Presented at the COMSOL Conference 2008 Hannover

Design of an Electrodynamically Actuated Microvalve Using COMSOL Multiphysics and MATLAB

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Introduction

Microvalves for use in microfluidic systems are an active topic of research in the MEMS field. Electrodynamic actuation, which involves the interaction between a coil and a permanent magnet, is of interest for microfluidic valves because of its large stroke and magnetic latching. This transduction method has received little attention for use in microvalves due to the difficulties associated with fabricating microscale permanent (hard) magnets. Recent advances, however, make improved microvalve designs for high pressure applications possible. Previous efforts have reported closing pressures in the tens of kilopascals. The goal of this design effort is to develop a microvalve to regulate the flow of gaseous fuels that is capable of a closing pressure of 1 MPa.

Design

The electrodynamic microvalve geometry is pictured in Figure 1. Attractive forces between soft and permanent magnets situated at the fluid inlet and valve cover, respectively, hold the valve closed. Passing a current density (J) through coils on the surface of the valve seat changes the magnetic field and allows opening of the valve with the help of the serpentine spring. A free body diagram of the forces acting on the valve cover is pictured in Figure 2.

Optimization

The objective for the design is maximization of the valve closing force while ensuring the ability to open the valve:

Objective Function

Maximize $f_{obj}\left(\overline{X}\right) = F_m\big|_{\substack{g=0\\J=0}} - F_m\big|_{\substack{g=0\\J=J_{max}}}$

Design variables

$\overline{X} = \left(a, t, t_u, r_i, a_c, t_c, g_c\right)$

Constraints

Geometric constraints
Upper and lower bounds

Results

Description	Symbol	Value
Beam width	b_t	8 μm
Beam height	h_t	16 μm
Beam length	L_t	225 μm
Number of serpentine sections	N	6
Spring stiffness	$K_{springs}$	21.6 μN/μm
Initial gap	g_0	23 μm
Valve cover radius	r_v	190 μm
Inlet radius	r_{in}	6 μm
Max inlet fluid force	$F_{f,in,max}$	122 μN
Max inlet pressure	p_{max}	1 MPa

Electrodynamic actuation has been shown in this work to hold considerable promise for use in high pressure microvalves.

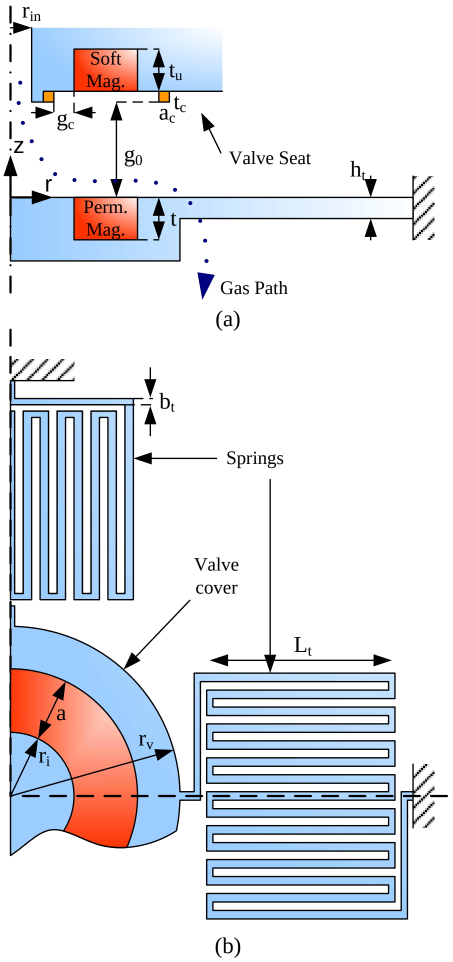

Fig. 1: Electrodynamic microvalve geometry: (a) partial cross-sectional view of mating components; (b) partial plan view of valve cover.

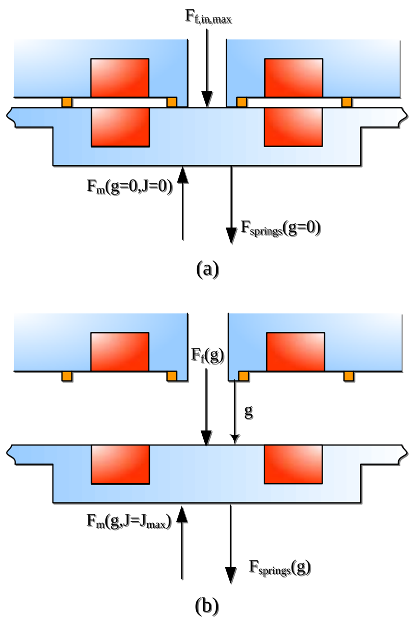

Fig. 2: Forces acting on the valve cover in the (a) closed and (b) open positions.

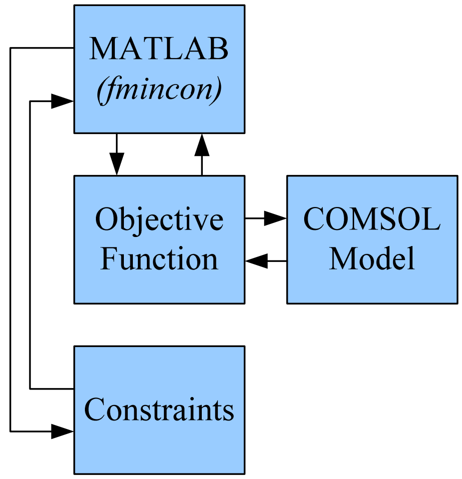

Fig. 3: Program flow of the optimization process.

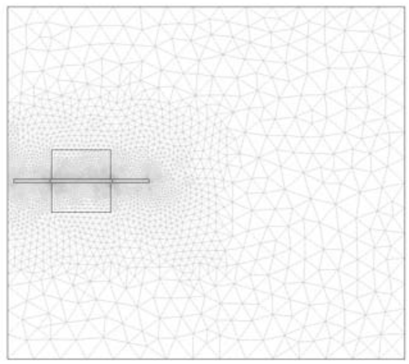

Fig. 4: Typical mesh of magnetic COMSOL model.

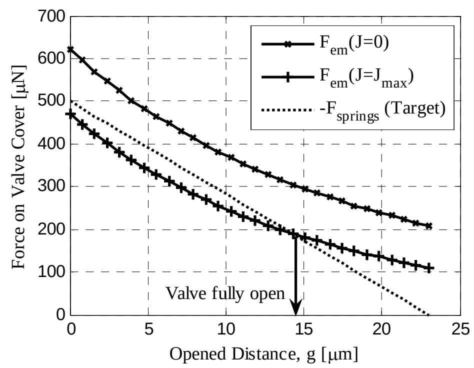

Fig. 5: Electromagnetic and spring forces acting on the valve cover.

Future Work

Inclusion of fluid forces, thermal analysis of heating in coils, estimation of dynamic characteristics

Acknowledgements

This material is based upon work[4] supported under a National Science Foundation Graduate Research Fellowship.