LOW ENERGY CONSUMPTION HIGH FLOW CONTROL SYSTEM USING SPOOL-IN- SPOOL DESIGN OF PROPORTIONAL VALVE

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ABSTRACT

Recently, in many mobile applications, great emphasis has been placed on reducing energy consumption, whilst maintaining the high hydraulic performance of the system. At the same time, a small size and, if possible, a low weight must be maintained if the system is used to be used on moving parts of machines.

All these requirements are met by our new high flow control system using the proven spool-in-spool proportional valves principle. This principle has now been enhanced using LS functionality directly on the spool incorporating a brand-new seven chamber design. Our spool-in-spool valve principle enables control of high flow rates and pressures through the valve with a very small solenoid. The large hydraulic power transferred by the valve and low-pressure losses of the solution, enable high dynamics and proportional controllability of the entire system.

The sandwich construction of the control block increases the variability of the entire device whilst space requirements are significantly reduced.

The function of the pressure compensator, together with the LS control of the hydraulic pump, eliminate the pressure drop in individual sections during simultaneous use and increase energetic efficiency of the solution. Everything is included in the individual sections.

Keywords: Proportional, Spool-in-spool, LS, High flow, Pressure drop, Small solenoid

1. SPECIFICATION OF PROJECT

Abbreviations:

PSVS: Proportional section valve system

PMVS: Proportional modular valve system

MPC: Main pressure compensator

(E)-LS: (Electronic) Load sensing

HIC: Hydraulic integrated circuit

PIB: Parts in body

PRV: Pressure relief valve

SIC: Screw in cartridge

1.1. Critical targets definition

- Fine proportional control in the beginning of flow scale. This practically means smooth and gentle control of heavy loads (p=150 bar at Q=0-20 l/min). The movement of the load is driven by a hydraulic motor and linear hydraulic cylinder, and both are in operation at the same time.
- The changes of the load or sudden reaching of cylinder end position must not influence the rotation part of the movement and vice versa. This leads to a solution with pressure compensating elements with every single proportional valve in the system.
- Fast acceleration of the load movements (to Q=80 l/min at Δp=10-14 bar) is required as well and hydraulic system must be able to provide that with full proportional control without excuses and interruptions.
- PSVS must work with common Load sensing concept which must fully cooperate with hydraulic drives incorporated in the base machine platform. PSVS can share pressure load information with the machine basis in two ways – hydraulically or electronically. And actually, the second way seems to have more benefits so all needed service ports for full E-LS control are included. The critical condition for LS system here is that when the proportional valve is in neutral position and actuator gets the external hit which causes pressure peak in the channels then this pressure peak must not be transmitted to main LS line. This will secure the LS pump drive is not disturbed by external influences and general pressure supply to the subsystem work calmly.
- Essential part of PSVS LS or E-LS system is also main pressure compensator (MPC). The purpose of that element is to unload the main pressure feeding line to tank line locally in PSVS central block to save as much energy as possible in shortest possible reaction time. MPC regulates the amount of available energy and saves the energy during all operations based on actual system demands as well.
- Space demand on complete solution is crucial. The PSVS must be light and compact as much is possible within physical laws.
- The overall system must work with the highest possible efficiency. This means the manifold design must respect the optimal oil flow path and internal channel shape and channels connections must be optimized.

1.2. PSVS conceptual art:

If we put the pure functional points of this system to the side and focus just on given space and given interface between basic machine platform and PSVS we see the traditional hydraulic components which are accessible on the market cannot do the job. An underlined point is the fixed displacement of ports on the machine platform this means PSVS must be in line with all details without exclusions. Considered options below:

Solution with SIC valves (HIC)

Screw in cartridges provides flexible basis for efficient mobile outdoor HIC in many cases. So mechanical valves like compensators or PRV seems to be the best option. Unfortunately, when we speak about proportional direction control functions 4/2, Q=80 l/min flow the SIC is not ideal. There is lack of performance or solenoids would need to be too big for the given space. Generally, the pressure losses are higher than other solutions.

