Low Noise, increased reliability, digital control - a new generation of radial piston pumps

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ABSTRACT

Low noise, greater reliability, easy control options are demands on modern piston pumps. To lower both, the noise emission and the high and low pressure pulsation the number of pistons of a radial piston pump (RKP) is increased from 7 to 9. By means of CFD and FE calculation the suction path of the RKP is optimized as a compromise between hydraulic (low pressure drop, small inductivity) and mechanic (small deformation, low stresses) functionality. Pressure drop along the suction path was reduced by 20%. The sound emission of the new radial piston pump generation was reduced by up to 5dB(A) in sound power, that corresponds to a reduction of wide more than 50%. A new stroke ring design eliminates a possible place of wear. The DCP (Digital Interface Pump) is a new servo radial piston pump adjustment based on a new pilot valve with digital onboard electronics offering an enhanced functionality.

NOMENCLATURE

d_{Tube}	Diameter of a tube/bore	mm
L_{Tube}	Inductivity of a tube/bore	kg/m^4
l_{Tube}	Length of a tube/bore	mm
p_1	Pressure at pump outlet	bar
p_{1Tube}, p_{2Tube}	Pressure at the ends of a tube	bar
Q_1	Flow at pump outlet port	l/min
Q_{Tube}	Flow through a tube/bore	l/min
V_{PC}	Volume of piston chamber	cm^3
ρ	Density	kg/cm^3

1   INTRODUCTION

Radial piston pumps are used as variable displacement pumps in many industrial applications, like injection moulding machines. Low noise, greater reliability, easy control options are demands on such pumps.

2   REDUCTION OF NOISE EMISSION

2.1   Increase the number of pistons

2.1.1   Reduction of dynamic loads

During one revolution of the pump each piston chamber is connected over an angle of 180° to the low pressure and to the high pressure side. During the transition process the pressure in the piston chamber is alternating between this two levels. The transition process is very rapid and is finished after approximately 1,5-2,5 ms. The pressure in the piston chamber acts as a dynamic force on the piston area and is transferred via slipper pad and stroke ring to housing and servo pistons. The resulting dynamic force leads to vibration and sound emission of the pump. As higher the piston diameter as higher are the dynamic forces. To reduce this forces at unvariable displacement volume the number of pistons has to be increased. An increased number of pistons allows the reduction of the piston diameter.

Figure 1 shows a comparison of forces between seven and nine piston rotating group of a radial piston pump. As expected the force amplitude (peak to peak value) of the 9 piston pump in x-direction is reduced to 65% and in y-direction to 90%.

2.1.2   Reduction of pulsation at pump outlet port

There are two main reasons for an unsteady flow at the outlet port of a piston pump. The first one is the sinusoidal movement of each piston as a result of the kinematics of the rotating group. The sum of any individual flow of that pistons, that are connected to the high pressure side, leads to the so called kinematic pulsation.

