

Embedding control in inchworm-based soft actuator

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Abstract—The development of an inchworm-based soft actuator with embedded control is presented. Design of pressure loss integrated on purpose within the actuator is being used to simplify the overall control of the actuator. The latter is based on multimaterial additive manufacturing. Dynamic model is compared to experimental behaviour. Prediction accuracy is encouraging and performances of interest for the applicative context.

I. INTRODUCTION

Soft fluidic actuators are of particular interest for the design of soft robots [1]. Motion is then obtained by pressurisation of an hermetic chamber built using a soft material, typically with a Young's modulus of a few GPa or less [2]. Numerous designs have been proposed, with for instance well known pneumatic artificial muscles. When large motions are needed, the bio-inspired inchworm kinematics have been successfully considered in mobile robotics [3], [4] and for manipulation [5]. In this latter case, one elongation motion and two clamping functions have to be triggered according to a pre-determined sequence. This increases the overall control complexity of an inchworm-based actuator, makes it potentially more cumbersome and limits its simplicity.

Several approaches have been considered accordingly to simplify control of pneumatic soft actuators. One option is to perform multiplexing with several addressable pneumatic chambers along a single line [6]. Specific valves have also been elaborated to simplify control in [7]. These approaches are of great interest to design what is considered by some authors as mechanical intelligence, and get a lower number of actuation or control components [8]. A complementary approach is to consider dynamic evolution of pressure in pneumatic systems and to use on purpose during the design the delays introduced by pressure losses. Lim [9] and later Gilberton [10] have considered the effect for mobile robotics. Here we push forward the concept, working on modelling to perform manipulation. First, we show that a simple pressure control associated to mechanical design of pressure loss can be used for manipulation with a soft actuator. Second we outline that motion performance can be predicted, and third that implementation using multimaterial additive manufacturing [11] is of interest to design a soft actuator for a challenging environment such as the medical field.

II. ACTUATOR PRINCIPLE

The soft actuator under consideration aims at manipulating surgical needles for insertion/retraction motions. A global

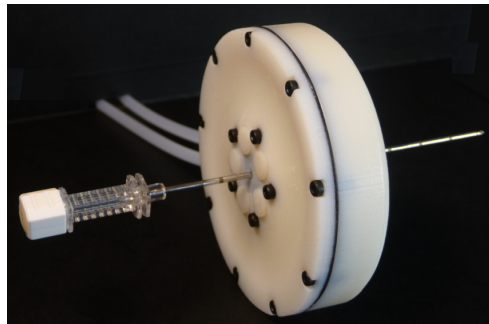


Fig. 1. Global view of the inchworm-based soft actuator.

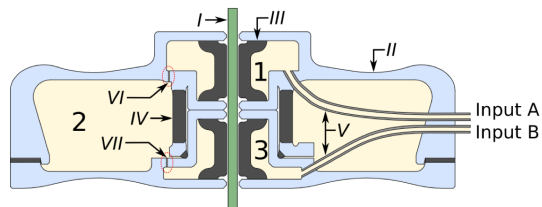


Fig. 2. Section view of the actuator.

view of the prototype is given in Fig. 1. Its outer diameter is equal to 74 mm and it is 24 mm thick. It is built using Polyjet multimaterial additive manufacturing (Stratasys Ltd., USA). The soft actuator is composed of (Fig. 2) two air inputs (A & B) and three chambers: two clamps (1 & 3) and an extensible chamber for needle motion (2). The extensible chamber uses the elastic properties of polymer material and the thickness reduction (II) in order to increase the deformation. An elastomeric cylinder (IV) closes the chamber 2. The chambers are connected by means of two micro-holes (VI & VII).

Multimaterial additive manufacturing allows first to produce the clamping devices with rubber-like materials to design them as pneumatic soft chambers, and at the same time to get radial compliance needed to avoid over constraining the needle. Second, the structural axial compliance obtained with MMAM allows the creation of the axial motion. Third, only two components are printed independently and then mounted altogether to obtain the full actuator.