Solution with CETOP valves (HIC)

CETOP proportional flow control valves could handle the flow so we could find valves with enough performance, but for the given space are also too big and they are less suitable for mobile outdoor applications. PRV or pressure compensators in CETOP housings provides very low-pressure losses on the other side they are space demanding too.

Solution combination of SIC and CETOP (HIC)

Combination of SIC and CETOP valves are the very efficient solutions for many kinds of applications. Unfortunately, the target flow demands Q=80 l/min makes this option also too big and too heavy.

Solution with section mobile bankable valves

The space issue could be solved by a bankable valve system. The given hydraulic interface can be additionally solved with a special interface plate but here we find problematic proportional flow control function with LS feature. The prop. control both directions Q=80 l/min at Δp=10-14 bar built in bankable section is known on the market but unfortunately it must be pilot operated, and every producer provides their own design and solution. Most of them have a design which cannot be easily adapted to the given interface and space. There is also an important question about the response of pilot operated proportional controls and its working characteristics.

HIC based on taylor-made casted housing with parts in body (PIB) valve versions. Bankable sections concept with special central inlet casted block.

According to the above analysis the concept has been evolved. HIC based on taylor-made casted housing with parts in body (PIB) valve versions. Bankable sections concept with special central inlet casted block. Proportional direction flow control pilot operated valve with floating spool concept and with direct load sense via the proportional spool´s 7th chamber architecture.

2. HISTORICAL EVOLUTION OF THE VALVE (COMPARISON)

To meet the definition of critical targets, we were inspired by development of our PRM8-10 CETOP 5 valve. We developed a new 7-chamber valve by extension with LS channels and tested the function together with external pressure compensator as modular assembly (PMVS). Based on the test results, we continued with development of a 7-chamber section valve with integrated pressure compensator in one housing. In the sub-chapters below, the individual phases of development are listed.

2.1. PRM8-10 valve

Figure 1: Pilot operated proportional directional control spool valve with high hydraulic power [1].

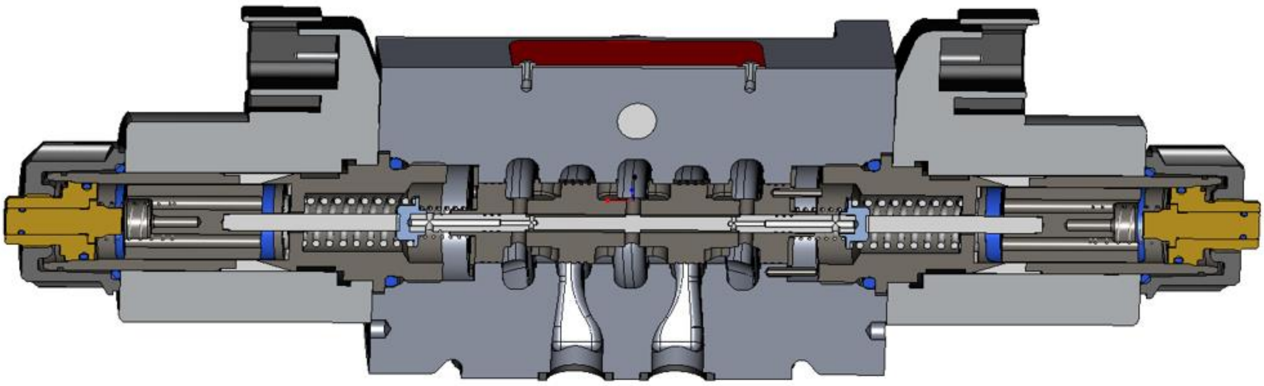

Figure 1: PRM8-10

2.2. 7-chamber valve

PRM8-10 valve extended by LS signal brings the valve with 7-chamber housing shown in **Figure 2**. The housing was produced by additive manufacturing technology. Thanks to that we have achieved a significant time reduction for producing the functional sample. It allows us to use a bigger chamber, channels and spool diameter as well, which cause lower pressure drop. It caused higher flow at the same inlet pressure as it is shown in **Figure 5**.