The second reason is the compressibility of the fluid. Before each piston can deliver a flow to the pressure side, the pressure inside the piston chamber must be adapted to the level of the high pressure side.
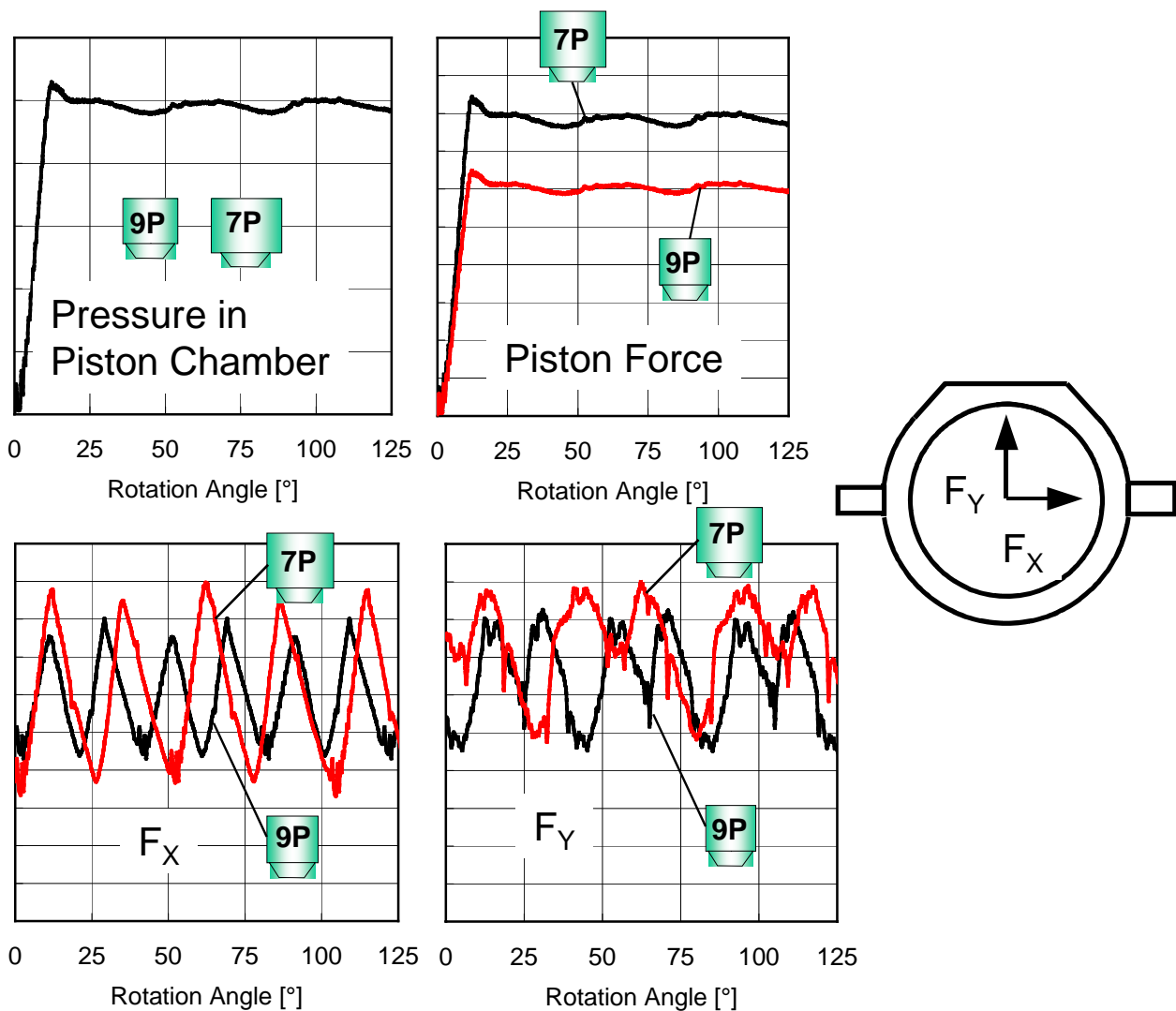
Figure 1: Comparison of Forces between 7 and 9 Piston Rotating Group

For this purpose a certain flow is necessary, that is be taken from the high pressure side and leads to a flow slack and increased pulsation.

Why is it important to reduce the flow pulsation at the outlet? The flow pulsation is transported into the hydraulic circuit and is transformed into a pressure pulsation. This pressure pulsation may lead to vibration and sound emission of parts, that are located far away from the pump.

Increasing the number of pistons from 7 to 9 has 2 effects: first the kinematic pulsation is reduced and second the size of the piston chamber at same displacement volume is reduced in a ratio of:

$$V_{PC-9} = \frac{7}{9} \cdot V_{PC-7}.$$ (1)

Both, reduction of kinematic pulsation and piston chamber volume reduce the pressure ripple on the high pressure side.

Amplitude and shape of the pulsation is also strongly influenced by the piston design. A lot of piston pumps are working with drilled pistons, as shown in *Fig. 2* above, to reduce the mass and the mass forces of the piston. The disadvantage of this design is the relative large dead volume V_{PC}, that leads to an increased flow/pressure ripple at the pump outlet port.

