Centrifugal pump simulation during waterhammer analysis

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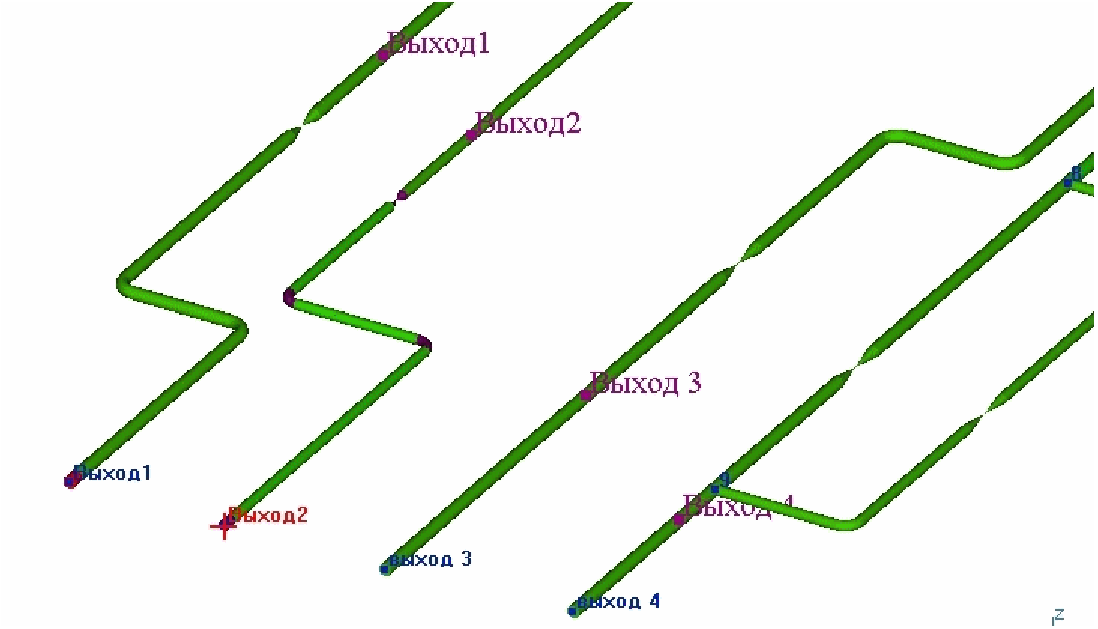
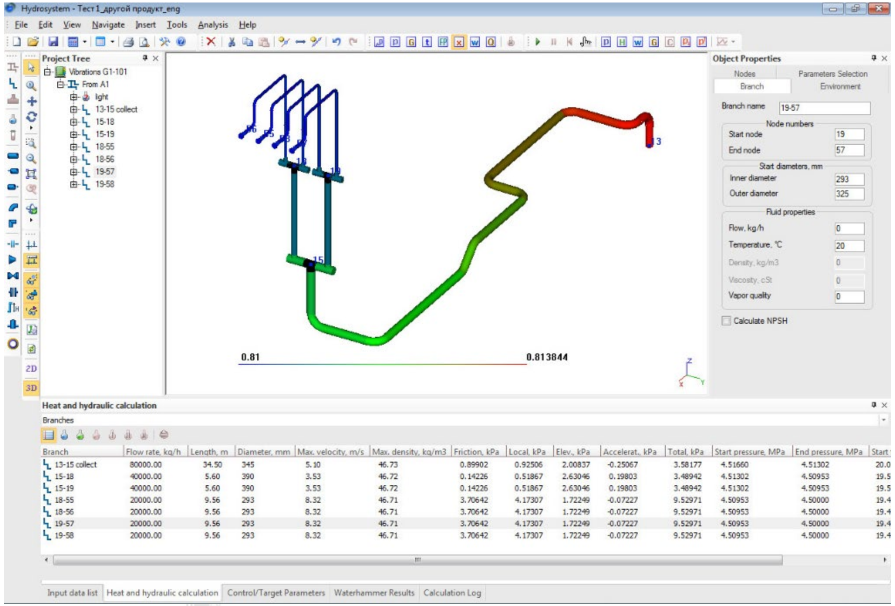
Where we have met dynamic pump simulation?

