EXPERIMENTAL STUDIES REGARDING THE BEHAVIOR OF A MECHANICAL SYSTEM WITH PNEUMATIC MUSCLE DRIVEN BY COMPRESSED AIR

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Abstract. *The objective of the paper is modeling the behavior of experimental pneumatic muscle wich performs a translational motion, using a bench with low pneumatic pressure . It will be determinated in FluidLab, the value of the force developed by the pneumatic muscle, taking account of the pressure load, the muscle is modeled in SolidWorks and simulated the behavior, depending on the texture turns and the material it is made, the virtual model is made in the experimental stand MatLab Simulink and set new directions for research.*

Keywords: pneumatic muscles, pressure, force, FluidLab, Matlab Simulink, SolidWorks

1. INTRODUCTION

The development of sensors, actuators and processors have led to the introduction of pneumatic systems. In parallel with their introduction in the mechanical systems, pneumatic individual elements have been developed continuously in terms of material, design and production process. Pneumatic muscles, usually cylinders are widely used in process automation. Recently, in robotics, the tendency is to use pneumatic systems as the main source of energy of motion. One of the most important attractions of the pneumatic system is low weight and behavior to motion. The contraction is due to air compression and, as such, may be influenced by controlling the operating pressure.
This is an important feature whenever there is an interaction between man and machine, or when delicate operations are to be performed (eg handling of fragile objects).
In various industrial applications are used pneumatic muscles as actuators which are less known, but their application is becoming increasingly high, because of the basic characteristic: the shrinking at supply pressure.

Studies on pneumatic actuator elements have led to the design of a pneumatic membrane during 1950-1960 and finally at the pneumatic muscles, which simulates human muscle movement, especially when they are willing antagonist.

Artificial muscle consists of a closed membrane, which under the action of air pressure, it expands radially, developing a force of contraction and body movement actuated along the longitudinal axis, similar to that generated by biological muscles.

The robots need to perform slightly better with a dynamic, it was used as a source the pneumatic muscles actuators for such systems.
Robots using pneumatic muscles have a low weight, high flexibility and a high degree of safety for operations carried out near people and in narrow spaces.
One of the applications of artificial muscle is a pneumatic presses (Figure 1).

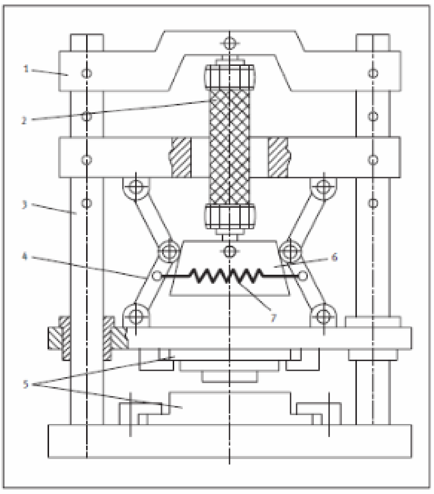


Figure 1. Pneumatic press

1 – Coupling loop, necklace
2 - Pneumatic muscles
3 - Column
4 - Articulated lever mechanism
5 - Shaped knife
6 - Block
7 - Wheel arch

In order to design a pneumatic press as having an artificial muscle actuator is required knowledge dependence of muscle force developed at pressure loading.

2. DESCRIPTION OF PNEUMATIC MUSCLE

Pneumatic muscles (Figure 2) can also be considered as actuators, they need of an internal or external force to return to its original state. This type of actuator can be used both horizontally and vertically. Pneumatic muscle is used to convert the pneumatical load to mechanical power. In the charge state, the pneumatic muscle develops a unidirectional pneumatic force, whose value depends on a certain diameter of muscle, on the loading pressure and the muscle length [2].

The main element of the muscle is a shaped membrane reinforced, a flexible tube is attached at the ends to fittings which transmits power to the mechanical system. While in the membrane is inserted or exhausted pressurized air, the muscle contracts or relaxes [3].

