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Push-Pull Electromagnet in Hydraulic Systems

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Abstract

Electromagnets are one of the key components in modern hydraulic systems, enabling precise and efficient control of hydraulic valves. The use of electromagnets in hydraulic valves offers several advantages, including fast response times, high forces with low power consumption and reliable linear motion. A disadvantage is that they only move in one direction, hence two electromagnets are required for full fluid control of 4/3 valves, which means two coils and, among other things, double control wiring. This disadvantage can be overcome by using a push-pull electromagnet, which can move in either direction depending on the polarity of the supply voltage.
This paper presents a study of push-pull electromagnets and the usage in various hydraulic valves to replace the standard two-coil solution.

The push-pull electromagnet consists of a setup with permanent magnets together with discs made of magnetically soft material. The armature is housed in plastic sleeves that allow it to move smoothly.

Keywords: Push-pull electromagnet, Hydraulic valve, Electromagnetic actuator, Bidirectional motion, Coil reduction, Mobile and industry hydraulics

1. INTRODUCTION

In the field of modern hydraulics, key requirements are not only reliability and precise control but also energy efficiency and component compactness. Traditional designs of electromagnetic actuators for 3-position hydraulic valves often employ two separate coils, one for each directional function. While this solution is tried and tested, it brings certain disadvantages, larger structural volume and more complex wiring.
An alternative to this classical approach is the use of a so-called push-pull electromagnet, which enables control of both directions of armature movement using a single coil with polarity reversal. This concept offers potential for design simplification, reduction of energy demands and optimization of system response. The paper will describe the functional principle of the push-pull electromagnet, its advantages compared to the traditional solution and practical aspects of its implementation in hydraulic applications.

2. PRINCIPLE OF THE PUSH-PULL ELECTROMAGNET

The push-pull electromagnet utilizes a reversible magnetic field to achieve movement of the armature in both directions. By changing the polarity of the supply voltage, both the “push” and “pull” effects can be realized. This makes it possible to replace two coils with a single one, reducing the number of components and simplifying the valve design.

The armature of the electromagnet consists of strong permanent magnets combined with discs made of magnetically soft material. The armature is mounted on plastic sleeves that allow smooth movement.

Although the push-pull principle is well known, it is rarely used in the field of oil hydraulics. Most electrohydraulic valves still rely on conventional single-direction electromagnets or a pair of coils for bidirectional movement. In contrast, the push-pull configuration is commonly applied in other areas, such as pneumatics, precision mechanics, automation, and drives for non-oil hydraulic systems (e.g., water hydraulics). These applications take advantage of the ability to generate bidirectional motion with a single coil to simplify design, reduce weight, and increase dynamics. As a result, the push-pull principle has proven effective where fast response or compact design are essential.

3. DESIGN SOLUTION AND PATENTED INNOVATION

One of the primary technical challenges in using a push-pull electromagnet for hydraulic applications is hysteresis – caused by the difference in magnetic behaviour during current switching on and off – which can adversely impact the accuracy and repeatability of the valve control. During the development of a new type of actuator, an innovative solution was proposed and patented, enabling active influence on hysteresis through a refined armature design.

The armature of the push-pull electromagnet consists of a series of magnetic and permanent elements arranged in a specific configuration: magnetic disc – permanent magnet – disc – magnet – disc. A key feature of this design is the variability of the diameters of the magnetic discs at the front and rear ends of the armature (Figure 3.1). By adjusting these diameters, the magnetic field distribution can be purposely influenced, thereby controlling the magnitude of hysteresis within the system.