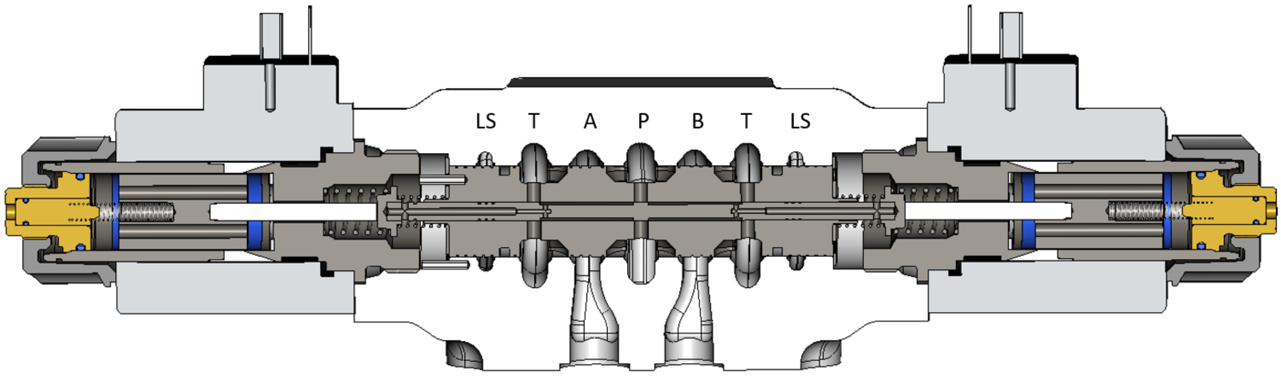

Figure 2: 7-chamber valve

This valve together with external two-way pressure compensator and connecting plate makes a modular assembly for initial testing to see, how the system works independently on the load. Load level was set up by pressure relief valve placed between channels A and B shown in **Figure 3.** During the measurement, we recorded the pressure values in the individual channels to know the pressure drop of the valve itself and all modular assembly.