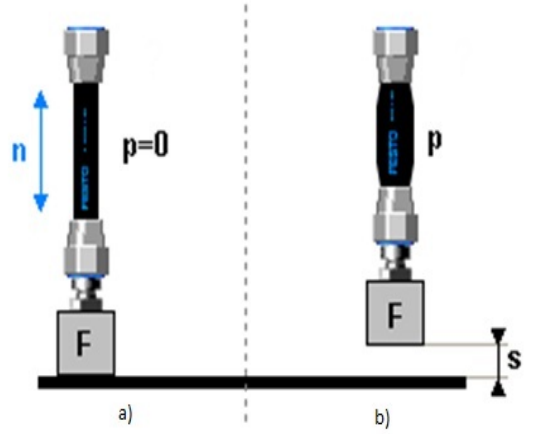


Figure 2. Unloaded pneumatic muscle and loaded with pressure

The power source of pneumatic muscles is a gas, usually air, entering or alighting from power generation with compressed air is easy, given the ambient pressure of about 100kPa, more energy can be transmitted by pressure only by negative pressure [8]
Acest tip de actuatori prezintă un raport putere – greutate foarte bun, îndeplinind condițiile de siguranță, şi simplitate. Cu ei se pot construi sisteme uşoare şi se pot adapta la temperaturi ridicate (Tabel 1)
This type of actuator has a ratio a power - good weight, satisfying the conditions of safety and simplicity. They can build low systems and can adapt to high temperatures (Table1)

Pneumatic muscles are formed from an inflatable rubber tube, usually neoprene (Figure 3), which is constrained by a nylon mesh (Figure 4).

Figure 3. Neoprene tube

Figure 4. Nylon mesh

Pneumatic muscles are motion mechanisms, their applications are in biomechanical, in robotics, in the motion control of materials handling, and other industrial applications.
Unlike ordinary actuators, pneumatic muscles have the highest tensile strength. When compressed air reaches the muscle, which is blocked at one end swells, the action of nylon net, forcing the muscle to shorten, reducing surface area to shrink the amount of compressed air work. Thus, power is automatically limited, making it ideal for absorbing shocks (Figure 5).

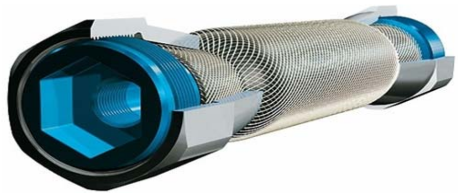


Figure 5. Pneumatic muscle

Tabel nr.1 – Pneumatic muscle characteristics

DMSP -10- 250N	
Compressed air port: DMSP -10- 250N	G1/8 (Depends on the selected connection adapter)
Contractible membrane External diameter Internal diameter Length	 14 mm 10 mm 250 mm
Maximum allowable tolerance connections	- Tolerance angle <1° - Parallelism tolerance: ± 0.5 % *) < 2 mm
Maximum allowable projection*) - DMSP -10- 250N	3%
Maximum allowed contraction*)	25 %
Range of allowed temperature	-5… +60°C
Maximum allowed load DMSP -10- 250N	30 kg
Hysteresis max.*)	Less than 4%
Relaxation max.*)	Less than 4%
Normal drain	Less than 1 l/h
Repetability	Less than de 1 % (cycle)
Flange connection Contractible membrane Adhesive for sealing heads	Aluminium; St (galvanized); Reinforced neoprene Loctite 243
Maximum lifting force at allowed pressure	630N
Pressure load	0-8 bar
Recommended operating pressure	0-6 bar
*)of nominal length	

3. PRESENTATION OF THE EXPERIMENTAL STAND

The purpose of this paper is to study the forces developed by the mechanical system with pneumatic muscle driven by compressed air.

