac{P_1 - P_V}{P_1 - P_2} \quad (1)$$

P_1 : Inlet pressure
P_2 : Outlet pressure
P_V : Vapor pressure

Hence, when the flow rate decreases from 300 L/m to 157 L/m, inlet pressure (P_1) of control valve exhibits pressure of 21.7 kg/cm^{2}G. Using flow coefficient, Cv of 2.3 the calculated outlet pressure (P_2) is 0.9 kg/cm^{2}A.

The vapor pressure is 0.54 kg/cm^{2}A at the fluid temperature of 48.9 ℃. Therefore,

$$\sigma = \frac{21.7 - 0.54}{21.7 - 0.9} = 1.01$$

3. Conclusions

A. No significant impacts on the internals of manifold orifice due to peak pressure has been observed, although chance of cavitation at the outlet of control valve is significant. Considering the peak pressure, as well as minimum pressure occurs in low flow rate conditions, the pressure transient is more so affected by the characteristics (modified equal percentage) of control valve. Thus, improving the safety of the operation entails proper selection of control valve with appropriate characteristics, and deduction and application of optimized control parameter is necessary.

B. Isolation valve of the orifice and control valve operate organically, therefore stroke time for valves need to be applied in order for both valves to cooperatively formulate an optimized operation.

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