OTHER APPLICATIONS (ACTUATOR, HYDROGEN PURIFICATION, AND ISOTOPE SEPARATION)

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Summary

The useful function of metal hydride is very simple: that of absorbing hydrogen. There is an exothermic reaction when absorbing hydrogen. However, many applications are being considered for metal hydride.

Recently, hydrogen has attracted considerable attention as a clean energy. It will be possible to manufacture hydrogen and metal hydride at low cost, and the durability and/or reliability of metal hydrides will be improved. In the future, metal hydride will be employed for many industrial and household uses.

1. Actuator

1.1 Principle of Energy Conversion

Thermal energy can be converted to mechanical energy using the reversible reaction of metal hydride with gaseous hydrogen. By heating the metal hydride, hydrogen equilibrium pressure increases and hydrogen is desorbed, whereas by cooling the metal hydride, hydrogen equilibrium pressure decreases and hydrogen is absorbed. In this way, it is possible to utilize the mechanical energy of the hydrogen gas pressure change by manipulating heat.

1.2 Characteristics of Metal Hydride Actuator

A metal hydride actuator has several advantages over other actuators that use power sources such as an electric motor, hydraulic pump, or air compressor:

(a) Metal hydride absorbs so much hydrogen gas that high mechanical energy can be obtained and consequently the unit can be made compact and lightweight. Output per weight of an actuator unit is large, compared to that of existing actuators.
(b) The structure of the actuator becomes simple.
(c) The heat drive mechanism does not produce any noise or vibration.
(d) The drive function using hydrogen absorption/desorption has a buffering effect and prevents extreme power surges or shock loads.

1.3 Demonstrating Equipment

Figure 1 shows a schematic diagram of the metal hydride actuator. Although any heat source is available for driving an actuator, a Peltier device is most suitable. A Peltier device can both heat and cool by changing the polarity of direct current, so the temperature control of the metal hydride is easier.

When metal hydride is heated, hydrogen gas is released and the piston is pushed up. When metal hydride is cooled, the hydrogen gas is absorbed and internal pressure decreases and the piston goes down.

A machine demonstrating the use of a metal hydride actuator is shown in Figure 2. The mass of the applied metal hydride is 12 g, and 50 kg of weight is pushed up with a stroke of 50 mm. The metal hydride employed was CaMmNiAl. The metal hydride powder was coated with Cu by chemical plating and solidified by compression in order to improve the thermal conductivity.

The Peltier device contacted the solidified meal hydride directly and was set in an aluminum container, which had the cooling fins to efficiently remove the heat produced in the Peltier device. Figure 3 shows a temperature-pressure response diagram. By heating for about 7 s, the hydrogen gas pressure rose from 0.3 MPa to 1 MPa. The time delay of the hydrogen gas pressure change to the metal hydride’s temperature change was as small as from 0.1 s to 0.2 s.

