CAVITATION

CAVITATION IN CONTROL VALVES

CAVITATION

Cavitation can be a damaging phenomenon and control valves are particularly exposed to this problem, even at moderate operating conditions.
The consequences can be destruction, noise, vibration and erosion, and cavitation can even change the fluid properties caused by vapor formation resulting in chocked flow and a drastically reduced performance of the valve.

In a control valve, increasing flow velocity through the control restriction (regulating plug and seat) will result in a corresponding decrease in static pressure.
Cavitation occurs when the hydrostatic pressure in high flow stream velocity drops to a critical value (vapor pressure) of the liquid.
In working conditions with high ΔP, steam bubbles are formed downstream of the regulating plug and seat.
These bubbles collapse with high energy when the high pressure area is reached downstream of the restriction and there is a reduction in stream velocity increasing the static pressure.

LIQUID - VAPOR PRESSURE

Cavitation is a dynamic process that can be influenced by liquid characteristics and temperature.

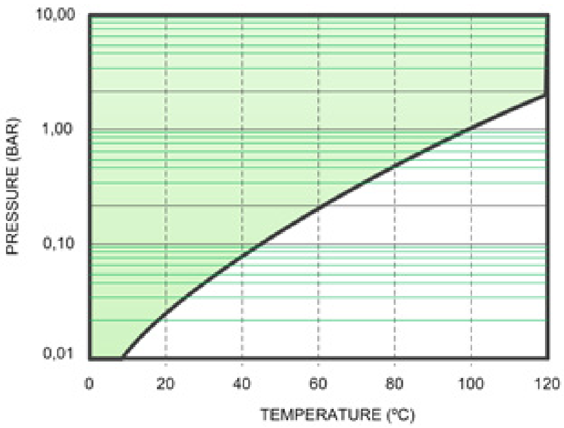

Fig 1 - Vapor/liquid chart

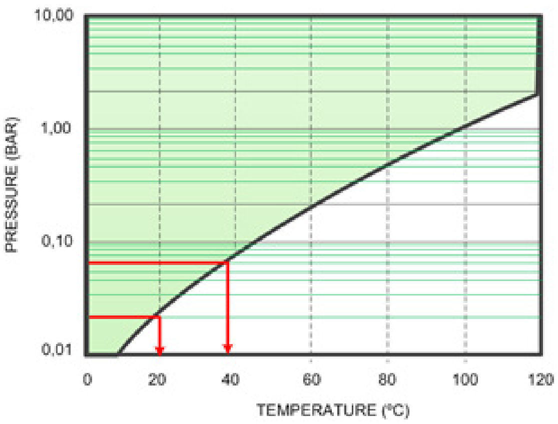

Fig 2 - At 20°C vapor is formed at 0.002 bar
At 40°C vapor is formed at 0.006 bar

VELOCITY IN CONSTRICTION

As observed in Fig. 3, the velocity of fluid in a constriction is approximately 40 m/s. The example shows a butterfly valve. However, in globe type valves the velocities near the plug and the seat are equal, producing a jet stream where vortices and seeds are formed and static pressure drastically decreases - and cavitation starts.

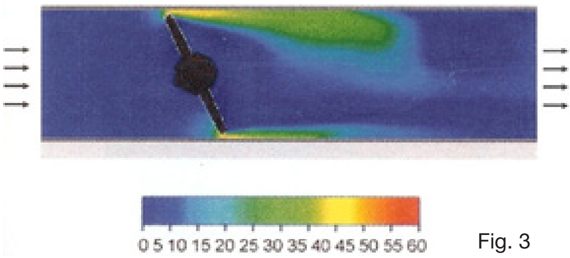

Fig. 3

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ENERGY EVOLUTION

The potential energy of a liquid is the sum of parts.

