# KTAH: DESIGN AND SIMULATION OF A PERISTALTIC TOTAL ARTIFICIAL HEART

Rebecca Bonato[1], Pierre Bourdin[1], Alejandro Penacho Riveiros[2], Salvar Andrí Johannsson[1], Matthildur Eysteindóttir[1], Ana Candela Celdrán[1], Emanuele Perra[1], Rosato Aurora[1], Georgios Andrikopoulos[3], Seraina Anne Dual[1],

1: Department of Biomedical Engineering, KTH Royal Institute of Technology; 2: Department of Intellligent Systems, KTH Royal Institute of Technology; 3: Department of Mechatronic and Embedded Control System, KTH Royal Institute of Technology

## 1- MOTIVATION

Heart failure affected 64 million people in 2017 worldwide, with around 23 million suffering from the end-stage condition [1]. Lack of heart donations motivates the development of total artificial hearts (TAH).

The **goal of this study** is to develop a prototype of a TAH that is capable of pumping at least **5 L/min** of blood. Furthermor, we aim to minimize the **shear stress** of the pumping mechanism in such a way as to limit **blood trauma** through a **valveless** design and to produce a **pulsatile flow** rendering a more physiological flow pattern than a continuous flow.

## 2- CONCEPT

The TAH prototype's design is based on a **peristaltic pump**'s working principles. The TAH is composed of two compliant silicone-based chambers, enclosed inside a stable 3D printed case. Each chamber replaces native a atria and ventricle.

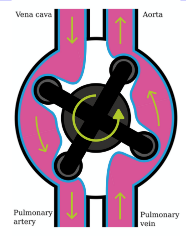

**Fig 1.** *Working principle*

**Fig 2.** *Final prototype*

A motor rotates with a low speed (60-70 rpm) and drives four rollers that propel the blood forward by the compression of the chambers.

## 3 - METHODS

### DESIGN

**Soft Chambers** has been casted using Dragonskin 20 Silicone (Shore hardness 20). Silicone is mixed, vacuum treated and poured through the inlet of the mold. Molds are 3D printed out of PLA.

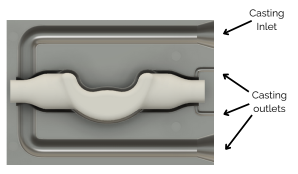

**Fig 3.** *Mold for silicon chamber*

**Actuation mechanism** is 3D printed out of ABS with carbon fiber reinforcement. Four 3D printed rollers are placed between the fan and the legs using bearings to reduce friction. The external case is assemblable.

**Motor and Electronics** was selected to provide a torque up 2.5 N*m. NEMA 24 bipolar stepper motor is used in combination with its respective driver and is controlled through an arduino.

