Springer Vieweg

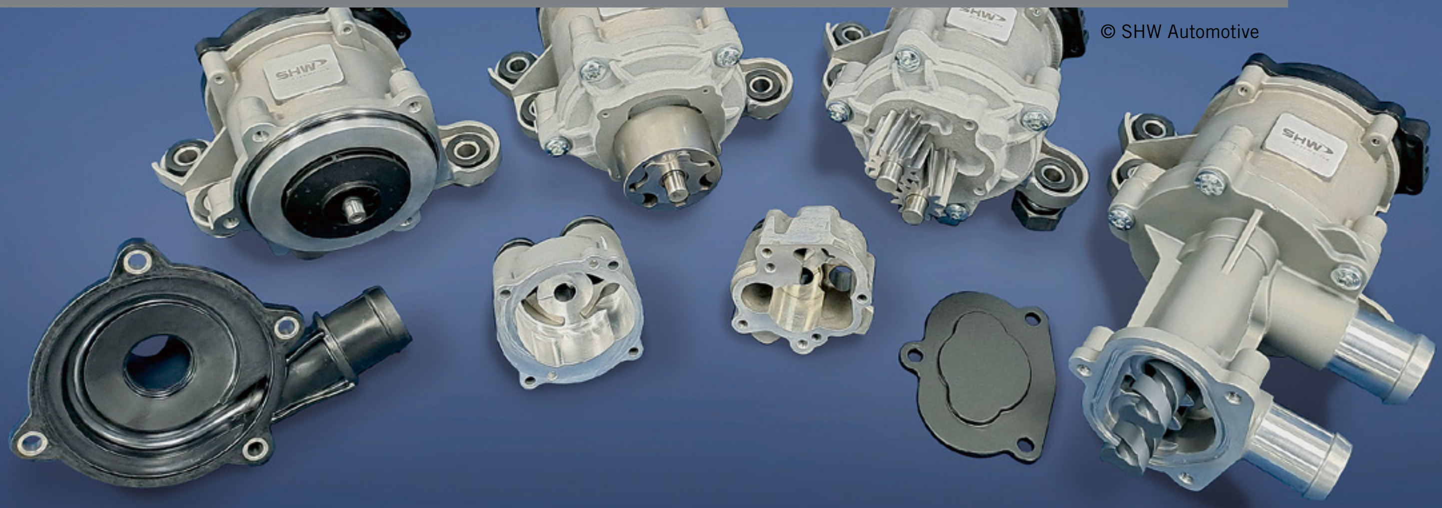
MTZ extra

THERMOMANAGEMENT

Comparison of Coolant Pump Concepts for Batterie Electric Vehicles

SHW

Concept Comparison of Electrically Driven Coolant Pumps for Battery Electric Vehicles



Temperature control of the battery cells is a key prerequisite for high-speed charging rates and long service lives of traction batteries. Cells can be cooled more effectively by circulating dielectric cooling media directly around them than by using base plates through which water-glycol mixtures flow. The physical properties of dielectric media and the high demands on energy efficiency require a different design of coolant pumps. This prompted SHW to investigate and evaluate possible alternatives to the centrifugal pumps used so far.

WRITTEN BY

Dr. Uwe Meinig
is Head of Advanced Development at SHW Automotive GmbH in Bad Schussenried (Germany).

Dominik Baur, M. Eng.
is a Design Engineer in Advanced Development at SHW Automotive GmbH in Bad Schussenried (Germany).

Significant amounts of heat must be dissipated to the environment via the cooling system and/or conveyed to the traction battery and the vehicle cabin for temperature control in internal combustion engine vehicles as well as in battery and fuel cell electric vehicles. Single-stage Centrifugal Pumps (CPs) are predominantly used for this purpose due to the relatively high flow rates and limited delivery pressures and now are almost exclusively driven electrically with variable speed control. Water-glycol mixtures are proven coolants for combustion engines as they offer advantageous properties regarding heat capacity, thermal conductivity and density. They are now also used for battery electric vehicles.

