EFRC Workshop Pulsations
Effects on valve performance

Gunther Machu

HOERBIGER Compression Technology

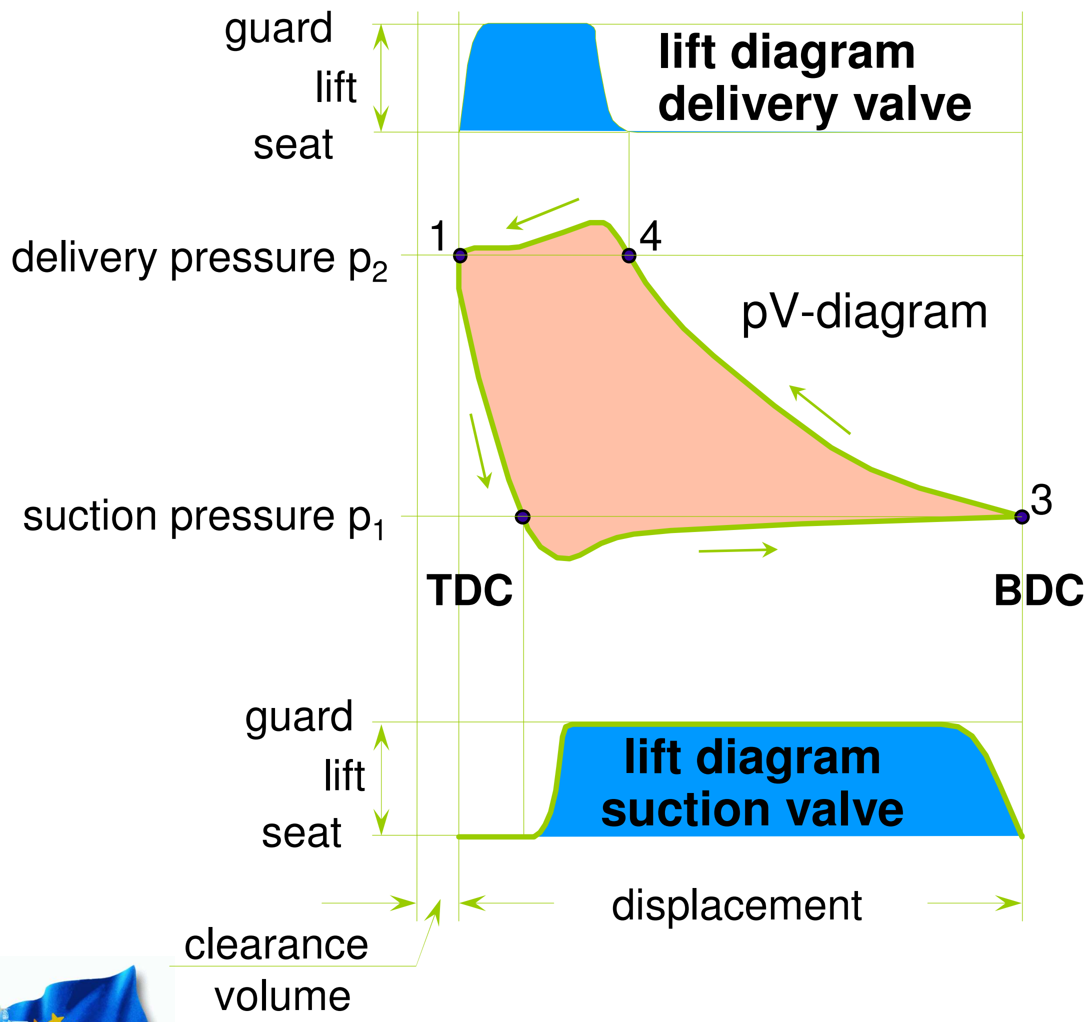
Contents

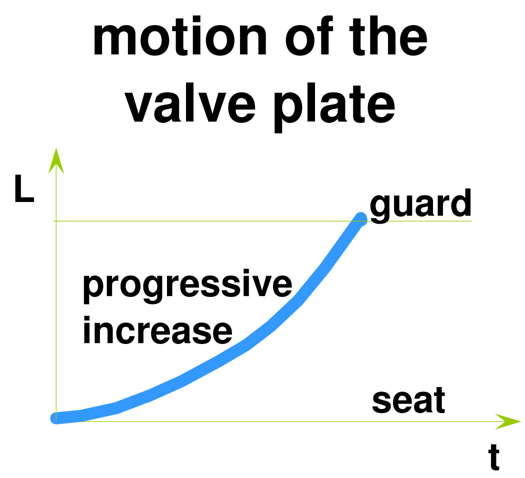
- ***Working principle of compressor valves***
  - Basic functionality
  - Overview different valve designs

- ***Valve dynamics – influencing factors***
  - Flow mechanics
  - Valve sealing element dynamics
  - Spring dynamics

- ***Effect of pulsations on valve dynamics***
  - In - cylinder wave propagation – example video
    - Effect on valve sealing element impact velocity
    - Effect on compressor performance:
      - Pressure overshoot during discharge stroke vs. valve efficiency
  - Line pulsations

