STAND FOR LOW PRESSURE ACTUATORS.
EXPERIMENTAL STUDY ON ARTIFICIAL MUSCLE

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Abstract. *The purpose of this paper is the presentation of the experimental pneumatic stand in the laboratory and the experimental study of the pneumatic muscle behavior, as part of the stand, using FluidLab. The pneumatic muscle movement depending on the pressure supplied will be analysed and its modeling and simulation will be performed in SolidWorks.*

Keywords: pneumatic muscle, pressure, motion, FluidLab, SolidWorks

I. INTRODUCTION

A new element developed and used in pneumatic actuation systems, is represented by the PAM (Pneumatic Artificial Muscles).
Pneumatic artificial muscle (Figure 1) is a contracting membrane that, under the action of air pressure increases its diameter and decreases in length. In this way the pneumatic muscle performs a specific stroke, dependent on the supply pressure.

Figure 1   Artificial muscles of different sizes

Pneumatic artificial muscles are contractile devices resembling linear motors powered by compressed air. Their concept is very simple: essentially the muscle is composed of a closed membrane that expands radially under the action of air pressure. The axial ends, connected by fittings to the body to be acted, get close to each other developing a force of contraction along the longitudinal axis similar to the force generated by skeletal muscles[3].

Artificial muscles have a great power – weight ratio, meeting the safety and simplicity conditions. They are ideal for shock absorption due to the action of the nylon mesh (a polymer, a thermoplastic material with high flexibility and strength) from the neoprene membrane.

Muscles are pneumatic actuators with a high degree of novelty and have started to be included in the composition of various equipment from various fields: robotics, aeronautics, medicine.

One of the applications of the artificial muscle is the pneumatic muscle-actuated isokinetic equipment, intended for the recovery of patients with severe post-traumatic disease affecting the bearing joints[1].

The equipment is intended to carry out continuous passive motions for the rehabilitation of the lower limb bearing joints (Figure 2 - representing a Fisiotek device)

Figure 2   Fisiotek recovery apparatus

For a better use of pneumatic muscle in recovery medical devices it is necessary to know the movement - pressure characteristic.

2. PRESENTATION OF EXPERIMENTAL STAND

The stand components are:
1. Compressor
2. A profile plate with pneumatic equipment.

3. Analog EasyPort

1. Compressor:

The compressor, Figure 3, provides an operating pressure of 6 bar to the stand equipment and a flow of 50 l / min. The maximum pressure developed is 10 bar. It is connected to a supply voltage of 230 V, it is lubricated with oil and extremely quiet.

Figure 3 Compressor

2. The stand's profile plate and pneumatic equipment Figure 5

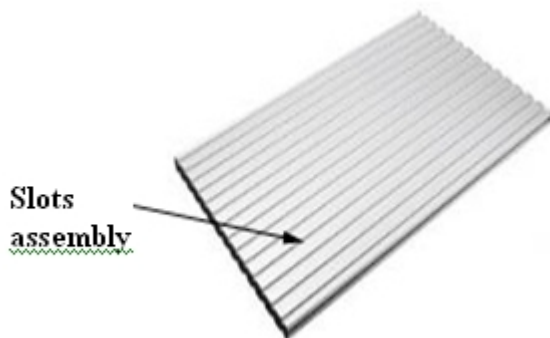The anodized aluminum profile plate is provided with assembly slits for determining the safety of equipment, Figure 4.

Figure 4 Profile plate

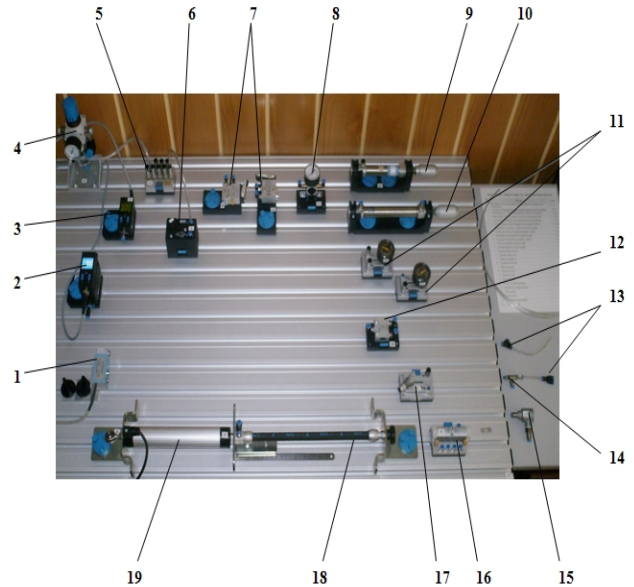The components of the laboratory experimental stand are shown in Figure 5.

