Soft and Noiseless Actuator Technology Using Metal Hydride Alloys to Support Personal Physical Activity

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1. Introduction

In an aging society with a declining birth rate, there is an increased need for home-based rehabilitation systems and human-centered robots for healthcare services. In particular, elderly patients who are required to lie in a reclined position due to stroke or bone fracture may suffer from disuse syndromes, such as bedsores, joint contracture and muscular atrophy (Bortz, 1984). It is difficult for these elderly patients to actively exercise for preventive rehabilitation. Thus, to manage these disuse syndromes, rehabilitation equipment and assistive devices, such as bedside apparatuses for the continuous exercise of joints and power assistance devices for standing and transfer hoists, must be developed. This equipment demands powerful and soft actuators in addition to human muscles (Bicchi & Tonietti, 2004).

However, there are currently no commercially available actuators with the desired characteristics, that is, human compatibility, softness (for safety), noiselessness and a high power-to-weight ratio. These technical requirements present a challenge to the development of rehabilitation and personal autonomy systems. To solve this challenge, various types of artificial muscle-like actuators, such as pneumatic muscle actuators, shape memory alloy actuators and polymer actuators, have been actively studied by material scientists and biomedical engineers. However, satisfactory artificial muscle technologies for rehabilitation or healthcare devices have not yet been realized.

In order to fulfill the above demands for the design of a human-friendly actuator, we originally developed several actuator systems using metal hydride (MH) materials as a flexible mechanical power source. MH actuators can, even in small and light packages, produce a powerful and soft force, because MH materials can store a large amount of hydrogen gas by controlling heat energy; this energy is about a thousand times larger than the volume of the MH alloy itself. Moreover, MH actuators have human-compatible traits, such as softness and noiseless motion, which are derived from the reversible thermo-chemical reaction of metal hydrides. An additional potential merit is that hydrogen is a

clean energy carrier candidate because it does not adversely affect the environment (Sakintuna et. al., 2007).

The purpose of this chapter is threefold: first, to overview the properties of MH materials for MH actuators; second, to describe the structure of MH actuators and a performance upgrade that installed a soft bellows made of a laminate film; and third, to show several applications of MH actuators in rehabilitation and assistive technologies that require a continuous passive motion (CPM) machine for joint rehabilitation and a power assistance system for people with restricted mobility.

Finally, we propose future work related to the further improvement of MH actuators to obtain more suitable devices in rehabilitation engineering and assistive technology.

2. Metal hydride alloys

MH alloys have the particular ability of storing a large amount of hydrogen, which can be approximately 1,000 times as large as the volume of the alloy itself. One of the conventional MH materials is a magnesium-nickel alloy (Mg_2Ni), which was discovered in 1968 at the Brookhaven National Laboratory in the USA (Wiswall & Reilily, 1974) and was the first practical MH alloy. Shortly thereafter, in 1970, a lanthanum-nickel alloy ($LaNi_5$) was discovered at the Philips Research Laboratories in the Netherlands (Van Mal et al., 1974). These successive discoveries triggered research on various MH alloys and opened new possibilities for their industrial development.

Moving from historical to scientific background information, metal hydrides (MH_x) are created by a chemical reaction between an alloyed metal (M) and hydrogen gas (H_2), as in the following thermochemical equation:

$$M + \frac{x}{2}H_2 \leftrightarrow MH_x + Q \qquad (1)$$

where Q is the heat of formation, and thus, Q > 0 J/mol for H_2. If this reaction proceeds at a fixed temperature, then a hydrogen pressure will advance up to an equilibrium pressure, which is called the plateau pressure. The PCT diagram (P: hydrogen pressure, C: hydrogen content and T: temperature) shows the basic characteristics of an MH alloy. As demonstrated in the PCT diagram in Fig. 1, controlling the temperature of an MH alloy can successfully change its plateau pressure. An MH alloy that absorbs hydrogen well for actuator applications would have a flat and wide plateau area in the PCT diagram. Moreover, the hydrogen equilibrium pressure is given as a function of the temperature of an MH alloy by the van't Hoff equation. Consequently, the logarithmic equilibrium pressure is proportional to the inverse function of the temperature, as shown in Fig. 2.

Furthermore, MH alloys are not combustible, so they are safe as hydrogen storage materials for fuel cells in road vehicles and other various mobile applications (Schlapbach & Züttel, 2001). Thus, we have determined that MH alloys should be used as the power source of actuation for assistive technology.
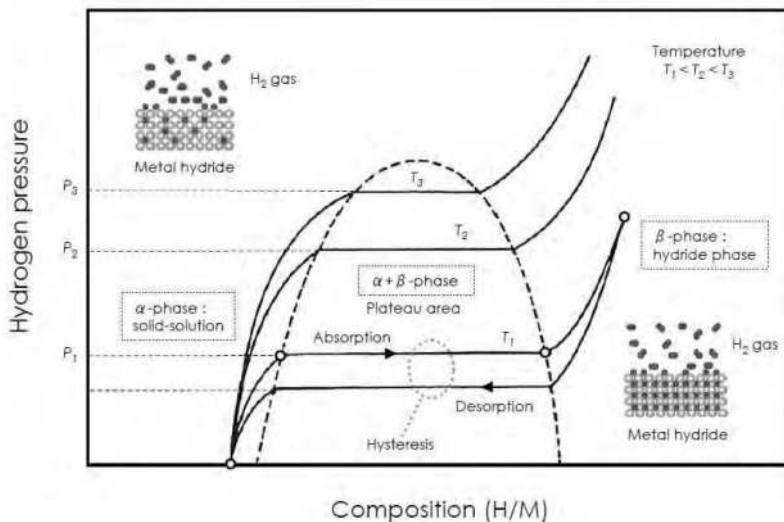
Fig. 1. Pressure-composition-temperature (PCT) diagram of a metal hydride (MH) alloy under hydrogenation.
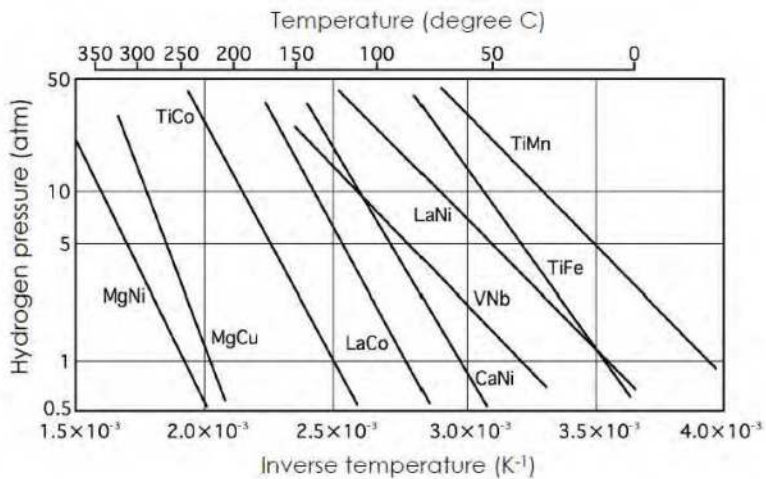

