Rehabilitation device for Ankle foot disorder using Pneumatic Artificial Muscle Actuator

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***Abstract*-Human Lower limb is a complex kinematic structure. It involves in the body balance and motor movements. The walking pattern of human being is called Gait. Any disorders in the lower limbs result in impaired Gait. The impaired Gait can be treated by Gait Rehabilitation. In this work, Pneumatic Artificial Muscle (PAM) is designed and fabricated to be used as an actuator for Ankle defects. The PAM is preferred because of the human like behavior. The modeling of PAM is done in Simulink environment using two models namely Geometric and Hill's model. Both the models are analyzed and compared to check whether the torque obtained is necessary for the ankle movement during Gait. The results obtained from the simulation are then validated with the experimental results.**

***IndexTerms*—Pneumatic Artificial Muscle, fabrication, geometric Model, Hill's Model, test setup.**

I. Introduction

Locomotion is necessary for each and every human being. Today, it is estimated that 1.6 per cent of the Indians are inflicted with locomotor disabilities [1]. Ankle joint plays an important role in Locomotion. The primary Degrees of Freedom (DOF) of the ankle is in the sagittal plane namely, the Dorsiflexion and plantar flexion movements The biological Calf muscles generate 80% of the mechanical work during each Gait cycle [2],[3].

Orthosis is a mechanical structure that maps on to the human anatomy [4]. It can be classified according to the joint for which they are designed [5]. The function of Ankle-Foot orthosis is to guide ankle dorsiflexion and plantarflexion, [6] Orthosis consists of sensors and actuators. The actuators convert one form of energy into the other. There are different types of actuators namely hydraulic, electrical and pneumatic actuators. The Pneumatic Artificial Muscle (PAM) is used in Pneumatic actuator.

II. Pneumatic Artificial Muscle

APneumatic artificial muscle consists of expandable tube, nylon braided sleeve and tube fittings. The nylon braided covers the tube and tube fittings are located at the ends of the tube.

When the pressurized air enters into the PAM, it inflates and results in radial expansion and axial contraction of the membrane thereby exerting a pulling forceon its load. The force and motion thusgenerated by this type of actuator are linear and unidirectional.

The PAMs function is similar to our human muscle and it can contract up to 37% of its original length. They are lighter inweight and compliant in nature and provide quick response. They possesshigh power to weight ratio,whichfacilitates direct connection.They provide easy replacement and safe operation [7]

The properties of the muscle depend on the following parameters [8].

- The initial angle between the fiber and rotational axis.
- The initial length of the muscle.
- The initial radius of the muscle

The weight of PAM is about 10% of the Pneumatic cylinder with the same diameter. [9].

III. Model of Pneumatic muscle Actuator

The Pneumatic Muscle Actuator consists of a Pneumatic artificial muscle, compressor, pressure gauge, solenoid valves, connectors, timer circuit, and shoe. The actuator is also modelled in the Simulink environment.

A.Experimental Model

The fabricated pneumatic artificial muscle is shown in the Fig. 1.The fabricated PAM is connected with two solenoid valve, one for inlet and another one for outlet valve. The timer circuit is used to control the sequence of solenoid valve operation. Since PAM can exert only unidirectional movement, two muscles should be connected in anatagonistic arrangement for bidirectional movement. The setup1 consists of three PAMs which is fixed at the front of the shin and setup2 consists of two PAMs is fixed at the back of the shin. The experimental model is shown in Fig. 2.

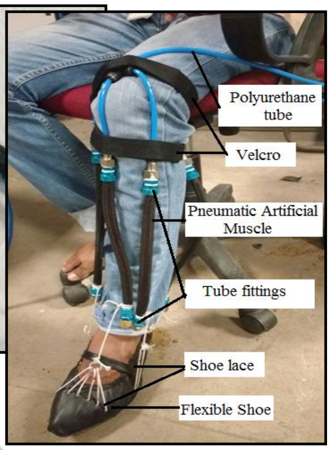


Fig. 1. Pneumatic Artificial Muscle.Fig. 2. Experimental model.

B.PAM Modeling

The modeling of PAM is done for the better understanding of muscle parameters [10]. It can be modeled using geometric, biomimetic or empirical methods.