BERNOULLI THEOREM

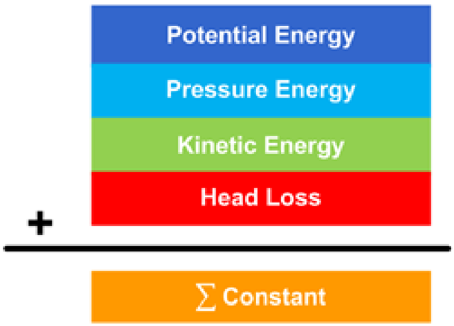

Fig. 4
Total energy of fluid:
Energi of pressure
Kinetic energy
Head loss

TYPE OF ENERGY

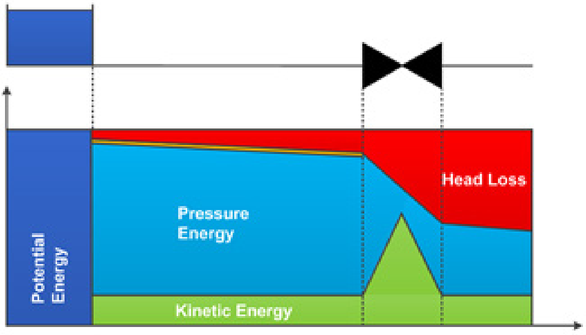

Fig. 5
The potential energy is the static charge in the tank.

ENERGY EVOLUTION IN RESTRICTION

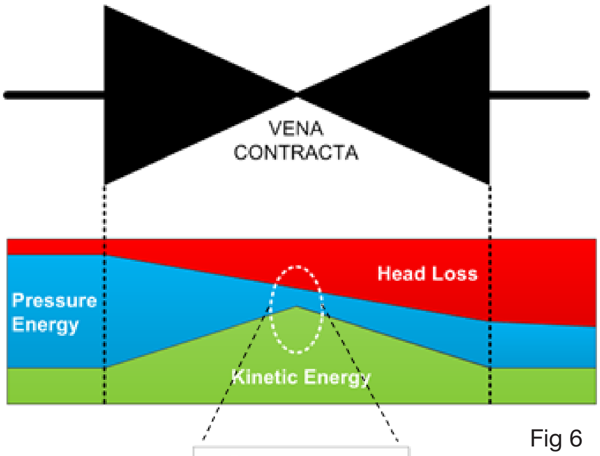

Fig 6

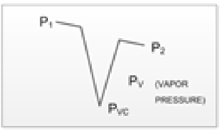

Fig. 7

As the velocity increases in restriction, kinetic energy as well as head loss decreases.

As the total sum of energy is constant, the pressure will decrease when velocity increases. If the pressure goes below the vapor point, steam bubbles will occur.

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CAVITATION IN CONTROL VALVES

NUCLEI AND VAPOR BUBBLES

When velocity increases upstream of restriction, laminar flow at the inlet of the control valve changes to turbulent flow.
Microscopic molecules of dissolved air, vapor or suspended solids are flowing with the water and can be termed cavitation nuclei. Nuclei in turbulent flow is in an instable equilibrium and as soon as the static pressure decreases in restriction, growth of steam is formed.
A small change in pressure in vortices will result in unlimited bubbles to grow and water temperature will anticipate bubble formation (Fig. 8).