To determinate the forces developed by the pneumatic muscle is considered the experimental stand as following:

Figure 6. Experimental stand

To achieve experimental research we choose the following pneumatic components (Figure 6):

1. Publisher analog signal: signal acquisition is part of the transducers;
2. 24 VDC Power Supply: fuel distributor and signal acquisition card
3. Compressor 8-10 bar maximum pressure
4. Pressure regulator and filter: shows a pressure control valve for compressed air at preset pressure and takes the pressure fluctuations
5. Pneumatic distribution is a block of compressed air in eight channels
6. Pressure traducer: a pressure sensor with integrated amplifier. Pressure to be measured is transferred into a silicon piezoresistiv hedged item and the generated signal is output voltage 0-10 V

7. Distributor 3 / 2 normally closed manually operated
8. Pressure regulator: compressed air supply to maintain the operating pressure and compensates the pressure fluctuations
9. Pneumatic muscle actuator, it is a pneumatic mechanism
10. Force transducer: record the forces acting on it and emits the voltage signal 0 - 10V
11. EasyPort acquisition card USB voltage output parameters store and transfer them to computer (by FluidLab).

4. PRESENTATION OF EXPERIMENTAL RESULTS

Experimental determinations are made on the evolution of the forces developed by the pneumatic muscle, depending on the pressure that is uploaded. For this purpose, we used a 1 kN force transducer and a pressure transducer [1].

The graphs of forces and pressures over time are made in software FluidLab.

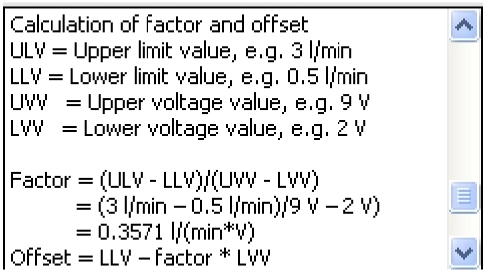
The experimental measurements are made at operating pressure allowed for pneumatic muscle: from 1 bar to 6 bar.

In FluidLab the channels where measurements are recorded we setted the: pressure, which is shown on Channel 0 and Channel 1 force (Figure 7).

To determine the values of forces depending on supply pressure of the pneumatic muscle, we need to set the FluidLab factor and compensation for both the pressure transducer and the force transducer according to Figure 7.

If these values are not correct set, there is the risk that the measurements performed with FluidLab to be incorrect.

The general formula for calculating the compensation and the factor is found in FuidLab software and has the following form:


Calculation of factor and offset
ULV = Upper limit value, e.g. 3 l/min
LLV = Lower limit value, e.g. 0.5 l/min
UVV = Upper voltage value, e.g. 9 V
LVV = Lower voltage value, e.g. 2 V

Factor = (ULV - LLV)/(UVV - LVV)
= (3 l/min – 0.5 l/min)/9 V – 2 V)
= 0.3571 l/(min*V)
Offset = LLV – factor * LVV

Figure 7. The formula for factor and compensation

Factor = (Final Value - Initial Value) / (value of maximum stress - minimum voltage value)
Pressure Factor = (Final Value pressure - baseline pressure) / (value of maximum stress - minimum voltage value)

Final Value = 10 bar pressure
Baseline pressure = 0 bar
Value of maximum voltage = 10 V Values undervoltage = 0 V
Pressure Factor = (10-0) / (10-0) = 1
Compensation pressure = - (baseline pressure - pressure x Value Factor undervoltage)
Compensation pressure = - (0-1 x 0) = 0
Force Factor = (Final Value force - baseline force) / (maximum stress value - minimum voltage value)
Final force value = 1kN
Initial force value = 0 kN
Values of maximum voltage = 10 V
Values undervoltage = 0 V
Force Factor = (1-0) / (10-0) = 1 / 10 = 0.1
Compensation force = - (baseline force - force x Value Factor undervoltage)
Compensation force = - (0-0, 1 x 0) = 0

The values obtained are entered in FluidLab program settings, and once setup is done, when pressure is supplied muscle (channel 0) is automatically recorded and the force value (channel 3) the appropriate pressure.