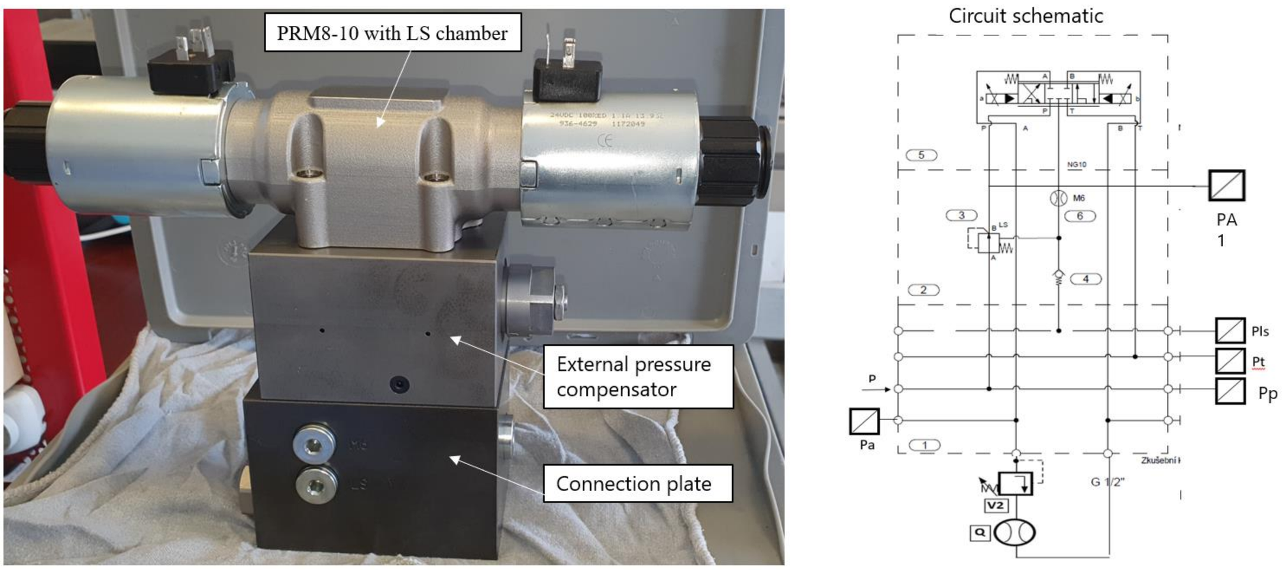

Figure 3: 7-chamber valve modular assembly - PMVS

2.3. 7-chamber section valve with integrated pressure compensator - PSVS

Figure 4: PSVS solution connected the benefits of the 7-chamber valve and pressure compensator (which is parts-in-body here) in one casted housing. Casted housing has even bigger channels then previous one shown in **Figure 2**. Here, we achieve even smaller pressure drops and even higher flow at the same inlet pressure as it is shown in **Figure 5**. At the same time, we reduced the overall size and mass as it is shown in **Table 1.**

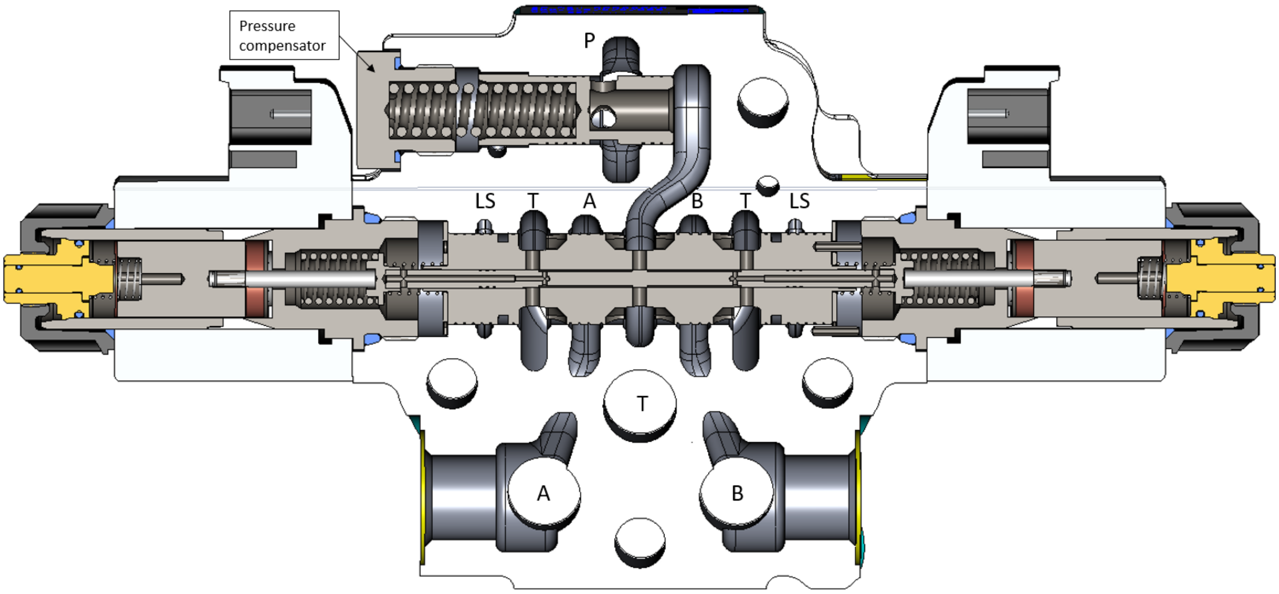

Figure 4: 7-chamber section valve assembly - PSVS

2.4. Measurement comparison

Figure 5 describes the flow through the valve as a function of actuating current at inlet pressure p_{in}=250 bar, oil viscosity ν=32mm^2/s, temperature T=40°C. Proportional function is controlled by our electronic control unit EL7-E [2] with frequency f=90 Hz and amplitude A=15 %. To be able to compare the results properly, the PSVS version was tested with no function of pressure compensator. That means the pressure compensator was fully open.

Measurement describes the flow increase of 7-chamber valves against the standard PRM8-10. With the PSVS the flow is more noticeable, Q=210 l/min. In percentage the value is 31 %.

