Pumps and Compressors 2009
with Compressed Air and Vacuum Technology

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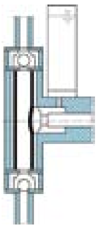

Hermetically sealed double hose-diaphragm pumps for the hydrotransport of sedimenting suspensions

Heinz M. Nägel

Hydraulic solids transport refers to the delivery of two-phase mixtures, whereby water (fluid) is the hydraulic carrier that conveys the solids along the rising main. Depending on their consistency, smaller particles with a maximum size of approx. 100 µm may be considered as secondary carrier fluid. They contribute to a reduction of the settling speed of carried solids vs. the fluid (water). Such transport is differentiated into homogeneous and heterogeneous mixtures. With homogeneous mixtures, solids and fluids are subject to equal distribution so that velocity distribution and volume concentration across the pipe section are likewise uniform. On the other hand, heterogeneous mixtures are subject to strong separation. The upper half of the pipe shows much lower solids concentration within the mixture than the lower half. Furthermore, the velocity of the mixture in the lower half of the pipe is considerably lower than in the upper half.

In principle, a higher concentration of fine solids (approx. ≥ 10 %) also means that the mixture tends to non-Newtonian behaviour (such as thixotrophy). Therefore, it is essential to take account of the so-called critical velocity vcrit. Falling below the critical velocity endangers the equipment, results in an uncontrolled exceeding of discharge head and possibly in blocked discharge and suction piping. This is referred to as gliding bed delivery (see Fig. 2). For this reason, it is essential that the velocity is always maintained in a higher range than vcrit.

Irrespective of whether the pumping of homogeneous or heterogeneous mixtures is concerned, the process industry reveals a positively changed ecological awareness. On the one hand this awareness evidences in stronger endeavours to avoid dangerous leaks and on the other hand in the higher awareness in terms of energy.

Fig. 1: Solid samples

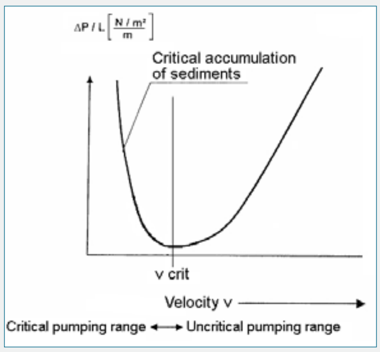

Fig. 2: Gliding bed transport

The development of reliably sealed pumps is likewise to be seen against the background of this tendency. Both performance and application spectrum of these pumps have been considerably extended so that they are now covering a range from small-size metering pumps to high-pressure process pumps with enormous driving power. However, the target of these developments was not only to avoid dangerous leaks, but likewise to reduce costs of repair and disposal for the benefit of increased economical quality rating and operating reliability. Hydraulically actuated diaphragm pumps with single or multi-layer diaphragms are normally applied for pressures ≥ 10 bar. The diaphragm serves as hermetical separation between the wet end and the hydraulic chamber.

In the event of sedimentations within the pump head or suction valve, there is an increased risk of excessive stretching of the diaphragm so that it may even be pressed into the suction or discharge check valves, which inevitably results in a failure of the single or multi-layer diaphragms (see Fig. 3). Such breakdowns can even not be avoided by the provision of double diaphragms since both diaphragms are subject to almost identical stress and will therefore rupture concurrently.

Hermetically sealed double hose-diaphragm pumps

Double hose-diaphragm pumps are effectively counteracting the disadvantage of traditional diaphragm pumps by means of modifying the flat diaphragm into a hose-diaphragm. The product is led in a linear flow path through the inside of the hose-diaphragm and is moreover in direct contact with the check valves only (see Fig. 4). This new diaphragm pump meets all criteria of a hermetically sealed, leak-free oscillating displacement pump and also offers a smooth pump chamber that is easy to be cleaned.

Working principle

The rotary driving motion of the pump reduction gearbox is converted to reciprocating action of the crosshead by the crank drive. The crosshead is connected to the piston. By means of hydraulic fluid the piston actuates both hose-diaphragms which not only enclose the conveyed fluid in a linear flow path, but also, simultaneously, provide double hermetic sealing from the hydraulic drive end. For general process engineering applications, the hydraulic fluid normally consists of hydraulic oil. As alternative option, non-compressible fluids with physiologically harmless lubricants that are compatible with the conveyed fluid are applied. Pumping action is effected by displacement of the inside volume resulting from contraction of the hose-diaphragms.