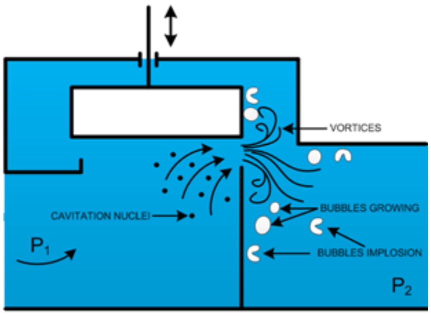

Fig. 8 - Globe type valve

BUBBLE COLLAPSE AND IMPLOSION

VAPOR BUBBLES GROWING

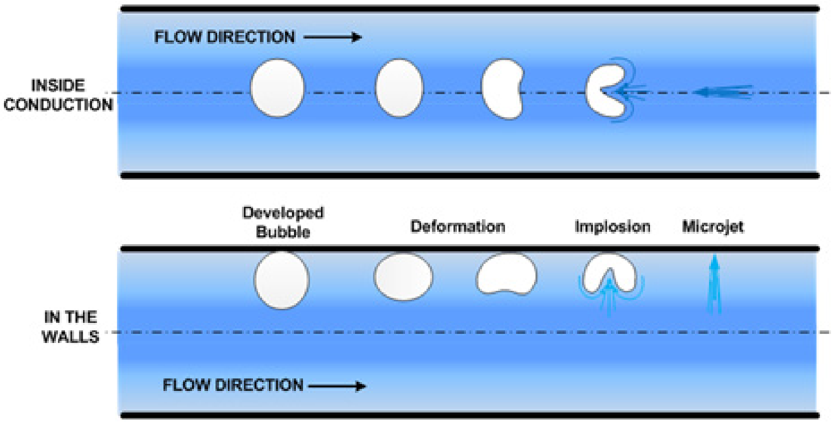

Fig. 9

Pressure recovery is inevitable in a control valve.
When velocity decreases downstream of restriction, static pressure increases resulting in collapsing and implosion of bubbles. The implosion generates high speed micro jets.

COLLAPSE OF A BUBBLE

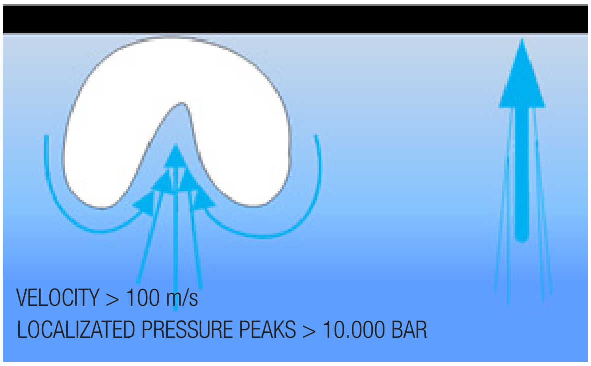

Fig. 10

The pressure in the bubble is equal to the vapor pressure. The ambient pressure at the implosion area corresponds to the downstream pressure. So, the differential pressure between the inside of a bubble and the implosion area define the cavitation intensity, increasing the damaging effect when P_2 - P_v increases.

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CAVITATION IN CONTROL VALVES

CAVITATION - CAVITATION FREE

The following drawings show a cavitation operation pressure reducing valve (P_1 - P_2B) and a cavitation free operator valve (P_1 - P_2A)

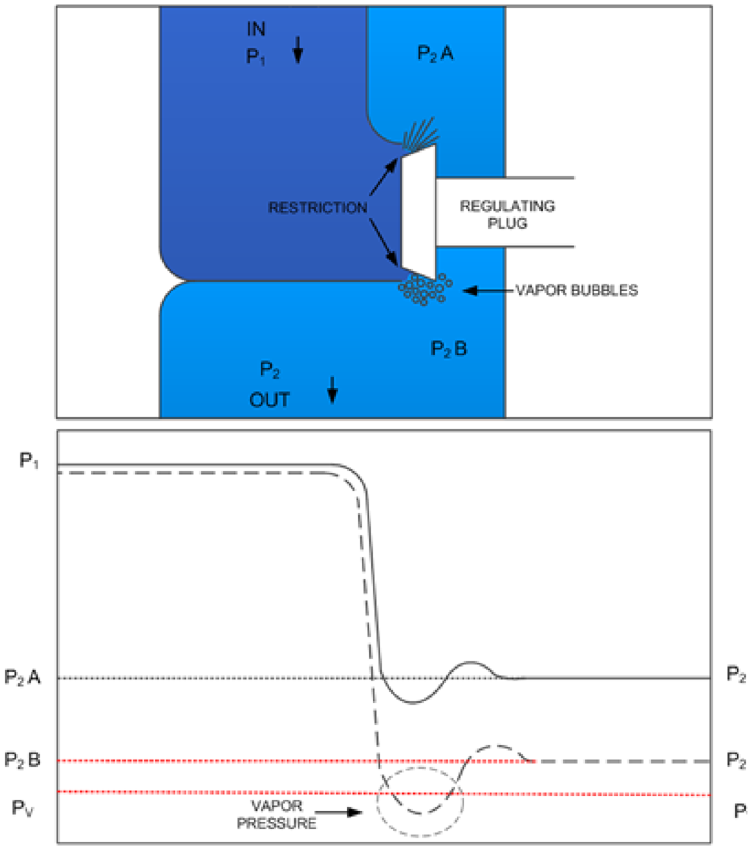


Fig. 11

WALL IMPLOSION AREA AND DAMAGING EFFECTS

The large volume bubbles start to collapse. This reduces the local pressure and causes the small bubbles to grow and then collapse.