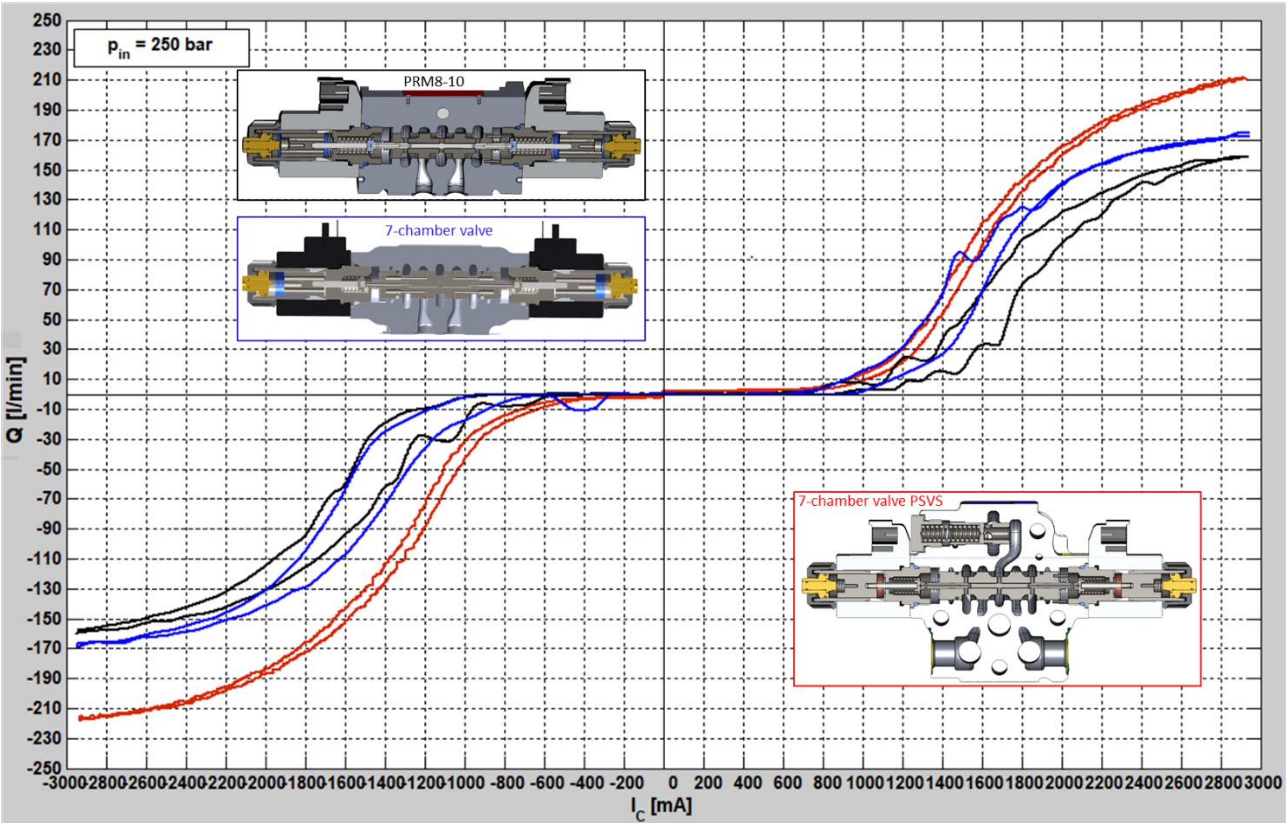

Figure 5: Flow characteristics comparison

Table 1 describes the size and the mass differences between Modular and Section solution. Here you can see massive improvement at both parameters with the Section solution.

Table 1: Modular and sectional comparison

parameters	Size HxWxL [mm]	mass [kg]
Modular solution	222x70x278	12
Section solution	127x48x278	4,4

3. PSVS - FINAL HYDRAULIC RESULTS

Figure 6 describes the flow through the valve as a function of actuating current at different inlet pressure. Pressure compensator is fully open. Other test conditions are the same as described in the chapter 2.4. The flow is limited by the flow value Q=220 l/min at the pressure p_{in}=300 and 350 bar. This is due to our test laboratory pump maximum.