Unlike so-called peristaltic hose pumps with mechanical drive, hose-diaphragms of the double hose-diaphragm pump are not squeezed. In step with the piston stroke, they are only subject to slight movement, comparable with that of a human vein. Elastic distortion of hose-diaphragms is path-controlled and effected in a concentric manner due to their inherent construction. The service life of hose-diaphragms is considerably extended beyond that of traditional flat diaphragms which reflects in very good MTBF (mean time between failure) & MTBR (mean time between repair) values.

As a result of hydraulic support, the hose-diaphragms are subject to little load even under higher working pressures. Thereby, the hydraulic

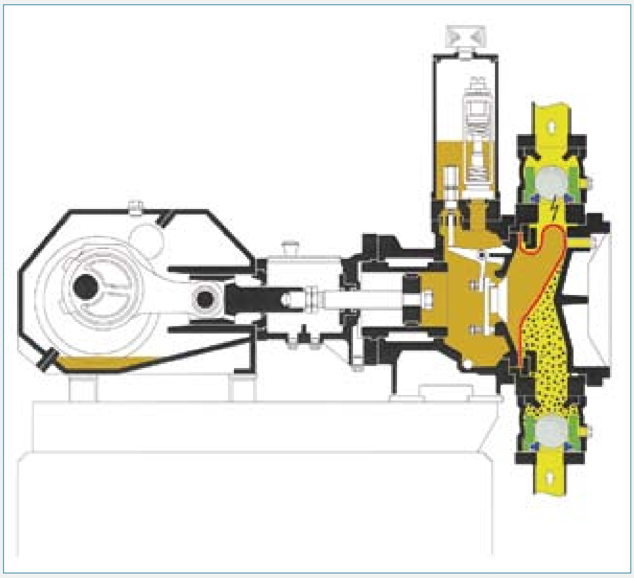

Fig. 3: Diaphragm failure as a result of sedimentation

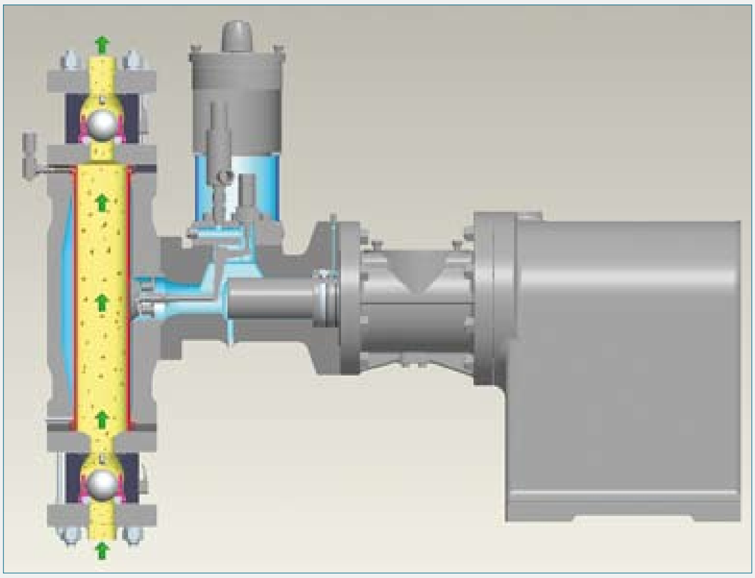

Fig. 4: Double hose-diaphragm pump

actuation system is fully separated from the wet end by means of a pair of redundant hose-diaphragms.

To compensate pulsations that cannot be avoided with reciprocating pumps, pulsation dampeners are available in the form of traditional air vessels or special hose-diaphragm pulsation dampeners with hermetical sealing of the fluid from the air cushion.

