A Laser-micromachined SMA Micro-robot

Fong-Fong Hui, Julia S. J. Qin, John D. Mai, and Wen J. Li

Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong

Abstract

A simple 3DOF micro-robot that is capable of moving inside pipeline-like environment, was developed using SMA actuators. The robot uses 10 SMA actuators, in which four of them are controlled independently, to move in an inch-worm fashion through pipelines and was also designed to bend around joints of pipelines. The prototype with 250mmx360mm body dimension (not including the legs) was developed. We are investigating the possibility of improving the time response of the robot by using novel designs for the SMA actuators. We have used Nd:YAG laser to micromachine SMA wires and prove that these micromachined wire-actuators can respond ~30% faster than conventional SMA wires at a transformation temperature of 34°C. This paper reports the design, functions of the micro-robot, and the results of preliminary experiments on improving the response of SMA actuators.

Introduction

Micro-robots are now participating in important roles in both industrial and medical field. There are many existing micro-robots using different kinds of elements including electro-rheological fluid, piezoelectric element, hydraulics pump, pneumatic microvalves and shape memory alloy (SMA) actuators. While further improvement in size and speed of the micro-robots is a current research thrust in many laboratories, using SMA actuators have obvious advantages over the others. The SMA actuators can produce large displacement and force, while maintaining relatively simplistic mechanical elements. Namely, SMA elements can serve as both structural and functional (actuation) parts. By employing current-heating as the heating source, it can directly interface between electrical signals and can be driven by repeating the heating and cooling process. It is expected that robotic systems using SMA actuators can be miniaturized significantly. Therefore, there has been increasing interest in the usage of SMA to make robotic actuators over the past ten to fifteen years. More and more studies of SMA for micro robot actuators are being done [1]. However, a major disadvantage is their relatively slow operating speed. Many work already attempted to solve this problem. Hunter [2] proposed processes to modify the material characteristics of commercially available SMA. Russell and Gorbet [3] use a mobile heat sink to improve the response of SMA actuators. In this paper, we propose a novel technique to improve SMA speed response by laser micromachining of SMA. As a consequence, we offer a simple robotic SMA mechanism that is viable for miniaturization and commercialisation.

Concept

The micro-robot is composed of three parts: one moving part and two clamping feet. By repeatedly changing the mode, the robot propels like a worm. The schematic diagram and locomotion concept of the robot are illustrated in Figure 1. SMA wire actuation is due to the resistive power dissipation and heat transfer. We increase the surface area of SMA wire using laser-micromachining, and hence, allowing the wire to increases its resistance and heat transfer surface area. Increased resistance affects the temperature rising time while the surface area affects the cooling time. Physical parameters of a cut wire governing the heat transfer analysis are shown in Figure 2.

Current Results

A prototype robot was built using 750μm SMA wire and 5mm SMA spring as actuators (Figure 1c). A laser-micromachined SAM wire is shown in Figure 3. Interferometric measurements of the grooves of a cut wire are shown in 3b-3d, which indicate that we can control the grooves to ~200μm currently. We expect to improve this to ~15μm by correctly tuning our laser system. Theoretical analyses on the governing parameters to increase time response were performed. The relationship between time to reach a set transformation temperature with a given electrical current and laser-micromachined wire radius is shown in Figure 4. It indicates that cutting the SMA wires is much more effective than increasing the supplied current. The time reduction in percent during both the cooling and heating cycles were calculated as a function of groove inner radius (Figure 5). As indicated by Figure 5, the grooves will affect the heating response time much more than the cooling response time, and the improvement in time response is asymptotic to diminishing groove radius. This proves that an optimal solution exist for a cut radius which will improve response time while not excessively sacrificing the structural strength of the wire. Experiments were also performed to validate the theoretical results. Comparison of time response for uncut and cut SMA wires is shown in Figure 6, which indicates that an improvement of ~30% is possible at a transition temperature of 34°C.

Future Work

With encouraging results from the laser-micromachined SMA actuators, we are devoting our efforts now to further optimisation of the time response by performing experimental and theoretical work to maximize the heat-transfer surface of given actuators. We are also extending our current work to 2-way SMA wires. Successful results will certainly improve travel speeds of SMA micro-robot significantly.

REFERENCES

1. Toshio Fukuda, Hidemi Hosokai and Isamu Kikuchi, "Distributed Type of Actuators by Shape Memory Alloy and its Application to Underwater Mobile Robotic Mechanism", IEEE Proceedings, pp.1316~1321 (1990)
2. Hunter, I. W. et al., 'Fast reversible NiTi fibers for use in micro-robotic", Proceedings of the IEEE Micro Electro Mechanical Systems Workshop, Aara, Japan, 1991, pp. 166-170
3. R. Andrew Russell, Robert B. Gorbet, "Improving the Response of SMA Actuators", IEEE International Conference on Robotics and Automation, pp.2299~2304,1995