Working principle of compressor valves



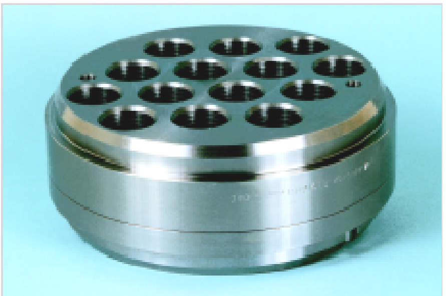


Overview different valve designs

Steel plates

Plastic profiled rings

Plastic plates



Poppet valves

Steel reed valves

Flapper valves

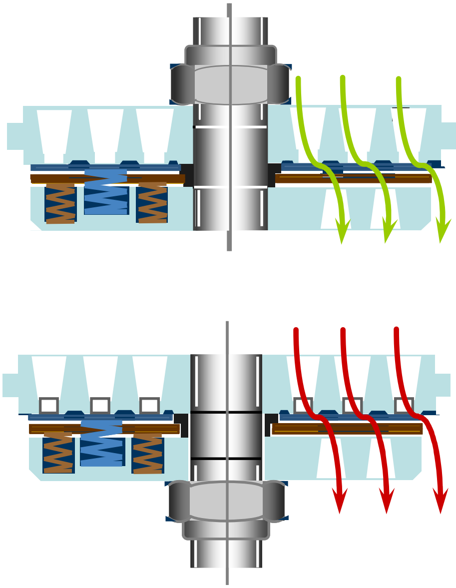
EFRC

Overview different valve designs

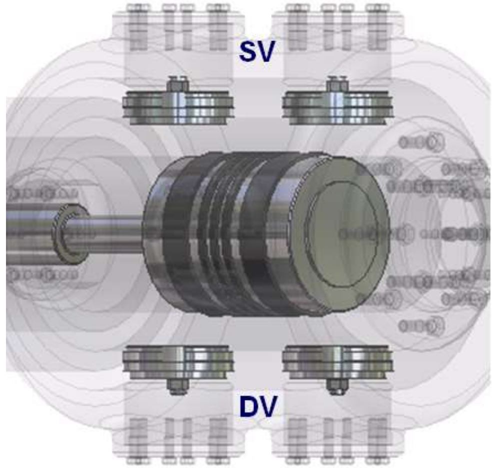
Steel plates

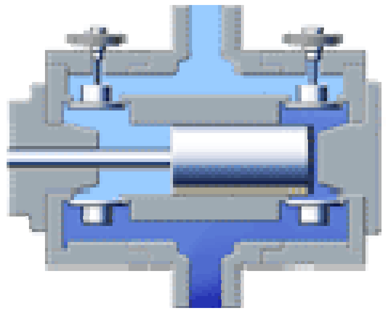
Plastic plates /
profiled rings

suction valve = intake



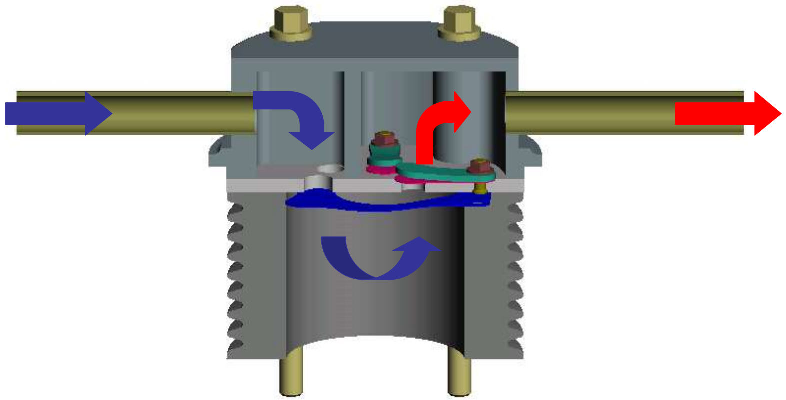
delivery valve = outlet

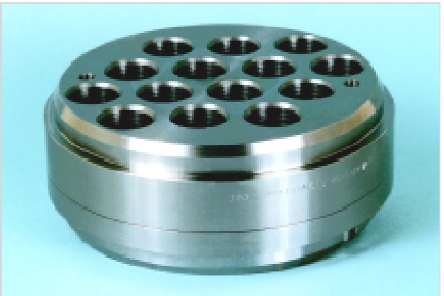


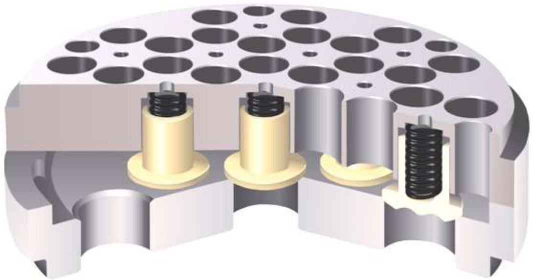


Overview different valve designs

Steel reed valves

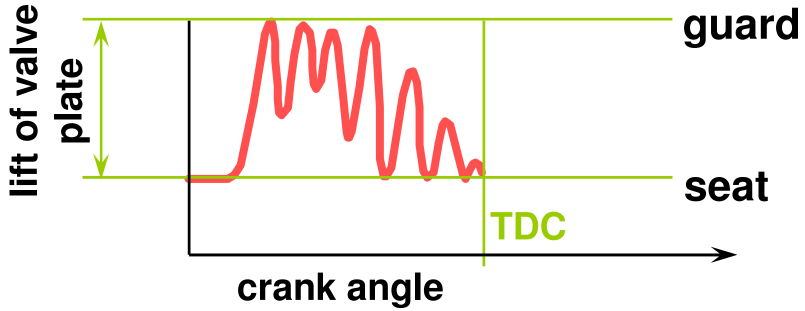




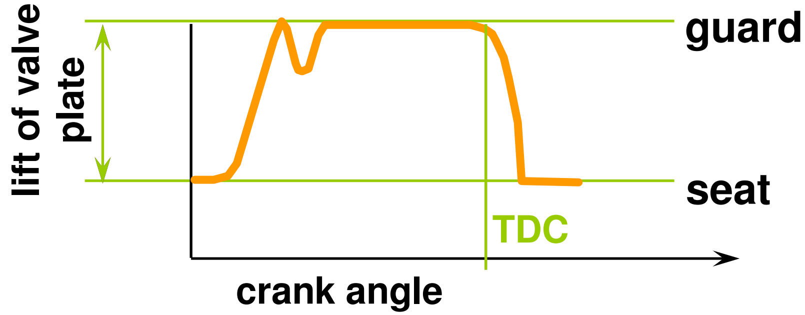


Poppet valves

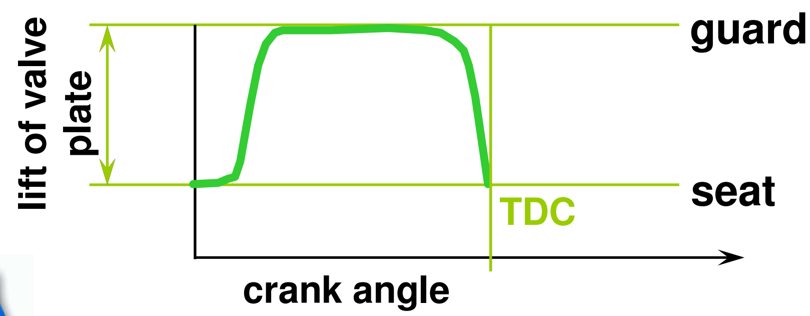
