Hydrodynamic calculation Needle valve - closing flow against the direction of movement of the piston

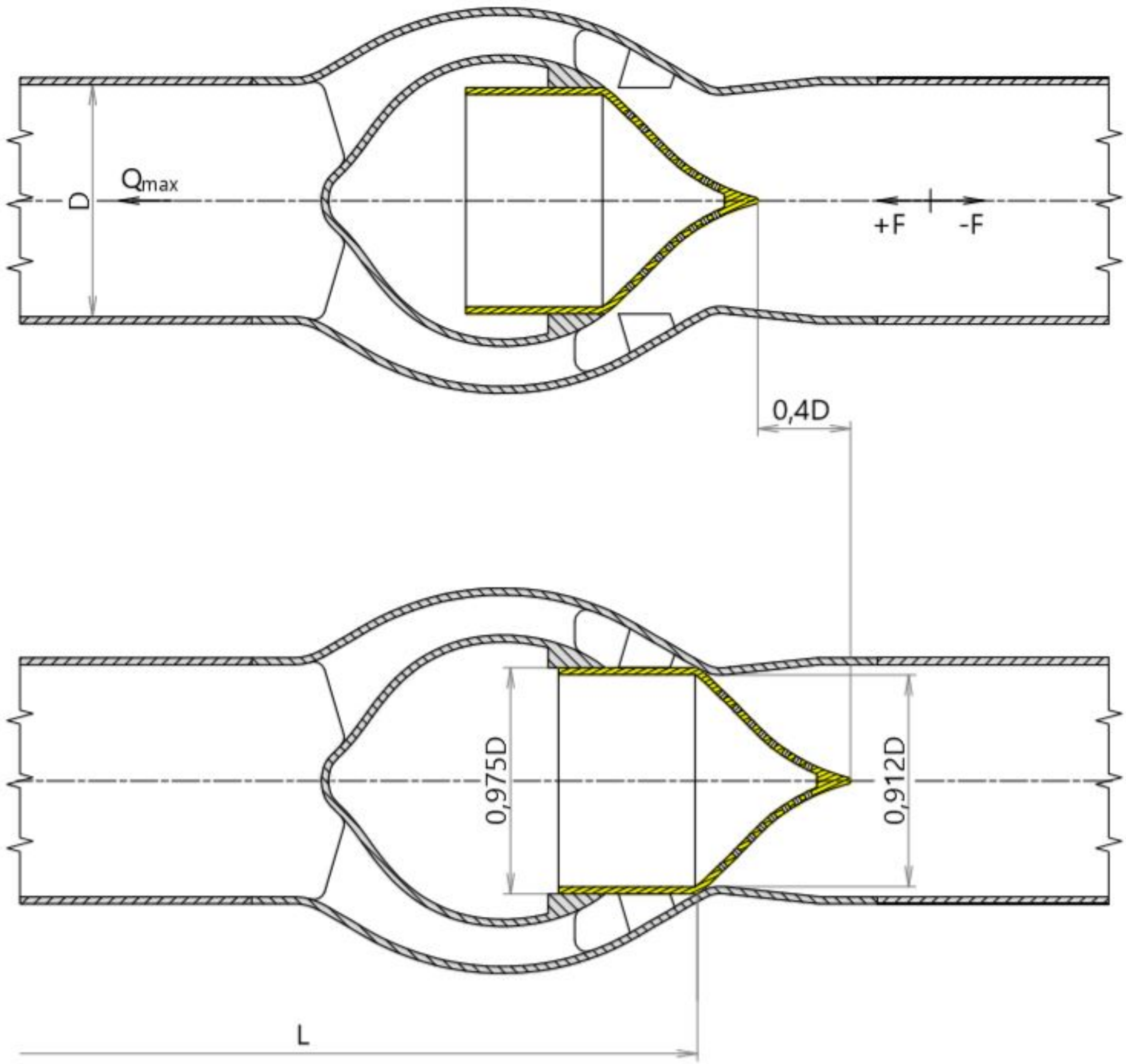

Fig.1

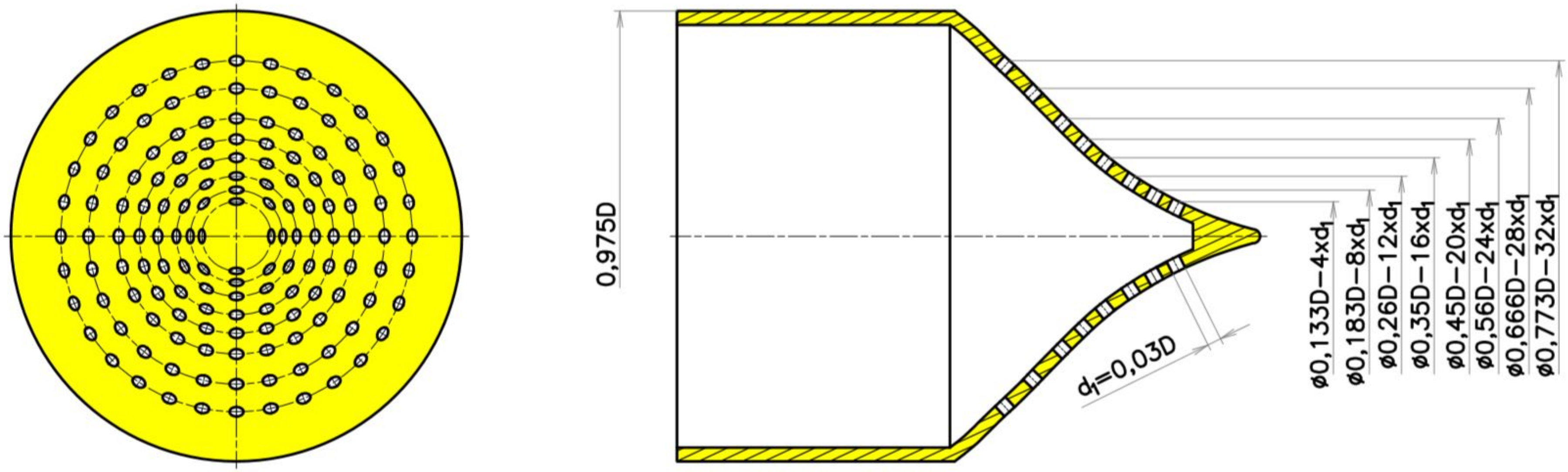
0,975D
d1=0,03D
ø0,133D–4xd1
ø0,183D–8xd1
ø0,26D–12xd1
ø0,35D–16xd1
ø0,45D–20xd1
ø0,56D–24xd1
ø0,666D–28xd1
ø0,773D–32xd1

Fig.2

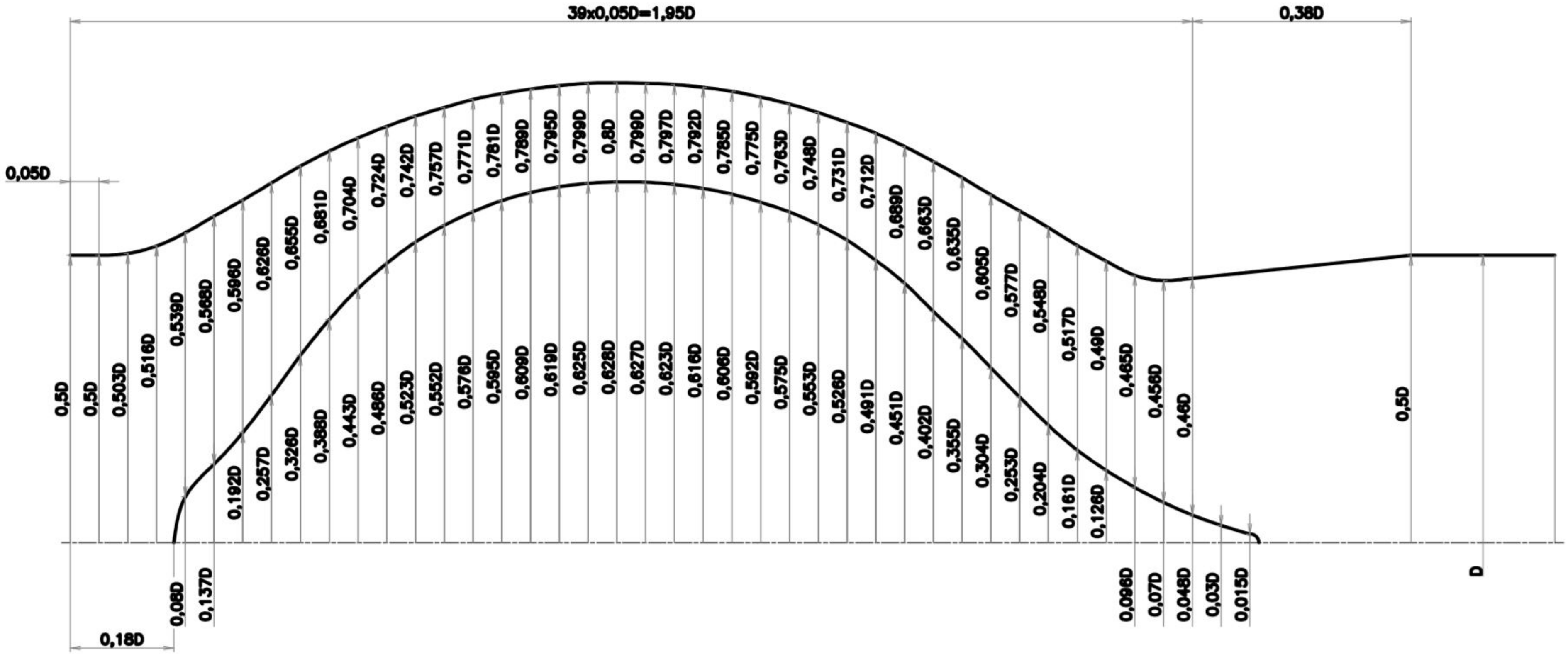
39x0,05D=1,95D
0,38D
0,05D
0,5D
0,5D
0,503D
0,516D
0,539D
0,566D
0,596D
0,626D
0,655D
0,681D
0,704D
0,724D
0,742D
0,757D
0,771D
0,781D
0,789D
0,795D
0,799D
0,8D
0,799D
0,797D
0,792D
0,785D
0,775D
0,763D
0,748D
0,731D
0,712D
0,689D
0,663D
0,635D
0,605D
0,577D
0,548D
0,517D
0,49D
0,465D
0,456D
0,46D
0,5D
D
0,192D
0,257D
0,326D
0,388D
0,443D
0,486D
0,523D
0,552D
0,576D
0,595D
0,609D
0,619D
0,625D
0,628D
0,627D
0,623D
0,616D
0,606D
0,592D
0,575D
0,553D
0,526D
0,491D
0,451D
0,402D
0,355D
0,304D
0,253D
0,204D
0,161D
0,126D
0,08D
0,137D
0,18D
0,096D
0,07D
0,048D
0,03D
0,015D

