Fuel Cell Muscles

J. Oh, M. E. Kozlov and R. H. Baughman

NanoTech Institute, the University of Texas at Dallas, Richardson, Texas, 75080, USA
Mikhail.Kozlov@utdallas.edu

ABSTRACT

Muscle-like fuel cell actuators that have performance exceeding that of natural muscle, are proposed for conversion of chemical energy in high-energy-density fuels to mechanical energy. The work aims at the development of fuel-powered muscles (actuators) for robotic and automotive applications. Because of more than 30 times higher energy density obtainable for fuels like methanol, compared to that for the most advanced batteries, the major expected benefits are dramatic increase in energy conversion efficiency, work capacity, power performance. In proposed actuator device one electrode acts simultaneously as a fuel cell electrode, and an actuator electrode. A combination of high-surface-area material, such as Pt black, and commercially available shape memory materials (metals and polymers) in the device enables high degree of conversion of the chemical energy of fuels to electrical energy and mechanical energy of elastic deformations.

Keywords: Fuel cell, actuator, shape memory alloy

1 INTRODUCTION

The primary goal of this work was to enable high-performance fuel-powered artificial muscles for use in autonomous robots, aerospace and automotive applications. Also, we intended to improve device power conversion efficiency to exceed the efficiency of conventional hydrogen fuel cells. These advances were achieved by merging the two types of fuel-powered muscles previously reported [1,2], into one active fuel-cell-artificial-muscle device.

2 RESULTS AND DISCUSSION

A fuel-powered muscle-like device needed for biomimetic robotics would be a major accomplishment, if this muscle can operate at volt potentials. Such volt potentials can be provided by a fuel cell and a mechanical force can be generated by a shape memory alloy (SMA) electrode. Two types of the fuel-powered artificial muscles based on this approach have been disclosed [1]; however, the design of a practical device required further research.

2.1 Device Design

We found that properties of the two types of fuel-powered muscles reported in [1] can be merged to provide benefits of both. In the “merged concept” muscle (Figure 1), the fuel (hydrogen) and oxidant (oxygen) are separated by a thin tubular proton exchange membrane (PEM) coated with a catalyst (Pt black) on inside and outside. The catalyst is in contact with an inner, shape memory alloy electrode (SMA-cathode) that may change dimensions upon heating to about 100°C and an outer electrode (Pt wire anode) wrapped around the nafion tubing. The design is enclosed in a plastic housing shaped as outer tubing. Upon purging

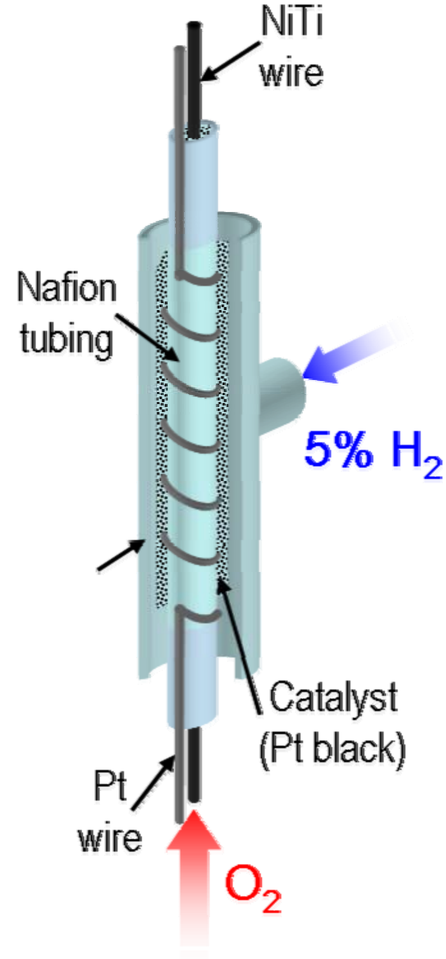

Figure 1. Fuel cell muscle capable of generating electrical and mechanical energy.

the inner tubing with oxygen and the outer tubing with noncombustible mixture of 5% hydrogen in an inert gas, the device is capable of generating voltage and some strain.