High operating safety

One of the distinct advantages of the double hose-diaphragm pump design is the linear flow path, so that it is especially conducive to the handling of suspensions, viscous slurries and fluids be they solids carrying, of abrasive nature or shearing-sensitive. With a maximum of linear flow lines, hose-diaphragms are capable of handling high rates of viscous slurries and other corrosive or erosive chemicals at minimum wear.

With hose-diaphragms there is no milling in the area of the clamping ring normally fitted to diaphragm pumps to allow for settling of solids which results in early diaphragm failure. On the one hand, hose-diaphragms are sized to guarantee almost zero milling in the clamping area and on the other hand, there is no milling radius required in the area of the conveyed fluid that would allow for the settling of solids. Design provisions ensure synchronous movement of hose-diaphragms and piston both under excess-pressure and vacuum conditions.

The unique operating reliability of the pump is amongst others expressed by the fact that the process fluid will neither come into contact with the pump head nor with the hydraulic drive end, even in the event that one of the two hose-diaphragms leaks or fails. The second hose-diaphragm ensures that pump operation can be maintained until the next planned shut-down of the unit. Leakage loss of hydraulic fluid is automatically compensated by the respective make-up system.

With traditional diaphragm and piston diaphragm pumps, however, it is essential that the selection of the construction materials for diaphragms and pump casings is made to meet the criteria of chemical resistance to the operating fluid. Especially with high-pressure applications and bigger pumps for the transport of aggressive and highly corrosive media this is associated with very high manufacturing costs.

High economical quality rating

With double hose-diaphragm pumps the selection of the pump casing is made in dependence on flow rate and working pressure, however it is not determined by the resistance to the conveyed fluid. This results in a unique economical quality rating.

respective duty. By way of example, with increasing valve size the weight of ball valves using steel balls likewise increases to such an extent that the pressure being built up in the gap can no longer provide sufficient lifting of the ball from the sealing face.

To counteract this problem, double hose-diaphragm pumps are provided with hollow steel balls, for example. The differential weight thereby makes the decisive difference, as evidenced by the mathematical demonstration as per Figure 6. The sizes being applied in this calculation are exemplary. The maximum (stable) gap between

Fig. 5

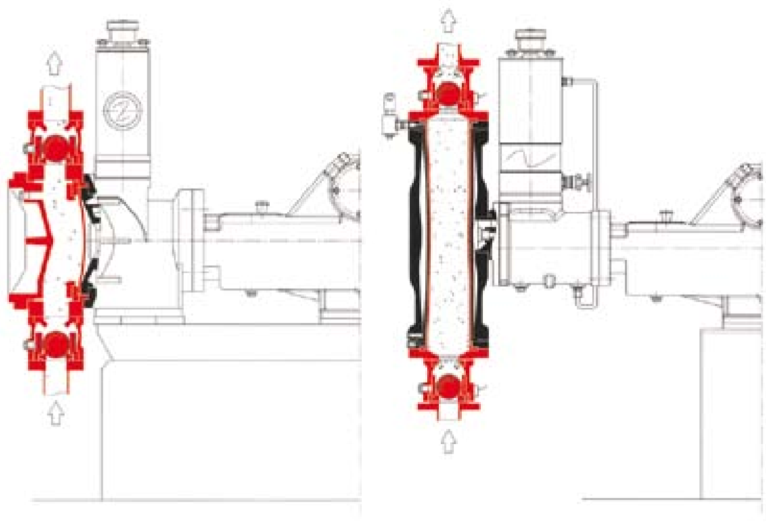

Fig. 5: Comparison of wetted parts

Downflow configuration avoids sedimentation

Double hose-diaphragm pumps with a maximum of linear flow lines are capable of handling fluids at higher viscosities, slurries and other corrosive and/or erosive chemicals with a minimum of wear. Therefore, they are especially suitable for the hydraulic transport of suspensions carrying solids that tend to settle. The cylindrical shape of the diaphragm panders to the flow behaviour and avoids the settling of solids.

