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(MCKIBBEN'S MUSCLE) Robots Make Our Work Lighter, But We Have Made the Robots Lighter.

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ABSTRACT: *Industrial robots, which are heavy moving bodies, show high risk of damage when working and also sessions in dense environment of other robots. This initiated the allure for lighter robot constructions using soft arms. This paper reports on the design of a biorobotic actuator. Data from several vertebrate species (rat, frog, cat, and human) are used to evaluate the performance of a McKibben pneumatic actuator. Soft arms create powerful, compact, compliance and light robotic arms and consist of pneumatic actuators like McKibben muscles. Currently there are some trajectory problems in McKibben muscles, which restrict its application. This paper presents solutions to certain problems in the McKibben muscles by the use of Electro Active Polymers (EAP). The main attractive characteristic of EAP is their operational similarity to biological muscles, particularly their resilience and ability to induce large actuation strains.*

Electro Active Polymers (EAP) as sensors, which simplify a robotic finger, models by acting like an actuator (sensor cum actuator). Ion-exchange Polymer Metal Composite (IPMC), one of the EAPs, has been selected by us ahead of its alternatives like shaper memory alloys and electro active ceramics and the reason for its selection is also discussed in this paper.

We devise a unique model to eliminate trajectory errors by placing EAP stripes in robots' joints, which can also be applied to current (heavy) robots actuated by motors. This paper would obliterate all the difficulties currently present in McKibben muscles system, which currently restricts its application. Adroit use of the solutions provided in this paper would abet researchers to produce highly efficient artificial muscles system. We give the idea of an artificial muscle system which consume "less energy & oxygen" than a natural one. Therefore we discuss the world's most energy efficient robot with our innovative idea.

Keywords: *Actuator, Analyzer, Electro Active Polymers (EAP), Fingers, Gripper, Robotic Hand, Sensors etc….*

I. INTRODUCTION TO MCKIBBEN MUSCLES

Industrial robots are very heavy and highly rigid because of their mechanical structure and motorization. These kinds of robots in the dense environment of other robots may hit and damage each other due to technical errors or during the training sessions. This initiated the idea of developing lighter robot constructions. Replacing heavy motor driving units, which constitute much weight of a robot with lighter McKibben muscles, will serve the purpose. The McKibben Artificial Muscle is a pneumatic actuator, which exhibits many of properties found in real muscle. American physician Joseph L. McKibben first developed this muscle in 1950's. It was originally intended to actuate artificial limbs for amputee's spring-like characteristics, physical flexibility and lightweight. Its main advantage is the very high force to weight ratio, making it ideal for mobile robots.

II. CONSTRUCTION

The device consists of an expandable internal bladder (a rubber elastics tube) surrounded by helically weaved braided shell made of nylon cloth which are attached to either sides like tendon-like structures. A McKibben Artificial Muscle can generate an isometric force of about 200 N when pressurized to 5 bars and held to a length of 14 cm. This actuator is relatively small.

Fig.1

WORKING:

When the internal bladder is pressurized, expands in a balloon-like manner against the braided shell. The braided shell acts to constrain the expansion in order to maintain a cylindrical shape.

Fig.2

As the volume of the internal bladder increases due to increase in pressure, the actuator shortens and produces tension if coupled to a mechanical load. This basic principle is the conversion of the radial stress on the rubber tube into axial stress and during relaxation of the muscle the reverse happens. A thin rubber bladder is used to transmit the entire pressure acting on it to the unstreachable outside shell. One end of the muscles is sealed where loads can be attached and the other end is for the air from the regulator as shown in figure 3.

By using a finite element model approach, we can estimate the interior stresses and strains of the McKibben actuator.