In order to further reduce the time required for fast battery charging and to avoid accelerated ageing of the traction batteries due to excess temperatures, manufacturers are working with alternative concepts for the temperature control of the battery. One option is to no longer cool the cells by coupling them to a base plate in the battery through which the cooling medium flows (drain cooling), but by using a cooling medium which circulates directly around the cells (immersion cooling).

A prerequisite for the practical implementation of this direct cooling concept is the use of dielectric (non-conductive) liquids (heat transfer oils). These cooling media are low-viscosity hydrocarbon compounds with densities up to 30 % lower than water-glycol mixtures, significantly lower thermal conductivity, and significantly lower heat capacities. As a result, the volumetric flow rate must be approximately doubled in relation to the desired cooling capacity [1].

In contrast to positive displacement pumps (gear, screw or vane pumps), CPs have a linear relationship between the density of the fluid to be pumped and the discharge pressure that can be achieved at a given pump speed. For this reason, a CP designed for water-glycol mixtures only achieves around two thirds of the delivery pressure when pumping dielectric coolants at the same speed. This central fact of CPs makes the use of variable speed, electrically driven positive displacement pumps particularly interesting for transporting low-density cooling media due to the greater independence between delivery pressure and volumetric flow rate. This article presents examples of various electrical pump concepts that could be used in temperature control systems of traction batteries in electric vhicles. It presents, explains, and evaluates the results of hydraulic measurements of several pumps on the test bench.

CENTRIFUGAL PUMPS

CPs are currently used almost exclusively as coolant pumps in automotive applications. CPs are turbomachines in which the kinetic energy of the rotating impeller is converted into the hydraulic energy (flow rate and pressure) of the fluid being pumped. According to the applicable similarity relationships of CPs, the driving torque of the pump increases quadratically with respect to delivery pressure (delivery head) while the driving power increases to the third power with respect to the pump speed [2]. Conventional single-stage CPs, **FIGURE 1**, used for pumping cooling media in cars can achieve an efficiency of approximately 70 % in relation to the mechanical driving power at the nominal operating point ($n_{nom.}$, $V_{nom.}$).

When pumping low-density media and/or for high delivery pressures, it is also possible to design multi-stage CPs, however with increased dimensions, costs and possible losses in efficiency.

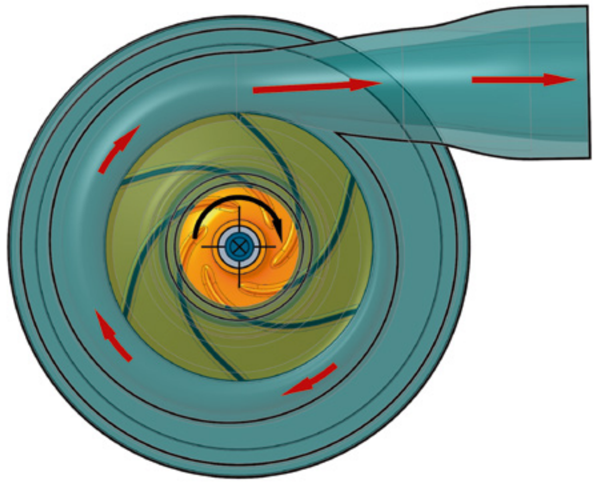


FIGURE 1 Illustration of a centrifugal pump (© SHW Automotive)

GEAR PUMPS

Gear pumps are positive displacement pumps that are designed either as External Gear Pumps (EGP), **FIGURE 2**, or as Internal Gear Pumps (IGP), **FIGURE 3**. If consequently designed, they can achieve a high efficiency over a wide speed range. Apart from leakage losses and the effects of cavitation, the flow rate is generally proportional to the angular velocity and substantially less dependent on the delivery pressure than the CP. Leakage losses only become proportionally significant in relation to the flow rate at low speeds and high delivery pressures, where the volumetric efficiency – the ratio between the actual and theoretical flow rate minus leakage losses – falls off more or less substantially.