- PASS/HYDROSYSTEM software
  - Surge add-on module



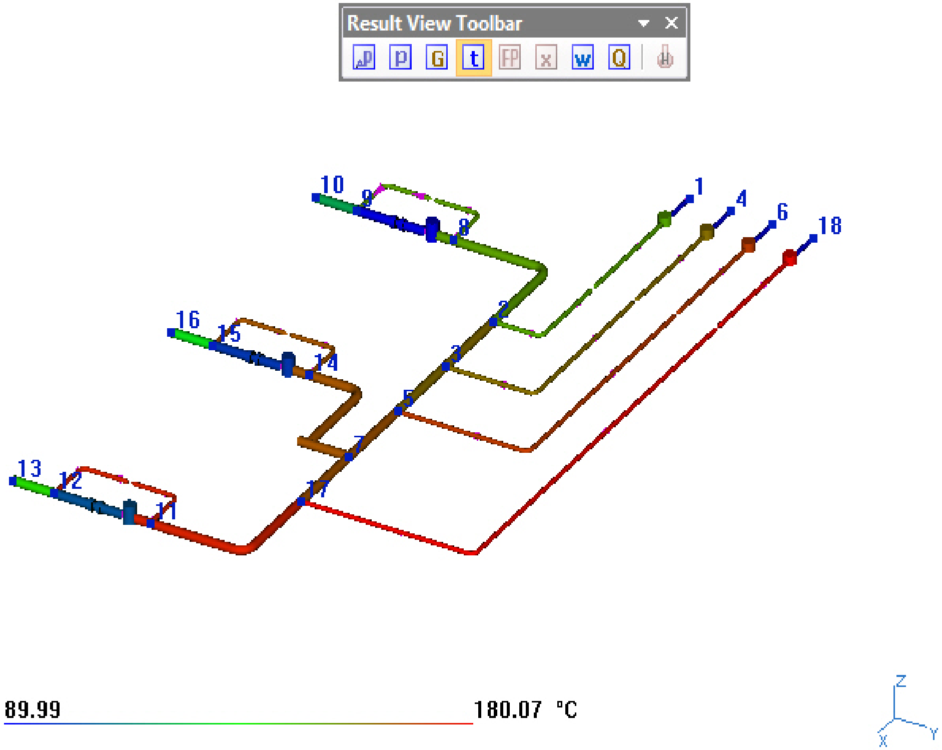
PASS/Hydrosystem | Experience and popularity

- Part of PASS product family
- First introduced in 1977
- Blessed by piping hydraulic world-known "guru" Idelchik
- Used by more than 600 companies worldwide
- Ideal tool for "day-to-day" operations in designing of any piping systems



PASS/Hydrosystem | Calculation capabilities

- Heat and hydraulic calculation of steady-state flow for:
  - Liquids
  - Real gases
  - Gas-liquid mixtures
  - Gas-liquid-liquid mixtures
  - Liquid-solid mixtures (a.k.a. ‘slurry’ flow)
- Surge analysis of transient liquid flow – water-hammer calculation
- Unbalanced forces calculation and transfer to PASS/START-PROF and other piping stress analysis software
- Suitable for piping systems of any complexity



PASS/Hydrosystem | Modules and features

PASS/HYDROSYSTEM

Hydro
Isothermal steady state flow calculation

NSS
Pipeline optimal nominal sizes selection

Surge
Transient liquid flow (waterhammer) calculation

Thermo
Heat and hydraulic steady state flow calculation

Multiphase
Gas-liquid and gas-liquid-liquid flow calculation

Solid phase
Settling “slurry” flow calculation

PCF
Import of piping model from PCF files

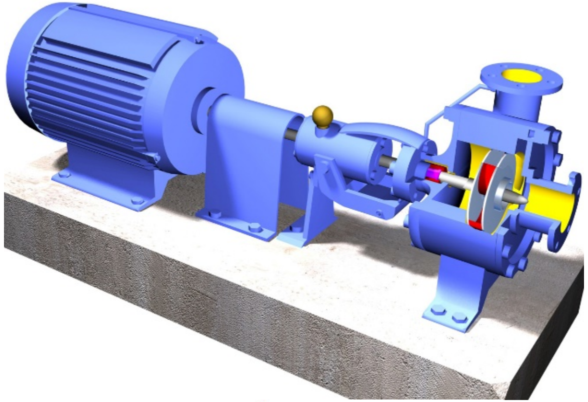
Thermodynamic libraries
Fluid properties and phase equilibria calculations (WSP, STARS, GERG-2008)

