Application of COR Pump Technology in Positive Displacement Machines

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Introduction

Pumps generally divided into hydrostatic and hydrodynamic. Hydro dynamical pumps operate on a hydrodynamic physical process in which there are pressure and energy changes in the proportional square of the speed of the rotor. Hydrostatic pumps (also known as positive displacement pumps) increase and decrease volume of the pump chamber during operating cycle.

Target properties of hydrostatic pumps are:

- Stable efficiency in wide working area (over different flow or pressure) with low noise emissions,
- high reliability at high mechanical and/or thermal loads,
- small size and weight, low price, easy assembly and servicing,
- possibility of integration with control devices (pressure, flow, temperature sensors),
- possibility of operating over wide viscosity range of liquids and
- low pulsation of pressure and flow.

The trends in the development of the positive displacement pumps are oriented towards achieving higher pressures and rotating speed of products. Less material consumption and simplified production technology solutions are motivations from the design and manufacturing aspect. Hydrostatic pumps are classified into two larger groups - to pumps with a translatory motion of liquid displacement element, and to pumps with a rotating element (shaft).

COR Pump Technology – Made by Injection Molding

To save weight and meet modern fuel efficiency standards, automotive engineers have learned to substitute plastic materials for metal wherever possible. Even beyond weight savings, versatile plastics offer numerous manufacturing efficiencies.

