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A FLUID POWER ACTUATION SYSTEM FOR SHAPE CONTROL OF AN ELASTIC ROD

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Abstract: *Fluid power actuators receive fluid from a pump (typically driven by an electric motor). After the fluid has been pressure, velocity, density, and directionally controlled, the actuator converts its energy to do useful work in various applications. In this paper a system of reversing channels embedded into an elastic rod is developed using fluid power as a continuous actuator. By adjust the fluid velocity, density, and eccentricity path of channels the shape and the deflection curve of the rod can be controlled. The governing equation of the equilibrium of the rod is obtained and the numerical solution for a parabolic eccentric path is presented. The extension of the present work is in design of modern aircraft wings for getting higher lift or drag at the time of take off or landing.*

Keywords: Shape control, Fluidic actuator, Eccentric path, Embedded channel, Elastic rod.

1. Introduction

Shape control of elastic rods by smart materials such as piezoelectric actuators was developed by Agrawal et al (1997) or shape memory alloys by Kelly (1998). Tesar (2013) gives a review of fluidic power actuators.

The main idea of the present paper has arisen from the pipes conveying fluid (Paidoussis and Issid, 1974). The author later added an extra control parameter to fluid induced dynamics problem by studying the dynamic behavior and stability boundaries of the elastic rods conveying fluid under axial load (Guran, 1994). In the present article, a new approach for static shape control of elastic rods is presented. The dynamic behavior is not considered.

2. Physical model and equilibrium of the elastic rod with fluidic actuator

Figure 1 shows the configuration of the embedded system. A channel is generated in the elastic rod for passing the fluid.

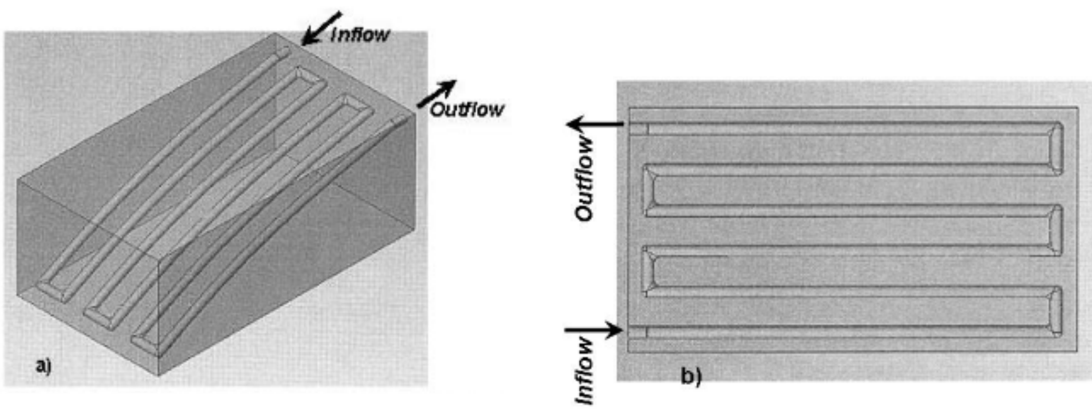

Fig. 1: (a) Configuration of fluid actuator system embedded in an elastic rod, (b) Plane

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The eccentricity path of the channel *E(x)* can follow any curve.

Shape and deflection at any point of the rod such as tip deflection can then be controlled by changing the velocity, density of the fluid or by variation of the eccentricity of the fluidic actuator.

The governing differential equation of small lateral motion assuming Euler-Bernoulli rod theory is derived by Guran (1994).

Here the nondimensional equation of the system is introduced by defining these nondimensional terms

$$x = \frac{X}{L}, \quad w = \frac{W}{L}, \quad e(x) = \frac{E(X)}{L}, \quad = VL\sqrt{\frac{m_f}{EL}}, \tag{1}$$

where L is the length of the beam. Then the nondimensional governing equation of the smart rod with embedded channel is rewritten

$$\frac{d^4w}{dx^4} + u^2\frac{d^2w}{dx^2} = -u^2\frac{d^2(e)}{dx^2}. \tag{2}$$

A clamped rod is considered in this paper for demonstrating shape control of elastic structures using fluidic actuators. The boundary conditions of a cantilever rod is

$$\mathrm{x} = 0 \rightarrow \begin{cases} w = 0 \\ \frac{dw}{dx} = 0 \end{cases}, \quad \mathrm{x} = 1 \rightarrow \begin{cases} M = 0 \\ V = 0 \end{cases} \Rightarrow \begin{cases} \frac{d^2w}{dx^2} = 0 \\ \frac{d^3w}{dx^3} = 0 \end{cases}. \tag{3}$$

3. Solution for parabola eccentricity path

The eccentricity path is assumed to be a polynomial of the second degree.

$$E(x) = C\,X^2. \tag{4}$$

The channels parameter is designed to gain (See Fig. 2)