Fig. 2. Relationship between the equilibrium hydrogen pressure and the temperature in various MH alloys.
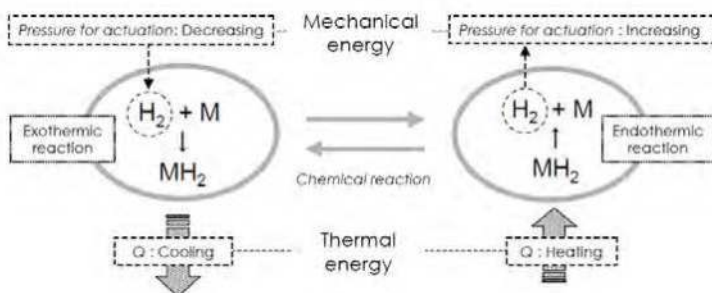
Fig. 3. Schematic illustration of actuation principles based on an energy conversion mechanism between heat and hydrogen pressure in an MH actuator.
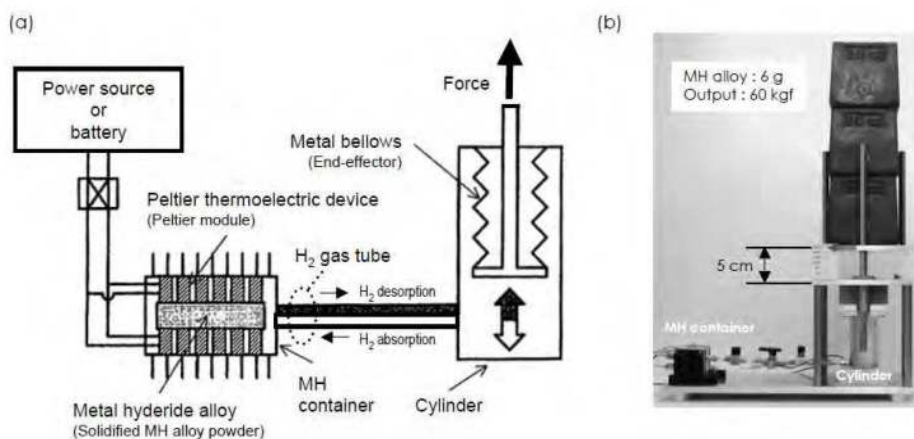

Fig. 4. (a) Basic structure of an MH actuator and (b) the assembled MH actuator using a metal bellows and a Peltier thermoelectric device.

3. Metal hydride actuators

3.1 Basic structure and characteristics

MH alloy actuators can not only store a large amount of hydrogen gas efficiently, but they also desorb hydrogen gas by controlling the temperature of the MH alloy. If this reversible chemical reaction is carried out in a hermetically closed container system, the heat energy applied to the MH alloy is converted into mechanical energy via an equilibrium pressure change in the container system, as shown in Fig. 3. The basic structure of an MH actuator system is shown in Fig. 4 (a). An MH actuator performs by using the hydrogen pressure generated by the MH alloy through heat energy, which is controlled by a device such as an electrically heated wire, a Peltier module (a thermoelectric heating/cooling device) or a solar collector.

MH actuators are composed of a solidified MH alloy powder, Peltier modules to electrically control the temperature of the MH alloy, a temperature sensor, a container for these elements, and an end effecter to transfer the hydrogen pressure into a driving force (Sasaki et al., 1986; Ino et al., 1992).

For example, the MH actuator system shown in Fig. 4 (b) has a 6-g MH alloy and a 36-mm-diameter metal bellows. This actuator can smoothly lift a 60-kg weight without any noise. The power-to-weight ratio of the MH actuator is also very high compared to those of conventional actuators such as electric motors and pneumatic actuators. However, a few weaknesses of MH actuators are their low energy efficiency and slow speed when Peltier modules are used as the thermal controller. However, the heat drive mechanism of the MH actuator does not produce any noise or vibration. In addition, the reversible hydrogen absorption and desorption of the MH alloy also has a buffering effect to cushion a human body and prevent mechanical overload. Therefore, MH actuators are suitable for use as a human-sized flexible actuator that can be applied to soft and noiseless rehabilitation systems and assistive devices.

3.2 The treatment of MH alloys

To improve the moving speed of MH actuators, MH alloy powders are chemical plated with copper, which conducts heat well, and are pressed during a solidification treatment. The MH alloy powders are coated with a 1.0-μm-thick layer of Cu (20 wt%) and solidified into a plate-like compact MH alloy by pressing them to a 3.0-mm thickness. After both treatments, a temperature control device, such as a Peltier, module is directly attached to the compact MH alloy.

Therefore, the heat conductivity of a Cu-coated MH alloy is approximately 50 times that of a bare MH alloy (Wakisaka et al., 1997). It has been found that the addition of copper yields a clear increase in the hydrogen absorption speed.

3.3 The composition of MH alloys

The $LaNi_5$ alloy is more suitable for use in an MH actuator than other compositions of MH alloys because the region of the plateau pressure in its PCT diagram is adequately flat and broad. Moreover, the hysteresis effect that is shown in the PCT diagram, which is inconvenient for controlling an MH actuator, is relatively small for the $LaNi_5$ alloy.

