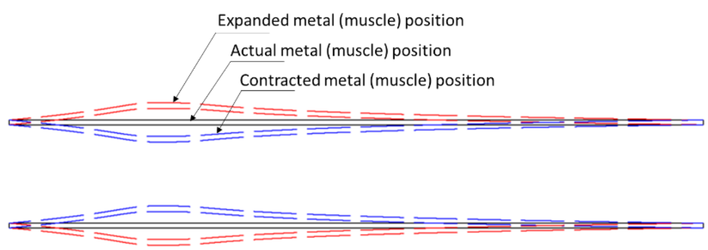
NSF Manufacturing Blue Sky Competition 2021

Lifelike metallic structures using Origami & Compliant Mechanism

Vanshika Singh

Intelligent (or smart) materials have been leveraged for quite a long time in the different fields of industry. To make these materials and structures smart, two approaches have been used. In the first method, external sensors and actuators were used to bring about shape change. In the second approach, special materials like Shape Memory Alloy were used after training. **The question that arises is can we make a metallic structure without any external device or special material that can change its shape or size significantly when subjected to different environmental conditions like temperatures, pressures, or other stimuli?** Here it is proposed to design and manufacture dynamic metallic structures via an Origami-inspired Design and Compliant Mechanism approach. Origami-inspired designs and Compliant Mechanisms have been successfully implemented for materials like polymers, nanomaterials, biomaterials. However, adoption of this technique to structural materials (e.g., stainless steels) that may operate in harsh environments are challenging due to their inherent properties. This challenge forms the motivation behind this idea.

Why do we need a Lifelike metallic structure? In nature, there are a plethora of self-acting mechanisms. In fact, the human body has a few great mechanisms like that of lungs, heart valves, veins in the lower leg, et cetera. The design of the lung makes for one of the most efficient heat exchangers with a significant surface area to volume ratio of 20,000 m^2/m^3. The Alveoli in the lungs expand and contract periodically and hence enhance the gas exchange across the wall. If similar movements of the alveoli walls can be achieved through metallic structural design, the potential for designing highly efficient components leading to lower harmful (CO_2, NO_x, SO_x, CO) emissions is possible. But can we make the walls of these heat exchangers movable? Can we make any metallic structures act like a muscle where the driving force is temperature or pressure fields as examples? Areas like in aircraft & gas turbine engines, automobile, refrigerators, robotics, space-exploration, where these lifelike structures can be implemented.



How can we design/make such structures (starting points)? The 16^{th}-century old Japanese art of paper-folding called Origami could be one of the best options to try out lifelike structures. The idea is to create structures that mimic the origami design using metals like aluminum alloys, steels, et cetera. The great challenge in this would be choosing appropriate material and designing & manufacturing the origami inspired metallic structure (specifically design & manufacturing of the high stiff and low stiff regions in the structure). The material for such structure must be capable of handling high plastic deformation.

How interdisciplinary is this domain? The concept of making metallic structures act like a living organism would require interdisciplinary efforts spanning material, manufacturing, bioengineering, heat transfer, design, and topology optimization. Material engineering could be used to optimize localized microstructural features and properties in the structure for the necessary performance. However, the final design must account for mechanical design criteria like low or high-cycle fatigue and maximum stress allowed. Bio-mechanisms like that of heart, lungs, leg veins, stoma (which are present under the leaf), et cetera for replicating it in mechanical structural designs. Manufacturing methods like additive manufacturing (Powder-bed fusion / Ultrasonic Additive Manufacturing) processes, hybrid manufacturing methods could be explored to achieve such designs. Topology optimization for creating metamaterial locally present in the structure in a combination of origami & compliant mechanism could also be performed to achieve an overall lifelike structure.