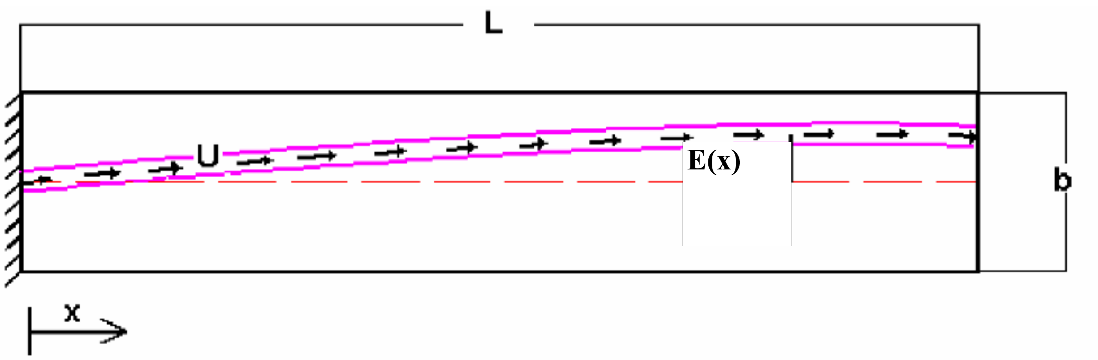

Fig. 2: Cantilevered rod with embedded channel

$$\begin{cases} E(0) = 0 \\ E(L) = \frac{b}{4} \end{cases} \Rightarrow C = \frac{b}{4L} = \frac{1}{4}a \tag{5}$$

where b and a are the width and aspect ratio of the beam respectively,

$$\frac{d^4w}{dx^4} + u^2\frac{d^2w}{dx^2} = -u^2\frac{d^2(e)}{dx^2} = -2u^2C\,. \tag{6}$$

This differential equation is solved considering the boundary conditions and the deflection curve of the beam is obtained

$$\mathrm{w(x,u)} = -\frac{2C}{u^2}\cos\big(u(1-x)\big) - Cx^2 + \frac{2C}{u}\sin(u\,x) + \frac{2C}{u^2}\cos(u)\,. \tag{7}$$

Shape of the beam is then plotted in Fig. 3 for several nondimensional velocities of the fluid. Deflection of the beam is a function of the nondimensional velocity of the beam as well as *x*.

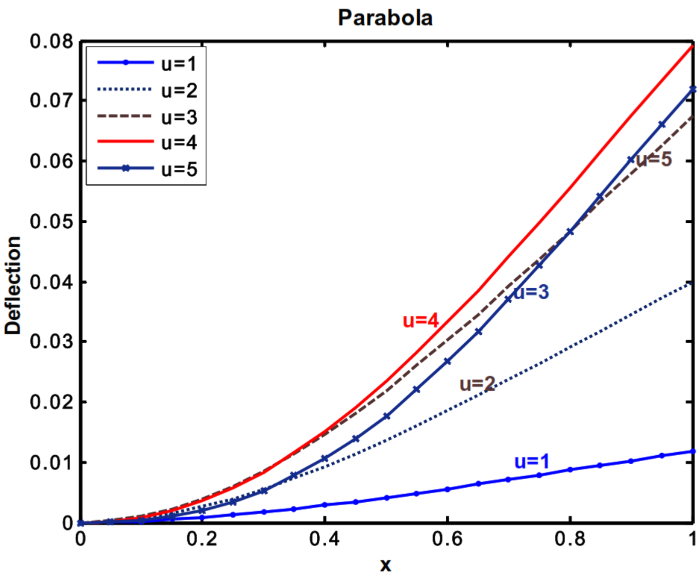

Fig. 3. Deflection of an elastic cantilevered rod with embedded channel with parabolic eccentricity path

This kind of rods can be considered as actuators or even grippers since deflection of its tip can be controlled by tuning the fluid velocity. Thus, tip deflection of the rod is separately studied.

$$w(1) = -\frac{2C}{u^2}\big(-1 + u\ \sin u + \cos(u)\big) - C = f(u) \tag{8}$$

Tip deflection of the rod with parabola eccentricity path equation is plotted in Fig.4, which indicates that increasing velocity will not always result in larger deflection.

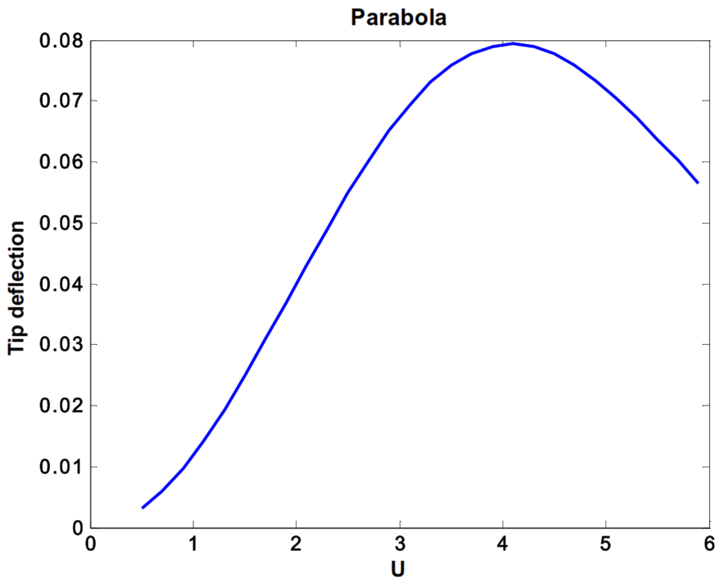

Fig. 4. Tip deflection of the Clamped beam Parabola

4. Conclusions

In this paper a novel idea is developed to control the shape of an elastic rod. A channel for passing fluid which can follow different curves is embedded into the system that doubles back. By adjusting the parameters such as density, velocity and also the eccentricity of the curved channel the desired shape of the elastic rod can be obtained. To demonstrate the use of the novel fluidic actuator in shape control of an elastic rod the analytical solution of the embedded system is solved for a parabolic eccentricity path of the fluid.

The idea can be applied in better design of robot grippers, prosthesis hands, aircraft wings, submarines and watercraft.

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