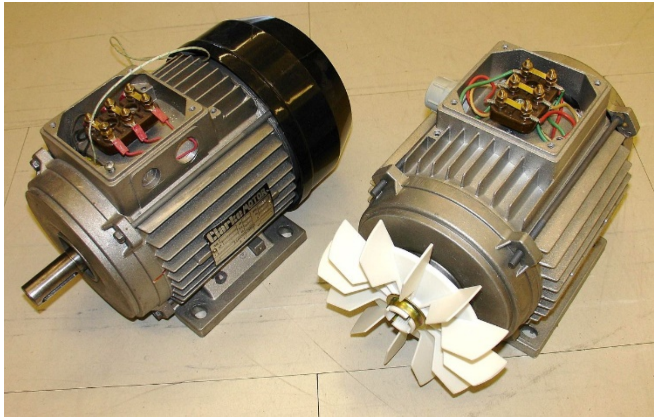
Spaix Quick&Easy
software for automatic pump selection (free for all Hydrosystem users)

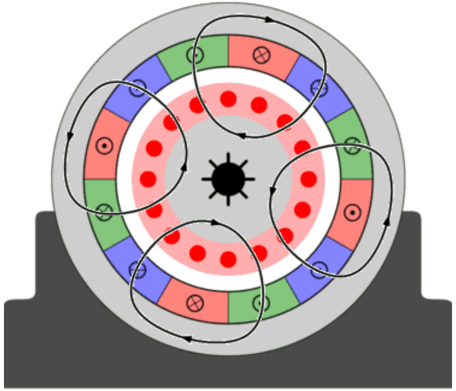
Profile Plot
Profile Plot in MS Excel

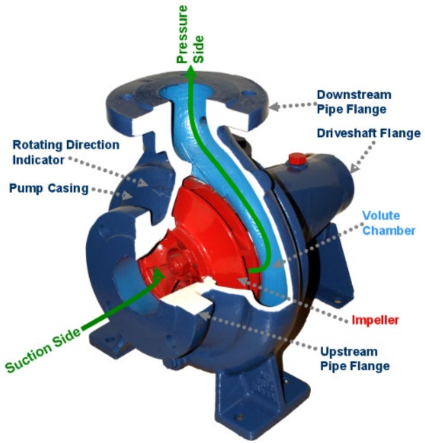
What type of pumps we are talking about?

- Centrifugal (or more general, rotodynamic) pump
- + Induction (or asynchronous) motor







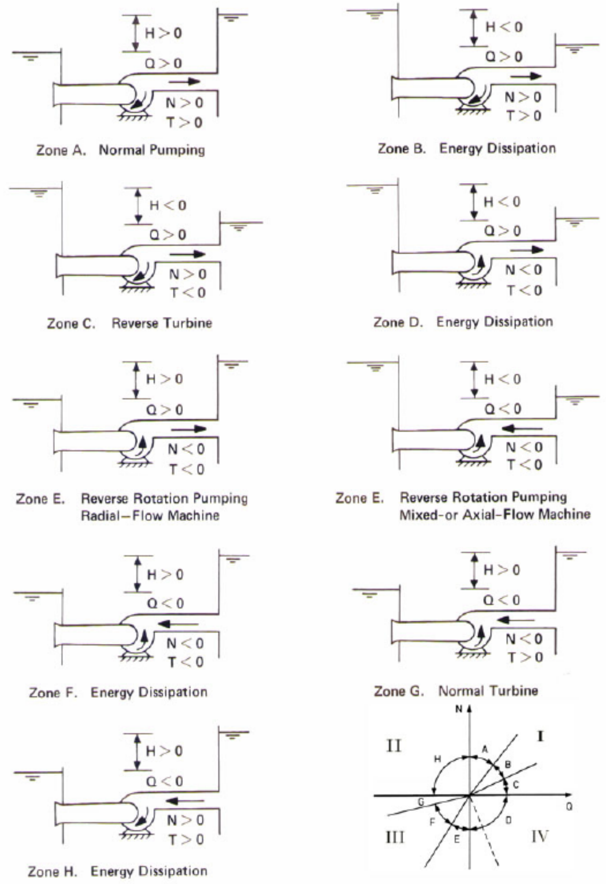


What transient operations we need to simulate?