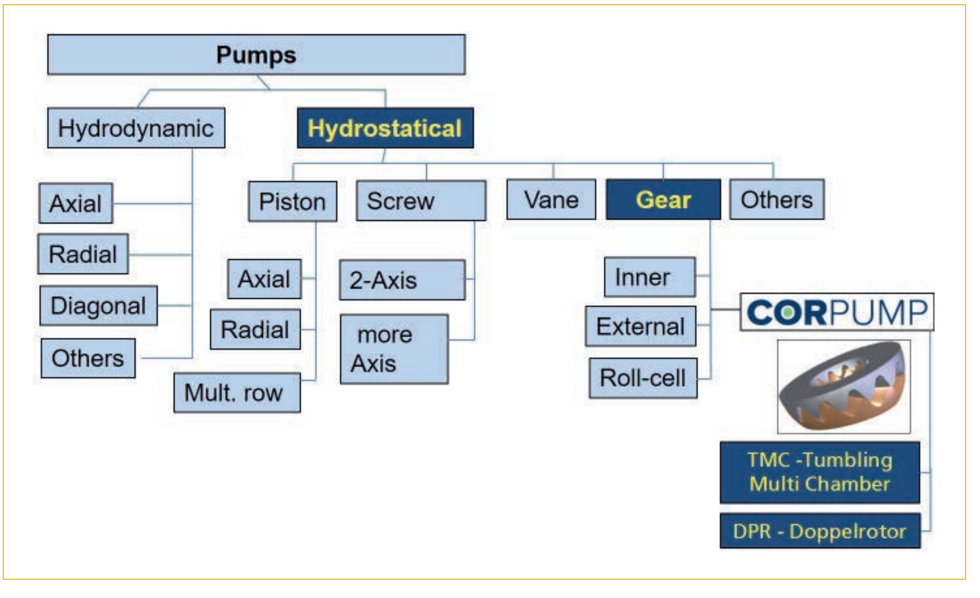

Figure 1 Pump technology classification

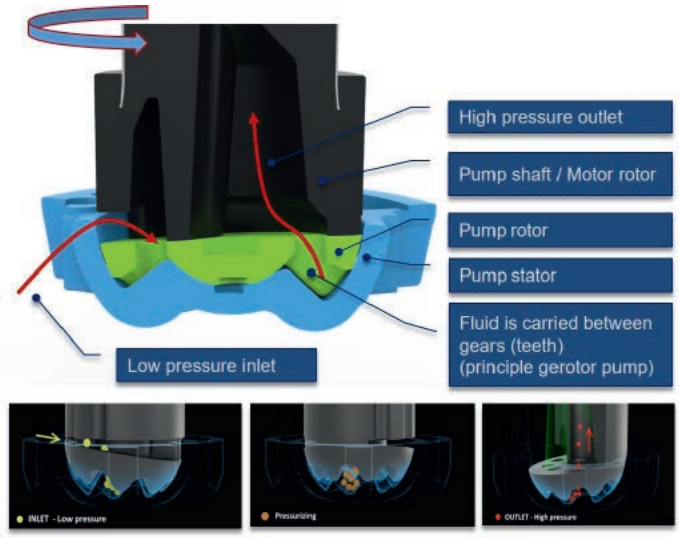

Figure 2 Basic components and engagement of fluid @ COR pump technology

Basically the pump design is based on 3-dimensional trochoid gear shape with function of pulsating chambers for volume displacement. The operating principle is based on the formation of the separate chambers, closed by two gearing topographies. When rotated, the chambers open (grow) and close (shrink) simultaneously and control fluid displacement precisely. Connection of the pulsating chambers with suitable control openings (with matching contours) results in the displacement effect. One of basic outputs of this pump design is pressure separation effect. The enveloping part (pump housing) also serves as a separating element between the pressure side and the suction side.

Compared to machining or die-casting, rapid, cost-saving material processing methods such as short cycle-time injection molding allow high-volume production, often with no secondary steps. Nonetheless, many automotive parts are made from metal. The applicative temperature and dimensional demands are often the deciding factors in terms of material chosen.

However, new developments in high dimensionally and thermally stable polymer resins and molding tooling techniques have shifted that balance, expanding the range of applications for which polymer materials may be used. One example of an automotive component now amenable to be made from high dimensionally and thermally stable polymer material is the COR pump technology where most important and demanding components are made with injection molding production process.

The COR pump is a new pump technology in group of positive displacement pumps. Basic pumping idea came from the axial piston pump family. The COR technology consist of 2 pumping principles: DoppelRotor (COR-DRP) and Tumbling multi chamber (COR-TMC). The COR pump system consists of 4 pieces of which 2 are rotating. No valves are needed. Most of the torque is converted into useful work as only one of the two rotating pieces is driven. Due to the design concept, the second one only needs torque to overcome its friction. The fluid is transferred through the center of the pump and transferred with the help of moving cavities and centrifugal force to the outlet on the periphery.

Figure 3 Exploded assembly of Pump Stator/ Rotor with Pump-Motor Shaft

COR-DRP is analogous to a non-orbital ge-rotor pump, as the fluid between the teeth is displaced by different rotational speeds of the rotors. COR-TMC is analogous to an axial piston pump, as the fluid is displaced by opening and closing of chambers.

The COR pump consists of a pump stator with a 3D inner gear shape with n teeth and a pump rotor with n+1 teeth, which fits on the stator shape under a certain angle. The gear shape (teeth) is arranged axially and the shape of the teeth enables simultaneous engagement, which ensures sealing between individual interdependent gaps.

COR pump advantages over other types of pumps are:

- Economically interested production price (all pumping parts are produced with injection molding of dimensionally stable polymer material with high mechanical & thermal performance),
- Robustness against particle contamination corrosion resistance,
- good hydraulic characteristics,
- small dimensions,
- high working pressure and
- bi-directional (backward) rotation.

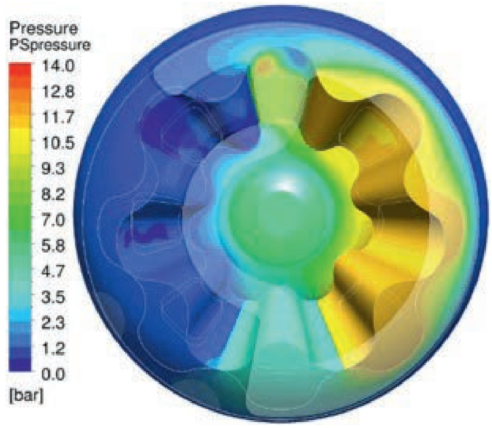

Figure 4 Pressure distribution on pump stator, which was obtaied from CFD analysis

Motion of the pump rotor is determined by the rotation of the rotor of the e-motor and with the position relative to the gear shape of the pump stator. Sliding movement occur on flat surfaces between pump rotor and the rotor of the e-motor.

