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A Modified Model Reference Adaptive Control for a Single Motor of Latch Type Control Element Drive Mechanism

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1. Introduction

A modified Model Reference Adaptive Control (MRAC) for a single motor of latch type Control Element Drive Mechanism (CEDM) is described herein. The CEDM has complicated dynamic characteristics including electrical, mechanical, and magnetic effects [1]. However, a control system for the CEDM should use only electrical control input, because there is no methods dealing with the mechanical and magnetic effects directly. The previous control system has utilized a Proportional-Integral (PI) controller, and the control performance is limited according to nonlinear dynamic characteristics and environmental conditions. The modified MRAC using system identification (ID) technique improves the control performance in the operating condition such as model parameter variation and environmental condition change.

2. Reference Model Selection

In this section, a reference model for the modified MRAC is selected using system ID technique.

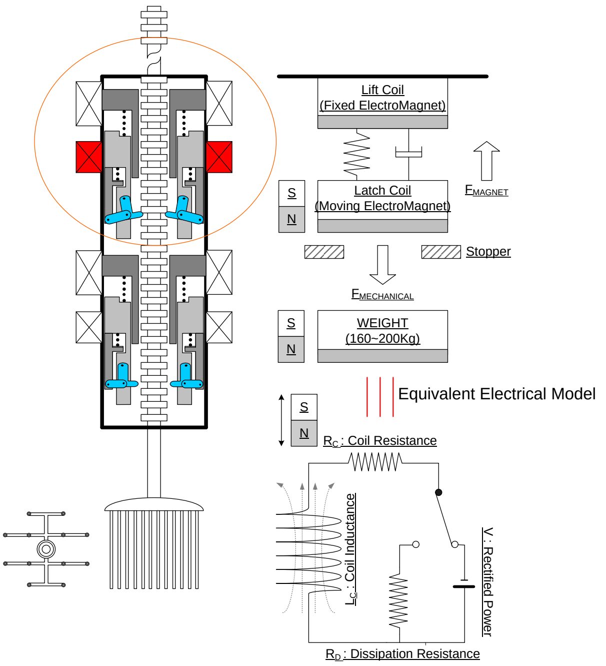

Fig. 1. An electrical equivalent control model of the CEDM

The CEDM has a specific linear motor configured as latch type coil stacks as shown in the Fig. 1.

2.1 System ID

The basic idea in the Fig. 1 assumes that the electrical equivalent model represents the CEDM dynamic behavior including mechanical and magnetic effects, although the model has some dynamic errors. Here, the electrical model is different from the electrical model derived from the bench-top resistance and inductance parameters. The equivalent electrical model by Kirchhoff voltage law and Laplace transform is written as follows:

$$\frac{I(s)}{V(s)} = \frac{1}{L_C s + R_C} = \frac{1/L_C}{s + R_C/L_C} \quad (1)$$

From (1), if white-box model ID with known model structure and unknown model parameter [2], the ID model is simplified as follows:

$$\frac{I_m(s)}{V_m(s)} \approx \frac{b_m}{s + a_m}, where\ a_m \approx \frac{R_C}{L_C}, b_m \approx \frac{1}{L_C} \quad (2)$$

Fig. 2 shows the system ID results from the step response experimental data using MATLAB.

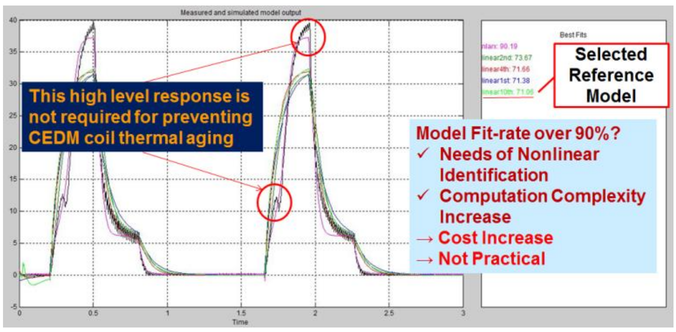

Fig. 2. System response results forced by test input using MATLAB

From Table I, the reference model is chosen as linear 1st order model for better H/W implementation.

Table I: ID Model Fitting Rate to the Real I/O Data

ID Methods	Fitting Rate (%)
Nonlinear ARX	90.19
Linear 1st order	71.38
Linear 2nd order	71.66
Linear 4th order	73.67

2.2 Reference Model Selection

The equivalent model (2) can be recommended as the reference model for applying MRAC technique. The un-modeled dynamics are considered as error between the reference model and the real CEDM model. Because the reference model is linear 1st order model, the computational complexity of a controller is minimized. Therefore, the most important performance of the modified MRAC is the error convergence.