Figure 5 The stand's pneumatic components

1- Force transducer (0-1kN); **2-** Flow sensor 0.1 – 10 l/min; **3-** Pressure sensor; **4-** Pressure regulator and filter; **5-** Manifold; **6-** 3/2-way valve with selector switch, normally closed; **7-** 3/2-way roller lever valve, normally closed; **8-** Pressure regulator with pressure gauge; **9-** Single-acting cylinder; **10-** Double-acting cylinder; **11-** Manometer; **12-** Shuttle valve (OR); **13-** Connectors (plastic tube 4mm diameter) ; **14-** One-way flow control valve; **15-** Quick exhaust valve; **16-** 5/2-way double pilot valve, pneumatically actuated, both sides; **17-** One-way flow control valve; **18-** Pneumatic Muscle; **19-** Potentiometric displacement transducer type, 100mm stroke

3. Analog EasyPort Figure 6

The EasyPort's function is to convert analog voltages from the analog sensors into digital values. The module is known as an ADC (Analogue-Digital Converter)
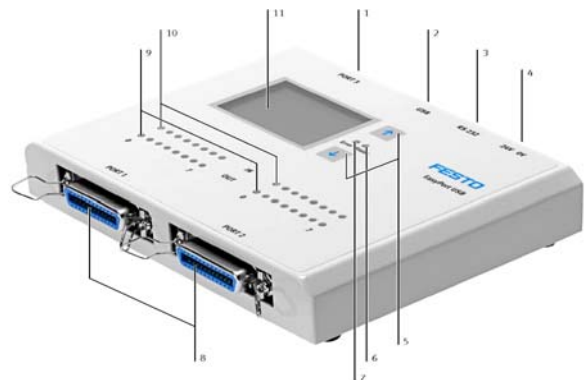

Figure 6 Analog EasyPort

(1) Sub-D socket (port 3)
(2) USB port

(3) RS 232 port
(4) Insulated terminals for power supply
(5) ↑↓ knobs
(6) Status LED (green)
(7) Error LED (red)
(8) SysLink interfaces (ports 1 and 2)
(9) Digital output status LEDs (yellow)
(10) Digital input status LEDs (green)
(11) Panel for EasyPort analog signals and for EasyPort USB layout addresses
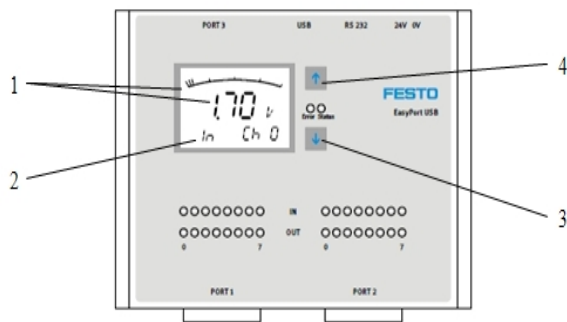
The EasyPort interface is shown in Figure 7

Figure 7 The EasyPort Interface

1-The input and output voltages of the selected analogue signal are displayed in the first line as a value, and additionally in the form of a bar graph.
2-Channel number and signal direction appear in the second line.
Meanings of displays: **In** = input signal,
    Out = output signal.
3-The analogue channel displayed on the LCD is selected with the ↓ button.
4-Various physical units of measurement can be selected with the ↑ button. The following are available: V, bar, PSI, MPa, l/min, °C [7].
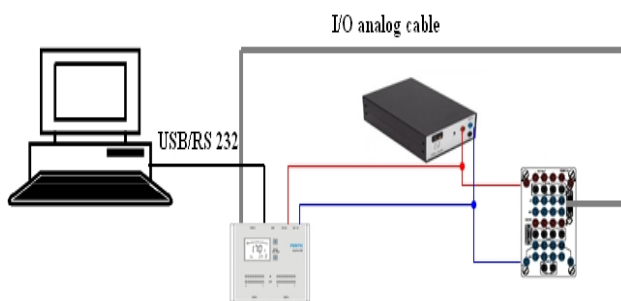
The EasyPortul connection is suggested in Figure 8.

Figure 8 Connecting to EasyPort

The EasyPort is connected to a PC via a USB cable or a RS232 analog cable; the connection to the modulator

(signal distributor) is done through an analog I / O cable. The EasyPort and the signal distributor signal are connected with power cords in parallel to a power supply voltage (input voltage: 85-265 V AC AC (47-63 Hz) Output voltage: 24 V curent (DC) current Output: max. 4.5 A; size: 75 x 155 x 235 mm)

3. EXPERIMENTAL DETERMINATION OF THE MOTION – PRESSURE CHARACTERISTIC

In a pneumatically operated facility, the pneumatic energy is converted into mechanical energy serving to engage the mechanisms of the installation.
Use pneumatic auxiliary devices with signal conditioning and processing functions, as well as functions of adjustment and control of the working medium parameters in the pneumatic circuits.

The stand components used experimentally to quantify the muscle contraction value depending on the pressure applied are shown in Figure 9
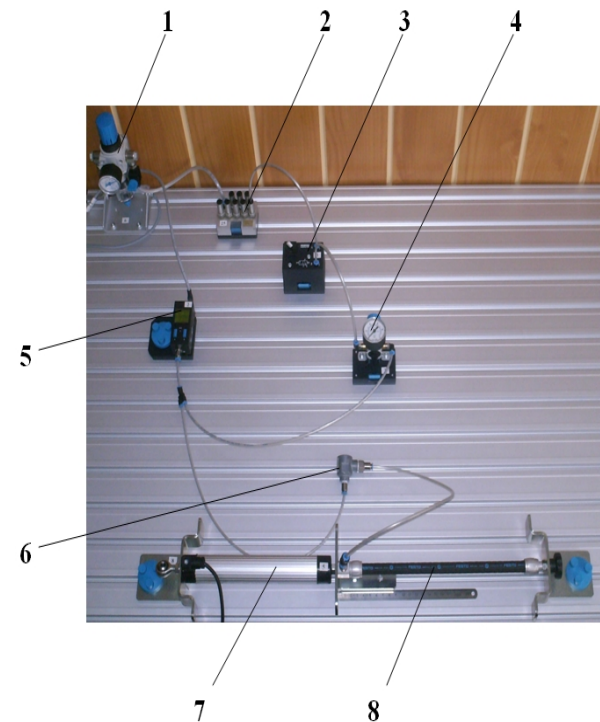

