Available online at www.sciencedirect.com

ScienceDirect

APCBEE Procedia 7 (2013) 54 – 59

Procedia APCBEE

www.elsevier.com/locate/procedia

ICBET 2013: May 19-20, Copenhagen, Denmark

Flexible Artificial Muscle Actuator Using Coiled Shape Memory Alloy Wires

Hironari Taniguchi*

Department of Electronics and Control Engineering, Tsuyama National College of Technology, 624-1 Numa, Tsuyama, Okayama 708-8509, Japan

Abstract

This paper presents a flexible artificial muscle actuator using coiled shape memory alloy (SMA) wires. The actuator mainly consisted of flexible materials and SMA wires and the fabrication was based on molding of silicon rubber. The actuator was also characterized by the motion with the body in flexion. We measured several characteristics to investigate a relationship between the bending angle of its body and the actuation. As the results, we confirmed that it was possible to actuate with the body in flexion.

Keywords: Shape memory alloy; Actuator; Artificial muscle; Silicone rubber

1. Introduction

Recently, robot technology itself has greatly advanced into such fields as medical care and welfare. It is therefore extremely necessary that its robot has low mass, small size, safety and user-friendliness. Conventional actuators like a DC motor and a hydraulic cylinder were used to be a drive source for the robot. However they have limited low mass and small size. We therefore focus on artificial muscle actuators as a new drive source of the robot. A lot of research has been conducted to develop artificial muscle actuators [1]-[6]. Some of them have proposed as a rubber artificial muscle actuator with pneumatic [7]-[12]. However, the system which includes the pneumatic artificial muscle actuator needs several peripheral equipments such as

* Corresponding author. Tel.: +81-868-24-8273; fax: +81-868-24-8273.
E-mail address: taniguti@tsuyama-ct.ac.jp.

doi:10.1016/j.apcbee.2013.08.012

an air compressor, electro-pneumatic regulators, and pressure sensors and so on. This tends to make the system relatively large and heavy. In this paper, we propose a flexible artificial muscle actuator using coiled SMA wires. Single SMA has a function as a sensor and an actuator. Moreover, it has small size, low mass and flexibility. We fabricated two types of the SMA flexible actuator. Type A was shaped like a cylindrical body. Type B was also shaped like a bellows. The actuators were characterized by the motion with the body in flexion. We measured the actuation and force characteristics to investigate a relationship between the bending angle of its body and the actuation.

2. SMA Flexible Artificial Muscle Actuator

2.1. Design and Driving Principle

The structure of the actuator is shown in Fig. 1 (a) and (b). We designed two different actuators; Type A and Type B. They consist of two coiled SMA wires, a piston made of resin, a SMA guide, a cap, a guide case made from silicone, a helical compression spring made from piano wire and a rod made from SMA or high-speed steel. The outer diameter, the length and the weight of Type A are 10/14 mm, 75 mm, and 4.76 g, respectively. Similarly, the outer diameter, the length and the weight of Type B are 14 mm, 72 mm, and 4.72 g, respectively. SMA wires (ACTMENT Inc: WDM0.3, diameter 0.3mm, Ni content 55.4%) are applied to the drive source of the actuator. It was made to memorize in the shape of a coil. The end of coiled SMA is connected with each other in series and the other end is also connected with a lead wire. The coiled SMA wires are fixed between the piston and the SMA guide and are inserted into the coil spring. The coiled SMA is used as a linear actuator in this case. It contracts by 3-4% when heated sufficiently to cause a phase change throughout its structure. Modulating the applied heating effort can control the contraction. Actuating the coiled SMA is used 'Joule heating' which is generated by electrical current. Electrical current flows into each coiled SMA wire via lead wires on the SMA guide. When electrical current flows into the coiled SMA wires, it is compressed to the length of the memorized shape and pushes down on the rod with the piston. When the electrical current is turned off, the coiled SMA wires are extended by natural cooling.