Working principle of compressor valves



valve flutter



delayed closing



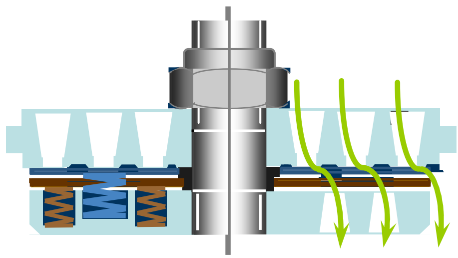
ideal motion of valve plate

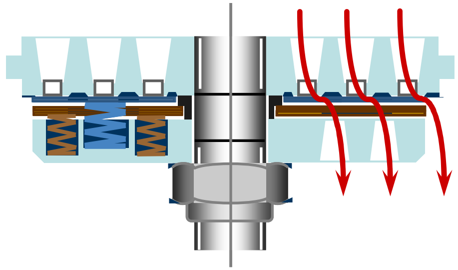
Valve dynamics

Flow mechanics – valve / ventilation losses

Valve losses are losses incurred in the valve

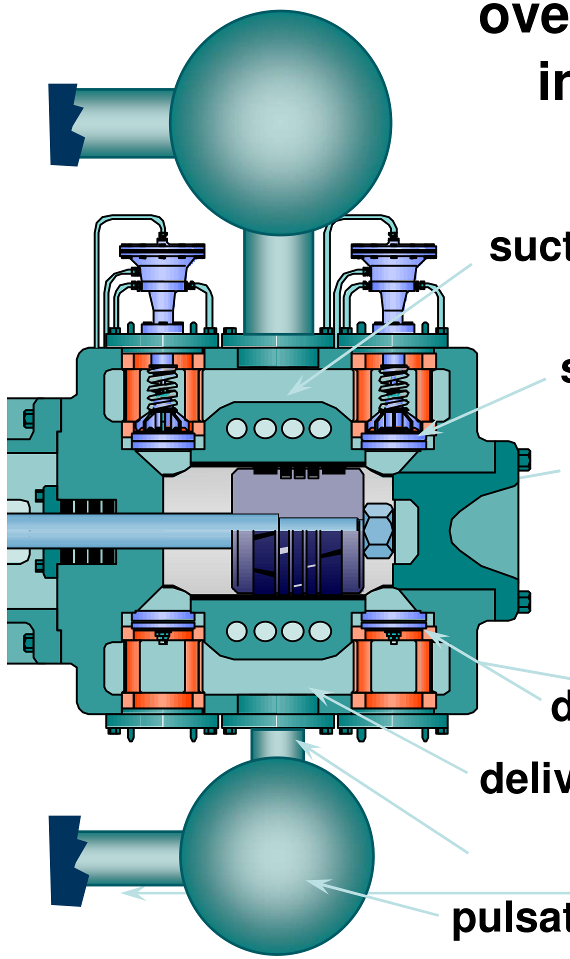
suction valve = intake





delivery valve = outlet

Ventilation losses are the overall losses incurred in:



Valves – power losses

- Power Losses

Pressure loss

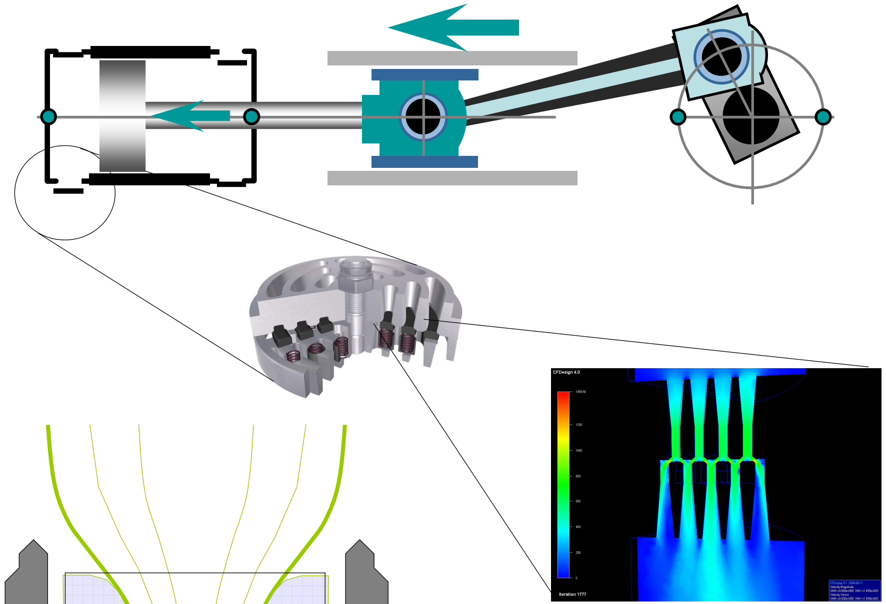
$$\Delta p \approx \rho\left(\frac{\dot{V}}{\alpha_{\Phi} \cdot \Sigma A_{Ventil}}\right)^2$$

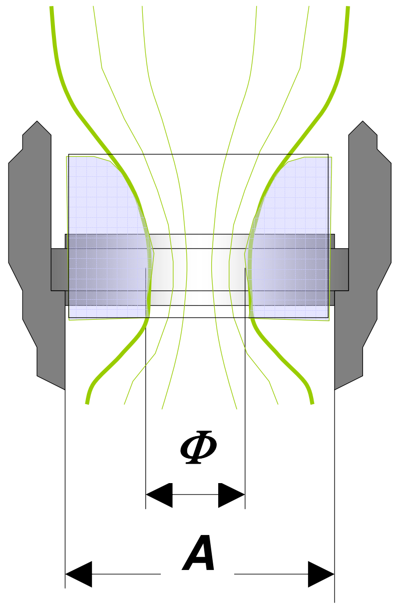
Similar valve clearance

$$(\Sigma A_{Ventil})^{\frac{3}{2}} \approx D^2 \cdot H \approx \dot{V} \cdot n^{-1}$$