Figure 9 The components used to determine the pneumatic muscle motion-pressure characteristic

1- Pressure regulator and filter
2- Manifold
3- 3/2-way valve with selector switch, normally closed
4- Pressure regulator with pressure gauge
5- Pressure sensor
6- Quick exhaust valve

7- Potentiometric displacement transducer type, 100mm stroke
8- Pneumatic Muscle

1. Pressure regulator and filter, Figure 9.1
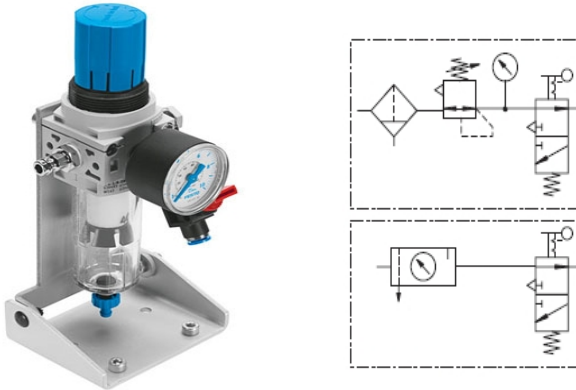
Figure 9.1. Pressure regulator and filter

Table 1. Technical specifications for the pressure regulator and filter

Medium	Compressed air
Design	Sintered filter with water separator, diaphragm control valve
Assembly position	Vertical ±5°
Standard nominal flow rate *	750 l/min
Upstream pressure max.	1600 kPa (16 bar)
Operating pressure max.	1200 kPa (12 bar)
Connection	Coupling plug fore coupling socket G 1/8 QS-plug fitting for plastic tubing PUN 6 x 1

* Upstream pressure: 1000 kPa (10 bar), Operating pressure: 600 kPa (6 bar), Differential pressure: 100 kPa (1 bar). [9].

2. Manifold, Figure 9.2
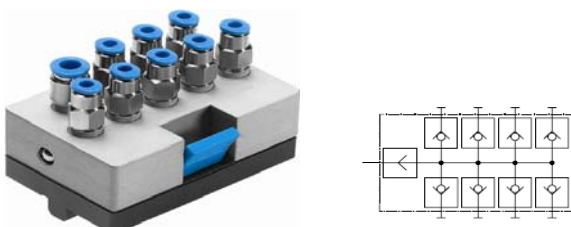
Figure 9.2 Manifold

The manifold with a common P-supply enables a control system to be supplied with compressed air eight individual connections. It is attached to a profile board with a clamping-quick release system[10].

Table 2. Manifold characteristics

Connection	1 QS-1/8-6 for plastic tubing PUN 6 x 1 8 QSK-1/8-4 for plastic tubing PUN 4 x 0.75

3. 3/2-way valve with selector switch, normally closed, Figure 9.3


Figure 9. 3/2-way valve

The valve is actuated by turning the selector switch. The switching status is maintained after the selector switch has been released [11].

Table 3. 3 / 2 distributing valve characteristics

Medium	Compressed air, filtered (lubricated or unlubricated)
Design	Poppet valve, directly actuated on one side, with return spring
Actuation	Selector switch
Pressure range	-90 – 800 kPa (-0.9 – 8 bar)
Standard nominal flow rate 1...2	60 l/min
Actuating force at 600 kPa (6 bar)	6 N
Connection	QSM-4 fittings for plastic tubing PUN 4 x 0.75

4. Pneumatic Pressure Regulator with quick couplers, Figure 9.4
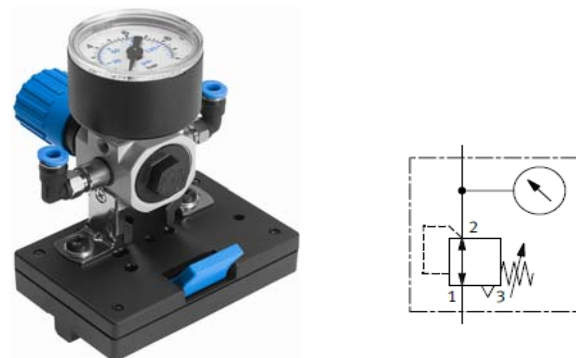
Figure 9.4 Pressure Regulator

The pressure regulator maintains the compressed air supply at the set operating pressure and compensates pressure fluctuations.

The direction of flow is identified by arrows on the housing. The pressure gauge indicates the set pressure.

Table 4. Technical specifications for the pressure regulator

Medium	Filtered, lubricated or unlubricated compressed air
Design	Diaphragm regulator
Standard nominal flow rate*	300 l/min
Supply pressure	1 – 10 bar (100 – 1000 kPa)
Pressure regulation range	0.5 – 7 bar (50 – 700 kPa)
Pneumatic connection	For plastic tubing with 4 mm O.D.