Compared to vane pumps, the tribological interaction between the moving components is more favorable, so that in principle, gear pumps can also transport media with comparatively poor lubricity, such as low-viscosity cooling me-

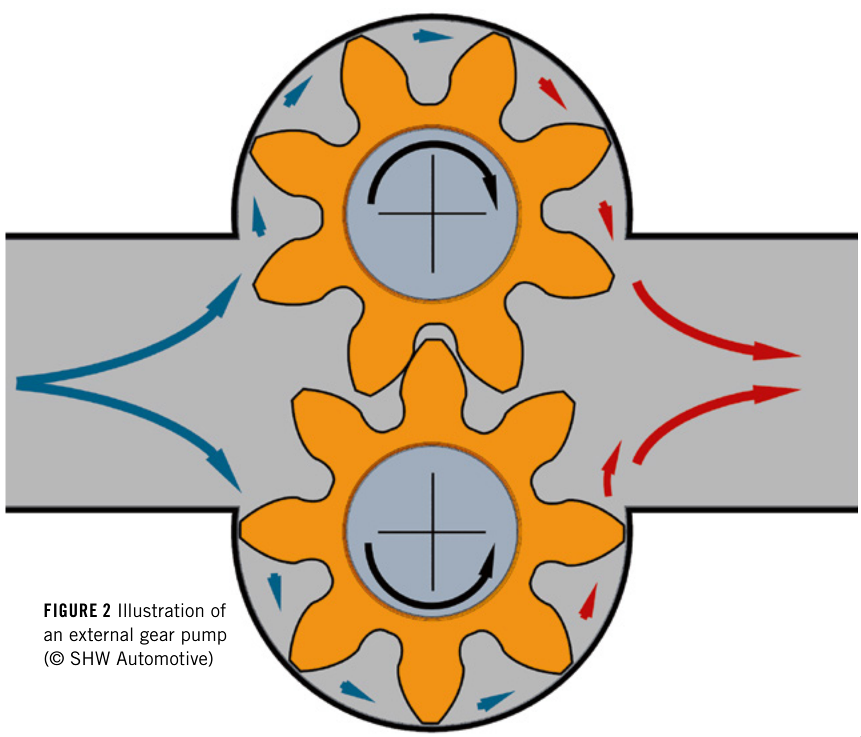


FIGURE 2 Illustration of an external gear pump (© SHW Automotive)

dia when designed suitably. IGP and EGP have two or more gear wheels that are meshed into one another and rotatably mounted with tight clearances in a housing equipped with pressure and suction ports. By rotating the pump shaft, the medium transporting pockets formed by the tooth gaps of gears and the housing walls are filled with fluid and moved from the suction side to the discharge side. The meshing of the teeth prevents the backflow of fluid from the pressure side to the suction side.

In order to prevent cavitation, the axial lengths and maximum operating speeds of the IGP are limited due to the axial filling of the transporting pockets through the suction kidney. In contrast, the EGP's medium transporting pockets are radially filled, which allows a considerably longer axial length and therefore a trimmer design.