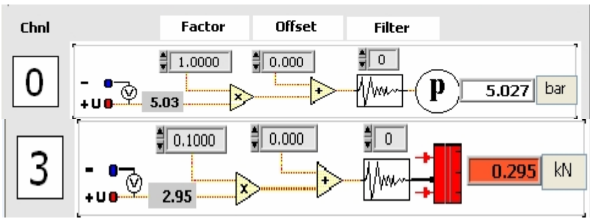


Figure 8. Set the working channel

The following figures are presented FluidLab image capture. The chart above shows the curve of each figure is the pressure that is loading the muscle (Figure 8-1 bar, ..., Figure 13-6 bar, gray) and in the chart below of each figure presents the force curve developed by the muscle in kN.

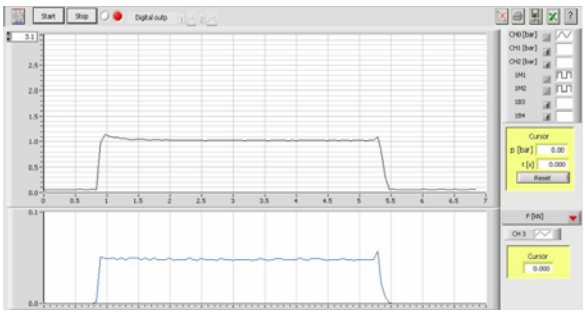


Figure 9 Force value at 1 bar pressure

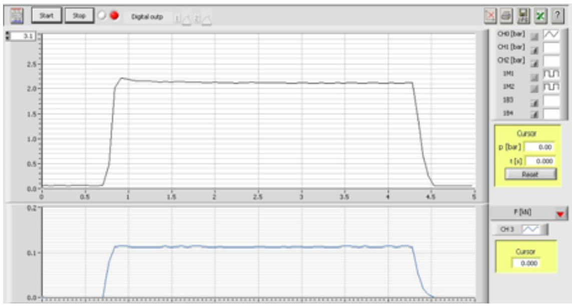


Figure 10 Force value at 2 bar pressure

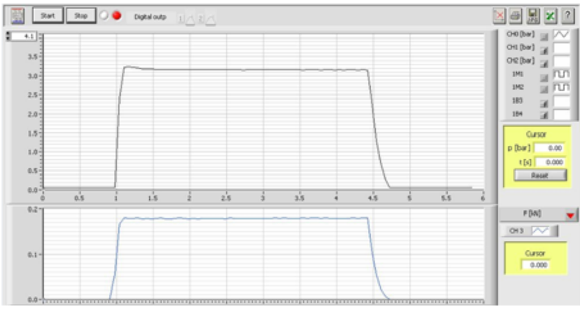


Figure 11 Force value at 3 bar pressure

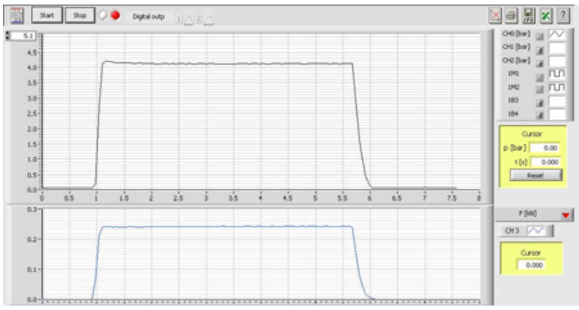


Figure 12 Force value at 4 bar pressure

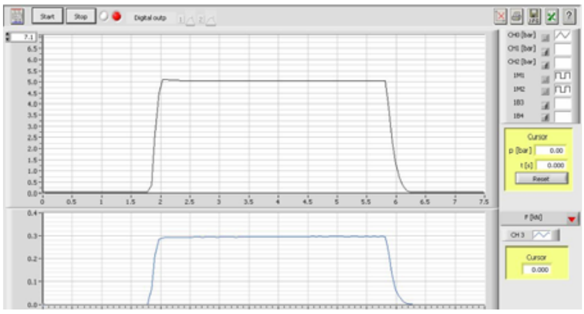


Figure 13 Force value at 5 bar pressure

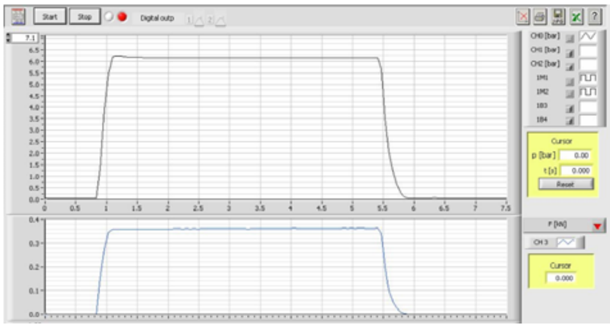


Figure 14 Force value at 6 bar pressure

As can be read on state graphs,the evolution developed by the muscle force charged at pneumatic pressure follows (Tabel 2):

Table no. 2 - Variation of force depending on pressure

Pressure (bar)	Force (kN)
1	0,05
2	0,12
3	0,18
4	0,25
5	0,30
6	0,36

It appears that increased pressure load, increase the force developed by muscles.

According FluidLab, the graphs obtained indicate when the pressure is stabilized, then the force tends to be constant action.

The force generated by this type of linear actuators in relation to pressure is unidirectional, it increases to maximum at the beginning of contraction and stabilizes once the volume is fully occuped [4].

