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A miniature proportional valve for a tactile display

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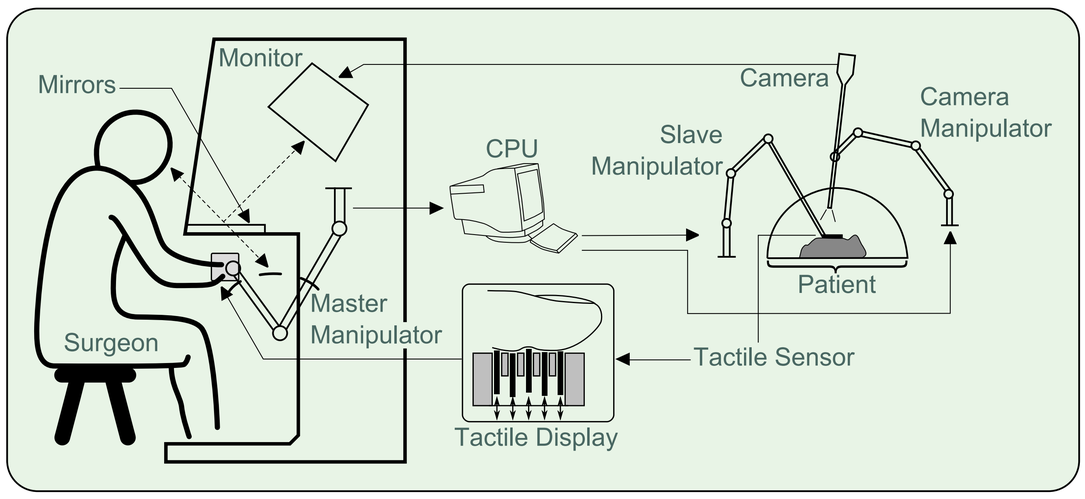
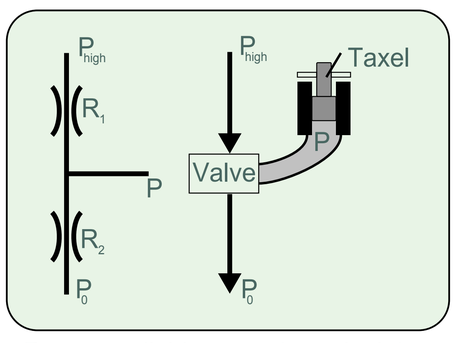
Abstract

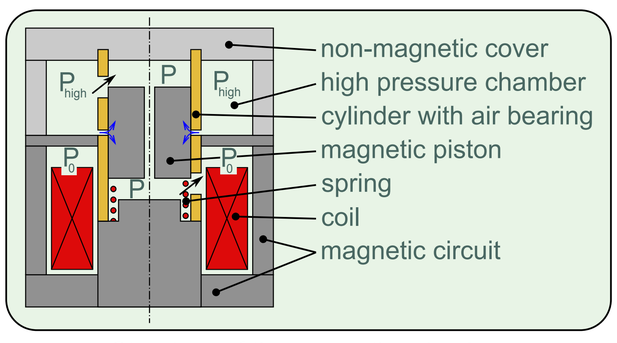
To return the feeling of touch to a surgeon during robot assisted minimally invasive surgery, a tactile display is necessary. Such a display usually consists of a large array of pins with challenging requirements for the actuators controlling the pins. A pneumatically controlled display has the advantage that the power can be generated at a distance, while the display itself is very simple. While this is not the first time pneumatics is used to actuate a tactile display, a satisfying valve has been missing. This valve is specifically designed to fill that gap.
The presented valve is a proportional valve, controlled by a reluctance actuator and capable of dealing with relatively high pressures. To eliminate friction of the piston, an air bearing is included. A prototype offers a proof of concept, but it needs to be optimised to reach a full pressure range.



Tactile feedback in robot assisted surgery



Pressure divider as valve principle.
The valve is connected with a taxel to press into the fingertip.



Structure of the proportional valve.
Dark grey represents the magnetic circuit.
Light grey represents amagnetic material.

