12.3.1. Cavitation

Of the greatest importance in connection with valves has to be „cavitation“. Cavitation develops if liquids - due to high velocity - evaporate temporarily in the interior of the valve. The bubbles filled with vapor proceed through the liquid flow in the direction of the valve outlet. Due to an inevitable pressure recovery behind the throttling area the bubbles reach a zone of higher pressure and this leads to a sudden implosion of these bubbles. The implosion effect forms micro jets with velocities of up to 500 m/s. During the impact of such micro jets on a firm body (e.g. valve body wall or trim), extremely high local pressure peaks occur which can destroy almost any material very quickly. With water as control fluid, the localized pressure peaks amount to forces of up to 1500 N/mm^2, a strain which is considerably higher than common valve materials with maximum allowable compressive strengths of 500 to 1000 N/mm^2, can withstand.

The onset of cavitation can be precisely predicted if the process data and the valve specific value x_{Fz} are known. The factor x_{Fz} can only be determined by measurements with water at suitable test stations. Details can be taken from the IEC-standard 60534, part 8-2. The most effective countermeasure is elimination of the cause. With cavitating liquids material destruction can be delayed, but not completely avoided. At the very least, the influencing parameters related to cavitation should be known if the cavitation cannot be avoided by any means. Comprehensive knowledge of the wear process at least allows a symptomatic abatement against early material destruction. As far as the intensity of cavitation is concerned, knowledge of the following parameters is important and helpful:

- x_{Fz} measured value of the control valve for onset of cavitation,
- Actual pressure ratio x_F,
- Critical damage pressure ratio x_{Fmr} (mr = Manufacturer recommended)
- Differential pressure $p_1 - p_2$,
- p_2 value of pressure,
- Geometry of the control valve behind the throttling area,
- Gas content of the liquid,
- Viscosity of the liquid,
- Surface constraint of the liquid,
- Density of the liquid.

SAMSON AG recommend also an application dependent valve operating limit called “manufacturer’s recommended limit” or x_{Fmr} factor[1] lean on the ISA RP 75.23 practice ($1/\sigma_{mr} \approx x_{Fmr}$).

The manufacturer’s recommended limit for cavitation. x_{Fmr}, is the limit suggested for a given valve. It may or may not coincide with other cavitation coefficients such as incipient damage or constant cavitation. Published values of this limit are based on experience and on the normal type of application for the valve. Published values may not be suitable for all applications. The manufacturer also should publish the criteria for the selection of x_{Fmr}.

The manufacturer always should be contacted to verify the recommended limit for each type of valve application.

1 Kiesbauer. J.: Control Valves for Critical Applications in Refineries. Hydrocarbon Processing Magazine. Gulf Publishing Company. Houston. June 2001. Vol. 80. No. 6. pp. 89-100

Avoid cavitation erosion		
Differential pressure ratio $x_F = (p_1 - p_2) / (p_1 - p_v)$ $x_F > x_{Fz}$: Cavitation and cavitation noise $x_F > x_{Fmr}$: Influence on flow rate caused by intensive cavitation with many imploding vapor bubbles $x_F > x_{Fmr}$ and $\Delta p > \Delta p_{crit.cav}$: Cavitation erosion highly probable !!!		
Valve type	**$x_{Fmr} \approx x_{Fid} \approx K_c$**	**$\Delta p_{Cav.crit}$ [bar]**
Single-stage globe valves	0.7	15
Single-stage globe valves, stellited or hardened plug/seat	0.7	25
Three-stage globe valves	1.0	100
Five-stage globe valves	1.0	200
Rotary plug valves	0.4	10
Butterfly valves and ball valves	0.25*	5*
* For larger sizes than 4 inch x_{Fid} and $\Delta p_{Cav.crit}$ need to be reduced to much smaller values		

