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High efficient Hydraulic Actuator Valve Sensor Unit without dedicated hydraulic supply (HAVSU)

Ralph Wassermann & Florian Hölzle

MAGNET-SCHULTZ, info@magnet-schultz.de

Abstract

MAGNET-SCHULTZ, specialists for electromagnetic solutions, has combined the advantages of fluid-power with the energy efficiency of sustainable electrified drivetrains, since purely electric actuators often lack power density and robustness in the demanding environment of applications in powerful modern electric drivetrains (EV, BEV and PHEV).

The highly innovative development resulted in an Actuator-Valve-Sensor-Unit (HAVSU) like not seen before in the vehicle industry. Adapted to the specific environment and requirements of electric drive axles, such a unit can actuate functions like disconnect and park-lock mechanics and supplement or substitute purely electric actuators with their well-known weaknesses in regards of robustness and power density.

The unit can provide force and stroke to the mechanism of the axle with high power-density and speed of hydraulics and is fully scalable to many other mobile and stationary applications.

1. GOALS

The main goal was to create an actuator providing all necessary functions for the typical applications in modern drivetrains and beyond, combining the proven advantages of hydraulics, like high power density, speed and robustness with an innovative layout with significantly reduced complexity, most efficient use of resources and small CO_2 footprint from cradle to grave.

Precisely the goals were:

(1) Stronger than purely electric driven actuators
(2) Less complex than common hydraulic systems

(3) Smaller and lighter than electric driven actuators
(4) More robust and durable in operation than electric actuators
(5) Less resource demanding, sustainable in production and more cost efficient
(6) Development according to the requirements of functional safety as defined by ISO26262
(7) Scalable to as many applications as possible (passenger car, truck & bus, off-highway, aerospace, defence, industrial)

2. Initial Idea

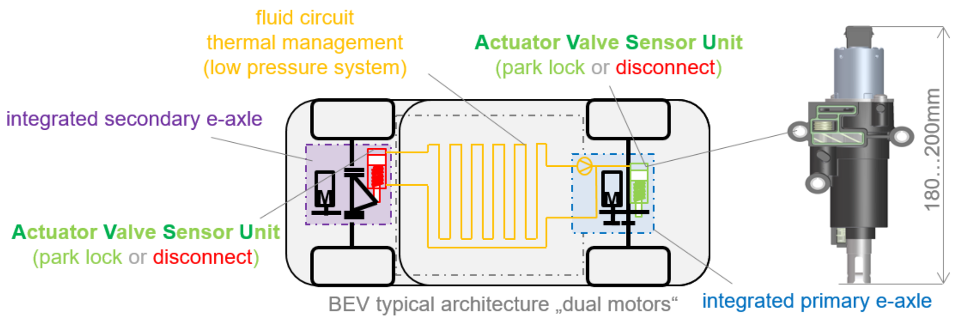

Figure 2.1: Typical architecture of a AWD EV

The invention has been inspired by the fact that e-axles generally need a thermal management or lubrication circuit to keep the system in an optimum state of operation. Thus, the creative idea was that exactly this fluid could be utilized in a second way to supply hydraulic actuators, even if initially not dedicated for this purpose.

But a major obstacle had to be overcome as a fluidic system primarily designed for thermal management is optimized to provide a high flowrate at low pressure levels and thus is not suitable to supply hydraulic actuators with sufficient pressure without boosting the fluid to higher pressure levels.

This innovative boost function is possible by blocking the hydraulic circuit for the very short actuation time of the actuator what leads to the pump working against a closed end. That on the one hand enables boosting the pressure up and on the other hand does not negatively affect the relatively slower responding thermal management system.

Once the actuator reaches its end position, the integrated solenoid-driven bistable locking mechanism is activated and secures the actuator stroke without the need of further supply pressure. After locking the actuator position, the integrated valve opens, and the thermal management is working freely with minimal pressure drop again.