* Primary pressure 10 bar (1,000 kPa), operating pressure 6 bar (600 kPa), differential pressure 1 bar (100 kPa) [12].
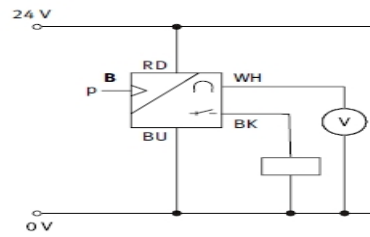
5. Pressure sensor Figure 9.5
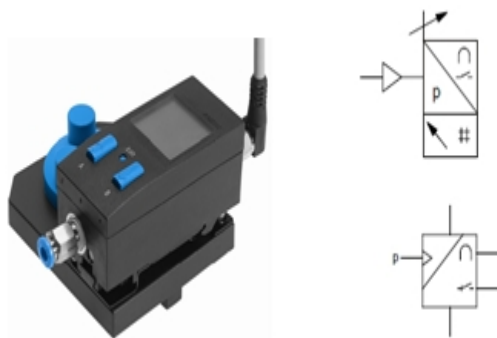
Figure 9.5 Pressure sensor

Table 5. Technical characteristics of the pressure sensor

Switching voltage	15 – 30 V DC
Residual ripple	Max. 10 %
Operating pressure	0 to 10 bar (0 to 1000 kPa)
Analogue output	0 to 10 V
Output function	Normally open contact, positive switching
Switching current	Max. 150 mA
Protection class	IP65
Connection	Plug M8x1
Cable	With 4 mm jack plug
Electromagnetic compatibility	CЄ
Emitted interference	Tested to EN 500 81-1
Noise immunity	Tested to EN 500 82-1

Note

The polarity of the applied voltage is to be observed for the correct functioning of the device [13].

Pressure sensor electrical connection.

6. Quick exhaust valve, Figure 9.6

Figure 9.6 Quick exhaust valve

The valve is used to speed up the draining of a chamber under pressure, by cutting short the distance traveled by the air in that chamber..The valve is equipped with movable sealing element, valve seat and silencer [2].

Table 6. Technical data of the quick exhaust valve

Medium	Compressed air, filtered (lubricated or unlubricated)
Design	Poppet valve
Pressure range	50 – 1000 kPa (0.5 – 10 bar)
Standard nominal flow rate 1...2 2...3	300 l/min 390 l/min
Connection	QSL-1/8-4, QSM-M5-4-I fittings for plastic tubing PUN 4 x 0.75

7. Potentiometric motion transducer, 100 mm stroke, Figure 9.7

Figure 9.7 Motion transducer

Table 7. Motion transducer general characteristics

Resolution	0.01[mm]
Max. travel speed	5[m/s]
Max. acceleration	200[m/s²]
Mounting position	Any mounting position
Driver, ball coupling	± 12,5[°]Angle offset
Connection	4-pin square plug

Table 8. Motion transducer electrical characteristics

Power supply	10[V DC][1)]
Temperature coefficient	5 [ppm / K]
Connection resistance tolerance	± 20[%]
Connection resistance	3[kΩ]
Interface	Analogue
Independent linearity	0.1 [%]

Stabilised power supply is recommended, max. 42 V DC permissible[12].

8. Quick coupling pneumatic Muscle Figure 9.8

Figure 9.8 Pneumatic Muscle

The stand's equivalent pneumatic scheme is:
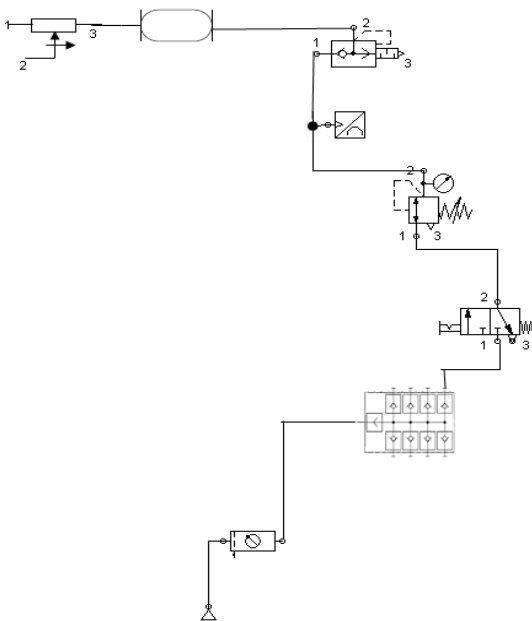
Figure 10 Pneumatic diagram

The maximum pressure supported by the muscles is 8 bar, the value for one contraction is 25% of its length in relaxed state.

The inner diameter is 10 mm and the nominal length is 250 mm; the working medium temperature: -5 ... 60 0 C [14].

The pneumatic muscle subject to tests is fixed at one end with a screw-nut assembly, the other end of the muscle acting on the rod of the potentiometric motion transducer (100mm stroke), which is as well secured with the help of a screw-nut assembly [2].

After the final assembly of the pneumatic devices and after the connections are made with connecting elements (4mm pneumatic hose) as shown in Figure 9, according to the wanted diagram, the stand is connected to the compressed air source and the power grid.