- Pump start-up (pump switched off -> operating at duty point)
  - From stopped pump (discharge valve closed) or from flow through non-operating pump
- Pump shut down (operating at duty point - >switched off)
- Pump is operating, transient from one duty point to another (pump is switched on, event is in piping system)
- Transient in non-operating opened pump (pump is switched off, event is in piping system)

Transient vs steady state modeling for pumps

- Curves from Manufacturer for steady-state operation
  - H(Q), P(Q) or Efficiency(Q), NPSHr(Q) for some nominal n (speed of rotation)
  - Limited zone of operation parameters
- In transient mode pump can go through unusual regimes (4 quadrants) with arbitrary Q and n !

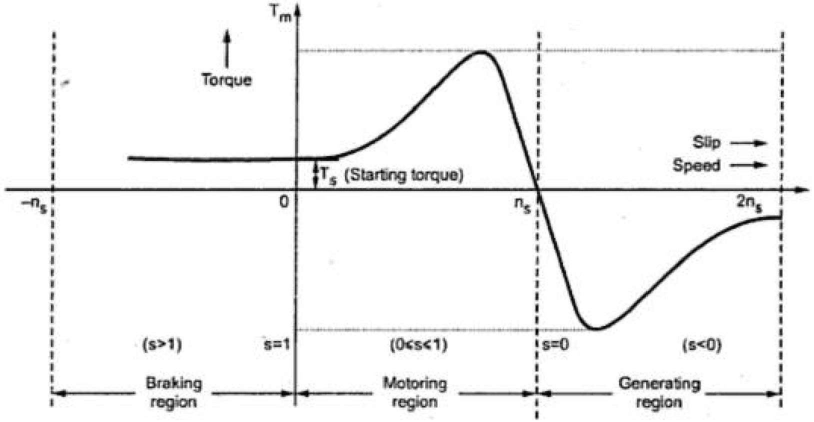


Mathematical model of the pump

- Equation of Torque balance
  - $2\pi J \frac{dn}{dt} = T_{motor}(n) - T_{pump}(Q, n)$
  - $J = J_{rotor} + J_{impeller} + J_{fluid}$
- Boundary conditions on pump for inlet and discharge piping (analysis by characteristic method)
  - $H_{outlet} - H_{inlet} = H(Q, n)$
- How to calculate $T_{motor}(n)$, $T_{pump}(Q, n)$, $H(Q, n)$

Mathematical model of asynchronious motor

- Slip $s = \frac{n_s - n}{n_s}$
- $T_{motor}(n) = \frac{2T_{cr}}{\frac{s}{s_{cr}} + \frac{s_{cr}}{s}}$
- For specific motor manufacturer usually gives
  - Stator magnetic field rotation $n_s = \frac{2f}{p}$,
    f – frequency of power supply, p – number of magnetic poles
  - T_{cr}, n_{cr} (critical parameters)
  - T_{nom}, n_{nom} (nominal parameters)
  - J_{rotor}



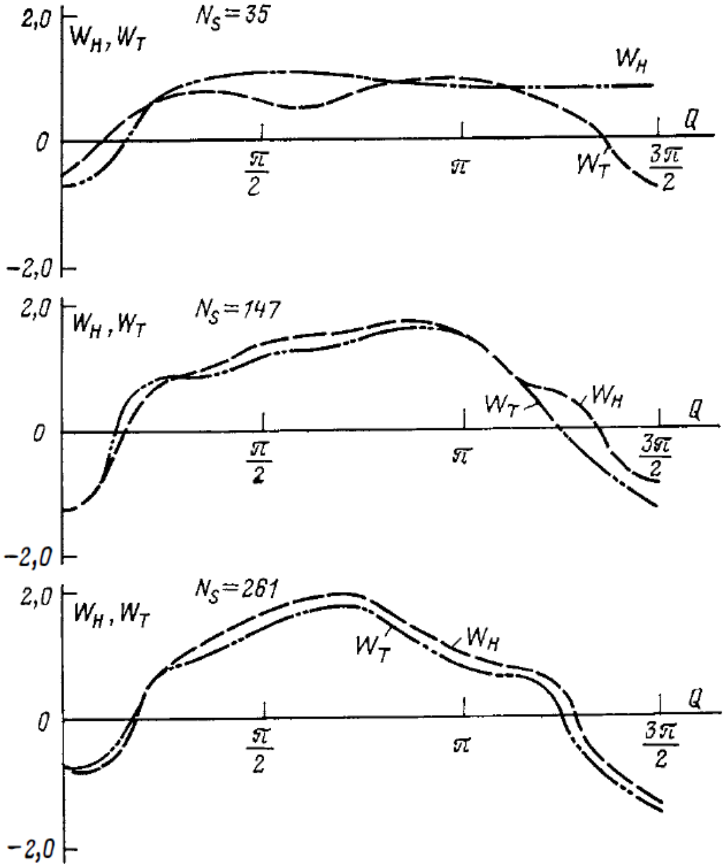
General description of pump by Suter curves