Pump rotor rotates with 1/8 of the angular speed of the shaft. In addition, pump rotor makes a change angle around the apparent point above the upper plane on the pump rotor. Composed motion causes the inter gap between the stator's gears and the rotor gears. As a consequence, there is a vacuum (under pressure) on one side and overpressure on the opposite side that causes suction and displacement of the pumping medium.

Figure 7, which shows the assembly of pumping parts, where red co-color depicts the pressure area and the blue part depicts the suction side of the pump. In addition to a pair of pumping parts, the pump consists of a motor rotor and a stator of e-motor. Electric motor rotor has 2 journal bearings positioned between the magnet of e-motor.

Performance Parameters of COR Pump

The sources of performance losses in the pump are divide into mechanical-hydraulic and volumetric. Mechanically hydraulic losses are divided into mechanical due to mech. (contact) friction, and into hydraulic due to viscous friction in the gaps, friction due to turbulent liquid flows and friction due to the difference in pressure in the system. Volumetric losses also include compression losses due to internal leakage, and loss due to compressibility of pumping fluid. The purpose of hydraulic pumps is to convert the mechanical energy into hydraulic. Efficiency characteristic is the parameter-defining ratio between input energy and useful energy on the exiting side of the system. The hydraulic power is defined with product of torque value and angular velocity on the shaft which drives the pump rotor: Hydraulical power is define as the product of pressure difference (output-input) and flow of liquid. Overall efficiency is defined with conversion of mechanical work into hidraulical power.

$$Pmeh(t) = M\ x\ \omega \quad | \quad P_{hidr} = \Delta p\ x\ Q \quad | \quad \eta_{m,h} = \frac{P_{hidraulical}}{P_{mechanical}}$$

In assembly, where electric motor is part of the pump, total efficiency of the system is defined as the ratio between hidraulical power on input and electrical power given from e-motor. Electric power is equal to the product of the DC current and the electrical voltage UDC. Total efficiency of pump is given as a combination of electrical current and voltage, pressure difference and liquid flow. The total efficiency of the pump can also be defined as product of volumetric efficiency, mechanial-hydraulical efficiency and efficiency of e-motor.

$$\eta_{pump} = \frac{P_{hidraulical}}{P_{electrical}} \quad | \quad \eta_{pump} = \frac{\Delta p\ x\ Q}{I_{DC}}\ x\ U_{DC} \quad | \quad \eta_{pump} = \eta_{vol}\ x\ \eta_{m,h}\ x\ \eta_{EM}$$

The volumetric efficiency is influenced by compression losses and losses due to internal leakages. Leakages within pump unit relate to the size of gaps between pump elements, pressure difference (input vs. output), rotation speed, volumetric displacement and viscosity of fluid. Volumetric efficiency is defined as the ration between real output flow and theoretical volumetric flow defined by pump ideal geometry. In positive displacement pumps, flow of a liquid is linearly correlated to rotation speed.

The internal leakage is one of the biggest sources of pump efficiency losses, through which the geometry is strongly influenced by the manufacturing process. It appears in the 3D shape of pump parts and in air gap in journal bearing of e-motor.

Flow-rate Simulation (CFD), Motivation, Goals & Results

To define best approach for CFD simulation of COR pump an review of the different methodologies used for the simulation of the flow rates generated by ge-rotor, external gear and crescent pumps was elaborated. Studies taking into account the influence on leakages of the interactions between the fluid and the mechanical parts where analyzed. The COR pump system includes a sophisticated software which enables to study the behavior of the fluid in four dimensions and to optimize conditions with regard to a given specification. The software also generates the necessary CAD data for the design of a pump.

Goals achievable with CFD simulations in R&D phase of COR pump:

- flow & flow ripple calculation
- pressure field & pulsation analysis
- volumetric loss calculation
- viscous loss calculation
- torque calculation
- volumetric, mechanical & total efficiencies

CFD simulation steps in COR pump technology consist of:

- Proparation of the geometry
- Mesh generation on pump parts, static & rotating geometry
- Setting of initial & boundary conditions (pressure, speed,..)
- Solving + monitoring the solution
- Results analysis

One important simulation step is mesh independence study where test of different mesh refinements are done to find optimal mesh density. Basic study of CFD simulation on COR pump technology was done on COR200 pump used for different applications in automotive industry (diesel fuel pump, ICE water injection pump, oil lubrication pump). Theoretical flow @ 3000 RPM is designed for 140,6 l/h. Simulated flow result at 0 bar is 140,0 l/h , at 10 bar 135,7 l/h. Simulated from ripple at 0