The following steps are taken to register the parameters with the help of FluidLab®-P program:

1- Start the FluidLab®-P program (Figure 11)

2- Choose the testing program from the main menu (see Table 9) "[-1-] Basic test" (Figure 11.1)

3- Select the program "[1.2] Meas. data acq.,p,q,F" (Figure 11.2) – The sub-structure is shown in Table 10

4- Open the electrical circuit diagram and connect the sensors as shown in Figure 11.3

5-Start the application to register the graph generated by the transducers.
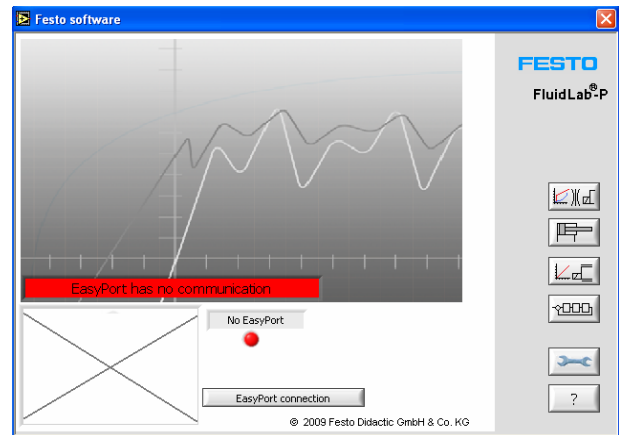
Figure 11 FluidLab®-P program interface

Table 1 Main Menu

	Program end
	Basic tests
	Cylinder controller
	Proportional technology
	Control technology
	Settings

	Help/Information
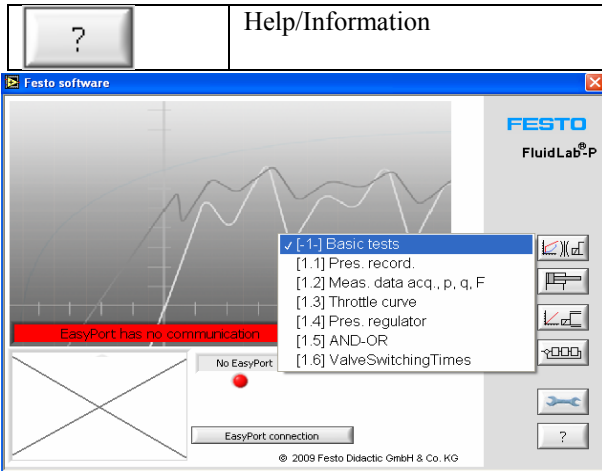
Figure 11.1, [-1-] Basic test
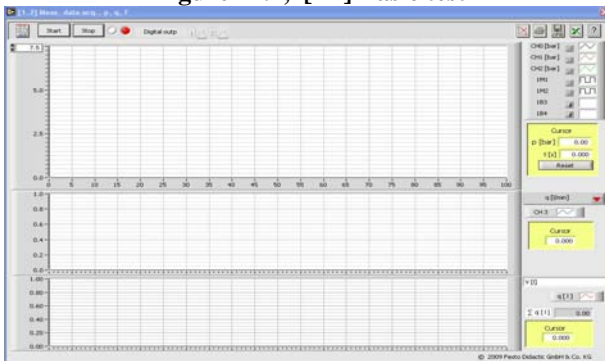
Figure 11.2 [1.2] Meas. data acq.,p,q,F

Table 2- All subprograms' structure

	End of subprogram
	Switch on the measurement process, green light is now illuminated
	Switch off the measurement process, red light is now illuminated
	Electrical circuit diagram
	Delete characteristic curve(s)
	Print screen
	Save screen to file (.jpg)
	Save data to text file (.txt)
	Background information
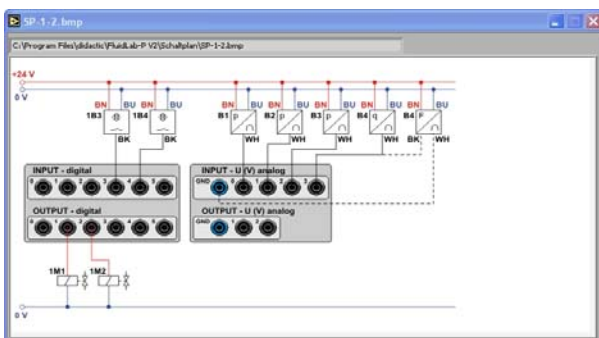
Figure 11.3 Electrical circuit diagram

Before starting the measurements, run the sensor operation test, and, if necessary, adjust the factor and offset.

Factor and compensation

The values resulted must be converted, because the physical and electrical signals are different.
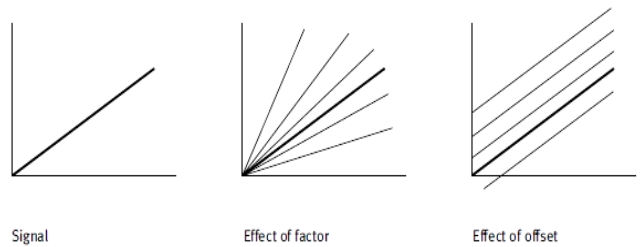
General formula for determining the factor and offset

Factor = (physical signal final value – Physical signal initial value) / (max. sensor voltage - min. sensor voltage)

Final pressure value = 10 bar

Initial pressure value = 0 bar

Max. sensor voltage = 10 V

Min. sensor voltage = 0 V

Pressure Factor = (10 bar – 0 bar) / (10 V – 0 V) = 1 (Figure 11.a)