Pressure loss for given delivery $\dot{V}$

$$\Delta p \approx \rho \cdot n^{\frac{4}{3}} \cdot \alpha_{\Phi}^{-2}$$



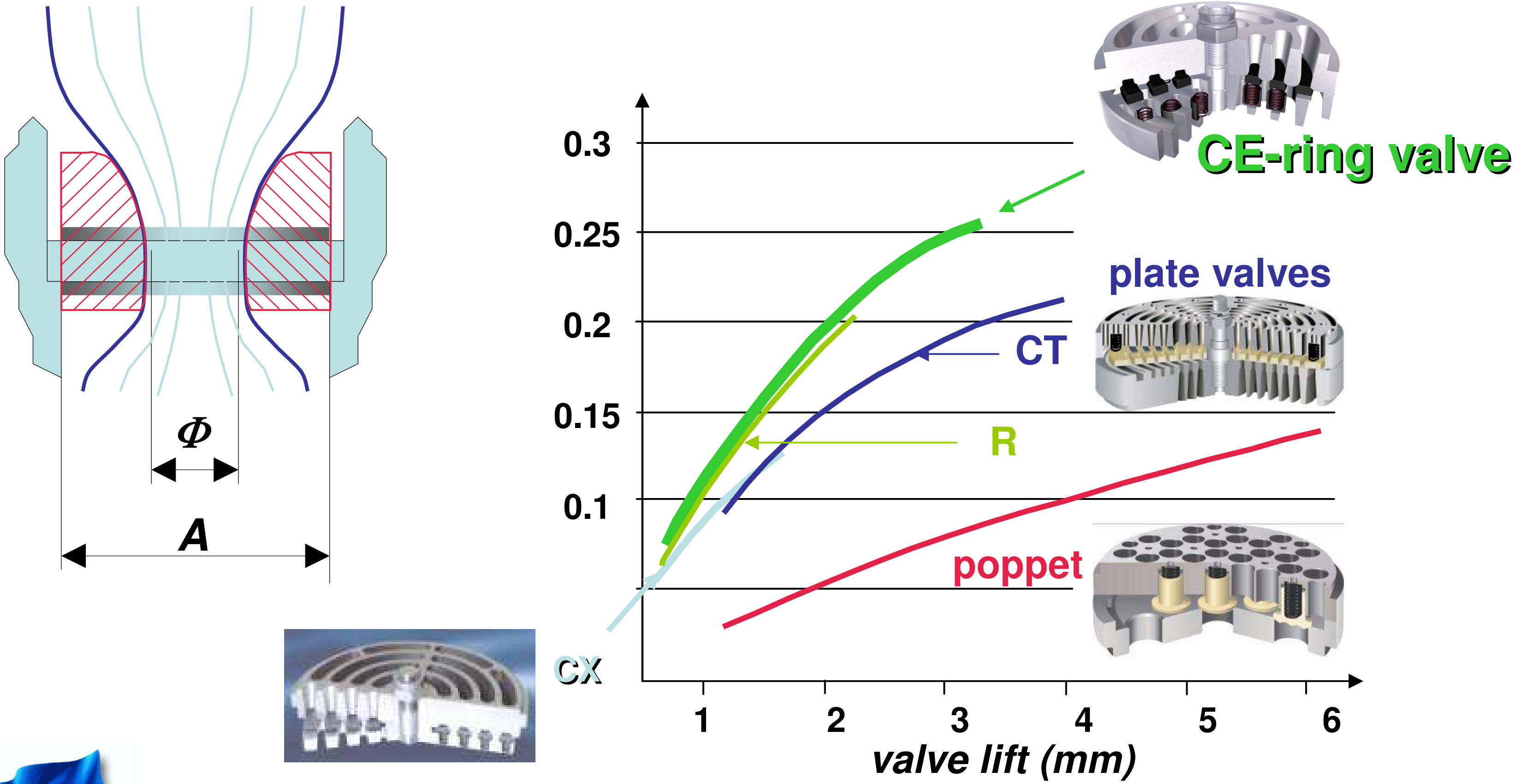


$\Phi = \alpha_{\Phi} * A$

α_{Φ} .. Valve efficiency

Efficiency coefficient for different designs

Valve efficiency $\alpha_{\Phi} = \Phi/A = \dfrac{\text{effective flow area}}{\text{valve nest area}}$