To avoid an additional dedicated electrically operated pilot valve, the valve had to be part of the solenoid-driven locking mechanism, which is anyways necessary to lock the state of the hydraulically actuated cylinder. Thus, it became possible to actuate the bistable lockable hydraulic cylinder with the same solenoid as the pilot valve for pressure boosting. Summarized up and due to the dual use of the highly integrated subsystems, pressure boosting requires no additional actuation principle than the already existing from similar systems with a common hydraulic pressure supply.

3. Functional Components

The unit consists of eight collaborating subcomponents.

(1) Hydraulic actuator, piston and cylinder rod – providing external stroke and force up to 800N (further scalable)
(2) Position sensor – monitoring the stroke-position of the cylinder rod
(3) Pilot valve – controlling the state of the main valve
(4) Main valve – switching the flow of the fluid in circuit ON/ OFF
(5) Locking mechanism – Locking the state of the hydraulic actuator
(6) Electromagnet – operating the pilot valve and locking mechanism
(7) Housing – providing mechanical interfaces and ensuring structural integrity
(8) Electrical connection – connecting all electrical subcomponents and building interface to the higher-level system (power supply, communication, sensing, diagnosis)

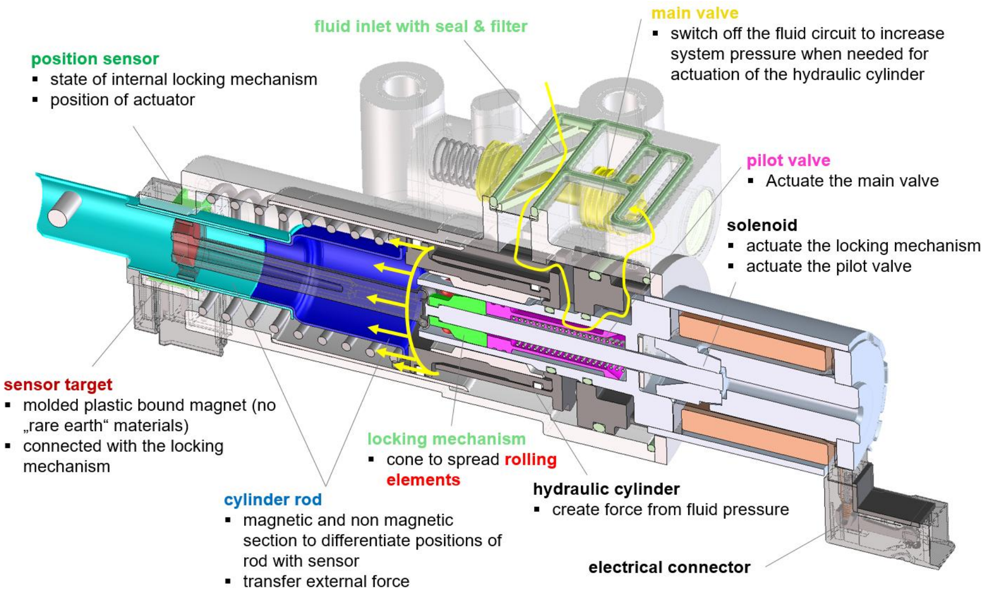

Figure 3.1: Integrated components and functions of the Hydraulic Actuator unit

The subcomponents are either controlled by the axle control unit (ECU) or with an onboard OBD-capable smart control unit as a ninth subcomponent.

All the required innovations of manufacturing technology to build those components were driven by MAGNET-SCHULTZ engineering. Especially the hybrid housing, spool valve and hydraulic manifold from thermoplastic materials and the two-component ferromagnetic / non-ferromagnetic cylinder rod. All chosen materials have been selected to be free of per- and polyfluoroalkyl substances (PFAS).

The weight of the unit is 0.46kg with a length of 180mm in the retracted position of the cylinder rod.