When MH actuators are used in a living environment, the response speed of an MH actuator depends on the initial setting value of the plateau pressure of the MH alloy at room temperature. Thus, an adjustment of the plateau pressure from the PCT diagram is important to achieve the desired mechanical behavior for each application.

The relationship between the hydrogen equilibrium pressure and the temperature is adjustable by changing the alloy composition with the addition of cobalt and manganese. We have selected two different $LaNi_5$ alloys for a comparative discussion. One is $LaNi_{4.45}Co_{0.5}Mn_{0.05}$ (MH-P), which is designed to have a plateau pressure at room temperature (20 °C) of 0.1 MPa. The other is $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ (MH-N), which is designed to have a plateau pressure at room temperature of 0.05 MPa lower than atmospheric pressure. The PCT diagrams of these MH alloys are shown in Fig. 5.
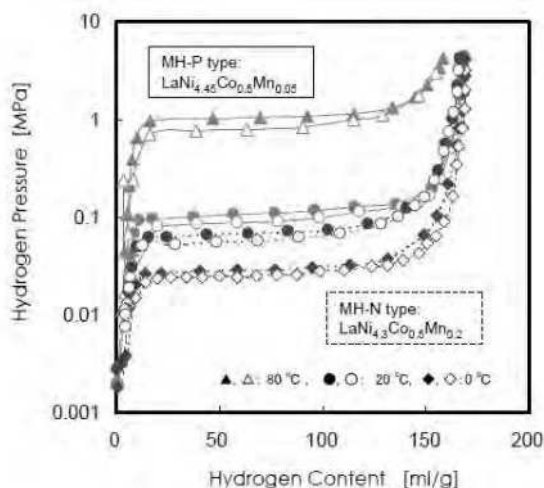
Fig. 5. PCT diagrams of the MH-P alloy (solid line) and the MH-N alloy (dotted line).
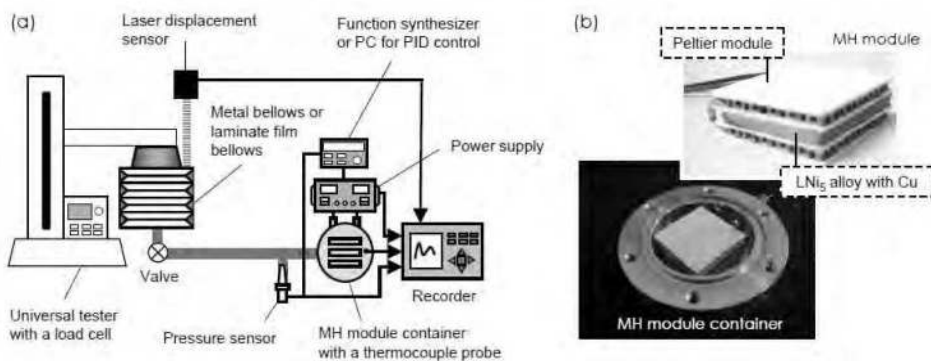

Fig. 6. (a) Experimental setup for the performance testing of the MH actuator and
(b) photograph of the MH module and its container.

The experimental setup to measure the mechanical behavior of the LaNi$_5$ alloys (MH-P
and MH-N) for the MH actuator is shown in Fig. 6. The LaNi$_5$ alloys were heated or cooled
by the Peltier modules that were connected to an electric power supply.

The up-down motion of the MH actuator that was installed with the MH-P alloy or the MH-
N alloy is shown in Fig. 7. When the weight of the load was 5 kg, the response speed of the
MH-P alloy in the heating phase (+5 V) was approximately twice as fast as that of the MH-N
alloy. In contrast, the response speed of the MH-P alloy in a cooling phase (-5 V) was
approximately twice as slow as that of the MH-P alloy. When the weight of the load was 0
kg, the response speed of the MH-P alloy in a heating phase was similar to that of the MH-N
alloy. However, the response speed of the MH-P alloy in a cooling phase was approximately

five times slower than that of the MH-N alloy. It has been found that a plateau pressure from the PCT diagram that is lower than atmospheric pressure can improve the slow shrinking (downward) speed of the cooling phase of an MH actuator (Ino et al., 2009a).
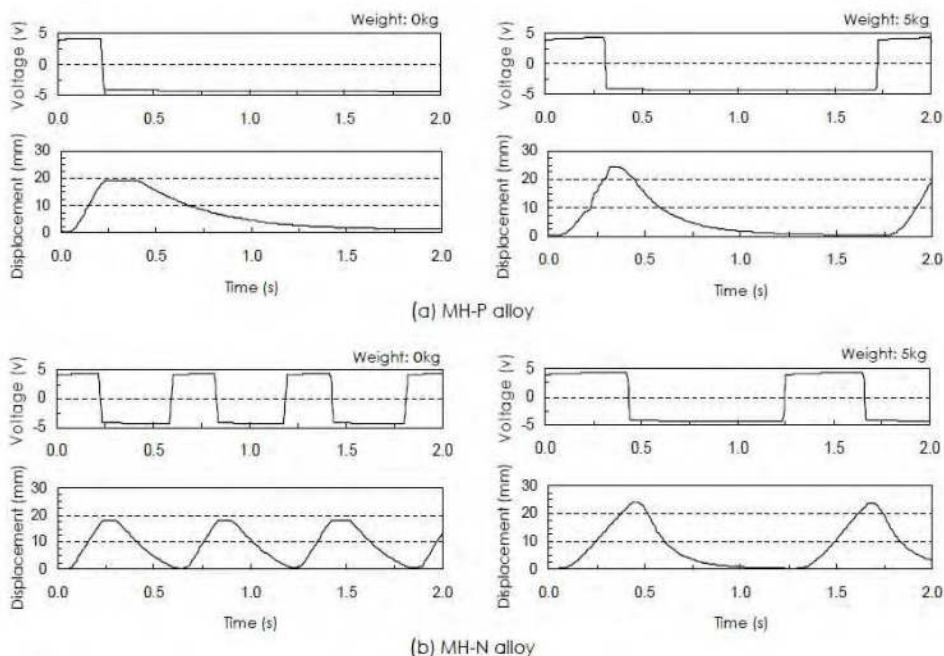

Fig. 7. Time traces of the displacement of the metal bellows supplying a rectangular input voltage to the Peltier elements in the MH module.