Fig.3

When designing a Needle valve, it is necessary to recognize several important parameters that express the hydraulic conditions and dynamic effects of flow in the valve. The basic parameters are the cavitation coefficient, the pressure loss, the flow rate and the resulting hydrodynamic forces acting on the movable part of the valve. You need to know the values of these parameters depending on the opening of the valve.

1. Calculation of pressure on the Needle valve during its rapid closure:

To calculate the pressure on the Needle valve, we need to know the rated net head at the zero flow (closed valve). Increase pressure on water hammer must be calculated before the hydrodynamic calculation of the Needle valve. The maximum flow rate must be defined in the open position, which must be closed safely. A must be a defined aerated space behind the valve due to the under-pressure behind the valve.
To calculate the pressure on the Needle valve because of the ignorance of the piping system, a calculation for a simple serial connection of the control valves (variable and constant resistance) will be used.

Relative Flow:

$$Q_p = \frac{f_r}{\sqrt{p + f_r^2(1-p)}}$$

Q_p	relative flow	[]
f_r	reduced free flow area in the throttle control system	[]
p	pressure parameter	[]

Reduced free flow area in the throttle control system:

$$f_r = \frac{K_Q}{K_{Qmax}}$$

f_r	reduced free flow area in the throttle control system	[]
K_Q	flow coefficient	[]
K_{Qmax}	max. flow coefficient	[]

Pressure parameter:

$$p = \frac{\Delta h}{h_0}$$

p	pressure parameter	[]
Δh	theoretical pressure in the closure at full opening	[m]
h_0	rated net head	[m]

Theoretical pressure in the closure at full opening:

$$\Delta h = \frac{v_0^2}{2g} * (\xi + 1)$$

Δh	theoretical pressure in the closure at full opening	[m]
v_0	valve speed	[m/s]
g	gravitational acceleration	[m/s^2]
ζ	local loss factor for open valve	[]

Valve speed:

$$v_0 = \frac{4Q_{max}}{\pi * D^2}$$

v_0	valve speed	[m/s]
Q_{max}	flow	[m^3/s]
D	valve diameter	[mm]

Flow in pipeline:

$$Q = Q_p * Q_{max}$$

Q	flow in pipeline	[m^3/s]
Q_p	relative flow	[]
Q_{max}	flow	[m^3/s]

The water speed in the pipeline:

$$v = \frac{4Q}{\pi * D^2}$$

v	the water speed in the pipeline	[m/s]
Q	flow in pipeline	[m^3/s]
D	valve diameter	[mm]

The pressure loss in the pipeline:

$$H_L = \frac{v^2}{2g}\xi$$

H_L	the pressure loss in the pipeline	[m]
v	the water speed in the pipeline	[m/s]
g	gravitational acceleration	[m/s^2]
ζ	loss factor	[]

Loss factor:

$$\xi = \frac{1 - K_Q^2}{K_Q^2}$$

ζ	loss factor	[]
K_Q	flow coefficient	[]

Pressure on the Needle valve (when closing the flow):

$$H_{v\ flow\ closing} = H_L + \frac{v^2}{2g} + \left(1 - Q_p\right) * (\Delta P + P_{atm})$$

$H_{v\ flow\ closing}$	pressure on the Needle valve	[m]
H_L	the pressure loss in the pipeline	[m]
v	the water speed in the pipeline	[m/s]

g	gravitational acceleration	[m/s²]
Q_p	relative flow	[]
ΔP	increasing pressure on water hammer	[m]
P_{atm}	under-pressure behind the valve	[m]

2. Calculation of pressure on the Needle valve

To calculate the pressure on the Needle valve, we need to know the rated net head at the zero flow (closed valve). The maximum flow rate must be defined in the open position, which must be closed safely. A must be a defined aerated space behind the valve due to the under-pressure behind the valve.
To calculate the pressure on the Needle valve because of the ignorance of the piping system, a calculation for a simple serial connection of the control valves (variable and constant resistance) will be used.

