HIGH-PRESSURE SHUT-OFF VALVE SUITABLE FOR HYDROGEN APPLICATIONS

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ABSTRACT

It is well known that the direct or indirect use of hydrogen in mobile applications plays a decisive role in the decarbonisation of this sector. Regardless of the use by means of fuel cell or modified internal combustion engine, various valve functions are required along the functional chain.
In mobile applications, the hydrogen is stored in high-pressure tanks with up to 1050 bar. For dispensed extraction, the shut-off solenoid valve size 32 mm is used as part of an on-tank valve.
The article describes the construction design and explains the design of the sub-functions, in particular the pilot-controlled valve function.

Keywords: hydrogen, shut-off valve

1. INTRODUCTION

For all necessary valve functions inside of a mobile fuel cell, Magnet-Schultz developed an entire valve platform. In those applications, the hydrogen is stored in high-pressure tanks with up to 1050 bar. For dispensed extraction, the shut-off solenoid valve (size 32 mm) is used in an on-tank valve. For the medium pressure range of up to 25 bar, a shut-off valve is also required (SOV). The modular system for this pressure range is completed with a flow control valve. Purge and drain valves are required at the outlet of the fuel cell to manage the emerging water.

As part of the Magnet-Schultz valve platform, this article presents the High-Pressure Shut-Off Valve with the pilot control inside the valve.

2. MEDIA CYCLE OF A FUEL CELL

Fuel cells are known to convert the chemical oxidation reaction of oxygen and hydrogen directly into electrical energy with a high degree of efficiency. In addition to electrical energy, the reaction products are heat and water. Consequently, the technical operation of such fuel cells requires the supply and discharge of the media hydrogen and water.

The media flows are shown schematically in **Figure 1** below. The necessary valves are also shown in this figure. This also includes the so-called on-tank valve, which in turn is an assembly with the High Pressure Shut Off Valve installed in it.