3. Modified MRAC

In this section a modified MRAC technique for the CEDM is introduced.

3.1 Modified MRAC Structure

The modified MRAC structure shown in the Fig. 3 has the following three (3) characteristics.

I. Identified Reference Model for applying mechanical and magnetic effects of the CEDM
II. Feed-forward gain for transient response improvement using identified reference model
III. 180Hz noise reduction filter for error convergence improvement using identified reference model

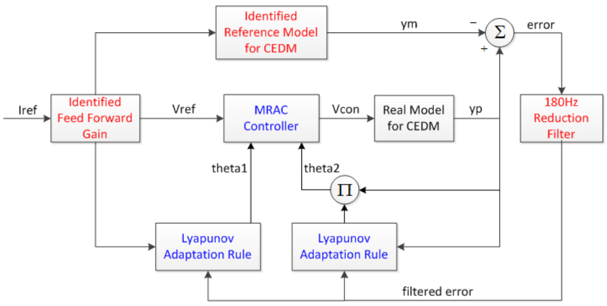

Fig. 3. Modified MRAC structure

3.2 Control Law from Lyapunov Adaptation Rule

From (2), the reference model is as follows:

$$\dot{y}_m + a_m y_m = b_m r \quad (3)$$

Here, the real model of the CEDM is assumed as follows for control law calculation:

$$\dot{y}_p + a y_p = bu \quad (4)$$

To decide the control law using Lyapunov adaptation rule, the following Lyapunov function candidate is considered:

$$V = \frac{1}{2}\gamma e^2 + \frac{1}{2b}(b\theta_1 - b_m)^2 + \frac{1}{2}(b\theta_2 + a - a_m)^2 \quad (5)$$

From (3), the control law is derived as follows [4]:

$$V_{con} = V_{ref} \times \theta_1 - y_p \times \theta_2, where\ \dot{\theta}_1 = -\gamma e r, \dot{\theta}_2 = \gamma e y_p \quad (6)$$

Gamma in (6) is tuned up close to zero (0) as possible for better error convergence.

3.3 Simulation Results

The modified MRAC Simulation result using MATLAB is shown in Fig. 4 and Fig. 5. Fig. 4 and Fig. 5 show the comparison results of control performance between a conventional PI control and the modified MRAC. Parameters used in the simulation are written as Table II.

Table II: Simulation Condition

CEDM Coil Parameter	Value
Bench-top Resistance	4.4 Ω
Bench-top Inductance	130 mH
Identified Resistance	4.87 Ω
Identified Inductance	454 mH
Abnormal Resistance	13.4 Ω
Abnormal Inductance	380 mH

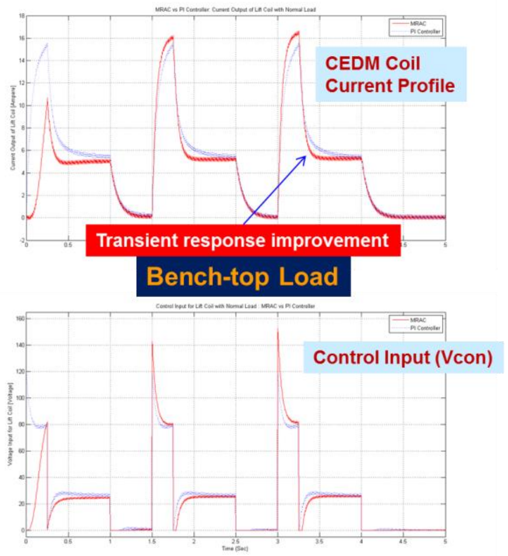

Fig. 4. Simulation results (PI vs modified MRAC) under bench-top load condition

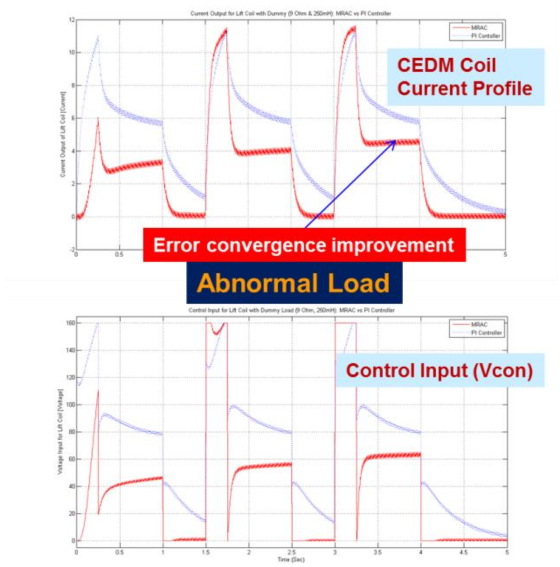

Fig. 5. Simulation results (PI vs modified MRAC) under abnormal load condition

3.4 Experimental Results

Test beds are configured as shown in Fig. 6.