4. FUNCTION

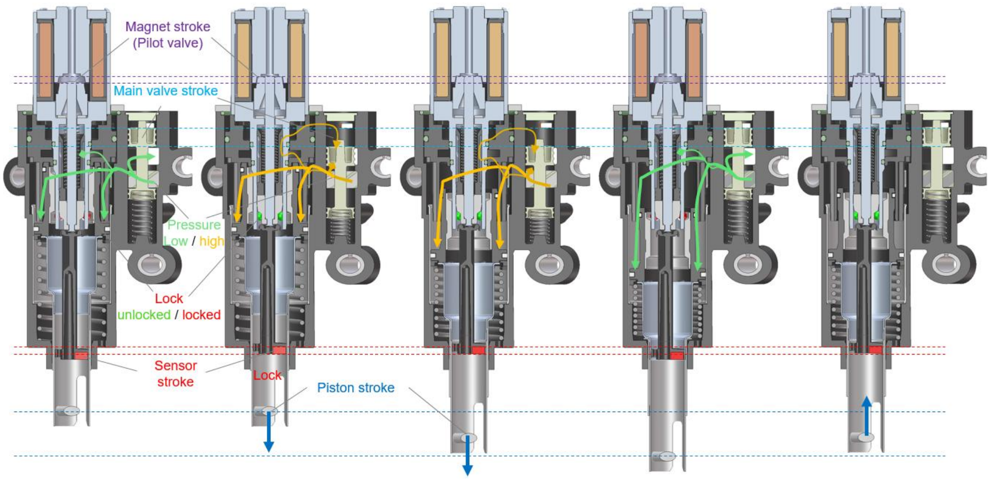

Figure 4.2: Main states of function of the Hydraulic Actuator unit

The HAVSU actuator can switch between five main states of operation.

First stage is the **Park State** (PS).

The solenoid is electrically OFF, no current flows through the coil. The locking mechanism is locked, the pilot valve is open. Pressure in the fluid circuit is low, and pressure drop in the main valve is very low, even if the pump is working at high flowrates. The hydraulic piston-rod remains retracted.

Second stage is the **Pressure Boost State** (PBS).

The solenoid is electrically ON, current is drawn. The locking mechanism, driven through the same armature rod as the pilot valve, is thereby released (unlocked) simultaneously with the opening of this pilot valve. Fluid is drawn from the main line and pilot pressure is applied to operate the main valve. The main valve closes to block the main circuit. Now the pump is triggered for increased performance to work against the dead end (closed line) what causes the pressure to rise immediately.

Third stage is the **Extraction State** (ES).

As soon as the pressure reaches the level needed to overcome the force of the return spring mounted on the cylinder rod, this cylinder rod starts to extract till its end stop. During this movement the boost pressure reaches its maximum.

Fourth stage is the **Drive State** (DS).

After the cylinder rod hits its end stop, the solenoid is switched OFF. The locking mechanism toggles to locked and the pilot valve releases the pilot pressure from the main valve; both through spring pretension. The cylinder rod is locked in the extracted position to remain in drive without pressurizing what means the boost pressure is no longer needed and falls back to normal mode.

Fifth stage is the **Retraction State** (RS).

If the retraction of the cylinder rod is desired, the first cycle "Boost stage" is repeated but with the pump switched OFF, so that the pressure reliefs. The locking mechanism is opened by the energized solenoid. With decreasing pressure and thus hydraulic force the return spring can retract the piston together with the cylinder rod to the retracted position. Afterwards the actuator returns to park or idle stage. With the solenoid OFF, the piston locked in retracted position, fluid passes the main valve with very low pressure drop if the pump is activated again to fulfill its supposed dedication.

Important note: Because thermal processes are slow compared to the few hundred milliseconds needed to extract the cylinder, this is usually easily acceptable for the main fluid circuit of the cooling-system to be interrupted for this short boost and extraction phase. This is why usually easily accessible cooling or lubrication systems are often appropriate for utilizing a HAVSU.

Dual Sensor Solution

Both independent strokes, the solenoid stroke (corresponds to locked / unlocked) including pilot valve state and that of the piston rod (park / not park) are monitored by only one 2D hall-effect position sensor with only one permanent magnetic sensor target. In known applications two separate sensors with two separate targets for each sensing function were necessary what offers plenty of advantages beginning from the often difficult supply chains of rare earth material for sensor targets or the chips itself and ending with quality by design.