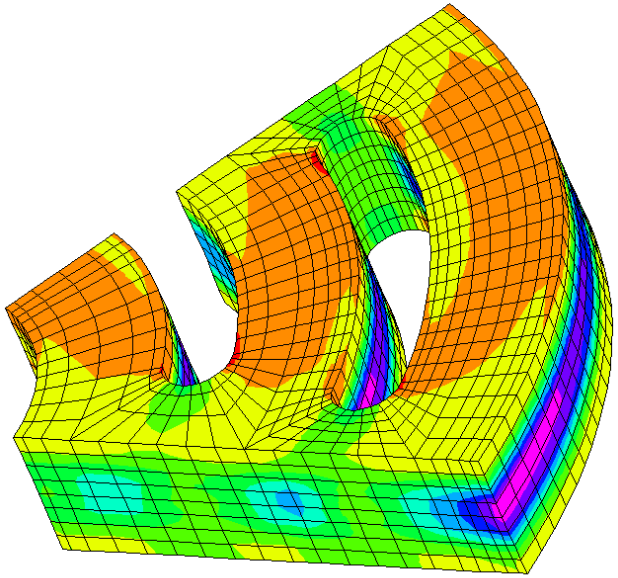


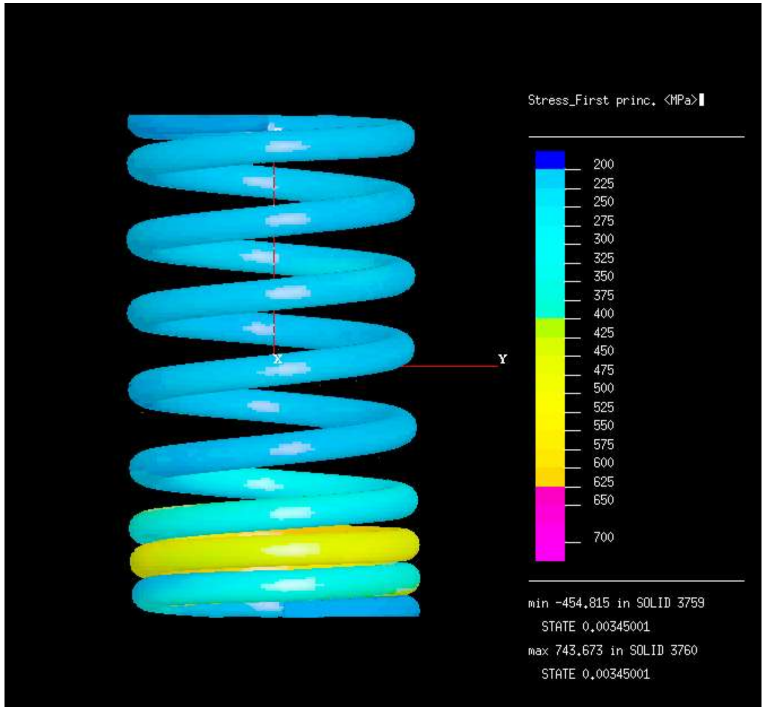
Sealing element dynamics

The impact velocity of the sealing element against the guard / seat is the most important design criteria for a compressor valve!

Stresses in the

- *Sealing Element and*
- *Closing Springs*

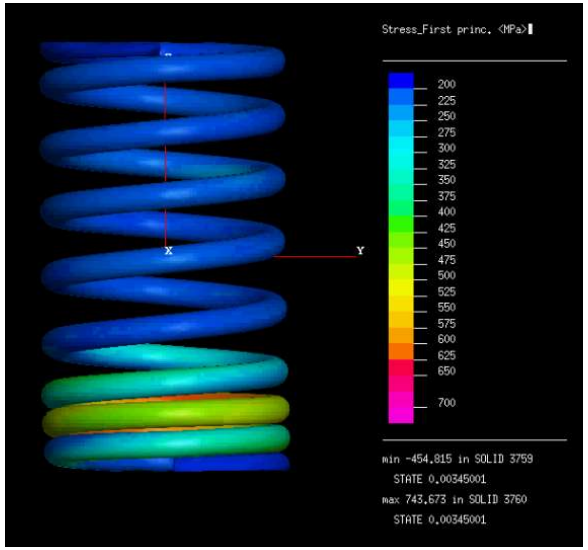




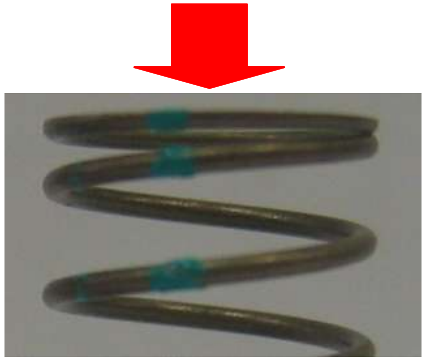
are directly proportional to the impact speeds!

Spring design

– **Dynamic & static spring criteria**
  - Solid height stress
  - Individual coil contact
  - Lift off



Shock



Dynamic stresses directly proportional to impact speed

Pulsations can lead to increased impact speeds, increasing the loading of the springs!

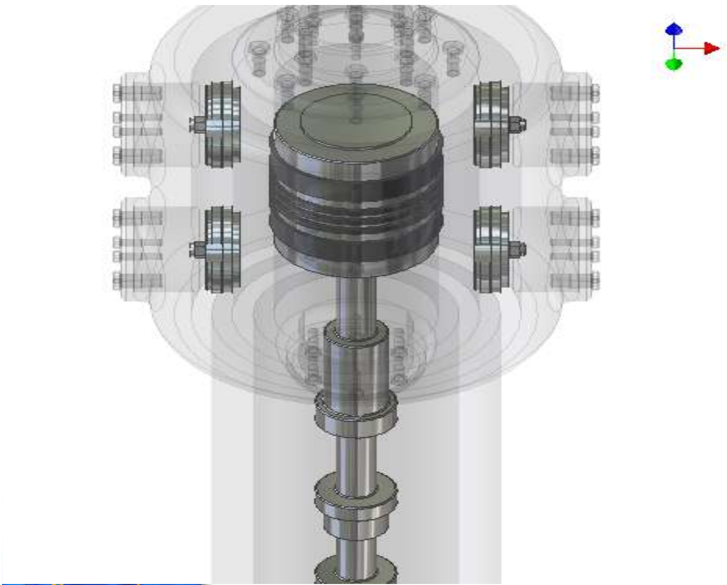
In – cylinder pulsations

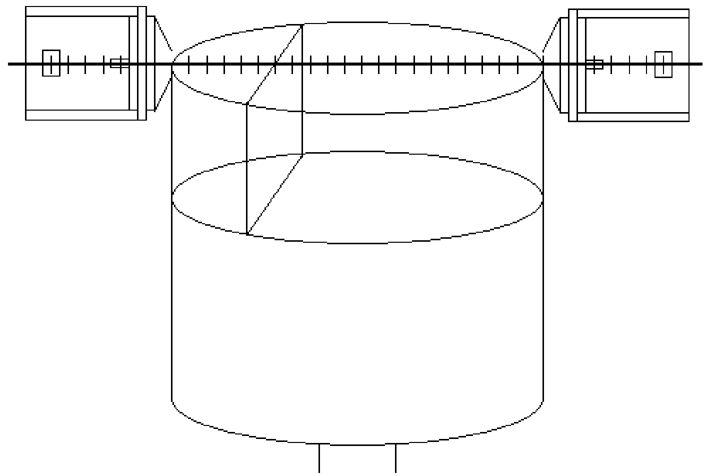
Industrial standard:

- Theory of M. Costagliola (1949) – assuming homogeneous cylinder pressure everywhere in the cylinder

Advanced model

Pressure depends on location – 1D model of wave propagation inside cylinder!