Table 12.3.-2: Coefficients for critical cavitation

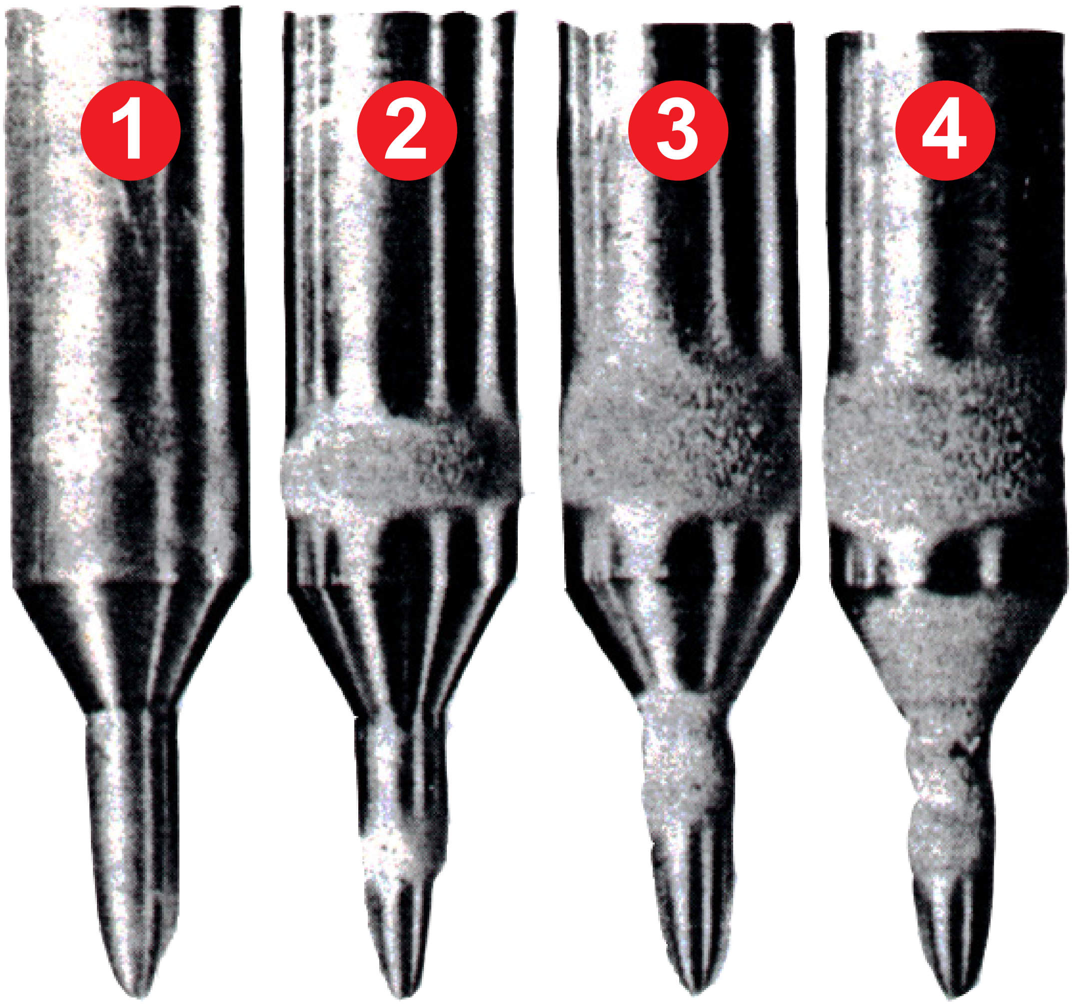

Figure 12.3.2.-1: Cavitations erosion at a Globe Valve

Cavitations erosion at a Globe Valve		
1	Δp = 33.4 bar	p_1 = 35.2 bar
2	Δp = 66.8 bar	p_1 = 70.3 bar
3	Δp = 101.6 bar	p_1 = 105.5 bar
4	Δp = 133.6 bar	p_1 = 140.6 bar

Table 12.3.2.-2: Cavitations erosion at a Globe Valve

The difference between the lowest pressure inside the vapor bubble (Figure 12.3.2.-3) and the pressure at the location of implosion is authoritative for the actual energy content.

For this reason, the intensity of cavitation and the destructive effects increase with an decreasing outlet p_2 pressure. When the valve specific pressure ratio x_{Fz} is exceeded, cavitation begins and the cavitation zone increases constantly with a further increase of the pressure ratio until the intensity and sound pressure level reach peak values. Near before this point “onset of choked flow” occurs (also known from a previous definition of the value K_c). Today we can correlate and predict damage if $x_F > x_{Fmr}$ and Δp exceeds a valve style specific $\Delta p_{crit.}$ damage potential. x_{Fmr} is lean on the ISA - RP75.23-1995 manufacturer recommended value $\sigma_{mr} = 1/x_{Fmr}$

