Design of a Model Reference Adaptive Controller Using Modified MIT Rule for a Second Order System

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Abstract

Sometimes conventional feedback controllers may not perform well online because of the variation in process dynamics due to nonlinear actuators, changes in environmental conditions and variation in the character of the disturbances. To overcome the above problem, this paper deals with the designing of a controller for a second order system with Model Reference Adaptive Control (MRAC) scheme using the MIT rule for adaptive mechanism. In this rule, a cost function is defined as a function of error between the outputs of the plant and the reference model, and controller parameters are adjusted in such a way so that this cost function is minimized. The designed controller gives satisfactory results, but is very sensitive to the changes in the amplitude of reference signal. It follows from the simulation work carried out in this paper that adaptive system becomes unstable if the value of adaptation gain or the amplitude of reference signal is sufficiently large. This paper also deals with the use of MIT rule along with the normalized algorithm to handle the variations in the reference signal, and this adaptation law is referred as modified MIT rule. The performances of the proposed control algorithms are evaluated and shown by means of simulation on MATLAB and Simulink

Keywords: Model Reference Adaptive Control, Adaptive Controller, MIT rule, Normalized Algorithm, Modified MIT rule

1. Introduction

Control system is a device to regulate or control the dynamics of any appliance or process. Adaptive control is one of the mostly applied control strategies to design modern control systems to have a better and more precise performance. Model Reference Adaptive Control (MRAC) uses a direct adaptive strategy with adjustable control parameters and a regulatory mechanism to regulate them. In comparison with well-known and simple control systems, structural fixed earnings of PID, adaptive control systems to control unknown parameter variation, and the environmental changes are very useful and effective.

The adaptive control system entails two loops as follows: one external loop with a normal feedback loop and an internal loop or a parameter adjustment loop. The present study deals with designing adaptive control systems using MRAC utilizing MIT rules to control second order systems.

2. Model Reference Adaptive Control System

2-1 Working principle

Model reference adaptive control strategy is used to design adaptive control systems working based on the principle of adjusting control system parameters. Therefore, the output of the real machine follows reference model output which has a similar reference input.

2-2 Constituents

Reference model: to create a simple reaction of an adaptive control system we use reference input.

Controller: it is defined through a set of adjustable parameters. In this research paper, we have used only one θ parameter to define control rule. The amount of θ mainly depends on adaptation earning.

Regulation mechanism: these elements are used to change control parameters. Therefore, the machine can obey the reference model. The mathematical approaches such as MIT, Lyapunov theory, and absolute error theory can be utilized to create an adjustment mechanism. In this article we have used MIT rule with a normalized algorithm and this technique is introduced as MIT rule. The major block diagram of MRAC system has been represented in figure 1. As it has been shown in the figure, $Y_m(t)$ is the reference model output, and Y(t) is known as the output of the real machine and their difference is shown with e(t).

$$e(t) = y(t) - ym(t) \quad (1)$$

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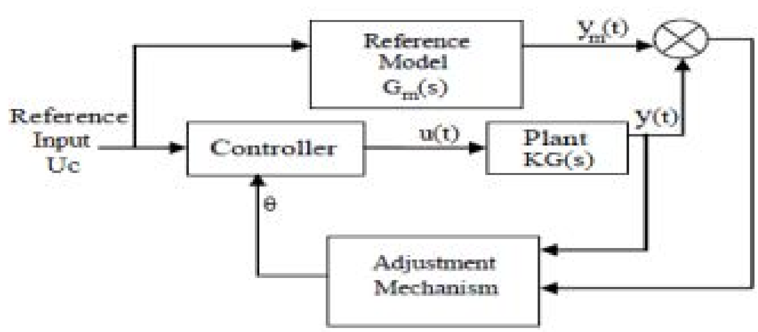

