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Design and Experimental Testing of a NiTi-based, High Frequency, Centripetal Multiple Actuator

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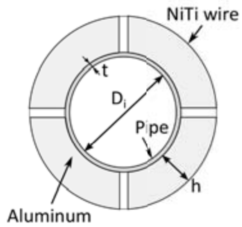
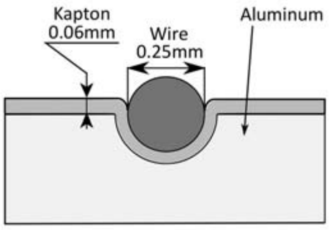
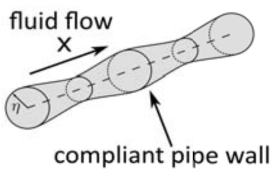
Objectives

The purpose of this work is to analyze complex systems with **multiple SMA actuators working at frequencies** greater than 1 Hz, which are **higher than those typical of NiTi actuators**. In details, we show the design, the development and the testing of a peristaltic experimental rig actuated by multiple shape-memory **NiTi wires**, each with a 0,25 mm diameter.





To improve the dynamic response of NiTi actuators we have **analyzed different forced cooling methods** [1]: low and high speed air cooling, fluid quenching, heat sinking, thermal gel. We decided to pursue a **heat sink method**, designing each centripetal actuator capable of radially and cyclically shrink a compliant silicone pipe containing fluid: four rigid, aluminum-made circular sectors are placed along the pipe circumference and provide the required NiTi wire housing, while converting a linear contraction of a heated SMA wire into a radial displacement. The aluminum assembly also acts as **geometrical amplifier** of the wire contraction, while the NiTi re-arm force is provided both by the fluid pressure inside the pipe, and (to a lesser degree) by the elastic reaction of the elastomer. Moreover, we investigated how the **diameter contraction is affected by various parameters** (NiTi groove design, thermal insulation tape thickness, duty cycle) as well as actuation frequencies up to 3 Hz.

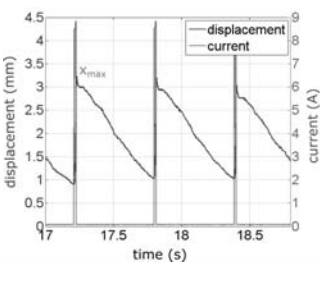


The positioning of the described SMA devices along the external surface of the compliant test section, allows to create **waves of wall-normal deformation traveling along the axial direction of the pipe**. Numerical simulations in an idealized setup suggested [2] that a turbulent wall flow could be transformed into fully laminar by this type of forcing.

Results

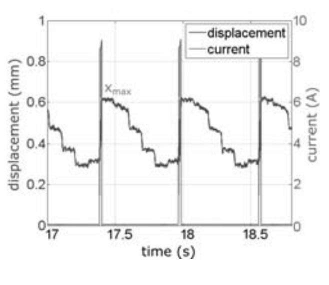
The performance of all the actuators is analyzed and **compared with the authority of the single actuator**, operating alone.

Displacement history for
1 actuator on:
(actuator freq 1.7Hz, duty cycle2%, square wave of current 9A)



Δx = 3.4 mm x_{max}= 3.24 mm

Displacement history
for **204 actuators on:**
(actuator freq 1.7Hz, duty cycle2%, square wave of current 9A)



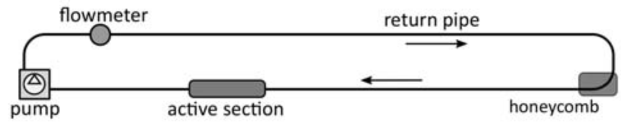
Δx = 0.31 mm x_{max}= 0.61 mm

The displacement history, taken when all the actuators are operative and considering the same actuation parameters, shows a decay in terms of actuation authority, both the cyclic displacement Δx and the peak value x_{max}. In addition, in the displacement history six steps are clearly visible, corresponding to the adjacent SMA wires actuation.

