MRAC Based PI Controller for Speed Control of D.C. Motor Using Lab View

SUMIT KUMAR SAR
M.TECH.
LILLIE DEWAN
PROFESSOR
DEPARTMENT OF ELECTRICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY KURUKSHETRA
INDIA
sinukumarsar@gmail.com, ldewanin@gmail.com,l_dewan@nitkkr.ac.in

Abstract –When the parameter of any systems changes with respect to time then the constant gain PI controller action is not effective. In case of MRAC based design the adjustable PI gain parameters corresponding to changes in plant will be determined by referring to reference model specifying the property of desired control system. This paper presents the method to design MRAC based PI controllerfor speed control of D.C. motor using Lab VIEW software tool.

Key words: MRAC, Adaptive Control, LabVIEW, DC Motor

1 Introduction

Since due to wear, aging, breakdown and the changes in environment where the plant operates, the parameters associated with it may undergo a change. In such case the constant gain PI controller cannot satisfy the performance specification. In such cases the MRAC (Model Reference Adaptive Control) is a good choice. The MRAC was first proposed to solve the autopilot control problem. In the MRAC system the desired performance are given in terms of a reference model and each time an error is generated by comparing actual and desired output and by considering this error , using suitable algorithm the gain expressions of the controller is obtained. [1,2]

LabVIEW (short for Laboratory Virtual Instrument Engineering Workbench) is a system-design platform and development environment for a visual programming language from National Instruments.[3],[7],[8]. This tool has wide range of application in all most all branch of engineering such as, in Robotics ,image processing, nuclear physics biomedical, adaptive and digital filter design, signal processing , spectral measurements, system identification , controller design like PID, Fuzzy logic controller etc. Specifically in control field it is widely used in temperature ,level , optimal, robust, adaptive controller design The speed of real time D.C. motor has been controlled and the model of closed loop system has found out using NI USB-6008 DAQ card.[9]. The PID controller has designed, using LabVIEW control system toolkit. D.C. servo motor position control has been achieved using PID control algorithms [10]. A novel hardware design methodology has been developed for digital control systems using LabVIEW FPGA module from National Instrument (NI) instead of Very high speed integration circuit Hardware Description Language (VHDL)[11]. LabVIEW 8.5 Package is used for design and implementation of a personal computer based closed loop DC motor speed control system.[12]. Aa PID controller is designed for speed control of D.C. motor for both simulation purpose and hardware implementation purpose using Lab VIEW 8.5.[13]

The MRAS based controller has been designed and tested through various software tool. In this paper an attempt has been made to design and implement the adaptive controller using the graphical programming language Lab VIEW.

This paper first introduces the D.C. motor, the MRAC control schemes and design procedure for PI controller using MIT rule. Next the adaptiveness of the designed controller is tested using Lab View software tool and finally ends up with the conclusions followed by references.

2 The D.C. motor

DC motor system is a separately excited DC motor, which is often used to the velocity tuning and the position adjustment. The well established control equivalent circuit of the DC motor using the armature voltage control method is shown in Fig.1

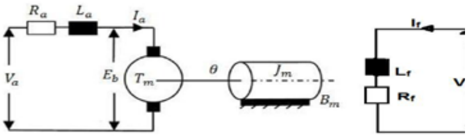


Fig. 1 Separately Excited DC Motor Model

Where Ea is the armature voltage. (In volt), Eb is back emf the motor (In volt) ,Ia is the armature current (In ampere) ,Ra is the armature resistance (In ohm) ,La is the armature inductance (In henry) ,Tm is the mechanical torque developed (In Nm) ,J is moment of inertia (In kg/m²) ,B is friction coefficient of the motor (In Nm/ (rad/sec)) ,ω is angular velocity (In rad/sec) [6].

In the above schematic of the D.C. motor using armature voltage control method a set of mathematical equation can be written representing it and by some arrangement its transfer function can be obtained as

$$G(s) = \frac{W(s)}{Ea(s)} = \frac{K_T}{(L_a s + R_a)(Js + B) + K_b K_T}$$

The above transfer function represented by a block diagram is as in Fig.2

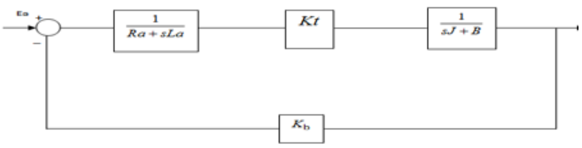


Fig2 .Block Diagram Of Separately Excited D.C. Motor

The armature inductance is very small in practice; hence, the transfer function of DC motor speed to the input voltage of equation can be simplified as

$$\frac{w(s)}{E_a(s)} = \frac{K_m}{\tau s + 1}$$

3 Model Reference Adaptive Control

The adaptive control theory provides an approach to design of uncertain systems. Unlike the fixed parameter controller the adaptive controller adjust their behavior on-line to the changing property of the controlled processes.

