# Electrorheological microvalves

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## Abstract

During the last few years microsystem technology development has focused on designing smaller and smaller solutions for micro scaled integrated systems. On the one hand microsystems are the spearhead for how to build function integrated systems. On the other hand they are simple and low-cost, for example hydraulic motion systems. Actuators are one part of these systems and they are realized for linear or rotational movements. The state of the art for creating linear movements are conventional cylinder or bellow actuators. All these actuators are running with a flowing medium, for example air, oil or a smart fluid like an electrorheological fluid. All of these media need to be controlled by special valves, which have to be a part of the hydraulic system next to the main actuator. The difficulties of these valves are that they need a lot of space and that they consist of many moving parts, which can be the reasons for leakage, wear and noise. One possible solution, to reduce the leakages in the valves design valves in special ways. Another way could be, to use valves without moving parts. Therefore, a smart fluid, for example an electrorheological fluid is needed. These smart fluids are able to generate an increasing flow resistance as a reaction to an electrical field. This flow resistance can be used to create a pressure difference, in front of the valve.

A state of the art development in the electrorheological technology are electrorheological valves for dampers or vibration decoupling with comparatively high dimensions. These outer dimensions hinder the use of this

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technology especially in small autonomous devices. This paper presents the design structure of a micro valve for electrorheological suspensions, particularly for those devices. This valve offers the possibility to generate a pressure difference by only using an electrical field. Consequently, the leakages, based on moving parts, are reduced. The MEMS-scale size reduction of the ER-valves offers the opportunity to integrate them into small actuators.

*Keywords: electrorheological valve, micro channel, hydraulic actuator, MEMS, electrorheological effect, micro valve, electrorheological bellow actuator.*

# 1 Introduction

Basically, an electrorheological fluid changes the flow properties depending to an applied electrical field. The requirements for this behaviour are small particles, which are distributed in a carrier fluid. These particles have the possibility to change their charge properties from balanced to dipole. Shortly after entering the electrical field, the particles have reached its dipole properties and they start attracting each other. The results of the attraction are stable chains between the electrodes.

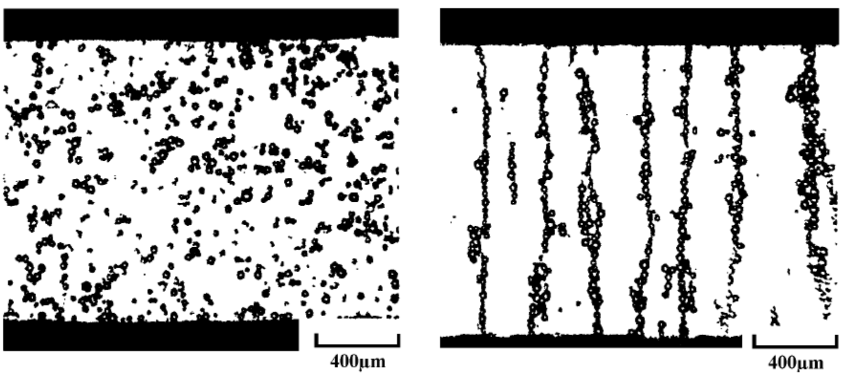


Figure 1: Picture of the chain building mechanism of the ER-effect [4].

When an electrorheological fluid passes the field evoking electrodes, the generated chains, which are consequently vertical orientated to the flow direction, are highering the flow resistance. The stability of the chains depends directly on the strength of the electric field. The necessary electric field strength for triggering the electrorheological effect ranges from 0.1 kV/mm to 5 kV/mm. The particle chains brake down when the fluid's flow creates a rising pressure in front of the electrodes. This pressure difference depends on several geometrical and physical properties [5]. In fact the flow velocity, the field strength and the gap height are the most important parameters for the type of system which is presented in this paper. State of the art for electrorheological valves, which are working with electrorheological suspensions are cylindrical valves with a gap height of 1 mm, a length of 300 mm and a diameter of 50 mm.

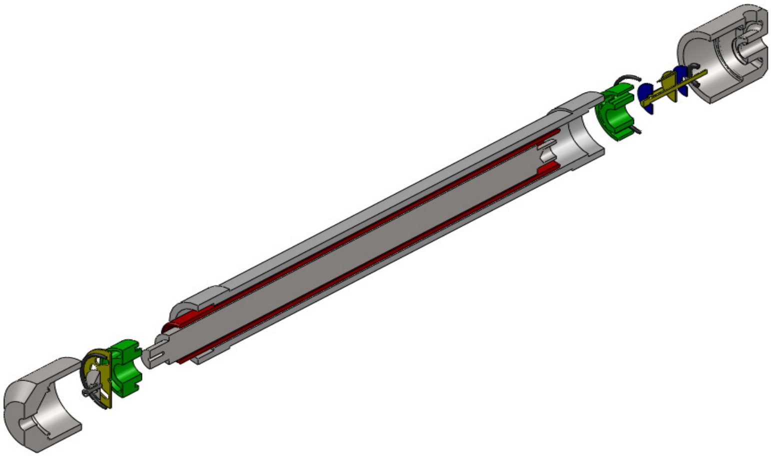

Figure 2: 3D-CAD-model of a conventional electrorheological valves [6].