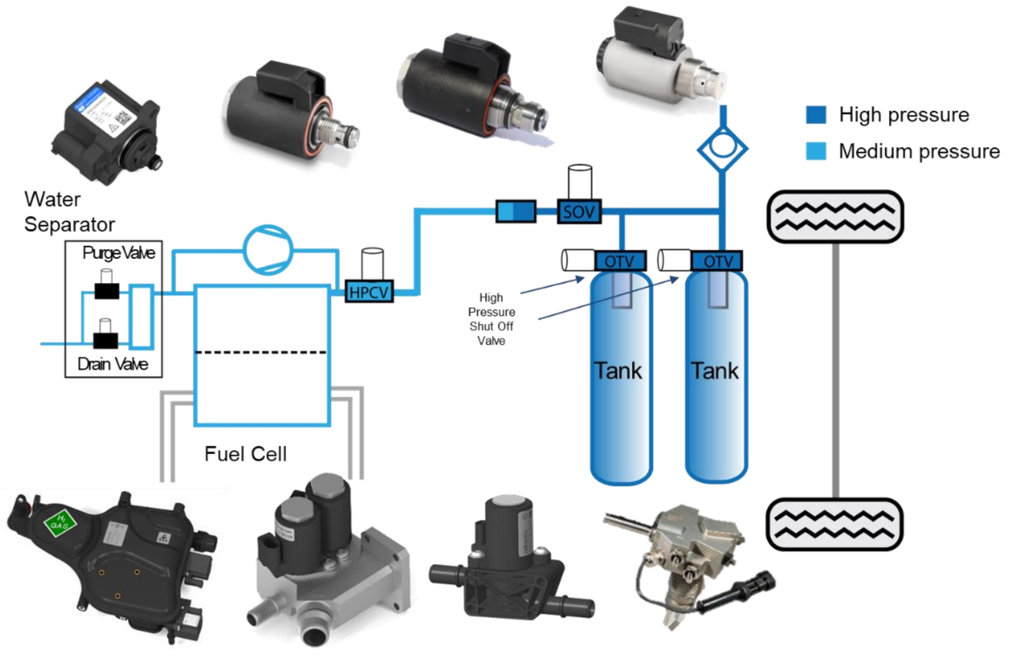

Figure 1: Media flows in a fuel cell

Because gaseous hydrogen has a low volume-specific energy density, it is provided at the input of fuel cells by high-pressure tanks. To increase efficiency, storage pressures of up to 1,000 bar are aimed for. The hydrogen must be supplied at this pressure level through the on-tank valves. A subsequent pressure-reducing valve depressurises to an average pressure level of approx. 25 bar. In addition, a shut-off valve separates the high and medium pressure cycle. A flow control valve is required at the inlet of the fuel cell to meter the hydrogen.

The water produced at the outlet of the fuel cell is deposited using a separator and discharged into the environment through a drain valve. The nitrogen produced as a by-product is discharged via a purge valve.

Magnet-Schultz offers a suitable solution for all required valve functions.

The focus of this article is on the On-Tank Valve, the basic structure of which is shown in **Figure 2** below.

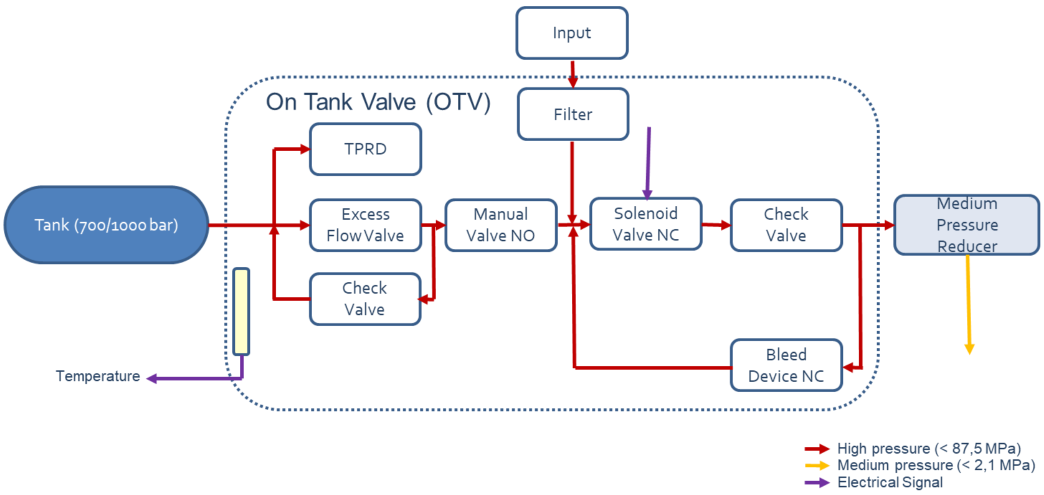

Figure 2: Structure of the On-Tank-Valve

The 'On-Tank-Valve' assembly consists of various components including the High Pressure Shut Off Valve, which is described below.

3. HIGH-PRESSURE SHUT-OFF VALVE

The High-Pressure Shut-Off Valve (**Figure 3**) has the following technical data:

- Rated working pressure (NWP): 0 ... 700 bar
- Maximum pressure (MAWP): 1050 bar
- Nominal width: 2.7 mm
- Type of voltage: DC, PWM
- Protection class: IP6K9K
- Testing according to EC79

Figure 3: High Pressure Shut-Off Valve

The patented design of the valve takes into account the increasing requirements from the application in mobile fuel cells and also shows functional advantages compared to the general state of the art:

- Increasing the nominal operating pressure
- Switching function independent of the counter pressure on the downstream circuit
- Constant switching times
- Low leakage

3.1. Functional description

Due to the extremely high working pressure, the state of the art usually works with a pilot control, as shown in **Figure 4**.