The main difference between the conventional control and adaptive control is the presence of adaption mechanism. The main issue in adaptation design is to synthesize an adaption mechanism which will guarantee that the control system remains stable and tracking error converges to zero even if the parameters are varied.

The block diagram of the MRAC system is shown IN Fig.3 [1] ,

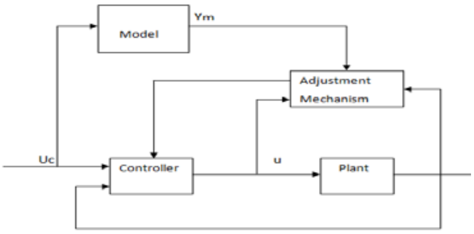


Fig. 3 MRAS Block Diagram

The system has an ordinary feedback loop composed of plant and the controller(also known as inner loop) and another feedback loop that changes the controller parameters(also known as outer loop). The parameters are changed on the basis of feedback from error which is the difference between the output of the system and the output of the reference model.

The MRAC technique is based on information u, y ,y_m & u_c for the design of the controller. The desired performance in MRAC is given in terms of a reference model which in turn gives the desired response to the command signal.

The key problem in MRAC is to determine the adjustment mechanism. There are various adjustment mechanism of MRAC system like MIT rule, Lyapunov theory, passivity theory etc. Here the MIT rule adaption mechanism is used to tune the controller parameter.

3.1 The MIT Rule

The time rate of change of controller parameter vector θ is proportional to negative gradient of *J*. The MIT rule approach aims to minimize the squared model cost function. Because as the error function becomes minimum there will be perfect tracking between actual plant output (y) and reference model output (y_m). In MRAC it is assumed that the structure of the plant is known although the parameters are not known i.e. the number of poles and zeros are assumed to be known but there locations are not known. [1],[2].

Mathematically if

$$e = y - y_m$$

$$J(\theta) = \frac{1}{2} e^2(\theta)$$

Then according to MIT rule

$$\frac{d\theta}{dt} = -\gamma \frac{\partial J}{\partial \theta} = -\gamma e \frac{\partial e}{\partial \theta}$$

Where J: cost function

θ: Controller parameter vector

e: Error between actual plant and reference model

y: Actual plant output

y_{m}: Reference model output

γ: Adaption gain

$\frac{\partial e}{\partial \theta}$: Sensitivity derivative of error w.r.t. θ

3.2 Design of PI controller using MRAC

The output of a PI controller in accordance to the error as input is given as

$$u(s) = [k_p + \frac{k_i}{s}]e(s)$$

Since it is assumed that the structure of the plant is known even though there exact parameters are not known, Now in this case the motor transfer function is of first order, where b=K_m/τ and a=$1/\tau$

$$\frac{y(s)}{u_c(s)} = \frac{b}{s+a}$$

After introduction of the PI controller to the plant the structure becomes

$$\frac{y(s)}{u_{(c)}(s)} = \frac{b(k_p s + k_i)}{s^2 + s(a + bk_p) + bk_i}$$

So the reference model can also be assumed of the form as so let it be

$$\frac{y_m(s)}{u_c(s)} = \frac{b_{m1}s + b_{m2}}{s^2 + a_{m1}s + a_{m2}} \quad \text{........(1)}$$

In this MRAC PI controller the plant ,model and controller can be put into a block diagram as follows

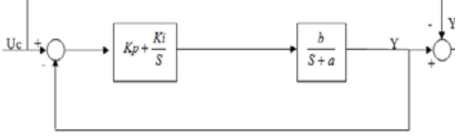


Fig 4 MRAC PI controller Block Diagram

Now the MIT rule can be applied to motor to obtain the controller parameters . Since the controller parameter vector u=[k_p , k_i] the MIT rule can be written as will be splitted up into two parts as follows

$$\frac{dk_p}{dt} = -\gamma_p (\frac{\partial J}{\partial k_p}) = -\gamma_p (\frac{\partial J}{\partial e})(\frac{\partial e}{\partial y})(\frac{\partial y}{\partial k_p}) \quad \text{..... (2)}$$

$$\frac{dk_i}{dt} = -\gamma_i (\frac{\partial J}{\partial k_i}) = -\gamma_i (\frac{\partial J}{\partial e})(\frac{\partial e}{\partial y})(\frac{\partial y}{\partial k_i}) \quad \text{........(3)}$$