Completely different is the piston design of the radial piston pump. The cup design, shown in *Fig. 2* below, is a closed piston with minimum mass and minimum dead volume. The result is a significant reduction of pressure ripple compared to a drilled piston.
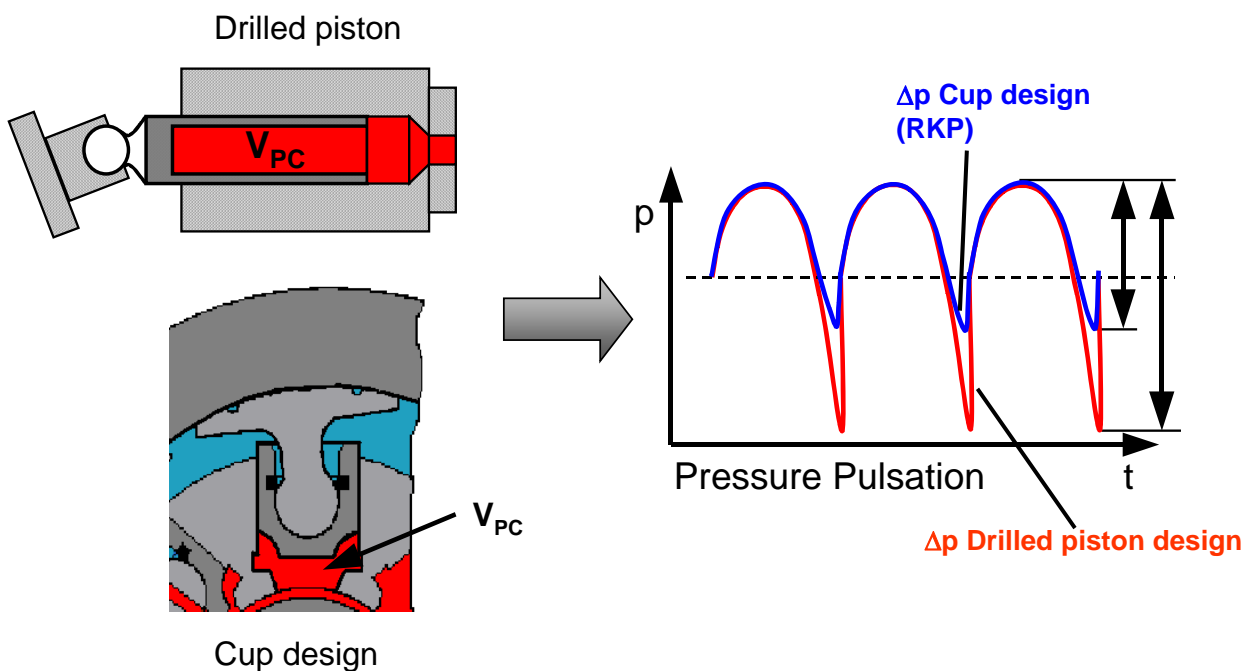

Figure 2: Influence of piston design on pressure pulsation at pump outlet port

2.2 Reduction of pulsation at suction port

The kinematic flow pulsation on the high pressure side occurs in the same way on the low pressure side. The result is a permanent flow and pressure ripple on the suction side even so when the pump is adjusted to a constant displacement volume. Among system parameters like length and diameter of suction hose the pulsation at suction port also depends on pumps geometric parameters.
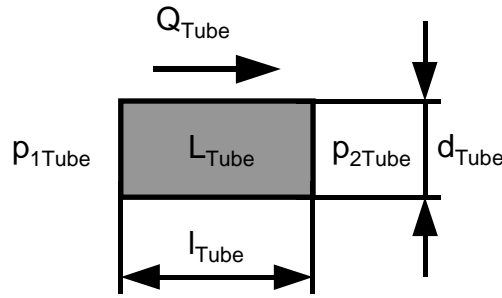

Figure 3: Inductivity of a tube/bore

On it's way from suction port to piston chamber the fluid has to pass housing and control journal first. The tightest position on this way is formed by several bores in the control journal. Using the geometric parameters, the hydraulic inductivity of a tube/bore (***Fig. 3***) can be written as:

$$L_{Tube} = \frac{4 \cdot \rho}{\pi} \cdot \frac{l_{Tube}}{d_{Tube}^2} \tag{2}$$

Equation (2) shows that the inductivity of a tube or a bore depends on two geometric parameters: diameter d_{Tube} and length l_{Tube}. The flow in consideration of the dynamics can be calculated as:

$$Q_{Tube} = \frac{1}{L_{Tube}} \cdot \int \left(p_{1Tube} - p_{2Tube} \right) dt \tag{3}$$

Equation (3) can also be written as:

$$\frac{Q_{Tube}}{dt} \cdot L_{Tube} = p_{1Tube} - p_{2Tube} \tag{4}$$

Equation (4) shows that amplitude and shape of the pressure pulsation in the bores of the control journal and therefore at the suction port of the pump depends on the size of the inductivity of the bores in the control journal. A reduction of the pressure ripple can be reached by decreasing the hydraulic inductivity. As the diameter of the bore can not be significantly increased due to stability reasons, the only possibility to decrease the inductivity is to reduce the length of the bore. *Fig. 4* shows how the length of the bores in the control journal is reduced at RKP-II compared to the old design.
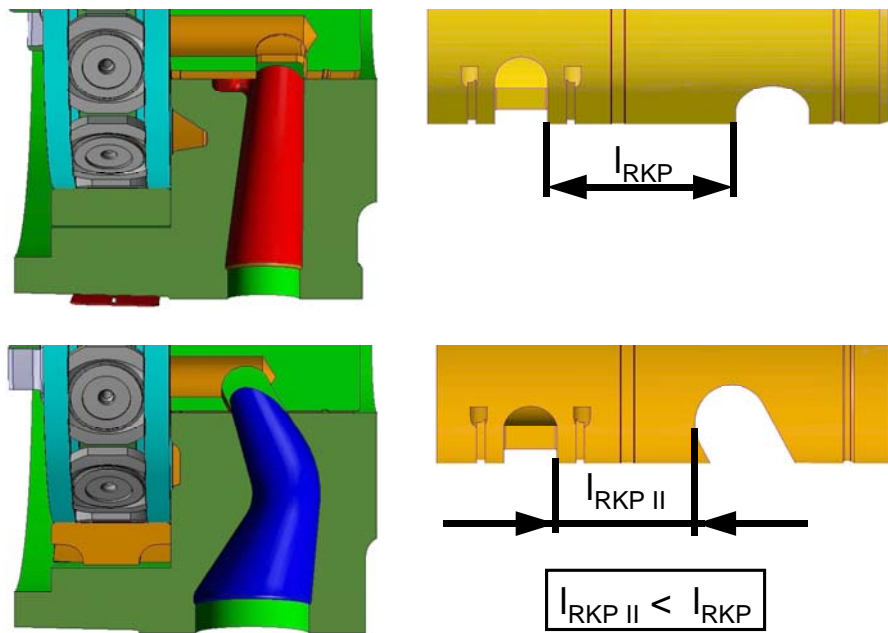
Figure 4: Reducing the hydraulic inductivity along the suction path

The minimum length of the bore is limited by the maximum permissible strength in control journal and housing. To find out the proper parameters a FE analyses was done (see also chapter 3.2).

2.3 Measurement of Sound Emission

Fig. 5 shows the sound power of three different radial piston pumps with a displacement of 80 cm^3/rev measured in an anechoic chamber. The sound power of the RKP80-II (9 pistons, sliding stroke ring, optimized suction port) compared to RKP80 (7 pistons, rolling stroke ring, standard suction port) is significantly reduced up to 4 dB(A). This is a reduction of more than 50% in sound emission. The 3rd pump is a RKP80 with 9 pistons and sliding stroke ring but with standard suction port. Compared to the two other curves it is possible to see the

influence of 9 pistons and optimized suction port on the noise emission. **Fig. 6** shows the sound power of a RKP100 (7 pistons, rolling stroke ring, standard suction port) and a RKP100-II (7 pistons, sliding stroke ring, optimized suction port). Depending on the operating point a maximum reduction in sound power up to 5,5 dB(A) is reached.
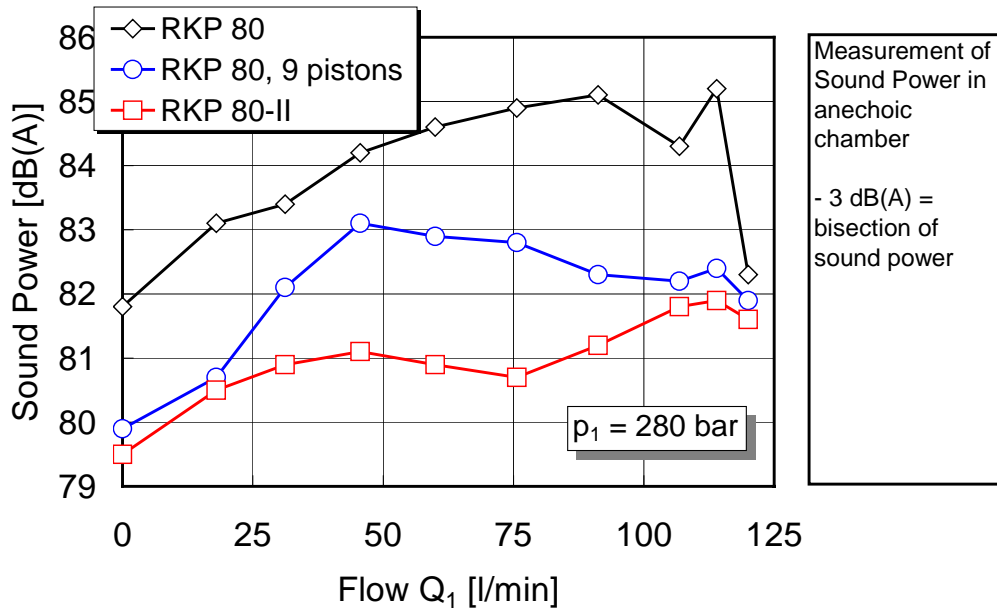