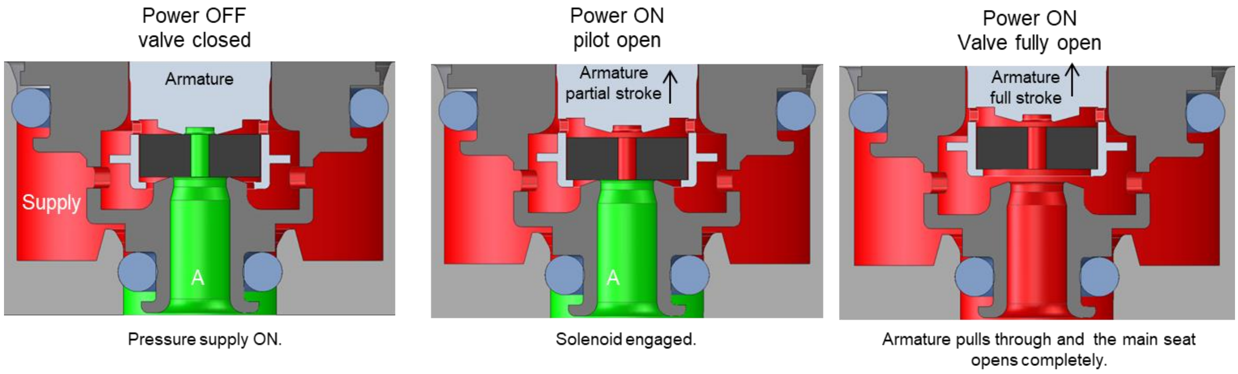

Figure 4: Opening process with back pressure support

When the valve is closed, both the armature and the sealing element in the valve are pressed onto the seat by the working pressure. If the solenoid valve is now energised, the armature opens the pilot control. This starts a pressure equalisation between the inlet side and the outlet. Only when a sufficiently high-pressure level is reached at the outlet, the valve element can fully open the main seat due to the magnetic force that is still applied.

The description of the process makes it clear that the opening behaviour is clearly dependent on the filling and thus the pressure build-up at the outlet. This means that the switching process depends on the design conditions in the overall system. There is also a dependency on the filling level of the storage tank.

The opening process of the technically optimised valve, which is also supported by a pilot control, is shown in **Figure 5**.

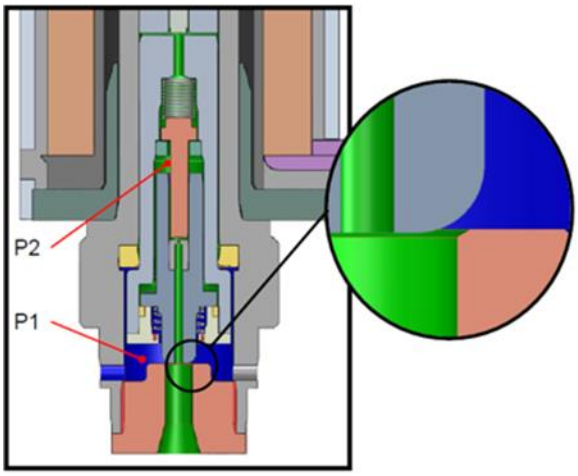

Figure 5: Opening process with optimised valve

In the initial state, the valve seat is also pressed onto the seat by the working pressure. The resulting sealing force results from the interaction of the working pressure at the inlet, the pressure at the outlet and the spring forces at the armature, the main plunger and the pilot valve.

When the solenoid valve is energised, the pressure-equalising armature moves against the spring force up to the mechanical contact with the pilot control. As a result, the pilot control nozzle is now opened as soon as the solenoid force overcomes the pressure difference at the pilot nozzle as well as the resulting spring forces.

As the process continues, the armature moves up to the mechanical contact with the main plunger and the seal installed therein. Due to the opening of the pilot plunger, pressure equalisation can now take place between the outlet and the armature chamber. This creates an opening pressure force so that, together with the resulting armature force, the main plunger opens slightly.