- To calculate $T_{pump}(Q,n)$, $H(Q,n)$ for turbulent quadratic flow, let's use affinity laws: H and T ~ $Q^2$and n^2
- Defining dimensionless Suter curves as
  - $\theta = \tan^{-1}(\frac{n}{n_{nom}}\frac{Q_{nom}}{Q})$
  - $W_H(\theta) = \text{sign}(H)\sqrt{\frac{|H|/H_{nom}}{(Q/Q_{nom})^2+(n/n_{nom})^2}}$
  - $W_T(\theta) = \text{sign}(T)\sqrt{\frac{|T|/T_{nom}}{(Q/Q_{nom})^2+(n/n_{nom})^2}}$
  - Where Q_{nom}, n_{nom}, H_{nom}, T_{nom}- values in pump B.E.P.

Where to find Suter curves?

- Using Suter curves we can calculate $T_{pump}(Q,n), H(Q,n)$
- But pump manufacturers don’t want to provide them…
- But there is some data for specific pumps!
- So we can try to use Suter curves for similar pump (or interpolate between several)
- How to define if pump is “similar”? Usually by the value of “Specific speed”: $N_s = \frac{n_{nom}Q_{nom}}{H_{nom}^{0.75}}$

Suter curves on Donsky's data



How to merge Suter curves with usual pump curve?

- For pump transient simulation we use Suter curves
- For pump steady state simulation we use “traditional” pump curves from manufacturer
- But they have to coincide with each other in corresponding region of θ values, otherwise simulation can give non-adequate results!
- We should correct general $W_H(\theta)$ for specific pump using $H(Q)$ curve from pump manufacturer!
- But… there is one important aspect to take into account!

“Floating” $\boldsymbol{n}$ and how to count it

- $\boldsymbol{n}$ is not equal to $\boldsymbol{n_{nom}}$ all over the manufacture $H(Q)$ curve
  - It is slightly “floating” between $\boldsymbol{n_{cr}}$ and $\boldsymbol{n_s}$!
  - Do manufactures really recalculate $H(Q)$ to $\boldsymbol{n_{nom}}$ to take this into account? Most likely no – we always use $H(Q)$ in steady state analysis without any correction
  - How to count it?
- Get real value of $\boldsymbol{n}$ (for fixed value of Q or θ) from equation
  - $T_{motor}(n) = W_T^2(\theta)[(Q/Q_{nom})^2 + (n/n_{nom})^2]T_{nom}$
- Then get corrected value of $W_H(\theta)$ using this value of $\boldsymbol{n}$

