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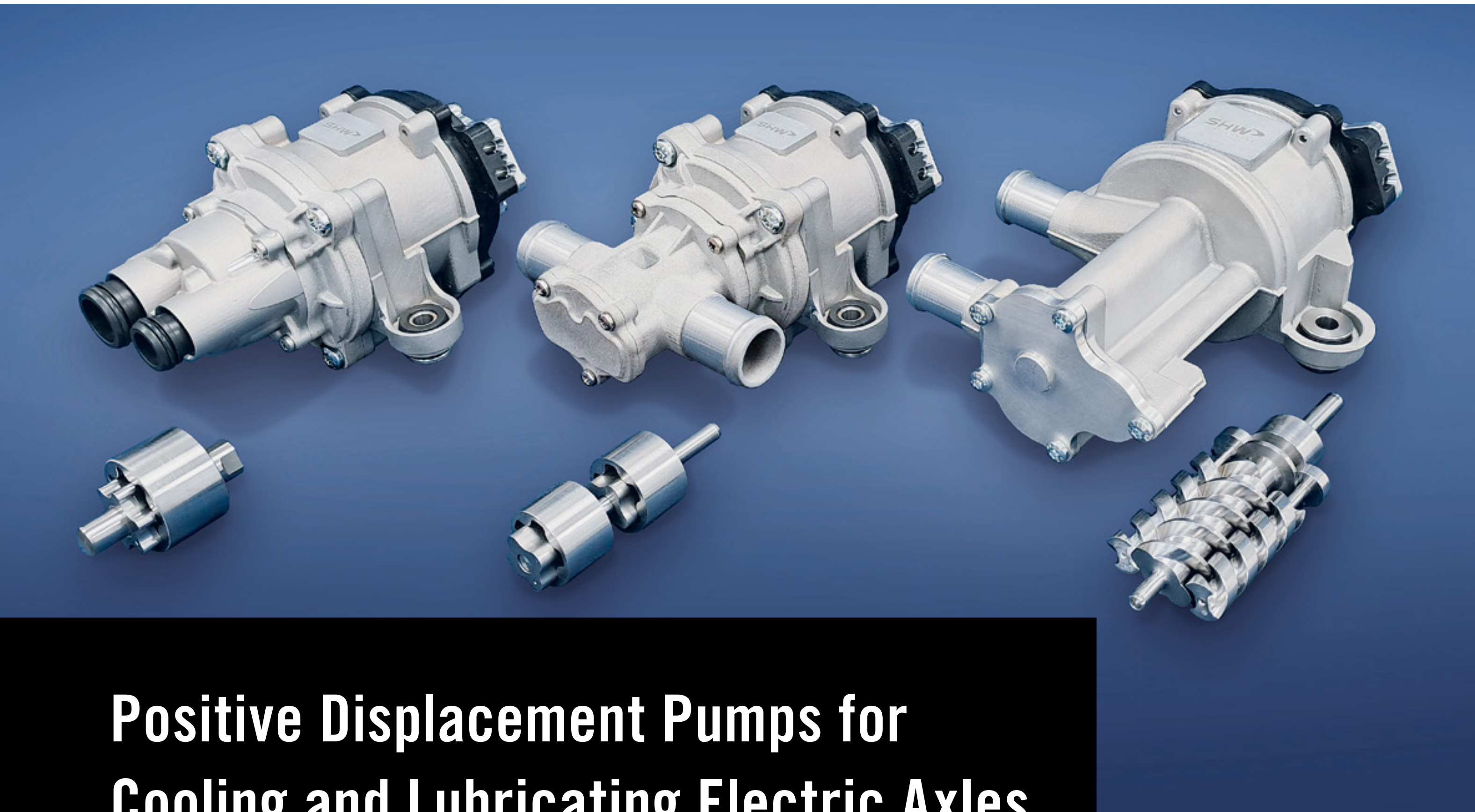
Thermal Management Systems

for Electric Axles with Electrically Driven Displacement Pumps

SHW



Positive Displacement Pumps for Cooling and Lubricating Electric Axles

To provide sufficient heat for battery and cabin heating in battery-electric vehicles despite the lower heat loss during operation, complex thermal management systems are required in which various cooling and lubricant circuits are used. SHW has investigated electrically driven displacement pump concepts for cooling and lubricating electric axles and presents optimization steps and new concepts.