In the final phase of bubble implosion, high pressure peaks are generated. In microseconds the impact of the fluid jet on hundreds of bubbles inside the valve results in mechanical vibration, noise and damages of the internal walls of the control valve.

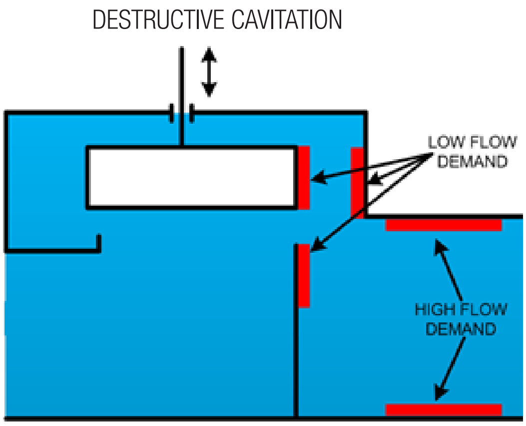


Fig. 12

CAVITATION

CAVITATION IN CONTROL VALVES

DESIGN OF THE CONTROL VALVE AND INFLUENCE ON CAVITATION DESTRUCTION DAMAGES - AVK SERIES 859 MODEL

The specific design of the pressure recovery areas in a control valve reduces the possibility of bubble implosion and collapse near the internal body walls. This prevents cavitation erosion in standard valves without specific anti cavitation trim.

REGULATING PLUG DESIGN

The parabolic design of a regulating plug ensures a smooth, precise and accurate regulation, reducing noise and vibration at low flow conditions.
In standard valves a lift of 10% represents a 15% increase of the K_V value. With the new design, a K_V value increasing 10% will generate a lift of 35%.

DIAPHRAGM CLOSING ANGLE

As the plug design associates with the angle of the diaphragm when the valve is closing, seat chatter will not occur and no stress (tension) is caused on the diaphragm.
This means that the valve is designed to precisely control any flow rate from zero demand and up to the maximum flow, without decreasing the valve performance.
At low flow conditions, noise and vibrations are minimized.

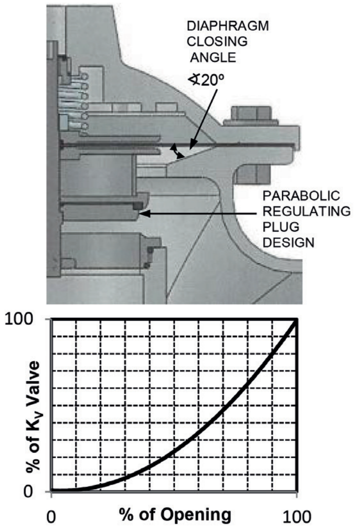
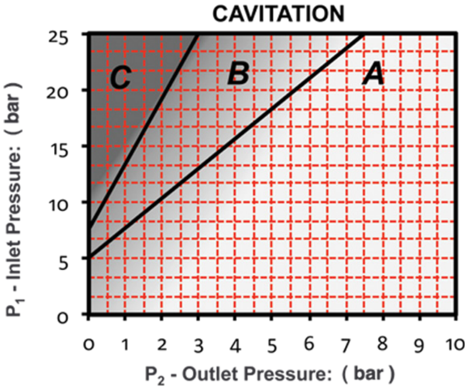


Fig. 13

ANTI CAVITATION SYSTEM

The cavitation chart (Fig. 14) ensures selection of the correct valve.
Locate the inlet and outlet pressures on the chart. If the selected point falls within the areas B or C, cavitation will occur.