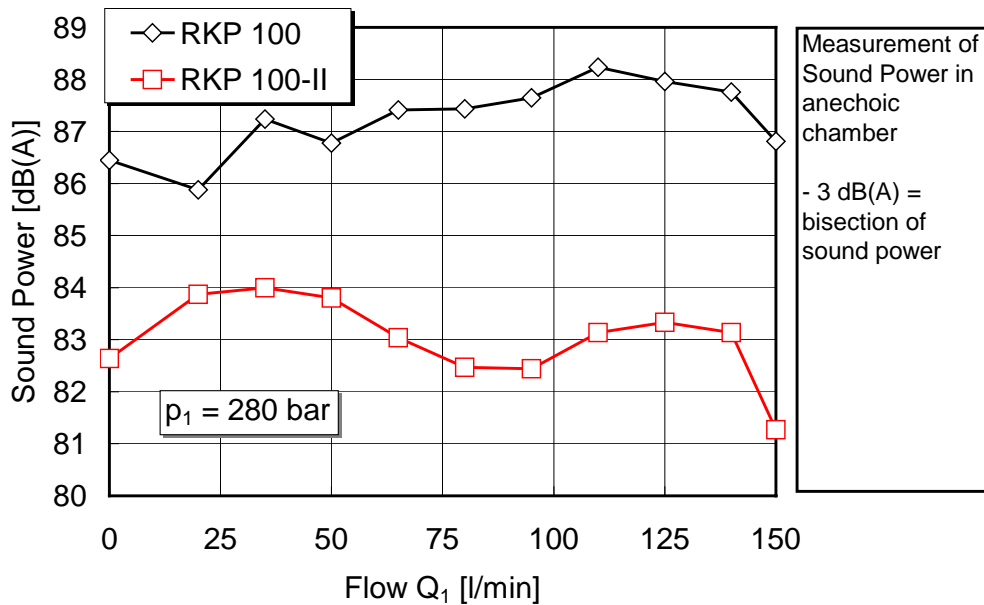Figure 5: : Measurement of Sound Power of RKP80, RKP80 with 9 pistons and RKP80-II (9 pistons, sliding stroke ring, optimized suction channel)

Figure 6: Measurement of Sound Power of RKP100 and RKP100-II

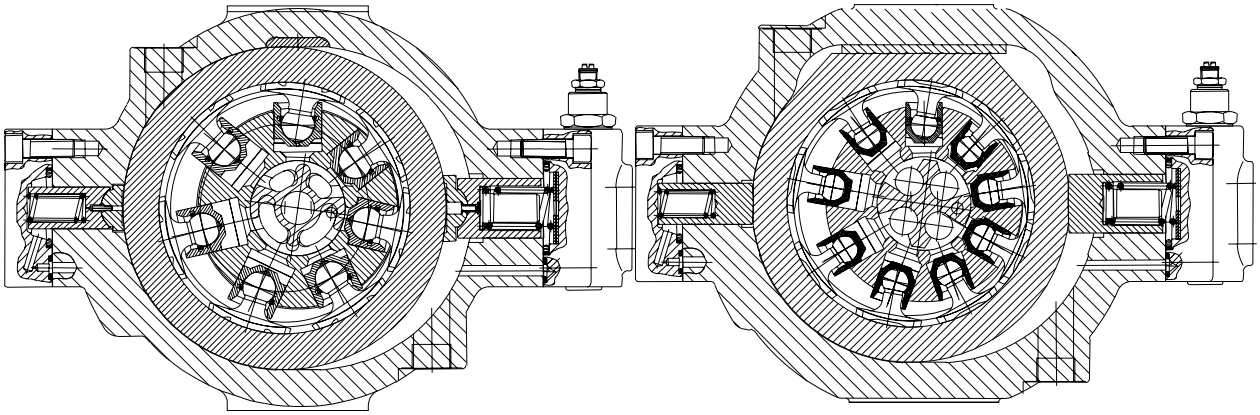## 3   INCREASED RELIABILITY

3.1   A new stroke ring principle

Figure 7: Radial Piston Pump with Rolling Stroke Ring (left)
and Sliding Stroke Ring (right)