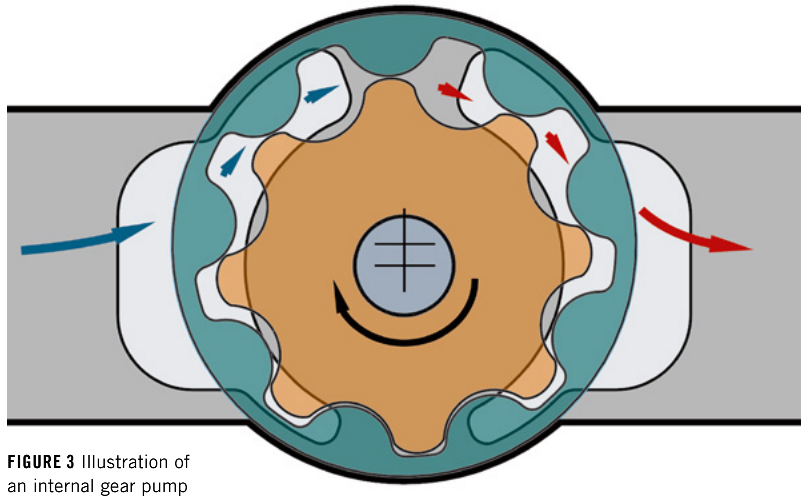


FIGURE 3 Illustration of an internal gear pump (© SHW Automotive)

SCREW PUMPS

The Screw Pump (SP), **FIGURE 4**, is a special type of EGP. In these pumps, the meshing gears are strongly inclined along the axis of rotation and thus take the form of threaded screws. The axial forces resulting from the helical gear thread are offset by axial thrust bearings either between spindles themselves and/or to the pump housing. Fluid delivery is continuous in the axial direction without significant pulsation. SPs can be designed with two and three spindles. The slim design of the spindles offers a small friction radius and the good tribological characteristics enable high mechanical efficiency as well as a high overall efficiency. However, the long linear sealing line between the transporting pockets demands high geometric precision of the spindles as well as low component tolerances of both spindles and housing which results in a significant cost disadvantage in terms of large-scale production.

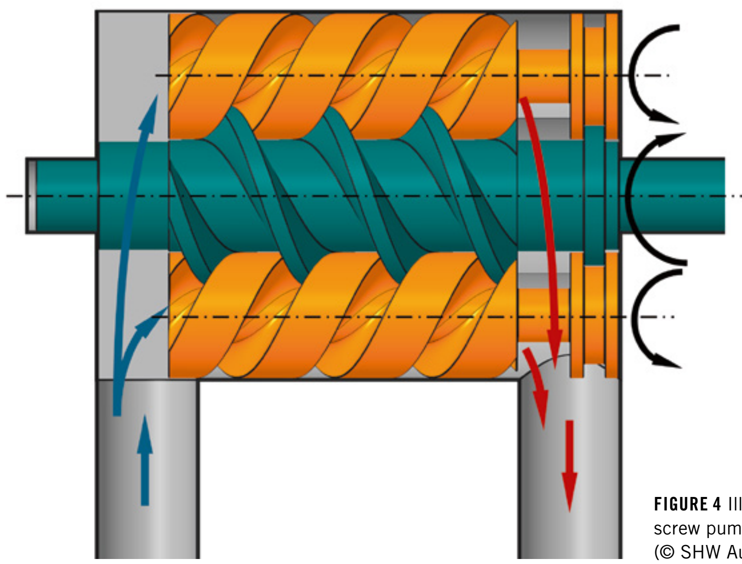


FIGURE 4 Illustration of a screw pump (three spindles) (© SHW Automotive)

MEASUREMENT OF THE VARIOUS PUMP CONCEPTS ON THE TEST BENCH

The mechanical power required to drive the pump as well as its efficiency essentially determine the weight, size and cost of the overall pump and in the case of electric pumps, the dimensions of the electric motor and the power electronics as well. This perspective forms the starting point for test bench measurements on a selection of various pumps with comparable delivery rates which are suitable for pumping dielectric fluids. The selection includes an EGP, an IGP, an SP and a CP.

The pumps were mounted with the same conditions sequentially on the test rig and operated at 3 bar. The flow rate and driving torque were measured in each case as a function of the driving speed. **FIGURE 5** shows an example of the setup used to measure the CP on the test rig.