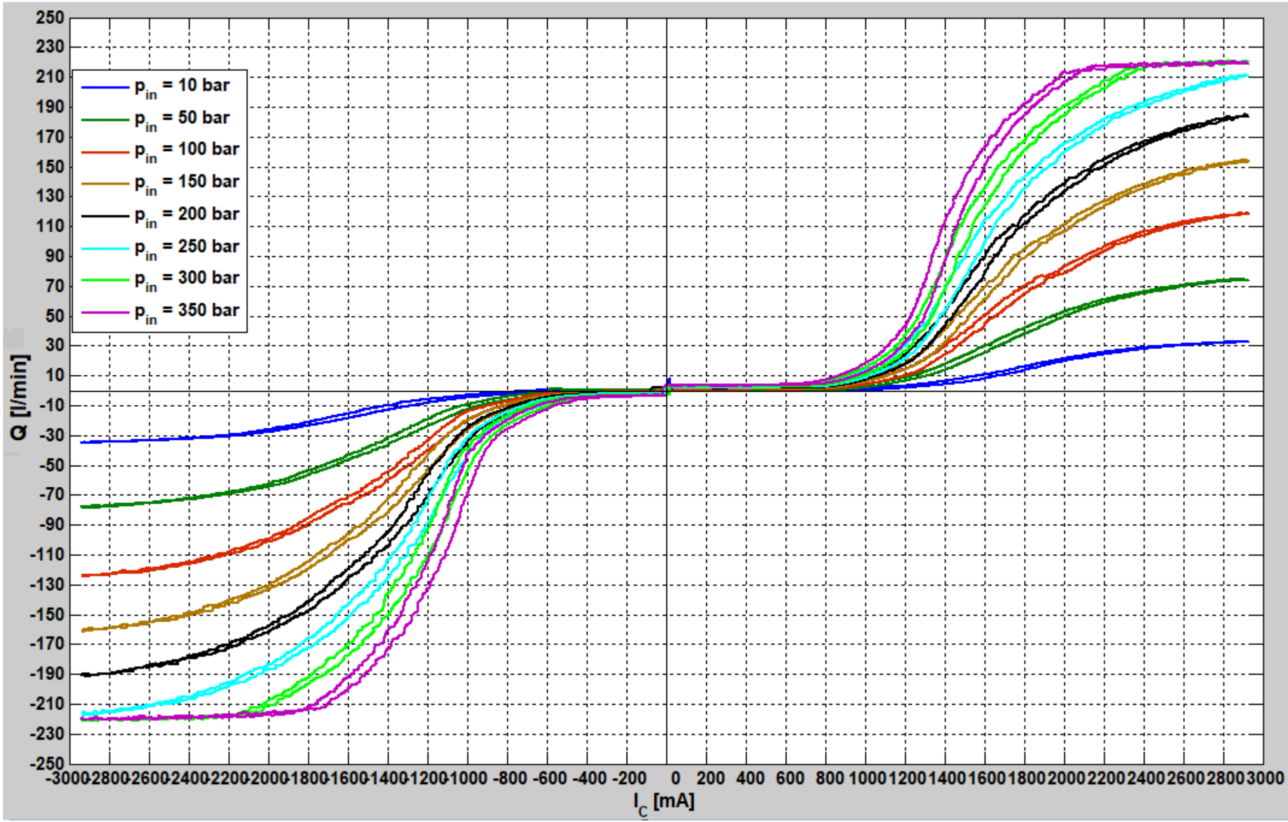

Figure 6: Flow characteristics with fully open pressure compensator

Figure 7 describes the flow through the valve with the different load between the channels A and B, as a function of actuating current at inlet pressure p_{in}=200 bar. Pressure compensator is fully open. Other test conditions are the same as described in the chapter 2.4.

