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Development of a Mechanical Actuator for Active Lenses

Angela C. Vargas, Paulo H. Picciani, Ricardo C. Michel*

Summary: Variable focus lenses can vary their shape and consequently their focus when a stimulus is applied. This kind of lenses, on some applications, has advantages over the regular lenses because of their smaller size and weight. Different types of stimulus can be used to change the shape of these lenses; the element that applies the stimulus is called actuator. Lenses deformed by a mechanical force are interesting devices that work in a way similar to human eyes. The muscles around a human eye compress or relax its lens every time a focus change is needed. On this paper we describe a voice coil actuator that applies mechanical force over a flexible polymeric lens, changing its shape and consequently its focus. The applied force, the deformation of the lens and its convergence power are functions of the driving current in the voice coil actuator. The maximum force applied by the actuator is 0.48N. The convergence power is also dependent of optical and viscoelastic properties of the lens material.

Keywords: active lenses; mechanical actuator; optics; refractive index; variable focus lenses

Introduction

Lenses are refractive elements that are used on different optical devices. Nowadays, the usual glass lenses were partially substituted by polymeric lenses principally to improve their impact resistance.[1] However, those lenses (glassy or polymeric) are rigid and consequently they have one format that defines their focus. On optical devices, where an adjustment of the focal is necessary, several lenses are used and the focus adjustments depend on translational movements between the lenses.[2]

In nature it is possible to find lenses that have not a rigid format, like the human eyes that can change their focus distance when the muscles apply a force over the crystalline.[2] This fact encouraged the research on artificial lenses that have the property of changing their shape and consequently their focus. Different approaches are explored in order to create variable focus lenses, including liquid lenses,[3,4] liquid crystal lenses,[5] flexible polymeric lenses[6] and combinations of the aforementioned.[7] All kinds of active lenses need an actuator, that is the element that provides the driving force, which can be temperature,[6] pressure,[7] magnetic force,[8] electric force,[3,4] among others.

Voice-coil actuators are normally used on the fabrication of speakers, hard disk drives and others. This kind of actuators is composed basically by an inductive coil and a permanent magnet; the force produced by this actuator is proportional to the applied driving current.[9] On this paper we describe a mechanical actuator that is capable of applying a force over a flat flexible polymer, deforming it and consequently making a lens. The convergence power of the lens is explored as being a function of the current applied to the voice-coil system.

Instituto de Macromoléculas Professora Eloisa Mano (IMA), Universidade Federal do Rio de Janeiro, Rio de janeiro, RJ, CEP: 21941-598, Brasil
E-mail: angecrisvar@ima.ufrj.br

Experimental Part

The sample was made of silicone. The liquid silicone was hand mixed with the catalyzer

(5%w/w) and 10% w/w of silicone oil (all from Epoxifyber®) on a cup and poured in a glass mold with dimensions of 12.5 cm × 8 cm × 2 mm. After 24 h, the sample was carefully removed from the mold and a circular sample with diameter 2.3 cm was cut using a circular cutter. The thickness of the sample was measured three times with the help of a caliper and the thickness average was registered. The refractive index of silicone gel was measured on an Abbe refractometer following the ASTM D542-50 standard using KCl solution on water 10%w/w as contact liquid.

A commercial speaker (Buster, BSLC-432) with impedance of 4 Ω was used to develop a mechanical actuator which was assembled to the sample chamber. The sample chamber was constructed with transparent acrylic plates and compounded of two parts; one fixed and the other left mobile. Polymeric samples were located in the chamber between two transparent screens, one of them shaped as a washer as can be seen on Figure 1.

When a current is applied on the coil, it moves toward the sample deforming it on one side and consequently forming a lens, as can be seen on Figure 2. As the focus changes, the divergence of the light beam also changes. The beam radius measurement was made after the focal distance.

The actuator was connected to an adjustable current supply (MINIPA, MPL-13). A laser beam (MELLES GRIOT, 05-LHP-551-478) of known profile was shone through the sample. A camera (BRIGHT, 0050-1.3Mpixel) was located along the ligthpath, just after the sample, in order to take pictures of the beam profile projected on a white screen (Figure 3). Changes on the beam profile are due to changes on the lens shape. The pictures were processed on the computer with the ImageJ software[10] (version 1.45k) in order to measure the radius of the beam profile on different distances. All measurements were performed on triplicate and the average of each point was registered and plotted.

The force applied by the voice-coil system was measured using an analytical balance (SHIMADZU, AY220). Over the balance was placed a support connected to the actuator system (Figure 4). When a current was applied, the actuator applied a force over the support and that force was registered on the balance.

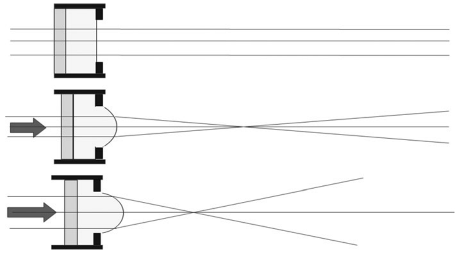

Figure 2.
Schematic performance of the actuator in focusing collimated light. The arrow indicates the amount of force applied over the mobile acrylic plate.