3.4 Laminate film bellows

To maintain impermeability against the hydrogen gas from the MH alloy, a metal bellows has been used as the end-effector of some conventional MH actuators. However, a metal bellows is made of stainless steel and is not very suitable, in terms of weight, softness and elongation rate, for rehabilitation equipment and assistive devices. For safety and comfortable usage, rehabilitation equipment and assistive devices must be light and soft compared to the human body. Therefore, instead of the metal bellows, we developed a soft and light bellows element made of a trilayer laminate film of polyethylene-aluminum-polyester (Ino et al., 2009b).

The weight of this laminate film bellows was about 20 times lighter than that of the metal bellows, and the elongation range of the laminate film bellows was approximately 30 times as large as that of the metal bellows. These mechanical properties of the laminate film are very useful in designing a soft MH actuator.

It is well known that a polymer-metal laminate film is a strong gas barrier to oxygen, water vapor and other substances in the packaging industry (Schrenk & Alfrey Jr., 1969). However, no experimental data exist about the hydrogen impermeability of laminate films and their adhesion area by thermo-compression bonding. Thus, the hydrogen impermeability of the laminate film bellows was tested by temporally monitoring the inner pressure and the displacement of a prototyped laminate film bellows that was filled with pure hydrogen gas at 20 °C. The amount of inner pressure and the displacement of the laminate film bellows were maintained over 250 hours, and it was found that the laminate film bellows is capable of maintaining a hydrogen gas barrier for at least ten days.
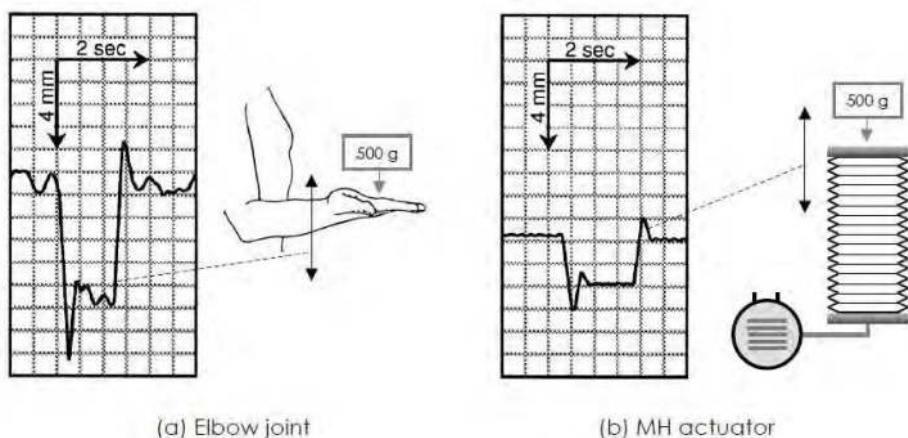

Fig. 8. Dynamic response of (a) the human elbow joint and (b) the metal bellows of the MH actuator under step loading.

3.5 The elasticity of MH actuators

The dynamic elasticity of an MH actuator with a metal bellows and the elbow joint of a healthy subject were compared through the step response by dropping a 500-g weight. Both displacement patterns of the step response were very similar to each other, as shown in Fig. 8. Thus, this compliant feature of MH actuators offers a solution for physical therapy and assistive technology applications.

The elasticity of an MH actuator adopting the laminate film bellows was also measured by a universal tester. The relationship between the stiffness and the strain of the laminate film bellows when the parameters were the initial inner parameters of the MH actuator is shown in Fig. 9. The stiffness increased with increasing strain on the laminate film bellows, and the rate of the stiffness change decreased with the increasing initial inner pressure of the soft MH actuator.

Moreover, the range of the variable stiffness of soft MH actuators with laminate film bellows is smaller than that of human muscle at full activation (approximately 100-200 N/mm; Cook & McDonagh, 1996). Thus, MH actuators are suitable for wearable force display systems,

such as rehabilitation equipment and power assist devices, from the viewpoint of mechanical impedance matching and safety in passive elasticity to reduce any potential danger to the human body.
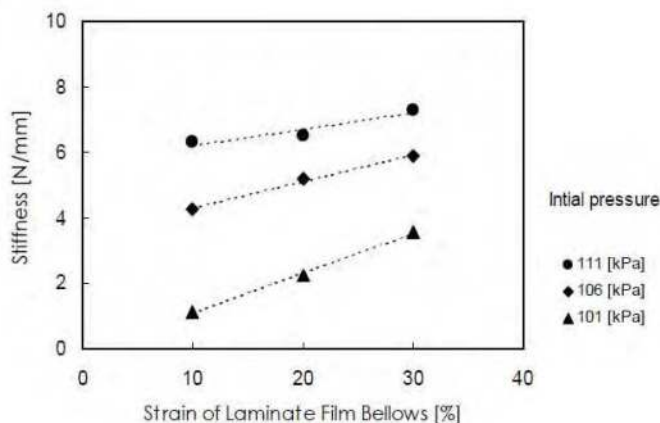

Fig. 9. Stiffness profiles of the MH actuator with the laminate film bellows.

4. CPM machine for joint rehabilitation

4.1 Background

Home rehabilitation devices for elderly people and stroke or joint injured patients are required in an aging society. Some healthcare techniques for joint rehabilitation include manual therapy and range of motion (ROM) exercises using a continuous passive motion (CPM) machine (Salter et al., 1984). The therapeutic effects of CPM, which are the prevention of joint contracture and muscular atrophy, and the increase of ROM after joint injury, fracture and immobilization, have been clinically shown in previous studies (Michlovitz et al., 2004). However, current CPM machines have some problems, such as a lack of the flexibility inherent to the human body, a bulky size for home use and the noise that is emitted from an installed electric motor and gears. These problems preclude ease and safety of use of the CPM machine at home and at the bedside. Hence, we have designed a compact MH actuator and prototyped a CPM device using it.