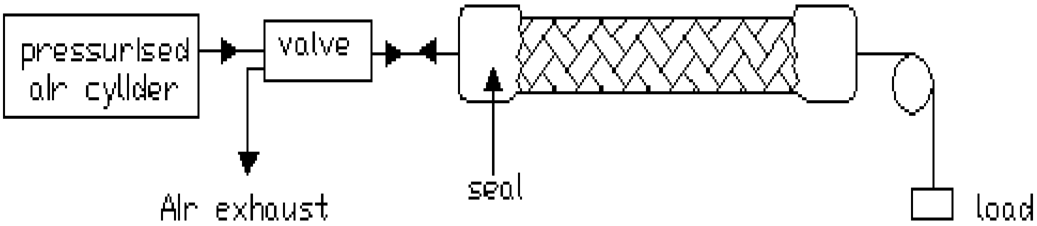


Fig.3

Performance Characteristics: The force generated by a McKibben Artificial Muscle is dependent on the weave characteristics of the braided shell, the material properties of the elastic tube, the actuation pressure, and the muscle's length.

Artificial versus Biological Muscle: The force-length properties of the McKibben actuator are reasonably close to biological muscle. However, the force-velocity properties are not. We have designed a hydraulic damper to operate in parallel with the McKibben actuator to produce the desired results.

Energy requirement: the energy requirement of a McKibben artificial robot is the least among all the robots. It is even less than that used up by the human muscle.

III. MCKIBBEN MUSCLES AS ACTUATOR

A PHYSIOLOGICAL MODEL

Two McKibben muscles put into antagonism define a rotoid actuator based on the physiological model of the biceps-triceps systems of human beings. The two muscles are the agonist and the antagonist and are connected by means of a chain and driving sprocket as shown in the figure 3.

The force difference between the two generates a Torque. An initial tension must be maintained against the passive tension found in human physiology. When the pressures are increased and decreased to P1 and P2 respectively, an angular deflection of θ is produced. The equation for the torque produced was deduced as:

$$T=k1\ (P1-P2)-K2\ (P1+P2)\ \theta$$

Where, k1 and K2 are constants. This equation is much similar and gives a near value to the one deduced by N.Hogan having the system of biceps-triceps as the basis.

$$T= Tmax\ (Ub-Ut)-k\ (Ub-Ut)\ \theta$$

Where Tmax, k are constants and Ub, Ut are normalized nervous control of biceps and triceps.

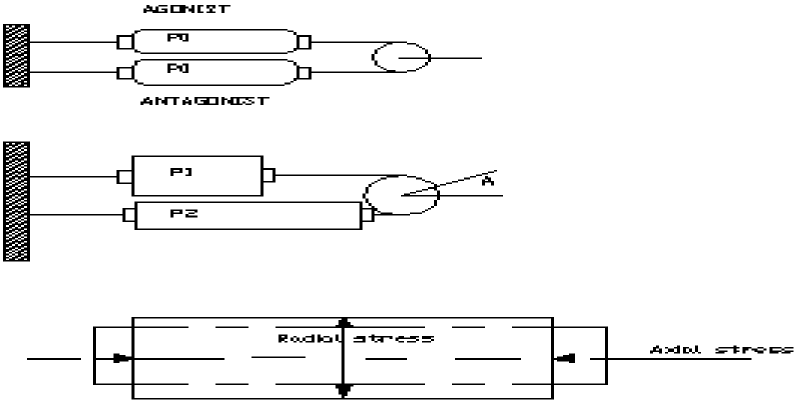


Fig.4

Advantages of the McKibben Artificial Muscle

- High force to weight ratio Size availability
- Flexible
- Powerful
- Damped
- Effective
- Lightweight
- Low-cost
- Smooth.

Electro active Polymer Artificial Muscles:

Electro active polymers (EAP) are being developed to enable effective, miniature, inexpensive and light robotic applications like surface wipers etc. The EAP material that is commonly used is known as IPMC (Ion- exchange polymer metal composite), which is dealt later. The EAP strip can be made as grippers and strings, which can grab and lift loads, among many other potential uses. These strips and strings have the potential to greatly simplify robotic spacecraft tasks.

