WHITE PAPER

Innovative drives for a new type of displacement control

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1. Introduction

*Electrification of hydraulic aggregates has been the trend in recent years, and those found in commercial and off-road vehicles are no exception to the trend. This evolution favors the development of components such as energy-efficient axles with ever-higher performance. In valve-controlled hydraulic systems, it is actually the drive that is the key issue: It runs continually, and thus, constantly consumes energy, which instead of being used, is simply dissipated into the environment in the form of heat. Sonceboz has developed an innovative permanent-magnet motor which manufacturers can use to drive their hydraulic linear actuators with better performance.*

The advantages of the solution are obvious: this new type of displacement control regulates the volumetric flow extremely quickly and independently from the combustion engine in the vehicle. The maximum torque of the motor limits the system pressure. With the new drive, linear actuators position themselves precisely. The biggest improvement is the enormous gain in efficiency. This is because once the actuator is positioned, the pump motor stops and consumes no further energy. In addition, this solution dispenses with control valves, so that this new type of electro-hydraulic linear actuator is not only more energy-efficient, but is also more compact and saves weight. Initially, the main areas of application are electro-hydraulic steering systems and/or spring damping systems in vehicles of every type. These very economical actuators can also bring benefits for machine tools, processing machines, tracking systems for solar modules, and many other linear drive applications.
The growing trend toward electrically powered sub-systems is triggering the development of this new type of electro-hydraulic actuator. In general the electrification refers to the vehicle’s electrical infrastructure to supply electrical energy and in this regard the conversion of ancillary units. The consistent implementation of displacement control (Fig. 01) with use of the latest motors and associated controllers permits a considerable reduction of the energy loss inherent in valve-controlled systems. In addition, the simpler design of the new systems brings clear advantages in terms of reduced weight and lower costs, compared to valve-controlled systems. These systems offer optimum energy efficiency, robustness and they are free from hysteresis, especially under dynamic loads. These are major benefits, compared to electro-mechanical linear actuators, such as electric spindles that until now have been the system of preference in various applications with lower load requirements. The increased use of electro-hydraulic actuators such as those presented here is based on the potential for overload protection, the bandwidth of the hydro-mechanical drive ratio and the implemented capture of the position.

![Diagram](image)

**Fig. 1:** The variable volume flow is obtained from fixed displacement pumps, driven by variable-speed permanent magnet motors, thus enabling delivery of the exact oil volume required for the linear positioning of the cylinder.

Direct coupling of the cylinder position or steering position to the pump drive using displacement control means that neither the temperature nor viscosity of the oil has any effect on the accuracy of positioning. The precision and dynamic response of these drives are as high that an axle steering system can achieve speeds up to 100 mm/s without problems and with a positioning accuracy better than 0.1 mm.

These electro-hydraulic actuators allow an axle steering system to be combined as a complete unit, which is then very simple to install (Fig. 02). This unit consists of a hydraulic steering cylinder with an integrated position sensor, a fixed bidirectional displacement pump and an electric motor with integrated controller; together with a casing that acts as an enclosure. The casing can be matched
to the dimensions of the customer’s specific installation space, so that together with the oil reservoir a closed circuit is created. Only a battery connection and CAN bus/controller connection is needed. This latter component processes the steering signals, and issues commands to the motor for positioning the actuator. An over center valve in the linear actuator stabilizes the steering system. This ensures that the steering system maintains the set position of the steering cylinder until a new steering command is issued.

**Fig. 2:** The electro-hydraulic steering unit consists of a motor pump unit, a steering cylinder, and an electric controller. The system is very compact and easy to install; all that has to be plugged in are the connections to the CAN bus and the battery.

The steering-system allows the vehicle to traverse tighter curve radii, and makes maneuvering much easier and more precise. Conventional mechanical systems have failed to develop well enough, in order to satisfy the constantly increasing demands of aggregate electrification. In hydraulic solutions with valve control, the hydraulic unit runs continuously, consuming energy all the time. Consequently, such systems are not a viable option for the future, and in particular, are totally unsuited for use in hybrid vehicles.