Moreover, the maximum value x_{max} remains unchanged while **increasing the actuation frequency**, meanwhile the cycle amplitude Δx reduces.
This effect is due to a shorter cooling time that results in lower percentage of phase transformation, thus reducing the wire recovery.

Methods

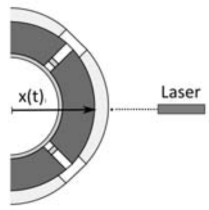
The experimental setup is made up of a **closed-circuit water pipe**. The active section has a 61mm inner diameter and is preceded by a straight smooth aluminum pipe to ensure a fully developed turbulent flow. A second smooth straight aluminum section connects the outlet of the test section to the pump and to the return pipe.

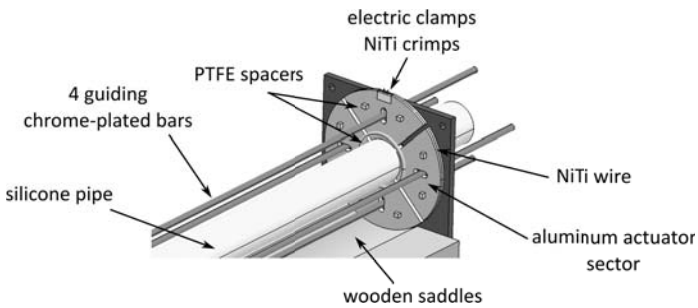


Data acquisition is managed by a personal computer, which also runs a LabVIEW DAQ software that acquires displacement time histories, together with the NiTi wire current measured by a current clamp. The actuator system is controlled by power MOSFET switches driven by DC power supply (average continuum power 5728W).

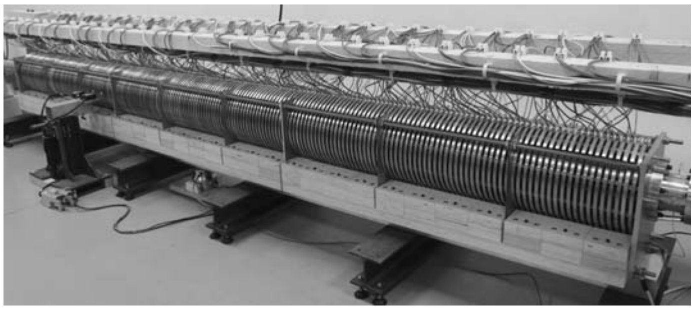
Since we are interested in evaluating the performance of our device for a continuous and cyclic actuation, we want to deduce peak-to-peak displacement from the temporal trace of peristaltic displacement.

The **radial external displacement** of the device is measured by means of an external **laser transducer**: this allows us to obtain the time history of the wall deformation at a sampling rate of 500 Hz.





We manage to make the **NiTi wire work at 3.5% in strain** and set an internal fluid pressure of 0.3 bar, in order to ensure an optimal working stress for the considered wire. Furthermore, numerical simulations impose fluid dynamics and design parameters to respect: actuation frequency, amplitude of the wall displacement, wavelength, phase velocity. We decide to discretize each wavelenght with 6 SMA actuators so that the **multiple actuators system is composed by 204 NiTi wires** and the corresponding 210 mm diameter aluminum support, acting also as heat sink.



Conclusions

We have presented the design, the development and the testing of a peristaltic experimental rig actuated by multiple shape-memory NiTi wires. The performance of all the actuators showed an actuation authority decay compared to the single actuator operating alone.
In fact, when all the actuators are operating, we observed a reduction of the Δx but also a lower value of x_{max}. Due to the requested high frequency, **the authority of all the actuators** acting quite simultaneously **increases the pipe internal pressure**, leading NiTi wires to work against re-arm forces higher than the designed ones.

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References:

1. Borlandelli et al., 2015, *Design and experimental characterization of a NiTi-based, high-frequency, centripetal peristaltic actuator*, Smart Mater. Struct. 24
2. Nakanishi et al., 2012, *Relaminarization of turbulent channel flow using traveling wave-like wall deformation*, Int. J. Heat Fluid Flow 35