DESIGN AND FABRICATION OF A TEST-BED AIMED FOR EXPERIMENT WITH PNEUMATIC ARTIFICIAL MUSCLE

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Abstract

Pneumatic artificial muscles (PAMs) are contractile or extensional devices operated by pressurized air. Similarly to human muscles, PAMs are usually coupled antagonistically. PAMs were first developed (under the name of *McKibben Artificial Muscles*) in the 1950s for use in artificial limbs. There is growing interest in the use of pneumatic artificial muscles for robotic applications due to their high power to weight ratio and the adaptable compliance. To control the actuator, we have to know its properties. The objective of this project was to design an apparatus which would enable experimental investigation of PAMs.

1. Introduction

The stand described in this paper is a didactic laboratory stand, which task is to enable investigations and gather knowledge of construction and the way of working such elements as: a Fluidic Muscle, a PLC controller, DSP systems as well as proportional pressure control techniques. It offers many didactic and investigative possibilities and thanks to applied solutions its development is easily available. The module structure of the research stand gives possibility to make its further development by adding extra modules that can be easily mounted on plates.

2. Materials and Methods

The stand was designed and visualised by utilisation of professional CAD software – Autodesk Inventor. Figure 1 shows a schematic representation of the experimental set-up that was used to carry on the research presented in this paper.

The experimental set-up consists of a slider mechanism. One side of the muscle is fixed to a load cell, while the other side is attached to the movable frame. The load cell (7923 type from MOM) is a 4 bridge element of strain gauges. It is mounted inline to the PAM on the fixed surface. The load cell measures the force exerted by the PAM. The tests are performed by changing the displacement of this slider. The linear displacement of the actuator is measured using a LINIMIK MSA 320 type linear incremental encoder. During each test, frame position, muscle force and applied gauge pressure are recorded. Since PAMs are one-way acting, two are needed to generate bidirectional motion: as one of them moves the load, the other one will act as a brake to stop the load at its desired position. To move the load in the opposite direction the muscles change function. This opposite connection of the muscles to the load is generally referred to as an antagonistic set-up: the driving muscle is called the flexor or agonist, while the brake muscle is referred to as the extensor or antagonist. The antagonistic coupling can be used for either linear or rotational motion. The PAMs were installed horizontally such that the only force present during activation was the small friction force of the slider mechanism. In the test-bed, two DMSP-20-200N-RM-RM type or two DMSP-10-250N-RM-RM type fluidic muscle (from FESTO) can mounted, with a pre-tension of about 15% (half of the maximum contraction ratio which is 30%). This work is the first fundamental step of a wider project, aimed at studying the humanoid robot.

Instead of second PAM a bias spring or an external load can attached with a flexible steel cables, producing the necessary counter force to pull the actuator back when it is not activated. In a spring, the stiffness is constant within a definite field.

We repeated experiments for several levels of pressures in the range from 0 to 5 bar. The air pressure applied to the actuators can regulated with two adjustable regulator type Festo VPPM-6L-L-1-G1/8-0L6H-V1N-S1C1. The proportional pressure regulators (PPRs) are controlled by voltage inputs. The main purpose of the PPR is to regulate the pressure entering the PMA. To measure the air pressure, two Motorola MPX5999D pressure sensors were plumbed into the pneumatic circuit. A National Instruments multi-IO card (Lab PC 1200) reads the signal of force, pressure sensors and incremental encoder into the PC. National Instruments LabVIEW will be used to monitor and collect the data imported through the DAQ card. It will also dispatch the control profiles for the PPRs. LabVIEW allows for the dynamic collection of data.