BUTTERFLY VALVE - CAVITATION EFFECT



Area A - Standard valve
Area B - Anti cavitation trim
Area C - Valves in series

Fig. 14

CAVITATION

CAVITATION IN CONTROL VALVES

ANTI CAVITATION SYSTEMS

In anti cavitation trim, a special seat and regulating sliding cage plug has been specifically designed to prevent cavitation damages on the valve at high differential pressure operation.
This results in a 3-stage efficient flow split and effective energy loss.

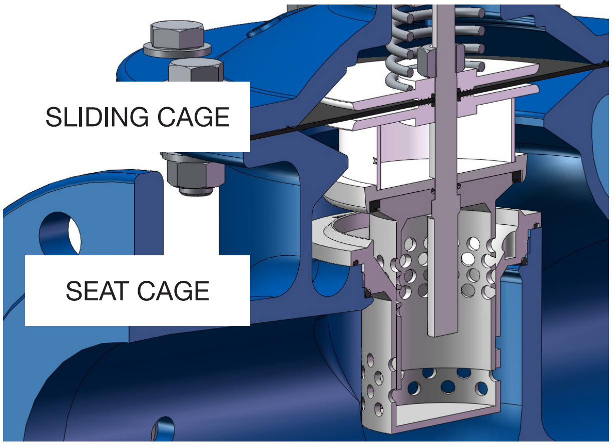


Fig. 15

ANTI CAVITATION SLIDE CAGE TERM

Locate inlet and outlet pressure on the cavitation chart (Fig. 14).
If the calculated point falls in area B, a slide cage anti cavitation trim must be specified.

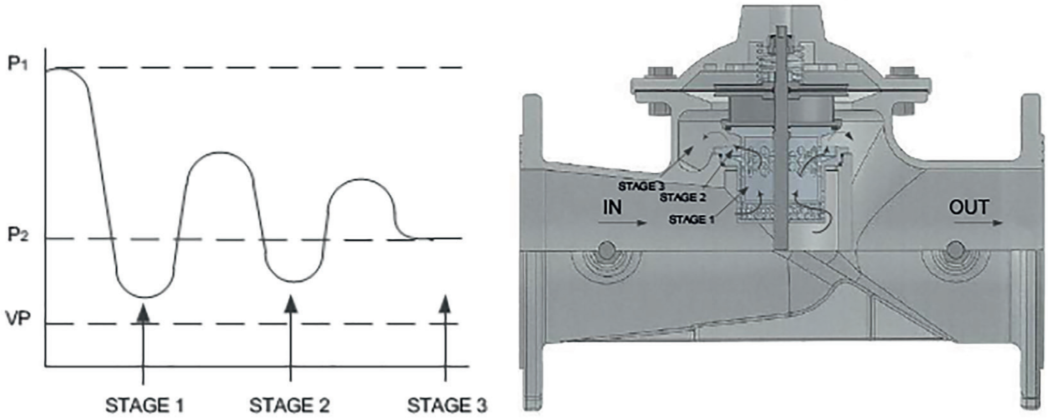


Fig. 16

A combined 3-phase multi stage operation
When the valve starts to open, flow converges in the seat cage. The slide plug cylinder opens the perforated slots on the seat cage at the same time as slots with a large area open in the upper part of the slide plug cylinder upstream of the seat.
The flow converges on the center of the cylinders and the slots act as flow dividers allowing potential cavitation to dissipate in this first stage.

The upper slots of the sliding cylinder will then again divide the flow and dissipate energy in a second stage preventing flow jets to stick to the body walls downstream of the seat, meaning that bubbles collapse with minimum energy without any cavitation effect and with low noise.

CAVITATION

CAVITATION IN CONTROL VALVES

VALVES IN SERIES

For high differential pressure operations or if the calculated point in the cavitation chart (Fig. 14) falls within the shaded area C, valves should be installed in series.

To prevent cavitation in high pressure drop applications, installation of two valves in series can be used.