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The significantly lower amounts of accumulated heat loss in Battery Electric Vehicles (BEVs) as compared to vehicles with combustion engines place high demands on thermal management. To provide the heat required to control the temperature of the traction battery and the vehicle cabin at low outside temperatures without significant loss of range, the functionality of the air conditioning system in modern BEVs is extended to include a heat pump mode. This makes it possible to diverge and raise the accumulated heat losses from the traction motor and electric axle drive via the heat pump to the temperature level required for heating the battery and cabin when operating the vehicle at low ambient temperatures [1]. Due to the low flow rates, higher delivery pressures and higher viscosities at sub-zero temperatures, positive displacement pumps are used for delivering the lubricating/cooling oil to BEV e-axles rather than centrifugal pumps. These electrically driven variable speed pumps are the favored choice for integration into compact oil management modules together with an oil/coolant heat exchanger and/or oil/refrigerant heat exchanger as well as a filter element and, if necessary, valves [2]. During a cold start drive-off at sub-zero temperatures (for example -30 °C), comparatively high amounts of heat loss accumulate in the e-axle due to the increased friction of the highly viscous lubricating/cooling oil under these conditions, which is then transferred as input energy (reservoir) to the heat pump circuit via the heat exchanger. This increased friction also affects the pump components moving in relation to one another resulting in an increased driving torque of the pump. To prevent overloading the pump at the low temperature operating limit and avoid oversizing the pump's electrical drive due to limited pump efficiency at the nominal operating point, it is beneficial to investigate the optimization potential regarding high overall efficiencies at high flow rates, but also low driving torques at low temperatures.

FIGURE 1 Test setup for measuring the pumps on the oil pump test bench (© SHW)

POSITIVE DISPLACEMENT PUMPS FOR ELECTRIC AXLES

Low viscosity lubricating oils are currently used for cooling and lubricating electric axles of BEVs. To minimize friction losses, the current trend is to further reduce the viscosity of these oils and to ensure sufficient boundary lubrication properties at high oil temperatures and heavy loads using additives [3]. Nevertheless, the low flow rates at relatively high delivery pressures still require the use of positive displacement pumps.

The sizing of the electric pump drive, designed as a brushless DC motor, and the associated control electronics, which define their costs and volumetric dimensions, is largely determined by the required power at the rated operating point as well as the maximum drive torque needed to overcome the viscous friction of the pump at the low temperature operating limit. This results in the demand for high overall pump efficiencies at the nominal operating point and the minimization of viscous friction on the pump's delivery elements. As opposed to mechanical pumps which are driven by an internal combustion engine, the variable speed of the electric drive offers the possibility of adjusting the pressure and flow rate of the pumped medium, regardless of the driving state of the vehicle, over a wide range using simply designed gear pumps.

The investigations presented here are based on a single flow Internal Gear Pump (IGP) (sample A, reference), that has long proven effective in electric pumps. This pump is compared with the prototype of a Dual Flow Internal Gear Pump (DFIGP), a so-called twin pump (sample B), designed for these tests. Aimed at reducing the friction radius and thus the driving torque, the delivery flow was divided between two identical individual gear sets in parallel with a correspondingly reduced diameter and number of teeth, driven by a common shaft and filled on both sides. These two IGPs are compared with a prototype of a three-spindle Screw Pump (SP) (sample C), which was also designed for this investigation.