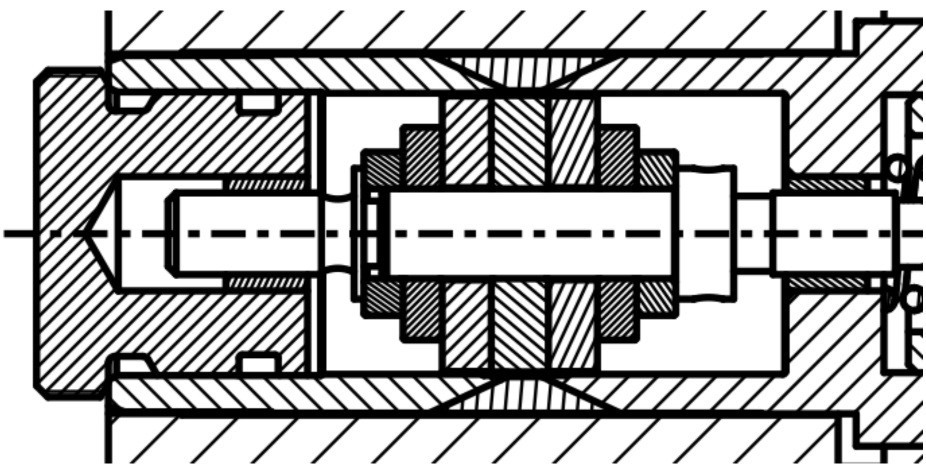

Figure 3.1. – Asymmetric armature design

Figures 3.2 (uncompensated hysteresis) and 3.3 (compensated hysteresis) illustrate an exemplary effect of hysteresis compensation. As seen in the uncompensated case, the valve opens abruptly without any sign of proportionality and remains fully open until the polarity of excitation changes; then it jumps to the opposite side and, with a slight indication of proportionality, stays open until the excitation ends, after which it closes. With hysteresis compensation, these abrupt changes in opening are eliminated, and the valve behaves proportionally throughout the entire operating range and for all pressure levels.

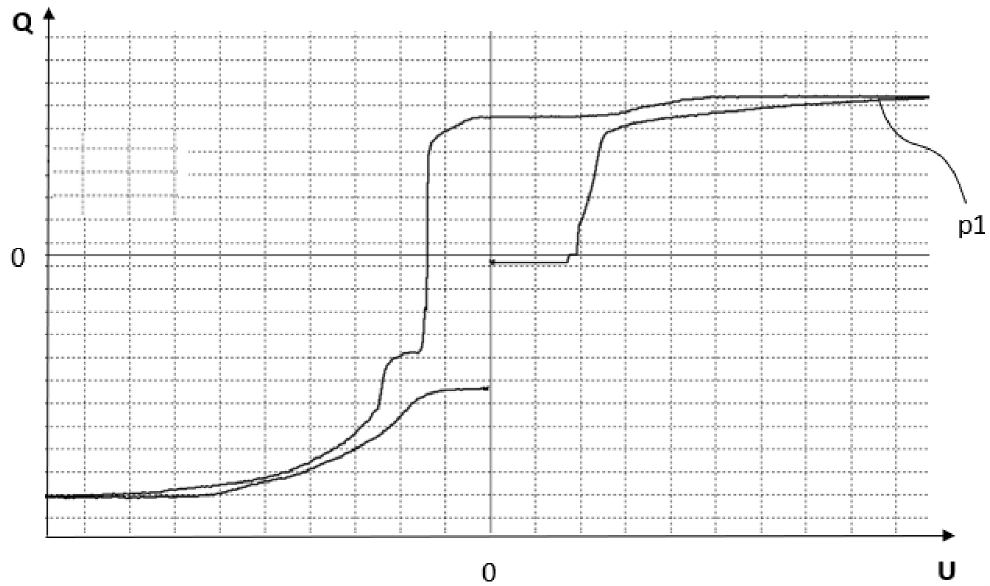

Figure 3.2. – Hysteresis of an indirectly controlled valve without hysteresis compensation (pressure p1)