But $e = y - y_m \Rightarrow \frac{\partial e}{\partial y} = 1$

And $\frac{\partial J}{\partial e} = e$

Using these relation in Eq.2 & Eq.3 it becomes

$$\frac{dk_p}{dt} = -\gamma_p (\frac{\partial J}{\partial k_p}) = -\gamma_p e(\frac{\partial y}{\partial k_p})$$

$$\frac{dk_i}{dt} = -\gamma_i (\frac{\partial J}{\partial k_i}) = -\gamma_i e(\frac{\partial y}{\partial k_i})$$

Now to find $\frac{\partial y}{\partial k_p}$ and $\frac{\partial y}{\partial k_i}$ Eq.1 can be used by differentiating it as follows

$$\frac{y(s)}{u_{(c)}} = \frac{b(k_p s + k_i)}{s^2 + s(a + bk_p) + bk_i}$$

$$\Rightarrow y(s^2 + s(a + bk_p) + bk_i) = b(k_p s + k_i)u_c$$

….(4)

Differentiating Eq.4 w. r. t. k_p

$$[y \frac{\partial}{\partial k_p}(s^2 + (a + bk_p)s + bk_i)] +$$

$$[(s^2 + s(a + bk_p) + bk_i)\frac{\partial y}{\partial k_p}] = \frac{\partial}{\partial k_p} bu_c (k_p s + k_i)$$

$$\Rightarrow \frac{\partial y}{\partial k_p} = b \frac{s}{s^2 + s(a + bk_p) + bk_i}(u_c - y)$$

.....(5)

Similarly differentiating Eq.4 w. r. t. k_i

$$[y\frac{\partial}{\partial ki}(s^2+(a+bk_p)s+bk_i)]+$$

$$[(s^2+s(a+bk_p)+bk_i)\frac{\partial y}{\partial k_i}]=\frac{\partial}{\partial k_i}bu_c(k_ps+k_i)$$

$$\Rightarrow\frac{\partial y}{\partial k_i}=b\frac{1}{s^2+s(a+bk_p)+bk_i}(u_c-y)$$

....(6)

Substituting Eq.5 & Eq. 6 in Eq.2 & Eq.3

$$\frac{dk_p}{dt}=-\gamma_p e\frac{bs}{s^2+s(a+bk_p)+bk_i}(u_c-y) \qquad \text{.....(7)}$$

And

$$\frac{dki}{dt}=-\gamma_i e\frac{b}{s^2+s(a+bk_p)+bk_i}(u_c-y) \qquad \text{.......(8)}$$

From these two equation the gain parameters can not be found out since the value of the a & b are not known.

So defining

$$a_{m1}=a+bk_p$$

$$a_{m2}=bk_i$$

$$\gamma^l=\frac{\gamma b}{a_{m1}}$$

Now Eq.7 & Eq.8 becomes

$$\frac{dk_p}{dt}=-\gamma_p{}^l e\frac{a_{m1}s}{s^2+s(a+bk_p)+bk_i}(u_c-y) \qquad \text{...(9)}$$

And

$$\frac{dki}{dt}=-\gamma_i{}^l e\frac{a_{m1}}{s^2+s(a+bk_p)+bk_i}(u_c-y) \qquad \text{....(10)}$$

Eq. 9& Eq.10 are the controller design equation i.e. the adaption mechanism of the controller, these two equation can be used in the MRAC block as represented in Fig.5.

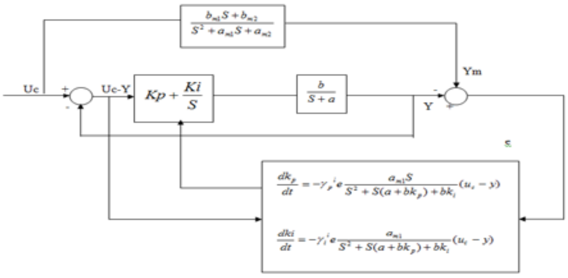


Fig 5 Block Diagram Of Adaptive PI Controller

4 LabVIEW

LabVIEW is a graphical programming language.The most important factor of Lab View is that not a single line code has to be written by following some particular syntax ,in this case the icons for various applications are readily available so it just need to dragging the various icons of interest and connecting them that will work satisfactorily.