This innovative design becomes possible, because the sensor target is connected to the solenoid on the one hand as well as to a tailored multi-material cylinder rod on the other hand. This cylinder rod is made of materials with different magnetic properties along its longitudinal axis, what enables it to act as a varying magnetic shield between the permanent magnetic sensor target, and the opposite positioned hall-effect sensor. Thus, the hall sensor is exposed to a stroke-dependent magnetic field as illustrated below:

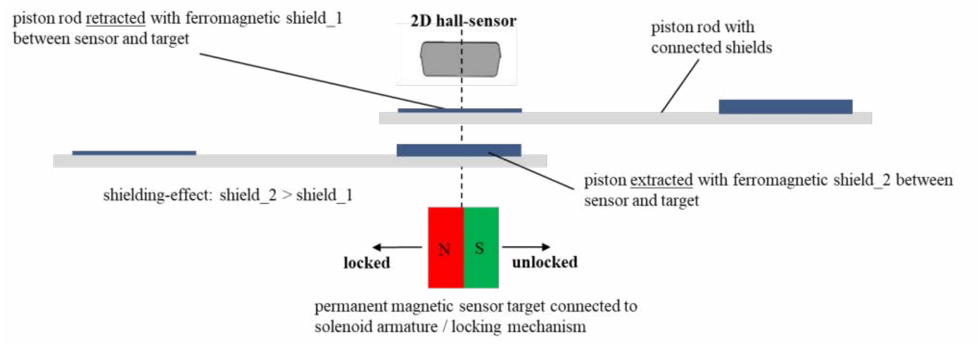

Figure 4.2: Dual sensor principle

To gain two independent positions signals of the 2D hall sensor, it is necessary to evaluate the sensor signal in two different ways. 2D hall sensors can measure the magnetic field strength in two planes perpendicular to each other (Bx, Bz; illustrated below), what is important for the dual sensor principle.

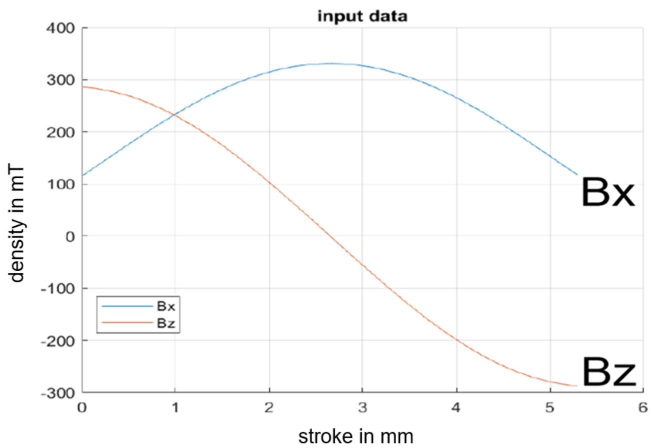

Figure 4.3: Raw sensor signal

For the evaluation of the stroke of the piston rod (retracted / extracted) it is necessary to calculate the stroke-dependent (through varying shield effect) absolute field strength of the target, which corresponds to the vector sum of the two evaluation planes of the 2D hall sensor:

$$B_{abs_s} = \sqrt{{B_x}^2 + {B_z}^2}$$

For the evaluation of the stroke of the solenoid (locked/ unlocked) it is necessary to calculate the stroke-dependent (through varying shield effect) angle between field strengths of the two perpendicular to each other evaluation. This angle is fully independent from the absolute field strength and thus from the shielding effect which is necessary for the before mentioned evaluation for the position of the piston rod. The angle corresponds to the trigonometrical relationship:

$$\alpha = atan2(B_x; B_z)$$

The Dual-Sensor Solution as well as the whole system Actuator-Valve-Sensor-Unit are patent pending.