4.2 The design of a hand and an elbow CPM machine

The prototyped hand CPM machine for a finger joint is shown in Fig. 10. This hand CPM machine was installed with a compact push-pull (double-acting) MH actuator that includes a small metal bellows covered with a stainless steel sleeve and a pair of MH containers with a 3-g MH alloy and a Peltier module. The output force and stroke of the compact push-pull MH actuator were approximately 100 N and 20 mm at maximum, respectively. The weight of the MH actuator was approximately 250 g. The hand CPM machine using this MH actuator was much lighter than conventional CPM machines, which are built up with an electric motor and gears.

To evaluate the dynamic behavior of the hand CPM machine, the MH actuator was given a voltage input to the Peltier module, and the responses were measured. For example, Fig. 11 shows the displacement pattern of the bellows cylinder by a rectangular voltage input applied to the MH module. It was observed that the motion of the push-pull MH actuator was noiseless and smooth within the allowable behavior for joint rehabilitation that was required by a delicate ROM exercise.

We also designed an elbow CPM machine using a pair of metal or laminate film bellows as shown in Fig. 12. In particular, the antagonistic mechanism composed of the double MH actuators using the laminate film bellows allows for compliant action of the human elbow joint and cutaneous surface. This antagonistic mechanism also takes advantage of the feature that its stiffness and position can easily be controlled based on the sum and difference of the inner pressure of both laminate film bellows, respectively (Ino & Sato, 2011).
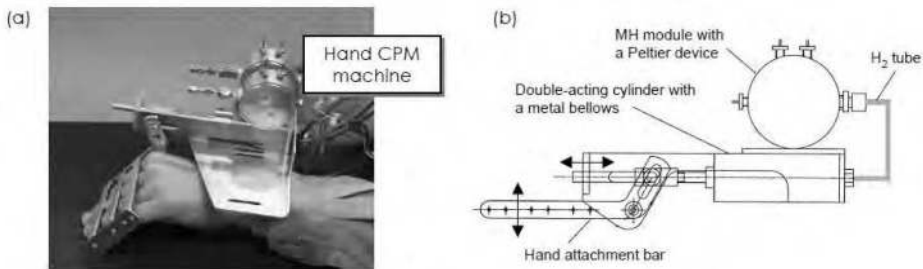

Fig. 10. (a) Photograph of a prototype hand CPM machine for a finger joint and (b) structural drawing of its double-acting MH actuator.
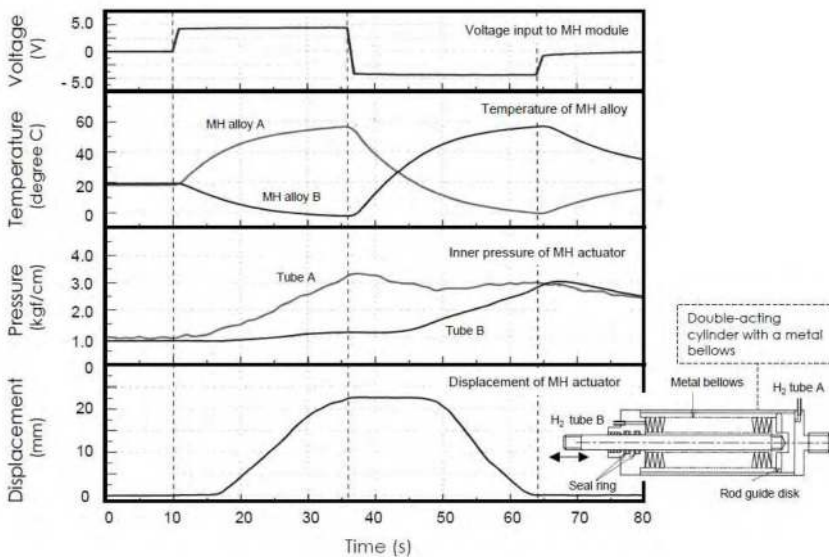

Fig. 11. Dynamic behavior of the compact double-acting MH actuator installed in the hand CPM machine.
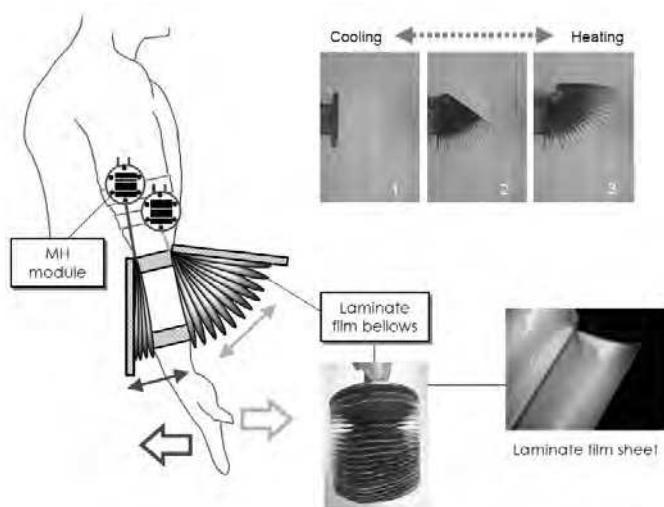
Fig. 12. Design image of an elbow CPM machine using a pair of laminate film bellows and MH modules.

5. Toe exercise system for pressure ulcer prevention

5.1 Background

The pathogenic mechanism behind pressure ulcers observed with bedsores is assumed to be related to defective blood circulation within the subcutaneous tissue (Jan et al., 2006). It is likely that the facilitation of blood circulation in sites that commonly develop pressure ulcers can prevent bedsores. Particularly, the passive exercise of toes may improve the blood circulation in convex portions of the lower limb, such as the lateral and medial malleolus and the first metatarsal head, and heal common pressure ulcers. If a passive exercise system can be applied to the toes and feet, then it is likely possible to reduce the volume of the system and provide a low physical burden to elderly and disabled people who require long-term bed rest.

To assess the usefulness of the passive exercise of toes for the purpose of preventing disuse syndromes, we performed measurements of the subcutaneous blood flow at a common site of pressure ulcers during passive toe exercises. We then developed a prototype motion-assist system for toe exercises using a fan-shaped MH actuator to easily fit various foot forms (Ino et al., 2010).