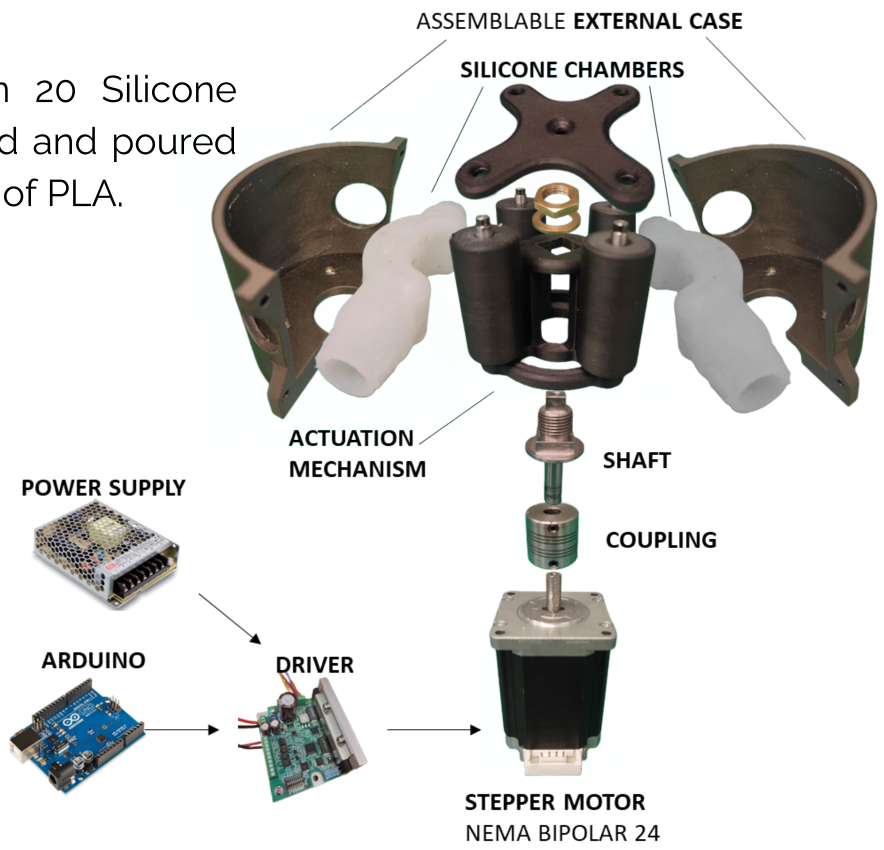


**Fig 4.** *Exploded view of the final prototype*

### TESTING

Testing has been performed using **Hybrid Mockloop** (Fig 6) [2]. It allows specific pressure to be applied as input and output and the flow to be measured. Only one chamber per time has been tested, resulting in asymmetry in the testing setup. Tests have been carried out with and without a mechanical valve (Fig 5) to compare performances.

**Fig 5.** *Valve used*

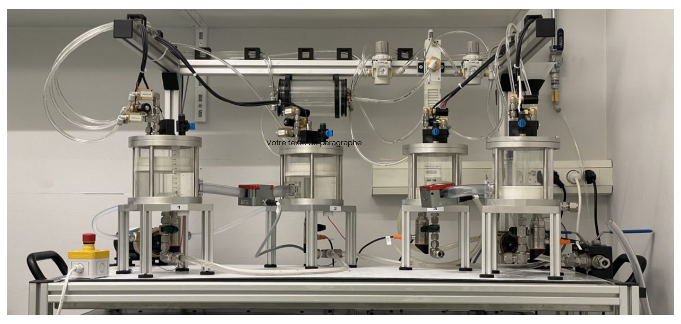

**Fig 6.** *Hybrid Mockloop [ 2 ]*

## 4 - RESULTS

The device produces a **pulsatile flow** evidenced by the fluctuating pressure (Fig.7) where the 'heart rate' obtained in bpm is equal to **4 times the speed** [rpm]. The measured flow increases with higher speeds and lower pressure difference (Fig. 8). The objective of 5 L/min has been reached only for all rotational speeds higher than 65 rpm.

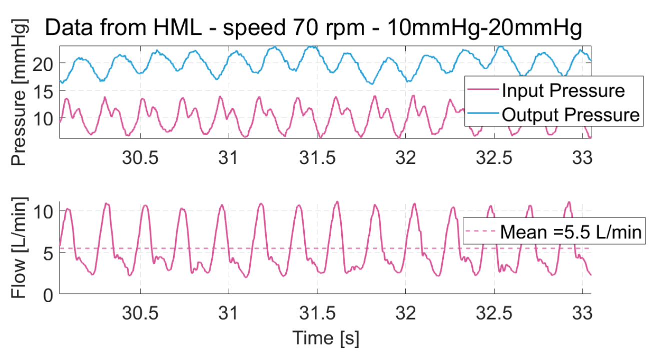


**Fig 7.** *Input and output pressures when the corresponding set value is 10 and 20 mmHg (top). Corresponding output flow (bottom).*