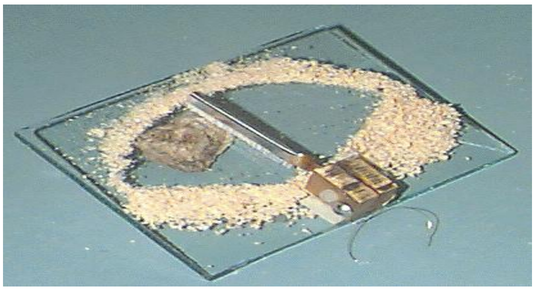


Fig. 5

When an electric charge follows through the ribbon, charged particles in the polymer get pushed or pulled on the ribbon's two sides, depending on the polarity. The net result: the ribbon bends. Four such ribbons can be made to lift a load. They can operate under cryogenic conditions like -140 degree Celsius. When the power supply is turned off, the cylinder relaxes, enabling it to lift or drop loads.

IV. INFLUENCE OF ELECTRIC FIELD (i.e. BENDING OF THE STRIP)

The bending can occur due to differential contraction and expansion of outer most remote regions of a strip if an electric field is imposed across its thickness as shown in figure. IPMC strips generally bend towards the anode and if the voltage signal is reversed they also reverse their direction of bending. Conversely by bending the material, shifting of mobile charges become possible due to imposed stresses. When a rectangular strip of the composite sensor is placed between two electrodes and is bent, a stress gradient is built on the outer fibers relative to the neutral axis (NA). The mobile ions therefore will shift toward the favored region where opposite charges are available. The deficit in one charge and excess in the other can be translated into a voltage gradient that is easily sensed by a low power amplifier. Since these muscles can also be cut as small as one desires, they present a tremendous potential to micro-electro-mechanical systems (MEMS) sensing and actuation applications.

V. ADVANTAGES OF EAP

- ♣ Can be manufactured and cut in any size and shape.
- ♣ Have good force to weight characteristics in the presence of low applied voltages.
- ♣ Work well in both humid and dry environments.

- Work well in cryogenic conditions and at low pressures.
- Unique characteristics of low density as well as high toughness, large actuation strain and inherent damping vibrations.
- Show low impedance.

VI. IPMC

Construction:

The IPMC are composed of a per fluorinated ion exchange membrane which consist of a polymer matrix that is coated on the outer surface with platinum in most cases (silver and copper have also been used).This coating aids in the distribution of the voltage over surface. These are made into sheets that can be cut into different shapes and sizes as needed.

Working:

Strips of these composites can undergo large bending and flapping displacement if an electric field is imposed across the thickness. A circuit is connected to surface to produce voltage difference, causing bending. Thus, in this sense they are large motion actuators. Conversely by bending the composite strip, either quasi-statically or dynamically, a voltage is produced across the thickness of the strip. Thus, they are also large motion sensors.

When the applied signal frequency is varied, so does the displacement up to a point where large deformations are observed at a critical frequency called resonant frequency. At resonant frequency maximum deformation is observed and beyond this frequency the actuator response is diminished. Lower frequencies (down to 0.1 or 0.01 Hz) lead to higher displacement (approaching 25 mm) for a 0.5cm X 2cm X 0.2mm thick strip and failed for other frequency values under similar conditions. IPMC films have shown remarkable displacement under relatively low voltage, using very low power. A film-pair weighing 0.2-g was configured as an actuator and using 5V and 20mW successfully induced more than 11% contraction displacement. Since the IPMC films are made of a relatively strong material with a large displacement capability, we investigated their application to emulate fingers. The gripper we suggested may be supported using graphite/epoxy composite rod to emulate a lightweight robotic arm.

Advantages of IPMC

- Light
- Compact
- Driven by low power & voltage
- Large strain capability

VII. MCKIBBEN MUSCLES AND EAP SENSORS

INTELLIGENT ROBOTS:

Developing intelligent robots requires the combination of strong muscles (actuators) and acute sensors, as well as the understanding of the biological model. Using effective EAP materials as artificial muscles, one can develop biologically inspired robots and locomotives that possibly can walk, fly, hop, dig, swim and/or dive. Natural muscles are driven by a complex mechanism and are capable of lifting large loads at short (millisecond) response times.. Since muscle is fundamental to animal life and changes little between species, we can regard it as a highly optimized system. The mobility of insects is under extensive study.