In the Geometric model, the PAM is modeled as a cylinder with zero or non-zero wall thickness with parameters length of the muscle h, diameter d and the initial angle α [10]. The muscle force developed due to geometric model depends on pressure P, length of the muscle L, braid length, B is [9]

$$F= (P.B^2 ((3L^2/B^2)-1))/4\pi n^2 \quad (1)$$

The hill model consists of a variable damper and the variable spring connected in parallel [11], [12].The muscle force generated by the Hill model is given by [8], [11]:

$$F=F_s +F_D \quad (2)$$

Spring force, $F_s=\pi r_o^2 (a (1-k)^2 - b)$

Damper force, $F_D= -C_d . v. p$

$a =3/\tan^2\alpha$, $b=1/\sin^2 \alpha$

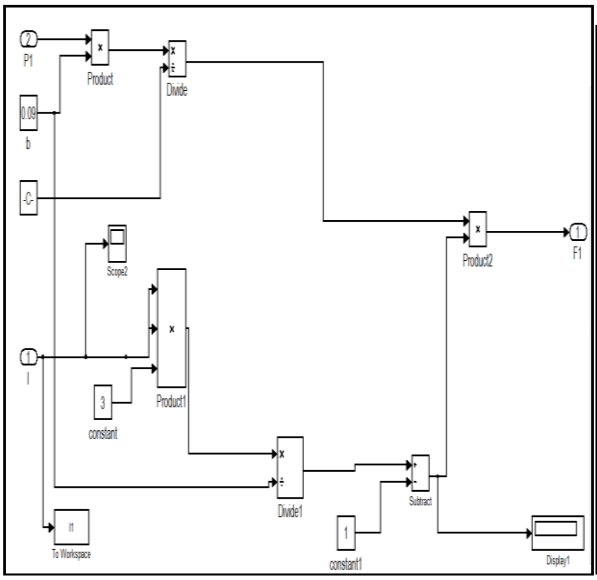
C. Simulation model

The Pneumatic Muscle Actuator is modeled in the Simulink environment using Geometric and the Hill's model. The source blocks, sink blocks and mathematical operations blocks that are used in modeling the actuator in the Simulink environment. The model consists of two subsystems:

- The force changes due to the changes in contractile element and the pressure in geometric model is shown in Fig. 3. And for Hill's model is shown in Fig. 4.
- The angle subsystem is shown in Fig. 5. The position of the angle is given by [11].

$$\phi''= (T-T_L)/J \quad (3)$$

T= (F1-F2).r, J- moment of inertia, r-radius of gear.



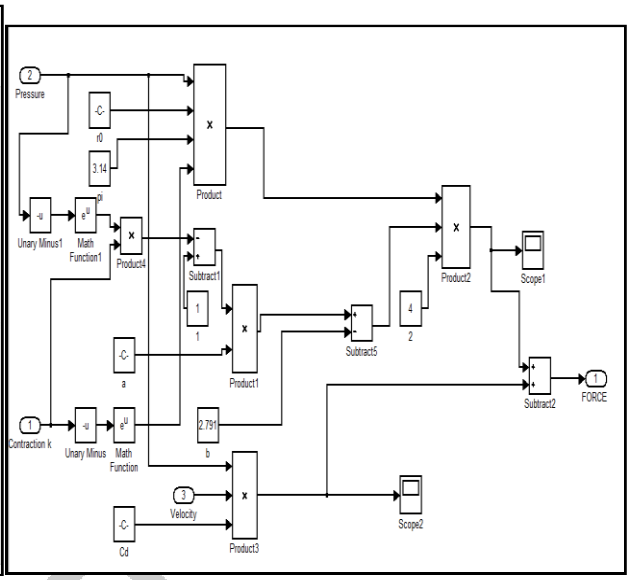


Fig. 3. Force subsystem of geometric model.Fig. 4. Force subsystem of hill's model.