The interest of the device comes from the micro-holes introduced to create communication between the chambers. This way, a square pressure wave applied on input A(B) create a periodic insertion(retraction) of the needle as schematically represented in Fig 3.

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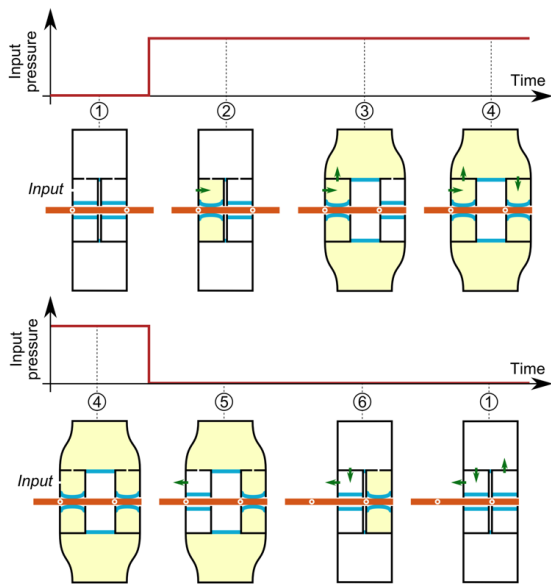


Fig. 3. Working principle (pressurized chambers are shown in yellow).

III. ACTUATOR MODELING AND EVALUATION

The actuator interest is related to the capacity to predict and adjust its motion characteristics and to ensure them in realistic implementation conditions. A model was then developed to determine the achievable motion. It takes into account air compressibility and the presence of subsonic and sonic flows inside the micro-holes that regulate the airflow timing. Due to space constraints, its development is not covered here, and we prefer put the focus on the prediction accuracy by confrontation to experimental results.

In Fig. 4, one can see the comparison of pressure evolution in clamp III of Fig 2 and needle motion as measured and compared to the computed value. Micro-holes have then a diameter of 1 mm, obtained by simple drilling, with input pressure of 2.1 bars. Model and experimental values are in very good accordance.

Force capability of the actuator is dependent on the clamps. The relationship between transmissible force of each clamp and the pressure is more difficult to establish, and the overall sustainable force more delicate to determine. We could identify that one way to adjust force capability is to modulate the duty cycle of the input square signal. It is observed that a duty cycle of 70% can avoid needle slippage under 1 N, the value encountered in the applicative context. The soft actuator is then capable of generating motions at 0.75 mm/s under 1 N using a 1 Hz control signal. This corresponds to the needed performances in the application.

IV. CONCLUSION

Results are encouraging on the use of inchworm-based soft actuator with embedded control by means of adequate pressure loss in their design. Model accuracy is interesting to achieve synthesis for given specifications. This opens the way to further investigation in design of soft actuators with

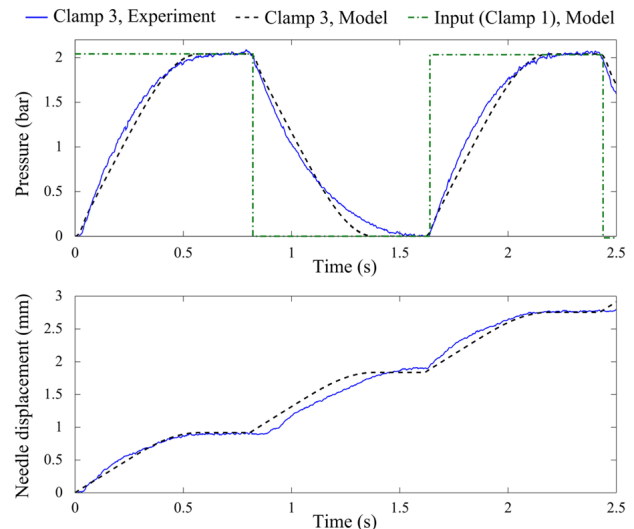


Fig. 4. Evolution of pressure in clamp III and needle displacement as predicted from the model and measured.

multiple chambers for more complex motions based on same principle.

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