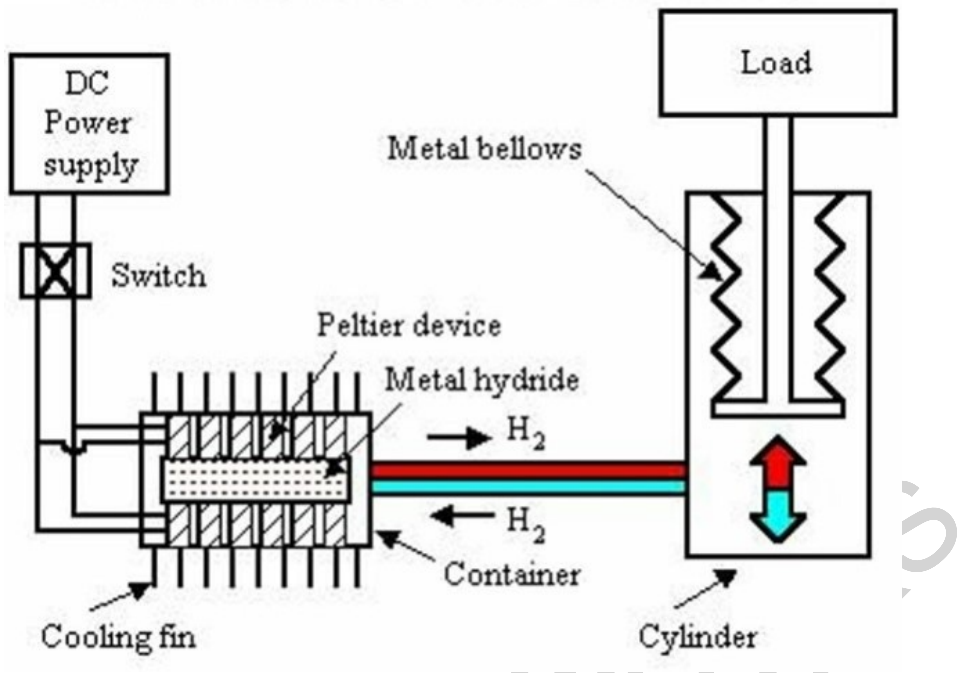

Figure 1. Schematic Diagram of a Metal Hydride Actuator

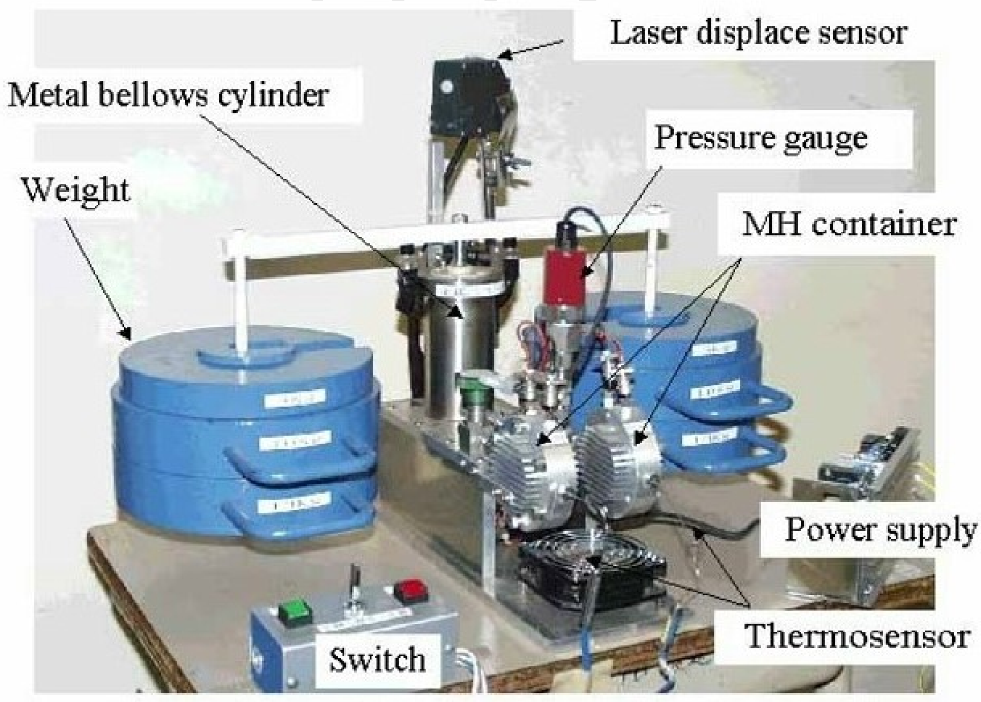

Figure 2. Machine demonstrating the use of a metal hydride actuator.