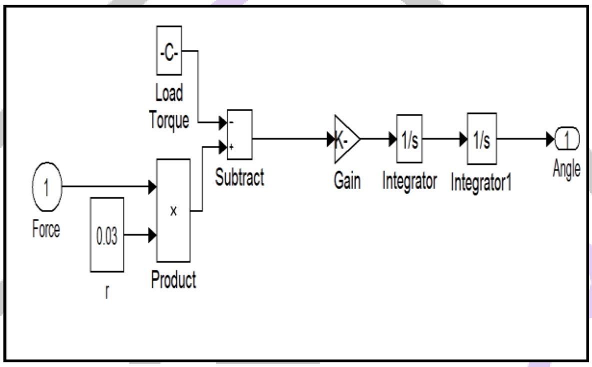


Fig. 5. Angle subsystem.

IV. Simulation And Experimental Results

The analysis is done on individual muscle with different lengths and different loading conditions under different pressures.From the results obtained, suitable muscle with larger pulling capacity is selected. It is based on the maximum change in length of the muscle.

A.Experimental results

Pneumatic artificial muscle with length 21.5 cm is tested under different pressures of with varying loads. The weight of hanger (100 gm) which carries the loads is also included for analysis. The diameter of silicone tube is 11.5 mm.The above step is repeated again for the length 12cm and the change in length is shown in the table 2

TABLE I. Change in length of PAM for different pressures (L=21.5cm)TABLE II. Change in length of PAM for different pressures (L=12cm)

Load	Pressure(bar)		
	2 bar	*3 bar*	*4 bar*
1000 gm + hanger	1.7 cm	2.7cm	3.7 cm
1500gm +hanger	1.6 cm	2.6 cm	3.2cm
2000gm +hanger	1.6 cm	2.6 cm	3.2 cm
3000gm +hanger	1.3cm	2.6 cm	3.1cm

Load	Pressure (bar)		
	2 bar	*3 bar*	*4 bar*
1000 gm + hanger	0.4cm	1.2cm	1.5 cm
1500gm +hanger	0.4 cm	1.2cm	1.5 cm

Load	Pressure (bar)		
	2 bar	*3 bar*	*4 bar*
2000gm+hanger	0.3 cm	1 cm	1.5cm
3000gm +hanger	0.3 cm	1 cm	1.5 cm

From both the analysis, it is concluded that increase in length of muscle increases the change in length of the Pneumatic Air muscle which is the important parameter of the Pneumatic Muscle Actuator to pull the leg. But the change in length is limited to 21.5 cm because if length is increased beyond 21.5 cm, it will not fit to the length of leg. Therefore, Pneumatic artificial muscle with length 21.5 cm and diameter 11.5 cm is suitable to construct Pneumatic muscle actuator for ankle foot orthosis.

B. Simulation Results

The model of the entire PAM based actuator system, based on the geometric and Hill's model approach is built in the Simulink software. Then the models are simulated to analyze the PAM muscle.

Before that a single PAM is modeled in the Simulink and the variations of length of PAM for different pressures and loads are determined. The change in length of the muscle (21.5 cm) for different pressures and loads are shown in Table III.Then the PAM of 12cm is tested under different pressures and loads and the results are shown in Table IV.

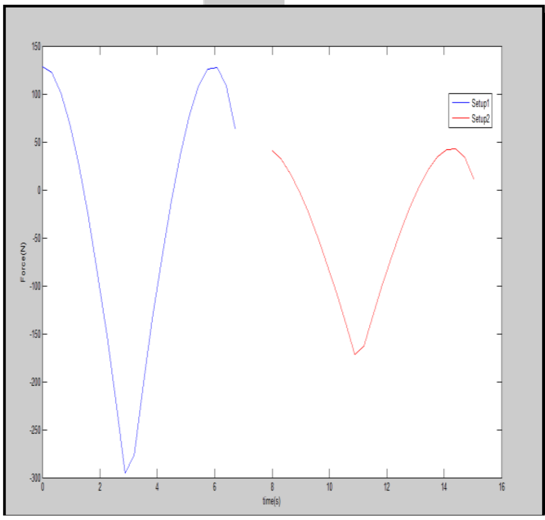
TABLE III. Change in length of the PAM(original length=21.5cm)