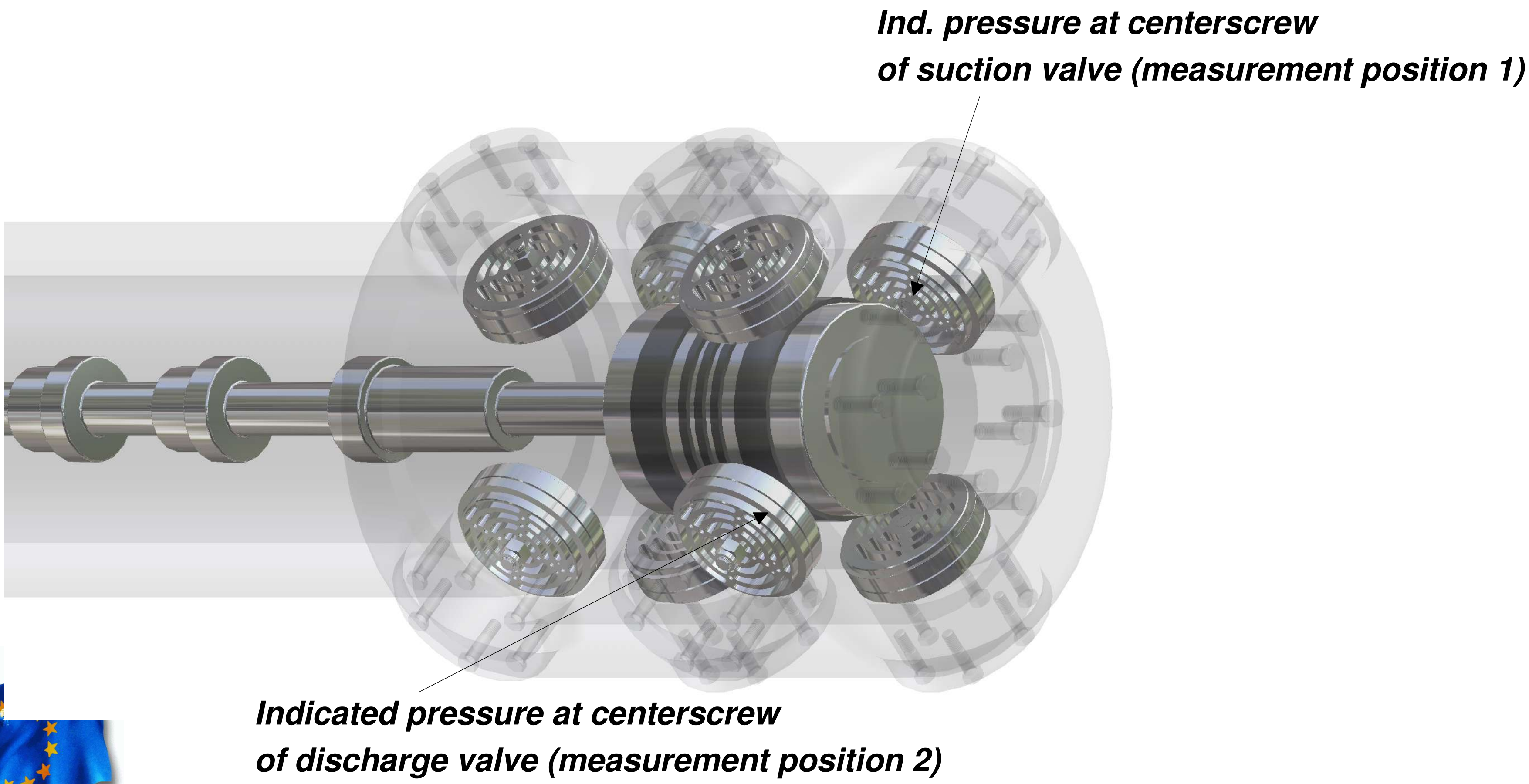


Result: sealing element impact velocity dramatically affected by pressure waves!

Validation with measurements

Propane application:

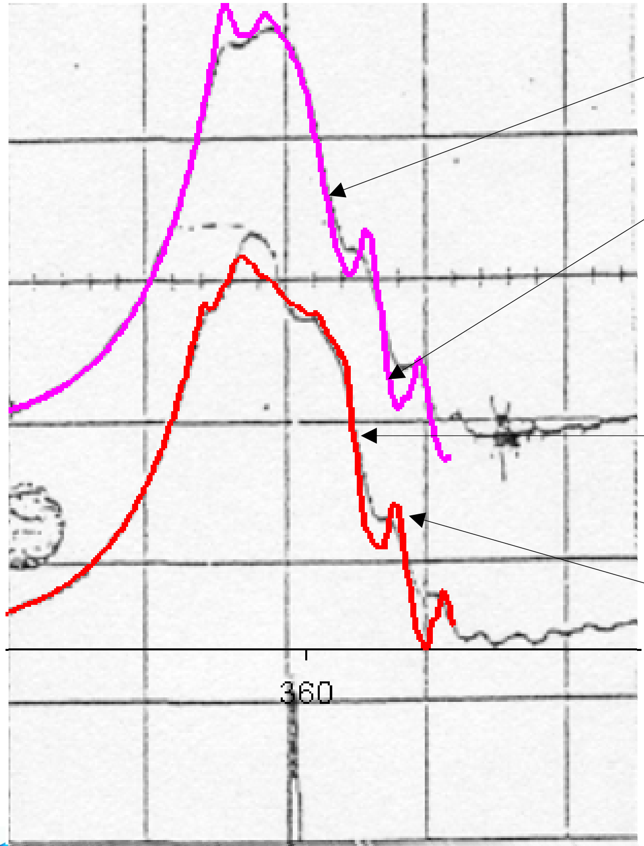
2nd stage, 346.1 [mm] bore, 139.7[mm] stroke, 1190[rpm], 3.9 – 12.6[bara]



Validation with measurements

Propane application:

2nd stage, 346.1 [mm] bore, 139.7[mm] stroke, 1190[rpm], 3.9 – 12.6[bara]