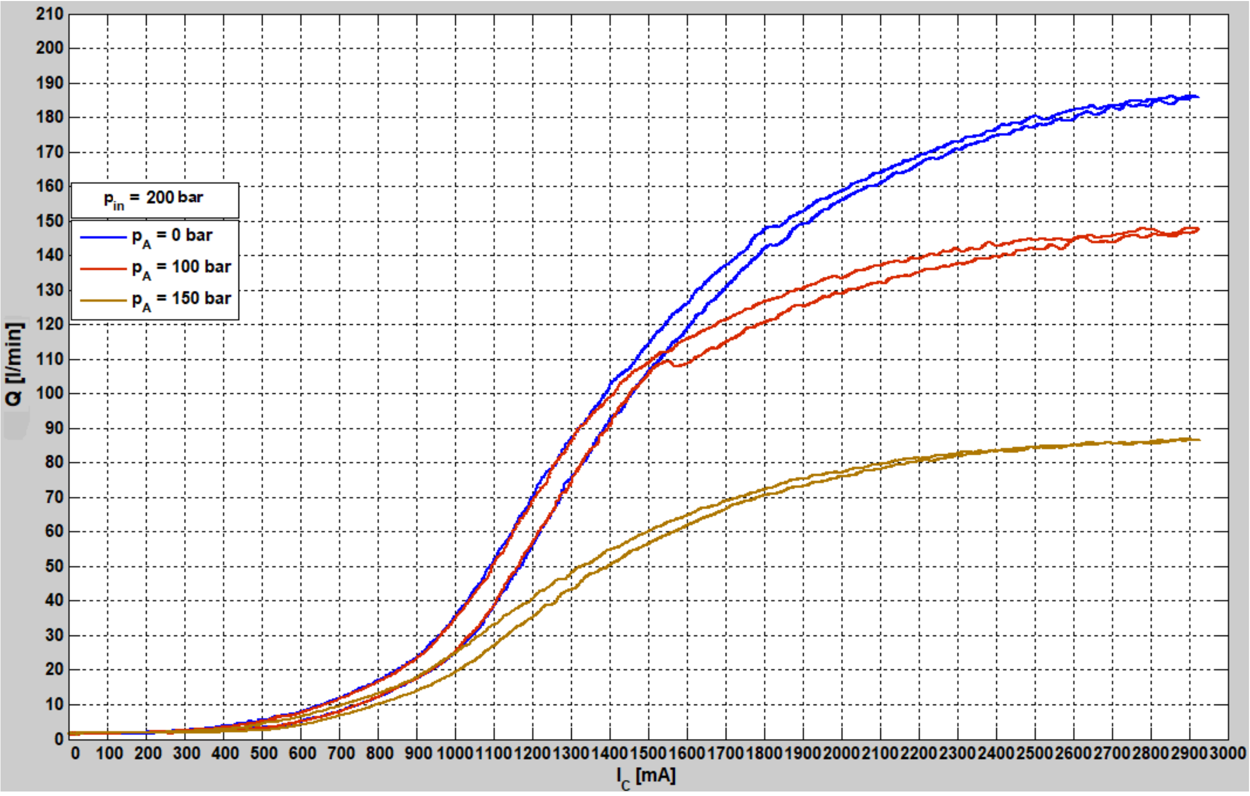

Figure 7: Flow characteristics with load and fully open pressure compensator

Figure 8 describes the flow through the valve with the different load between the channels A and B, as a function of actuating current at inlet pressure p_{in}=200 bar. Other test conditions are the same as described in the chapter 2.4. Pressure compensator is here in the function, set on the value Q=80 l/min and works the same with different loads.