The pressure in the armature chamber is then equalised again so that the main plunger can open completely using spring force. The valve is now fully open.

3.2. Static interpretation

The description of the opening process illustrates the complex functional sequence in which the resulting spring forces and pressure build-up processes act and influence each other due to the pilot and main controls.

Proven FEM simulation programmes can therefore be used for the basic interpretation. Since the construction provides for a pressure-balanced armature, the design of the magnetic circuit is primarily focussed on the ability to overcome the resulting spring forces. The corresponding results can be seen in **Figure 6**.

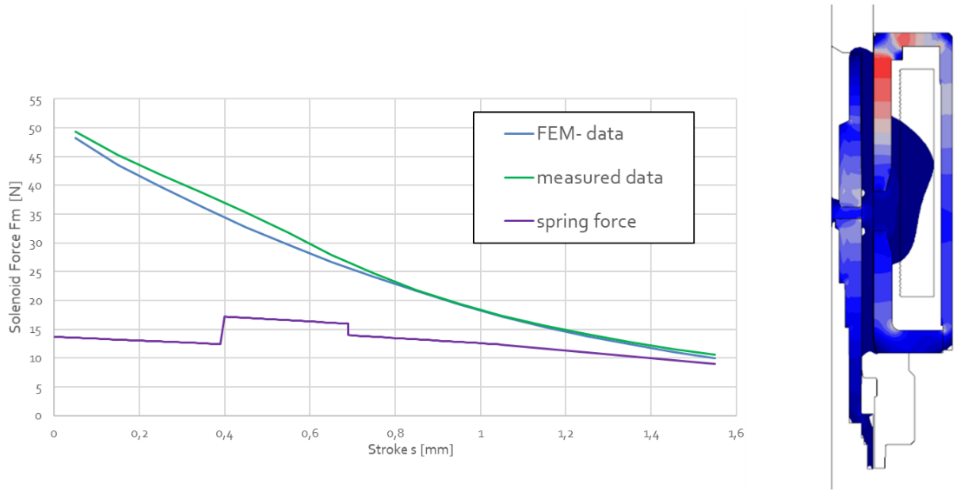

Figure 6: Force-stroke behaviour (solenoid)

The mass flow of the main seat was calculated using CFD simulation (**Figure 7**). The simulation result checks which variation arises starting from the selected stroke point (0 mm). The current interpretation is almost optimal, taking into account the tolerances that occur

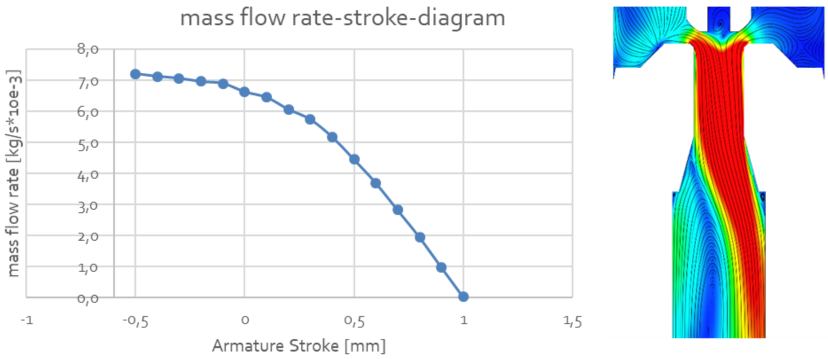

Figure 7: Mass flow over main valve seat

3.3. Transient layout

Due to the complexity of the functional processes, a dynamic simulation is also suitable in addition to the static calculations. At the same time, the complexity requires a systematic approach with the final goal of a multi-domain simulation. In preparation for the complete transient simulation, a 2D model of the construction was first derived. Due to the rotationally symmetrical design, such a derivation is possible (see **Figure 8**).