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K_Q	flow coefficient	[]
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Pressure parameter:

$$p = \frac{\Delta h}{h_0}$$

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h_0	rated net head	[m]

Theoretical pressure in the closure at full opening:

$$\Delta h = \frac{v_0^2}{2g} * (\xi + 1)$$

Δh	theoretical pressure in the closure at full opening	[m]
v_0	valve speed	[m/s]
g	gravitational acceleration	[m/s^2]
ζ	local loss factor for open valve	[]

Valve speed:

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v_0	valve speed	[m/s]
Q_{max}	flow	[m³/s]
D	valve diameter	[mm]

Flow in pipeline:

$$Q = Q_p * Q_{max}$$

Q	flow in pipeline	[m³/s]
Q_p	relative flow	[]
Q_{max}	flow	[m³/s]

The water speed in the pipeline:

$$v = \frac{4Q}{\pi * D^2}$$

v	the water speed in the pipeline	[m/s]
Q	flow in pipeline	[m³/s]
D	valve diameter	[mm]

The pressure loss in the pipeline:

$$H_L = \frac{v^2}{2g}\xi$$

H_L	the pressure loss in the pipeline	[m]
v	the water speed in the pipeline	[m/s]
g	gravitational acceleration	[m/s²]
ζ	loss factor	[]

Loss factor:

$$\xi = \frac{1 - K_Q^2}{K_Q^2}$$

ζ	loss factor	[]
K_Q	flow coefficient	[]

Pressure on the Needle valve:

$$H_v = H_L + \frac{v^2}{2g}$$

H_v	pressure on the Needle valve	[m]
H_L	the pressure loss in the pipeline	[m]
v	the water speed in the pipeline	[m/s]
g	gravitational acceleration	[m/s²]

3. Accuracy of measurements:

Line pressure was measured on vertical U-tubes with fill, limit relative error in pressure measurement:

$\delta_p \leq \pm 1\%$

When measuring water flow using a calibrated Venturi tube, the limit relative error was not higher as:

$\delta_Q \leq \pm 1{,}5\%$

Limit relative medium speed error *v*:

$\delta_v = \pm 1{,}8\%$

Limit relative error of the flow coefficient μ:

$\delta_\mu = \pm 2{,}3\%$

Limit relative error of cavitation factor σ:

$\delta_\sigma = \pm 2{,}7\%$

Limit relative error of the hydrodynamic force coefficient k_x:

$\delta_{k_x} = \pm 3{,}3\%$

Limit relative error of the coefficients of maximum amplitudes of pulsations of hydrodynamic forces:

$\delta_{a_x} = \pm 9{,}3\%$

4. Guideline for the use of the hydrodynamic characteristics of the Needle valve:

In the annex section of Fig. 4 to 7, charts of dimensionless coefficients are constructed. These graphs are the basis for constructing the hydrodynamic characteristics of the Needle valve for the projected water dam.

Cavitation number:

$$\sigma = \frac{10 - 0{,}1 + h_0 - H_L}{H_v}$$

σ_α	cavitation number	[]
h_0	rated net head	[m]
H_L	the pressure loss in the pipeline	[m]
H_v	pressure on the Needle valve	[m]

Forces on the piston in axis x (when closing the flow):

$$F_{x\,flow\,closing} = \frac{\pi D^2}{4} * \rho * g * H_{v\,flow\,closing}\left(\left(\left(1 \pm \delta_{k_x}\right) * K_x\right) - \left(\left(1 \pm \delta_{a_x}\right) * a_x\right)\right)$$

$$\delta_{k_x} = 0{,}033$$

$$\delta_{a_x} = 0{,}093$$

$F_{x\,flow\,closing}$	forces on the piston axis *x* (when closing the flow)	[kN]
D	valve diameter	[mm]
ρ	density of liquid	[Kg/m^3]
g	gravitational acceleration	[m/s^2]
$H_{v\,flow\,closing}$	pressure on the Needle valve	[m]
δ_{kx}	limit relative error of the hydrodynamic force coefficient	[]
δ_{ax}	limit relative error of the coefficients of maximum amplitudes of pulsations of hydrodynamic forces	[]
K_x	coefficient of hydraulic force in the axis x	[]
a_x	the amplitude of the hydraulic force to the axis x	[]

