CFD Analysis of Cone Valves for Oscillating Positive Displacement Pumps

The performance of oscillating positive displacement pumps depends on the condition of the valves. Especially abrasive and highly viscous media are challenging for the material. Valves that are used in FELUWA MULTISAFE® pumps are characterised by their high wear resistance. Hence, the extension of the valve service life increases the availability of the pump and the persistence of other system components. An experimental evaluation of the influencing factors of abrasive and highly viscous media on the wear of cone valves was carried out by means of a CFD-analysis.

FELUWA MULTISAFE® Pumps

FELUWA MULTISAFE® double hose-diaphragm pumps are available for flow rates up to 1,350 m³/h and pressures up to 350 bar (Figure 1). It is a hermetically sealed, leak-proof oscillating displacement pump. The double hose-diaphragm is a further development of the conventional diaphragm piston pump with several advantages. The diaphragm separates the pump casing from the fluid and allows the medium a linear flow path without any deviation. When aggressive fluids or slurries are conveyed, the pump casing is also reliably protected against wear. Besides that, the secondary hose-diaphragm ensures that no slurry enters the hydraulic unit of the pump to protect workforce and the environment. Thanks to this unique design, the check valves are the only real wear parts of this pump and are designed to handle particles up to 10 mm in diameter. Dynamic behaviour and robustness are the main goals in valve design.

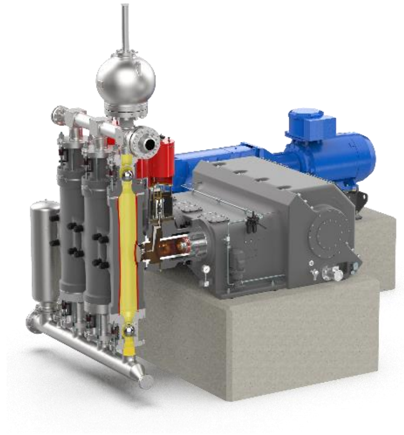
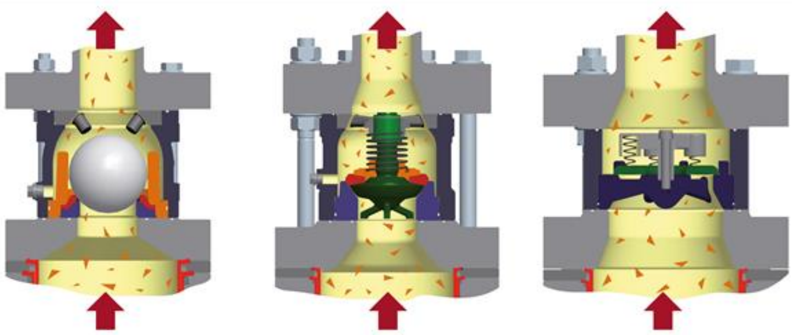


Fig. 1: FELUWA MULTISAFE® Pump

In general, valve wear is caused by particles contained in slurries and their movement on the surfaces. Guide surfaces are also affected by wear due to the relative moving of the guide-face-pair according to valve kinematics. Size distribution, hardness of the particles and the rheological properties of the carrier fluid are decisive for the abrasive behaviour of the medium. But wear is also affected by the flow velocities. The velocities need to be kept below a certain level in order to prevent excessive wear.

Three different valve types are available for the use in positive displacement pumps: ball valves, cone valves and plate valves. As part of the CFD analysis cone valves have been evaluated regarding velocity and wear. Cone valves are used for fluids with high solids content and have the advantage over ball valves that they are not limited to lower stroke rates and sizes. Besides, ball valves are selected to convey chemically aggressive fluids. Plate valves are suitable for higher stroke rates, but only to a limited extent for fluids containing solids.



From left to right: ball valve, cone valve, plate valve

CFD-analysis and 1D-FSI-model

By means of the CFD analysis, the flow rate can be calculated with high accuracy. As part of a study, complex kinematics simulations were also carried out.