Development of EAP actuators is expected to enable insect-like robots that can be launched into hidden areas of structures to perform inspection and various maintenance tasks. In future years, EAP may emulate the capabilities of biological creatures with integrated multidisciplinary capabilities to launch space missions with innovative plots. Some biological functions that may be adapted include soft-landing like cats, traversing distances by hopping like a grasshopper and digging and operating cooperatively as ants.

VIII. DEVELOPMENT OF EAP FOR SPACE APPLICATIONS

Since 1995, under the author’s lead, planetary applications using EAP have been explored while improving the understanding, practicality and robustness of these materials. EAP materials are being sought as a substitute to conventional actuators, and possibly eliminating the need for motors, gears, bearings, screws, etc. Generally, space applications are the most demanding in terms of operating conditions, robustness and durability offering an enormous challenge and great potential for these materials.

A comparison between IPMCs and other types of actuators is given below:

PROPERTIES	Ionic polymer –Metal Composites (IPMC)	Shape Memory Alloys (SMA)	Electro Active Ceramics (EAC)
Actuation Displacement	>10%	<8% short fatigue life	0.1-0.3%
Force (Mpa)	10-30	About 700	30-40

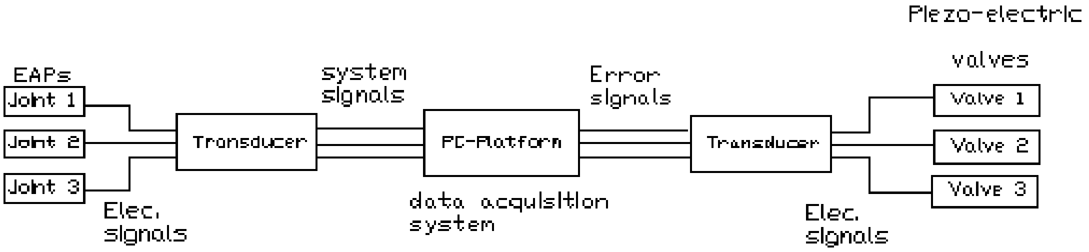
Reaction speed	Micro sec to second	Sec to min	Micro sec to sec
Density	1.25 g/cc	5-6g/cc	6-8g/cc
Drive voltage	4-7 V	NA	50-800V
Fracture Toughness	Resilient, elastic	Elastic	Fragile

Table 1

IX. SUGGESTIONS

EAP AS SENSORS:

This paper suggests placing of EAP strips (IPMC) at each joint of the robot with each and fixed to each arm as shown in diagram. Relative angular deflections of the arms bend the strip (mechanical deformation), which generates current. During robot's training session the current signals from each joint is converted (using transducer) into data signals for a PC-platform data acquisition system which stores the data as a base. During the robot's regular work, the signal from each joint is analyzed for every microsecond and compared with the stored database. Any variation would develop error signals, which are processed for correction signals by the system. These signals are then used to control the piezo-electric or high-speed matrix pneumatic valve which regulates the air flow to muscles.



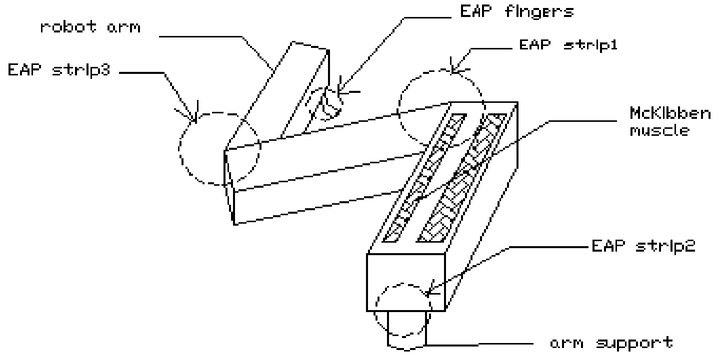


Fig.6 Inserting EAP stripes 1, 2, 3 in the robot arm

X. EAP FINGERS

This paper suggests two or more EAP (IPMC) strips supported by an epoxy/graphic composite holder can act as robotic fingers (lifters and grippers).When the stripes are actuated by passing current, the fingers bend outwards to allow the object in.