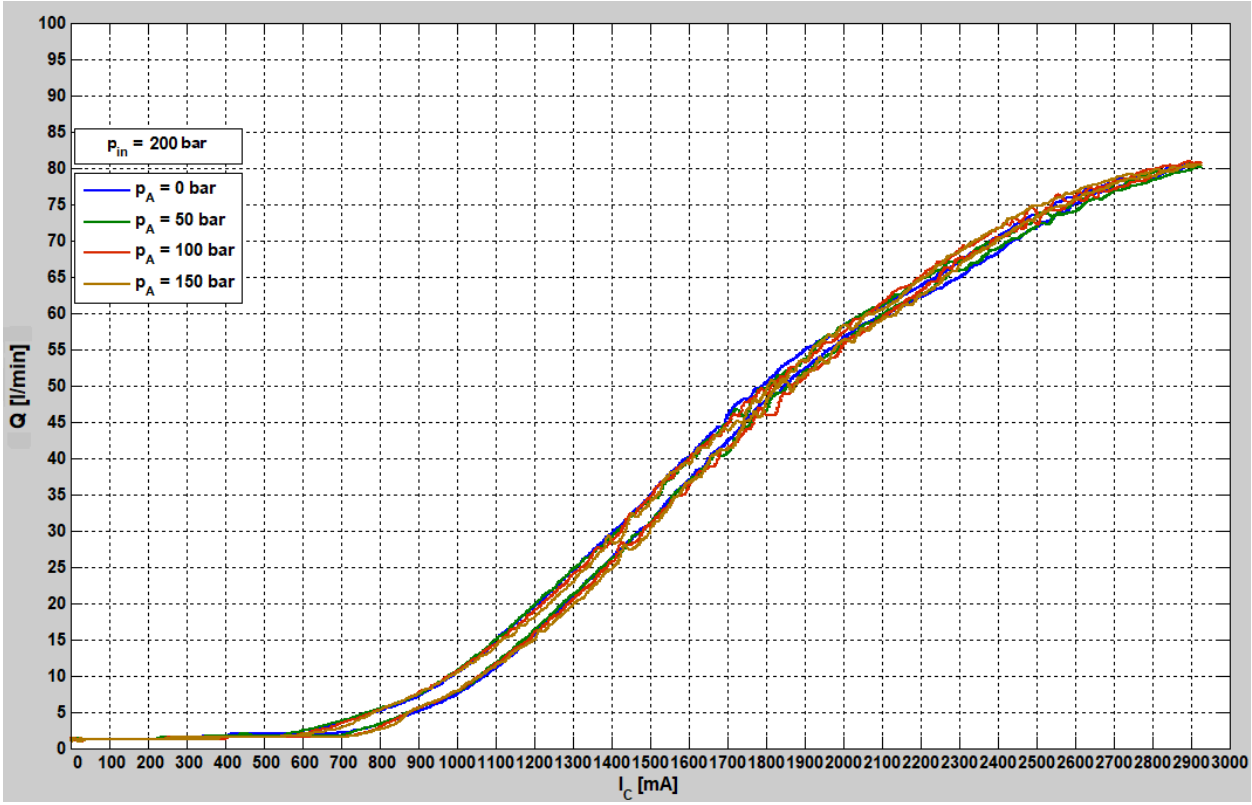

Figure 8: Flow characteristics with load and working pressure compensator

4. SUMMARY

In our paper, we describe the development and measurement results of a proportional, indirectly controlled spool valve for high flow rates. The basic requirement for a solution consisting of a high-flow valve with a pressure compensator, which are implemented in one small sandwich casting, are met. Due to the use of the electromagnet size NG06 and high transmitted power, the ratio of electromagnetic control to controlled hydraulic power is high.

By increasing of the spool diameter and optimizing the casting channels, we made the valve more efficient compared to the CETOP version PRM8-10 by 31% at p_{in}=250 bar, while maintaining the proportional function.

By implementing a pressure compensator and LS control in each sandwich, we have reduced flow fluctuations when several sections are operating at the same time.

We can use two different spool connections in sections. The spool that is closed without the signal - - 3Z11 and the spool that has channel P closed and channels A and B led to the tank - 3Y11.

The ability to connect multiple sections with two different spool connections allows us to cover a wide range of functions in mobile applications.

NOMENCLATURE

Q	Flow	l/min
p_{in}	Inlet pressure	bar
p_A	Load pressure	bar
Ic	Actuating current	mA
H	Height	mm
W	Width	mm
L	Length	mm
M	Mass	kg
f	Frequency	Hz
A	Amplitude	%
T	Temperature	°C
ν	Kinematic viscosity	mm^2/s

REFERENCES

[1] https://www.argo-hytos.com/ - PRM8-10 Data sheet

[2] https://www.argo-hytos.com/ - EL7-E Data sheet