Fig.1. Model Reference Adaptive Control System

1) MIT rule

MIT rule was first created by researchers in Massachusetts Institute of Technology (MIT) in 1960 and was utilized to design an autopilot system (automatic pilot). MIT rule is used to design a controller with MRAC sketch for any system. In this rule, the expense function is defined as follows:

$$e^2 J(\theta)= /2 \quad (2)$$

Where, e is the error between machine input and the model and θ is the adjustable parameter. The parameter θ is adjusted in a

way that the function of expenses is decreased to meet 0. For this reason, changing the θ parameter in the direction of negative gradient J is maintained.
This means:

$$\frac{d\theta}{dt} = \gamma \frac{\partial J}{\partial \theta} \qquad (3)$$

And regarding equation (2)

$$=-\gamma e \frac{\partial e}{\partial \theta} \frac{d\theta}{dt} \qquad (4)$$

Where, the relative deviation of $\frac{\partial e}{\partial \theta}$ is stated as system sensitivity deviation. This equation shows that how error amount changes regarding the parameter θ and equation (3) defines the parameter θ considering the time. Therefore, the expense function of J(θ) is reduced to 0. Y is a positive amount which represents adjustment earning of the control system.
Let's presuppose that the process is linear considering the transfer function of KG(s), where K is the unknown parameter and G(s) is second order auxiliary transfer function. Our goal is to design a control system and thus the processes can follow the reference model with transfer function of $G_m(s)=K_0G(s)$, where K_0 is the known parameter (auxiliary parameter).

$$E(s) = KG(s) - K_0\, G(s)U_c(s) \qquad (5)$$

The definition of control rule:

$$u_c\mathrm{u(t)} = \theta^{*} \qquad (6)$$

Regarding equation (5,6) and partial differentiation

$$\frac{K}{K0} = \mathrm{KG(s)Uc(s)} = \frac{\partial \mathrm{E(s)}}{\partial \theta}\mathrm{Ym\ (s)} \qquad (7)$$

Considering equation (4) and equation (7), we can observe that:

γ^' - = ym =-γe K/K0 dθ/dtym e (8)

Equation (8) has created a rule to adjust parameter θ and Simulink model has been represented in figure 2. Regarding the results of simulation we can see that the machine reaction depends on adjustment earning Y. In some industrial machines, the amounts higher than Y can be identified as system inconsistency factor and it is necessary to select such a parameter.

3. Optimized VSD Controller

The solution that we have proposed is to adjust PI factors automatically based on system behavior. Here the key is to drive electro-motor with nominal speed while the compressor pressure and adjusted pressure are extremely different and decrease the motor speed while the compressor pressure is close to adjusted value.

Screw compressor modeling combines the analysis of thermodynamic and fluid flow processes. Both are dependent on the screw compressor geometry and combining them in a mathematical model is a complex process [7]. Thus, the proposed method is based on actual experiences and practical tests.

3-1- P Coefficient Adjustment

In order to adjust P factor, it is needed to compare compressor output pressure with adjusted pressure which is defined as error. The amount of error controls the P factor. While the error is more than 0.3, the P factor is constant and was measured from the VSD control of an air compressor as 300.

$$P(n) = 300\ (Set\ by\ Operator), if \quad |Error(n)| > 0.3 \tag{9}$$

To obtain reasonable system gain, in the moment the error value is less than 3, the P factor will decrease as follows:

$$P(n) = 110.3 \times exp(|Error(n)|), if \quad |Error(n)| <= 0.3 \tag{10}$$

In this system, the pressure amounts are normalized.The result is depicted in fig.2. And it shows the small overshoot of system [8].

3-2- I coefficient adjustment

While a compressor is operating, the motor speed it is being sampled by control system to obtain a period cycle. Also the maximum and minimum amounts of a period cycle were compared. The motor speed vibrations are high if the maximum and minimum amounts of motor speed are more than 100 RPM.