Forces on the piston in axis x:

$$F_x = \frac{\pi D^2}{4} * \rho * g * H_v\left(\left(\left(1 \pm \delta_{k_x}\right) * K_x\right) - \left(\left(1 \pm \delta_{a_x}\right) * a_x\right)\right)$$

$$\delta_{k_x} = 0{,}033$$

$$\delta_{a_x} = 0{,}093$$

F_x	forces on the piston axis *x*	[kN]
D	valve diameter	[mm]
ρ	density of liquid	[Kg/m^3]
g	gravitational acceleration	[m/s^2]
H_v	pressure on the Needle valve	[m]
δ_{kx}	limit relative error of the hydrodynamic force coefficient	[]
δ_{ax}	limit relative error of the coefficients of maximum amplitudes of pulsations of hydrodynamic forces	[]

K_x	coefficient of hydraulic force in the axis x	[]
a_x	the amplitude of the hydraulic force to the axis x	[]

5. Dimensioning aerated hole:

To reduce valve vibration, pulsation of hydrodynamic forces and erosion effects of cavitation by aerating the area behind the valve. The aerated hole should be large enough for air flow to reach according to research results.

$Q_{air} = Q_{max} - Q$

Effective closing time factor:

$$c_{ef} = min\left[\lim_{\propto \to 90} \frac{0{,}1}{[Q_{ps} - Q_{ps+10}]}\right]$$

c_{ef}	effective closing time factor	[]
Q_{ps}	relative flow in position n	[]

Under-pressure behind the valve:

$$P_{2air} = min\left\{1 * 10^5; (1 - Q_p) * min\left(\frac{L * v * \rho}{t * c_{ef}}; 1 * 10^5\right)\right\}$$

P_{2air}	under-pressure behind the valve	[Pa]
v	speed in pipeline	[m/s]
ρ	density of liquid	[Kg/m^3]
Q_p	relative flow	[]
L	the length of the pipeline behind the valve	[m]
t	valve closing time	[s]
c_{ef}	effective closing time factor	[]

Air velocity:

Air velocity in the narrowest cross section

$$v_{air} = min\left\{0{,}7 * \sqrt{\frac{2 * P_{2air}}{\rho_{air}}}; 250\right\}$$

v_{air}	air velocity	[m/s]
P_{2air}	under-pressure behind the valve	[Pa]
ρ_{air}	air density	[Kg/m^3]

Air flow area of the aerated hole:

The minimum flow area of the aerated hole is located in the shell of the needle valve. Air flow area of the aerated hole need not be one, but there may be several. To calculate the area of the aerated pipeline the air velocity should not exceed $v_{air} = 50m/s$

$$f_{air} = \frac{Q_{air}}{v_{air}}$$

$Qair$	air flow via the aerated hole	[m^3/s]
f_{air}	the flow area of the aerated hole	[m^2]
v_{air}	air velocity	[m/s]

When calculating the aerated hole, the ability of the aerated device to assess whether it meets all the under-pressure and air flow rates. At low pressure parameters p<0,2 there may be a small under-pressure behind the valve that the aerated device may not be functional and therefore the hydrodynamic calculation must be calculated without aerated.

6. Conclusion:

The needle valve must be placed in a straight diameter D from the hydraulic point of view. The influence of cavitation on pressure losses, flow rate and dynamic effects of the water jet will not be seen in the initial stage (when the first steam bubbles are formed), but only during fully developed cavitation.

Literature:

Miroslav Žajdlík: Hydraulické charakteristiky troch úprav kuželových uzáverov 1970
Miroslav Nechleba: Vodní turbíny jejich konstrukce a příslušenství 1954
V. Kolář, St. Vinopal: Hydraulika průmyslových armatur 1963