Load	Pressure (bar)		
	2 bar	*3 bar*	*4 bar*
1000 gm + hanger	4.3 cm	4.8cm	5.1 cm
1500 gm +hanger	3.5 cm	4.3 cm	4.7 cm
2000gm+hanger	2.7 cm	3.7 cm	4.3 cm
3000 gm +hanger	1.4 cm	2.8 cm	3.5 cm

TABLEIV. Change in length of the PAM (original length =12 cm)

Load	Pressure (bar)		
	2 bar	*3 bar*	*4 bar*
1000 gm + hanger	2.4 cm	2.7 cm	2.8 cm
1500 gm +hanger	1.9 cm	2.4 cm	2.6 cm
2000gm +hanger	1.5 cm	2.1 cm	4.3 cm
3000 gm +hanger	0.7 cm	1.5 cm	1.9 cm

From the above two analysis, it is seen that the PAM of longer length has larger pulling capacity. Therefore the PAM of length 21.5 cm is used to build the Pneumatic Actuator model.At time t=0, the inlet valve to the setup1is openedand the pressure is increased in the PAM1, PAM2, PAM3. At t=4, the pressure is gradually decreased by opening the outlet solenoid valve. Therefore a total of time t=8s is used to inflate and deflate the PAM. (Fig. 6.) The same process is repeated for the Hill's model.The force generated in the geometric model decreases as the pressure in the muscle increases; this is in inverse to the working of the PAM



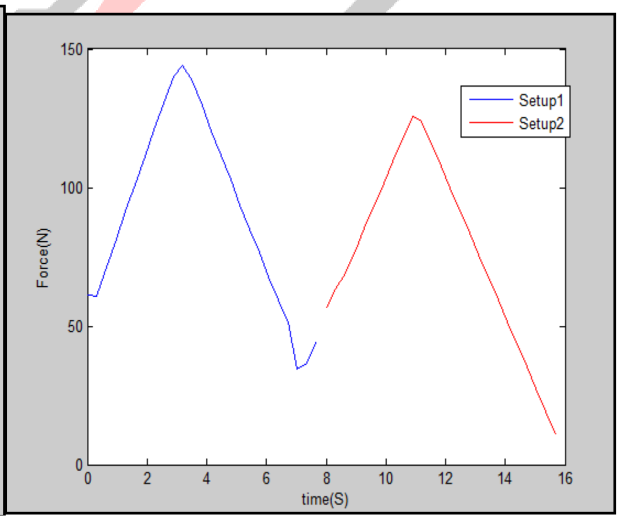


Fig. 6. Force generated by the PAM-Geometric Model.Fig. 7. Force generated by the PAM- Hill's Model.

The Hill's model gives the desired results since the muscle is modelled has a spring and damper. Using the force from the muscle the angle response is generated. (Fig. 8.)

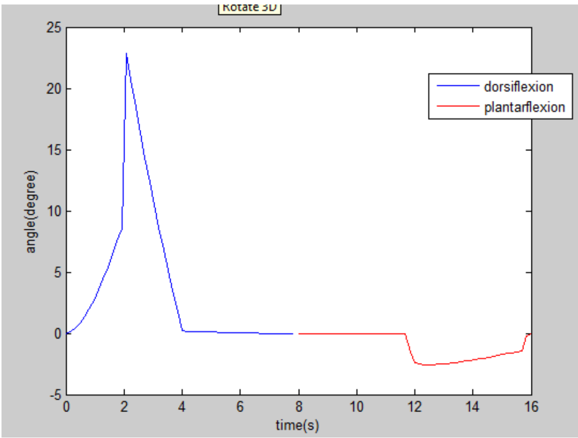


Fig. 8. Angle response of the PAM.