In Figure 15 it is shown the characteristic force – pressure.

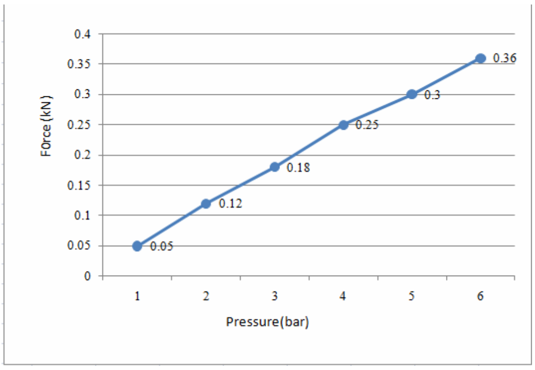


Figure 15 Variation of force depending of pressure

5. ANALOG WITH PNEUMATIC CYLINDER WITH EASY ACTION

Research in the field have shown that, unlike a pneumatic cylinder, muscle develops a force larger than this.

The main differences between the pneumatic cylinder and pneumatic muscle, it consist in constructive material. This pneumatic cylinder is made entirely of stainless steel and therefore the reaction is delayed in deployment. The level of forces depends on the distance between the cylinder and fixing force traducer. The distance between the two is greatly diminishing the value of forces.

Pneumatic muscle is superior in utility, because it is made of lightweight materials, and the main item that makes the movement is a contractible membrane that is neoprene with nylon mesh. Thus, the traducer recorded forces were high, depending on the maximum pressure load of muscle.

In order to highlight differences in the behavioral loading with pressure of the single action cylinder and the pneumatic muscle, we measured the amount of force they developed at the supply pressure of 6 bar.

Advance theoretical force of the pneumatic cylinder (neglecting internal friction) is given by the pressure acting on the piston surface from which subtracting the spring reaction force [5].