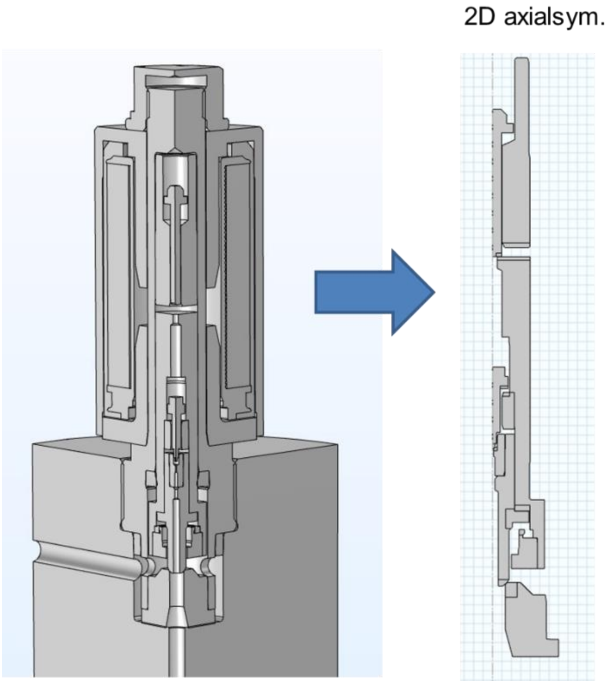

Figure 8: Derivation of the 2D model for transient magnetic force simulation

Thus, in a first step, the magnetic circuit could be calculated transiently in isolation (see **Figure 9**).

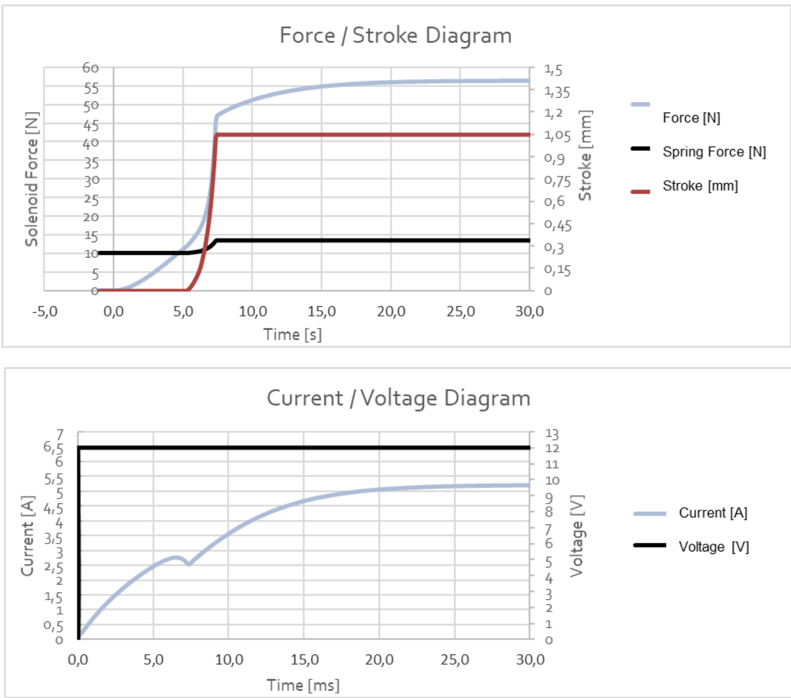

Figure 9: Transient magnetic behaviour

The complete 3D model is required for the CFD calculation. In order to gain experience with the transient flow simulation, water was used as an alternative medium instead of the compressible gas (see **Figure 10**).