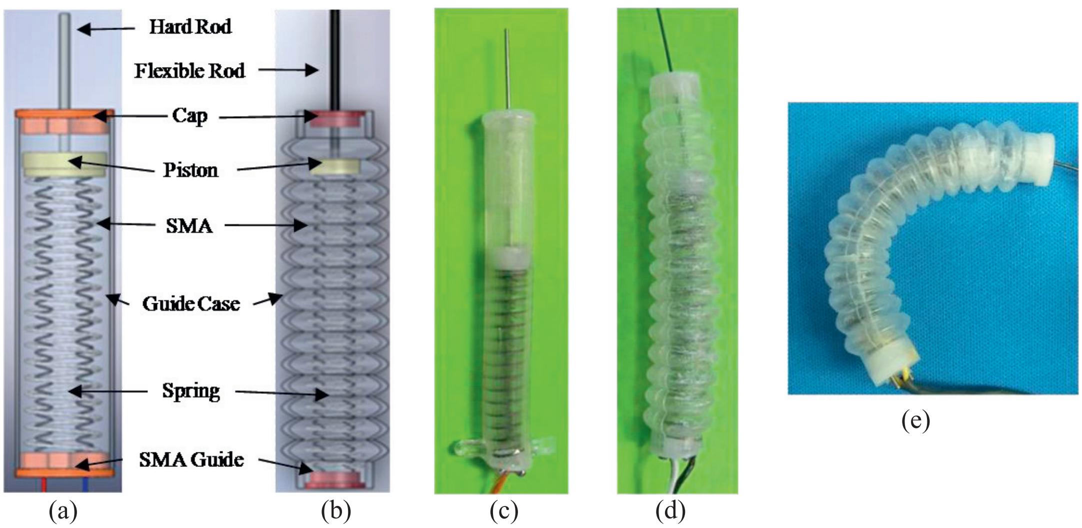


Fig. 1. Structure of (a) Type A and (b) Type B of the actuator; Photographs of (c) Type A; (d) Type B and (e) the bending the Type B

2.2. Fabrication

The transformation temperature of the SMA is decided by nickel content and heating temperature at the time of shape memory treatment. In this time, the shape memory treatment heated SMA fixed in the shape of a coil for 40 minutes at 623 K using the electric furnace. Then it was cooled rapidly with water. According to the reference [13], we guessed that the transformation point of a coiled SMA was about 328 K. The photograph of the manufactured actuator is shown in Fig. 1 (c) and (d). Fig. 1 (e) also shows the photograph of bending the body. The actuator has a concept that we can use with the actuator in flexion like Fig. 1 (e). The guide case of the actuator is fabricated from silicone rubber (Shin-Etsu Silicones Inc: KE-1603). In addition, silicone grease (Shin-Etsu Chemical Inc: G40-100) is applied to the piston and the inside of a guide case to operate smoothly. The rod is made of a SMA wire with superelastic characteristic to give flexibility to the rod. The superelastic characteristic lowers the transformation point of SMA greatly. Therefore, at normal temperature, even if it adds load, the characteristic which returns to the original form is shown. We gave the superelastic effect with making itself memorize the shape of a straight line to a SMA wire (ACTMENT Inc: WDM0.6, diameter 0.6mm, Ni content 56.05%). Therefore, SMA can be bent like wire as the load is applied and if the load is removed, it will return to straight line form again.

3. Characteristics of SMA Flexible Artificial Muscle Actuator

3.1. Actuation Performance

We describe the actuation performance to explain the relationship between the bended guide case and the actuation. Fig. 2 shows the system configuration of experiment. The actuator was fixed the parts of cap and SMA guide and was controlled by electrical current which was adjusted using a stabilized power supply. As the center of its actuator was bent from 0 to 90 degrees every 10 degrees, we recorded the motion with electrical current of 0.7 A by a video camera. Thus, we calculated the maximum displacement from several recorded images using image processing software (ImageJ; National Institutes of Health, USA). In addition, this experiment was conducted in a state with no wind and temperature of 294 K.

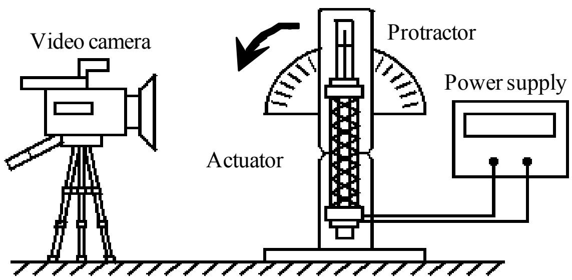
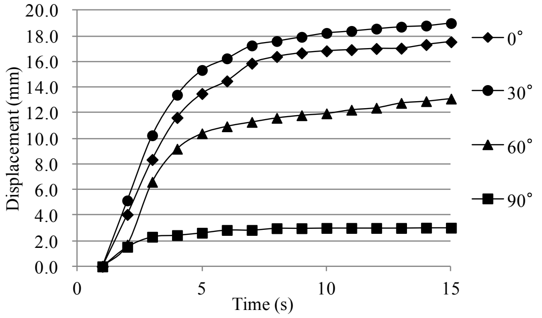


Fig. 2. System configuration diagram of the actuation performance experiment

The experimental result is shown in Fig. 3; left of figure for Type A and the other one for Type B. The vertical axis represents displacement and the horizontal axis represents time. Both the charts, excluding the measurement result as 90 degree for Type A, showed a sudden increase for approximately 5 seconds. After 5 seconds, it tended to increase a little. Fig.4 shows the result of the maximum displacement. The vertical axis represents the maximum displacement and the horizontal axis represents the bended angle of actuator. When it was bent at 90 degrees, the displacement of Type A/B was 3.0/7.6 mm. According to Fig. 4, Type A showed the value with the constant maximum displacement to 40 degrees. However, it decreased greatly after 40 degree. From this result, we found that Type A run down to generate friction between the piston and the guide case. Type B also decreased linearly. It means that the friction between the hole of cap and the rod is reduced by the rubber case shape of bellows.