5. PERFORMANCE DATA AND TEST RESULTS

The test results with the mock-up samples of the actuator-unit showed great success. The tests included basic functional test, durability test, environmental testing from -40 to +150°C and in-system tests.

The following figure 5.1 shows a typical operating cycle and table 5.1 gives an overview of the technical data measured.

Durability tests confirmed the expected life-length and environmental testing showed no malfunctions, e.g. in thermal cycling or under vibrations and mechanical shocks acc. to well-known automotive standards like LV124.

The successful results have been confirmed by the system-level test and were honored by customers.

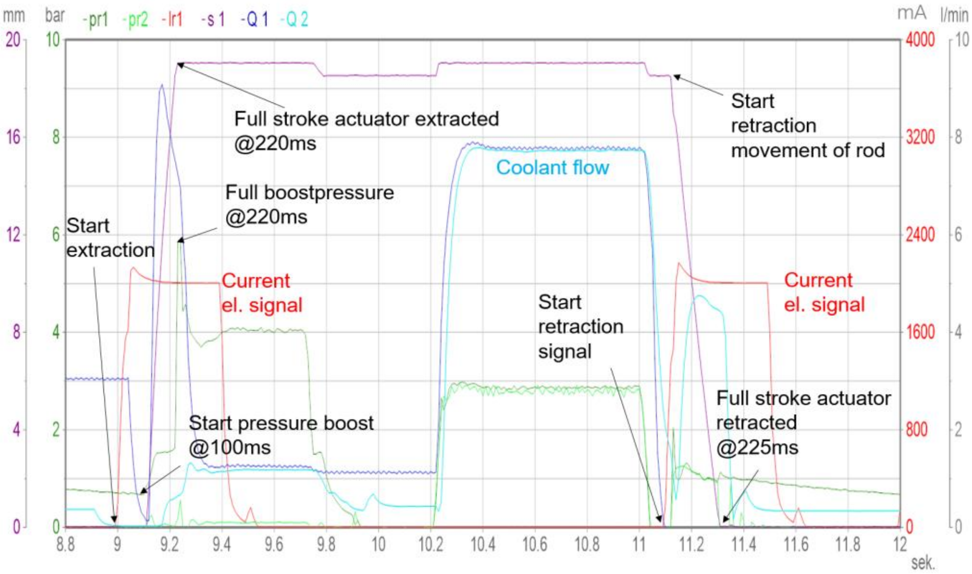

Figure 5.3: Measurement el. current, flow-rate, pressure and stroke over time @ 45°C

Characteristic	**Unit**	**Typical spec.**	**MSM-HAVSU**
Supply Voltage	V	24 / 48	24 / 48
Operating current	A	<3	1.5
Pull in current	A	<3	1.5
Holding current	A	<0,6	0.2
Switching time solenoid (locking mech.)	ms	<50	<20
Pressure build up time (boost)	ms	-	100
Stroke hydraulic	mm	15…50	19.5
Piston area (specific type; scalable at will)	mm²	-	780
Force potential (scalable at will)	N/bar	-	78
Burst pressure	bar	>60	>60
Max. operating pressure	bar	-	20
Max Force (scalable at will)	N	1000	1560
Switching hydraulic (extracting)	ms	<300	<100…220(T)
Switching hydraulic (retracting)	ms	<300	<100…220(T)

Flow-rate main valve (e.g. cooling circuit)	l/min	-	8…15
Pressure drop	bar	<0,1	<0,1
Leakage idle mode @ 1 bar	ml/min	-	<5
Leakage during extracting phase @ 10 bar	ml/min	-	<50
Weight (specific type)	kg	-	0.46

Table 5.1: Summary technical data

The actuator meets all typical specifications regarding dynamic stroke behavior. Especially the very low leakage in idle mode results in very high efficiency.

6. EXAMPLES FOR APPLICATIONS

Lockable linear actuator units including position feedback are highly suitable for applications requiring:

(1) High force density without a full hydraulic infrastructure.
(2) Precise positioning and closed-loop control.
(3) Fail-safe locking for safety-critical systems.
(4) Energy efficiency through bistable lockable hydraulic cylinder which only needs hydraulic actuation for change of state.

