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DESIGN AND CONSTRUCTION OF A HUMANOID ARM DRIVEN BY PNEUMATIC MUSCLE ACTUATOR

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Abstract: Electrics, hydraulics and pneumatics can be the main motion power of industrial robots. Pneumatic cylinders, pneumatic motors, pneumatic stepper motors and pneumatic bellows are widely used in industrial environment due to their power/weight ratio, power/volume ratio, strength, compactness, simplicity, reliability and cost. Disadvantages of pneumatic actuators can be summarized as follows: difficult to control accurately, air compressibility, compliance and noisiness. Relatively new type of the pneumatic actuators is the pneumatic artificial muscle (PAM) or pneumatic muscle actuator (PMA). Fluidic Muscle made by Festo Company is one of the most investigated commercially available PMA. Pneumatic muscle actuators can be used in industrial environment as well as in prosthesis or rehabilitation devices. In this paper a humanoid arm actuated by Fluidic Muscle is developed and presented.
Keywords: pneumatics, pneumatic muscle actuator, Fluidic Muscle, humanoid arm

INTRODUCTION

Automation and robotics have become well-grounded in the industry. Modern manufacturers and companies could hardly operate without robots and automated processes [1], [2]. In this study pneumatic muscle actuator as one of the least investigated type of actuators but an important driver element is applied.

History of PMAs dates back to 1930s. Unfortunately, due to lacks in technology the production was limited. In 1950s, Joseph L. McKibben was the first who designed an artificial muscle for practical use in medicine. McKibben is often mentioned as the pioneer in PMA. In 1980s, engineers in Birdgestone Company in Japan produced the so called Rubbertuator PMA. Recently, the most often applied is the Fluidic Muscle and also the Shadow Air Muscle (SAM) produced by the Shadow Robot Company.

The structure of the most PMAs can be divided into two main parts: a flexible membrane (e.g. latex, silicone rubber or chloroprene) and a load carrying element (e.g. nylon, fiberglass or aramid). On the basis of their connection, Daerden in [3] discriminates braided muscles, netted muscles and embedded muscles (Figure 1).

The difference between netted and braided muscles is in the density of the threads in the braided mesh shell (network of load carrying element) surrounding the membrane: it is higher for the braided muscles. In embedded muscles the loaded threads are settled into the elastic tube. In the paper this type of muscles is considered [4].

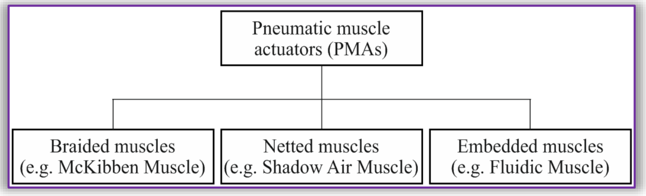

Figure 1. Classification of PMAs

Working principle of PMAs is simple: when a PMA is pressurized, the flexible membrane tends to increase its volume against the braided mesh shell which is non-extensible, therefore the actuator will be shortened and a pulling force will be produced if the muscle is connected to a load [5-7].

This flexible actuator shows similarity to human muscle, because the force and motion generated by PMA are linear and unidirectional. For two-direction motion an antagonistic pair of PMAs or a spring returned PMA has to be used [8]. Typically, one muscle moves the load, while the other serves as a brake. During the motion in opposite direction the mechanisms commute their action. These serially connected muscles are named antagonistic pair: the muscle for motion is a flexor while the braking muscle is named an extensor or antagonist [9].

PMAs differ from general pneumatic cylinders as they have no inner moved parts and there is no sliding on the surfaces. The main disadvantages are nonlinear and time variable behaviour, existence of hysteresis and step-jump pressure. This is why number of control schemes and static and dynamic models can be found in the literatures [10-19].

This paper is organized in 5 sections. After Introduction, in Section 2 the design process and the 3D printing are described. A key moment of the design and construction (choosing PMA) is presented in Section 3. Section 4 shows the assembling and testing the arm. The paper ends with Conclusions (Section 5).

For this study DMSP-10-250N-RM-RM (with inner diameter of 10 mm and initial length of 250 mm) type Fluidic Muscle is selected.

DESIGN AND 3D PRINTING

The humanoid hand was designed with the help of the Autodesk Inventor software (Figure 2). As a first step, the digits of the fingers were made. For reasons of practicality each finger was designed to be the same length and instead of three degrees of freedom they were provided with two ones meaning that the upper digit was designed to be bent at a 45° angle.

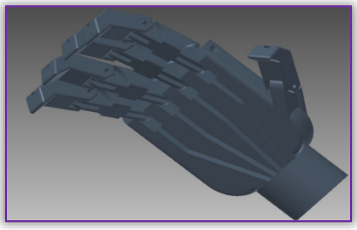

Figure 2. 3D plan of the hand

PLA (polyactic acid) was used as the base material for 3D printing which is a biodegradable and thermoplastic polymer. It is produced from high-starch grains (Figure 3).

The printing of the fingers took a total of 6 hours and 10 minutes at a speed of 40 mm/s with a layer resolution of 300 microns and a printer nozzle of 0,4 mm diameter. During this time the printer used up 32,85 m of 1,75 PLA fiber filament (total mass: 98 g). During printing the temperature of the platen was 60°C and the temperature of the nozzle was 222°C.