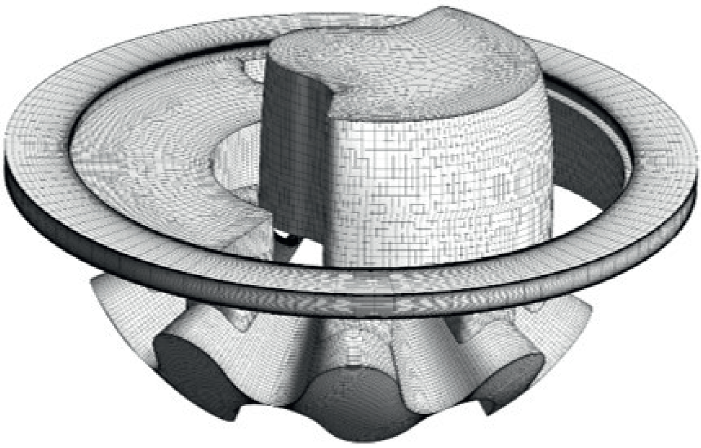

Figure 4 3D Morphing mesh setup for CFD simulation

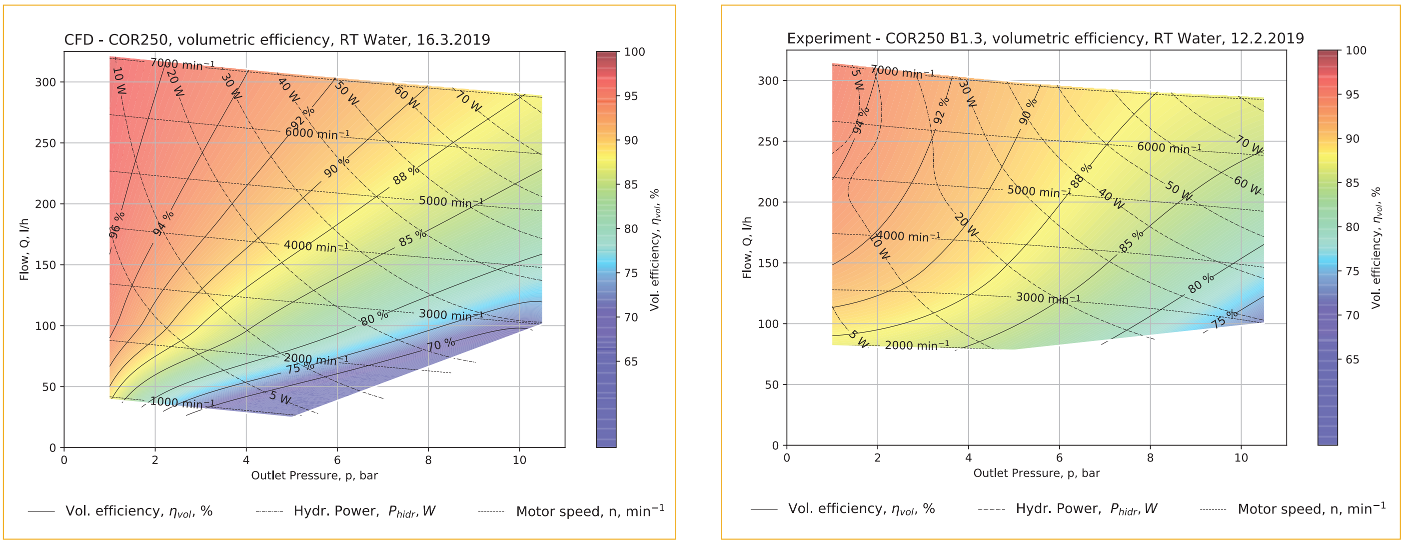

Figure 5 COR200 Pump Volumetric efficiency (water @ room temperature). Comparisson between CDF simulation (left) and experiment (right)

bar is 8 l/h (5,8 %) and at 10 bar 9,2 l/h (7,3 bar). During CFD simulation, also calculation of 5 leakage paths was done with analyzation of separate contributions. Comparison of CDF simulation and experimental result shows lees than 5 % difference.