The unique advantage of this system is the operation without a dedicated high-pressure hydraulic supply through utilizing an existing low-pressure fluid circuit, e.g., for cooling or lubrication. Dedicated on-demand pressure boosting makes these actuators perfect for modern architectures in many next-generation platforms (e.g. trucks, buses, aerospace, defense, automotive) by moving towards more electric systems and reducing or removing centralized hydraulic supplies.

However, certain functions still require high forces that pure electromechanical actuators struggle to deliver efficiently. By tapping into an existing low-pressure circuit (e.g. 1–3 bar) and locally boosting pressure (e.g. up to 10–50bar), the actuator eliminates the need for a full hydraulic system with reduced weight, complexity and costs as well as minimizes leakage risk and maintenance combined with the typical high force capability and power density of hydraulic actuators.

Possible application fields and examples:

Automotive

- **Transmission Actuation**, Gearshift or clutch actuators in hybrid/EV drivetrains where no hydraulic system exists.
- **Parking Lock Mechanisms**, securely locking the driveline without relying on mechanical-only solutions. Figure 6.1 illustrates the HAVSU in one of our already a realized application.
- **Active Aerodynamics**, spoilers or air flaps that need high force and locking at extreme speeds without adding hydraulic complexity.
- **Cooling on Demand** solutions where the airflow through radiators is a controlled for expample by air flaps to optimize overall aerodynamic drag losses.

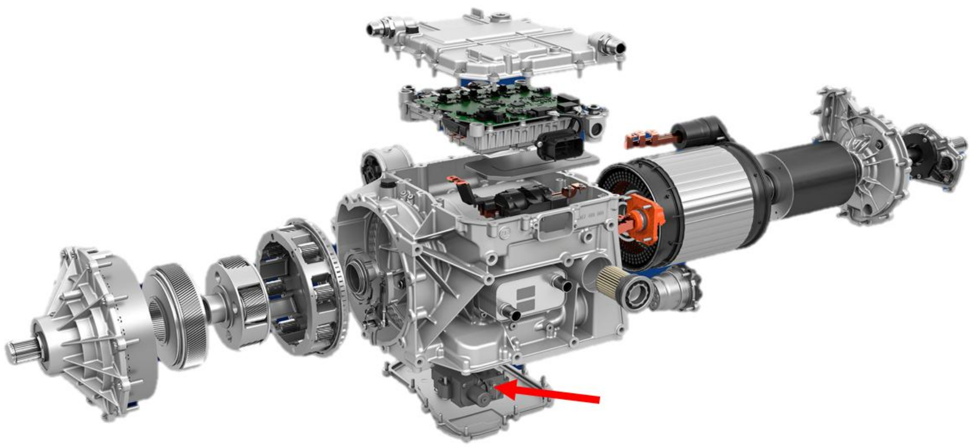

Figure 6.1: Actuator as park-lock-application in e-axle, image courtesy of ZF Friedrichshafen AG [1]

Truck & Bus, Rail and other On- and Off-Highway applications

- **Steerable Axles and Axle Locks,** for controlling auxiliary steering axles and lock them at highway speeds without a central hydraulic system.
- **Suspension Height Adjustment**, for suspension systems, actuators can provide precise height control and secure locking during loading and unloading.
- **Heavy-Duty Doors and Ramps**, passenger doors or wheelchair ramps require strong actuation and safe locking, ideal for local hydraulic boosting.
- **PTO clutches** for distributing mechanical power to auxiliary units.
- **Thermal flow control** especially for large heating circuits, e.g. bus passenger compartments

Aerospace

- **Door-actuators** could extend/ retract and lock doors in position, leveraging low-pressure cooling circuits for energy supply.
- **Flight Control Surfaces**, high-force actuation with fail-safe locking for flaps or stabilizers in “More Electric Aircraft” designs.
- **Cargo Doors**, large and heavy doors require strong actuation and locking, perfect for local pressure boosting.