It provides the flexibility of integration of data acquisition with the process control application software for automated test and measurement applications.

The above block diagram can be programmed using Lab View software tool and the result can be verified as follows [3-5]

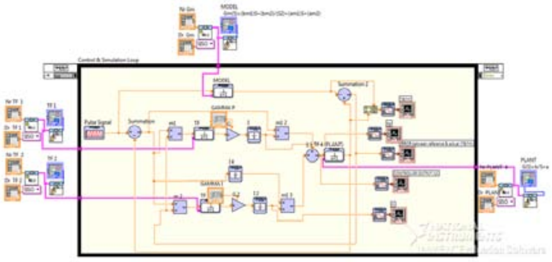


Fig6 VI of Adaptive PI Controller

Executing the above VI the following are observed

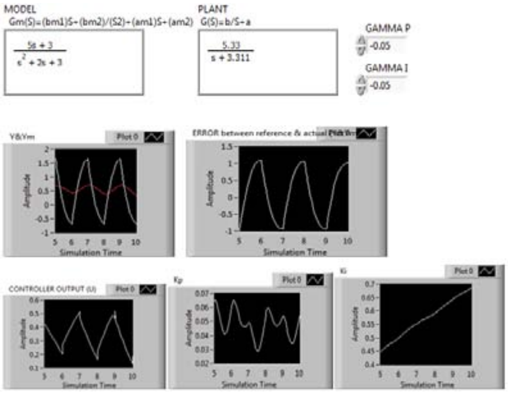
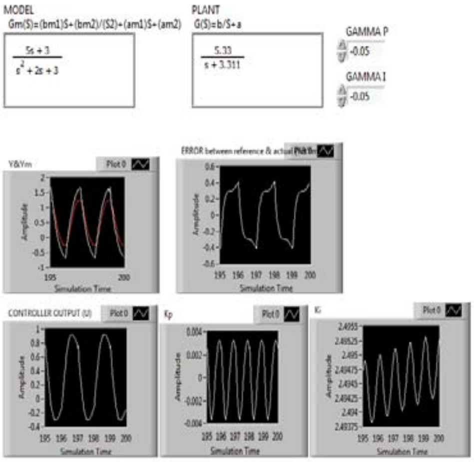


Fig. 6.1(A) Simulation Result of Motor Transfer Function

In the above VI if the simulation time is increased the following are observed


MODEL Gm(S)=(bm1)S+(bm2)/(S2)+(am1)S+(am2)

$\frac{5s+3}{s^2+2s+3}$

PLANT G(S)=b/S+a

$\frac{5.33}{s+3.311}$

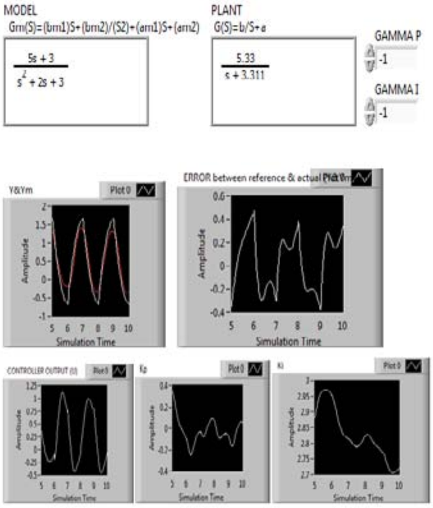
GAMMA P -0.05

GAMMA I -0.05

Observation

By increasing the execution time of the program the transient portion has died out and the output is tracking the desired output.

In the above VI if the adaption gain parameter is increased then the following are observed.