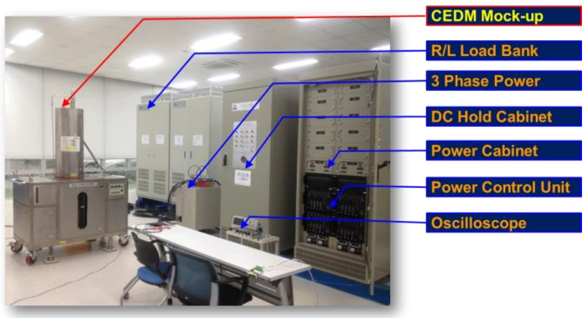

Fig. 6. Test bed configuration for the CEDM

Experimental results are as show in Fig. 7 and Fig. 8.

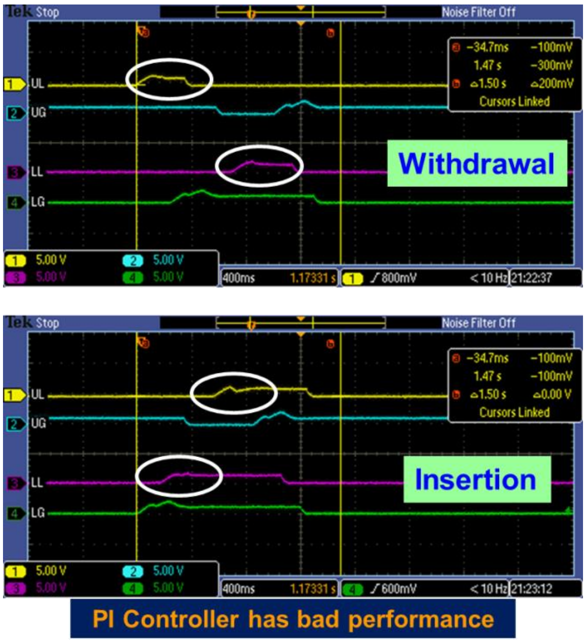

Fig. 7. Experimental results of PI controller under abnormal load condition

The conventional PI controller shows limitation under abnormal load condition. Transient response shows lowered performance. The high level current can not be reached at the target reference value. On the other hand, the modified MRAC shows the improved results in the transient response and the error convergence as shown in Fig. 8.

4. Conclusions

The modified MRAC using the identified reference model with feed-forward gain and 180Hz noise reduction filter presents better performance under normal and/or abnormal condition.

The simplified reference model can make H/W implementation more practical on the viewpoint of less computation and good performance. Actually, the CEDM controller shall be capable of controlling 101 control element assemblies (CEAs) individually in the nuclear power plant. Because the load conditions and the environmental condition around the 101 CEAs are all different minutely, the proposed modified MRAC can be a good practice. The modified MRAC controller will be applied in the real nuclear power plant later and this will overcome some weak point of PI controller.

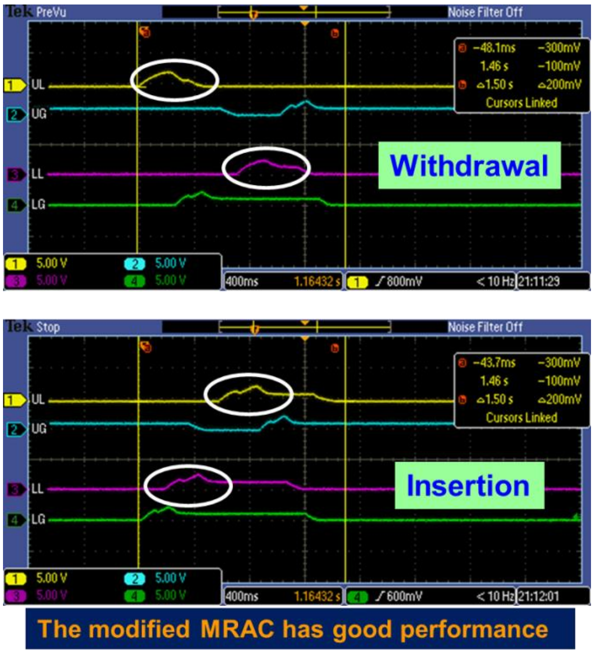

Fig. 8. Experimental results of the modified MRAC controller under abnormal load condition

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