

Terfenol-D 액츄에이터의 히스테리시스 모델링과 제어

박영우*(충남대 메카트로닉스공학과), 임민철(충남대 대학원), 김도연(LG 화학)

Hysteresis Modeling and Control of Terfenol-D Actuator

Y. W. Park(Mechatronics Eng. Dept. CNU), M. C. Lim(Graduate School, CNU), D. Y. Kim(LG Chemical)

ABSTRACT

This paper proposes a systematic approach for an accurate control of the Terfenol-D actuator taking into account hysteresis, modeled by applying the classical Preisach operator with memory curve. A desired input displacement is calculated by using the hysteresis inverter, which is fed into the actuator. Then the PI compensator corrects the error between the commanded and actual displacements. Experiments with the step responses show that the PI controller settles in 70 ms and the hybrid controller in 20 ms. It means that the concurrent application of two control schemes is effective to control the actuator.

Key Words : Magnetostriction (자기변형), Terfenol-D (터페놀-디), Hysteresis (히스테리시스), Preisach model (프라이자크 모델), hysteresis inversion (히스테리시스 역변환)

1. Introduction

Magnetostriction is a phenomenon consisting in the deformation of a ferromagnetic material when it experiences an applied magnetic field. The magnetostrictive materials (e.g., Terfenol-D) have been widely studied for mechanical actuation purposes, thanks to their ability to exert high forces. Nevertheless, hysteresis in the magnetostrictive materials hinders the wider applicability of them in actuators. The use of a non-linear model or non-linear inverse model in a control configuration has been shown to significantly enhance the performance of the hysteretic materials [1,2]. In literature, several models, based on the Preisach model [3], have been proposed to describe on a phenomenological basis the memory effects of real materials (magnetic and magnetostrictive materials, or superconductors). Thus, this paper proposes a systematic approach for an accurate control of the Terfenol-D actuator taking into account hysteresis effect.

2. Hysteresis Modeling

Hysteresis in Terfenol-D is modeled by applying the classical Preisach operator with memory curve, and formulated, according to [3], as

$$y(t) = \Gamma[x](t) = \iint \mu(\alpha, \beta) \hat{\gamma}_{\alpha\beta} x(t) d\alpha d\beta \quad (1)$$

where, $\hat{\gamma}_{\alpha\beta}$ = relay operator, α and β = up and down relay's switching values, and $\mu(\alpha, \beta)$ = a weight function to be determined by a suitable identification procedure.

The weight function can be determined by measuring the first order reversal curves experimentally. The Terfenol-D actuator, due to the capacity of the windings or other practical reasons, have to be operated with their inputs within a specific range. As a consequence, we will not be able to visit the whole Preisach plane and identify the measure everywhere during the identification process. It is assumed that the input range is $[u_{\min}, u_{\max}]$. In Fig. 1, the big triangle represents the whole Preisach plane, while

smaller triangle is the region we can visit and denote it as Ω_1 . The region outside in Ω_1 the Preisach plan is denoted as Ω_0 . Since the input $u(t)$ never goes beyond the limits, states of hysterins in Ω_0 remain unchanged. The input is increased to u_{max} and then decreased to u_{min} . Then some piecewise monotone continuous input $u(t)$, $t \in [0, T]$, and the output $w(t)$ is measured. In this work, the input is current to the Terfenol-D actuator and the output the corresponding displacement from the Terfenol-D actuator, as shown in Fig. 2.

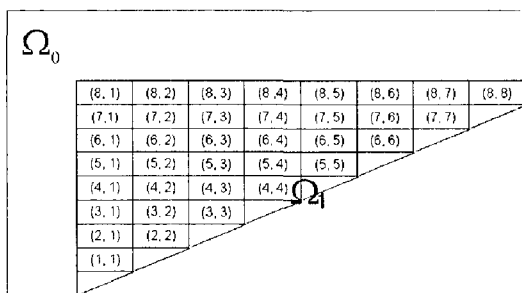


Fig. 1 Discretization of the Preisach plane (L=9)

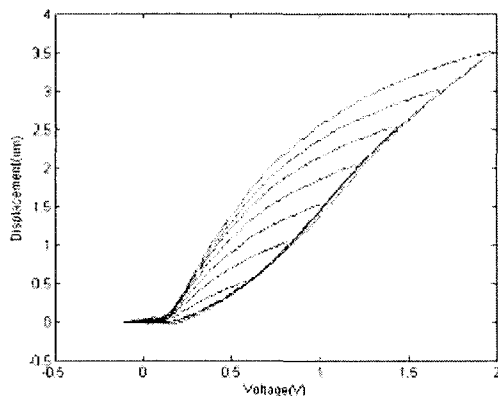


Fig. 2 First order reversal curve of the Terfenol-D actuator

The hysteresis inversion algorithm for the resulting Preisach operator, based on the theory of strictly-increasing operators, is called closest match algorithm [4]. The closest match algorithm tries to find the input yielding the closest match to the desired output rather to find the exact match to the desired output. Also, PI control scheme is incorporated into the full control schemes as a compensator. Using these concepts, the controller is built on a PC with a data acquisition board, and contains the hysteresis inverter and PI compensator. A desired input displacement is calculated by using

the hysteresis inverter. The calculated input displacement is fed into the Terfenol-D actuator, and then the PI compensator corrects the error between the commanded and actual displacements. The proposed control scheme is shown in Fig. 3.

