Laboratory Exercise 4

Fabrication and Testing of a Soft Pneumatic Actuator/Gripper

Name: **JMBAG:**

Preparation

- Not required.

Introduction

Soft robotics is a subfield of robotics that deals with the design, fabrication, and control of compliant (soft) structures. It combines knowledge from multiple branches of engineering and science, such as mechanical engineering, control engineering, materials science, etc. With the growing interest in developing better and smarter soft robotic solutions, special attention is paid to soft grippers that can be attached to either a rigid or soft body.

This laboratory exercise will cover **the application of** (a) **a pneumatic actuation** as one of the most common actuation methods for soft grippers, and (b) the most commonly represented **fabrication methods** for soft structures, i.e. casting in combination with additive manufacturing.

Pneumatic Actuator

The pneumatic actuator converts the energy of pressurized/compressed air into mechanical motion. An example of the pneumatic actuator is the **PneuNets (pneumatic networks)** bending actuator originally developed by the Whitesides Research Group at Harvard (see Fig. 1). These pneumatic networks consist of a series of chambers and channels in which the behavior of the structure can be mechanically programmed as desired by changing the geometry. For example, changing the thickness of the chamber walls will affect the overall stiffness of the pneumatic actuator, making it more or less prone to bending.

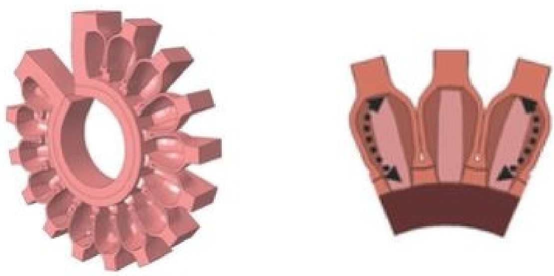

Figure 1: Visual representation of a loaded PneuNets actuator. After compressed air enters the internal structure, which consists of chambers and channels, the pneumatic actuator inflates and generates motion. During the actuation phase (compressed air is inside the PneuNets actuator), expansion occurs in the most compliant areas.

Laboratory Exercise Description

Due to the special fabrication requirements of the PneuNets actuator, **this laboratory exercise is performed in three runs**. Firstly, you will fabricate the PneuNets actuator as described in the laboratory exercise in two runs (2 hours + 1 hour). Once you fabricated your PneuNets actuator, you will group with other students (a team of 2 or 3) to form a soft gripper from your soft actuators. Finally, in the third and last run, you will test and evaluate your soft gripper's performance on the given set of objects (2 hours).

Assignments

Task 1: Fabrication of the PneuNets Actuator (2 points)

For the fabrication of the PneuNets actuator you will need the following:

- **two 3-D printed molds** (a chamber mold that consists of two pieces, and a bottom layer mold),
- **a piece of office paper cut based on the bottom layer mold geometry**,
- **Ekstrasil RTV-2 silicone rubber**,
- **a pneumatic hose**,
- **lab gloves**,
- **a copper thin rod**,
- **a syringe**,
- **a mixing cup**,
- **a spatula**,
- **a mass scale**,
- **a flat screwdriver**,
- **an instant glue** and
- **scissors**.

In this document, a fabrication process overview is given. However, to prepare more in detail, and for better understanding, please check the PneuNets actuator fabrication guidelines. There you will find detailed explanations with accompanying videos and images.

The fabrication of the actuator is divided into four steps:

1. silicone rubber preparation (1st run),
2. silicone rubber pouring (1st run),
3. actuator curing assembling (1st & 2nd run),
4. air source connecting (3rd run).

1. Silicone Rubber Preparation

1. Take the mixing cup, spatula, mass scale, and two-component silicone rubber.
2. In the mixing cup, prepare the two-component silicone rubber in a 100:3 ratio for optimal properties. You will need **35 g of silicone rubber mixture**.
3. Mix the mixture thoroughly for 6 min.