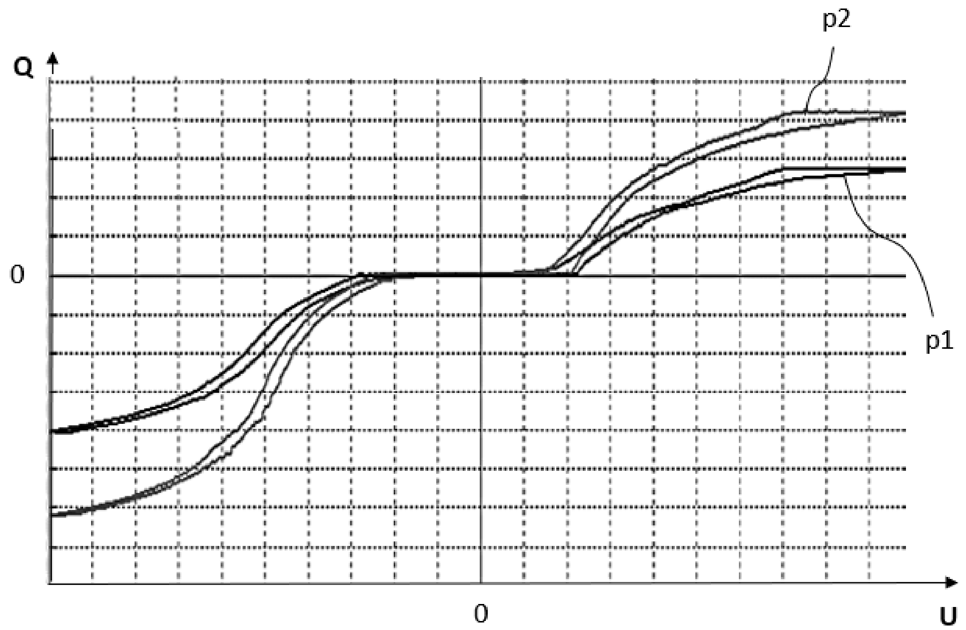

Figure 3.3. – Hysteresis of an indirectly controlled valve with hysteresis compensation (at pressures p1 and p2)

3.1. Advantages Compared to Two-Coil Systems

Overall dimensions of the valve are reduced, allowing it to be used in applications where the two-coil version cannot be installed due to space limitations.

The usage in CETOP valves opens up other possibilities for this type of valve, such as the possibility of mounting a position sensor on the spool and using its sensor output, either as a feedback function or as a safety function.

There are numerous additional to this technology:

- **Reduced material consumption** – Eliminating the second coil means less copper, plastic, and insulating materials. Copper mining and plastic production are energy-intensive processes with high CO_2 emissions, so using fewer of these materials directly improves the ecological footprint of manufacturing and supports circular economy principles.

- **Lower energy demands** – Push-pull systems operate with a single coil and optimized magnetic flux control, which reduces current load and idle-state losses.

- **Smaller carbon footprint** – Lower material and energy consumption during both production and operation significantly reduce emissions throughout the entire life cycle. Optimized hydraulic systems can achieve emission reductions over their lifetime, especially when combined with intelligent electronics and regenerative control strategies.

- **Longer component life and less waste** – Fewer parts mean fewer potential failures, reducing maintenance frequency and the need for spare parts. This not only saves costs but also reduces industrial waste, contributing to sustainability goals.

- **Economic competitiveness** – In addition to environmental benefits, simplified design reduces assembly time, wiring complexity, and storage costs. Combined with lower energy bills, this represents a significant advantage in total cost of ownership for OEMs and end users.

3.2. Challenges of Integration into Control Systems

One of the main obstacles preventing wider adoption of push-pull electromagnets is the need to adapt control systems for bipolar control. Although most modern control systems already support polarity reversal or can easily implement it through a simple firmware update, the use of push-pull electromagnets in the hydraulic sector is not common.

The key factor, therefore, is awareness and cooperation with system integrators [1].

4. CASE STUDIES AND APPLICATIONS

Push-pull electromagnets can be applied both in stationary equipment and in mobile hydraulics, for example in agricultural machinery, construction equipment, or mining systems. Thanks to their compact dimensions and high reliability, they are ideal for environments with high vibrations and limited space. In some applications, they have also proven effective in systems requiring fast response and low energy consumption. The proportional valves were controlled by the EL7-IA3 electronics [2], which is specifically designed for use with valves equipped with push-pull electromagnets.

4.1. Tested Applications

4.1.1. Electromagnetic Direct Operated Screw-In Valve (SD2E-A4/H3)

Successful implementation of a bidirectional push-pull electromagnet has been achieved on the originally two-coil, electromagnetically operated screw-in valve SD2E-A4/H3 (Figure 4.2.). The valve is designed for installation in a standard A4 cavity, 3/4-16 UNF thread. An example of the valve used in an application where it controls the direction of fluid flow and thus the direction of actuator movement - or stops it - can be seen in Figure 4.1..