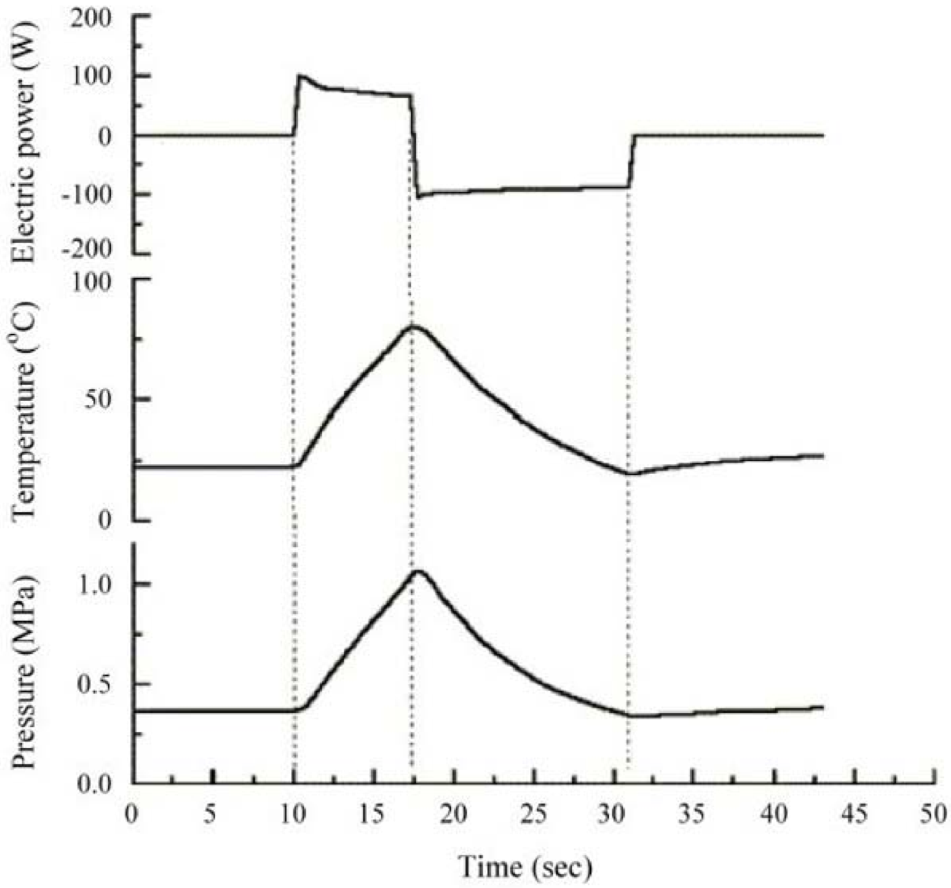

Figure 3. Temperature Pressure response diagram

1.4 Compliance of Metal Hydride Actuator

The actuator is driven by heat, so the actuator efficiency (η = power output/consumed electric power) itself is less than that of an electric actuator, directly using electric power.

However, its power output per weight is large and it is suitable for use as a human-sized actuator for medical and rehabilitation use with the features of being noiseless and smooth acting. Another characteristic of the metal hydride actuator is its compliance with the human body.

Figure 4 shows a comparison of compliance properties between the human elbow and the metal hydride actuator. The vertical position change with an incremental load of 500 g was measured by laser displacement measuring equipment.

It can be derived that the displacement-time pattern of the metal hydride actuator is very similar to that of the elbow joint. Thus, the metal hydride actuator can be used in various rehabilitation applications requiring a human-like response.