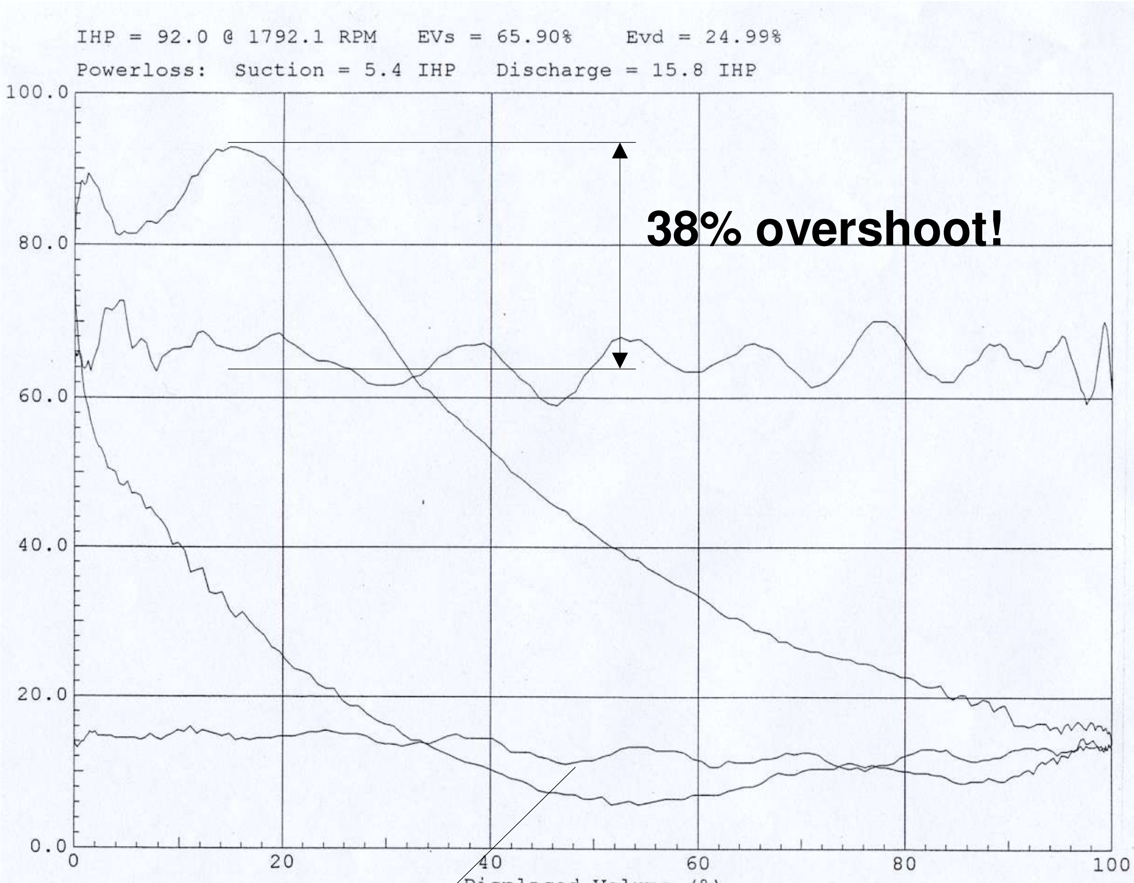
Measurement position 1 (SV)

Simulated curve at pos. 1 (SV)

Measurement position 2 (DV)

Simulated curve at pos. 2 (DV)

Effect on compressor performance



Looks like it's the valve's flow losses -

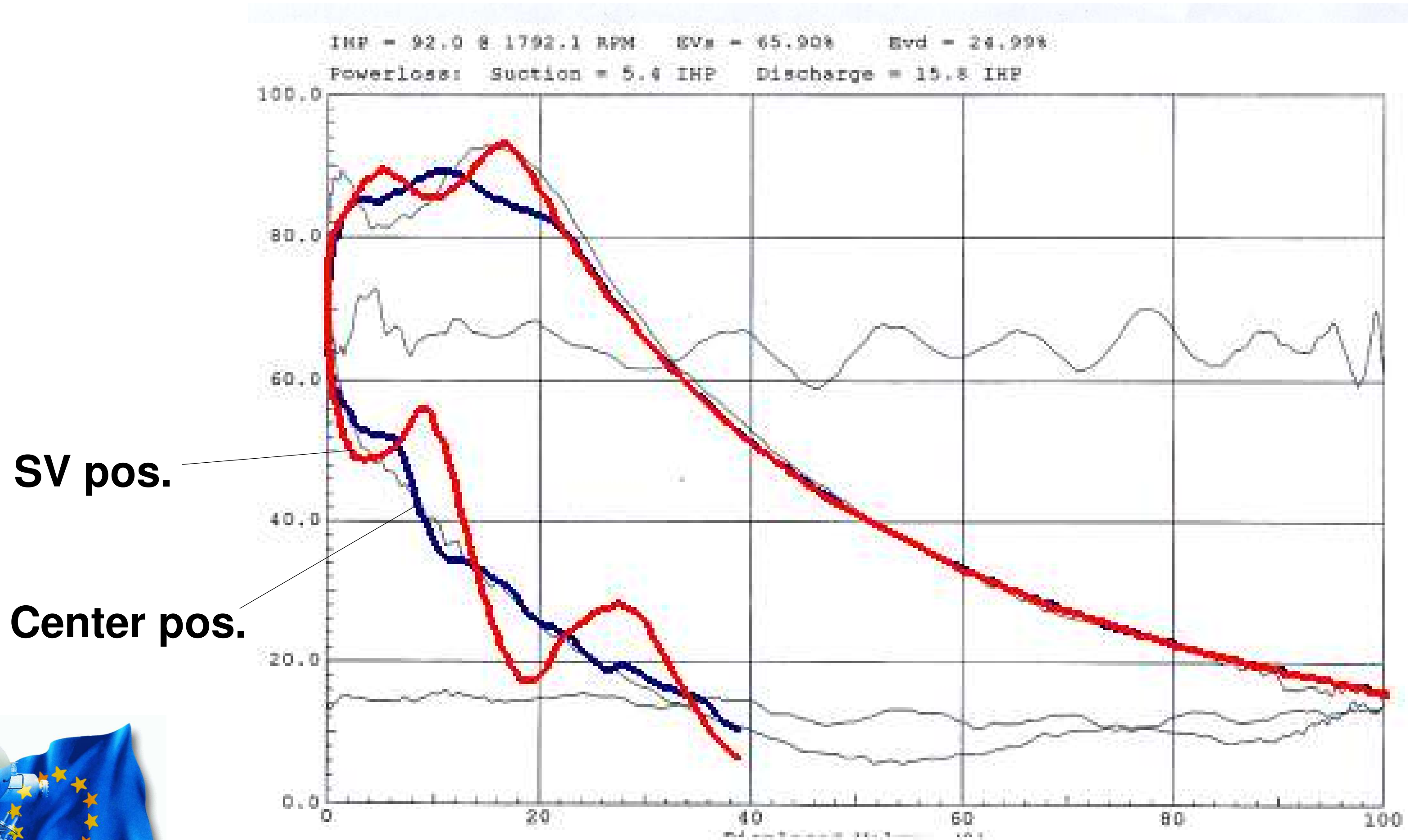
This is not true – It's a pulsation effect!