For the design and optimization of positive displacement pumps and turbomachines, a broad portfolio of design and simulation tools are available, which are being continuously improved regarding the accuracy of the simulation results in close cooperation with the developers of the software manufacturers. For the exact prediction of the functional characteristics of IGPs, a template was developed which utilizes known component tolerances and operating conditions to calculate key functional data such as volumetric flow and driving torques during the design phase of the pump [4]. The particular conditions during a cold start at very low temperatures and very high oil viscosities require special simulation models that go beyond the assumption of isothermal conditions. To predict cold start behavior, an additional template was therefore developed that can simulate the heating of the fluid due to high viscous friction with known component tolerances [5]. This enables targeted digital development and simulative optimization of the pump topology and gear set geometry before entering the prototype phase. The designs of the IGP and DFIGP are based on the results of these tools.

MEASUREMENTS ON THE OIL PUMP TEST BENCH

The three concept samples were mounted one after another on the oil pump test bench, **FIGURE 1**, to measure the driving torque, volumetric flow and pressure pulsation as a function of the pump speed at 25 and 80 °C. The pump is mechanically coupled with the variable speed electric drive of the test bench using a torque measuring flange and a shaft coupling. The 3-bar delivery pressure difference can be adjusted with a throttle and is measured by absolute pressure sensors arranged close to the suction intake and discharge output. Additionally, a pressure pulsation sensor is also mounted near the pump's discharge output. The flow rate is measured by a screw spindle volume flow sensor. A data acquisition system records the sensor signals, which are then displayed in the desired format for evaluation and analysis.