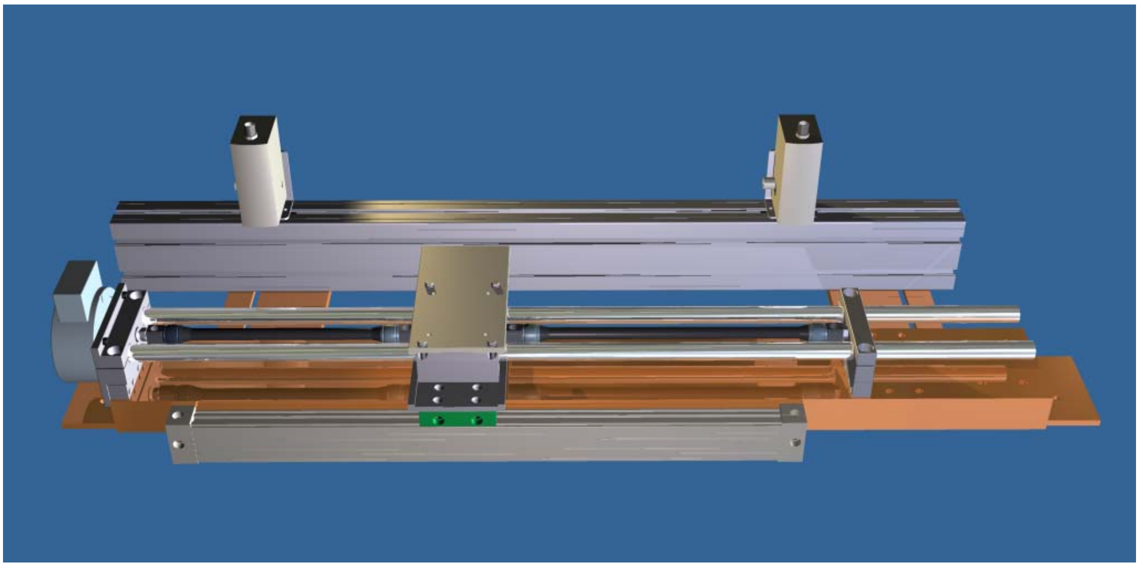

Figure 1. The view of the stand for Fluidic Muscle investigations

With the specially constructed dynamic testing machine, we are able to measure the static and dynamic characteristics of several versions of these actuators. The photos of the set up are shown in Fig. 2-5.

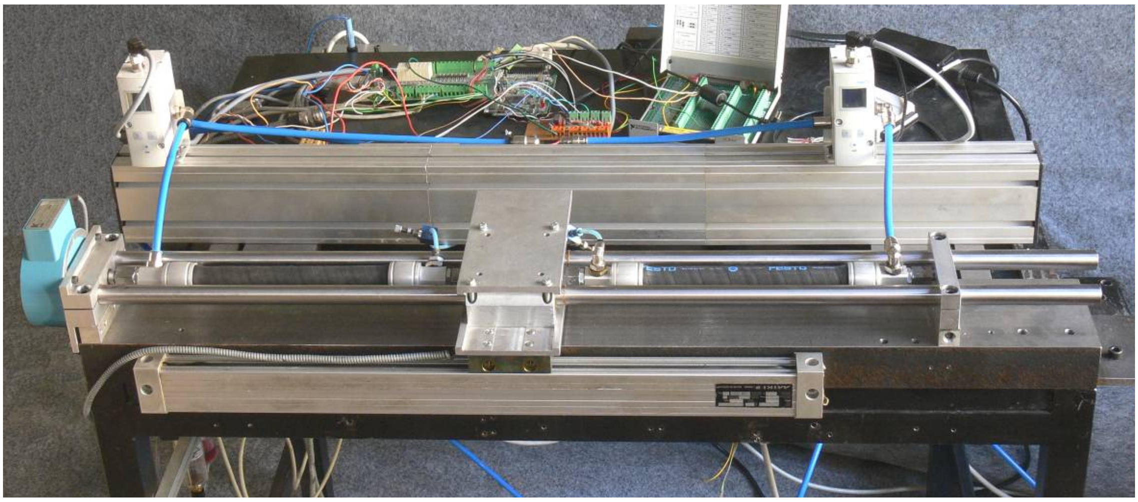

Figure 2. The photo of the stand for Fluidic Muscle investigations (two antagonistic muscle)