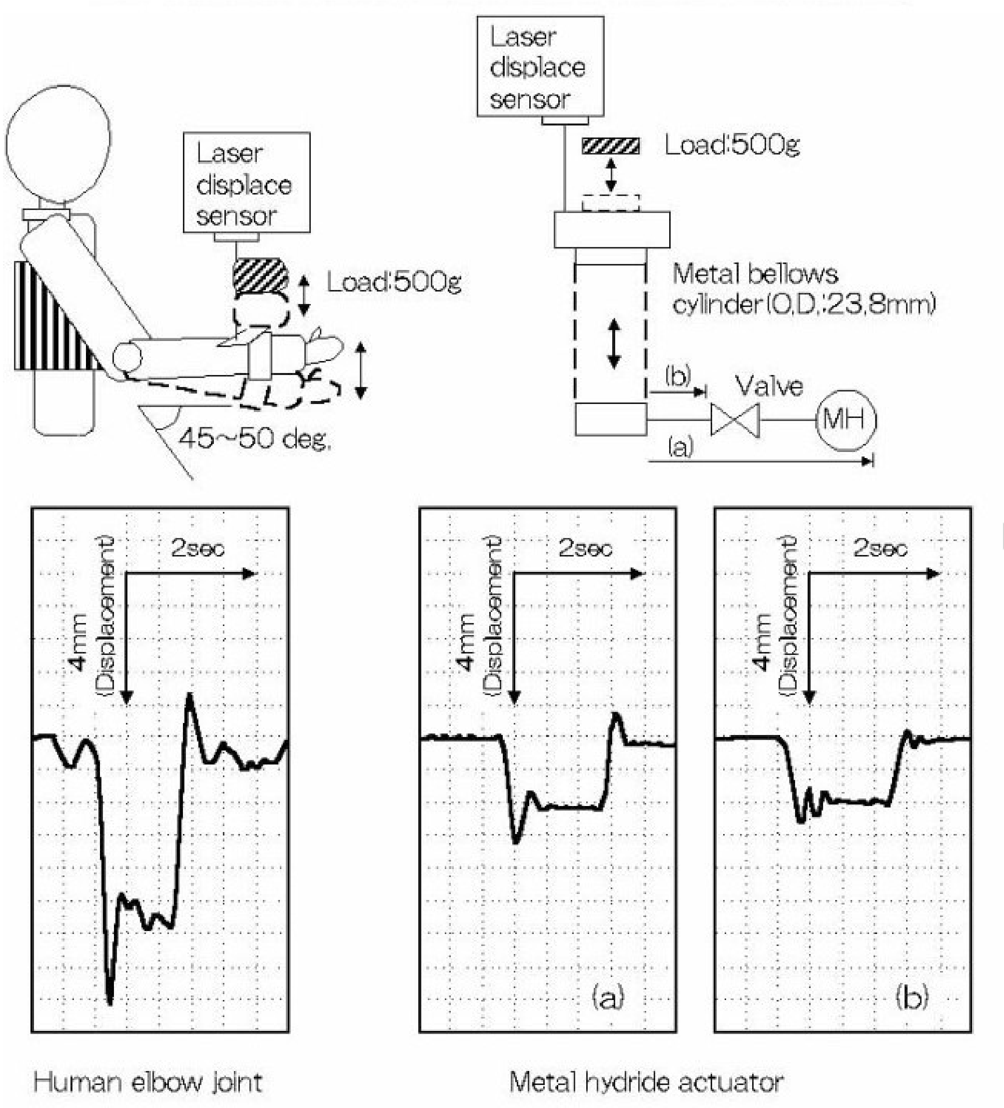

Figure 4. Comparison of compliance of the human elbow joint and metal hydride actuator.

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Bibliography

Kabutomori T., Wakisaka T., Tsuchiya K., and Kawamura H. (1998). Improvement of hydriding properties of Zr_1Ni_1 alloy by adding third transition metals for tritium recovery. *Journal of Nuclear Materials*, **258–263**, 481–487. [Effect of substitution of Ni by transition metals on equilibrium hydrogen pressure and pulverizing property.]

Libowitz G. G. (1965). *The Solid-state Chemistry of Binary Metal Hydrides*, pp. 50–90. W.A. Benjamine, Inc., New York. [Explanation of isotope effect of hydrogen.]

Massalski T. B. (1990). *Binary Alloy Phase Diagram, Second Edition*, ASM International, pp. 1515, 2073. [Phase diagram of V-H and V-D.]

Sandock G. D. and Goodell P. D. (1980). *Surface poisoning of $LaNi_5$, FeTi, and (Fe, Mn)Ti by O_2, CO and H_2O*. *Journal of Less-Common Metals*, **73**, 161–168. [Effect of impurity gas element on the hydrogen absorption.]

Sheridan III J. J., Eisenberg F. G., Greskovich E. J., Sandrock G. D., and Huston E. L. (1983). Hydrogen separation from mixed gas streams using reversible metal hydride. *Journal of Less-Common Metals*, **89**, 447–445. [Separation of hydrogen from ammonia feed gas.]

Takeda H., Satou J., Nishimura Y., Kogi T., Fujita T., and Wakisaka Y. (1993). *JSME-ASME ICOPE-93*, **1**, 339–344. [Introduction of hydrogen purification system and application to generator.]

Tanabe T., Yamamoto T., and Imoto S. (1983). Recovery of hydrogen isotopes using uranium bed. *Journal of Less-Common Metals*, **89**, 393–398. [Separation and purification of hydrogen isotope using uranium.]

Wakisaka Y., Muro M., Kabutomori T., Takeda, Shimizu S., Ino S., and Ifukube T. (1997). Application of hydrogen absorbing alloys to medical and rehabilitation equipment. *IEEE Transactions on Rehabilitation Engineering*, **5**(2), 148–157. [Characteristics of metal hydride actuator and its applications.]

Biographical Sketches

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Toshiki Kabutomori was born 23 April 1954, in Japan; he received his education from the Department of Applied Physics, Hokkaido University with M.Sc. degree in solid state; had been engaged in research and development in Muroran Research Laboratory of the Japan Steel Works, Ltd.; received a doctor’s degree from Hokkaido University in material engineering; is the Committee Staff of The Japan Institute of Metals (1998–); has published over 30 papers and expositions on the metal hydride and their application systems and is manager of Hydrogen Energy Center headquarters of JSW.

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