Since 2005 electro-hydraulic steering systems with permanent magnet-excited motors have been used in fork-lift trucks. The advantages of this type of rear-axle steering system could be used, because fork-lift trucks won’t run on public roads. Due to the enormous high functional safety requirements for vehicles on public roads, such steering systems can currently be used only for pusher and tag axles of busses, commercial vehicles, and trailers. A clever concept guarantees safety when using such systems: in the event of energy loss a safety valve opens and either releases the pressure from the steering system into the reservoir or switches a hydraulic accumulator into the circuit. This ensures that if the wheels are no longer being steered, they will slowly return to the straight-ahead position. A redundant design of the steering system for the front axle steering of
agricultural machinery will probably assist the breakthrough to Steer-By-Wire, thereby making the underfloor linkages from the steering column redundant.

Electro-hydraulic linear actuators offer ideal conditions for axle steering systems. With highest precision, safety and economy they open up a very interesting potential for energy saving. Due to the omission of valves and other peripheral components they lead to a significant reduction in weight. Thereby they offer a major contribution to the optimization of the overall efficiency of the vehicle. The advantages of innovative displacement control can be used to optimum effect in rear-axle steering systems for busses, HGVs, and earth-moving and construction-site vehicles.

3. The drive system for the hydraulic power package

The key to this new approach to the solution concept is the use of highly efficient, permanent-magnet, synchronous motors (PMSM), or brushless DC motors (BLDC), from Sonceboz. Thanks to their very high power density, the CPM range of motors from Sonceboz has very high energy efficiency, and when coupled with a suitable controller, can be controlled with great precision. The exceptionally high controllability of these motors means that they can be used for direct actuation of the hydraulic cylinders via the pump. The volume that is delivered is most likely proportional to the displaced volume in the hydraulic cylinder, and hence, to the position of the piston rod. We speak of this as displacement control. In conjunction with the pump, cylinder, and position sensor, the motor constitutes a closed control circuit; within which the pump delivers oil for just the exact time, and with just the required flow volume demanded by the steering angle sensor to the ECU of the vehicle; until the required position of the hydraulic cylinder has been reached. A position sensor is incorporated into the hydraulic cylinder of the electro-hydraulic actuator, for the nominal-actual value comparison feedback to the controller. The positional accuracy of the cylinder is determined, not by the motor, but by the position sensor; it achieves a precision better than 0.1 mm.

Motors are available from Compact Power Motion (CPM) of Munich, now part of Sonceboz, with powers up to 3 kW for use in mobile machines, busses, and commercial vehicles, with 24-V on-board electrical systems (Fig. 02).

Based on the manufacturer system requirements, Sonceboz used an existing modular system, and took only a very short time to successfully realize a tailor-made, highly efficient, compact electric drive, with integrated control electronics. The drive system used here is based on the CPM90 range. The numbers represent the rotor diameter in millimeters. This is a brushless DC motor, with an external rotor, and integrated CAN bus-capable controller (Fig. 03). The power and control electronics are capable of high phase currents up to 225 A, for an electrical machine in 4-quadrant operation.
## 4. CPM90 product

**CPM90 product family**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>up to 3 kW at 24V and 6kW at 48V</td>
</tr>
<tr>
<td>Torque</td>
<td>up to 14 Nm (at 48V)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Ø 130 mm, length 118-140 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>1.3 to 3.5 kg</td>
</tr>
<tr>
<td>Voltages</td>
<td>24 to 72 V DC</td>
</tr>
<tr>
<td>Rotational speed</td>
<td>up to 7000 rpm</td>
</tr>
<tr>
<td>Connector</td>
<td>Integral, pin configuration to customer’s requirements</td>
</tr>
<tr>
<td>Controller</td>
<td>Instantaneous / speed control</td>
</tr>
<tr>
<td></td>
<td>Power / battery current control</td>
</tr>
<tr>
<td></td>
<td>Energy recuperation (4-quadrant controller)</td>
</tr>
</tbody>
</table>

**Fig. 3**: The CPM90 is a brushless, permanent-magnet synchro-motor with external rotor and has a fully integrated CAN bus-capable controller.

