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Material Science – Extra

Material Analysis of Bio-inspired Artificial Muscles

This paper will refer to the bio-inspired artificial muscles known as the McKibben artificial muscle. Information is summarized from the paper “Modelling of the McKibben artificial muscle: A review” by Bertrand Tondu. This paper will explain artificial muscle and its functions, as well as how the McKibben artificial muscle works. The McKibben artificial muscle will be broken down and its components and their functions will be explained. There will also be a material analysis of the components.

Artificial Muscles: Definition and general information

Artificial muscle is a device that can help replace the function of a real muscle, which is to move bones and allow for body movements. But not all actuators can just be called artificial muscles. For some scientists, artificial muscles must be able to convert chemical energy into mechanical energy. But others also consider actuators that are purely mechanical to be artificial muscles, such as the McKibben artificial muscle. Even though it is purely mechanical fluidic, it is still able to be used for actuation. Nevertheless, it is still bio-inspired, therefore making it an interesting “artificial muscle” to look at. In order to achieve the biomimetism for the McKibben, multiple difficulties in the areas of elastic and soft materials were combined, making it difficult to have an accurate model of the system.

To further understand the principles of artificial muscles, the equilibrium principle should be introduced. This principle is also known as the open-loop positioning stability and it is the general principle that makes up artificial muscles. This principle states that when there is constant stimulus, artificial muscles will respond by changing its shape, therefore changing its initial equilibrium position. This is a mimic of the adaptation characteristic of biological muscle tissues. This principle supports the claim that McKibben would be more than just an actuator and that it can be considered an artificial muscle; one that is a fluidic mechanical cylinder.

For an artificial muscle to be ideal, the cylinder that represents the muscle bulk – which is often controlled by pressurizing the cylinder- must be able to reduce its length (contract). At the same time the radius of the cylinder should also increase. These actions are biomimetic. When muscles contract, they shorten in length and a bulk can be seen (radius of muscle belly increases).

Most fluidic artificial muscles follow the principles described earlier, but there are difficulties in achieving a greater contraction in the cylinder, making it inefficient. This makes the McKibben the simplest artificial muscle that fits most closely to the ideal artificial muscle, therefore making it one of the most efficient.

The McKibben Muscle: How it works

The McKibben artificial muscle is an artificial muscle with one of the simplest designs. The main component of the McKibben is the pressurized cylindrical tube. The other major component is a double-helix-braided sheath that covers the cylinder. (See Figure 1).

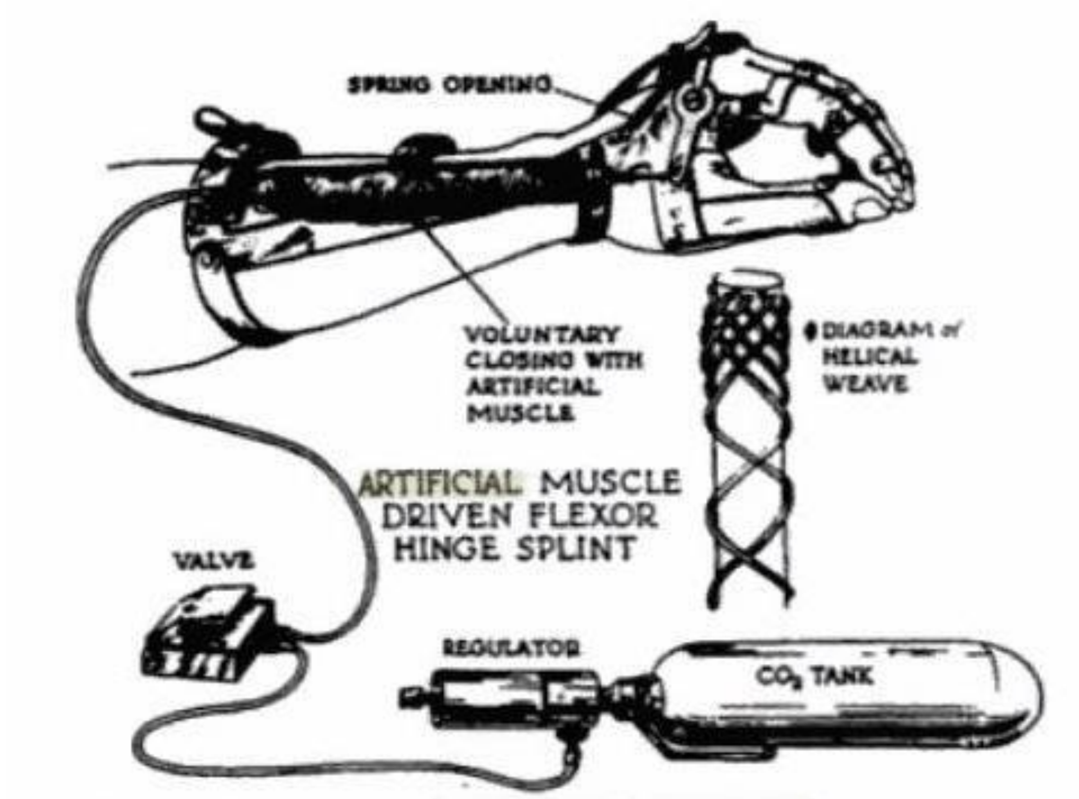

Figure 1: The McKibben artificial muscle (system)

The cylindrical tube is made from a rubber inner tube. When pressure is generated, the free end of the artificial muscle (unattached to pressure source) is contracted. The tube is able to shorten because its circumference is also expanding. In the meantime, the braided sheath functions to keep the tube in its cylindrical shape.