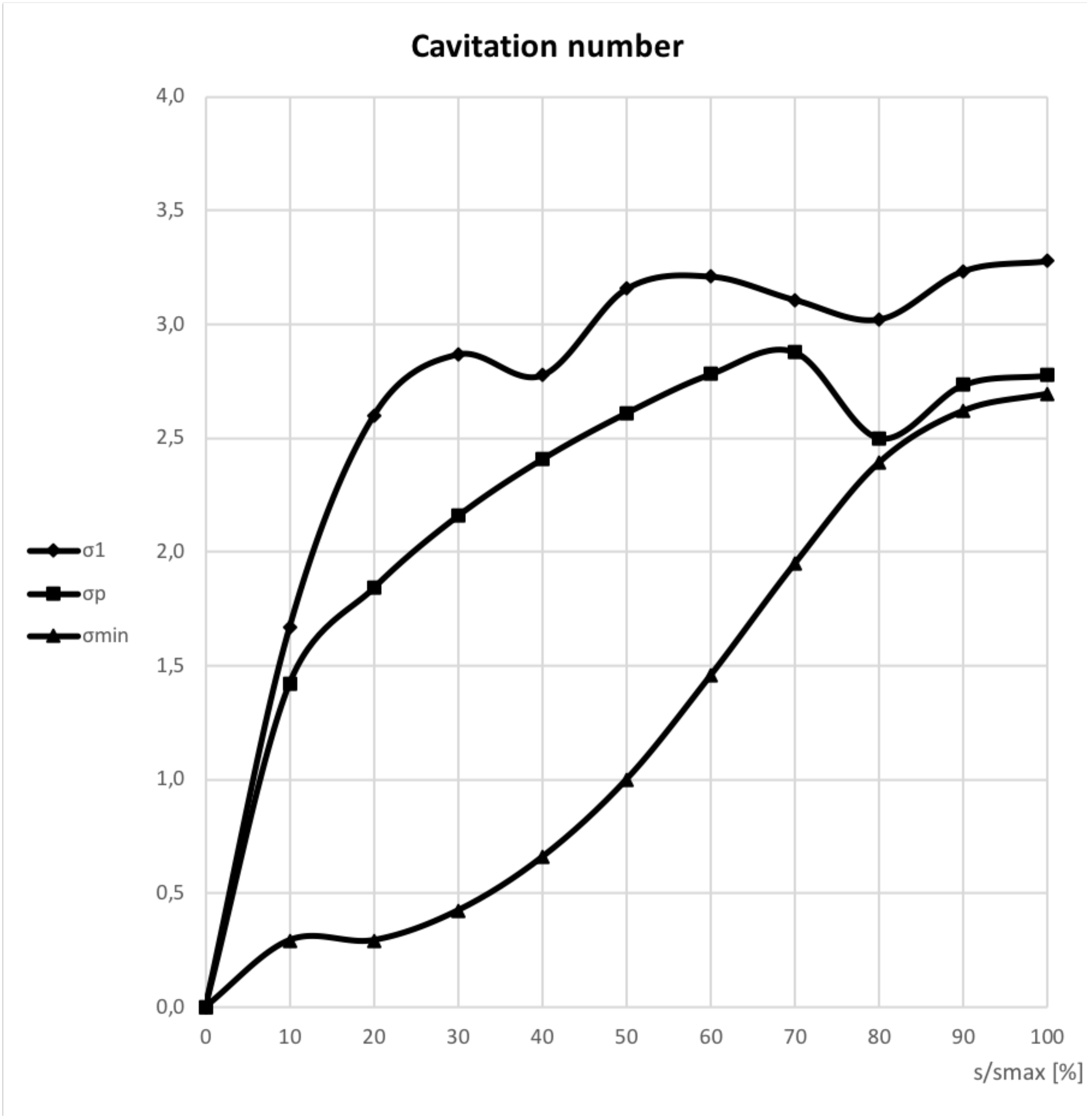
Cavitation number
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
10
20
30
40
50
60
70
80
90
100
s/smax [%]
σ1
σp
σmin

Fig.4

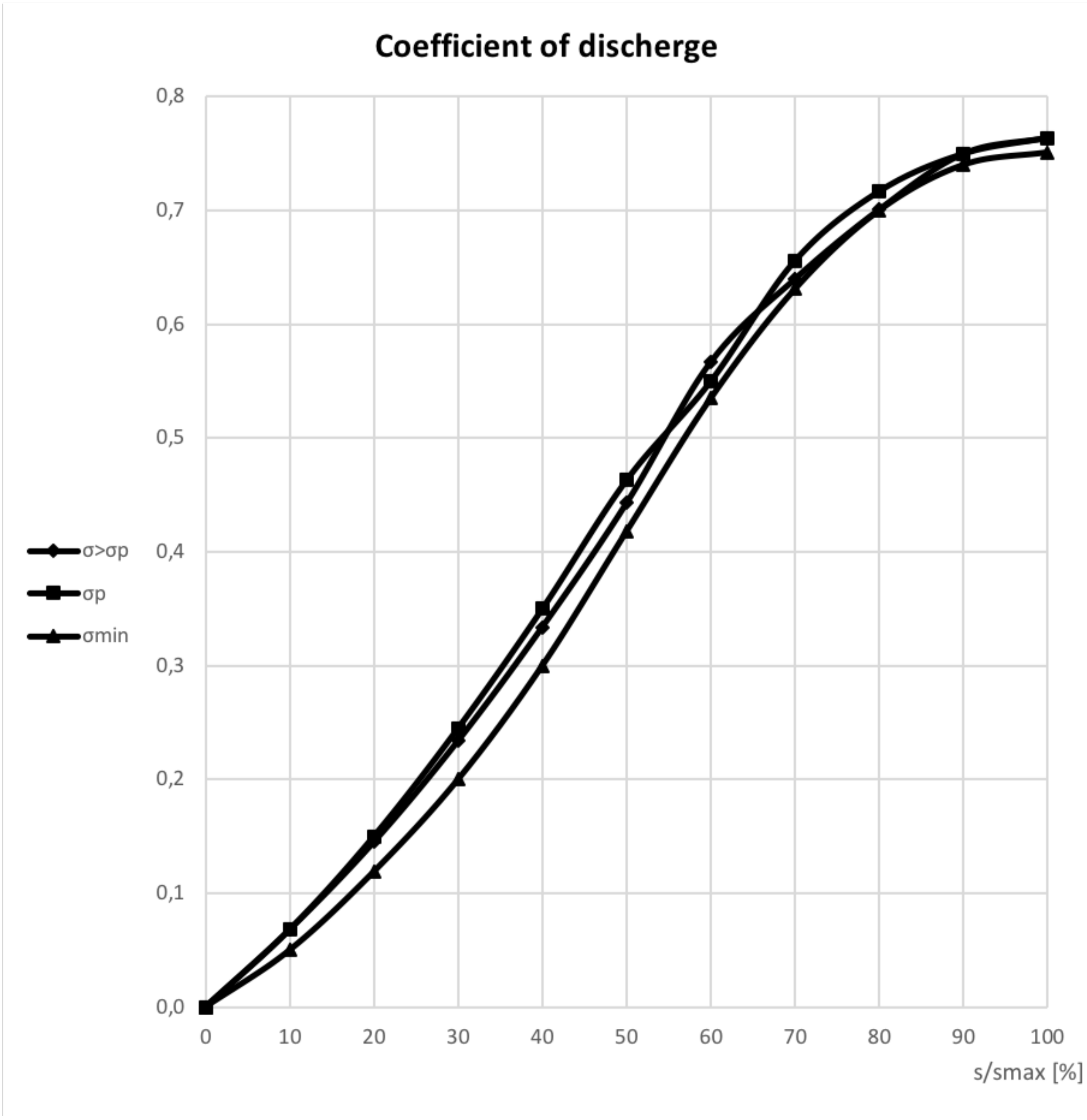
Coefficient of discherge
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
0
10
20
30
40
50
60
70
80
90
100
s/smax [%]
σ>σp
σp
σmin

