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A Study on Internal Shape of the Pressure Transmitter Relieving the Water Hammer Pressure

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Abstract. When the pipe is suddenly closed, the fluid in the pipe is compressed in the closed part and the kinetic energy is converted into pressure energy and the pipe moves back and forth at high pressure. This phenomenon is called water hammer, and the water hammer can damage the pipe or the devices installed in the pipe. Particularly, when a pressure sensor mounted on a pipe is exposed to high pressure, there is a high possibility of malfunction or damage. Therefore, in this study, we tried to find a shape which can reduce the damage on the sensor through computational fluid analysis. before the actual experiment using Pulse-Snubber shape. The change in pressure was confirmed through computational fluid analysis When a narrow Pulse-Snubber was used, the peak pressure was lower and the occurrence time was delayed. This study is expected to be helpful in technology used in protecting pressure sensors.

Keywords: water hammer, pressure sensor, pulse snubber

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1. List of symbols used in the paper

E_v = bulk modulus of elasticity of the fluid

E = Young's modulus

α = compressional wave speed

ρ = Density

L = Pipe length

C_w = Wave speed during water hammer

H = Piezometric head
Q = flow rate
D = inner diameter

δ = pipe wall thickness

t = round trip time of compressional wave

2. Introduction

Transient flow is very important in designing and explaining a pipe. Water hammer is one of the most common examples of transient flow in pressure pipelines. The water hammer phenomenon refers to a phenomenon in which the kinetic energy of the fluid in the pipe is converted into pressure energy when the pipe is closed by a valve, etc (A. Kodura, 2016).

By the water hammer, kinetic energy of the fluid changes into pressure energy. Because of the pressure energy, the fluid makes excessive vibration, cavitation, and unpleasant sounds while moving back and forth (A. Bergant, A.R. Simpson, 2005) (Min-Ku, Hwang, Jin-Seok, Do, Tae-on, Hwang, 2020) (Byung-Soo, Shin, Bok-Ki, Min, 2018).

Pressure fluctuation due to water hammer has a great influence on the life and stability of the pipe. Although various ways to alleviate the impact of water hammer such as changing the physical properties of the pipe (Ali Triki, 2016) or using additional parts have been tried (A Al-Khomairi, 2010), those parts are hard to utilize due to their price or restrains in installation. Therefore, increasing the closing time of the valve is the most typical way of reducing water hammer phenomenon (Jong-Ho, Park. & Han-Yung, Park, 2011) (Yeon-Hwa, Ji, 2021) (S. Y. Na, H. J. Son, 2020).

P. D. Howel numerically analyzed that the pressure sensor mounted on the pipe could be damaged by cavitation which is occurred when the pressure of fluid falls below vapor pressure due to water hammer. Thereafter, he insisted that CFD analysis is necessary (P D Howel, 2006).

In order to protect the sensor from shock caused by unexpected continuous overpressure such as water hammer, Hyundai Kefico studied the structure of the pipeline where fluid flows, and registered a patent for a structure that can prevent shock (Jong-Yoon, Yoon, 2013).

According to the above studies, it can be confirmed that the water hammer phenomenon adversely affects the pipe or parts mounted on the pipe. Therefore, in this study, a flow field equipped with a pressure sensor is modeled. And using Ansys Fluent, a commercial analysis code, water hammer phenomenon caused when valve is closed suddenly was analyzed. Applying this result and Pulse-Snubber shape, pressure at the sensor was measured. Two conditions, without Pulse-Snubber and narrow Pulse-Snubber shape, were compared. At the same time, pressure at the sensor was measured.

3. Body

3.1. Numerical Analysis

For the analysis of water hammer, the following governing equation is presented (M. Hanif Chaudhry, 2014).

$$\frac{\partial H}{\partial t} + \frac{a}{c}\frac{\partial Q}{\partial x} = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + ac\frac{\partial H}{\partial x} + RQ|Q| = 0 \tag{2}$$

Equation (1) is a continuity equation, Equation (2) is a Momentum equation. The propagation velocity theory in the pipe (3) is expressed by Joukowsky's equation and (4) is the round trip time of the wave. (Mohamed S. Ghidaoui, Ming Zhao, Duncan A. Mclnnis, 2005) (J. Twyman, 2016).

$$C_w = \sqrt{\frac{\rho}{E_p D}} \tag{3}$$

$$t = \frac{2L}{\quad} \tag{4}$$

3.2. Pulse-Snubber Model

A shape in which a pressure sensor is inserted in the middle of a pipe with a length of 500 mm and a diameter of 10 mm was modeled. According to the shape of the pipe moving from the pipe to the pressure sensor, that is, the shape of the Pulse-Snubber, the pressure touching the sensor was measured and compared. Fig. 1 shows the shape without Pulse-Snubber, Fig. 2 shows the shape with the entire Pulse-Snubber pipe having a diameter of 0.5 mm.