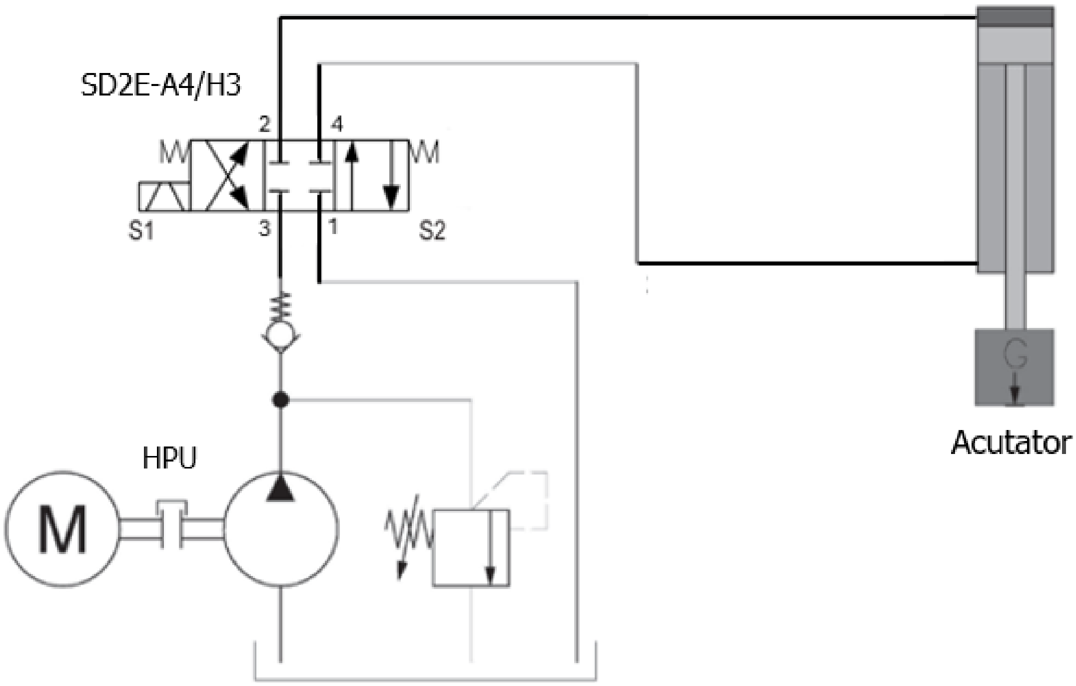

Figure 4.1. Example of using the SD2E-A4/H3 valve in a hydraulic circuit

Comparison of the original design and the new solution with a push-pull electromagnet, Figures 4.2 [2] and 4.3. The hydraulic part of the valve, including the spring and shims, is identical for both types; the push-pull version has a special chamber in the control system for integrating components from the standard two-coil version.