The delivery pressure difference is determined from the recorded values of the pressure sensors located close to the suction and discharge ports, while the delivery flow rate is measured using a Coriolis mass flow sensor with low pressure loss. The test rig offers an adjustable medium temperature control from 20 to 130 °C as well as precise torque and speed logging. The sensor signals are recorded using a data acquisition system and then visualized in the desired form for evaluation and analyses.

FIGURE 6 shows the results of the measured pumps at 30 °C and 3 bar discharge pressure. The tested positive displacement pumps (EGP, IGP SP) achieve consistent high overall efficiency at low speeds. Except for the SP, the overall efficiency of these pumps drops significantly at higher speeds due to increasing fric-

FIGURE 5 Test setup for measuring the pumps on the test rig (© SHW Automotive)

tional power loss and when approaching the starting point of cavitation. The overall efficiency of the SP remains visibly high, over 65 %, up to 8000 rpm due to the considerably smaller friction radius of the thin spindles.

The tested CP was designed for water-glycol mixtures and exhibits low overall efficiency at low speeds compared to the positive displacement pumps. It then rises steadily with increasing speed to a maximum value of 55 % at 7500 rpm. The maximum delivery pressure difference at 8000 rpm of only 2 bar is due to the low density of the transported medium.

Increasing the maximum pressure to 3 bar is obtainable by modifying the design, for example, an impeller with low specific speed (n_q) or with a two-stage design. However, an increase in the overall efficiency is not expected. As long as the starting point of cavitation for the respective pump is not reached, the pressure pulsation of the four pumps examined remain at acceptable levels.

SUMMARY AND OUTLOOK

A number of car manufacturers are investigating direct cooling of the battery cells using heat transfer oil to realize very short charging times of traction batteries in electric vehicles. The significantly lower density and the enhanced lubricating properties of dielectric fluids as compared to water-glycol mixtures, result in modified boundary conditions for the conceptual selection and design of electrical cooling pumps.

Due to the physical principles of their design, (single-stage) centrifugal pumps can only achieve higher pressures and efficiency at high speeds, that is, when approaching the nominal working point. In contrast, positive displacement pumps deliver high pressures at low speeds with high overall efficiencies. However, the efficiency of gear pumps drops off more or less dramatically with increasing speeds depending on the concept and design of the pump.

In comparison, screw pumps can deliver high overall efficiencies over a wide speed range with good acoustic properties. The reasons for this lie particularly in the small friction radius due to a small spindle diameter and the continuous delivery of the medium. The major disadvantages of this design are the poor scalability with regards to flow rates as well as the high requirements on the geometric precision (tolerances) of the spindles in relation to each other and to the housing around the spindles. This is due to the long linear sealing zone between the spindles and makes it much more difficult to use cost-effective plastic parts.