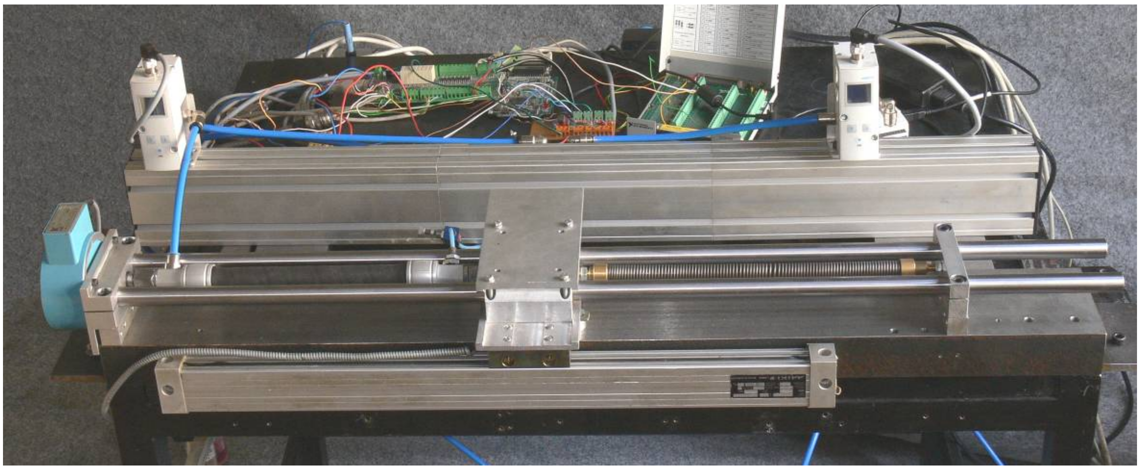

Figure 3. The photo of the stand for Fluidic Muscle investigations (one muscle and one spring pair)

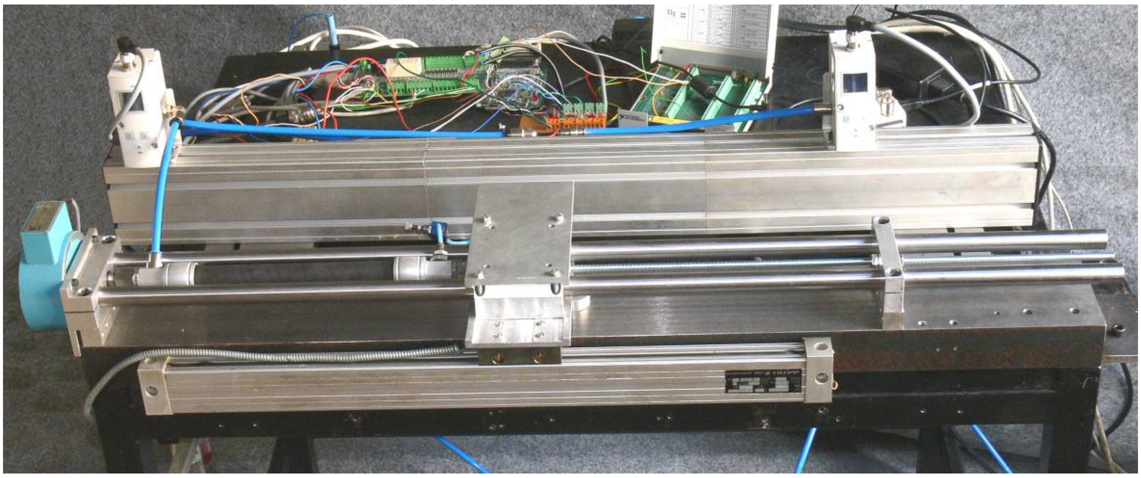

Figure 4. The photo of the stand for Fluidic Muscle investigations in fixed slider position