Note: suction losses appear quite usual, discharge losses ~ 3 times higher

Validation with measurements

Natural Gas Application:

1st stage, 387.4 [mm] bore, 76.2[mm] stroke, 1790[rpm], 2 – 5.3[bara]



Line pulsations: effects on valve dynamics

Question:

How would a 7% peak to peak line pulsation affect valve dynamics?

(MW = 28.22 kg/kmol,

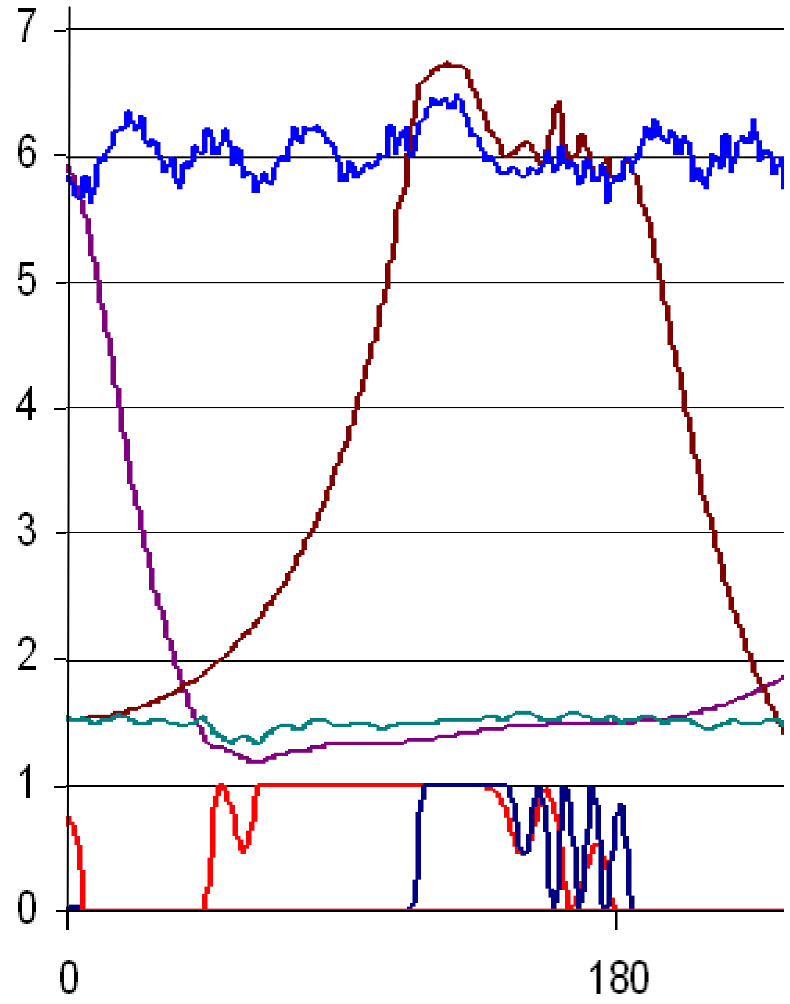
p_s = 1.5bara, p_d = 6bara)

Original valve design – no pulsations:

- *no late closures*
- *Impact within design limits*

With pulsations:

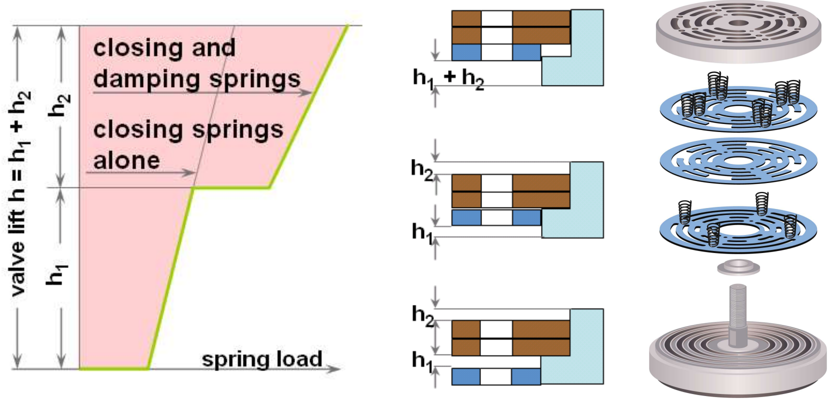
- *Late closing of discharge valve, increased closing speed*
- *Increased valve flutter – increased wear*



Now, what can be done

Measures to reduce impact speeds: advanced designs

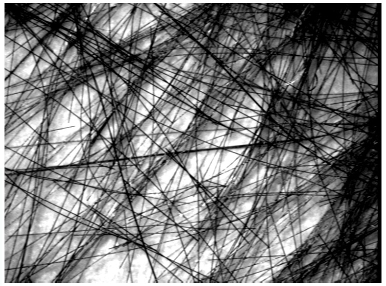
double damped valves

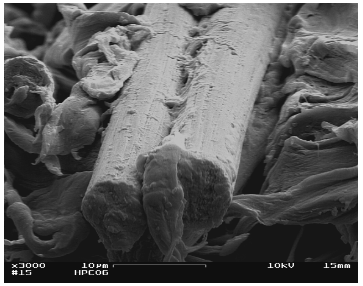


ring valves with sync. plates

Advanced nonmetallic sealing elements:

- can withstand higher impact speeds





Summary

- ***Although it seems simple, valve design and the effect of pulsations requires a lot of facts to be considered!***

- ***Understanding of***
  - *Flow mechanics*
  - *Valve dynamics*
  - *Spring dynamics*
  - *Sealing element material characteristics*

  mandatory!

Thank you!

EFRC