In order to ensure sufficient lifting of the valve body from the sealing face (according to the particle size), the weight of the valve body has to be individually adapted to the the ball and the sealing face results from the comparison of forces. On the one hand, the weight of the balls is known. On the other hand, the compression force of the flow is to be calculated. This force is resulting from the differential pressure between the valve inlet and the gap between ball and ball seat. The two compression forces for different lifts reveal that the lower weight of balls allows for a higher gap. Whilst the hollow ball is held at 8 mm (in the example), the gap of the solid ball is restricted to 6 mm. Just these 2 mm can make the decisive difference that avoids the clamping of solids. By means of an unrestricted eluding in all directions, the ball provides for a maximum opening gap and allows for an unobstructed flow.

Data (by way of example):		Calculations:	
Weight of solid ball	m_{VK} = 10.4 kg	Weight force of solid ball	$F_{G.VK}$ = 104.3 N
Weight of hollow ball	m_{HK} = 5.99 kg	Weight force of hollow ball	F_{GHK} = 59.9 N
Diameter at the valve inlet	d_{VE} = 97 mm	Resultant lift	h_1 = 10 mm
(contact surface of the ball)			h_2 = 8 mm
Volume flow of the pump	Q_P = 50 m³/h	Pressure at the gap	
Fluid density	ρ_M = 1 kg/dm³	– Hollow ball	F_{Sp1} = 63.7 N
Ball diameter	da =137 mm	– Solid ball	F_{Sp2} = 106.8 N

Fig. 6: Calculation of pressure and lifting at valve ball gaps

General formula for the calculation of pressure at valve ball gaps:

$$F_{Sp\,x} = \frac{d_{VE}^2 \times \rho_M \times \pi}{8} \left[\left(\frac{Q_p}{\pi \times d_{VE} \times h} \right)^2 - \left(\frac{4Q_p}{\pi \times d_{VE}^2} \right)^2 \right]$$

(x = Index for solid or hollow ball)

By this means, failures and losses of flow due to blocked check valves are effectively avoided.

When handling particularly heavy solids and heterogeneous mixtures, the traditional pumping principle is literally turned upside down, which means a flow from the top to the bottom of the pump (see Fig. 7). Irrespective of whether the traditional pumping principle from the bottom to the top or downflow configuration with flow from the top to the bottom is applied, handling of fluids carrying large solids requires special and custom-tailored check valves. With traditional transportation, the utilisation of ball valves, spherical cap ball valves, spring-loaded cone valves or hollow ball valves allows for the handling of the individual fluids at the respective mass flow rates and sedimentation behaviours.

Depending on the technical physics of the demand, downflow valves can likewise be provided with different closing systems. These can both be spring-loaded spherical cap ball valves (see Detail "X" of Fig. 7) or special ball valves with floating balls, such as hollow steel balls (see Detail "Y" of Fig. 7). Both of the aforementioned systems can avoid hitting coarse solids that are included in the fluid, if these valves are designed with rough guides.

In case of critical process conditions, in which the continuous flow must by no means be interrupted, double valves are applied (such as illustrated by Detail "X" of Fig. 7). Double valves are also of cassette design and characterised by linear flow. Backflow leaks resulting from jammed solids are reliably prevented.

Efficiency even at extreme pumping temperatures

Also in terms of pumping temperature the modular system of double hose-diaphragm pumps includes a great variety of options: Normally,