The fingers are then de-energized by reducing the voltage. During the training session, the maximum and minimum voltages required for opening and closing respectively is stored in the database. When the object having less/more dimension (than the standard) is gripped, the additional bend produced in the strips would generate current which is sensed and processed for dimensional inaccuracy and the object is rejected. The error signals can also be possessed for correction signals, which control the manufacturing machines.

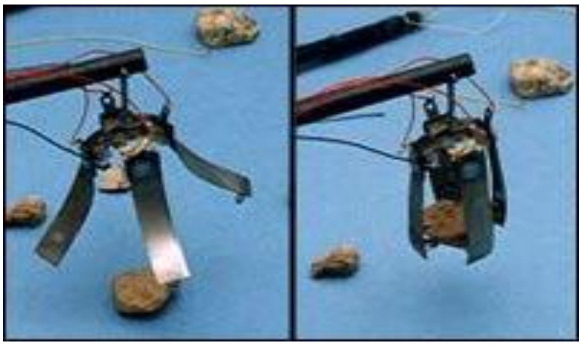


Fig. 7

XI. EAP AS DAMAGE ANALYSER

Since the equation for the stress on an EAP stripe is available, the force with which a robot arm hits any obstacle can be analyzed. Having known the geometry and material properties of the arm, the analysis will infer the replacement or extension of life span of that arm without getting into the depth study of the damage caused which takes time and money. The stress acting on the metal composite can be calculated using the following equation.

$$s = k\,(C0, Ci)\,E^2$$

Where k (C0, Ci) is an electromechanical coefficient and E is the local electric field.

XII. DESIGN OF INTELLIGENT ROBOTIC HAND:

Fig. 8 An EAP actuated hand with fingers

The robotic hand muscles are made up of McKibben muscles while the fingers are supported with EAP strips which can act as sensors as well as actuators and can be used for lifting loads as shown in the diagram 8.

XIII. DESIGN OF MUSCLES FOR HUMAN BEINGS-BIONIC MEN

The McKibben muscles along with the EAP strips can be used to replace damaged muscles for handicaps. Years from now, the McKibben muscles could also conceivably replace damaged human

Fig. 9

These Biorobotic muscles:

- ✓ Reduce the metabolic cost of locomotion.
- ✓ Reduce the level of perceived effort.
- ✓ Improve gait symmetry as measured by kinematics and kinetic techniques.
- ✓ Consume less oxygen and energy than even a natural system.

XIV. CONCLUSION

Electro active polymers are changing the paradigm about the complexity of robots. In the future, we see the potential to emulate the resilience and fracture tolerance of biological muscles, enabling us to builds simple robots that dig and operate cooperatively like ants, soft-land like cats or traverse long distances like a grass hopper. The observed remarkable vibrational characteristics of IPMC composite artificial muscles clearly point to the potential of these muscles for biomimetic applications such as swimming robotic structures, wing flapping flying machines, slithering snakes, heart and circulation assist devices, peristaltic pumps etc..It has recently been established that the tweaking of the chemical composition of IPMC the force capability of these muscles can be greatly improved. IPMCs are the artificial muscles that give space robots animal-like flexibility and manipulation ability based on a simple, light-weight strip of highly flexible plastic that bends and functions similarly to human fingers when electrical voltage is applied to it. Two EAP actuators are used as miniature wipers to clear dust off the viewing windows of optical and infrared science instruments. Studies made by robotics specialists and neurophysiologists suggest that McKibben artificial muscles can be used to develop Biorobotic arms for handicaps. Years from now, the McKibben muscles could also conceivably replace damaged human muscles, leading to partially “bionic men” and “bionic women” of the future.

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