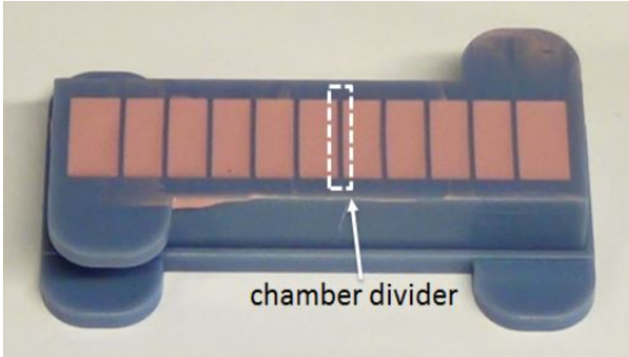

Figure 2: Make sure that the tops of chamber dividers are visible. This ensures that the chambers remain separate in the final cured piece!

2. Silicone Rubber Pouring

1. Assemble the chamber mold and make sure that the connection is tight.
2. Slowly pour the mixture into the main chamber mold, making sure that each chamber fills up.
3. Fill the base mold **slightly below half of its depth with mixture**, tilting the base mold until it is evenly spread out. You can also use the spatula to evenly distribute the mixture along the base mold.
4. Pop the bubbles (residual air) in the mold. Each bubble after curing represents a weak spot in the material and can deteriorate your soft actuator's performance.
5. Remove the excess mixture with a spatula to wipe off excess silicone rubber.
6. Make sure that the tops of the chamber divider are still visible (see Fig. 2) - **double-check that**.
7. Pop any bubbles in the base mold and add the piece of paper on top of the poured mixture. **Press the paper gently so it sticks, but not so hard that it reaches the bottom surface of the base mold.**
8. Spread a thin layer of the mixture using your spatula over the inserted paper ensuring that your paper is trapped inside the mixture.

1st run is completed - wait for silicone rubber to cure

3. Actuator Curing and Assembling

1. Once the chamber mold is cured, **you can open it with the help of a flathead screwdriver**. Pry one end of the mold apart, working your way around each side. **Do not be afraid to pull harder when opening - silicone rubber is hyperelastic, so it is more likely for it to deform than break**.
2. Do not remove any excess material once you have unmolded the top piece (the one with chambers!). **Do not unmold the base mold!**
3. Visually expect your finger to see if there is anything inconvenient.
4. At this point, you should have the unmolded top piece (the one with chambers). Now it's time to join/bond the top and bottom pieces. **The best way to bond silicone rubber with silicone rubber is to use silicone rubber**.
5. Prepare the 10g of the silicone rubber mixture using the same instructions as above.
6. Add the remaining half of the material to the base mold (the one that remained unmolded) and **slightly submerge the top piece into it**. Once it is settled, press it down gently. **Do not press too hard, because you can block the air channel.** Wait for the actuator to be cured entirely.

2nd run is completed - wait for silicone rubber to cure

4. Air Source Connecting

1. Using a thin rod, you will need to enter the inside of the actuator. Your goal is to reach the central channel without damaging the actuator.
2. Using the thin rod, insert the pneumatic hose in the actuator. Finally, take a syringe, and inflate the actuator to make it bend.

Task 2: Assembling and Testing of the Actuator/Gripper (2 points)

Together with other students (2 or 3) use the given 3D-printed finger connector that will serve as the palm of your gripper. To connect the fingers to the gripper, use instant glue as the bonding element.

Once you fully assembled the soft gripper, please attach a photo of it in the following box:

The final part of this laboratory exercise is the testing of your soft gripper. On the given set of objects test and validate the gripper's performance.

Finally, once you completed all the tasks answer the following questions:

a) Which of the given objects was the most difficult to grasp? In your opinion, what is the reason for that?

b) How did you approach the object during grasping (parallel to the ground, perpendicular to the ground, etc.) and why did you choose that approach? Do different approaches affect the gripper's performance?

c) What are the limitations of your soft gripper? How could you tackle them?

d) How does the number of fingers affect the gripper's performance (consider only 2 or 3-fingered soft grippers)? What are the pros and cons of your specific gripper configuration?

e) What would be the next steps in developing a better, more robust version of the soft gripper that you currently have?

Exercise submission

Create a .zip archive containing: 1. this .pdf file with completed answers and 2. a video file (.mp4, .avi, or similar) showing your soft gripper in action, i.e., gripping **at least** three objects from the given set of objects. Upload the archive to Moodle by the deadline.