Fig. 7 shows on the left side a radial piston pump with a rolling stroke ring. Under certain conditions (small pressure, high viscosity) the stroke ring tends to an uncontrolled rotation. This leads to friction and might lead to wear on stroke ring, housing and servo piston slipper pads. The new stroke ring design is shown in ***Fig. 7*** on the right side. This new stroke ring disposes of a plane surface that slides to a counter surface in the housing. The rotational degree of freedom is eliminated, an uncontrolled rotation of the stroke ring is not longer possible.
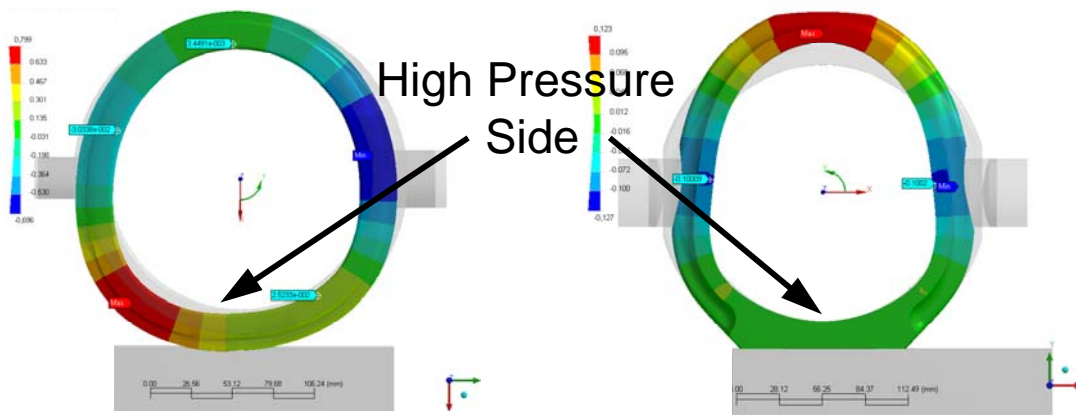

Figure 8: Optimization of sliding stroke ring design in terms of stresses and deformation

Fig. 8 shows the calculated deformation between a rolling and sliding stroke ring. The largest deformation of the rolling stroke ring occurs on the high pressure side. The deformation behavior of the sliding stroke ring is different. Due to the stronger design on the contact surface between stroke ring and housing the sliding stroke ring shows a higher stiffness on the high pressure side. This helps to minimize the gap between stroke ring inner diameter and slipper pad outer diameter under pressure and therewith to minimize the flow losses at this point.
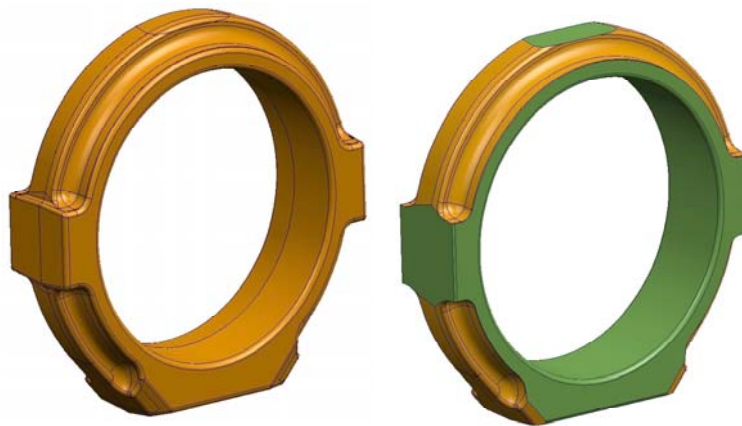

Figure 9: Sliding Stroke Ring Design: Raw Part (left) and Finish Part (right)

3.2   Reduced flow losses, improved resistance against cavitation

Poor suction conditions, caused by long suction lines and/or unsuitable fluid viscosity might lead to cavitation inside housing, control journal and rotation group. To avoid cavitation it is necessary to reduce the pressure drop along the suction path inside the pump. For this purpose a Computational Fluid Dynamics (CFD) calculation in combination with a FE stress and deformation analyses was started in order to find an optimum compromise between hydraulic and mechanic functionality (*Fig. 10* and *Fig. 11*). As a result, the pressure drop along the suction line could be reduced by 20%.