Offset = - (Physical signal initial value - Factor * Minimum voltage)
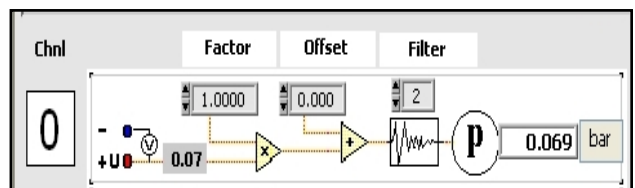
Pressure offset = - (0 – 1 x 0) = 0 (Figure 12.a)

Figure 12. a) Compensation and factor adjusted for the pressure transducer
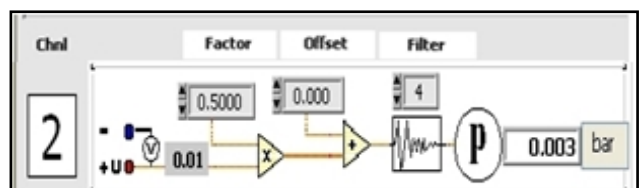
For the motion we have: (Figure 12.b)
Sensor advance (feed)   Range: 0 – 5 cm
Voltage   Range: 0 -10 V
Factor: (5 - 0) / (10 - 0) = 0,5
Offset: -(0 – 0,5*0) = 0

**Figure 12. b) The factor and compensation adjusted for the motion transducer**

For measurements there will be used pressure values ranging from 0.5 to 5 bar. The pressure will be adjusted from 0.5 bar 0.5 bar. The pressure is turned on from the the manually-operated NC (normally closed) 3/2-way distributor, Figure 9.3, and the air pressure is adjusted with the quick coupling air pressure regulator, Figure 9.4, to reach the desired range.
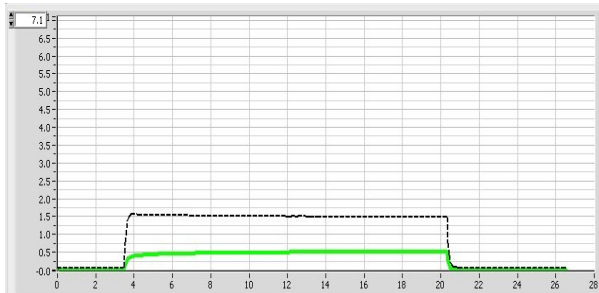
4. EXPERIMENTAL RESULTS

The graphs curves in Figure 13 (a-i) are represented in different colors, for easier tracking of the results, as follows: the black dashed lines represent the time-related pressure and the continuous green line represents the time-related movement.
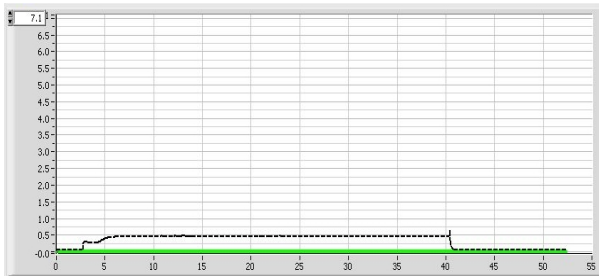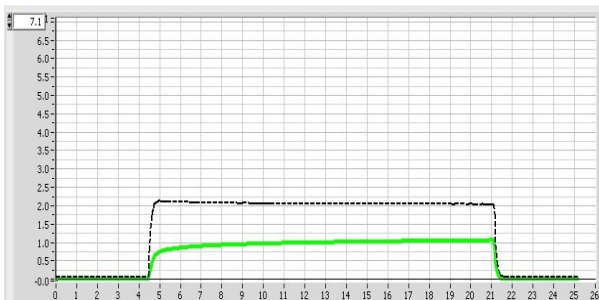
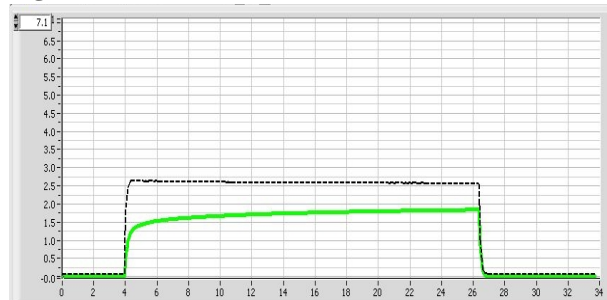**Figure 13 a) Pressure = 0.5 bar; motion =0,11cm**
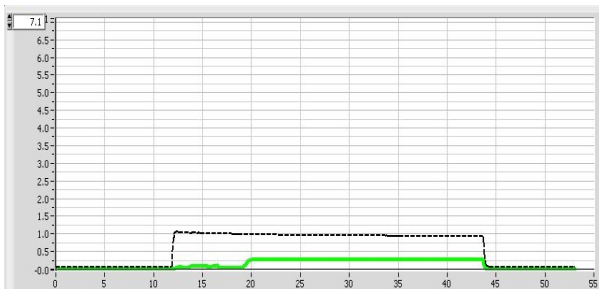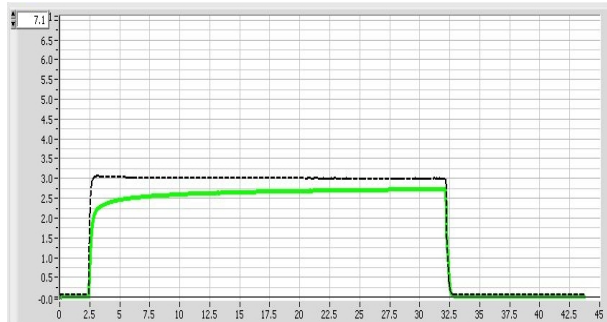
Figure 13 b) Pressure = 1 bar; motion =0,48cm