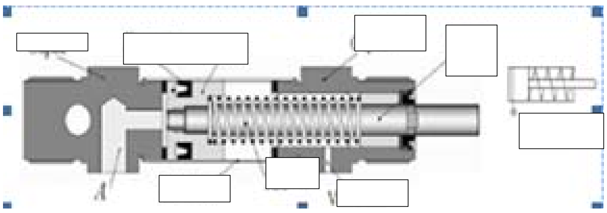


Figure 16 Pneumatic cylinder with a single action

Tabel nr.3 Characteristic of Pneumatic cylinder with a single action

Pneumatic cylinder with a single action	
Working environment	Compressed air
Piston diameter	Ø8 mm
Force developed at 6 bar	139 N
The maximum recording distance	Maximum 50 mm
The value of the return spring force	13,6 N

It notes the evolution of the two loaded pneumatic devices at operating pressure recommended 6 bar, as Figure 17 or Figure 18.

The behavior of the two devices is different and results from experimental measurements, that the force developed by the pneumatic muscle is twice the value developed by the pneumatic cylinder.

Pneumatic cylinder develops a force of 0.139 kN at 6 bar supply, and a pneumatic muscle force 0.360 kN at the same pressure.

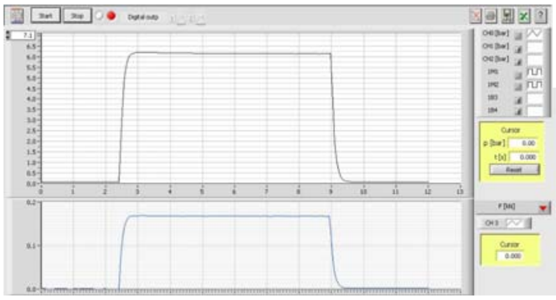


Figure 17 The pneumatic cylinder force at 6 bar

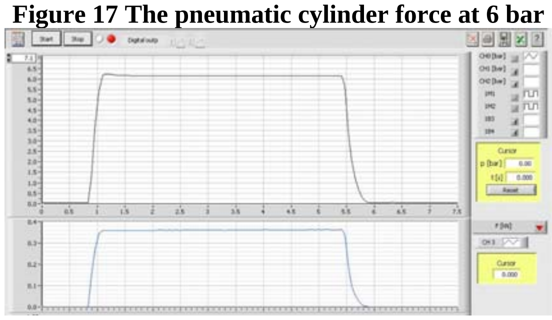


Figura 18 The pneumatic muscle force at 6 bar

6. FUTURE DIRECTIONS FOR RESEARCH

The behavior of pneumatic muscle studied in terms of layout turns (texture) and nylon fiber is made of membrane material and in terms of its diameter [9]. Because of the laboratory bench has only one pneumatic muscles, this study is only possible on a virtual model.

A first line of research would be studying the behavior of pneumatic muscle using SolidWorks. In this respect, it was modeled in SolidWorks pneumatic muscle (Figure 16). The membrane was embodied in an elastic, flexible, with good resistance in time. Pneumatic muscle membrane consists of two components: wire, nylon and rubber.

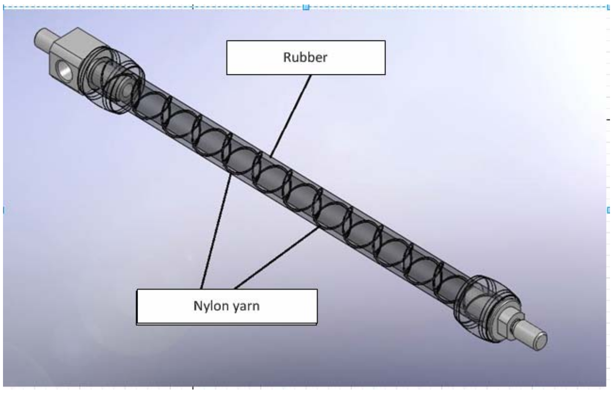


Figure 19 Arrangement of nylon yarn

Nylon yarn arrangement within the membrane is shaped as a helix with a number of turns on a certain length with a departure angle determined and constant throughout the membrane length.