Defense

- **Weapon Stations**, positioning and locking of turrets or launchers without a full hydraulic network.
- **Armored Vehicle Hatches and Ramps**, heavy hatches need secure locking and high force in compact systems.
- **Stabilization Systems,** radar, missile or laser weapon platforms requiring precise positioning and locking under harsh conditions.

7. BENEFITS OF THIS INNOVATION

The integration of all necessary functions is successfully combining the proven advantages of hydraulics (high power density, robustness) with an innovative layout providing significantly reduced complexity and CO_2 footprint of supply chain, system manufacturing and system operation.

The key advantages versus purely electric actuators can be summarized as follows:

(1) Higher force density: Hydraulic boosting enables compact actuators to handle heavy loads.
(2) Fail-safe locking: Integrated hydraulic lock ensures safety even in power loss scenarios.
(3) Energy efficiency: Uses existing low-pressure fluid, reducing electrical power demand.
(4) Simplified architecture: No need for centralized hydraulic systems, ideal for electrified platforms.

The benefit also includes the reduction of weight, overall size, number of parts and assembly steps as well as improved efficiency of electric energy and use of material resources in the system and whole supply chain.

The lean design with highly integrated functions result in a significant cost reduction compared to alternative systems that combine actuators with separate, external valves and sensors.

At least one electromagnetic valve and one sensor could be saved compared to alternative and less integrated solutions, even without taking the pump and further components of a dedicated system into account.

The innovation is showing great benefits and uniqueness for the markets by bridging the gap between great power density provided by hydraulics, functional robustness, energy-savings and cost effectiveness compared to standard actuator technologies.

Further the innovation has the potential to provide substantial competitive advantages in the mass market of next generation electric vehicles (NGEVs) launched in the second half of the decade and beyond, to make such cars affordable to a broader customer base.

The actuator is fully scalable to different force and stroke requirements as well as environmental conditions in automotive, all mobile or industrial applications.

Thus, a high degree of innovation has been achieved and provides high flexibility for additional applications and future innovations and platforms in a variety of industrial sectors.

Figure 7.4: 3D view of the Actuator-Valve-Sensor-Unit (HAVSU)

8. REFERENCES

[1] https://www.zf.com/products/de/cars/edrive/select.html

Biographies

Ralph Wassermann graduated in mechanical engineering in 2006, specializing in precision engineering and fluid systems. His early work focused on electro-pneumatic micro-valves, laying the foundation for his expertise in miniaturized actuator technologies.

Today as Director of Design and Development at MAGNET-SCHULTZ, he leads the creation of innovative electromagnetic components and systems for demanding industrial applications. His work bridges the gap between theoretical engineering principles and practical, production-ready solutions. He uses his ability to integrate mechanical design with fluid dynamics and electromagnetic functionality, driving forward the development of compact, energy-efficient actuators with high reliability and precision. His leadership fosters interdisciplinary collaboration across mechanical, electrical, and manufacturing teams. With a strong focus on quality, functionality, and system integration, he ensures that every product meets the highest technical standards while being cost-conscious and committed to sustainable resource use.

Ralph's engineering philosophy combines deep technical expertise with strategic thinking and a passion for innovation. His contributions have helped position MAGNET-SCHULTZ as a technology leader in the field of actuator and sensor systems.

Florian Hölzle holds a master's degree in mechanical engineering (2014) and has over a decade of experience in the development and design of electromagnetically actuated hydraulic systems, with focus on automotive powertrain solutions.

Since joining MAGNET-SCHULTZ in 2014, he has combined deep technical expertise with leadership responsibilities, managing complex projects from concept to implementation. His role includes full technical accountability and customer-oriented project management, ensuring innovative, reliable solutions tailored to client requirements.

Florian is recognized for his ability to bring engineering excellence together with strategic customer engagement, driving successful outcomes in a highly competitive automotive sector.