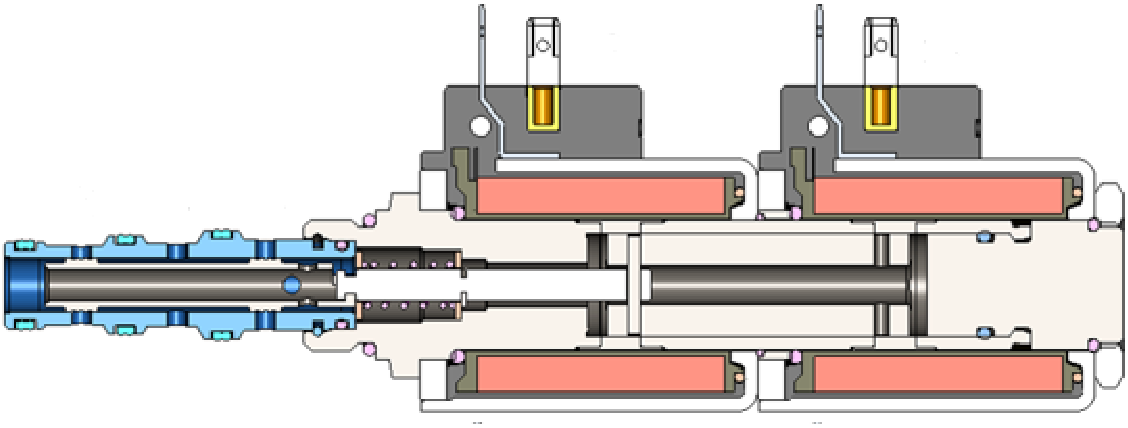

Figure 4.2. – SD2E-A4/H3

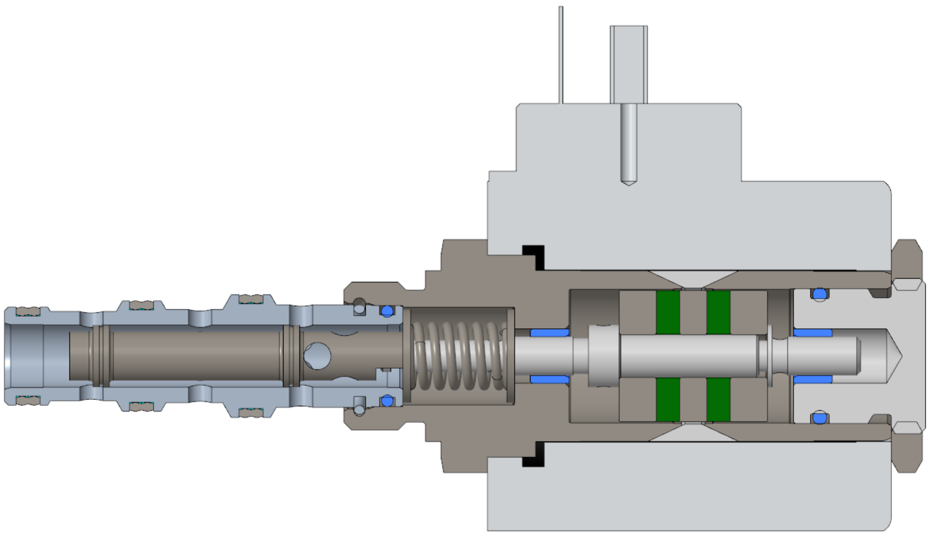

Figure 4.3. – SD2E-A4/H3 with push-pull electromagnet

The valve was tested with different spool types (thus with the effect of different flow forces). A full-fledged replacement – that means same power limits – for the standard version with two coils could successfully be proven.

4.1.2. Electromagnetic Direct Operated Proportional Valve (PRM2-063Z11/15)

A directly controlled proportional CETOP valve (Figure 4.4), combined with a push-pull electromagnet, exhibited significant hysteresis (Figure 4.5), which would need to be reduced, for example, by using electronics and internal feedback from the spool position.