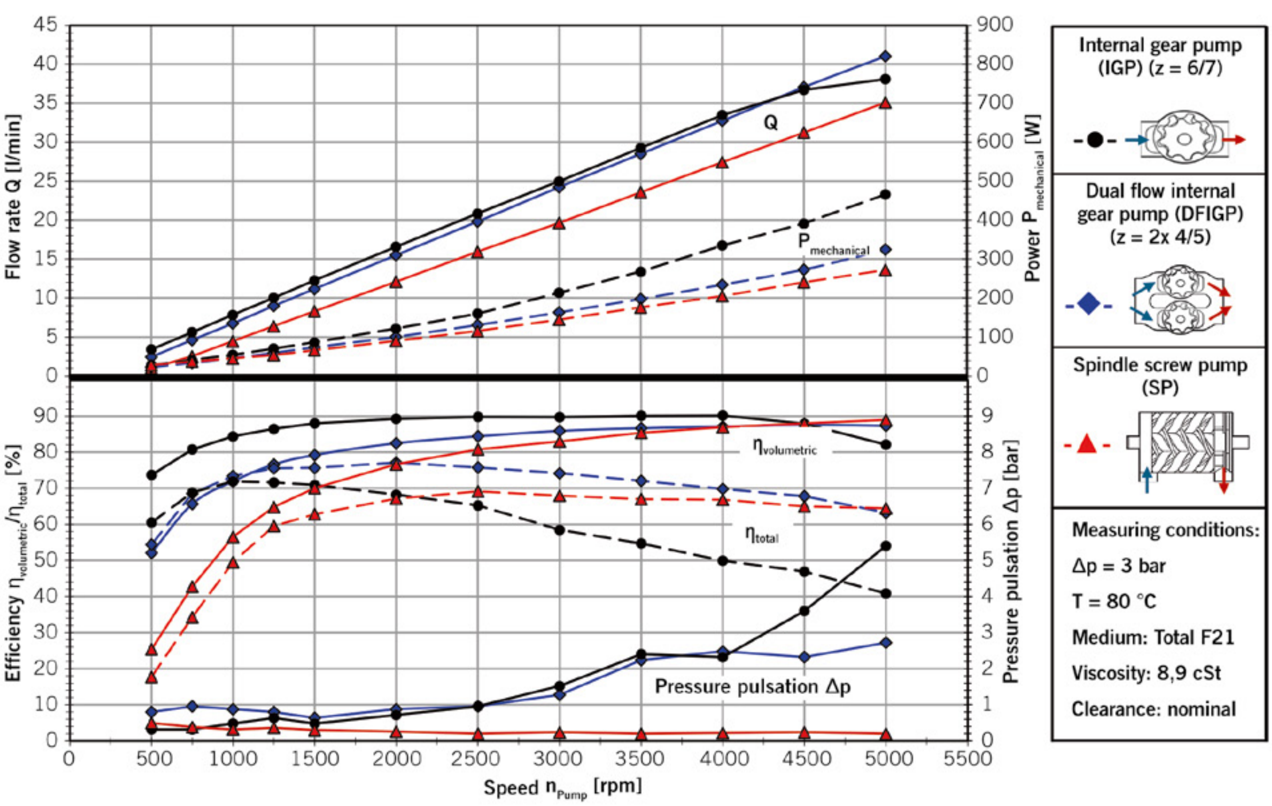
FIGURE 2 shows the volumetric flows, the mechanical driving power, the volumetric and total efficiencies and the pressure pulsation at the discharge output as a function of the driving speed for the three pumps tested at an oil temperature of 80 °C and an oil viscosity of 8.9 cSt. All pumps measured show the linear increase in flow rate with increasing speed as is characteristic of positive displacement pumps. Only for the IGP, the flow curve drops off starting at a speed of 4000 rpm due to the onset of cavitation. As expected, the IGP exhibits relatively high volumetric efficiencies, even at low speeds. Splitting the flow into two streams leads to lower volumetric efficiencies in the DFIGP due to longer sealing line lengths. The long linear sealing lines between the spindles also result in low volumetric efficiencies at low speeds for the SP, which also reduce the level of overall efficiency in this speed range. With increasing speeds, the volumetric efficiencies of the three pumps come together. Due to the viscous friction, particularly between the outer surface of the outer rotor as well as the end surfaces of the gear set to the housing, the overall efficiency of the IGP decreases steadily with increasing speed, while the overall efficiency of the SP remains between 65 and 70 % over a wide speed range. The overall efficiency of the DFIGP even reaches more than 75 % in the speed range between 1500 and 2500 rpm and approaches the values of the SP with a steady progression at 5000 rpm. Due to its design principle, the pressure pulsation of the SP is very low in the pressure line. The pressure pulsations of the IGP and DFIGP are significantly higher than the SP, but overall at an acceptable level. Only in the IGP does the pressure pulsation increase sharply when the cavitation speed is exceeded.

FIGURE 3 shows the corresponding measurement results at an oil temperature of 25 °C. As expected, the significantly higher viscosity (48.5 cSt) as compared to measurements at 80 °C causes an increase in volumetric efficiency at low speeds for all three pumps. At the same time, however, a steady drop in overall efficiency with increasing speeds results from the significantly increased viscous friction between the running gear and the respective housing surfaces.

MEASUREMENT OF STARTING TORQUES IN THE REFRIGERATION CHAMBER

In a second step, the starting torques of the prototype pumps were measured in the refrigeration chamber at -30 °C, at a speed of 400 rpm and a delivery pressure of 4 bar, **FIGURE 4**. Apart from an additional pressure relief valve and a torque measuring shaft positioned close to the

FIGURE 2 Comparison of the delivery characteristics of the pumps tested at an oil temperature of 80 °C and a delivery pressure difference of 3 bar (© SHW)