Fig.5

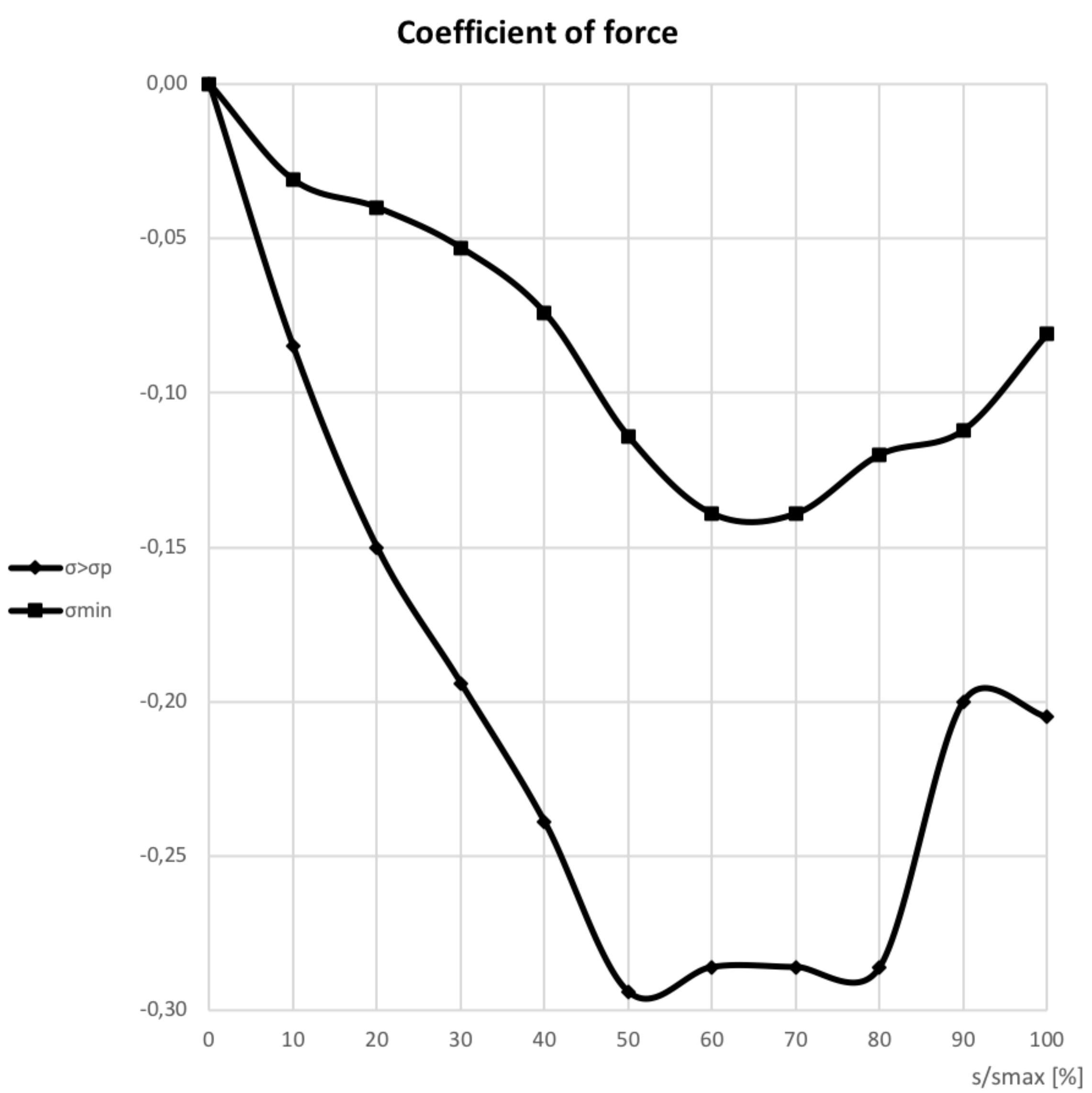
Coefficient of force
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
0
10
20
30
40
50
60
70
80
90
100
s/smax [%]
σ>σp
σmin