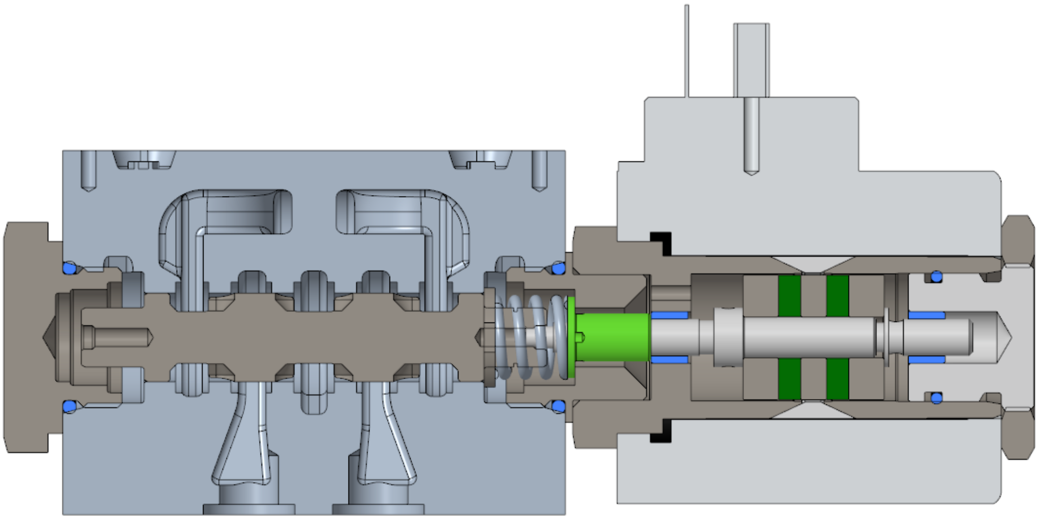

Figure 4.4. – PRM2-063Z11/15 with push-pull electromagnet

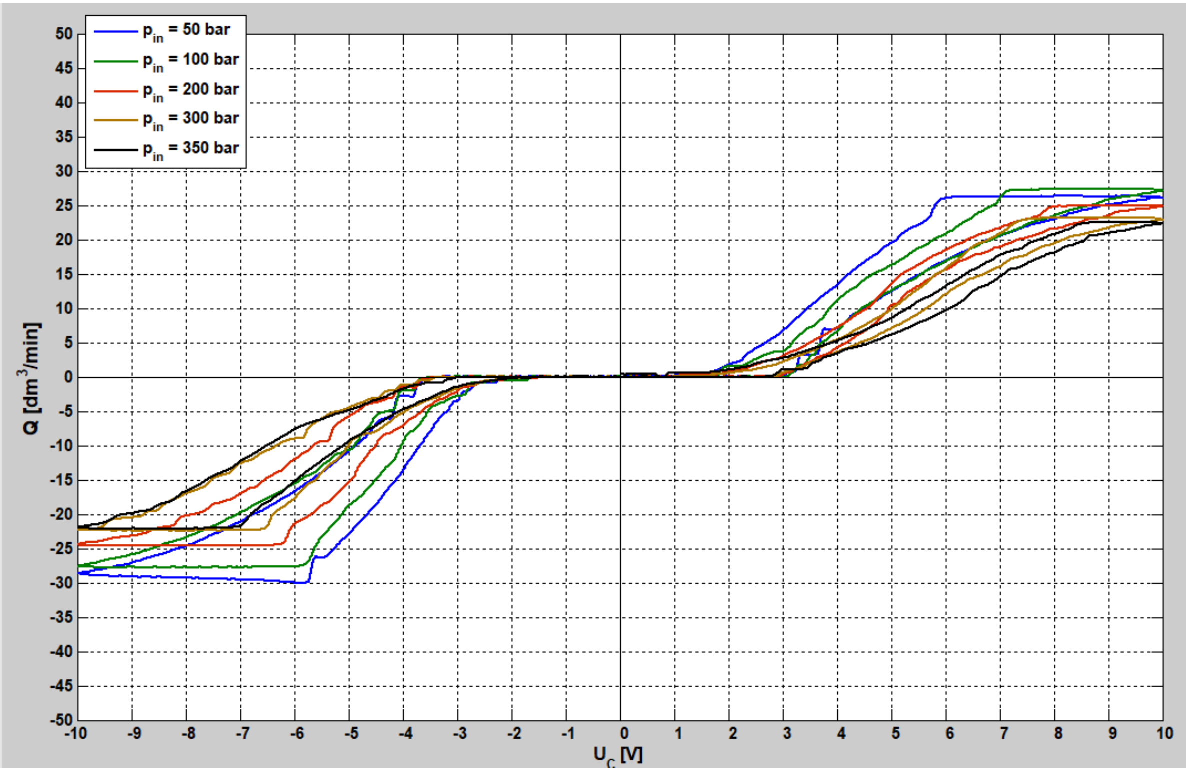

Figure 4.5. Flow curves of the PRM2-06 valve with a push-pull electromagnet

4.1.3. Electromagnetic Pilot Operated Proportional Valve (PRM8-063Z11/15)

Valves that are particularly suitable for the use of push-pull electromagnets are pilot operated valves (Figure 4.6.), because the principle of the pilot and follow-up spool [3] compensates for the lower force of the push-pull electromagnet compared to the two-coil design. Thanks to the indirectly controlled spool, equivalent performance to the two-coil variant can be achieved, even with the lower available force of the electromagnet. At the same time, this type of valve allows hysteresis reduction using an armature with discs of different diameters (Chapter 3). Hysteresis and performance of the valve modified in this way are then identical to the two-coil version (Figure 4.7.).