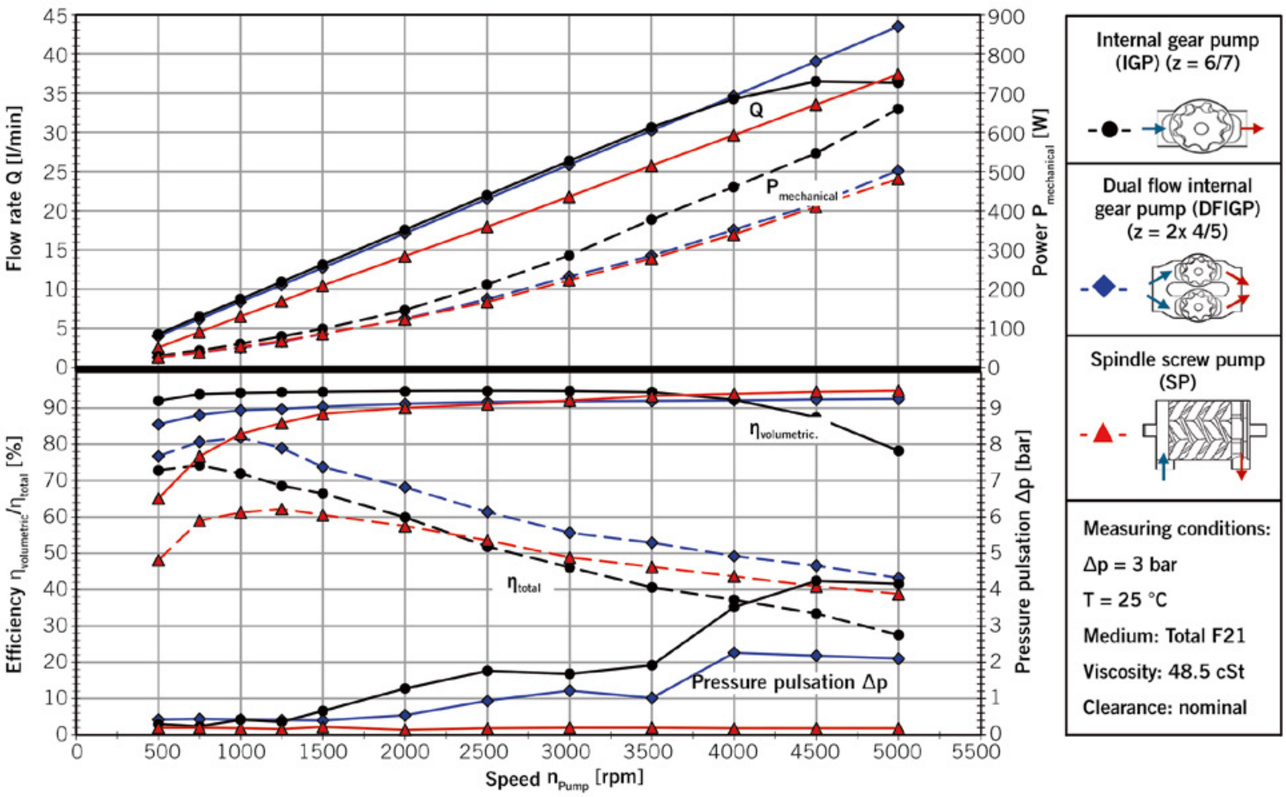


FIGURE 3 Comparison of the delivery characteristics of the pumps tested at an oil temperature of 25 °C and a delivery pressure difference of 3 bar (© SHW)

pump, the test setup, the measurement technology and data acquisition correspond to those of the oil pump test rig. **FIGURE 5** shows the time recordings of pressure, torque and volumetric flow of the pump during start-up. The driving torque mean values of the DFIGP with nominal clearances (blue curves) are on average more than 12 % lower than those of the IGP and also at a slightly lower level than those of the SP. By doubling the clearances between ring gear and housing (red curves) of the IGP and DFIGP as well as additionally doubling the axial clearances of the delivery elements to the housing (green curves), the driving torques at cold temperatures can be significantly reduced. However, increasing these clearances results in significant efficiency losses at low speeds and high oil temperatures.

