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# Modelling of an uniaxial single-sided magnetically actuated cell-stretching device

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ABSTRACT

This paper reports the modelling approach and optimization of a magnetically actuated cell-stretching device. The paper first describes the numerical simulation of the actuation system consisting of a permanent magnet and an electromagnet. The magnetic flux density and magnetic force were verified experimentally over the range of superimposed magnetic flux density from 186 mT to 204 mT. The relative errors for magnetic flux density and magnetic force are 5% and 15%, respectively. This systematic modelling approach provides a reasonable numerical model for optimizing the electromagnetic actuator of the cell-stretching device. The induced actuation force was then coupled with the structural analysis of the cell-stretching device to determine the acceptable distance between the two magnets. The results suggested that this actuation system is capable of precisely predicting the behavior of our existing cell-stretching device.



## 1. Introduction

Mechanotransduction is the process of converting mechanical stimuli into biological electrochemical signals, which guides cell behavior, growth and morphology of cells [1–4]. Mechanotransduction has been reported as an important factor for maintaining cellular homeostasis [5–7]. Therefore, dysfunction or irregularities in cellular mechanotransduction may well result in diseases such as heart failure, asthma and cancer [8,9]. For this reason, mechanotransduction has become an increasing interest for researchers in fields such as bioengineering and regenerative medicine. However, controlling the complexities associated with a cell's physical *in-vivo* microenvironment is a hubris task, which has led to the development of *in-vitro* devices. *In-vitro* cell stretching devices are designed to mimic the cells physical microenvironment and provide a greater insight into the complex mechanotransduction mechanism.

Micropipettes or tweezers are two common *in-vitro* stretching methods used for introducing mechanical force into cells [10–14]. A number of commercial cell-stretching platforms are currently available. For example, Flexcell (Flexcell International Corporation) is considered the most elegant cell-stretching platform in the market. This system incorporates pneumatic actuators to induce a homogenous strain to a membrane, where cells are cultured [15–17]. Strex Systems (STREX Inc.) and ElectroForce (Bose Corporation) are other cell-stretching systems, which also have been widely used [18–21]. Apart from commercial cell-stretching systems, several custom-made cell-stretching devices have been reported in the literature over the last decade [22–26].

Common actuation methods for stretching cells grown on an elastic membrane include: electromagnetic, piezoelectric, optical and pneumatic actuators [22,27–31]. Ursekar, et al. [25] developed a cell-stretching device with indenter design and utilized a stepper motor to induce homogenous strain onto a thin membrane. Nava, et al. [27] introduced optical actuation for cell-stretching purpose. Huang and Nguyen [22] utilized pneumatically actuated multilayerd microfludic device for uniaxial cell stretching. Fior, et al. [24] designed an microelectromechanical systems (MEMS) device with externally controlled piezoelectric actuation system. Apart from these common methods, dielectrophoresis, electro-thermal and electrostatic actuations have also been reported for cell-stretching applications [32–34].

All existing cell-stretching methods have some advantages, but very few devices fulfill the general requirements for robust cell stretching research, such as: precise strain patterning, compatibility with a variety of microscopes and/or imaging systems (for analysis) and high experimental throughput. System modelling and simulation are also imperative, to obtain optimised parametric val-

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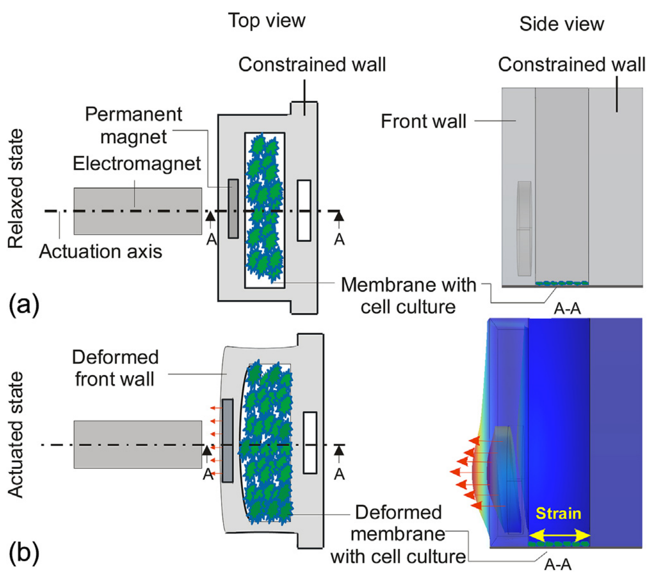


**Fig. 1.** Operation concept of the cell-stretching device (top view and side view): (a) Relaxed state; (b) Actuated state.