5.2 The effect of passive toe exercise

The subjects' toe joints were alternately bent and stretched within a specified ROM using a thermoplastic attachment connected to the shaft of a DC servomotor, as shown in Fig. 13. This toe exercise motion induced by the servomotors lasted two minutes with a 6-s cycle time and was initiated after keeping the subjects in a supine position at rest for 10 minutes. Subcutaneous blood flow was measured at the base of first toe and at the lateral malleolus

using a laser blood flow meter. The blood flow rate data were acquired for one minute before exercise (pre-exercise), two minutes during exercise (mid-exercise), and one minute after exercise (post-exercise) in each trial. Ten healthy subjects (20 to 80 years of age) participated in this experiment after giving informed consent.

From the experimental results, the blood flow rate at the base of the first toe during the exercise was significantly higher ($P < 0.02$, Friedman test) than before the exercise, as shown in Fig. 14 (a). Similarly, the blood flow rate at the lateral malleolus exhibited the same trend ($P < 0.02$, Friedman test), as shown in Fig. 14 (b).

The subcutaneous blood flow at common pressure-ulcer sites on the foot was increased in spite of a lack of active exercise (self-exercise). One of the factors contributing to increased blood flow during passive toe exercise is assumed to be the mechanical deformation of capillaries in the subcutaneous tissue, due to the extension and flexion of the toe joints. In addition, the effects of the mechanical muscle pump may be due to the cyclical, passive motion of the toe joints.

These results suggest that the continuous passive exercise of toe joints using some type of actuation device may be a valuable healthcare apparatus to help prevent disuse syndromes such as pressure ulcers and soft tissue contracture induced by ischemia.
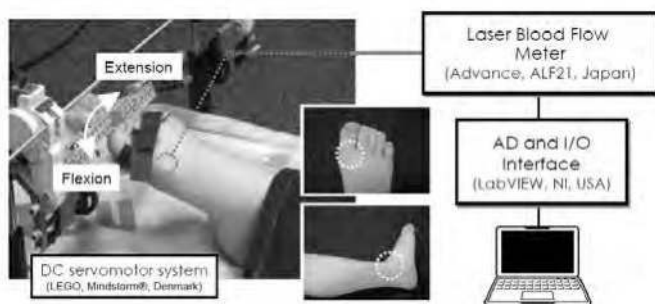

Fig. 13. Experimental setup for the continuous passive exercise of toe joints using a DC servomotor and the measuring site of subcutaneous blood flow in the foot.
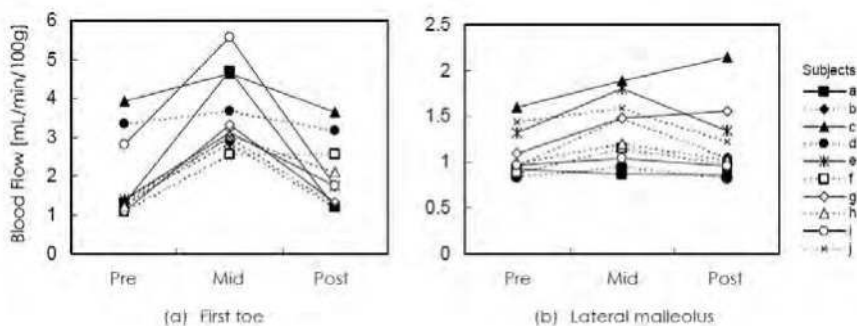

Fig. 14. Subcutaneous blood flow rate of pre-, mid-, and post-passive exercise at the following: (a) the base of the first toe and (b) the lateral malleolus.

5.3 Range of motion and force

The target force and angular ROM required to design the passive toe exercise apparatus were measured in a clinical physical therapy practice, as shown in Fig. 15.

The results of both the maximum applied force and the ROM of the metaphalangeal joint of the toes at flexion and extension during the manual passive exercise by a skilled physical therapist are shown in Fig. 16. The mean maximum force at extension was approximately 35% higher than that at flexion. Meanwhile, the mean maximum ROM at extension was approximately 20% lower than that at flexion. The measured values of the maximum force (flexion: 7-14 N, extension: 9-20 N) and the maximum ROM (flexion: 24-47 deg., extension: 16-40 deg.) also varied with each subject.

It is suggested that passive exercise systems must be adjustable with regards to the output force and the working angle to account for the physical variations of individual patients.
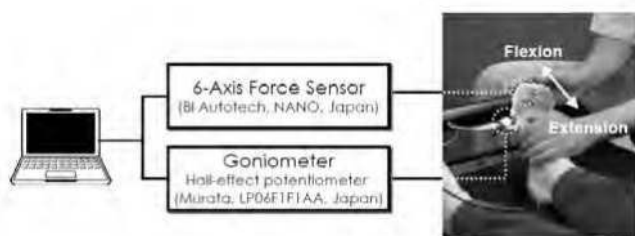

Fig. 15. Experimental setup for measuring the force and angular ROM required to design the passive toe exercise apparatus.
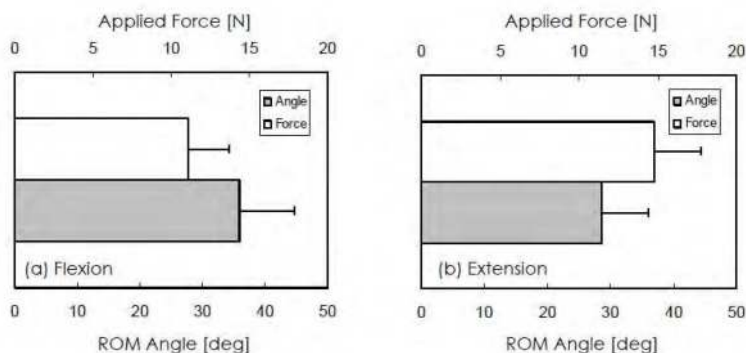

Fig. 16. Maximum force and angle applied manually to toe joints for passive ROM exercise by a physical therapist.

5.4 The design of a toe exercise system

A prototype of the passive exercise system for foot and toe pressure ulcer prevention consisted of two fan-shaped MH actuators with a thermoelectric control device and laminate

film bellows, several pressure sensors, a bipolar power supply and a personal computer with a PID controller. A photograph and a block diagram of the prototype apparatus are shown in Fig. 17.