The comparison graph for the experimental and simulation results for various loads at different pressures are shown below. The graph for the PAM of length 21.5 cm are shown in the fig 9,10,11 and 12 for various loads

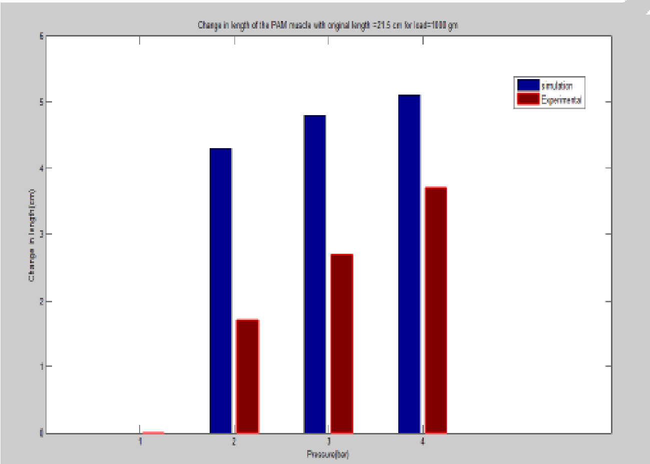


Fig. 9. Change in length of the PAM(original length=21.5 cm) with load =1000gm

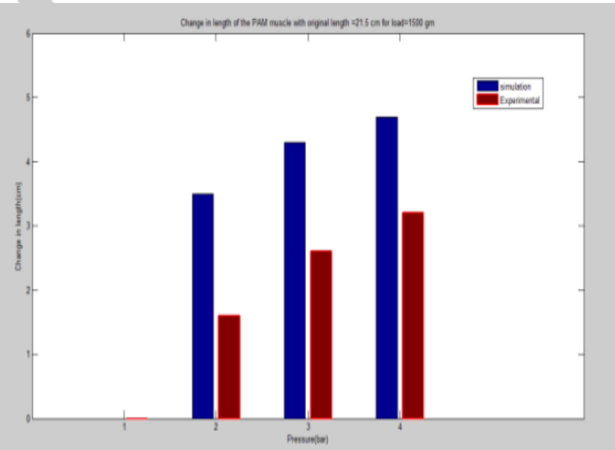


Fig. 10. Change in length of the PAM(original length=21.5 cm) load =1500gm

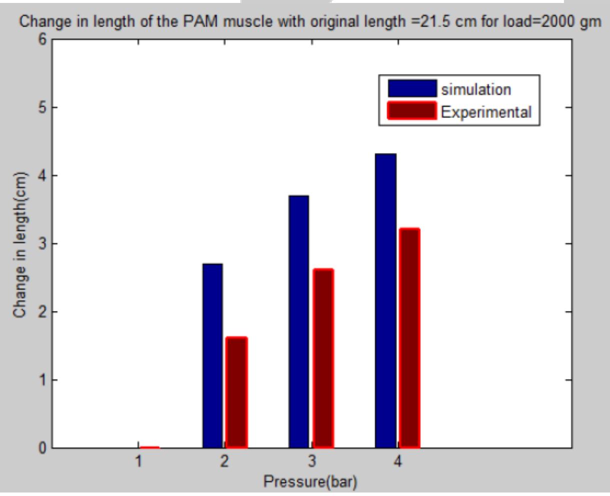


Fig. 11. Change in length of the PAM(original length=21.5 cm) with load =2000gm.

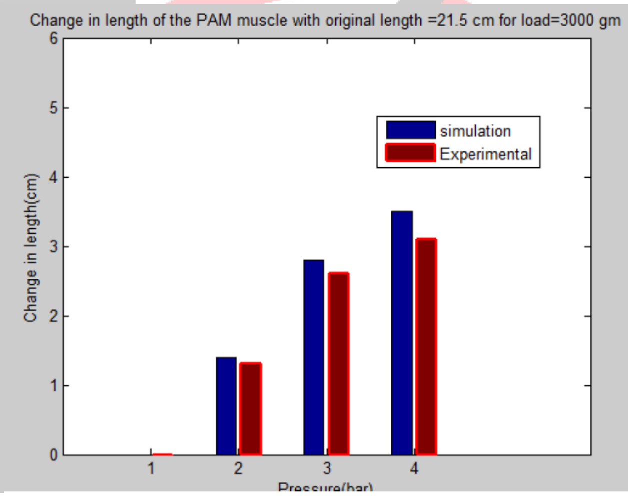
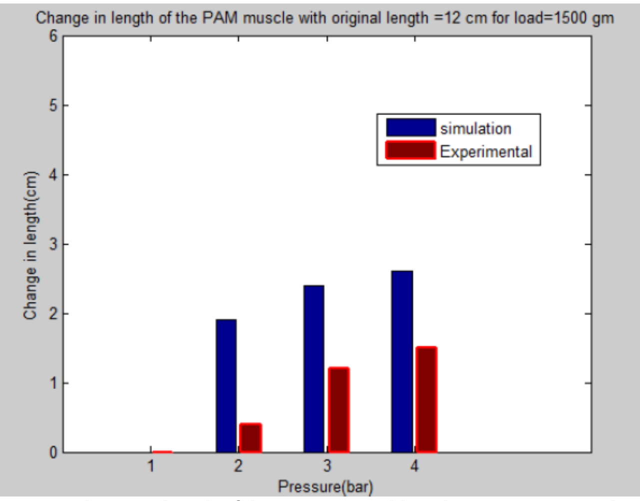


