Advances in the development of tunable lenses in Mexico

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Abstract—Advances in the development of tunable lenses have produced more compact, simple and lightweight optical systems. There are different types of tunable lenses; among the simplest we can find liquid and solid lenses, which only require a mechanical mount to change the shape of the lenses. We present the analysis and results that were obtained recently from these two types of lenses which have produced an improvement in the quality of images formation as well as some of their future applications.

In recent years various types of tunable lenses have been developed and have attracted much attention due to their notable advantages against classical lenses and their potential applications in such areas like ophthalmology, machine vision, microscopy, laser processing, lens cameras phones, etc. due to the possibility of making lighter, simpler and more compact optical devices; such devices are optical systems capable to change their own focal length by modifying some of their physical parameters and this can be achieved by several means [1]. Different technologies are being explored in order to let tunable lenses efficiently respond to a wide variety of stimuli such as mechanical, hydraulic/pneumatic, electromagnetic, photo-thermal, fluid flow and electro-chemical [1-4]. Hydraulically or pneumatically technologies used in tunable liquid lenses commonly include an external pump that introduces a fluid into a lens-shaped elastomer made chamber and induces pressure variations causing a change in its focal length [3-5]. It has also been demonstrated that electromagnetic activation, thermal induction, electrochemical effect and changing refraction index are used in tunable lenses [6-9]. Tunable lenses were also used in a photodetectors array [10].

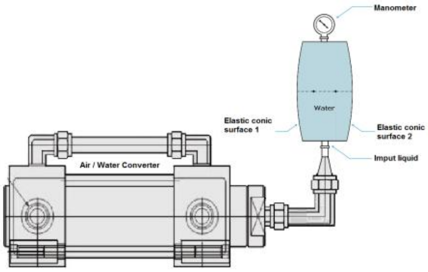

Fig. 1. Schematic diagram of the variable focal length liquid tunable lens.

In this direction, we have developed two types of tunable lenses; the first type is a liquid lens with a variable focal length that consists of a mechanical mount that houses a liquid medium, two elastic membranes, a conduit to removed air from the chamber, a manometer and a system to introduce and remove liquid from the chamber of lens [5]. The liquid pressure on the membranes surfaces causes thickness and curvature changes. A schematic diagram of the system is shown in Fig. 1.

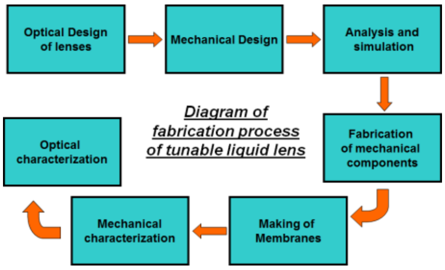

Fig. 2. Process to fabricate a tuneable liquid lens.

To improve the opto-mechanical performance, management and cost of this type of lens, we proposed a different class of mechanical mounts and membranes with different surface profiles to reduce optical aberrations.

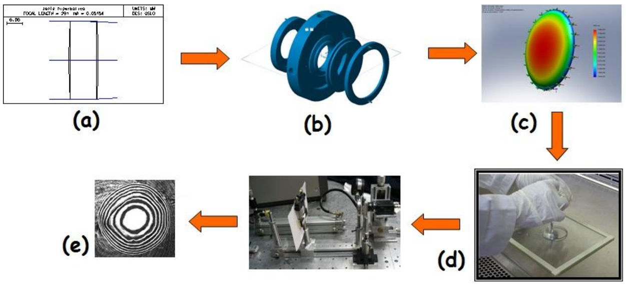

Fig. 3. Graphics stages to elaborate the tunable liquid lenses.

The process begins with opto-mechanical design, then opto-mechanical analysis and simulation. Using the finite element and ray tracing, software is made to finally manufacture a 3D prototype in order to perform functional tests and a mechanical characterization of elastic membranes and components as well as a characterization of the lens optical quality (these elastic membranes are made of Sylgard 184 Silicone Elastomer [11]). Figures 2 and 3 show diagrams of the described process above.