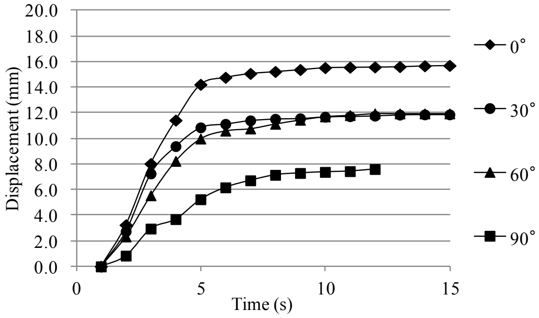


Fig. 3. The displacement characteristics; left of figure for Type A and right of figure for Type B

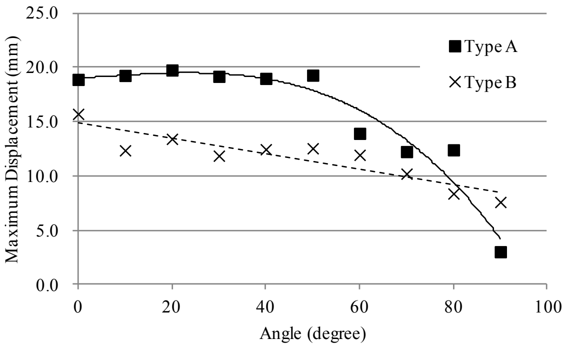


Fig. 4. Maximum displacement characteristics

3.2. Force Performance

We investigated the maximum force to obtain the relationship between the bended guide case and the force of the actuator. The bending angle of guide case was changed from 0 to 90 degrees every 10 degrees. Fig. 5 shows the system configuration of experiment. The actuator was fixed on a protractor and the rod was connected with a force gauge (IMADA Inc: ZPS-DPU-50N). We measured the maximum force with electrical current of 0.7 A and the data was recorded by a personal computer simultaneously.

The force experimental result is shown in Fig. 6; left of figure for Type A and the other one for Type B. Fig. 7 also shows the result of the maximum force characteristic. In the measurement results for Type A, we found that there is no force more than 70 degrees and the force decreased substantially between 30 and 40 degrees. This phenomenon depends on the shape deformation of its guide case with the bending angle. On the other hand, we confirmed from the measurement results for Type B that the force decreased gradually. It means that the results are less affected by the shape deformation. Furthermore, from the both measurement results we found that the coiled SMA contact with a compression spring when the guide case was bent. Therefore, a circuit for the controlling shorted out and the coiled SMA was not enough heated.

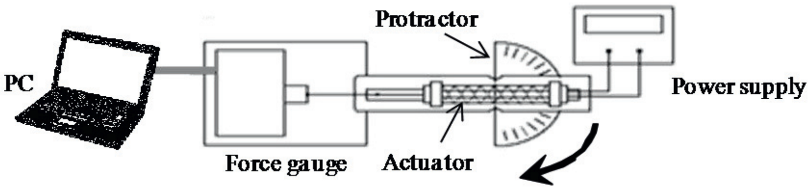


Fig. 5. System configuration diagram of the force performance experiment

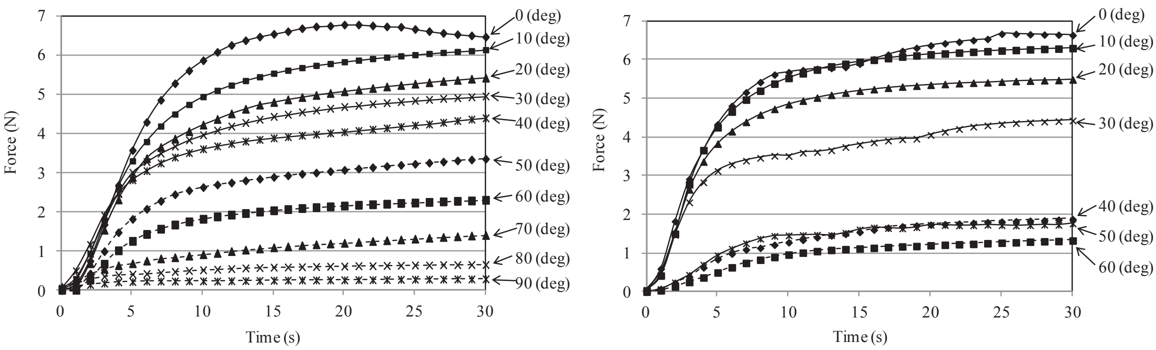


Fig. 6. The force characteristics; left of figure for Type A and right of figure for Type B