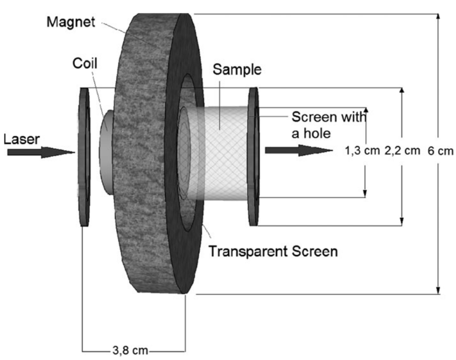

Figure 1.
Actuator's design.

Results and Discussions

The sample obtained was transparent (Figure 5) and with a thickness of 2.18 mm ± 0.06 mm; the refractive index of the silicone gel was 1.4057 ± 0.0028.

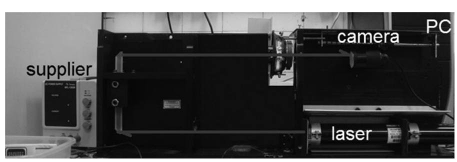

Figure 3.
Experimental arrangement.

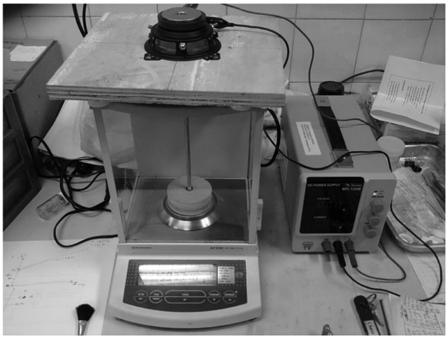

Figure 4.
Experimental design for the force measurement.

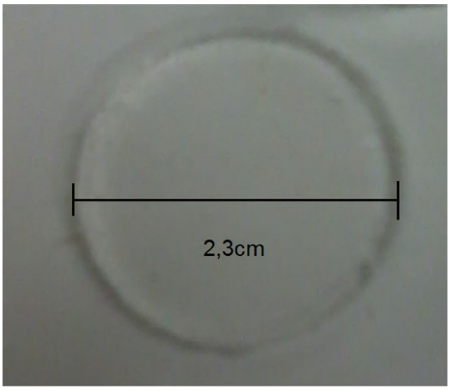

Figure 5.
Silicone sample.

The actuator was developed using a commercial speaker and modified as reported. The Figure 6 shows the actuator and the sample holder. The actuator was fixed on a metallic support to give it more stability and it was aligned with the laser beam and the camera.

The camera and the white screen (Figure 7) were placed in front of the silicone lens along the light's path. This sensor can be moved along a rod in order to obtain images of the laser beam profile, after the sample, on different distances from the lens.

The measurements of the mechanical force applied by the system on the material for each current are shown on Figure 8.

The force applied by the actuator increase with the current and can be fit by a polynomial function of order 2. The voice coil behavior can be described by two equations, the force principle of Lorentz[*] and the Hooke's law[†] both of them being linear equations which suggests a linear relationship between the force and the current applied to the system, therefore the polynomial behavior was not expected. The reason for this behavior is under investigation.

Figure 8 also shows the maximum force exerted by the voice-coil actuator; this maximum force is function of the maximum current that the voice-coil can safely accept. This maximum force give us an idea of the softness of the materials that can be used to form a lens on this equipment, that is, materials that can be elastically deformed when submitted to forces below the maximum force (soft elastic materials).

The diameter of the laser beam profile at different positions of the camera for three different driving currents was plotted in Figure 9.

With driving current at 0.00A and no holder, the diameter of the beam has a slight slope, which can be explained by the form that the lens acquired on the mold. When the holder is used it is possible to observe an increase on this slope caused by the increase of applied pressure. For driving currents other than 0.00A the light beam diameter increases linearly with the distance from the camera to the sample. This implies that a lens is formed and that the measurements are been made after the focal point. Figure 9 also shows that the slope of the curve increases with electrical current in the coil, this shows that the deformation on the lens is a function of the current density. However each new increment in deformation needs a bigger increment in current, due to the storage and dissipation of energy in the bulk of the material, as function of its viscoelasticity. This suggests a possibility of

[*] Lorentz principle F = kBLIN where F: force, k: constant, B: magnetic flux density, L: length of a conductor, I: current, N: number of conductors.

[†] Hooke's Law F = -kX where F: force, k: constant, X: distance.