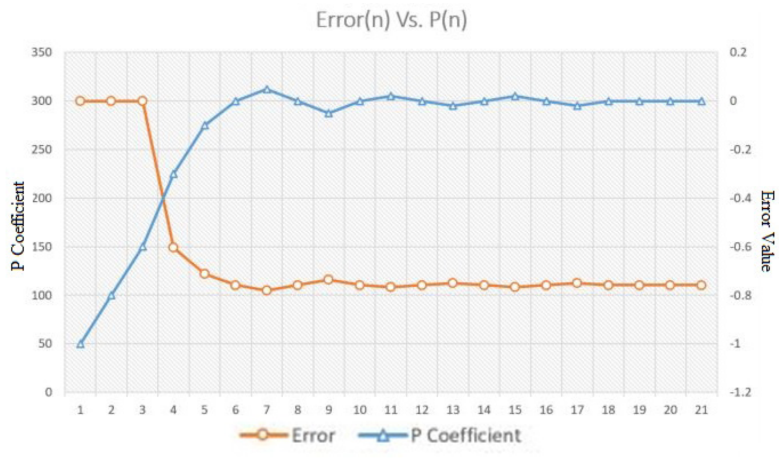

Fig.2. "P" coefficient changes in proportion of error changes

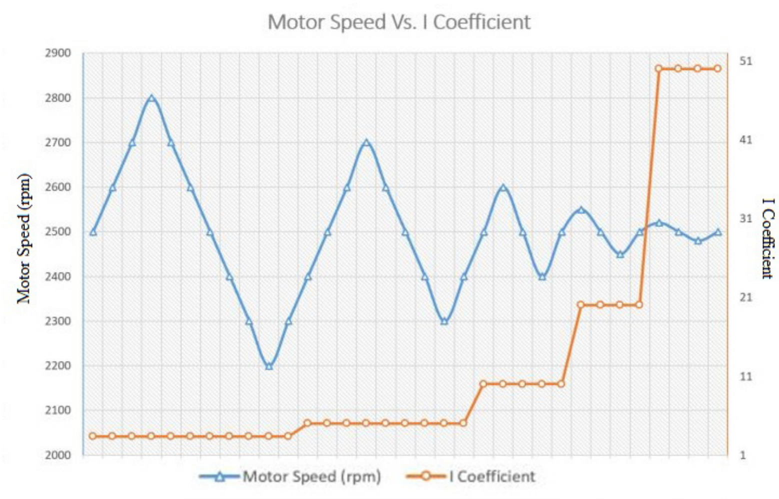

Fig.3. Effects of variation of "I" coefficient magnitude on motor speed vibrations

It can be seen in fig.3 that when the amplitude is more than 100 RPM, the I coefficient is increased as follows:

$$I(n) = 100[0.05\, x\, [max(Pres(n)) - min(Pres(n))]]; \quad if\ cycle\ available\ \&\ I(n) < 50 \tag{11}$$

$$\mathrm{I(n)} = 50; \quad \text{if cycle available } \&\ I(\mathrm{n}) \geq 50 \tag{12}$$

The control system will fix the I factor while the amplitude is low. This value is measured from VSD controller.

$$I(n) = 3.3(default\ value);\ no\ cycle; \tag{13}$$

4. Modular Controller Board

The proposed controller board presents practical features for subsequent uses and also it is particularly designed for industrial applications. All the parameters (except motor speed) are measured by this hardware. At the input level; there are 2 inputs to connect to pressure sensors and 2 inputs for RTD temperature sensors, and for the speed monitoring the Combivis 5 software is used.

To simplify hardware renovation and maintenance job, the essential components such as pressure and temperature sensors inputs, the current command output, and the Modbus network are implemented on various modules. In addition, the screen and control knobs are designed separately due to easier installation. Controller board is shown in fig.4, the overall architecture and the modular parts are presented in (a) and (b), respectively.

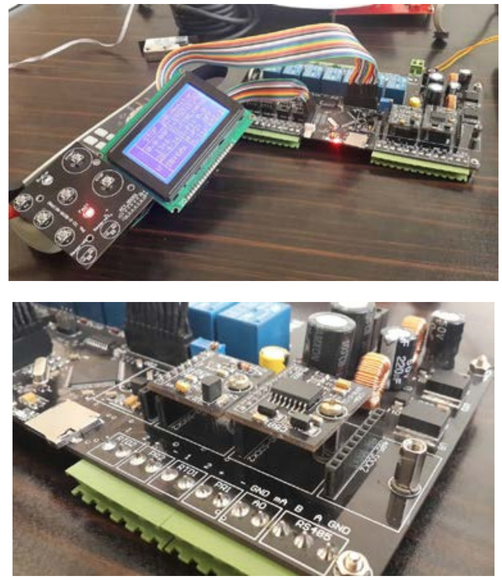

Fig.4. (Upper) Controller board. (Down) Modular parts of controller board

5. Practical Test Results

The designed controller board is tested on GA111 compressor of Atlas Copco Company which is shown in fig.5. Following diagrams are obtained from discrete data produced by Combivis 5 software which is able to connect to the mentioned compressor inverter. The responses of proposed optimized VSD in comparison to VSD are shown in fig.6 and fig.7. As it is shown in fig.6, after about 2 seconds the output pressure tracks the set-point adjusted by operator with an extremely low overshoot and acceptable oscillation (1% of full-scale value). The result shows that pressure stability is improved 40%. Fig.7 shows the electro-motor speed vibrations improvement of optimized VSD control compared with VSD control.