Valve design

Aim: drive a tactile display with 100 taxels (tactile pixels)

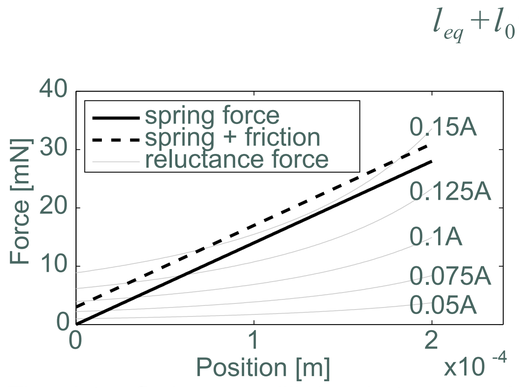
Requirements:
- regulate a pressure of 600 kPa proportionally
- 20 Hz bandwidth
- limited size, power consumption and price

Two variable hydraulic resistances, consisting of two 100 µm holes, regulate the pressure in a pressure divider. An electromagnetic reluctance actuator controls the position of the valve piston which in turn blocks the holes and thus changes the hydraulic resistances.
An equilibrium between the spring force and the reluctance force determines the position of the piston.

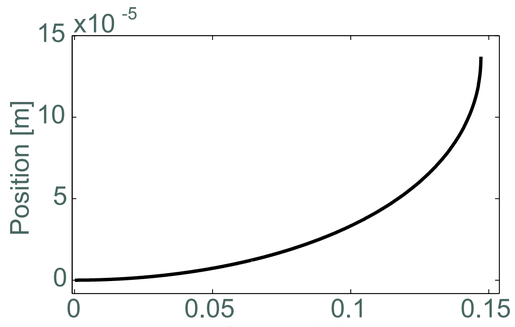
$$kx = \frac{\mu_0 S N^2 I^2}{2(l_{eq} + l_0 - x)^2}$$

Beyond a certain position, there is no stable equilibrium. Therefore, the air gap in the reluctance actuator has to be at least three times the desired displacement of the piston.

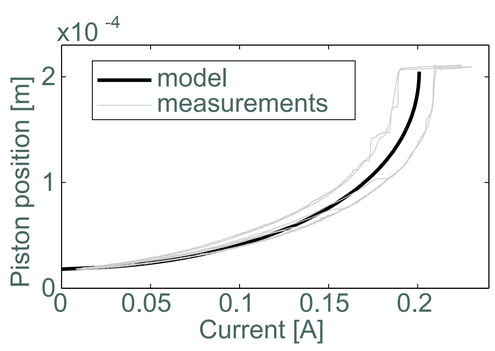
$$l_{eq} + l_0 = 3x_{max}$$



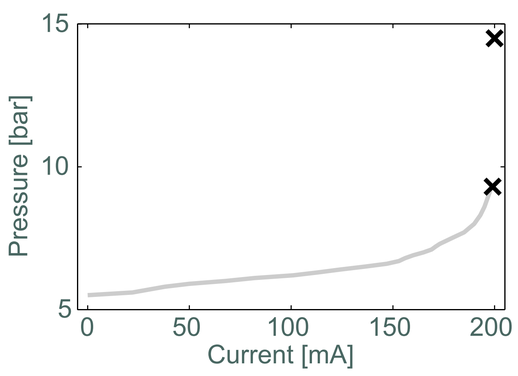
The piston finds an equilibrium between spring force and reluctance force. If the current becomes too high, there is no stable equilibrium and the piston jumps to its end position.



Theoretical characteristics of the reluctance actuator.



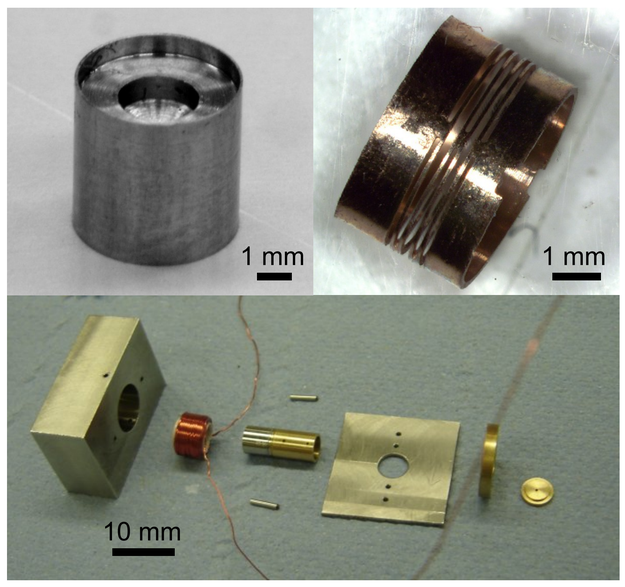
Comparison between experimental results of the reluctance actuator and a fit model.