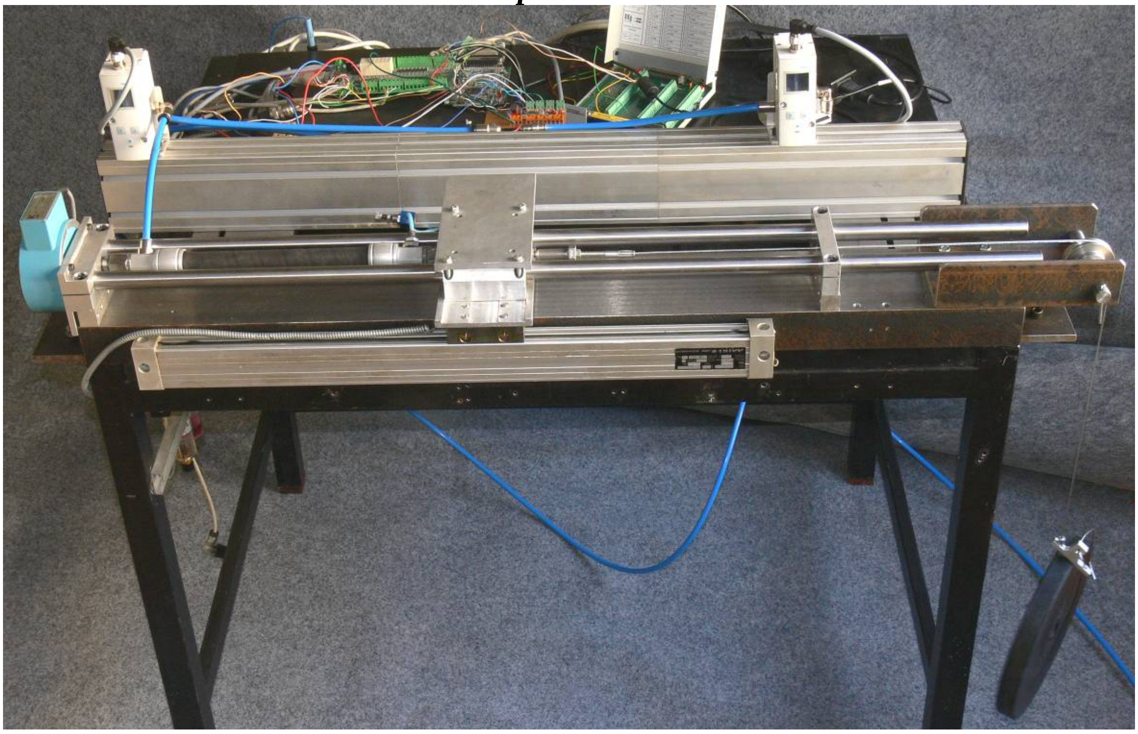

Figure 5. The photo of the stand for Fluidic Muscle investigations with external load

The fluidic muscle can be used as an actuator or a spring. If internal pressure is changed, the muscle can set an external load into motion like an actuator (Figure 6). If the external load is changed, the fluidic muscle reacts like a spring by changing its length. Contraction of the fluidic muscle is thus dependent upon internal pressure as well as external load (Fig. 7).

To see how the device operates, two basic experiments can be considered. In both cases a PAM of an arbitrary type is fixed at one end and has a mass hanging from the other. In the first experiment, shown in Figure 6, the mass M is constant and the pressure difference across the membrane, i.e. its gauge pressure, is increased from an initial value of zero. At zero gauge pressure the volume enclosed by the membrane is minimal, Vmin, and its length maximal, $l$max. If the muscle is pressurized to some gauge pressure $p1$, it will start to bulge and at the same time develop a pulling force. The mass will thus be lifted until the generated force equals Mg. The membrane's volume will then have grown to $V1$ and its length contracted to $l1$. Increasing the pressure further to $p2$ will continue this process. From this experiment two basic actuator behavior rules can be deduced: a PAM shortens by increasing its enclosed volume, and it will contract against a constant load if the pneumatic pressure is increased.