Those valves are able to generate a switchable pressure difference up to 80 bar. In order to reach this switchable pressure difference the electrorheological suspension needs to be conditioned to 60°C and an electric field strength of 5 kV/mm is necessary [7, 8].

This high voltage is a considerable barrier for a commercial break through, since high voltage supply means high risks for the user. To prevent the risks strict safety measures generates at height costs have to be installed. One suitable way to lower the necessary voltage is to reduce the gap height. The reducing of the gap height means in the same way to reduce the flow rate, which is the first step into the group of microfluidic applications.

## 2 Considering the gap height of microvalves

Several measurements reveal that the minimum gap height for the use of the electrorheological suspension Rheoil 4.0 is 110 μm. Nevertheless, at this gap height the suspension's temperature is limited to 25°C. Operating the fluid at higher temperatures or in valves with smaller gap heights may result in flashovers destroying the electrodes and the fluid. Operating the hydraulic system at temperatures higher than 25°C, the minimum gap height has to be increased to 280 μm.

By choosing this temperature-independent, minimum gap height of 280 μm the required voltage of 5 kV can be minimized to an required of 1 kV. Subsequently, the operational voltage remains in a low-voltage spectrum, increasing the general acceptance of the technology. There is another big advantage from transitioning the electrorheological technology into the micro scale. Squeezing down the gap height means raising the flow velocity of the electrorheological suspension inside of the valve. Since the electrorheological effect is dependent to the flow velocity, smaller voltages are necessary to trigger the electroreological effect in low gap heights than in high gaps, favouring the microvalve.

Another major issue designing the electrorheological microvalves can be found in the field of the production technology. A huge amount of space has to be kept available to integrate these valves into conventional hydraulic system [9]. Because of the dimensions and the used materials for the negative and the positive electrodes these valves need to be manufactured using conventional 3D production technologies. The scaling potential of these macro-technologies is limited, especially with regards to the high tolerance requirements of electrodes in electrorheological microvalves. Because of this fact, the manufacturing method needs to be changed into the micro-manufacturing – especially the 2.5-dimensional manufacturing [3]. Micro design and production principles originating from microelectronic fabrications such as sandwich construction and circuit board manufacturing need to be adapted and transferred for the production of the electrorheological microvalves.

## 3 Design of the microvalve

To use the maximum effect of the sandwich technology, the microvalve has been designed of two function layers (A, C) and one spacer (B) in between.

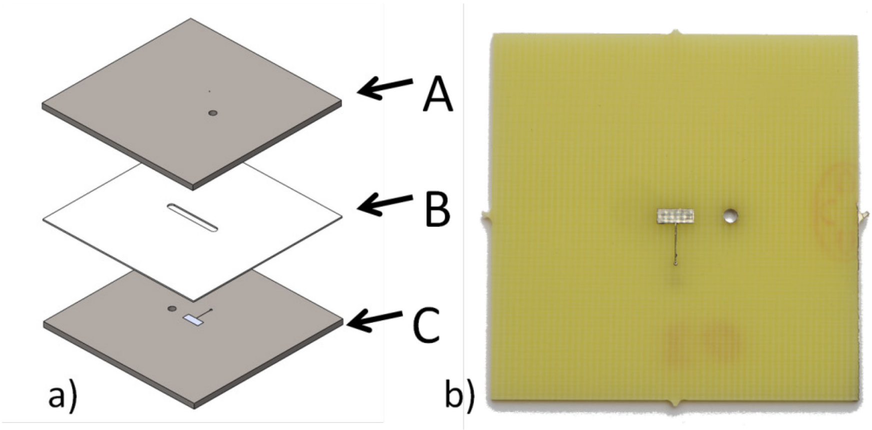


Figure 3: a) Exploded CAD-model of the micro-valve, b) photography of a function layer.

