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Development and testing of stiffness model for pneumatic artificial muscle

Marc Doumit[a], Justin Leclair[b]

[a]Assistant professor at the University of Ottawa, Ottawa, ON, Canada, K1N 6N5
[b]Department of Mechanical Engineering at the University of Ottawa, Ottawa, ON, Canada, K1N 6N5

marc.doumit@uottawa.ca
jlecl033@uottawa.ca

Abstract

Human mobility assist technologies currently rely on complex actuation system or on passive elastic elements to restitute mobility to individuals with motion impairments. These mobile technologies require actuators with a very high power-to-weight ratio such not to hinder their efficiency. One such actuator is the pneumatic artificial muscle (PAM), which consists of a soft elastic bladder, filled with air surrounded by a wire meshing. Whereas PAMs are generally used and modeled as active actuators, their use and model development in passive applications have been limited. The development and validation of a stiffness model would bridge the gap towards applying PAMs as passive components on assistive technologies. This paper presents the development of a stiffness model taking into account internal muscle pressure, muscle geometric parameters and friction in the muscle wall.

Keywords: **Pneumatic Artificial Muscle, Stiffness Modeling, Assistive Devices**

I. INTRODUCTION

Assistive technologies enabling human ambulation either rely on powerful actuators and complex control system to enhance physical abilities, or use passive mechanical components for correction, support or protection. The complexity of emulating human legged locomotion, or gait, has caused limitations in the development of exoskeletons capable of restoring normal gait patterns in non-paralyzed individuals, while keeping the device light and easy to use.

Pneumatic Artificial Muscles (PAMs), compliant yet powerful and light in weight, present a unique set of characteristics compared to other mechanical actuators. Furthermore, PAMs present a non-linear force-length behaviour similar to that of biological muscles [1], making them attractive for human mobility applications. However, the need for a local high-pressure source presents a significant challenge to the application on PAMs to widespread use on mobility devices by limiting their range. In contrast, PAMs can be implemented as unpowered actuators that act as non-linear elastic elements. By using a PAM passively, it is possible to pre-inflate it, and then install it on the assistive technology, thereby significantly increasing the range of the device. This also reduces the effect of settling time for pneumatic system, as limited amount of air is in the system at all times.

Recent studies by Wiggin et *al*. [2], [3] have shown the success of purely passive devices to reduce the amount of energy consumed below the energy for walking without a mobility device. The implementation of non-linear passive components such as the PAM could further improve the effectiveness of such mobility devices.

The present article describes the development of a novel stiffness model for PAM to be used as the main elastic component for a passive assistive device such as in [2].

II. BACKGROUND

A. General Behaviour

The PAM is a pneumatic actuator significantly differing from common pneumatic cylinders. It is composed of an internal elastic bladder around which an inelastic braided mesh is wrapped, secured in place and sealed with end fixtures, as shown in Figure II-1. Upon inflation, the bladder expands radially causing an increase in braid angle, resulting in the overall muscle to shorten. This contractile behavior is non-linear and presents and hysteresis through a contraction-relaxation cycle.

Since the PAM structure consists of few light components, the overall PAM is light in weight. Typically, a 30 cm long PAM weighs approximately 0.1 kg to 0.2 kg [1]. When the PAM motion is prevented during pressurization, the muscle will generate a significant amount of contraction force. For example, a 2 cm diameter muscle pressurized at 200 kPa can produce a 800 N force [4]. Over a normal contraction cycle, a PAM is expected to contract approximately 30% its original length.

B. Construction

In terms of material, the PAM internal bladder can be made of different elastic material, such as butyl rubber, silicone or latex.