Example: P_1: 18 bar, P_2: 3 bar

Valve 1 will reduce the high inlet pressure to an intermediate pressure and valve 2 will reduce the pressure further to the final control pressure.

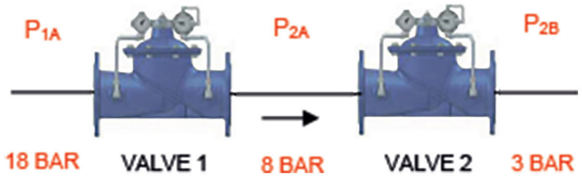


Fig. 17

As the cavitation chart (Fig. 14) shows, the valves will operate cavitation free.

CAVITATION IN TANK LEVEL CONTROL VALVES

In this specific application (ON/OFF float, Electric control valves), the differential pressure is usually too high and the valves will operate at a high level of cavitation intensity.

There are two ways to solve this problem:

- Application of a valve with anti cavitation slide cage trim
- Application of a specific valve with a diffuser to control level and also cavitation intensity and flow rate (Fig. 20)

The control of a maximum flow rate in level control valves is essential for the correct operation of the hydraulic system limiting the liquid velocity in upstream piping and preventing the inflow of air in air vents due to the excessive velocity.

Example:

Installed pipeline: DN100
Installed control valve: DN100 reduced bore
Inlet pressure: 14 bar
Outlet pressure: 0.5 bar

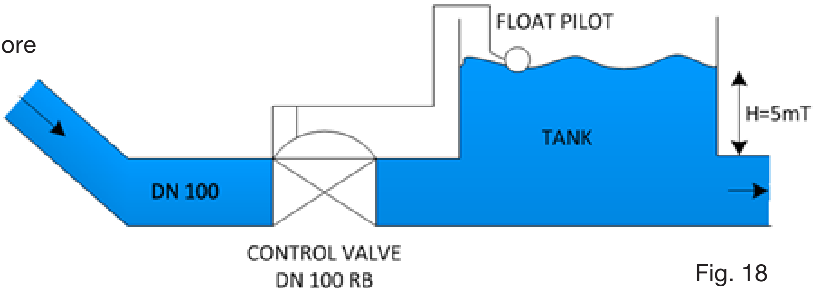


Fig. 18

According to the K_V chart, the value to DN100RB is 95.

K_V values per DN

	DN								
Model	**50**	**65**	**80**	**100**	**125**	**150**	**200**	**250**	**300**
1	44	76	116	175	NA	400	710	947	1355
2	NA	53	83	119	135	202	435	734	990

Fig. 19

1 - Full bore
2 - Reduced bore
K_V: Cubic meters of water, at 18°C flowing through the open valve in one hour with ΔP=1 bar

CAVITATION

CAVITATION IN CONTROL VALVES

CALCULATIONS

Maximum flow rate of the installed valve for the indicated working conditions

$Q = K_V \cdot \sqrt{\Delta P}$ $Q = 95 \cdot 3.7$ $Q = 350\ m^3/h$

Maximum flow velocity in the pipeline for the indicated working conditions

$V = \dfrac{354 \cdot Q}{DN^2}$ $V = \dfrac{354 \cdot 350}{10{,}000}$ $V = 12\ m/s$

If for any reason the control valve opens fully, the velocity in the upstream pipeline is 12m/s, excessive for every water distribution system, causing the inflow of air in pipes and the collapse of other control devices (pressure reducing valves, rate of flow control valves).
Also the upstream pressure will decrease in other level control valves in the system.

CONTROL VALVE WITH DIFFUSER

To prevent a system collapse, install a specific valve and a correctly sized diffuser (Fig. 20).