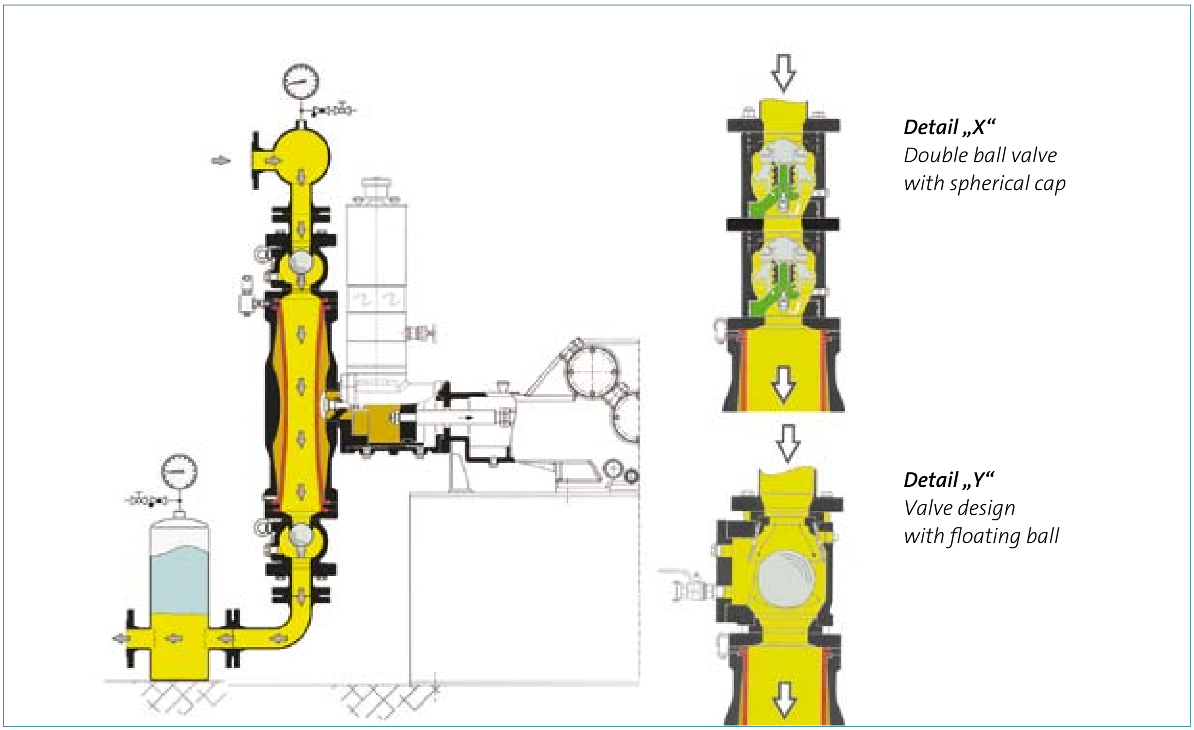

Fig. 7: Downflow configuration

elastomer hose-diaphragms are applied for temperatures < 130° C. For higher temperatures of < 200° C the utilisation of PTFE mixtures has proven successful. These have been especially developed for the utilisation with hose-diaphragms. PTFE is also specified if the conveyed fluid is of particularly high corrosiveness. To master extreme pumping temperatures of 200° C plus, double hose-diaphragm pumps are provided with a convector face between wet and drive end. This intermediate piece contributes to efficient heat dissipation. Such designs can additionally be provided with a double redundant diaphragm, which means that these pumps are designed with a combination of a pair of double hose-diaphragms and a flat diaphragm (see Fig. 8).

Diagnostic systems for an early detection of faults

The double hose-diaphragm pump design is based on many years of experience in the field of oscillating displacement pumps and the demand for predictive maintenance. Therefore, permanent condition monitoring is in first instance directed to the reliable detection of leaks in terms of hose-diaphragms and check valves. The early detection of even smallest leaks avoids unplanned downtime of the facility and allows for a long-term planning of maintenance work.

Hose-diaphragm condition monitoring

At the heart of this pump there is a redundant pair of hose-diaphragms

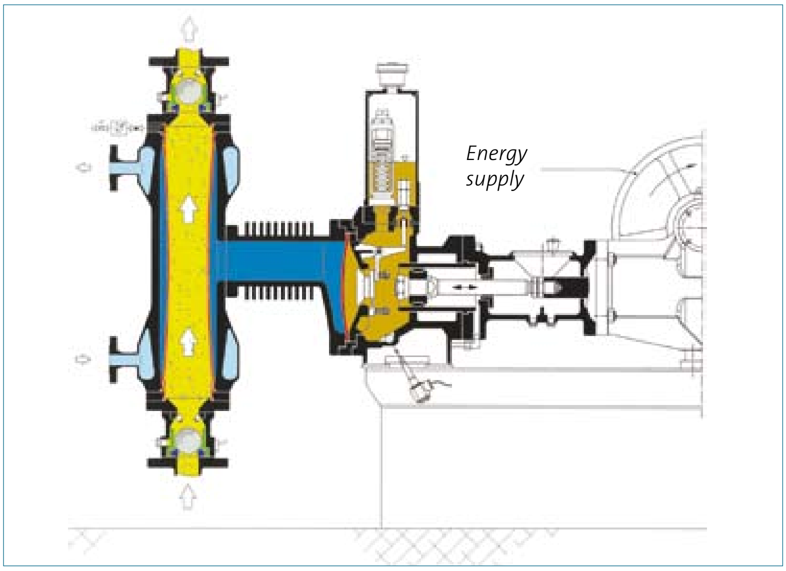

Fig. 8: Double hose-diaphragm pump with additional flat diaphragm as well as convection section and cooling jacket (option)