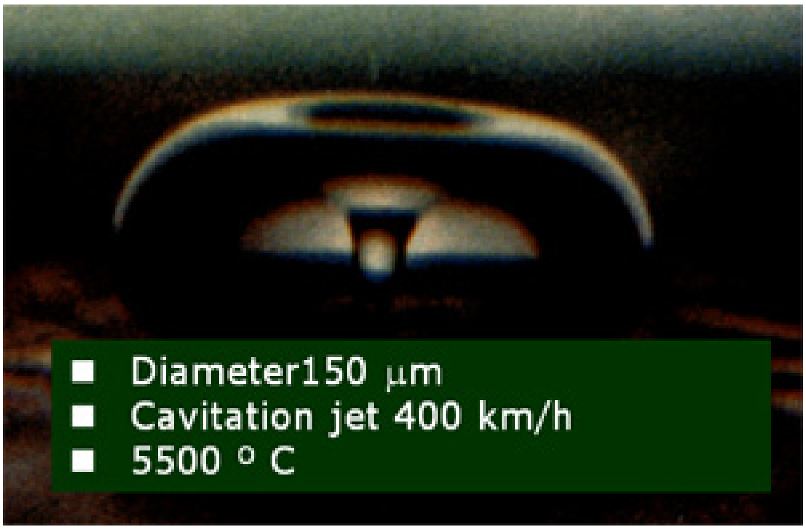

Figure 12.3.2.-3: Vapor bubble, microscopic picture of the cavitation process

Also at this point the maximum number of cavitation bubbles exists. These then implode in a zone of higher pressure again. During a further increase of the pressure ratio x_F the intensity of cavitation decreases again through the increasing vapor content of the liquid. This effect is also used for some applications to reduce the intensity of cavitation and the sound pressure level by adding an inert gas to the liquid immediately before the valve entry. However, this trick simply moves the onset of cavitation towards smaller critical pressure ratios x_F.

An increase of the liquid viscosity decreases the number of bubbles as well as the size of bubbles. In addition, the kinetic impulse becomes smaller during the strike of the micro jet onto the material surface than it does in the case of lower viscosity. The surface tension of the liquid also influences the cavitation process. The smaller the surface tension is, the sooner the liquid cavitates. The implosion forces, however, decrease with lower surface tension. This explains, for example, the relatively high resistance to wear of a relatively soft stainless steel valve trim with cavitating petroleum. A higher fluid density also causes a higher intensity of cavitation under identical process conditions. The developing pressures are approximately proportional to the square root of the fluid density. The process of cavitation-erosion i.e. the material removal per time unit is shown schematically in Figure 12.3.2.-4. The material removal depends on the operating time and can be subdivided into three different ranges and which is characterized by a different wear behavior in each range.

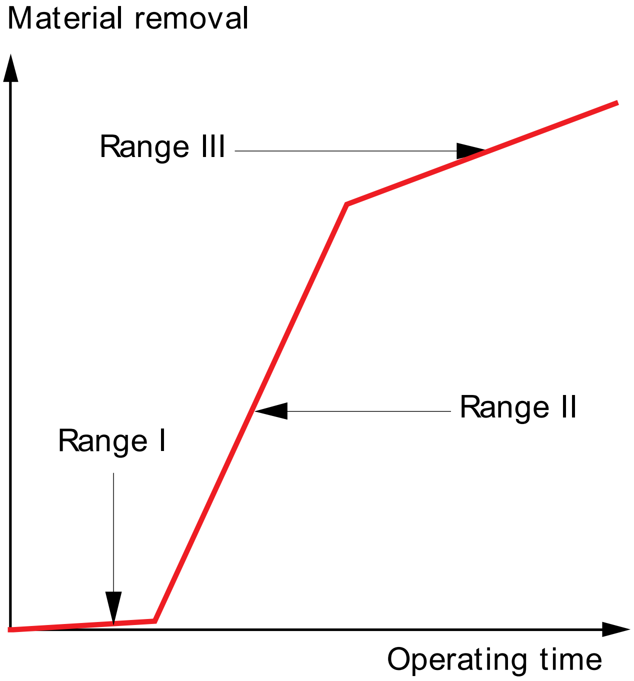

Figure 12.3.2.-4: Material removal vs operating time for steel with cavitating liquids

In the first phase, essentially only a plastic deformation of the surface occurs in the case of ductile materials. The material removal is hardly perceptible. In the second phase, cracks and splintering begin since the deformability of the material becomes gradually exhausted. In this range an almost linear material loss per time unit occurs. In the third phase, the jagged surface causes a decrease in activity of the micro jets. Therefore this phase is characterized by consider¬ably less material loss per time unit.

The resistance of various materials to cavitation has been tested in many practical experiments and can therefore be reliably predicted. This knowledge is used in order to achieve higher durability. Without dealing with this topic in too much detail, it was found that the following parameters influence the resistance to cavitation:

- Tensile strength of material,
- Modulus of elasticity,
- Vickers hardness,
- Corrosion resistance.

Naturally the cavitation resistance of metallic materials increases with greater tensile strength, hardness, good corrosion resistance and high deformability. However, the fact exists paradoxically that, especially elastic materials e.g. valve linings of hard rubber or similar, often show a higher resistance to cavitation than essentially harder metals. Ceramic materials have proven especially problematic in spite of their high hardness and otherwise excellent characteristics against abrasion. Small cracks usually appear in ceramics after a short operating time due to the extremely high cavitation impact and the lack of plastic deformation. With increasing operation time the number of micro-cracks increases and eventually a flaking of small pieces develops and this leads to a very dramatic material removal.