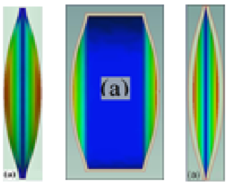

Fig. 4. Three different membrane profiles were analysed to tunable lens.

In order to achieve good performance of the opto-mechincal system shown in Fig. 1, several membrane profiles were proposed to improve the quality of image formation. Plane, spherical and conic profiles were analyzed as seen in Fig. 4. The initial curvature of spherical profiles was calculated with the aid of a third order theory for the case of a lens with minimal longitudinal spherical aberration (LSA) and in the case of a parabolic profile, we used the Kingslake formula [12] for a plano-convex lens with conical surfaces. Equations (1)-(3) provide us the radii of curvature of the surfaces of each lens respectively.

$$r_1 = \frac{2n\,f\,(n-1) \pm \sqrt{\left[2nf\,(n-1)\right]^2 - 4n(n-1)^2\,\varepsilon\,f\,(1-q^2)}}{2n(1+q)}, \qquad (1)$$

$$r_2 = \frac{-2n\,f\,(n-1) \pm \sqrt{\left[2nf\,(n-1)\right]^2 - 4n(n-1)^2\,\varepsilon\,f\,(1-q^2)}}{2n(1-q)}, \qquad (2)$$

and

$$\frac{\left[\varepsilon - Bn/(n+1)\right]^2}{\left[Bn/(n+1)\right]^2} + \frac{Y^2}{B(n-1)/(n+1)} = 1. \qquad (3)$$

Where n is the refraction index of the membrane, q is the shape factor, p is the position factor, f is the effective focal length, B is the back focal length, ε is the axial thickness of the lens, Y is the semi diameter of the lens, and K the conic constant given by $K = -1/n^2$, we used two similar plano-convex membranes to the conic lens [13].

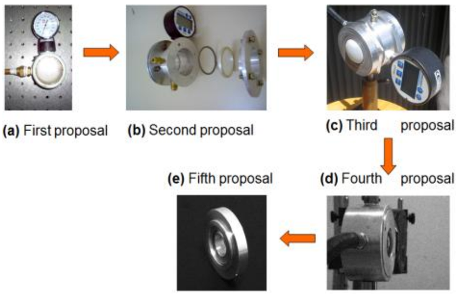

Fig. 5. Evolution of mechanical mounts designs.

The shape of the mechanical mount was also optimized, it started with a width of 5cm and we accomplished to reduce it up to 1cm width as seen in Fig. 5.

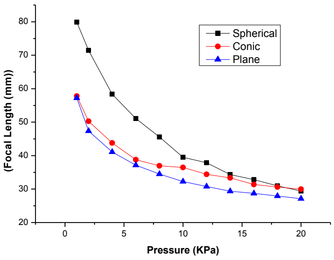

Fig. 6. Behavior of the focal length with respect to the applied pressure.

The curves of several membrane profiles in Fig. 6 show the behavior of the focal length with respect to the change of pressure applied. Similarly, in Fig. 7 we show the variation of spherical aberration of the proposed elements with the pressure.

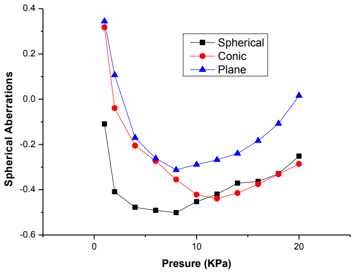

Fig. 7. Variation of spherical aberration with respect to the applied pressure.

From Fig. 6, it can be noticed that the focal length drops as the applied pressure by the liquid medium increases. In Fig. 7, we show how the spherical aberration decreases with pressure values from 0 to 10MPa, but increases with pressure values above 10MPa [14].

The second type of lens that we have developed is a tunable Solid Elastic Lens (TSEL); in this type of lens its shape is modified when radial stress is applied directly onto the perimeter of the lens by means of a rotating cogwheel mechanism that applies continuous linear stress as seen in Fig. 8. The SEL is made of Poli-dimethilsiloxane (PDMS) Sylgard 184 elastomer. By using an elastic material as main body of the SEL, the original shape of the lens can be deformed, and recovered when the radial forces are withdrawn.