The other rules can be derived from the second experiment, shown in Figure 7. The gauge pressure is now kept at a constant value p, while the mass is diminished. In this case the muscle will inflate and shorten. If the load is completely removed, as depicted by Figure 7 (c), the swelling goes to its full extent, at which point the volume will reach its maximum value, Vmax, the length its minimal value, $l$min, and the pulling force will drop to zero. The PAM cannot contract beyond this point, it will operate as a bellows at shorter lengths, generating a pushing instead of pulling force. This means that a PAM will shorten at a constant pressure if its load is decreased and its contraction has an upper limit at which it develops no force and its enclosed volume is maximal. Concluding from both experiments a fifth rule can be added: for each pair of pressure and load a PAM has an equilibrium length.

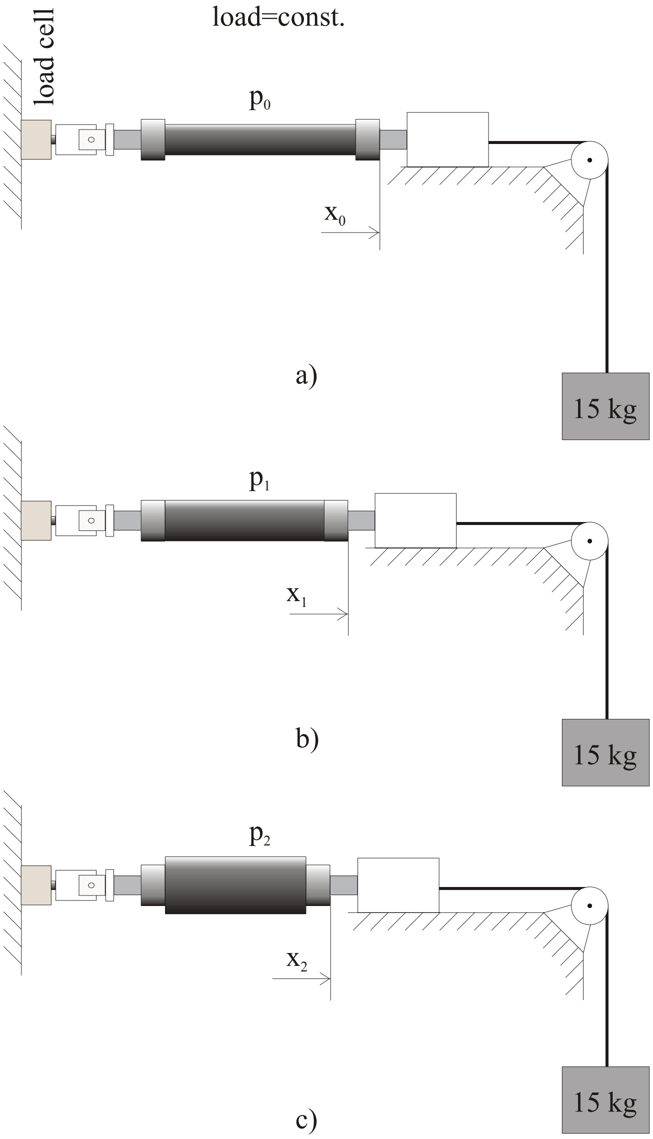

Figure 6. PAM at constant load

This behavior is in absolute contrast to that of a pneumatic cylinder: a cylinder develops a force which depends only on the pressure and the piston surface area so that at a constant pressure, it will be constant regardless of the displacement.