Working conditions:
P_1: 14 bar
P_2: 0.5 bar
Maximum flow rate: 70 m^3/h

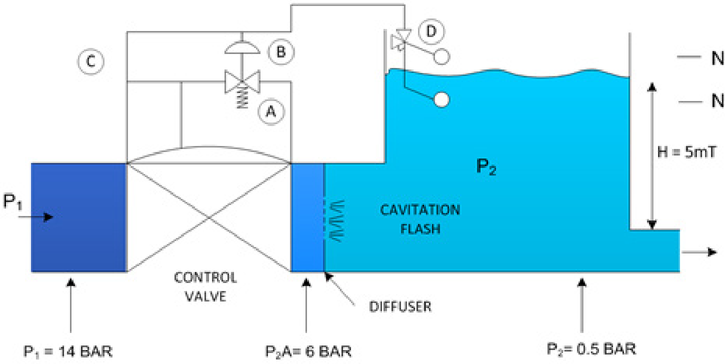


Fig. 20

- A - Pressure reducing pilot
- B - Hydraulic module
- C - 1.5 mm Ø restriction orifice
- D - Float pilot (ON - OFF)

A + B: Pressure reducing hydraulic shut off pilot

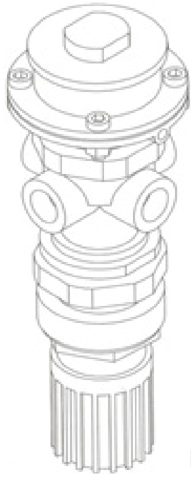


Fig. 21

When the N_2 level is reached, the hydraulic module (B) opens the pilot (A).
The main valve reduces the pressure to a stable level of 6 bar upstream of the diffuser (pressure reducing pilot is set to 6 bar).
When the N_1 level is reached, the hydraulic module (B) closes the main valve.
To increase the maximum flow rate, increase the set pressure of the pilot (B).
To decrease the maximum flow rate, decrease the set pressure of the pilot (B) but maintain the cavitation free values (Fig. 14).

Diffuser calculation:

P_1: 6 bar
P_2: 0.5 bar
Maximum flow rate: 70 m^3/h
Maximum velocity: 2.5 m/s

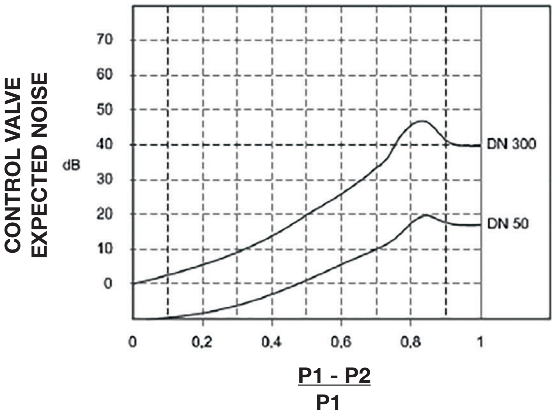
The cavitation chart (Fig. 14) shows that the valve is cavitation free reducing P_1 from 14 bar and P_2 from 6 bar. Cavitation or flash will be located in the center of the pipe downstream of the diffuser.

CAVITATION

CAVITATION IN CONTROL VALVES

EXPECTED NOISE IN CONTROL VALVES

Cavitation is a complex phenomenon. Many of the effects and causes of cavitation have not yet been explained or understood. Recent investigations show that intensity of cavitation is not directly proportional with the increase of ΔP. This means that maximum cavitation intensity can occur e.g. in a DN150 valve reducing the pressure from 16 bar to 3 bar and intensity of cavitation falls when the inlet pressure increases to 18 bar. Also, if working conditions are maintained, changing of valve size does not mean that the maximum cavitation intensity is the same for similar pressure conditions.



PRESSURE	
BAR	dB
0	0
5	50
10	65
15	70
20	75
25	80

Fig. 22

Example:

P, = 10 bar; P_2 = 6 bar
DN300 0.6 = 28dB
Working Pressure: 10 bar = 65 dB
Total: 28+65 = 93 dB
Cavitation: 0.7-1

CONCLUSIONS

The term cavitation is derived from the Latin *cavitare* which means the formation of cavities.
In control valves this is a damaging phenomenon. However, cavitation is not only causing problems. It can also be usefully applied in the industry (surfaces cleaning), medicine (non-invasive operations) and water industry (sewage treatment plants dissolving minerals from organic material).