Approximate Linear Modeling of Pneumatic Artificial Muscle
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Abstract—The paper presents manufacturing a pneumatic artificial muscle (PAM) with the most basic shape and identifying it as an approximate linear model. To understand characteristics of the PAM, it is necessary to grasp the model well, but it is difficult to model pneumatic system due to its compressibility. Although the pneumatic pressure is basically nonlinear, we assume that it shows linear behavior within narrow operating region. The relationship between output force and input pneumatic pressure is acquired using conventional bode plot technique and derived as a linear transfer function.

I. INTRODUCTION

A pneumatic artificial muscle (PAM) is one of the contractile and distensible actuators operated by the pressurized air. The PAM driven by a pneumatic source was for the first time developed in the 1950s and applied to prosthetics [1]. The PAM is based on the shape of a PET mesh tube wrapped around the outside of the silicon pouch, and the expansion length of the PAM changes depending on the angle of the mesh. Both ends of the PAM are equipped with pneumatic and fixing fits. In recent years, the role and necessity of robots in human society increase accompanied by industrial development of rigid robots. The rigid robots have affected to many parts of our lives through a variety of service robots, domestic robots, robotic pets, and so on.

Due to the aging of society, the population of elderly people is rapidly increasing, and the birth rate is decreasing, and the pace of entry into the aged society is recently accelerated. The rigid robots are substantial and relatively easy to control using the electric motors, but there is a great risk of being used together around people because of their rigidity. As an alternative, soft robotics composed of soft materials is getting more and more popular. The robots composed of soft materials such as silicone have the advantages of being able to be used safely around people thanks to their intrinsic compliances. In particular, there are growing interests in soft actuators that work in a variety of ways with different shapes in order to replace conventional electric motors. Among the various types of soft actuators, the paper deals with a McKibben type actuator [2]. However, since a pneumatic source is used instead of electricity, the actuator is controlled according to the intensity of air pressure. In general, air does not form a definite shape because it is a compressible gas unlike water or oil, thus its mathematical modeling becomes difficult. In order to do the modeling, we have to grasp the characteristics of the pneumatic pressure system. In the paper, we try to draw a bode plot of the pneumatic pressure regulator system because the bode plot technique is relatively easy to analyze the frequency properties of the system. Although the actuator system using pneumatic pressure is not an LTI (Linear Time Invariant) system, we assume it to be LTI system.

II. MANUFACTURING AND EXPERIMENTAL SETUP

This section describes the manufacturing process of the PAM. All processes of the manufacturing are depicted in Fig. 1 with numbers ranged 1 to 11. The PAM is usually composed of silicon. For this purpose, Dragon Skin 30 A/B materials are used to make the body of PAM. The PAM body shape is made in cylindrical shape. The mold for the production is designed using SolidWorks and then fabricated by 3D printing.

First of all, first thing to do is to make the mold to pour the silicon. Put the Dragon Skin 30 main material A and the hardener B in a same container, then mix them in an exclusive mixer. In fact, this process is to remove air bubbles existing inside the silicon, this operation may not completely remove air bubbles, so the degassing work is done once more with the vacuum chamber. After slowly pouring it into the prepared 3D printed mold, the degassing is conducted in the vacuum chamber one more time. To make an air tunnel in the silicon body, put and fix the rod in the middle of the mold. This operation should also be careful and slow, so that no air enters. As shown in process number 5 of the Fig. 1, close the top cover and place it in the oven and leave it at about 70 degrees for about one hour. After this hardening process of silicon, it is necessary to block one side in order to form an air pouch as shown in process number 8 of the Fig. 1. After the silicon body is completed, insert pneumatic fits for one side and the other for fitting fits, and then put on a conductive fabric sensor on it. This fabric sensor was knitted with conductive and non-conductive yarns in order for measuring electric resistance variations. Electric wire is connected for measuring the resistance variations according to length and volume variations of the PAM. Photos and additional explanations of the degassing were suggested and illustrated in the Fig. 1.

Experimental testbed to measure the frequency response of the PAM actuator is proposed as shown in Fig. 2. The testbed consists largely of three parts such as fixture, pneumatic power source and control circuit. The fixture consists of aluminum frames, and the PAM actuator is bolted to the center using a 3D printed connector. A pressure regulator is used to control the pneumatic power source (Regulator: ITV 1031-21N2BL4). Its input voltage is ranged DC 0 ~ 5V and the corresponding output pressure is ranged from 0.7 to 70 psi(4.82bar). The control circuit was configured using NI-ELVIS II. It is a comprehensive instrument for various electrical experiments including an oscilloscope and a function generator. Also, it offers a variety of instrument launchers and is therefore well suited for...
various experiments. It can directly read the electric voltages at the pressure regulator and draw the bode plot together with the loadcell values (corresponding to output forces of the PAM) and the voltages of pressure regulator (corresponding to input pneumatic pressures of the PAM).

III. EXPERIMENTAL RESULTS

Experiments were conducted with the testbed described in the previous section. The pressure regulator voltage as chirp signal was applied to the PAM actuator because the chirp signals contain various frequency components. The output forces were measured with the loadcell. Now it is possible to draw the bode plot by calculating the amplitude ratio between the input and output corresponding to the frequencies contained in the chirp. The input pressure voltage was limited with amplitude of 2V to prevent the PAM from bursting.

Fig. 3 shows the bode plot between input pressure and output force of the PAM. It is composed of a pair of magnitude and phase plots. The above one is the magnitude plot drawn by changing the frequency of the sinusoidal waveform contained in the chirp. The below is the phase plot corresponding to phase delay according to the frequency change. The bode plot obtained from experiments lets us know that there are two poles in the system, which are located at 3Hz and 7Hz, respectively. Also, the DC gain could be obtained by looking at the lower frequency component of the magnitude line. Finally, transfer function $G(s)$ can be obtained as follows:

$$G(s) = \frac{185.158}{s^2+53.407s+414.53} \quad (1)$$

IV. CONCLUSIONS

The manufacturing process of the PAM was illustrated in the paper, and we discussed an approximate linear modeling of the PAM. The experiment was conducted to determine the relationship between force (output) and pressure (input) to understand the characteristics of the PAM. The pressure signal was applied as a chirp signal to the PAM and the bode plot was obtained between them. Finally, the linear mathematical model was derived as the transfer function, although the pneumatic system must actually be a nonlinear system composed of compressible gas.

REFERENCES