A basic advantage of the radial piston design is shown in *Fig. 12*: due to the radial movement of piston and cylinder block a radial force acts on the fluid and helps to fill the piston chamber. The combination of flow optimized suction channel, radial acting forces in the rotating group, that support the filling process, and completely nitrated or hardened sliding surfaces of the rotating group make the RKP-II more reliable in respect to cavitation.
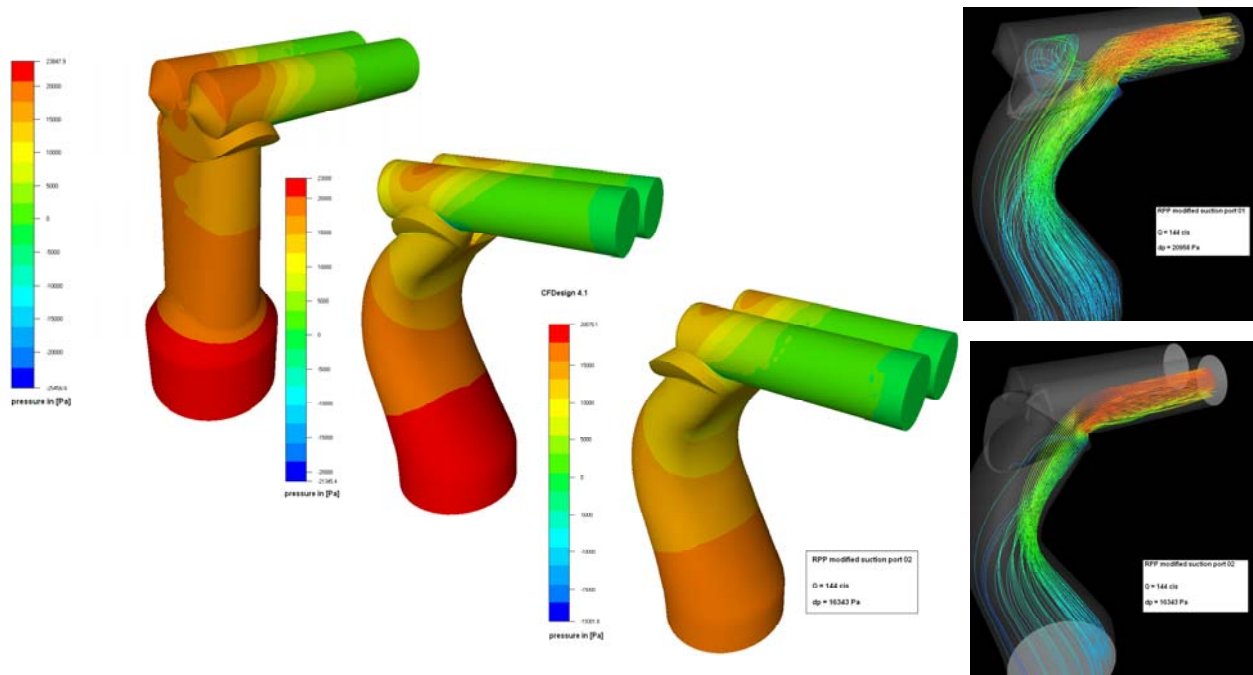
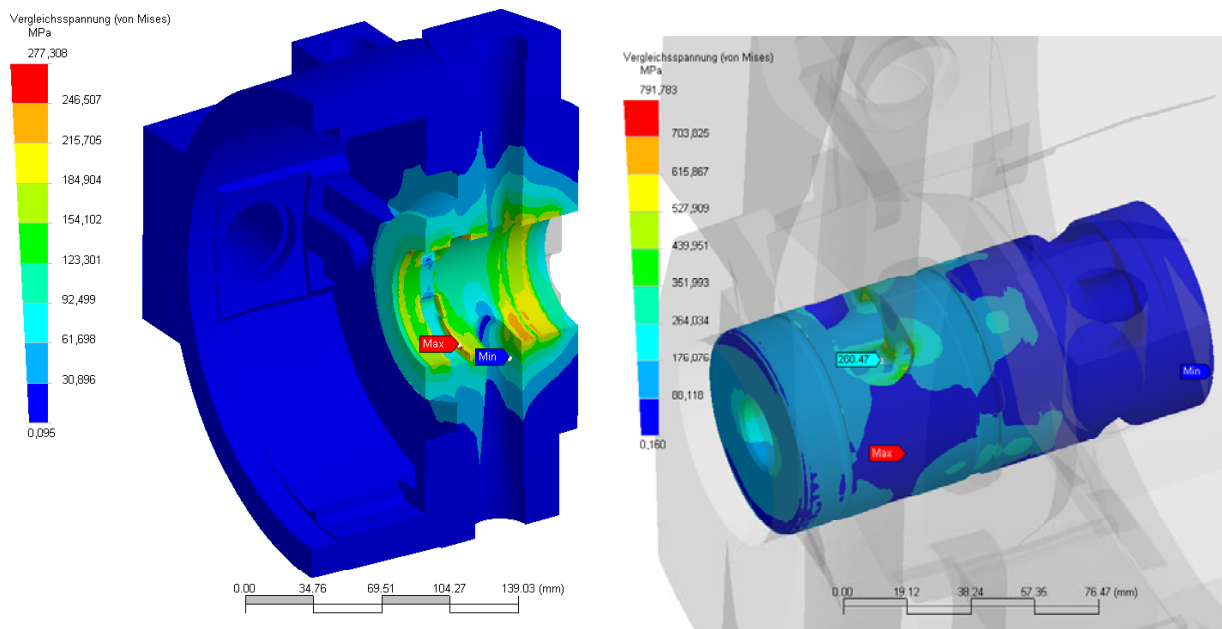*Figure 10: Use of CFD calculation to minimize flow losses along the suction path*