Fig. 12. Change in length of the PAM(original length=21.5 cm) with load =3000gm.

The Change in length of the PAM for the length12cm for the simulation and experimental model are shown in fig 13,14 and 15 for various loads at different pressures.



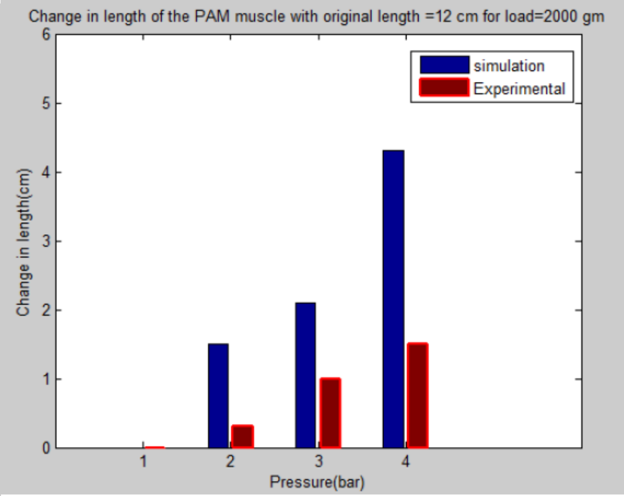


Fig. 13. Change in length of the PAM(original length=12cm) with load =1500gm

Fig. 14. Change in length of the PAM(original length=12 cm) with load =2000gm

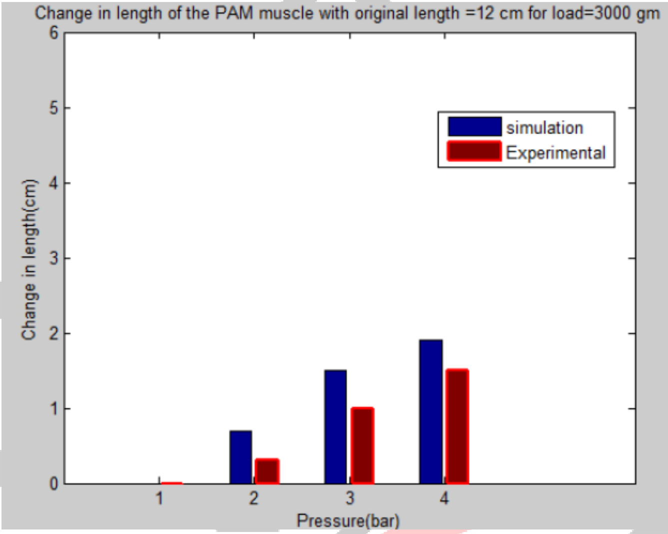


Fig. 15. Change in length of the PAM(original length=12cm) with load =3000gm

V. Conclusion

In this project, Pneumatic Muscle Actuator is designed and fabricated using Pneumatic Artificial Muscle (PAM). The individual PAM are tested under various loads for the different lengths. The Pneumatic Muscle Actuator is modeled in the Simulink environment using Geometric and Hill's model. Both the models are analyzed and validated with the results from experimental model. The Hill's model approach gives us the desired results.The fabricated device can be used for the rehabilitation of the people with ankle defects.

VI. Acknowledgment

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