The functional layers are carrying the electrodes, which generates the main function of the electrorheological micro valve. The electrodes are 2 mm wide and 5 mm long. The space around the two electrodes is only that big, to make the handling of the valve easier. In addition, each function layer has a fluid inlet or outlet. However, the function of the microvalve is generally generated in the same way as in the conventional macro-scaled electrorheological valve besides the fact that conventional electrorheological valves are often designed in a concentred cylindrical design type and the microvalve in a planar stacked design type. The electrorheological suspension streams through the inlet of one of the function layers, passing the two electrodes (D), and leaves the microvalve at the outlet. To ensure, that the electrorheological suspension uses only the way between the two electrodes, the spacer (B) has got a long flow channel, which directly connects the inlet- and the outlet.

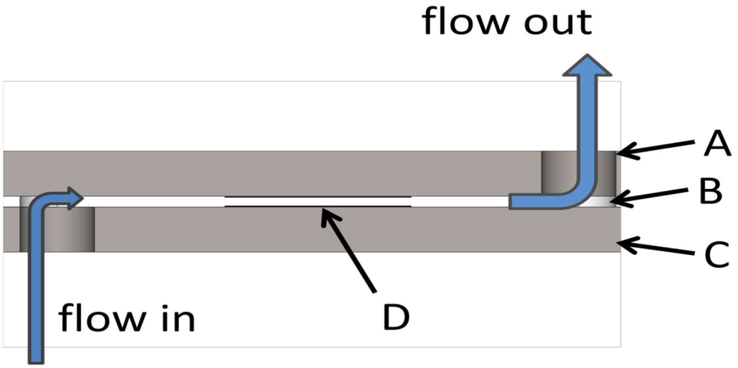


Figure 4: Longitudinal section of the micro-ER-valve.

One of the main issues connecting the three layers was to ensure a highly precise adjustment of the two electrodes concerning parallelism, equidistance and compliance with the designated gap height.

After the process of structural adhesive bonding the layers to each other, there was only the chance to measure the gap height by using computer tomography.

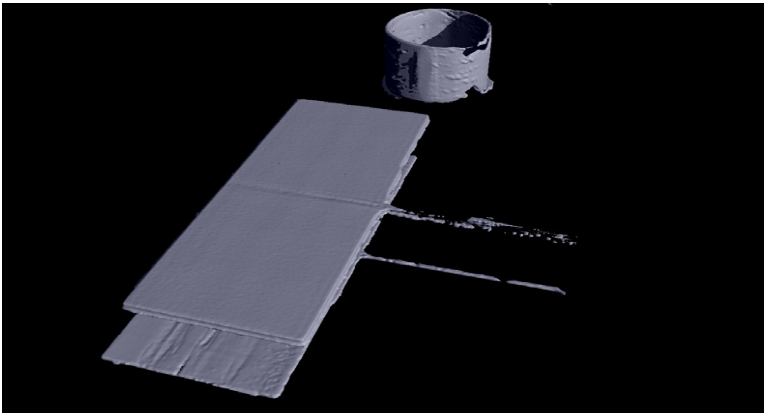

Figure 5: 3D-μCT-photograph of an electrorheological microvalve.

The computer tomography enables a non-destructive look inside of the electrorheological microvalve, because the metallic electrodes absorb and spread the x-ray radiation and gets visible as grey or white portions of the pictures.

It is even possible to generate a 3 dimensional picture as shown in figure 5. This picture shows the inlet at the top of the picture. In the middle there are the two electrodes with the supply wires for the voltage, where the distance between them is visible.