Based on appropriate simulations for the optimization of efficiency and costs, particularly under partial-load conditions, and with the necessary ability to withstand temperatures, the core length of the stator has been determined to be 45 mm, together with the number of windings per slot (n=9) and the residual induction class of the magnets. During the subsequent evaluation of the concept, this drive demonstrated its potential by achieving power consumption at certain points well below the reference points set as requirements by the OEM. These results, together with the integrated system implementation developed by the manufacturer, promise to make a major contribution to reduce the load on commercial vehicles’ on-board electrical systems, and achieving reductions in fuel consumption in operation (**Fig. 04**).
### CPM for rear-axle steering with pusher and tag axles

- **Power:** nominal: 1.7 kW
- **Torque:** nominal: 7 Nm
- **Dimensions:** Ø 130 mm, length 130 mm
- **Weight:** 3.5 kg
- **Voltage:** 24V DC (18-32V DC)
- **Rotational speed:** up to 3700 rpm
- **Protection class:** IP6k9k
- **Connector:** Integral, pin configuration to customer’s requirements
- **Controller:** Instantaneous / speed control
  
  Power / battery current control

![Efficiency Map](image)

**Fig. 4:** CPM90 Power Pack efficiency as a function of torque and speed

In the complexity of the overall system development and application, the concept of a drive with an integral controller, including matching application and diagnostic software, proved to be very efficient. The use of the modular e-drive CPM90 allowed the time for development and validation of the range of possible and simple variants to be greatly shortened. The motor and controller together form a unit with matched characteristics. This eliminates the need for subsequent selection and matching of the electric machine and the controller. Basic requirements such as the standards used in automotive industry and CAN communications were already incorporated into the concept evaluation. Necessary changes to the system controls could be implemented very simply, using the existing library of software.

This allowed the manufacturer to concentrate its full attention on the application and validation of the system within the vehicle. The sophisticated and user-friendly control and diagnostic software permitted the company to work efficiently when developing applications. A high torque density and efficiency over a wide operating range of the drive concept, together with an identical parts strategy,
due to the modular concept, opened up the path to further applications with lower or higher power requirements. The CAN bus capability and the compact design of the CPM90 series permit installation and system integration, without creating problems in complex overall systems (Fig. 5).

*Fig. 5: The flat and integrated design permits installation without creating problems in the customer's application.*

*Note: The values were determined on a system after warming up, with a coil temperature of 80 °C, rotor temperature of 60 °C, and an electronics temperature of 85 °C. Because of production tolerances and component tolerances, the performance data for individual systems may vary from the specified values by ±5 %.

5. Outlook

The range of possible applications for this new type of displacement control is very wide. It is a very simple and cost effective design, coupled with the energy consumption advantages of displacement control. It can be used with a pump that operates only when flow volume and/or pressure are required. Linear movements are generated by hydraulic techniques with a requirement for high actuation forces, in conjunction with good dynamics, and a challenging standard of precision for control and positioning. This opens up a wide range of innovative and very economical areas of application, even over and above axle steering.

6. New type drive developments open up new perspectives

The reduction of CO₂ emissions and the requirement for increasing energy efficiency of vehicles and industrial plants are a central challenge for today and tomorrow. In the development of new vehicles and machines the future belongs to compact and light-weight electric motors. For this growing market, Sonceboz offers appropriate developmental competence and a product portfolio consisting of motors, alternators, and controllers suitable for both vehicles, and power units.
The powerful CPM90 DC technology is suitable for a wide range of further applications. Apart from rear-axle steering, these are:

- Electro-Hydraulic Power Steering (EHPS)
- Intralogistics (drives for automatic conveyor vehicles) with the facility for recuperation
- Automotive/non-road systems (fans / air conditioning / pump drives)
- Electrically-powered recreational and service vehicles
- Electric scooters

Increasing the operating voltage to 48 V, for instance, allows the efficiency advantages of the concept to be transferred to higher power classes.
Our core competencies consist of design, development and production of mechatronic drive systems, and electric motors that operate in harsh environments. We are committed to improving safety, decreasing energy consumption, and minimizing the impact on the environment. Our focus on innovation, best in class quality, and unique service are the keys to our success for worldwide OEM customers and their suppliers.