Experiment & Validation Results COR200

Beside CFD simulations, physical validations and performance testing performed on COR pump technology under different conditions. Pump design with integrated motor. Reference performance testing done on COR200 pump in water liquid at room temperature. Results show stable flow at constant e-motor speed at pressures up to 10 bar. Volumetric efficiency up to 90 % observed at flow around 180 l/h up to 10 bar. Same pump design were tested in oil fluid at temperature range between −20 °C and 80 °C to determine electrical power change (increase / decrease) due to change of viscosity of oil. Characterization of COR200 pump at different pressures and temperatures show stable flow of liquid and different testing conditions (temperature, pressure). Performance testing in transmission oil at 50 °C done on COR200 pump with integrated motor done up to max pressure of 7 bar (flow around 200 l/h) and/or flow up to max 300 l/h at 2 bar of pressure. Maximal power consumption of integrated motor/controller can be up to 230W. Noticed volumetric efficiency over temperature rage −20 °C – 80 °C is >90 %, with overall system efficiently up to 70%. Pressure drop over pressure range was measured in range <1 % / bar).

Durability testing done at 60 °C at constant pressure of 3 and 7 bar. Flow drop in range 3 – 8 % was noticed in duration of 10.000 h. 3D optical scanning of surface on pump elements shows wear in range 5 – 20 microns and confirm that pump has self-adaptive behavior during lifetime.

Performance testing at pressures up to 20 bar done with external e-motor in speed range between 1000 and 5500 RPM at temperatures between −10 °C and 80 °C. Results shows >96 % of volumetric efficiency at temperatures between 0 °C and 30 °C. Drop of volumetric efficiency <1 % / bar was observed over tested pressure range. Required torque between 0,2 – 0,4 Nm was measured to achieve pressure 5 – 20 bar at −10 °C with aprox 50 % of torque decrease at temperature 80 °C. 60 – 75% of pump total efficiency in pressure zone 5 – 20 bar at temperature of oil 80 °C measured.

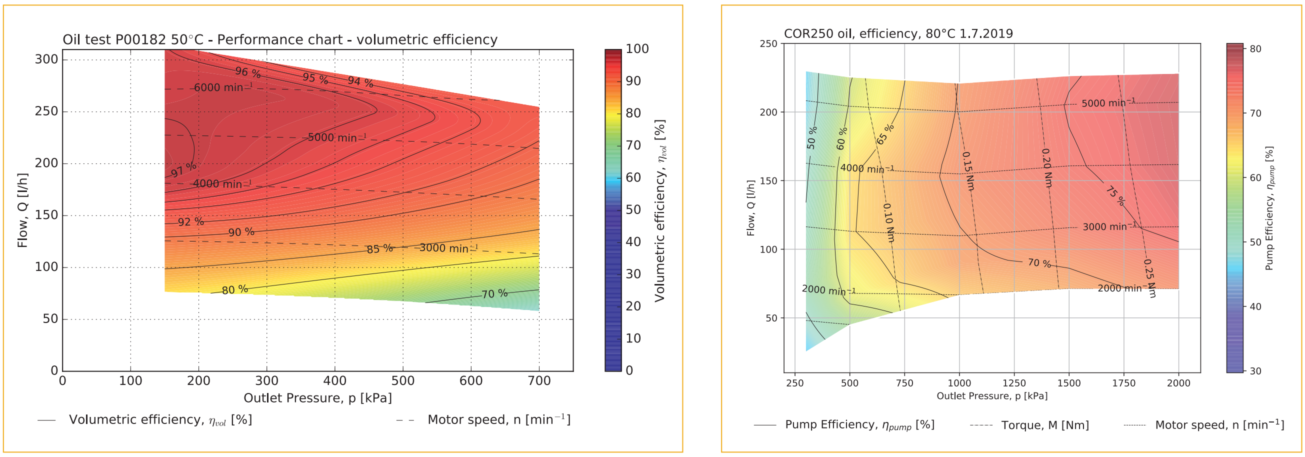

Figure 6 COR200 Pump Volumentric efficiency (oil @ 50°C) – left, and COR200 Pump total efficiency (oil @ 80°C) – right