Dimensionless Torque Equation

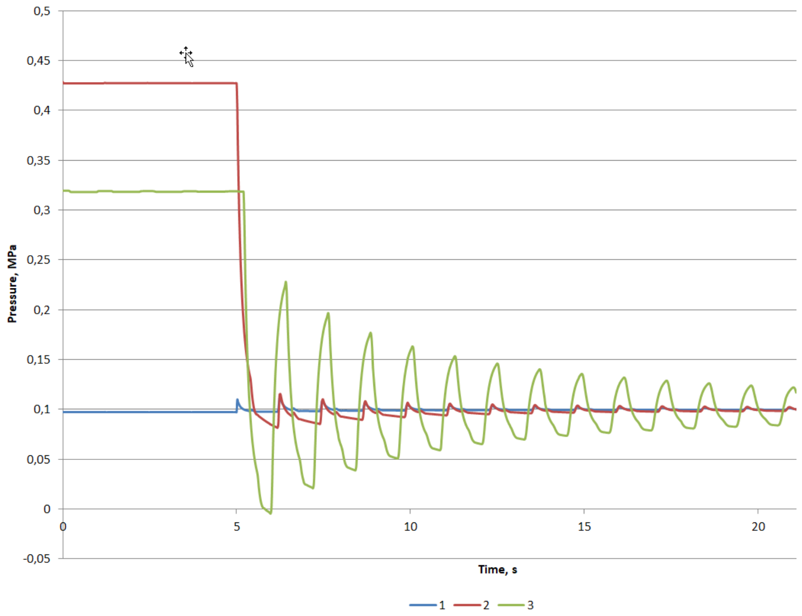
- Equation
  - $2\pi J \frac{dn}{dt} = T_{motor}(n) - T_{pump}(Q, n)$
- Can be put in dimensionless form
  - $T_r \frac{d\beta}{dt} = \frac{1}{T_{nom}} [T_{motor}(\beta) - T_{pump}(q, \beta)]$
  - $\beta = n/n_{nom}, q = Q/Q_{nom}$
  - $T_r = 2\pi J n_{nom}/T_{nom} > 2\pi J_{motor} n_{nom}/T_{nom}$ is time characterizing pump transient behavior (usually from 0.05 to 5 s)

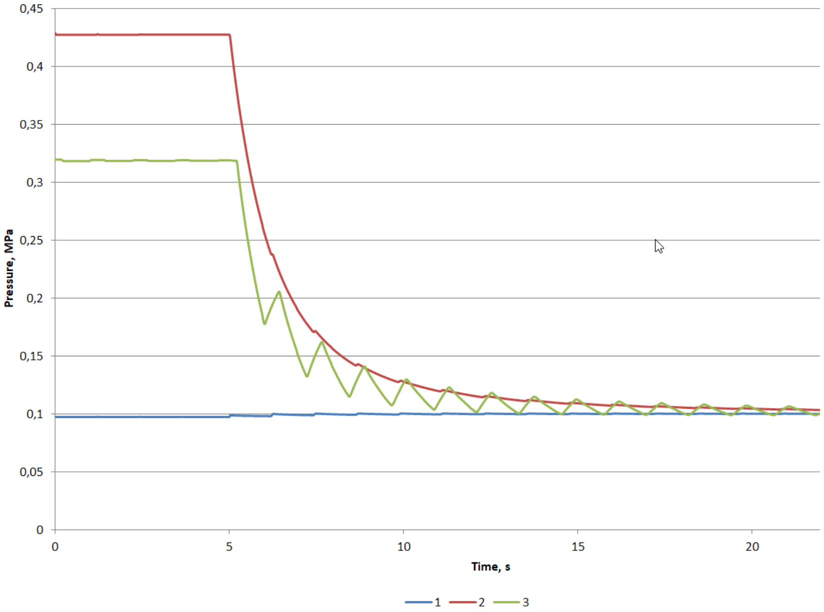
Pump start-up and shut down – rule of thumb

- If $T_r \gg$ time of wave travel via piping $(2L/c)$, dynamic effects of pump transient operation are not significant
- Otherwise they should be analyzed!