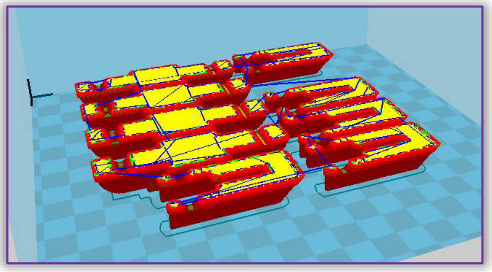

Figure 3. Fingers in the 3D printer's slicing program

The printing of the hand (Figure 4) with the same parameters as the ones used for the fingers took altogether 7 hours and 30 minutes. This required a total of 46,83 m of 1,75 PLA fiber filament (total mass: 140 g).

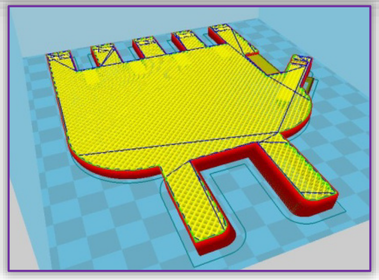

Figure 4. Hand in the 3D printer's slicing program

Figure 3 and Figure 4 show the slicing program of the 3D printer. The parts in red represent the outer layer of the body, which the printer builds at a slow speed. The green and yellow parts refer to the filling of the body where the head works at a higher speed. Blue shows the lines where the head is inactive.

CHOOSING PNEUMATIC ARTIFICIAL MUSCLE

Moving the fingers of the humanoid arm requires one or more PMAs. The first step in sizing the Fluidic Muscles was determining the correct diameter [20]. The diameters and corresponding maximum forces of the muscles are the followings:

- 5 mm - 140 N,
- 10 mm - 640 N,
- 20 mm - 1500 N,
- 40 mm - 6000 N.

Since the 10 mm PMA's maximum force is the closest to the force developed by a human hand this diameter was chosen (Figure 5).

After deciding on the diameter the length of the muscle had to be determined. It is clearly visible in Figure 5 that at 800 kPa (8 bar) of maximum pressure the extent of the greatest contraction is 25%, and that the exerted force is 0 N. In that case, the maximum contraction of a 250 mm long muscle is 62,5 mm. Since the required range was 45-50 mm, a muscle of 250 mm length and 10 mm in diameter was chosen.

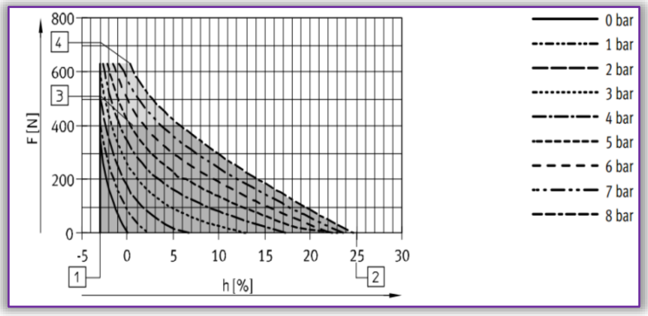

Figure 5. DMSP-10 muscle's force-contraction (relative displacement) diagram [21]

ASSEMBLING AND TESTING THE ARM

The humanoid arm consists of 3 main parts. One of them is the forearm. Since 3D printing is still a relatively expensive technology these days, the forearm was made from a 480 mm long and 63 mm diameter PVC tube. Another part is the muscle and the device holding it. The device consists of 2 shackles and a rail. The back shackle was fixed to the arm and the front shackle to the rail which made it possible for the muscle to move linearly. The third and final part is the hand. The humanoid arm is visible in its assembled form in Figure 6.

Figure 6. Assembled form of the arm

The last step was testing the arm. The first test was carried out without PMA. By pulling the shackle back the fingers closed, while letting go of the shackle caused the rubbers to pull them back into their original (straight) position.

As the next step, the arm was tested with pressurized air. It was made to hold a filled and cylinder-shaped 250 ml volume plastic bottle. The pressure was continuously increased in the muscle. At a pressure of 600 kPa the arm was able to hold the bottle. Following this success, it held several other common household objects. Figure 7 illustrates a few examples of them.

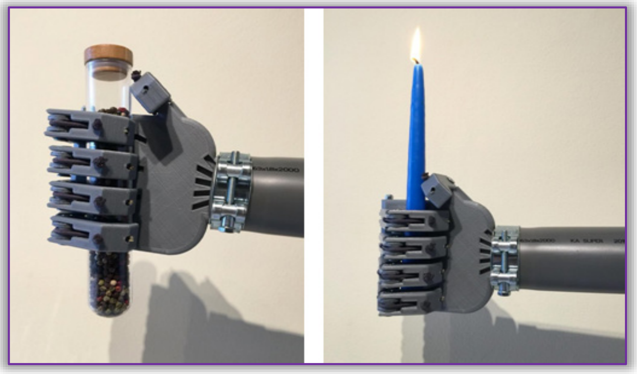

Figure 7. Holding some common household objects

CONCLUSION

The main aim of this work was to design and produce a humanoid arm that can be moved at the fingers by a pneumatic artificial muscle. Based on the results it can be concluded that the humanoid arm meets the objectives as it performs the expected task (moving the fingers).

Since pneumatic muscles were available only in limited numbers it is only possible to move the fingers together, but by using more muscles it can be used as the hand of a humanoid robot as well.

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