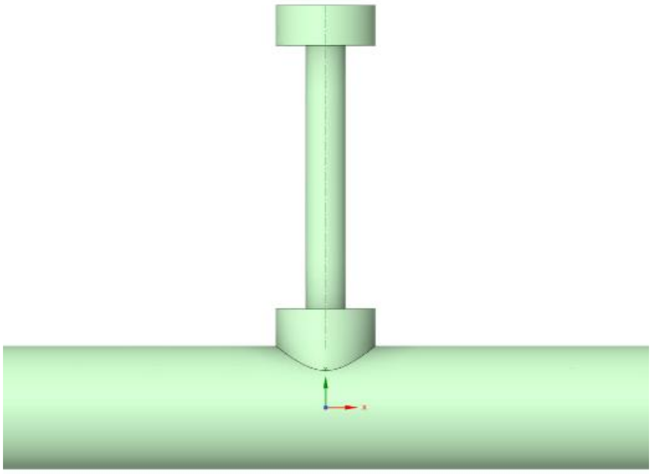

Fig. 1: Without Pulse-Snubber

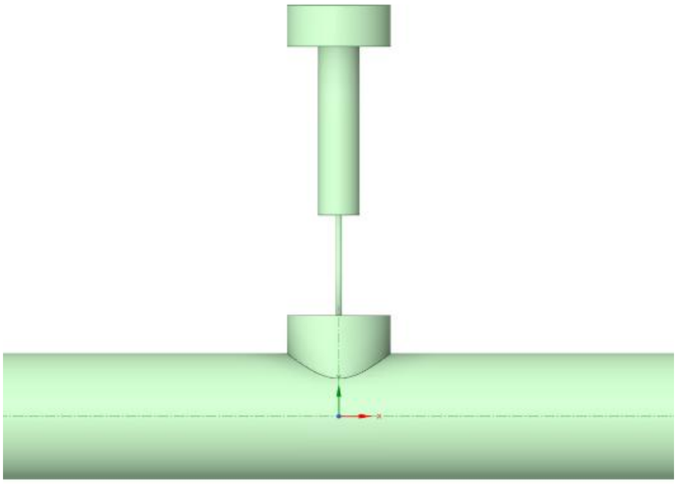

Fig. 2: Narrow Pulse-Snubber

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4. Conclusion

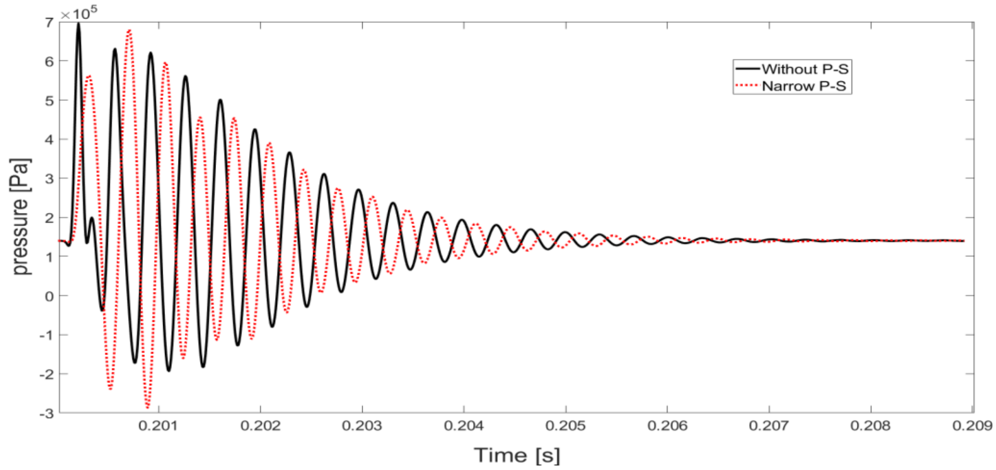

Fig. 3: Pressure variation

Table 1: Top 10 Peak Pressure

No.	Without P-S [Pa]	Narrow P-S [Pa]
1	696,249.2815	563,295.1301
2	631,256.7243	680,249.0571
3	621,334.8152	596,401.1399
4	561,583.5953	455,423.6722
5	500,720.2765	453,669.0314
6	425,330.437	390,039.1578
7	366,061.1882	321,718.913
8	311,287.5601	274,937.5847
9	271,244.2963	253,087.1737
10	237,231.3097	219,403.1359
Avg.	462,229.9484	420,822.3996

Table 2: Top 10 Peak Time

No.	Without P-S [s]	Narrow P-S [s]
1	0.20021	0.20031
2	0.20057	0.20071
3	0.20092	0.20107
4	0.20126	0.2014
5	0.2016	0.20174
6	0.20194	0.20208
7	0.20228	0.20243
8	0.20262	0.20276
9	0.20296	0.2031
10	0.2033	0.20344

Table 3: Compare results Without P-S and Narrow P-S

	Pressure difference	Peak Time difference
Value	8.96%	0.000138s

Fig. 3 shows a graph comparing the pressure of the shape without the Pulse-Snubber and the shape with the existing shape. Through the transient analysis, water was allowed to enter at a speed of 2 m/s at the Inlet from 0 to 0.2 seconds. After 0.2 seconds, the boundary condition was changed to 0 m/s at the Inlet and the wall at the Outlet to set a sudden closure. The turbulence model used was the *K-e* model, and it was calculated by the simple method. Time steps up to 0.2 seconds were 0.01 seconds, and from 0.2 seconds on, time steps of 1e-5 were used.

For shape comparison, the pressure and time of the top 10 peak points of the pressure change shown in 3 are shown in Table 1 and Table 2, and Table 3 compares the results values. According to the values in Table 3, when Narrow P-S was used, the pressure got 8.96% lower, and in the perspective of time, 0.000138 seconds were added. Therefore, we could see that two symptoms, pressure decrease and time-delay, depend on presence of the Pulse-Snubber. In this paper, the water hammer analysis was conducted without considering cavitation. Since cavitation is naturally accompanied when water hammer occurs (Angus R. Simpson, E. Benjamin Wylie, 1991), a multiphase flow analysis considering cavitation should be conducted in future studies, and the shape of a new Pulse-Snubber that can prevent sensor damage due to cavitation should also be considered.

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