2.2 Operation and Performance

As in conventional PEM fuel cell, hydrogen on the anode side diffuses to the anode catalyst where it dissociates into protons and electrons. The protons are conducted through the proton exchange membrane (nafion) to the cathode, but the electrons are forced to travel in an external circuit because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons and protons to form water and heat. Unlike conventional fuel cell, the heat produced in the process of the fuel-cell-muscle operation is consumed to induce dimensional changes in the NiTi electrode. The device can be controlled by hydrogen supply/interruption or shorting of the inner and outer electrodes.

In our experiments the fuel-cell-muscle (FCM) generated voltage of about 0.9 V and power in milli-watt range. Shorting electrodes caused drop in voltage followed by quick voltage recovery after the short was removed.

In contrast to the internal combustion engines, fuel cell efficiency is not limited by Carnot Cycle and can reach about 50%. Because of high power density and relatively low operating temperature, PEM fuel cells are promising power conversion devices for mobile and stationary applications. The need for efficient energy conversion equipment is especially urgent for autonomous systems, robots in particular.

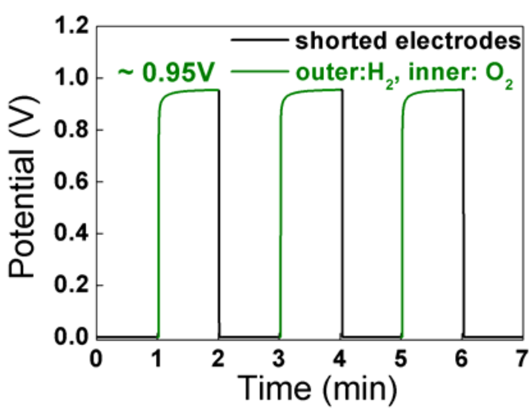

Figure 2. Voltage generation by the fuel cell muscle. Cycles of electrode shorting and voltage recovery are shown.

In proposed device (Figure 1), the PEM fuel cell operation is combined with highly efficient shape memory alloy actuation. The latter enables conversion of heat produced by the fuel cell into mechanical energy of linear displacements needed for many artificial muscle applications. The conversion of the waste heat into mechanical energy substantially improves the overall fuel-cell-muscle efficiency. Moreover the direct mechanical output from FCM eliminates electrical and mechanical loses imposed by the energy transformation chain “electric power source - electric motor - linear displacement system” typical for traditional designs. As a result overall FCM efficiency will exceed the efficiency of conventional hydrogen fuel cells. Also using FCM in autonomous robots as a source of electrical and mechanical energy greatly reduces weight associated with the conventional power generation and transformation systems.

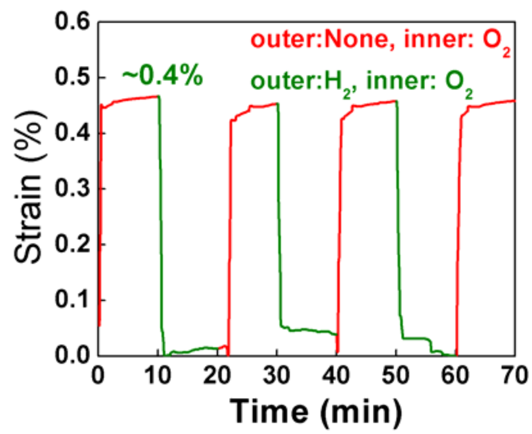

Figure 3. Strain generation by the fuel cell muscle. Cycles of expansion-contraction are controlled by hydrogen supply interruption.

In performed mechanical tests the inner shape memory alloy electrode of FCM was loaded with 150 MPa load. Cycles of expansion-contraction of the electrode were induced by the interruption of hydrogen supply. Reproducible strain generation of about 0.4% was observed (Figure 3). Further improvement in the generated strain required fine tuning SMA transition temperature.

3 CONCLUSIONS

A prototype of fuel cell muscle capable of generating electrical and mechanical energy have been built and successfully tested. Important advantages of proposed device are the scalability of the design for a continuous manufacturing process, and the ability of assembling the devices in arrays in order to provide required electrical and mechanical output.

REFERENCES

[1] V. H. Ebron, Z. Yang, D. J. Seyer, M. Kozlov, J. Oh, H. Xie, J. Razal, J. P. Ferraris, A. G. MacDiarmid, and R. H. Baughman, Fuel powered artificial muscles, Science, 311, 1580-1583 (2006).

[2] D. J. Seyer, M. Kozlov, J. Oh, R. H. Baughman, J. Ferraris, and W. Macaulay, Fuel powered artificial muscles, PCT Int. Appl. 2007.