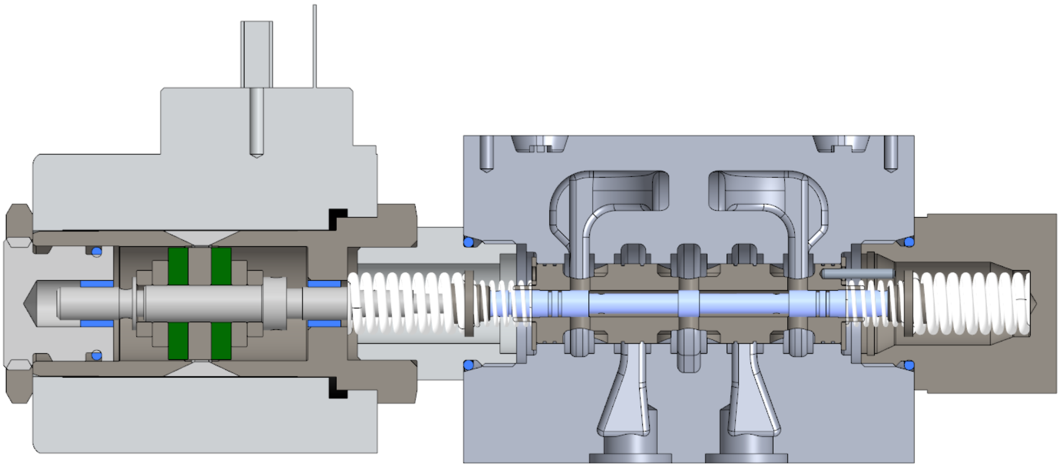

Figure 4.6. – PRM8-063Z11/15 with push-pull electromagnet

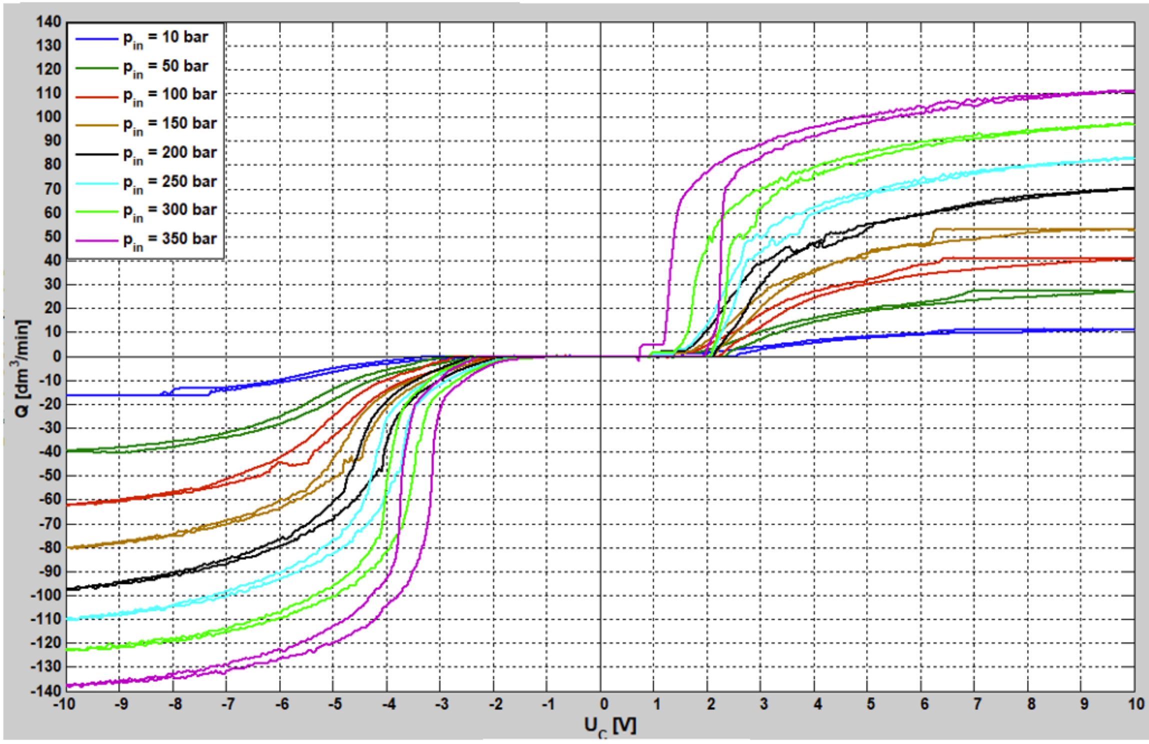

Figure 4.7. Flow curves of the PRM8-06 valve with a push-pull electromagnet

5. CONCLUSION

Push-pull electromagnets represent an interesting, modern, efficient, and environmentally friendly solution for controlling hydraulic valves. Thanks to successful tests, case studies and the patented design solution, their full-scale deployment in industrial practice can be confirmed. The remaining challenge is awareness and cooperation with integrators, but the potential of this technology is significant. Their ability to provide fast response, high performance, and reliable linear motion is essential for automation and safety applications. Their broader adoption depends on overcoming communication barriers between component manufacturers and system integrators.

6. REFERENCES

[1] Danfoss (2024). *Directional Control Valves – Push Pull Valves*.
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Biographies

Filip Vlach works as an R&D Designer specializing in hydraulic systems. His expertise includes the development of electromagnetic actuators, particularly push-pull designs, with a focus on energy efficiency, hysteresis reduction and ecological aspects. He is also engaged in designing electronics for proportional valves, position sensors, and hydraulic components, covering calculations, simulations, and testing. Filip has experience in creating innovative solutions for both mobile and industrial applications and is a co-author of patented technologies. Currently, his work focuses on integrating electromagnetic and electronic components into hydraulic systems to enhance reliability and optimize performance.