Under the condition that car manufacturers, when using dielectric fluids,

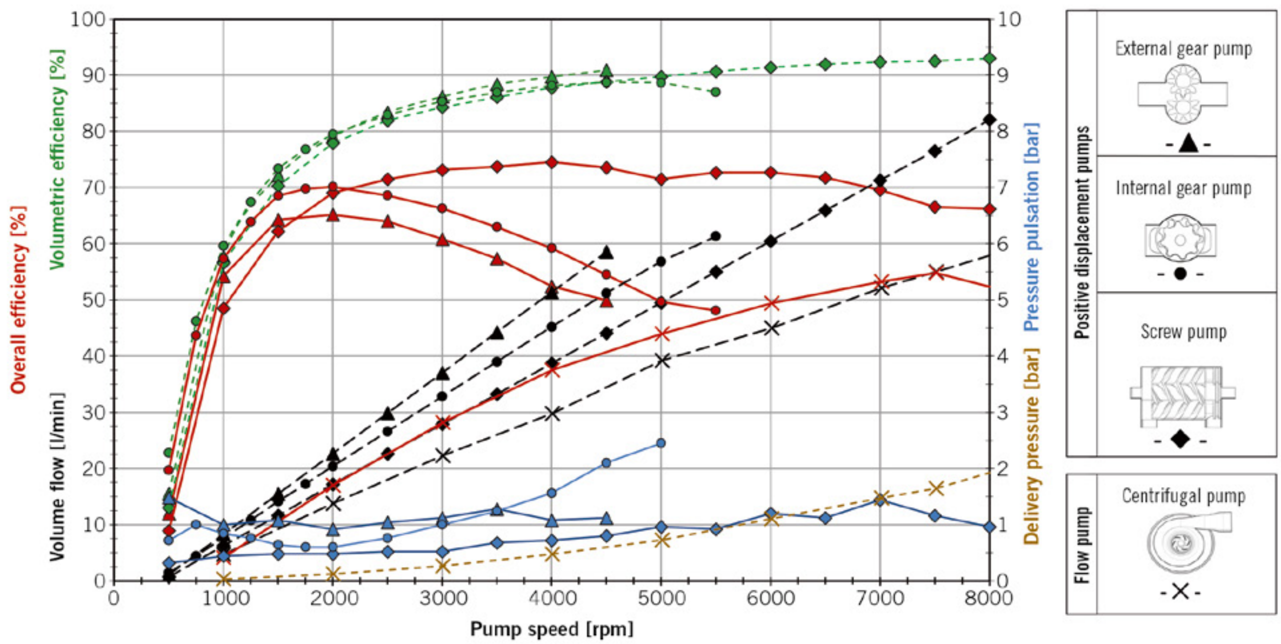


FIGURE 6 Comparison of the delivery characteristics at 3 bar delivery pressure; pumped medium: heat transfer oil: 2.8 cSt and 30 °C; density: 778 kg/m³ (© SHW Automotive)

require delivery pressures where single-stage centrifugal pumps reach their conceptual limits, it is worthwhile to investigate the optimization potential of conventional positive displacement pumps in more detail. A report on the results of these optimization steps is planned for a follow-up article.