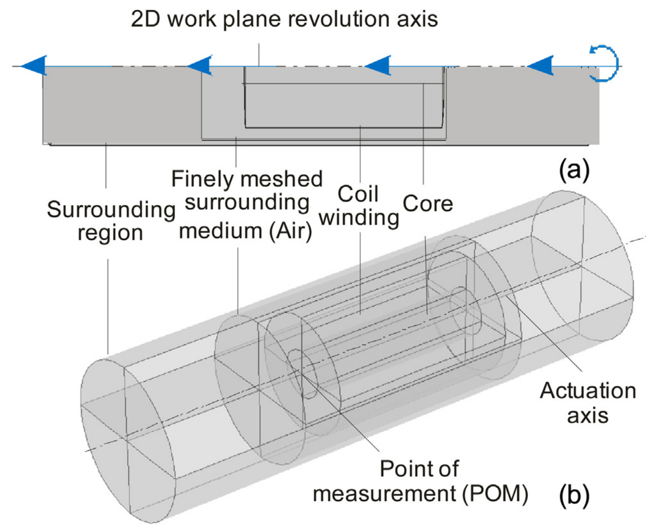


**Fig. 2.** The geometry of the electromagnet: (a) 2D Work plane; (b) 3D view.

ues in the design and the operation of a cell-stretching devices. System optimization with finite element analysis (FEA) will help to achieve the above requirements and the optimal operation of a cell-stretching device.

Our previous report on the single-sided uniaxial magnetically actuated cell-stretching system elucidates the design, simulation and characterisation of the developed stretching device platform with preliminary experimental observations of olfactory ensheathing cells *in vitro* [26]. The previous model incorporates a simple structural model. The present paper focuses on the coupled simulation of an electromagnetic actuator using an electromagnet and a permanent magnet for the uniaxial cell-stretching device. Experimental data subsequently verified the simulation results, which was demonstrated through optimizing the distance between the permanent magnet and the electromagnet.

## 2. Device concept

The present numerical study uses the previously reported cell stretching device design as an example, Fig. 1. The cell-stretching system includes a PDMS device and a permanent magnet (PM) with a diameter of 15 mm and thickness of 2 mm embedded into the front wall of the device. The permanent magnet is actuated by an electromagnet (EM) controlled by the programmable direct-current (DC) power supply. A mounting platform provides a support for the PDMS device and maintains the alignment of the PM and EM along the actuation axis. The 200-μm thick deformable PDMS membrane was bonded to the bottom of the PDMS device using oxygen plasma. Fig. 1 illustrates the operation concept of the actuation system. Once the EM is activated, the magnetic force acting on the PM deforms the front wall of the PDMS device, consequently causing the membrane to be stretched uniaxially along the actuation axis.

## 3. Modelling approach

### 3.1. Modelling the electromagnet

The finite element analysis (FEA) model was implemented in COMSOL Multiphysics 5.2 (COMSOL, Inc., MA, USA) utilising AC/DC and structural mechanics modules for the optimisation of our existing cell stretching device [26]. For computational simplicity, the transient nature of the problem is modelled in two quasi-static steps. The first step includes modelling of the actuation system and the calculation of the magnetic force. The second step includes coupling of the magnetic force from the first step with a structural model to determine the strain on the membrane.

The calculation of the magnetic force was further divided into two subtasks. The first task includes modelling the EM and its validation with experimental data to confirm the stability of the model. The second task introduces the PM into the already optimised EM model environment (task 1) to obtain a superimposed actuation condition of the complete cell-stretching device. Once more, experimental data was used to validate the results of the second task.

The linear relationship between the actuating current $I$ and the generated magnetic flux density was used to model EM in COMSOL Multiphysics 5.2. Considering the EM as an induction coil in an ideal state and neglecting environmental disturbance, the flux density is determined as:

$$B = \mu N I, \quad (1)$$

where $B$ is the magnetic flux density (in T), $I$ is the current (in A); μ and $N$ are the magnetic constant and the number of turns, respectively.

A static study in AC/DC module with magnetic fields was considered for modelling the EM in COMSOL [35]. The geometry mainly consists of the EM core, the coil and the surrounding medium for magnetic field propagation. The dimension of the EM model was taken from the actual EM [MK magnets, Seoul, Korea] of our existing cell-stretching device. For better visualisation of the simulated magnetic field, a 2D work plane modelling approach was first considered. Subsequently, the 360° revolution option in COMSOL was utilized to build the 3D EM model with the core and the coil winding. The EM measured 40 mm in length with a core diameter of 10 mm and an outer coil diameter of 25 mm (Fig. 2). The surrounding medium was confined in a cylinder that had a diameter of 15 mm and length of 52 mm.

Furthermore, iron, copper and room air were selected to constitute the cylinder core, the coil and the medium domain, respectively. The cylindrical coordinate system was used. Multi turn coil study was selected for the EM modelling assuming the following equation;

$$J_e = \left(\frac{N I_{coil}}{A}\right) e_{coil} \quad (4)$$