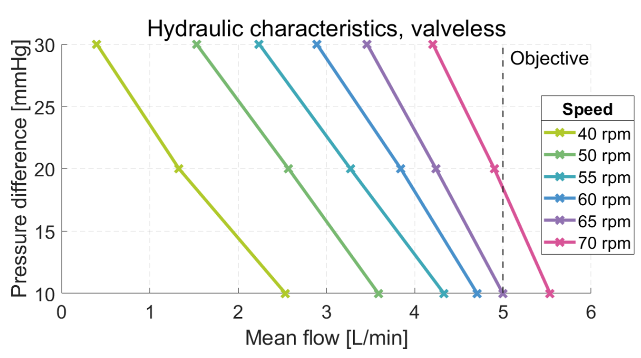


**Fig 8.** *Effect of the pressure difference on the flow for different speeds*

Increasing the output pressure results in the appearance of **backflow** (Fig. 10). The use of a valve can mitigate this problem, improving flow for all working conditions (Fig. 9). In any case, the device provides sufficient flow even **without** the use of a **valve** for low pressures and pressure differences.

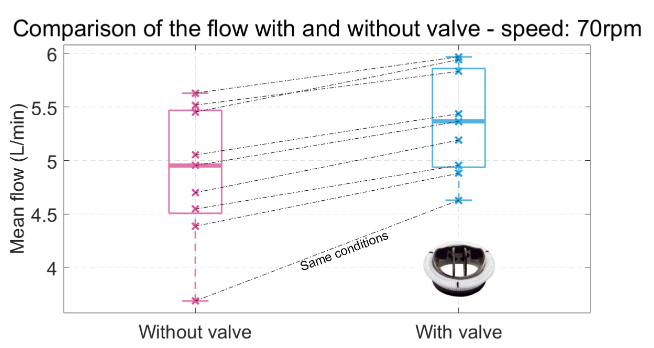


**Fig 9.** *Comparison of the output flow with and withot valve at different pressures.*

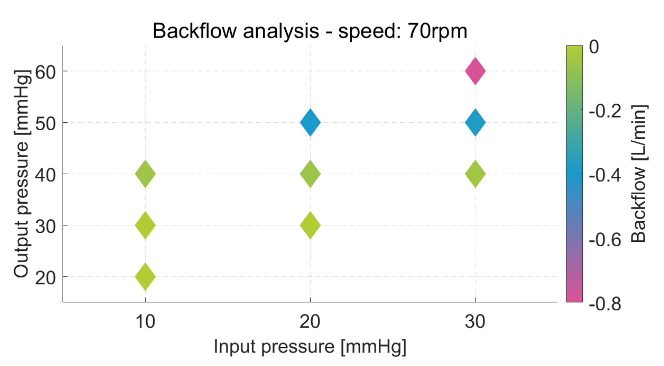


**Fig 10.** *Backflow analisys at different input and output pressures*

## 5 - DISCUSSION and FUTURE WORK

We created a functional TAH based on a novel peristaltic methods to pump **5L/min**. The prototype works valveless and produces a pulsatile flow. Our main goals have thus been reached. However, several issues need to be dealt with :

- **Weight & Size :** Due to the current motor weight, the TAH currently weights **1.8 kg**. Motor design was not a focus of this study, but should be optimized to meet weight targets.
- **Power consumption :** Currently, the heart has a power consumption of **21,6 W**, which is expected to reduce through motor optimization. However, this can only be partially solved. Indeed, the mechanism is subjected to high friction as a result of compression of the thick silicone walls, which is currently required for sealing.
- **Durability :** Soft material durability has not been tested at the moment, however the same prototype was used for all experiments.
- **Biocompatibility**: The current materials used are not **biocompatible**, but this could be achieved with further specific studies.
- **Pulsatility:** The frequency of the pulsatility is equal to 4 times the speed of the motor producing a higher then physiological **flow pulsatility**. Currently is not known if a higher then physiological pulsatility has negative physiological consequences, and therefore this should be studied further [3].
- **Backflow:** a careful study of the backflow is necessary to understand whether it is due solely to the asymmetry of the setup (and thus related to the testing method) or other design factors come into play.

Work will be continued by some team members next year, but also by another team that will take the lead of developing the total artificial heart.

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***References:***

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***Contact:***