Results of the 1D-FSI-model

Figures 3 and 4 show different lift curves of the cone valve under varying conditions. In these cases, valve lift is applied over a crankshaft angle for a discharge stroke, where 0° is the start of the stroke. The standard conditions are 90 spm, 16 bar discharge pressure, a spring stiffness of 3 N/mm and spring preload of 50 N. Any deviations from that standard condition are shown in the corresponding legend. The graphs show that the operating conditions, Figure 3, have a big impact on the valve kinematics. The stroke rates in Figure 3a illustrate that the maximum valve lift rises with increased pump speed. This is rather easy to explain, because the flow rate increases proportionally to the pump speed and the valve forces automatically increase with the flow rate. Due to the enormous computing times, a separate model was developed that can predict valve kinematics with high accuracy using CFD results. The computational effort is reduced considerably allowing extensive parameter studies.

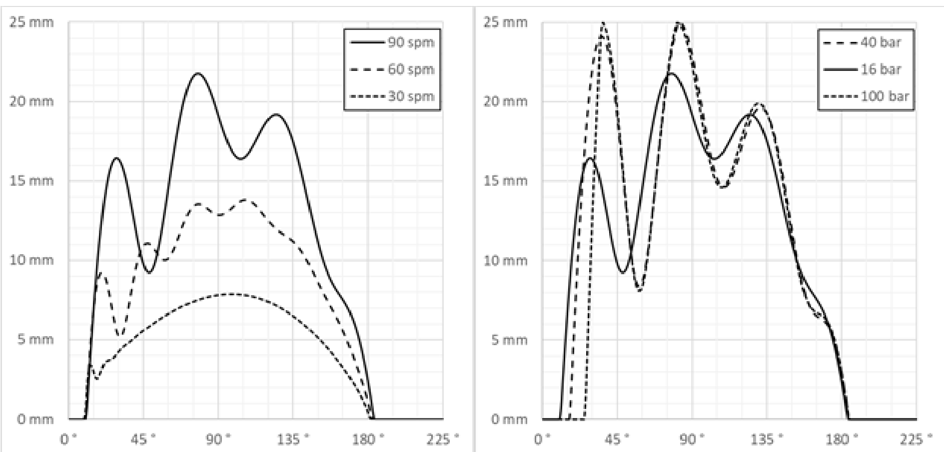


Fig. 3a: Lift curves for different stroke rates 3b: Lift curves for different discharge pressures

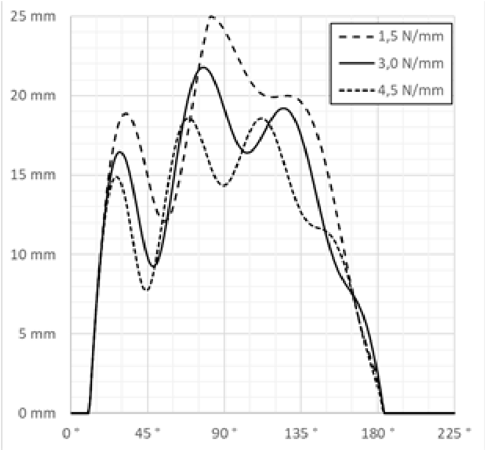


Fig. 4a: Lift curves for different spring rates

The opening starts more and more delayed with increased discharge pressure. Further delayed valve opening increases the initial motion sequence until hitting the stroke limiter.

In Figure 4a the influence of the spring stiffness is shown. Higher spring rates improve the dynamic behavior, the oscillating amplitude is reduced and the risk of an impact on the stroke limiter is reduced.

Thus, it is evident that valves cannot be considered separately. Prior to optimisation structural parameters such as spring preload or spring rate have to be taken into account, but also the influences of operating conditions such as operating pressure and stroke rate as well as the characteristics of the pumped medium. Hence, a complex CFD parameter study cannot be carried out.

Results of the erosion simulation

In general, the erosion simulation is the second step and is based on the standard flow simulation. The difference is that the solids need to be included as a second phase in the flow.