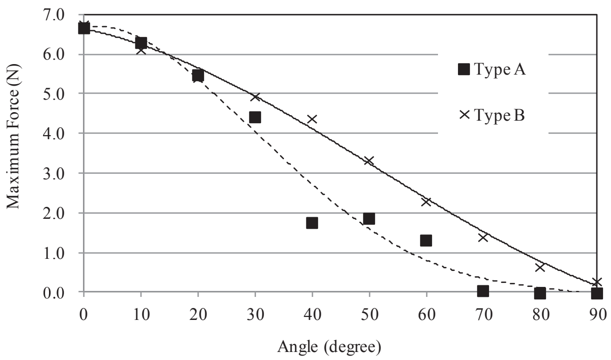


Fig. 7. Maximum force characteristics

4. Conclusion

The purpose of this study is to develop a novel artificial muscle actuator. In this paper, a flexible artificial muscle actuator using coiled shape memory alloy wires is proposed. This paper also describes the design, the driving principle, the fabrication and the results of its experimental evaluation. Especially, the actuator has a concept that we can use with the actuator in flexion. Thus, the guide case of the actuator is fabricated from silicone rubber and we investigated the actuation and force performance. From the experimental results, we confirmed that it is possible to move the actuator when the center of its actuator was bent from 0 to 90 degrees. However, the displacement and force were both decreasing gradually with the increase in the bending angle. We found that the main reason for this is the shape deformation of its guide case.

Acknowledgements

This research has been financially supported by the Wesco Scientific Promotion Foundation. This result in the manuscript is a part of the three-year project.

References

[1] P. Cottinet, D. Guyomar, J. Galineau, and G. Sebald, "Electro-thermo-elastomers for artificial muscles," Sensors and Actuators A, vol. 180, pp. 105-112, April 2012.

[2] K. Takashima, J. Rossiter, and T. Mukai, "McKibben artificial muscle using shape-memory polymer," Sensors and Actuators A, vol. 164, pp. 116-124, September 2010.

[3] B. Tondu, R. Emirkhanian, S. Mathe, and A. Ricard, "A pH-activated artificial muscle using the McKibben-type braided structure," Sensors and Actuators A, vol. 150, pp. 124-130, December 2008.

[4] K. Takemura, S. Yokota, and K. Edamura, "Development and control of a micro artificial muscle cell using electro-conjugate fluid," Sensors and Actuators A, vol. 133, pp. 493-499, May 2006.

[5] S. Hara, T. Zama, W. Takashima, and K. Kaneto, "Polypyrrole-metal coil composite actuators as artificial muscle fibres," Synthetic Metals vol. 146, pp. 47-55, August 2004.

[6] K. Jung, J. Nam, and H. Choi, "Investigations on actuation characteristics of IPMC artificial muscle actuator," Sensors and Actuators A, vol. 107, pp. 183-192, June 2003.

[7] T. Akagi, S. Dohta, Y. Kenmotsu, F. Zhao, and M. Yoneda, "Development of smart inner diameter sensor for position control of Mckibben artificial muscle," Procedia Engineering, vol. 41, pp. 105-112, 2012.

[8] Noritsugu, T., Takaiwa, M., Sasaki, M. and D., 2009. Development of Power Assist Wear Using Pneumatic Rubber artificial Muscles, Journal of Robotics and Mechatronics, 21-5, p. 607.

[9] Kobayashi, H., Shiban, T., Ishida, Y., 2004. Realization of all 7motions for the upper limb by a muscle suit, Journal of Robotics and Mechatronics, 16-5, p. 504.

[10] Akagi, T., Dohta, S., 2007. Development of McKibben Artificial Muscle with a Long Stroke Motion, Transactions of the JSME(C), 73-735, p. 2996.

[11] Wakimoto, S., Suzumori, K., Kanda, T., 2005. "Development of intelligent McKibben actuator with built-in soft conductive rubber sensor," Proceedings of The 13th International Conference on Solid-State Sensors, Actuators and Microsystems, Vol. 1, pp. 745-748.

[12] Yoneda, M., Akagi, T., Dohta, S., Zhao, F., 2011. "Development of a Rubber Artificial Muscle with Inner Diameter Sensor and Its Application," Proceedings of 11th International Conference on Fluid Control, Measurements and Visualization (FLUCOME2011.12), Taiwan, No.29, pp.1-6.

[13] ACTMENT Company Profile. ACTMENT Co.,Ltd.. [Online]. Available: http://www.actment.co.jp/actment_ENG.pdf