Experiment & ValidationResults COR600

Pressure (bar)	Flow (l/h)	Motor Torque (Nm)	Temp. (°C)	Pump efficiency (%)
5	550	0,5		45
15	550	1,1	30	65
25	550	1,75		70
5	500	0,4		46
15	500	1,25	100	52
25	400	1,9		45

COR600 pump prototype designed and produced to test pump performance up to 25 bar and flow up to 1000 l/h. Motor torque measurements at different temperatures of oil (30 °C and 100 °C) for output pressures between 3 and 25 bars and liquid flows between 100 l/h up to 1000 l/h done at motor speed range 1000 – 5000 RPM. Table represent required motor Torque at different output pressures & fluid temperatures at motor speed 3000 RPM and output flow between 400 and 550 l/h

Volumetric efficiency of pump unit at output pressures from 5 to 25 bar measured in range 93 – 97 % at output liquid flow between 200 and 800 l/h at oil temperature 30 °C.

At 100 °C, oil temperature volumetric efficiency dropped for aprox 10 % due to lower liquid viscosity and consequently increased internal leakage in pump unit.

Conclusion – Benefits of the COR Pump Technology

The trochoid gearing is not fundamentally new. In an axial arrangement, however, it leads to complex free-form surfaces, which became manageable only with new computing design (FEA, CFD, ...) and production technologies (CNC, Ind 4.0, ...)

The COR technology allows the construction of a gear pump with very good overall efficiency for the range of middle pressures.

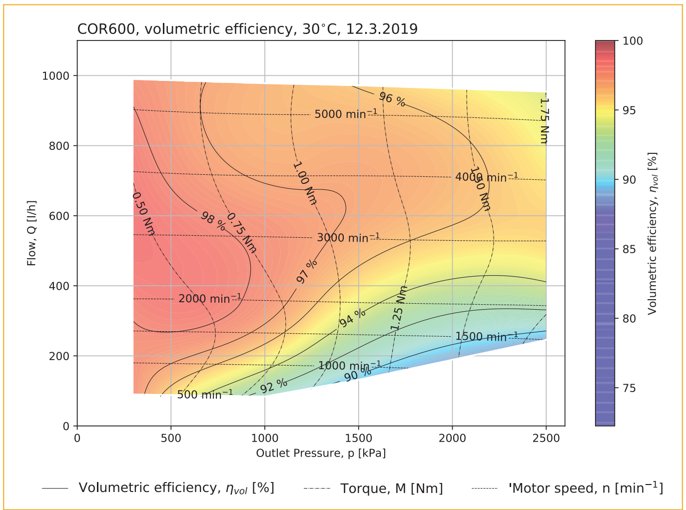

Figure 7 COR600 Pump volumetric Efficiency (oil @ 30 °C)

The feasibility of the COR technology in plastics leads to cost advantage. Due to the design variability of the gearing, the COR technology can be adapted for use in various media (liquids and gases). The trochoid rotating shape allows the simultaneous engagement of all gears, so that self-contained chambers arise.

The main advantages of COR technology are:

- Cost advantages, due to small number of parts and production in plastic injection molding,
- Low wear, due to hydraulic or pneumatic balancing of the rotors,
- Particle resistance, by axial displacement of a rotor,
- Self-priming,
- Pumping fluids and gas (2-phase possible),
- Simplified assembly / disassembly,
- High reliability (small number of components),
- High ratio : liquid displacement / pump size.

COR pumps are suited for – but not limited to – mobile and stationary applications using various drives (mechanical, electrical dry or wet running motors, others) as for example:

Pumps
- Oil Pumps (automotive, industrial, residential)
- Mechanically controlled oil pump (automotive)
- Fuel (diesel and gasoline) pumps (automotive, industrial)
- Circulator pumps for water (automotive, industrial, residential)
- Circulator pumps is solar application for water/glycol (industrial, residential)
- Pressure booster pumps for water
- Carbonator pumps for aqueous suspensions
- Chemical pumps for various liquids
- Transfer pumps for various liquids (portable or stationary)

Compressors
- Small compressors (automotive, industrial, residential)
- Compressor for fuel cells
- Compressor for refrigerant liquids
- Heat pumps

More information about COR pump technology

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