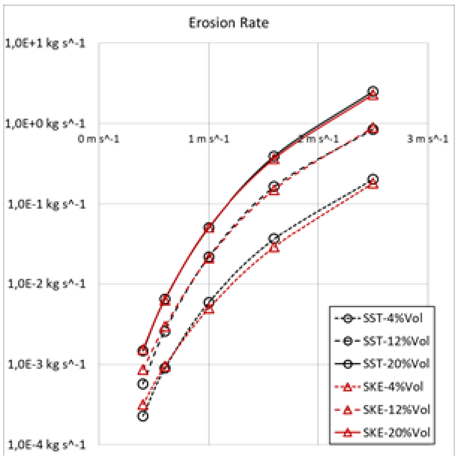


Fig. 5: Calculated overall erosion rates for different concentrations of a sand-water slurry

The mass fraction is considered as normally distributed with particle diameters between 25 and 500. The particle mass flow is converted according to the corresponding volume concentration. The volume concentration is varied between 4 and 20% and the valve inlet velocity between 0.4 and 2.5 m/s. The results of these calculations are shown in Figure 9 for the SST and the SKE turbulence models. For the three concentrations, a correlation between velocity and overall erosion rate can be given in an exponential law with an exponent between 3.5 and 4.1. In the valve a combined erosion mechanism of sliding and hitting as shown in Figure 6 can be observed.

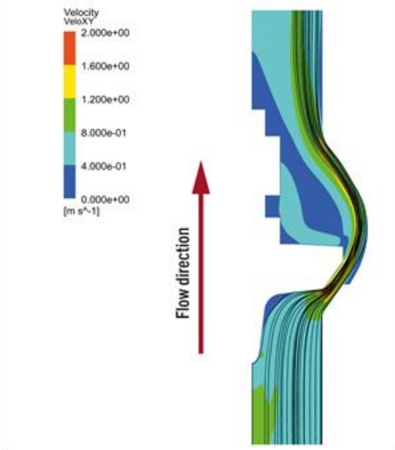


Fig. 6: Velocity field and particle tracks

The highest erosion rate is in the redirection zone downstream the gap between valve cone and valve seat. An exponent in this order means an increase in speed of a factor 2; the erosion rate rises by a factor 11-17. A doubling of the concentration leads solely to an increase of the erosion rate by a factor 3-4. Therefore, the solids content should always be increased by increasing the concentration, since otherwise the wear increases significantly.

Conclusions & Outlook

This paper presents a valve design process including the consideration of valve kinematics and wear locations. The valve kinematics are introduced as a 2-step model consisting of an intensive numerical investigation of the flow and a one-dimensional fluid structure interaction approach. This method could successfully be verified by experimental data and by comparison with full fluid structure interaction simulations. Compared to a full fluid structure interaction simulation, the advance of this design process is that the numerical investigation is decoupled and therefore needs to be done only once and not for each combination of any operating conditions and design parameters. This results in a flexible model which is also beneficial for the design, while a full FSI is solely useful for the final design verification. Another advantage is that this model can be independently adjusted without the valve geometry until ideal valve performance is achieved in the 1D-FSI model. In the second step, the geometric parameters of the valve design are adjusted until the pressure losses and valve forces meet the determined input data. This is one objective of the current research progress.

The implementation of erosion in the design process enables the engineer to identify weak spots at an early stage of the design process. Velocity is a crucial factor since wear increases along with velocity to the power of 4. Further investigations on wear are another objective of the current research progress. FELUWA has set up an in-house high pressure test rig with a pressure range up to 160 bar and a flow rate up to 15 m^3/h, consisting of a high pressure slurry pump, a temperature regulated mixing tank and the related measurement technology in order to verify and validate the erosion model with respect to check valves. The goal is to develop an independent model for erosion alike the 1D-FSI model.

The use of these calculation models enables FELUWA to continuously optimise the valves for the MULTISAFE® pumps and to select the best valve with the best wear resistance for the individual application.