The extension and flexion motion of the toe joints was derived from a pair of laminate film bellows that spread out in a sector form in a plastic case. The motion of the toes in the passive exercise system was gentle and slow enough to facilitate subcutaneous blood circulation. During the operation of the apparatus, the various subjects' toes, of variable size and shape, always fit into the space between the antagonistic laminate film bellows. The mechanical features of the actuator and the toe exercise system are shown in Table 1.

The motion patterns for the joint exercises were produced by the regulation of the pressure combination of both MH actuators. Linear control over the flexion and the extension angle of the toes was obtained by altering the difference between the inner pressures of each laminate film bellows or a pair of the MH actuators. The stiffness of the movable part inserted between both of the laminate film bellows was determined by evaluating the sum of the inner pressures of both bellows. Thus, both the angle and the stiffness of the movable apparatus were easily controlled independently.
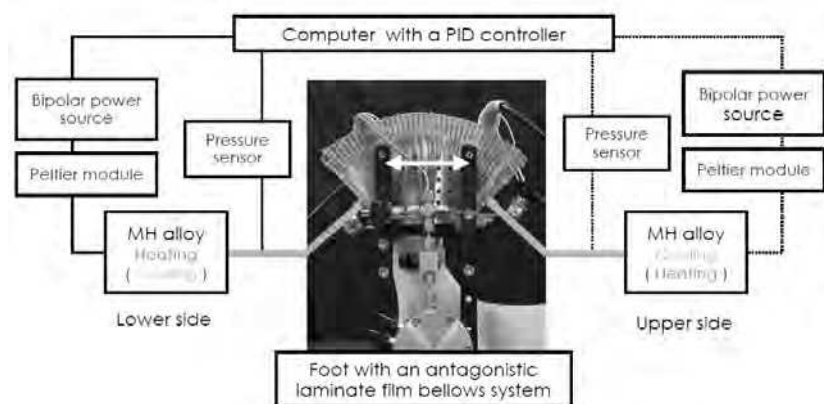

Fig. 17. Block diagram and photograph of the prototyped passive toe exercise apparatus.

	MH actuator with laminate film bellows	Passive toe exercise apparatus
Size	75 mm dia, 23 mm thick / MH container 100 mm dia, 10 mm thick / Laminate film bellows	120 mm x 210 mm x 120 mm
Weight	300 g / MH container 40 g / Laminate film bellows	2 kg
Force (Pressure)	< 100 N (0.03 MPa gauge)	< 30 N (0.1 MPa gauge)
Stiffness	< 10 N/mm	< 10 N/mm
Working range	0-200 mm	± 45 deg

Table 1. Mechanical features of the soft MH actuator using the laminate film bellows and the passive toe exercise apparatus.

6. Transfer assistance system for lower limb disability

6.1 Background

Physically vulnerable people who find it difficult to stand up by themselves due to some illness, injury or age, need help moving between a wheelchair, a bed, a toilet seat, a bathtub or a car seat. Transfer assistance systems for these people are required to be sufficiently safe and powerful to lift their body. In the assisted transfer motion, a physical and mental load exists between the vulnerable people and their helpers at any time. However, securing mobility through transfer assistance tools facilitates personal autonomy in the daily lives of disabled people. Thus, we developed a transfer hoist, which was installed with a high-powered MH actuator, based on an ergonomic motion analysis of transfer behaviors (Tsuruga et al., 2001).

6.2 The analysis of transfer motion

The transfer motion of subjects was simultaneously measured by a three-dimensional motion capture system including three 60-Hz infrared cameras, a force plate, an electromyogram (EMG) telemeter and a personal computer. The subjects were five young men between 20 and 30 years of age and three elderly men of approximately 60 years of age, and they participated in this experiment after giving informed consent.

The muscle activity of the subject's lower limb and the center of pressure (COP) amplitude while standing from a 50-cm height seat are shown in Fig. 18. The standard height of a wheelchair seat is 50 cm in Japan. As a result, the activity of the anterior tibial muscle in the leg was great at 60 degrees and plateaued from 70 to 90 degrees as a function of the ankle joint angle. Meanwhile, the activity of the rectus femoris muscle in the thigh was high at 90 degrees of the ankle angle and plateaued from 60 to 80 degrees of the one. The peak lateral amplitude of the COP indicated that the instability of the standing motion was significantly increased at an ankle joint angle of greater than 70 degrees. These plotted patterns of the muscle activity of the lower limb and the COP amplitude in the young subjects were similar to the elderly subjects. From these results, the suitable angle of the ankle joint at the early standing phase ranged from 60 to 70 degrees. Because joint stiffness is more typical in the elderly than the young, the setting angle of the ankle joint applying a transfer assistance system should be approximately 70 degrees.

We measured the tilting angle of the subject's trunk at seat-off when the angle of the ankle joint was set at 70 degrees. From the experimental results, the tilting angle of the trunk of the young and the elderly was approximately 35 degrees and 45 degrees, respectively.

6.3 The design of a mobile floor hoist

A prototype of the mobile floor hoist for transfer assistance is shown in Fig. 19. The mobile floor hoist had a height of 120 cm and a width of 70 cm. To prevent a fall with the knee flexed during standing and to transfer the user's body stably and safely, the mobile floor hoist had various protective parts, such as a kneepad, an arm pad and a chest pad, which provided a cushioning function. The design of these cushion pads was based on the measurement of the ergonomic motion analysis described above. For example, the kneepad had a variable positioning mechanism to follow the change of the ankle joint angle during