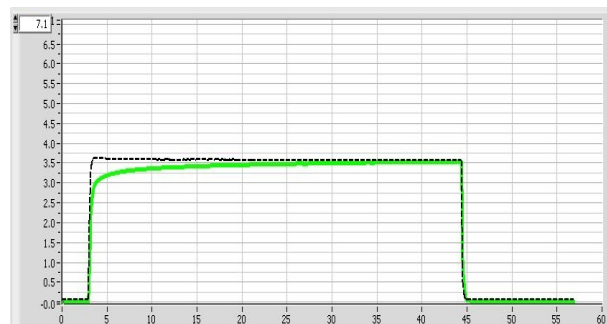**Figure 13 c) Pressure = 1.5 bar; motion =0,67cm**

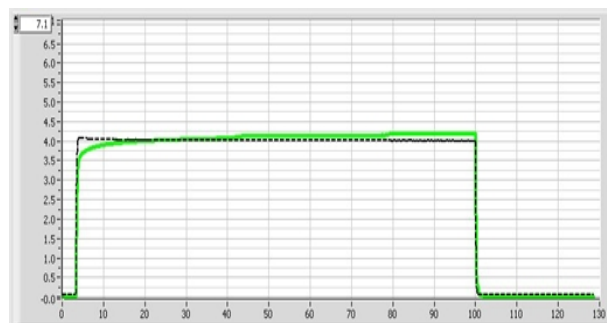**Figure 13 d) Pressure = 2 bar; motion =1,07cm**

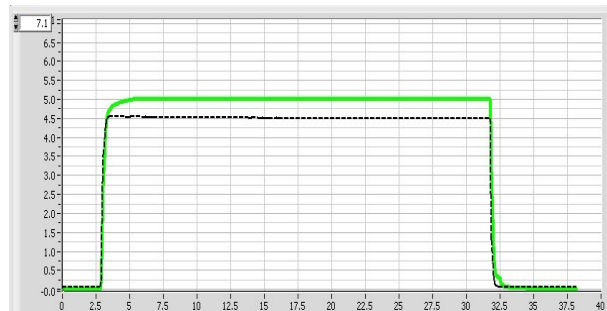**Figure 13 e) Pressure = 2.5 bar; motion =1,84cm**

Figure 13 f) Pressure = 3 bar; motion =2,74cm

Figure 13 g) Pressure = 3.5 bar; motion =3,51cm

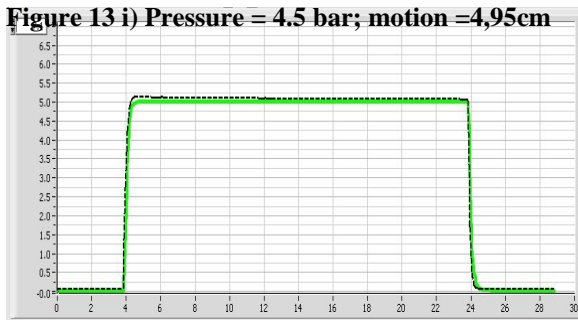**Figure 13 h) Pressure = 4 bar; motion =4,23cm**

Figure 13 i) Pressure = 4.5 bar; motion =4,95cm

Figure 13 j) Pressure = 5 bar; motion =5,00cm

Figure 13 (a –i); Representation of time-related pressure and movement

For a more accurate and clear reading of the graphs, the FluidLab ®-P program allows setting to different scales (Figure 14 pos. 1) and reading the values with the cursor. There is a cursor for the abscissa, which shows the time (10,093 s) and a cursor for the ordinate axis, showing either the pressure or the motion (5.03 cm), depending on the curve it is positioned on. These values can be read in the "cursor" area (Figure 14 pos.2).

Figure 14 Caption example on 5 bar; 1=scale, 2=cursor

It appears that the loading pressure increases as the movement increases; when the pressure reaches the set value, after a certain period of time, the movement reaches its peak. The sudden release of pressure (allowed by the quick exhaust valve, Figure 9.7) the movement returns to the zero point it started from. It is noted that the stroke length is directly dependent on the supply pressure.

The status graphs show the evolution of the pneumatic muscle motion, depending on the pressure it is loaded with (Table 11):

Table 11. Motion variation depending on pressure

Pressure (bar)	Motion (advance) (cm)
0.5	0.11
1	0.48
1.5	0.67
2	1.07
2.5	1.84
3	2.74
3.5	3.51
4	4.23
4.5	4.95
5	5.00

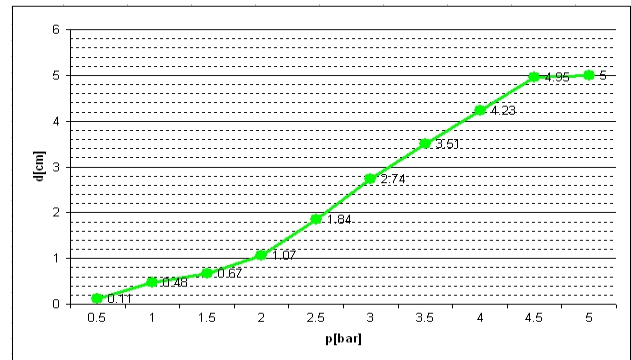Figure 15 presents the motion – pressure characteristic.

