Pressure transmitter design

Liquid (water) hammer phenomenon

How to protect your system from damage caused by water hammering
What is not widely acknowledged is that the situation before the pressure peak is the actual reason for the possible damage of the components which form part of the system - and that this also applies to pressure transmitters. If the pressure is measured before and after a valve in a system with a given liquid flow, sudden closing of the valve will cause pulsating pressure on the inlet as well as the outlet of the valve. This can be demonstrated, both by simulation as well as in practice, on a system as outlined on Fig. 1.

Pressure transients
Fig. 2 and Fig. 3 show the measured and simulated pressure transients in front of and behind the valve immediately after closing of the valve. The pressure transients or the variation of pressure in front of the valve (Fig. 2) correspond to what could be expected by closing of the valve. It appears from Fig. 3 that the pressure on the outlet of the valve will, however, reach absolute zero, i.e., vacuum, immediately after closing of the valve. If this vacuum creates a formation of gas pockets in the dead volume in front of the pressure transmitter sensor (Fig. 4), by cavitation or in other ways, the subsequent rise in pressure will have the effect that liquid will be hammered against the sensor causing possible damage to the pressure transmitter.

Cavitation:
Formation of “gas pockets” when the pressure gets below the vapour pressure of the liquid. If these “gas pockets” are imploded (exploded) at a material surface, this surface is exposed to heavy mechanical stress (pressure) in the implosion area.

Liquid hammer: Liquid backlash.
Due to the kinetic energy, a deceleration of liquid, for example by closing of a valve, will cause the liquid to collapse when the pressure gets below the vapour pressure of the liquid. The liquid flow continues until the “suction” power in the cavitation area has reached a size which turns the liquid flow. When the liquid returns it will result in high pressure peaks that are non-uniformly spread on the surface that it hits.
The effects of pressure transients

The two figures 5 and 6 show a cross section of the pressure transmitter (B) mounted in front of the valve, the valve itself and a cross section of the pressure transmitter (C) mounted behind the valve.

Fig 5 shows the liquid condition at the separation diaphragm of the pressure transmitters during the vacuum situation at transmitter C (immediately after closing of the valve).

Solving pressure peak problems

Fig 6 shows the liquid condition at the transmitters at the first pressure peak after closing.

It appears that the separation diaphragm is deformed on the transmitter (C) that is mounted after the valve. This is due to a non-uniform pressure distribution on the diaphragm when the liquid hammering hits.

It is not the pressure peak itself that causes damage to the sensor, but the condition before the peak occurs. This conclusion only applies to sensors with a very high degree of safety towards static overload pressure, as for example, the monolithic silicon pressure sensor. A sensor with a low degree of safety towards static overload can be damaged by the pressure peak itself.

The conclusion also explains why the problem can be observed at a pressure range of 1 bar as well as at a pressure range of 400 bar.

In the test system, the actual problem does not occur on the inlet of the valve, but, on the contrary, it occurs on the outlet (Fig. 3). In practice, it is therefore often difficult to find the right place to look for the problem.

The phenomenon has been observed on various applications, thus it is now possible to point them out in advance and propose a solution.

The solution consists of a specially designed nozzle with a precision laser drilled orifice mounted in the pressure port of the transmitter.

The function of the nozzle is not to protect against pressure peaks. To a very high degree this is secured by the nature of the silicon pressure sensor (overload pressure: 10 - 20 × measuring range).

The function of the nozzle is to prevent the gas pockets that may result in the creation of the dangerous non-uniform pressure peaks (cavitation and liquid hammer) shown in Fig. 5 and Fig. 6.

A benefit of the nozzle design solution is that it does not increase the total time constant perceptibly: Mechanical + electronic time constant is typically 1 mS for Danfoss pressure transmitters.

For viscosity larger than standard hydraulic oil (32 cSt), it can be stated as a rule-of-thumb that the time constant in mS increases by approximately 2 - 3% of the viscosity increase in cSt (mm²/s).
Conclusion
All pressure transmitters in the HEAVY DUTY series based on the piezo resistive design are delivered with the specially designed nozzle and thus comply with our philosophy that pressure must not be a problem for a pressure transmitter (gauge) regardless of how erratic the pressure appears, as long as the stated maximum limits for the pressure range in question have been complied with.

The problem does of course not occur in all liquid systems, but our experience show that the phenomenon can occur in a wide range of plant, such as hydraulic presses, mobile cranes, braking systems for windmills, diesel engines, refrigeration systems with NH₃, etc.

Prevention
Prevention of “the liquid hammer phenomenon” must take place during dimensioning of the plant.

In situations where it is not possible to eliminate liquid hammer problems by dimensioning it is necessary to use components that resist the operating and environmental influences they are exposed to.

By using Danfoss pressure transmitters of the HEAVY DUTY series a reliable pressure measurement is obtained, also during critical conditions.

Fig. 7
After closing the valve vacuum and cavitation only occurs in the pipe due to the restriction in the nozzle.

Fig. 8
Liquid backlash creates high pressure peaks. Due to the uniform pressure profile at the diaphragm and the high degree of safety of the silicon chip towards overpressure, the pressure peak will cause no damage of the sensor.