Suction & discharge valves in cassette design

A diverse range of cone, ball or spherical cap ball valves with metal and soft sealing is available for optimum adaptation to the individual application conditions. Even under high pressure these valves provide reliable protection from the impact of backflow from the pipework. Due to the low wear of these valves, gap leakage is reduced to minimum even after a longer period of operation. All variations are of cassette design, easily removed and refitted by means of jacking screws without prior dismantling of piping.

(two hose-diaphragms which are arranged one inside the other) although it requires only a single one to operate. The quality of the primary hose-diaphragm, which is in contact with the conveyed fluid, is individually adapted to the respective operating conditions. The primary hose-diaphragm is hydraulically coupled to the secondary hose-diaphragm (facing the hydraulic fluid). The space between both hose-diaphragms is at zero pressure. In the event that one of the hose-diaphragms leaks or fails, either conveyed fluid or actuation fluid will get into the intermediate space. The pressure that is built up as a result of such infiltration is automatically led to the condition monitoring system of the hose-diaphragms. In any case, an early warning is ensured and the functional efficiency is maintained until the unit allows for shutdown and repair.

Improved power efficiency by means of web service

The Internet is gradually evolving into a comprehensive medium for the transport of all kinds of data. Until 2015, the number of Internet users is expected to increase to approx. five billion. The industry is also increasingly focussing on wireless data communication and appreciates the new perspectives resulting thereof. Also under the aspect of improved energy efficiency and the avoidance of unplanned standstill, custom-tailored detectors have been developed for the early detection of wear in check valves. The measuring principle is based on the analysis of the solid-born sound of check valves and capable of detecting leaks between valve seat and ball or cone, even if the loss of output is still < 1.5 %. Due to the valve monitoring system it is by way of example no longer required to remove all six valves of a triplex pump in order to find out which of these is actually worn. A valve performance monitoring system provides reliable information, as to which of the valves is leaking and might need replacement. The respective notification is transmitted via a potential-free contact and provides the operator the possibility of a predictive maintenance and precise determination of MTBR values and may contribute to a considerable reduction of maintenance costs.

By means of enhancements of the existing diagnostic systems and the utilisation of touch panels, clients are offered by now an HMI (Human Machine Interface) with full integration of pump diagnostics into industrial control systems option. The touch panels are integrated into the control cabinet and give the operator information about prevailing operating data and readings, such as stroke rate, suction pressure, discharge pressure pulsations, hydraulic and gearbox oil temperatures or the condition of hose-

Abb. 9

Abb. 10

diaphragms and check valves as well as possible losses of flow and efficiency resulting thereof. The system also makes a noticeable contribution to the reduction of energy costs. Touch panels are moreover an optimum starting basis for web service, which renders site service in many cases unnecessary.

In the event that several pumps are discharging into a common main, the variable frequency drive is provided with special control software and incremental encoders which allow for an angular synchronism of the operation and ensures compensation of pulsations (see Fig. 9).

Summary

With a pulsating vein as displacement means, the double hose-diaphragm pump (see Fig. 10) typifies Bionics in Pump Design and provides for a smooth and linear flow throughout the pump without deviations. Double hose-diaphragm pumps are based on modular design. With a great variety of gearbox sizes they are available as simplex, duplex, triplex, quadruplex and sextuplex units for flow rates ranging from 0.1 to 600 m³/h and max. working pressures of 320 bar. They ensure high availability and protection against excess-pressure as well as unfavourable suction conditions, even under most arduous operating conditions.

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Fig. 9: Double hose-diaphragm pumps with incremental control of variable frequency drives and touch panel

Fig. 10: Double hose-diaphragm pump on the test rig

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