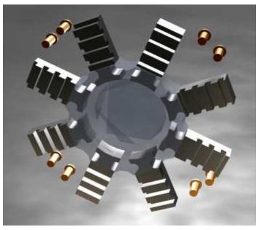

Fig. 8. Mechanical system for applying radial forces to the SEL.

A mechanical mount system was proposed to manipulate the SEL. The mount had to be able to apply uniform pressure onto the SEL in order to modify its physical parameters. Different kinds of mounts were analysed in to ensure that radial forces were homogenously applied onto the elastic material, changing from 8 to 12 cows encrusted in the PDMS (see Fig. 9), which forms the lens body.

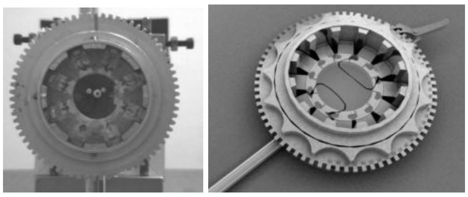

Fig. 9. Mechanical mount of SEL with 8 and 12 cows.

Recently, we have developed two different types of mechanical mounts as shown in Fig. 10. We have also designed SELs with different surface profiles to minimize spherical aberration by using spherical and conical profiles as we did in the case of liquid lens.

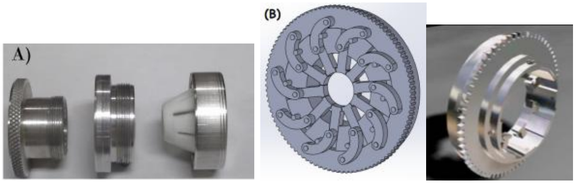

Fig. 10. Proposed mechanical mounts for the manipulation of the SEL.

The complete process used to fabricate tunable solid elastic lenses is as follows: to perform an adequate opto-mechanical design; simulations and analysis with finite element software to optimize the lens shape; manufacturing process; and finally, evaluation of the quality of image formation made by the SEL. See Fig. 11.

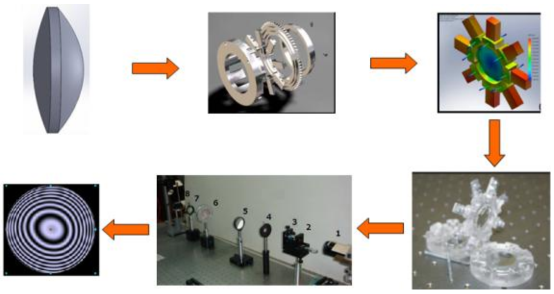

Fig. 11. Graphics stages to elaborate tuneable Solid elastic lens.

We analysed the SEL when radial stress is applied directly onto its perimeter when an angular rotation of the cogwheel is applied. Graphs describing the behavior of the back focal length and Seidel aberrations with the angular rotation of the cogwheel are shown in Figs. 12 and 13.

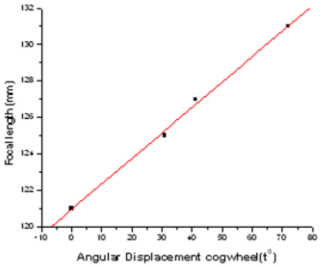

Fig. 12. Graph of back focal length with respect to angular displacement of the cogwheel.

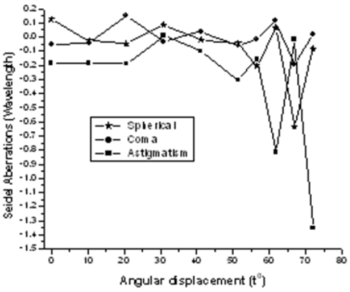

Fig. 13. Changes in aberrations with angular rotation of the cogwheel.

In conclusions, a study of two types of tunable lenses has been presented as well as the evolution of some mechanical mounts and surface profiles with the main goal of producing a functional and ergonomic design to improve the quality of image formation made by the lenses. From our experience in this study we infer that it is possible to develop new proposals of tunable lenses which may be a combination of these, or even add mechanisms capable of modifying the shape of both surfaces of the lenses separately and improving the optical quality of image formation.

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