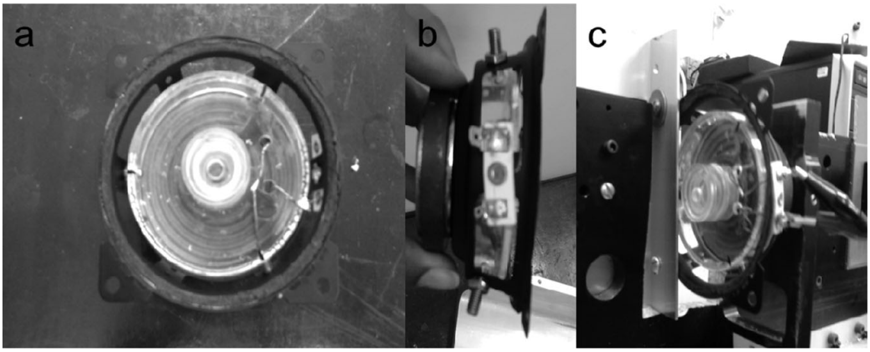

Figure 6.
Actuator. a) frontal view, b) lateral view, c) isometric view.

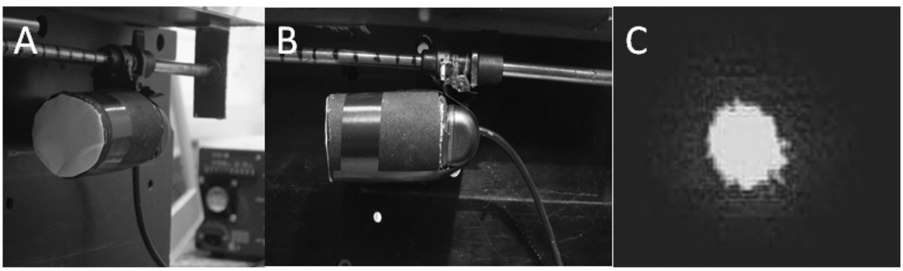

Figure 7.
Sensor. a) Isometric view; b) Lateral view; c) light beam profile picture.

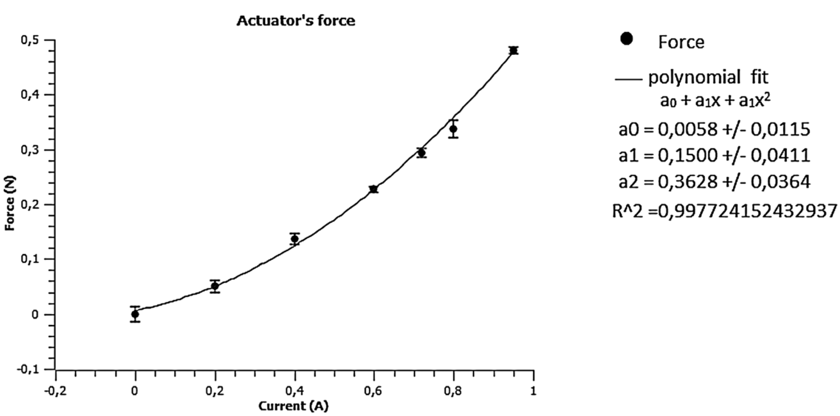

Figure 8.
Force Applied by the actuator. ● Experimental results; — Linear regression.

accessing the viscoelastic parameters of the lens material through the measurement of the image produced as a function of the applied current.

Conclusion

An actuator for active polymeric lenses was developed that is able to apply a force over

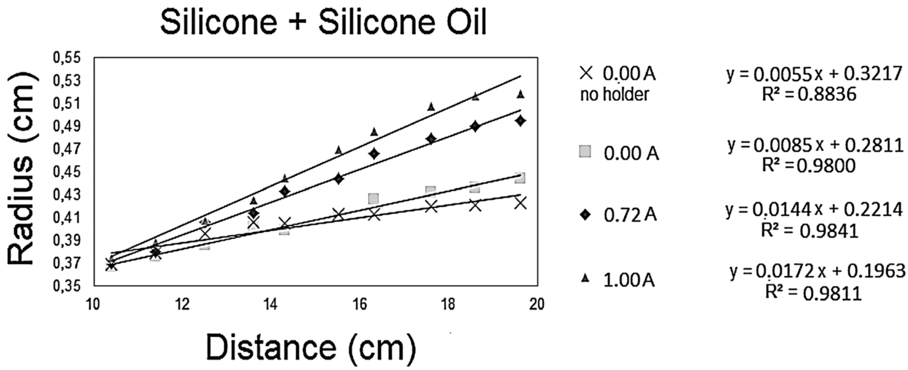

Figure 9.
Beam's radius behavior with the distance. ■ Current = 0.00A, ◇ Current = 0.72A, ▲ Current = 1.00A, X Current = 0.00A and without the holder.

a soft polymeric material deforming it on a lens shape. The convergence power of the lens is function of the driving force applied and some properties of the polymeric material like refraction index, softness and elasticity. These properties are dependent of the kind of polymer used, the presence of additives and the presence and degree of crosslinking. The maximum force applied by the actuator is equivalent to 0.48N.

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