Fig.6

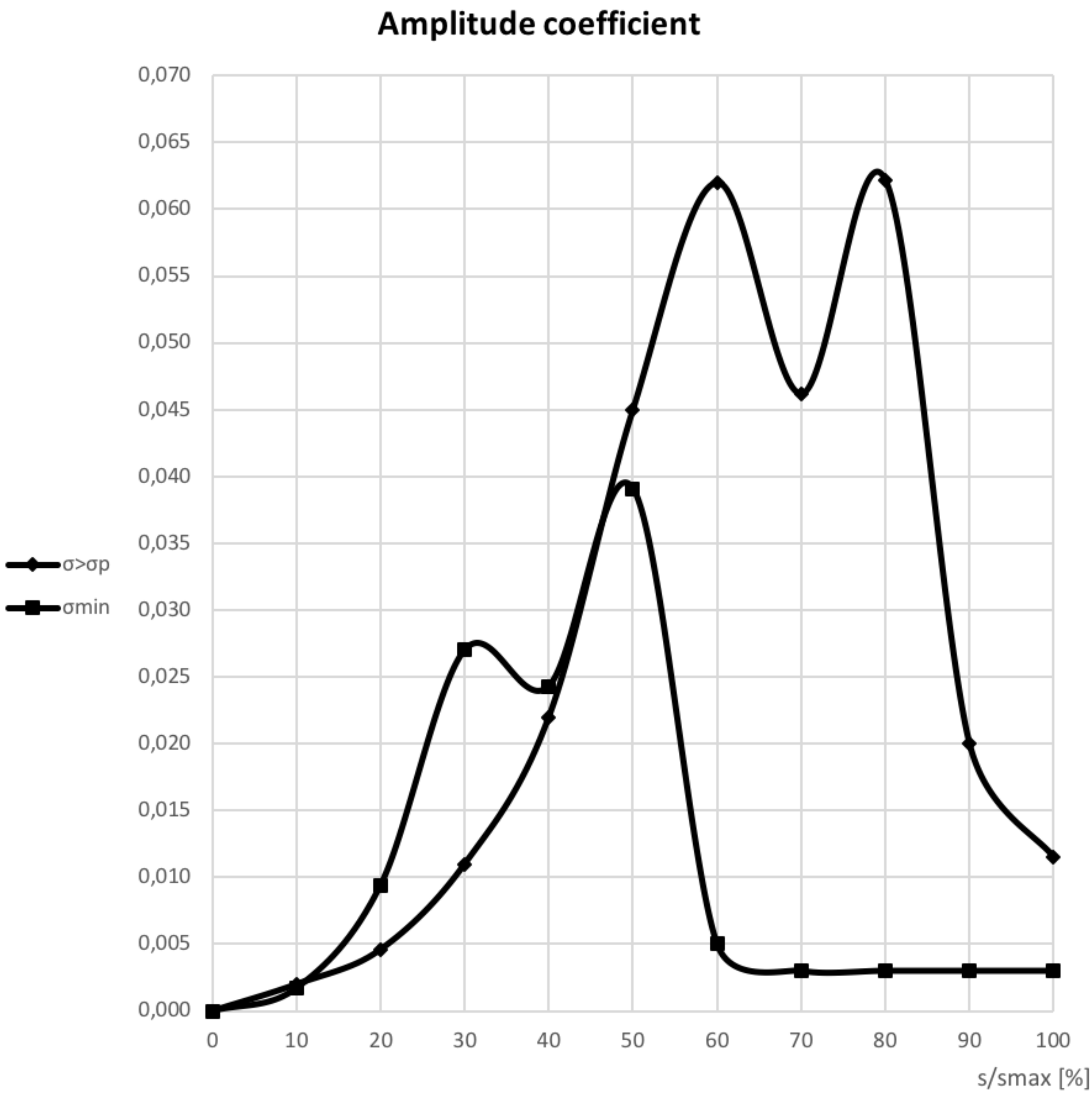
Amplitude coefficient
0,070
0,065
0,060
0,055
0,050
0,045
0,040
0,035
0,030
0,025
0,020
0,015
0,010
0,005
0,000
0
10
20
30
40
50
60
70
80
90
100
s/smax [%]
σ>σp
σmin

Fig.7