Figure 15 Motion - pressure characteristic

As the pressure in the muscle increases, it will shrink, while increasing its diameter, which causes the stressing of the reinforcement mesh fibers.

The muscle contraction power is limited by the amount of the total power of the individual fibers constituting the membrane material. The muscle force of contraction depends on the muscle length and the pressure applied.

The distance that the muscle extends on is limited by the tight bonds of the membrane; a thin-wall membrane allows a larger swell, which further on twists the nylon fibers composing it.

Researches in the field have shown that, compared to a pneumatic cylinder, the muscle develops a greater force than the cylinder [6].

If a force is applied on a part of the muscle, this will produce an irregular bulge, which may cause the membrane to break and eventually be destroyed.

5. FUTURE DIRECTIONS FOR RESEARCH

Our future researches will focus on the influence of the membrane texture and material on the movement – pressure characteristic.

As the laboratory stand has only one pneumatic muscle, this study is only possible on a virtual model. In this respect, there was performed a pneumatic muscle modeling in SolidWorks, as shown in Figure 16.
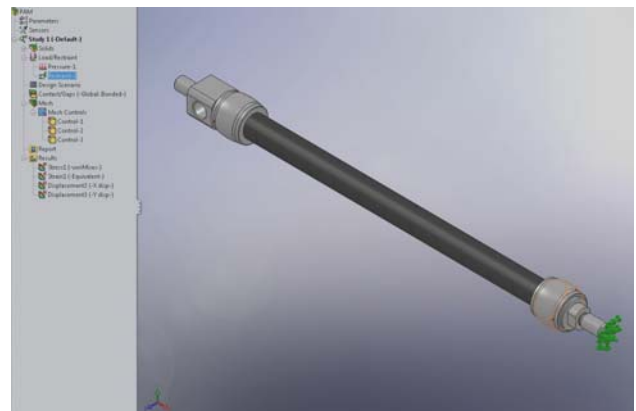
Figure 16 Pneumatic Muscle

The following SolidWorks library materials were used:
- for fittings and bolts – a high purity aluminum-based alloy, (1060 Alloy)
- for nylon yarns – Nylon 6/10;
- for membrane – Rubber (elastic polymers)
Simulations will be performed to determine the movement - pressure characteristic depending on the various materials and textures of the membrane.

6.CONCLUSIONS AND CONTRIBUTIONS

The movement-pressure characeristic determined by experimental measurements in FluidLab, on the experimental stand, shows that the pneumatic muscle movement is directly dependent on air pressure that the muscle is loaded with.

When the pressure reaches the set value, the movement rate reaches its maximum and remains constant, unless pressure leaks occur. Under the pressure of the compressed air, the muscle swells and shrinks its length and when the air fills the entire volume, the advance reaches its maximum. The distance on which the muscle swells is limited by the tight bonds of the membrane.

The muscle movements, measured with the position transducer, were validated also using the ruler in the laboratory.

The experimental measurements show that the pneumatic muscle movement does not vary in a perfectly linear manner depending on pressure, which makes the precise control difficult.

7. REFERENCES

[1] Deaconescu Andrea, Deaconescu Tudor-Pneumatic Muscle Actuated Robotized Arm for Rehabilitation Systems

[2] Dragan L. – Possibilities of using artificial muscles to drive prostheses / orthoses - Annals of the Oradea University, vol V(XV)/ 2006 Fascicle of Management and Technological Engineering

[3] Daerden, F. – Muscles, Multibody Mechanics Research Group, Brussel,2002

[4] Dragan L., Ciupe V. - Some experimental results regarding the mobilization of a revolute joint by means of fluidic muscles - Annals ofthe Oradea University, vol VII(XVII)/ 2008 Fascicle of Management and Technological Engineering

[5] Fluidic Muscle DMSP, with press-fitted connections, Fluidic Muscle MAS, with screwed connections www.festo.com

[6] Festo Didactic GMbH & Co. – TP101 Transparency set, 2000

[7] Festo Didactic GmbH & Co. KG and Art Systems – FluidSim 4 Pneumatics, User's Guide, 2007

[8] Ichim I. – Pneumatic applied to logistic systems, Annals of the OradeaUniversity, vol VI(XVI)/ 2007 Fascicle of Management andTechnological Engineering

[9] **www.festo-didactic.com** the code of the pressure regulator and filter ("152894") is entered in the "Search" window

[10]**www.festo-didactic.com** the code of the manifold ("152896") is entered in the "Search" window

[11]**www.festo-didactic.com** the code of the NC 3/2-way distributor ("152863") is entered in "Search" window

[12] **www.festo-didactic.com** the code of the quick-coupling pressure regulator ("539756") is entered in the "Search" window

[13] **www.festo-didactic.com** the code of the pressure sensor ("539757") is entered in the "Search" window

[14] **www.festo-didactic.com** the code of the pneumatic muscle ("544311") is entered in the "Search" window.