MODEL Gm(S)=(bm1)S+(bm2)/(S2)+(am1)S+(am2)

$\frac{5s+3}{s^2+2s+3}$

PLANT G(S)=b/S+a

$\frac{5.33}{s+3.311}$

GAMMA P -1

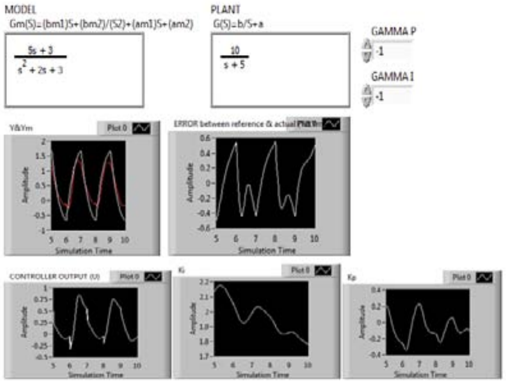
GAMMA I -1

Fig 6.1(B) Simulation Result Of Variation Of Adaption Gain

Observation

By increasing the adaption gain value the transient died out rapidly and the tracking is also happening fastly ,so the controller designed here is acting satisfactorily .

To see the adaptive nature of the designed controller the plant parameter can be varied by keeping the reference model as it is before and the response can be checked


MODEL Gm(S)=(bm1)S+(bm2)/(S2)+(am1)S+(am2)

$\frac{5s+3}{s^2+2s+3}$

PLANT G(S)=b/S+a

$\frac{10}{s+5}$

GAMMA P -1

GAMMA I -1

Fig 6.1(C) Simulation Result Of Variation Of Plant Parameter

Observation

Even though the parameters of the plants are varied and the reference model is same as before due to the adaptive nature of the controller still the actual and the desired outputs are tracking properly and hence the designed controller is working satisfactorily.

5 Conclusion

The simulation results reveals that the proposed method is an effective control scheme for the plants having time varying parameter. The designed PI controller using MRAC scheme for motor can faithfully adjust controller parameters corresponding to change in plant parameters. In case of the adaptive controller design the adaption gain has selected manually and the variation in the response has observed, an algorithm can be developed to find this adaption gain . Apart from this the controller that has been designed and simulated can be implemented in a physical motor and its performance can be tested

References

[1] Astrom, K.J., and B. Wittenmark; Adaptive control; 2nd Edition: Prentice-Hall ,1994

[2] Narendra, K.S. and A.M. Annaswamy; Stable Adaptive System: Dover Publication,2005.

[3] Lab VIEW Basics I Course Manual, National Instruments, 1999

[4] Lab VIEW PID Control Toolset User Manual, National Instruments, 2001.Liau, J. C., A Study of Lab VIEW Aided in DC Motor Speed Monitoring System. National Taiwan Ocean

University Department of Mechanical & Mechatronic Engineering, 2000.

[5] Using the LabVIEW PID Control Toolkit with the LabVIEW Control Design and Simulation Module Sep 2009

[6] Kuo, B.C.and F.Golnaraghi; Automatic Control System : John Willey 2003

[7] Spoelder, H.J.W., "*Virtual instrumentation and virtual environment*", IEEE instrumentation and measurement magazine, 2(3), 14–19, 1999

[8] Saco, R., Pires, E.,Godfrid, C., "*Real Time Controlled Laboratory Plant for Control .Education*", *IEEE Frontiers in Education Conference*, pp. T2D12 – T2D16, 2002

[9] Kiran Raj A S , Manoj Kumar T, Mansi S Surana, Prem Kumar M P, Suchithra R , Varun K "LabVIEW Based PID Speed Control and System Identification of a PMDC Moter", International Conference on Computing and Control Engineering (ICCCE 2012), 12 & 13 April, 2012 .

[10] U. Karthikeyan and K.R. Jayachitra, "Real - Time DC Servo Motor Position Control by PID Controller Using Labview", Conference on Computing and Control Engineering (ICCCE 2012), 12 & 13 April, 2012.

[11] Fakhrulddin H. Ali, Mohammed Mahmood Hussein and Sinan M.B. Ismael Iraq J., "LabVIEW FPGA Implementation Of a PID Controller For D.C. Motor Speed Control", Electrical and Electronic Engineering Vol.6 No.2, 2010.

[12] Areej Alaa Hassen, "Real Time Digital Speed Control System for DC Servo Motor Using LabVIEW", Eng. & Tech. Journal ,Vol.28, No.6, 2010.

[13] EFFIZUL SYAFRIN BIN ABU BAKAR, "Lab VIEW PID speed controller for DC motor", (This project is submitted as partial fulfilment of the requirements for the award of the Degree of Bachelor of Electrical Engineering (Electronics) Faculty of Electrical & Electronics Engineering University Malaysia Pahang 17 NOVEMBER 2008).