Fig.5. GA111 compressor of Atlas Copco Company

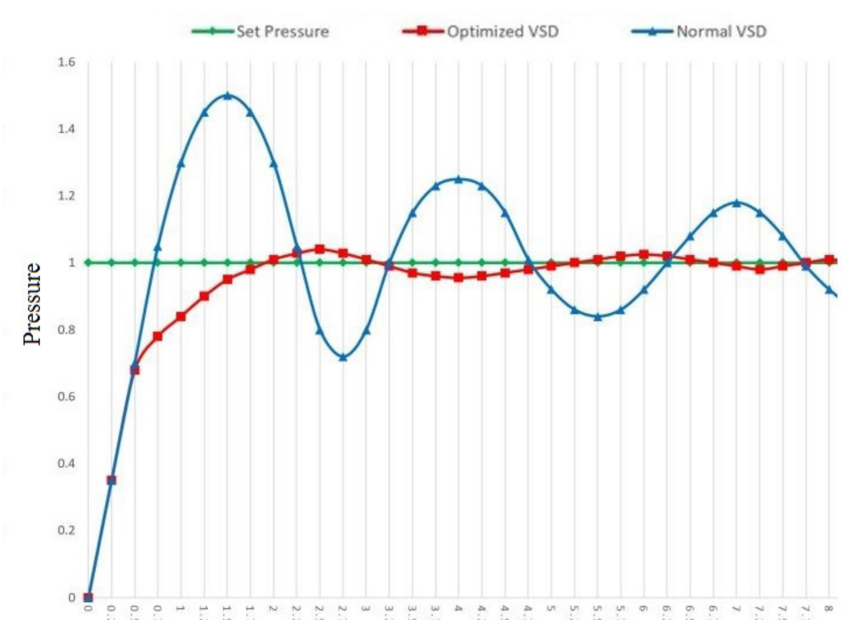

Fig.6. Comparison of output pressure of VSD and optimized VSD

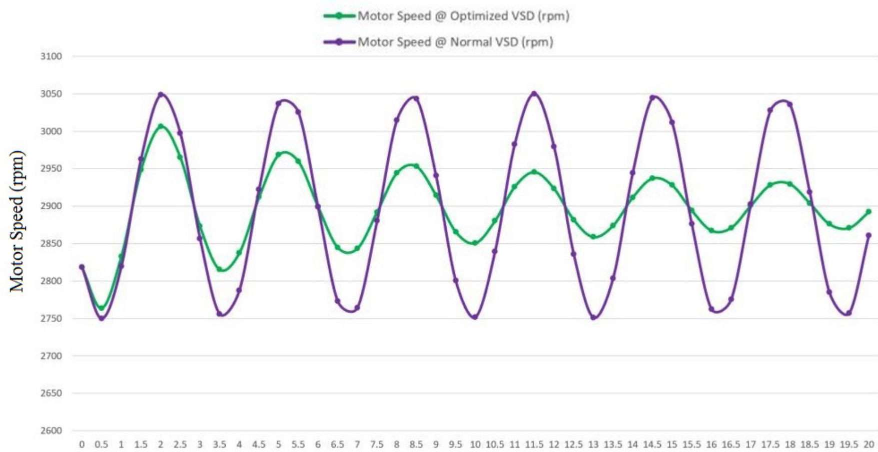

Fig.7. Comparison of speed of VSD and optimized VSD electro-motor

6. Conclusions

In this paper, a new method of screw air compressor control has been described. The complexity of an air compressor modeling made us to present this algorithm through actual experiences and practical tests. This project includes software and hardware designing for VSD controller optimizing purpose. The prototype electrical board was built and has been tested on a GA111 compressor. It has been proved that PI factors adjustment improves the pressure and motor speed vibrations stability. Reasonably good success has been achieved such as energy saving, system stability and depreciation reduction. Analysis of optimized VSD control effects is given through this practical test.

This article and further works could be helpful for this high consumption system to favor system stability and electrical power saving. Further works would be dedicated to torque stability using a closed loop system. Also it is used to test this method on a high range compressor (e.g. 250 kW).

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