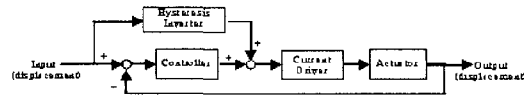


Fig. 3 Proposed control schemes

3. Experimental Results and Discussions

3.1 Experimental Procedure

Experiments are performed to show the effectiveness of the proposed control schemes. Figs. 4(a) and (b) show a schematic diagram and a photo for the experimental setup. Experimental setup consists of the Terfenol-D actuator, a coil driver for current amplification, power supply, a capacitive sensor with the resolution of 1 nm for the displacement measurement, and a controller. The experiments are performed on an optical table for eliminating possible disturbances such as vibration, shock, etc. The Terfenol-D actuator is mounted on a minivise normal to the top of the optical table, and the capacitance sensor is placed above the actuator with the aid of a magnetic stand. Two experiments are performed with the step responses; one is controlled by using the PI control and the other by using the PI control with hysteresis inversion. As the current flows through the coil, the Terfenol-D expands along the axis. This expansion causes the decrease in the gap between the sensor and actuator.

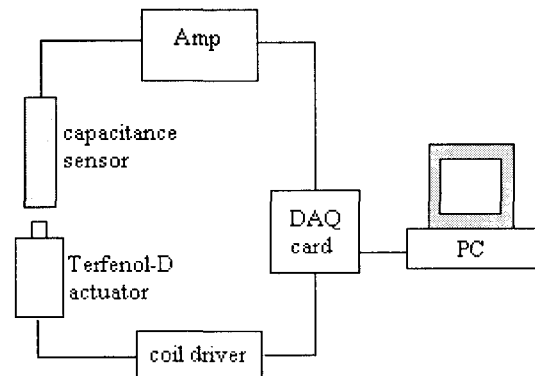


Fig. 4(a) Schematic diagram for experimental setup

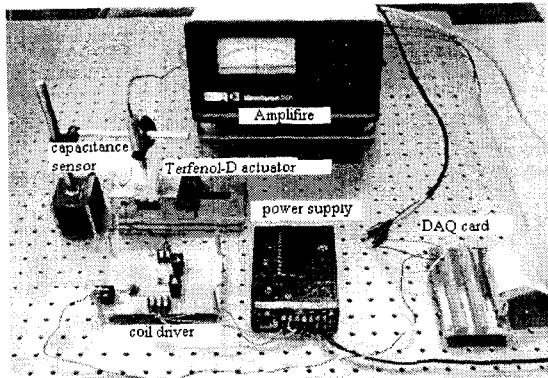


Fig. 4(b) Photo for experimental setup

3.2 Experimental Results and Discussions

Table 1 shows the weight function obtained from the Fig. 1. These values are used to compensate the hysteresis in the Terfenol-D actuator.

Figs. 5(a) and (b) show the step responses with the PI controller and with the hybrid (PI+hysteresis inversion) controller, respectively. In each figure, the inset marked as (b) is the enlargement of the inset marked as (a). It is found that the tracking accuracy with the hybrid controller is better than that with the PI controller. It is also found that the response time with the hybrid controller is faster than that with the PI controller. That is, it settles in 70 ms with the PI controller and that in 20 ms with the hybrid controller. This is because of the capability of the Preisach model to predict and linearize the hysteresis.

Table 1 Weight function obtained

.02	-.02	-.005	-.005	-.01	-.02	-.09	.225
.025	-.025	-.005	-.01	-.02	-.09	0.21	
0.01	-.015	-.01	-.015	-.09	0.21		
.025	-.035	-.02	-.095	.195			
.005	-.025	-.09	.195				
-.035	-.06	.195					
0.02	.265						
.795							

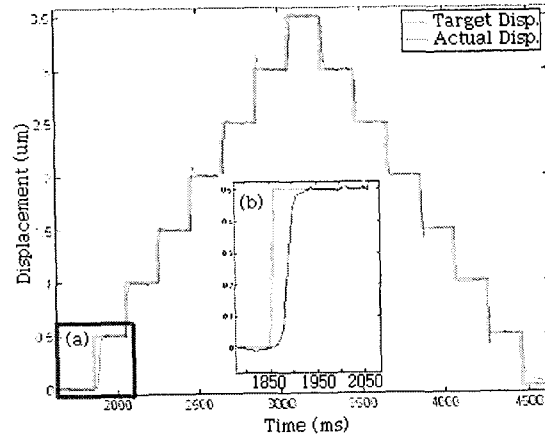


Fig. 5(a) Step response with PI controller

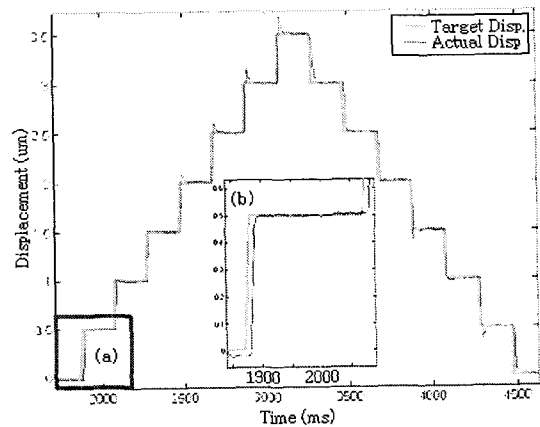


Fig. 4(b) Step response with hybrid controller

4. Conclusions

Hysteresis in the Terfenol-D hinders the wider applicability of them in actuators. In this work, hysteresis inversion with PI control is proposed and applied to the Terfenol-D actuator. The hysteresis is modeled by using the classical Preisach operator with memory curve. Experimental results show that the tracking accuracy and response time with the hybrid controller are better than those with the PI controller. Therefore, it can be concluded that the concurrent application of two control schemes is effective to control the Terfenol-D actuator.

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