FIGURE 4 Test setup for measuring the starting torques of the pumps in the refrigeration chamber at -30 °C (© SHW)

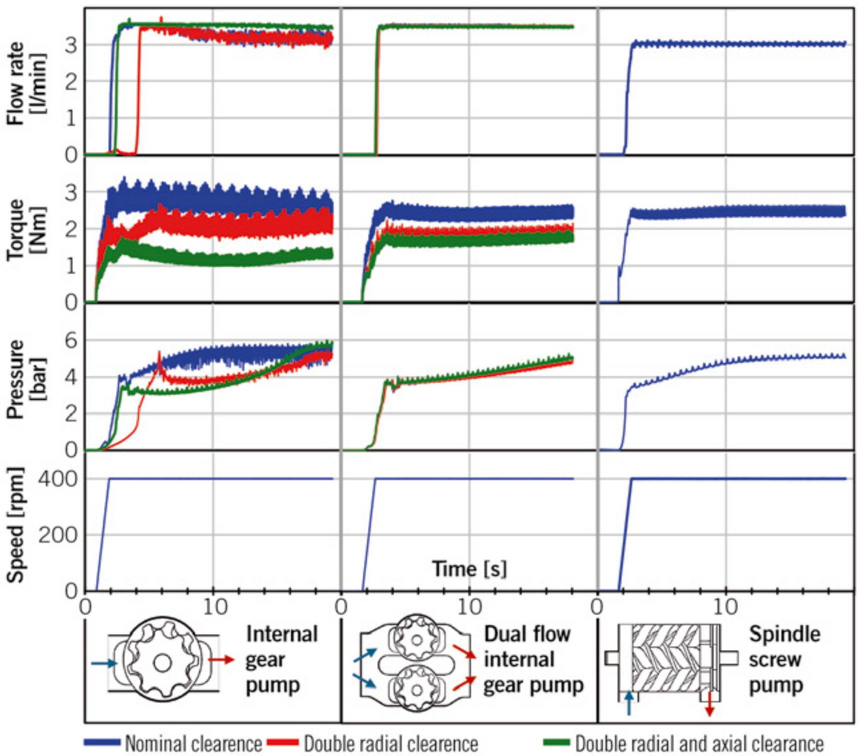


FIGURE 5 Comparative representation of the drive torque time records during the start-up of the pumps at -30 °C in the refrigeration chamber (medium: Total F21, kinetic viscosity 1779 cSt) (© SHW)

SUMMARY AND OUTLOOK

For electrically driven pumps, the maximum drive torque and the maximum mechanical drive power are the determining factors for the volumetric dimensions, the weight and also the costs of the electric motor and the associated power electronics. With this in mind, various positive displacement pump prototypes with comparable delivery rates for conveying cooling/lubricating media to electric axles of BEVs were designed, optimized in simulation, constructed and tested on test rigs at SHW.

In addition to a conventional internal gear pump which served as a reference, a dual flow internal gear pump, in which the flow rate of the single-flow IGP is divided between two correspondingly smaller individual gear sets driven by a common shaft and a three-spindle SP were investigated.

Due to the considerably reduced friction radii on the delivery elements, the DFIGP has a significantly higher overall efficiency at higher speeds compared to the IGP. At 80 °C, 3 bar delivery pressure and 5000 rpm, the overall efficiency of the DFIGP is 70 %, a remarkable 20 %-points higher than that of the IGP with the same delivery rate. Additionally, the cavitation limit is shifted to higher speeds. This opens up further potential for reducing the friction radius of the gear set as well as reducing the weight and dimensions of the pump and the electrical drive by increasing the nominal speed.

The measured results of the SP are at a comparable level, both in terms of overall efficiency and driving torques at -30 °C, to the investigated DFIGP. The SP only shows a clear advantage in terms of pressure pulsation, which is considered uncritical. The DFIGP concept developed at SHW presents a powerful and energy-efficient pump type that achieves the very high efficiency levels of a three-spindle screw pump with limited production costs and good scalability and is also applicable to additional high-volume applications beyond the BEV application considered here.

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