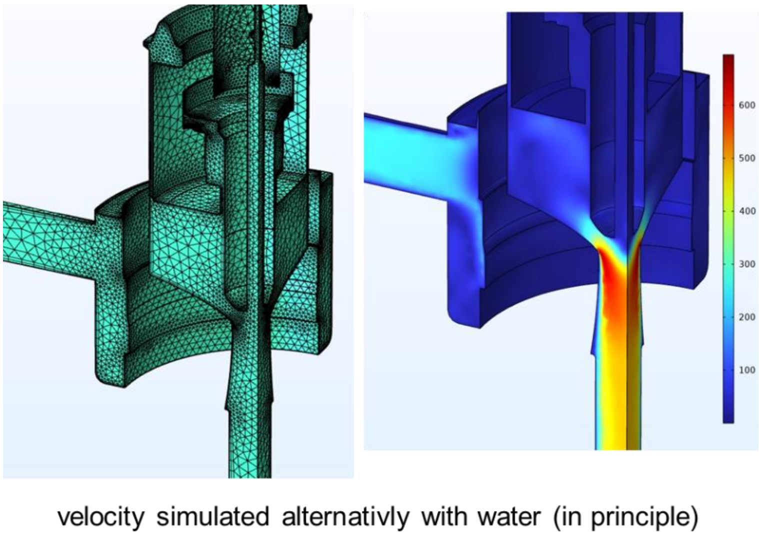

Figure 10: CFD calculation alternatively with water

The multi-domain calculation requires specific interventions in the FEM model. In the case of mechanical contact points, only partial areas of the functionally relevant individual parts should be modelled using structural mechanics in order to reduce the calculation time significantly. In the case of relevant air gaps in the magnetic circuit, the mesh structure must be suitably adapted manually (see **Figure 11**).

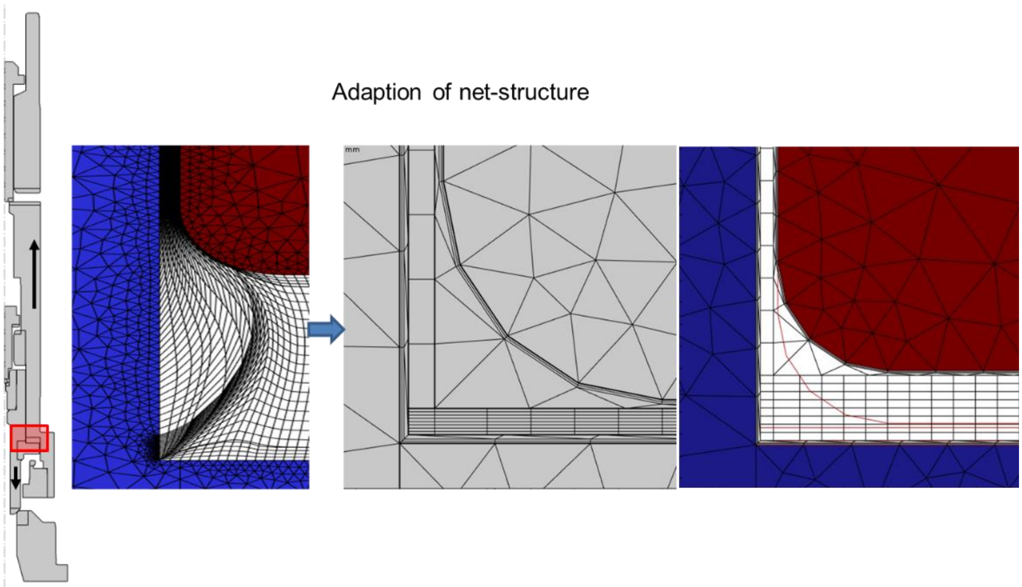

Figure 11: Adaptation of the network structure in magnetically relevant air gaps

The preparatory work described herein for the full transient simulation of solenoid valves has not yet been completed and represents a current intermediate step.

4. CONCLUSION AND OUTLOOK

The patented High Pressure Shut-Off Valve developed by Magnet-Schultz is able to switch a usable mass flow for mobile fuel cells with a very limited solenoid size. The special feature is the design of the pilot control, which ensures reliable valve opening with a constant switching time regardless of the back pressure.

For support and further optimisation, a complete transient calculation of the valve is aimed for. The preparatory steps for the static and dynamic simulation of individual functional elements described in this article were carried out for this purpose.