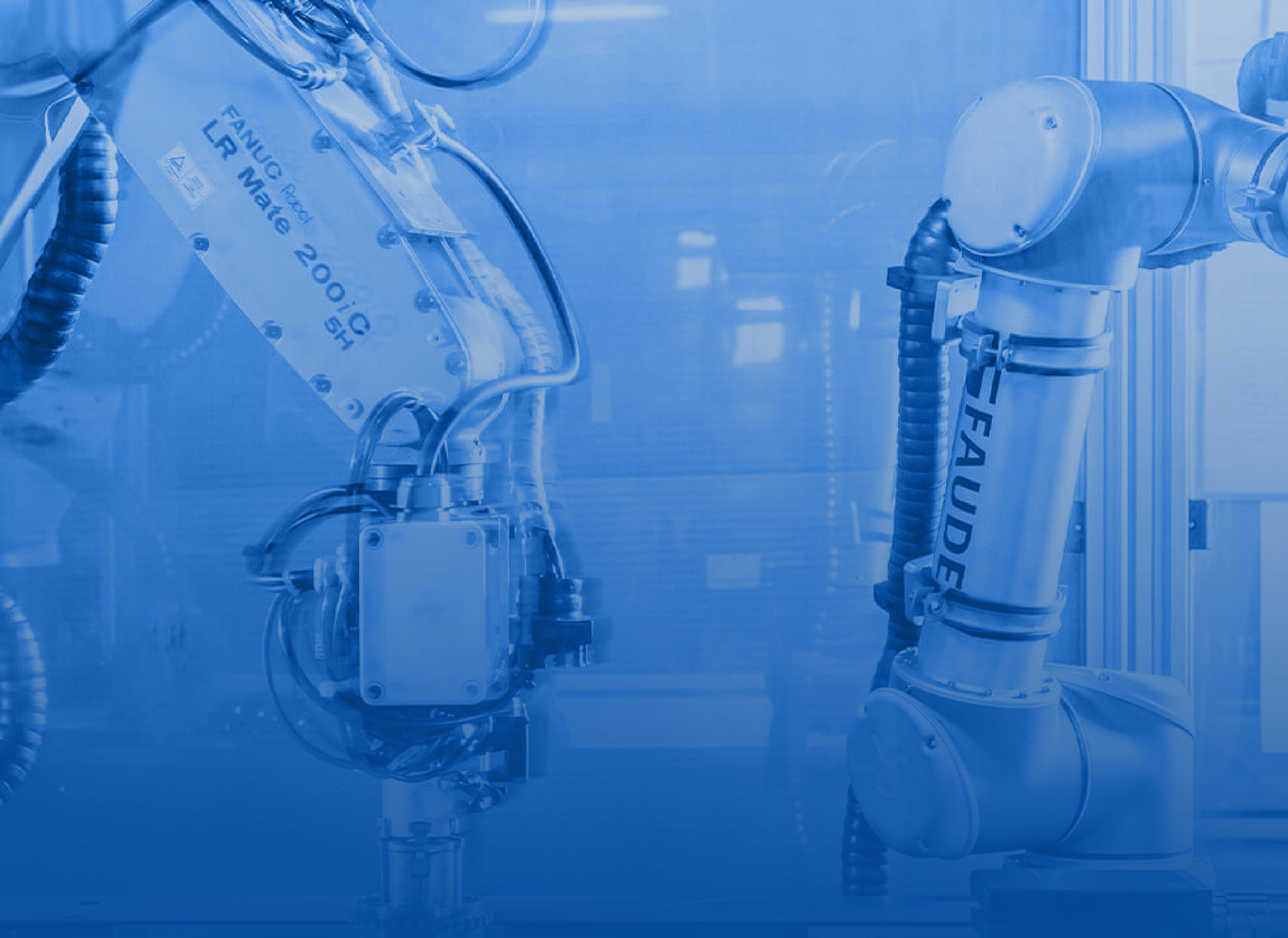
REFERENCES
[1] Azzouz K.: Novel Thermal Management Module for Batterie Immersive Cooling. European EV Thermal Management Summit, Frankfurt am Main, 2023
[2] Gülich, J. F.: Kreiselpumpen – Handbuch für Entwicklung, Anlagenplanung und Betrieb. Wiesbaden: Springer Vieweg, 2013
[3] Tschöke, H.; Gutzmer, P.; Pfund, T. (eds.): Elektrifizierung des Antriebsstrangs Grundlagen – vom Mikro-Hybrid zum vollelektrischen Antrieb. Berlin: Springer Vieweg, 2019
[4] Liebl, J.; Lederer M.; Rohde-Brandenburger, K.; Biermann, J.; Roth, M.; Schäfer, H.: Energiemanagement im Kraftfahrzeug. Wiesbaden: Springer Vieweg, 2014
[5] Meinig, U. et al.: Energieeffiziente Nebenaggregate – Schlüsselkomponenten für energetisch optimierte Fahrzeuge. Expert-Verlag, 2017

IMPRINT:
Sonderausgabe 2024 in Kooperation mit SHW Automotive GmbH, Enzisholzweg 11, 88427 Bad Schussenried;
Springer Fachmedien Wiesbaden GmbH, Postfach 1546, 65173 Wiesbaden, Amtsgericht Wiesbaden, HRB 9754, USt-IdNr. DE81148419

MANAGING DIRECTORS:
Stefanie Burgmaier | Andreas Funk | Joachim Krieger

PROJECTMANAGEMENT: Anja Trabusch

COVER PHOTO:
© stock.adobe.com, zhu difeng | SHW Automotive



SHW Automotive GmbH
A member of the Pankl Group

Enzisholzweg 11
88427 Bad Schussenried
Telefon: +49 7361 502-1
E-Mail: info@shw.de

www.shw.de

Find us on social-media