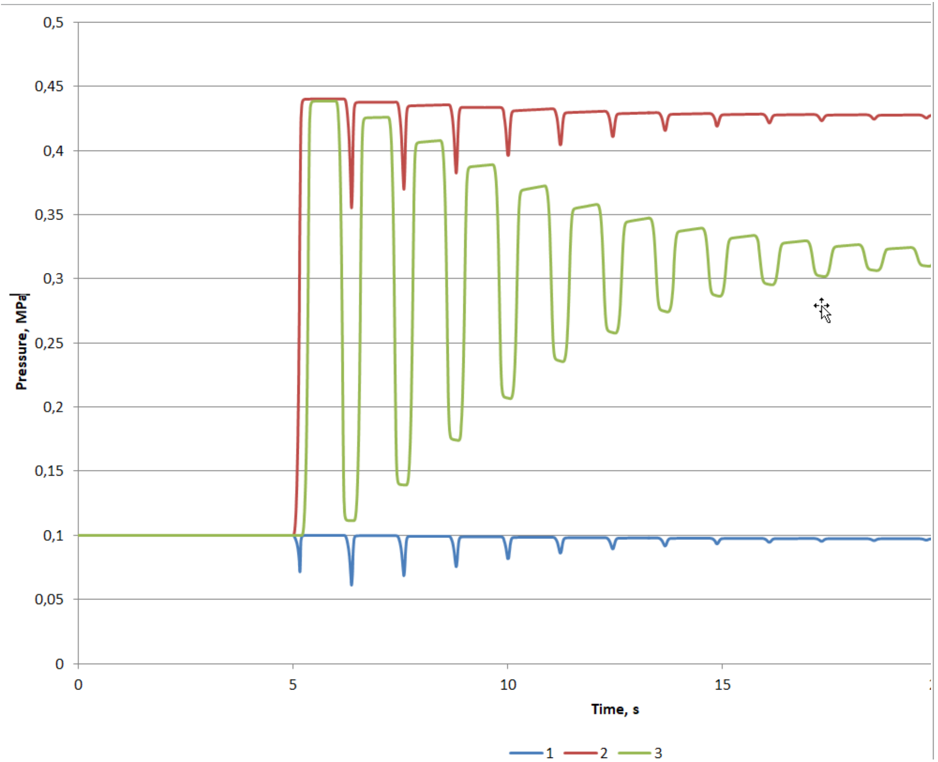
Example – pump shut down

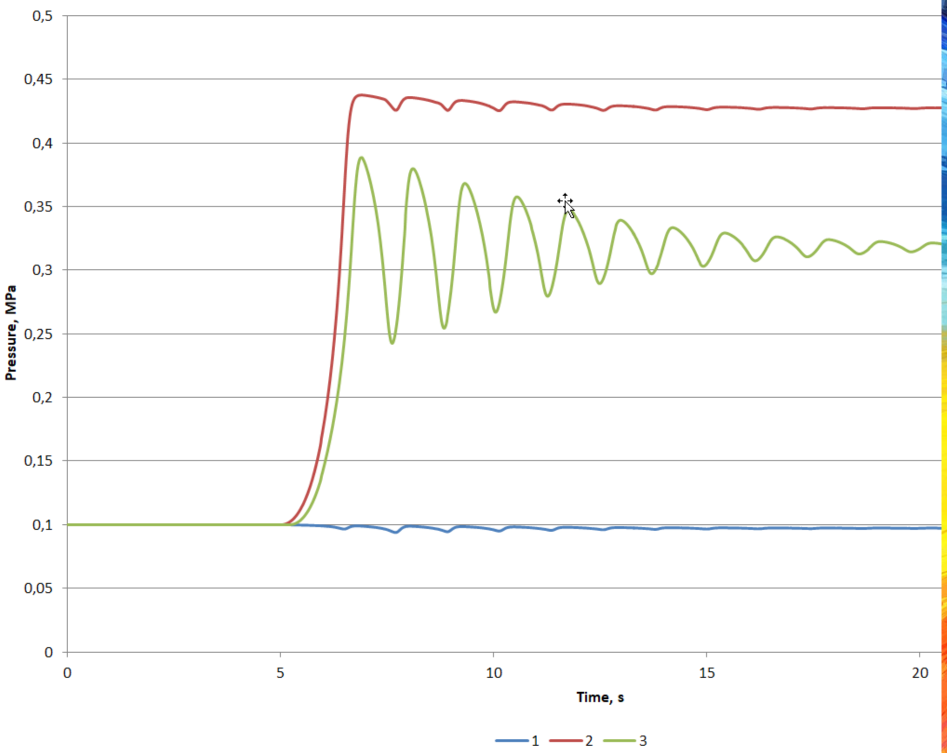
- Discharge piping length 600 m. T_r - 0.2 s and 2 s.
- Points: 1 – pump inlet, 2 – outlet, 3 – middle of discharge piping





The same example – pump start-up





Questions for further investigation

- More data for Suter curves are needed!
- Other parameters (besides N_s) for pump description
- How to deal with high viscosity fluid (when flow is not quadratic or even laminar)? Could HI viscosity corrections be used?
- How to deal with pump transient flow for settling slurries?
- How to deal with cavitation in the pump in transient operation?

THANK YOU FOR YOU ATTENTION!
Please visit PASS booth!