Figure 11: Optimization of suction path in housing and control journal in terms of stresses and deformation
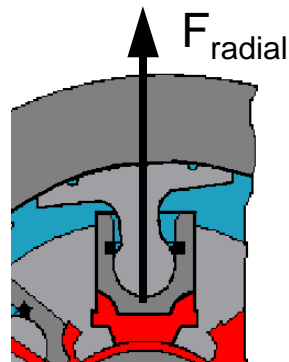
Figure 12: Radial acting forces in the rotating group support the filling process
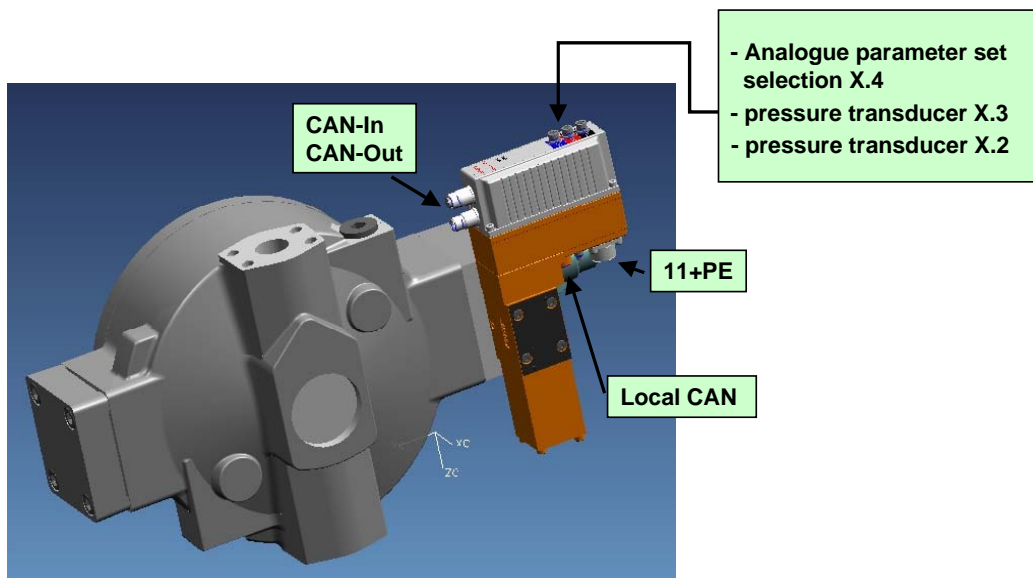
4 DCP – A DIGITAL CONTROLLER FOR THE RKP

Figure 13: Digital Control Pump - DCP80-II

The DCP (Digital Interface Pump) is a new servo hydraulic pump adjustment based on a new pilot valve with digital onboard electronics.

The DCP can be controlled in two ways:

1. via analogue interface: 2 x 0..10V-signal for pressure and flow command; optional 1 x 0..10V parameter set selection

2. via CAN open - interface, according to VDMA-device-profile DS408 (pQ-functionality) + many extensions

The advantages of the DCP are:

- improved dynamics

- improved pressure regulator with „1-parameter-adjustment"

- parameters online switchable (as well in analogue mode !)

- 2nd pressure transducer connectable

- improved diagnostics

- factory-set leakage compensation

- faster set up

- less wiring (no external card required)

- pre-calibrated ex works (easy field exchange)

- master-slave-mode

- hybrid mode (= regenerative mode)

- implementation of the new software function „local holding pressure transition" .

CONCLUSION

This paper deals with the advantages of a new generation of a radial piston pump. This new generation is characterized by:

- a significant reduced sound emission (up to 5 dB(A) in sound power compared to the old design)

- an improved reliability by a new stroke ring design and a flow optimized suction path

- a new servo hydraulic adjustment in combination with a digital control valve with on board electronics.

The design optimization was done by using modern design tools like FE and CFD analyses.

The combination of the reliable, noise optimised RKP-II pump and the digital control valve with on board electronics is a sophisticated solution for all kind of demanding servopump applications.