SolidWorks Simulation is the application of constraints and pressures on the inside of the membrane (Figure 17), which causes a force. By inserting several nylon wires will get a structure more resistant to pressure.

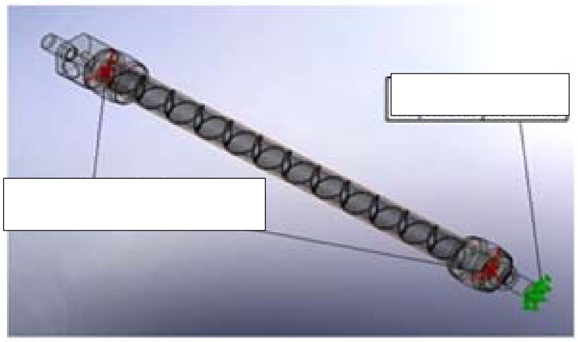


Figure 20 Application of pneumatic pressure and coercion on the muscle

The determinations that will be done and also the results, woul be the objective for a future work.

A second line of the research would be studying the behavior of pneumatic muscle using MatLab Simulink.

In this regard, we have achieved in MatLab Simulink software, mathematical modeling and simulation, virtual model of experimental stand to investigate the behavior of pneumatic muscle under the influence of pressure [7].

Virtual model is shown in Figure 18.

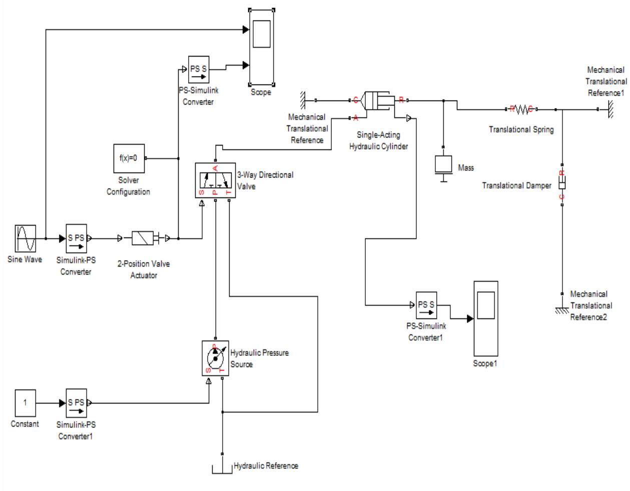


Figure 21 The pneumatic virtual booth

In the Virtual Model, we treated muscle with a pneumatic cylinder, because the software does not mark artificial muscle library. The study of pneumatic muscle behavior based on virtual model and experimental validation of the results measured by the laboratory bench is the real subject of future research.

7. CONCLUSIONS

The measured characteristic of force – pressure of the pneumatic muscle determined by experimental bench in FluidLab has a linear form.

When the pressure is stabilized, the force tends to remain constant. Under the pressure of compressed air, muscle contraction, and when the air fills the volume force is stabilized.

In the case of pneumatic muscle, with reinforced neoprene contractible membrane with nominal length of 250 mm external diameter 14 mm, 10 mm internal diameter, was found experimentally that the maximum force that can develop it is 0.36 kN (36 kgf) at a pressure of 6 bar load. This is the maximum operating pressure recommended for this type of pneumatic muscles.

Knowing the maximum force that can develop artificial muscle, is required for use in the design of new products, such as pneumatic presses.

Our future research will focus on the influence of membrane material texture and the characteristic power - pressure.

Compared with the single action cylinder is found experimentally that the force developed by the pneumatic muscle is twice the value in a supply of 6 bar.

Constrain added to the

Another future goal, is to find a mathematical relationship to calculate the force developed by the pneumatic muscle, taking into account the supply pressure and other parameters. This relationship can be validated by experimental measurements. It would be particularly useful for design of industrial equipment driven by pneumatic muscles.

Pneumatic muscle actuator is considered as one with a very exciting future in terms of industrial applications.

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