On a deeper level, the inner tube experiences circumferential stress as there is constant pressure. This stress is converted into a contraction force. This force in turn decreases the contraction ratio, which is the ratio of how much the length has reduced to its original length.

Inner Tube Function

The inner tube's main function is to provide stability as it creates a "ballooning effect". The ballooning effect is the one that is explained above and is responsible for contraction.

Because the stress in the inner tube is circumferential, the stress and strain relationship on the rubber material is not linear.

The inner tube can be made out of rubber or rubber-like materials (elastomers). This is because it must be able to resist elongation breaking, which means that it must be flexible. This makes rubber a suitable material.

Because of the ballooning effect, this component has a “ballooning constraint”. This refers to how much the rubber tube can inflate until it is constrained by the covering braided sheath. This constraint determines how long the material will last and is measured in cycles of contraction and elongation. There has to be a balance between the large pressure range working inside the tube and the lifespan of the material. Large pressure range means more loads can be carried, but the lifespan of the rubber material will not last as long; and vice versa. In order to achieve the maximum potential (where the best balance is found), the material for the tube must be soft rubber. Not only that, the rubber cannot be too thick. If the following is done, the desired pressure range will be reached.

But by using soft rubber, the fragility of the McKibben muscle is increased. This is because soft rubber is highly sensitive to environmental conditions. The more the surface of rubber is exposed to oxidation, light, or heat, the shorter the lifespan of the rubber. The lifespan is also shortened even more if the rubber is under stress. The only type of soft rubber that is not ideal is natural rubber. This is because natural rubber has a high permeability to gases.

Just like biological muscles, artificial muscles can also experience fatigue. Although the kind of fatigue artificial muscles experience can be called mechanical fatigue. This is due to the growth of cracks in the rubber materials, which slowly occurs when the material experiences a load or when it is deformed.

Braid Function

The main role of the braided sheath covering the rubber inner tube is to transmit the pressurized forces. By doing so, it is able to transform the circumferential stress (from the pressurized inner tube) into a linear contraction force. This means that it puts stress on the rubber tube.

The braided sheath is a resemblance of a flexible joint structure. It is custom to constant adaptation as the pressure inside the rubber tube constantly changes back and forth, which in turn causes the shape of the rubber tube to shift back and forth. The braided sheath has to constantly adapt to the shape.

The material that makes up the braided sheath may differ depending upon how much load the artificial muscle is needed to carry. But the key characteristics in the materials is in its flexibility. The material should be flexible, as it has to be adaptive to the changing shape of the inner tube. It has to be strong enough to not break when stretch. In figure 2 below, load-velocity diagrams of two braided sheaths made out of two different materials are shown. The one on the left is braided with rayon, while the one on the right is braided with iron. Rayon is a fiber, while iron is a metal. Since rayon is a much more flexible material, it allows the artificial muscle to function better and carry more load (due to being able to generate faster contractions).

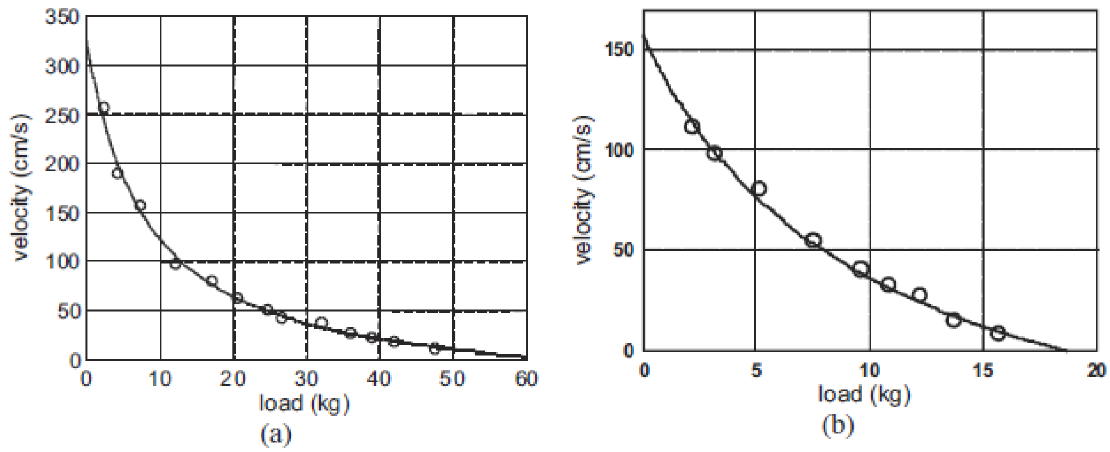

Figure 2: Velocity-load relationships of two different McKibben muscles. A is rayon-braided; B is iron-braided.

To conclude, for the McKibben artificial muscles to reach its maximum potential, there are key characteristics the materials must have. The key characteristic for the inner tube rubber is its softness. Meanwhile, the key characteristic for the braided-sheath is the flexibility of the material.

Advantages and Disadvantages

Because of its simple design, the McKibben is easy to be implemented for use, not to mention its amazing biomimetic of the skeletal muscles and its behavior. The simple design also results in the McKibben muscle not being too heavy. Because there is no static friction, the McKibben muscle is able to perform a smooth and even contraction action.

But because a source is needed to generate pressure, a tank is often needed, which is quite inconvenient.

For modelling, it is also difficult to model friction. This is because the actual contact surface of the strands of the braids is very difficult to accurately determine. This results in the questioning of the validity of the models.

Source

Tondu, Bertrand. "Modelling of the McKibben artificial muscle: A review."*Journal of Intelligent Material Systems and Structures* 23.3 (2012): 225-253.