transfer motion. Each mechanical part of the hoist adopted a module fashion to adjust easily according to the various physical features of users. A double-acting MH actuator with two MH modules for the lifting mechanism was installed in our mobile floor hoist. The double-acting MH actuator could control its own stiffness and position by changing the balance between the inner and outer hydrogen pressures of a metal bellows in a cylinder. This double-acting MH actuator could lift up to a 200-kg weight to a 35-cm height.
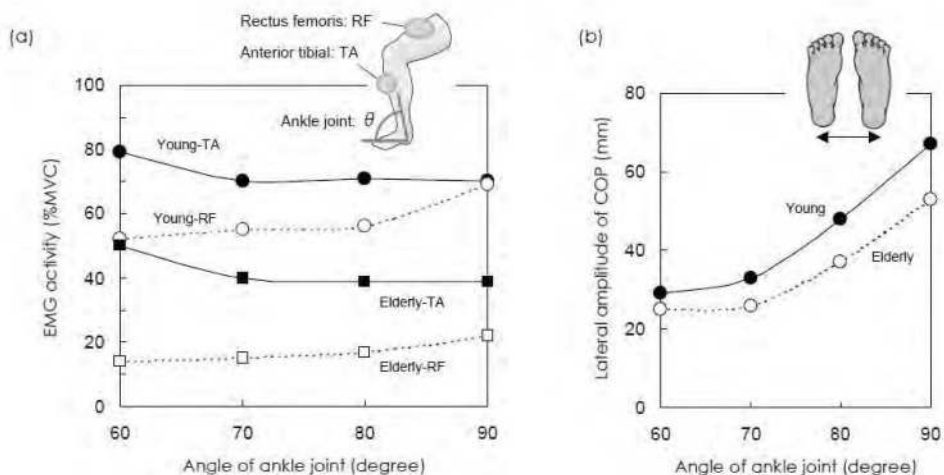

Fig. 18. Comparison of the muscle activity of a lower limb and the COP amplitude while standing from a 50-cm height seat between young and elderly subjects.

Fig. 19. Photograph of a prototype mobile floor hoist for transfer assistance.

6.4 The design of a seat lifter for a wheelchair or toilet

A wheelchair is one of the most popular pieces of assistive technology equipment for the elderly of people with a lower limb disability. Recently, the wheelchair has been significantly improved, and many types have been developed to conform to the lifestyle of wheelchair users. When using a wheelchair, however, some fundamental tasks that require a standing position, such as reaching a tall shelf and cooking in the kitchen, are still difficult in daily life. Thus, we developed a wheelchair with a seat lifter using an MH actuator to improve the quality of life for wheelchair users.

The assistive devices for lifting the body must secure long and smooth stroke motion for users. Therefore, a hybrid MH actuator that uses a tandem piston cylinder with a hydraulic converter was especially developed, as shown in Fig. 20. When hydrogen gas flows into the lower piston, silicone oil in the lower piston moves into the upper piston, depending on the inflow of the hydrogen gas. By using this hybrid driving mechanism with a hydrogen-hydraulic system, the stroke displacement becomes doubled compared with a typical MH actuator that is driven by only hydrogen gas.

This hybrid MH actuator containing a 40-g compact MH alloy could lift an 80-kg weight to a 40-cm height, as shown in Fig. 20 (b). The lift speed was approximately 20 mm/s, and the total weight of the lifting unit including the MH actuator with the tandem piston cylinder was approximately 5 kg.

A prototype of the toilet seat lifter using an MH actuator is shown in Fig. 20 (a). The toilet with a seat lifting function has a similar hybrid MH actuator system to that described above. This toilet MH actuator system containing a 150-g MH alloy compact could lift a 100-kg weight to a 35-cm height. The lift speed was approximately 10 mm/s. The heater and the cooler of the MH alloy adopted the sheath heater made of electric heating wire and the water jacket utilized tap water in-house to save energy.

This toilet seat lifter was installed in a smart house, the Welfare Techno House (WTH) in Japan, which was built to investigate the daily well-being of elderly people (Tamura, 2006).
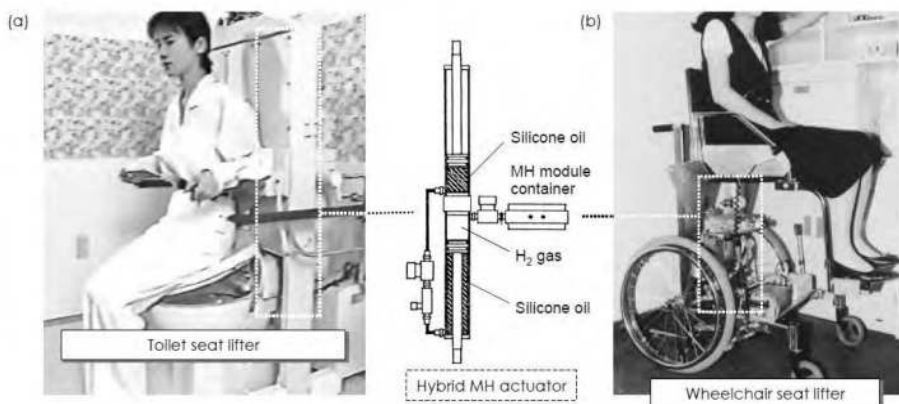

Fig. 20. Photograph of a portable lifter using the MH actuator for (a) a toilet seat and (b) a wheelchair seat.

7. Conclusion

In this paper, we described a soft and noiseless actuator using a MH alloy and its applications in assistive technology and rehabilitation engineering. The MH actuator mentioned above have various unique features, such as a high force-to-weight ratio, low mechanical impedance, noiseless motion and a muscle-like actuation mechanism based on expansion and contraction, which differs from conventional industrial actuators. From these distinctive features, we think that MH actuators are suitable force devices for applications in human motion assistance and rehabilitation exercise.

However, technical challenges also remain regarding the motion speed and energy efficiency of MH actuators, most of which can be overcome through the improvement of Peltier thermoelectric devices (the heat-pump module) and a heat sink material to facilitate waste heat management (Sato et. al., 2011).

Our aim is to develop a new human-friendly actuation device with targeted applications for quality-of-life technology for active health promotion and to facilitate the personal autonomy of elderly and disabled people (Cooper, 2008). While soft and noiseless MH actuators are under development for a CPM machine for joint rehabilitation, a toe exercise system for pressure ulcer prevention and a transfer assistance system for lower limb disability, they can also be adopted for other applications: an active prosthesis and orthosis, a compact wheelchair lift for a low floor vehicle ramp assembly, a haptic display for a sensory substitute or virtual reality. MH actuators have great potential to enhance the physical affinity of assistive technology, rehabilitation engineering and human-machine interface technology, and the sophistication of the MH actuator is a part of our ongoing studies.

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