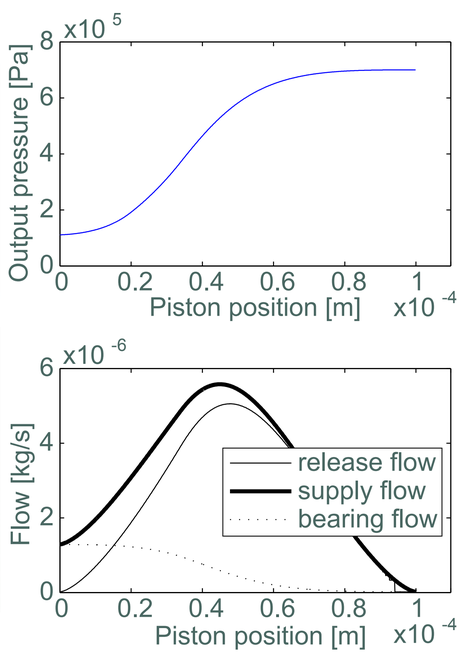
Experimental characteristic of the valve prototype. The x's indicate unstable jump.

Air bearing

Reluctance force < 50 mN
Even a very small amount of friction ruins performance and decreases the range of the piston. An air bearing is introduced.
- no friction
- additional flow
- pressure range of the valve decreases
- 12 holes with 30 µm diameter
- air gap between piston and cylinder of 4 µm



Parts of the valve prototype. Upper left: steel piston.
Upper right: phosphor bronze spring.
Bottom: the different valve parts before assembly



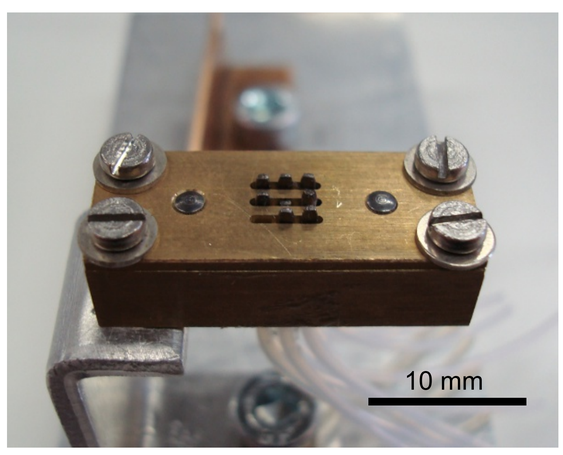
Influence of air bearing on valve characteristics.

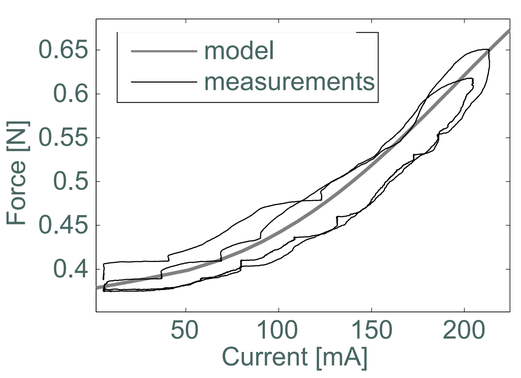
Prototype and results

All parts are custom made. The reluctance actuator is tested in a separate prototype and shows a close correlation with the model.
The air bearing results in a very smooth operation of the valve.
The pressure range of the proportional valve is currently limited to 5.5-9.5 bar with a supply pressure of 14 bar.

Further improvements

- improvement of the sharpness of the piston edges
- optimisation of the air bearing
- optimisation of the position of the piston





As validation, the valve is connected with a single taxel of a lightweight tactile display.
While the prototype has a limited range and the proportional valve needs to be improved, the initial results are promising.

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