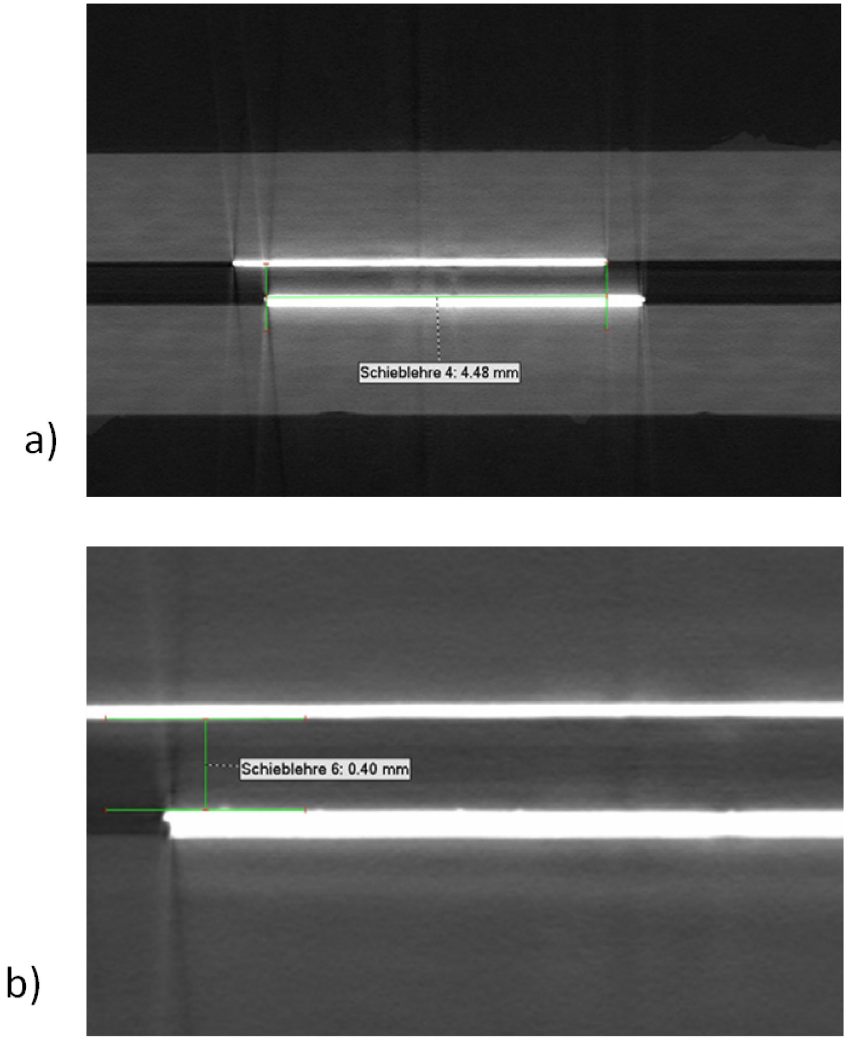


Figure 6: Longitudinal section µCT-photographs of the electrorheological microvalve.

In contrast to the intention to generate a valve with a length of 5 mm and a gap height of 280 µm, the gluing process generated a horizontal displacement of 0.42 mm (Figure 6a) and a gap height displacement (vertical) of 120 µm (Figure 6b). This displacement generates a homogeneous electrical field with a length of 4.48 mm, a width of 2 mm and a gap height of 0.4 mm.

## 4 Performance of the microvalve

Nevertheless, the electrorheological microvalve is able to generate a switchable pressure difference which is generated only by applying an electrical voltage to the electrodes.

By changing the volume flow and the voltage it is possible to detect the switchable pressure difference.

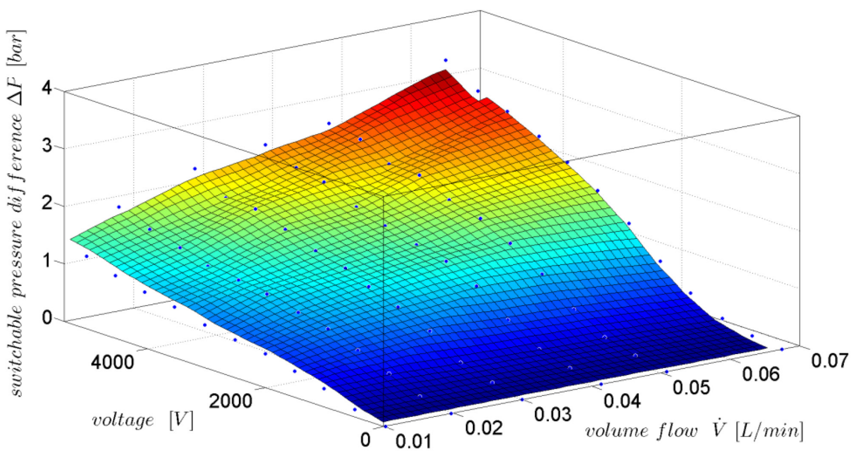


Figure 7: Switchable pressure difference of the micro-ER-valve.

Figure 7 shows the performance of the previously explained valve. It is obvious, that even with a voltage of 1 kV a switchable pressure difference can be generated. Another interesting effect is that it is possible to switch the pressure in front of the valve in a few milliseconds from 0 bar up to 3.5 bar by using a higher voltage. It is particularly impressive how small the volume flow could be, and that the chain building mechanism is still working at the slowest measured volume flow of 10 ml/ min.

## 5 Outlook

This paper presents the design and the production of an electrorheological microvalve which is able to generate a pressure difference at a volume flow of 60 ml/min up to 3.5 bar only by changing the electrical field strength.

The outer dimensions of the described microvalve provide the opportunity to integrate it into actuators for linear and rotational movements. Thereby, it is a predestined solution for the integration in the center of a bellow actuator.

Another advantage is based on the manufacturing principle. The 2.5-dimensional manufacturing principle offers the opportunity to combine several valves in a very small assembly. Especially the possibility to extend the number of valves by simply adding more layers to the valve stack, it is possible to easily react to every change in the surrounding hydraulic system.

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