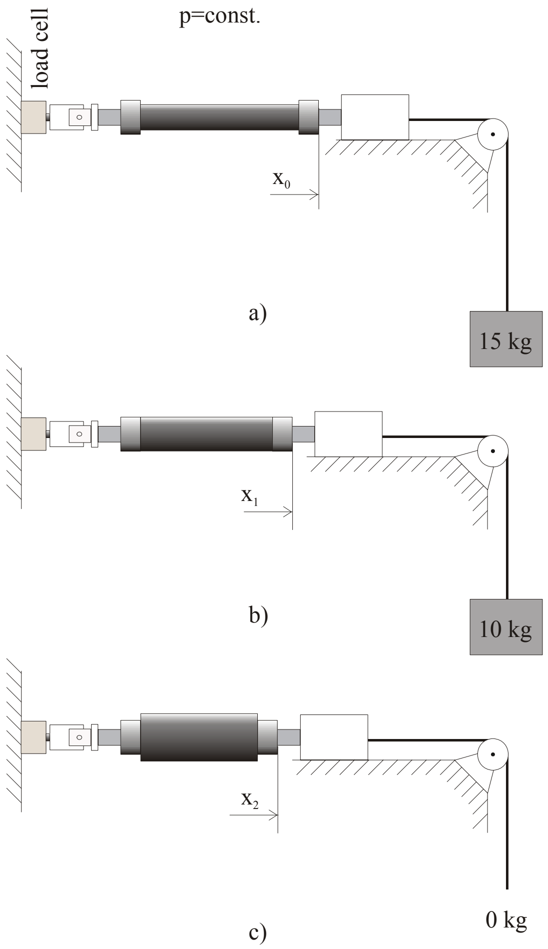

Figure 7. PAM at constant pressure

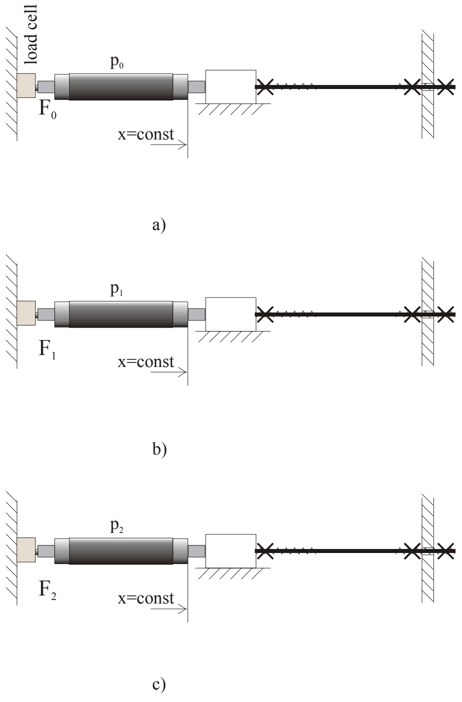

Figure 8. PAM at fixed position

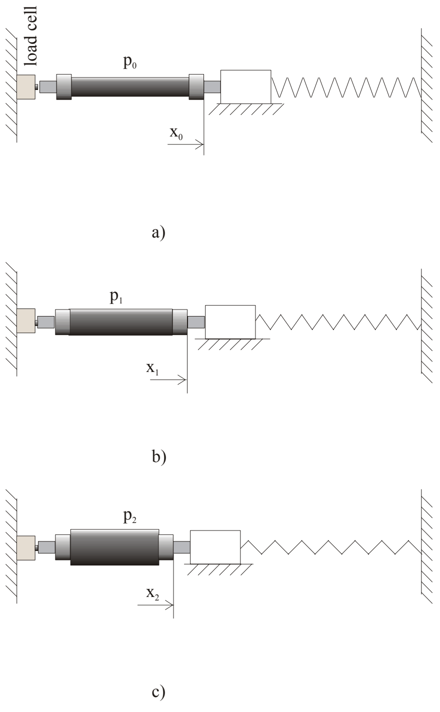

Figure 9. PAM with bias spring

3. Results and Discussion

A pneumatic artificial muscle (PAM) is essentially a volume, enclosed by a reinforced membrane, that expands radially and contracts axially when inflated with pressurized air. Thereby, the muscle generates a unidirectional pulling force along the longitudinal axis. When neglecting the membrane's material deformation and the low inertial muscle properties, the generated force is expressed as:

$$F = -p\frac{dV}{dl}$$

with p the gauge pressure inside the muscle, dV the enclosed muscle volume changes and dl the actuator length changes. The volume of the actuator increases with decreasing length until a maximum volume is reached. At maximum contraction these forces become zero; at low contraction these forces can be very high. Depending on the geometry and type of membrane, the specific force characteristic alters. Several concepts of PAM have been developed over time.

Static load tests on real muscles are.

This work is the first fundamental step of a wider project aimed at studying the PAMs. With the help of this test-bed we can carried out several static and dynamic investigations (Figure 8-9).

References

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