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DESIGN AND CONTROL OF LORENTZ FORCE MICRO ACTUATOR

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ABSTRACT
In this current paper LabVIEW based PID control system, DAQ Modules, L298N Motor Driver and Potentiometer Feedback Device is used to control the linear motion of voice coil motor in micron. All the program and control logic is written in LabVIEW software, which gives controller signal/data to DAQ module. DAQ systems are bridge fulfilling the gap between the LabVIEW software and other hardware. Different DAQ Module like NI 9401 is used to drive VCM in forward and backward direction, NI 9269 DAQ Module is used to control PWM signal and NI 9205 DAQ Module is used to acquire Potentiometer data. Motor Driver L298N is used as amplifier for our Voice Coil Motor. Potentiometer is used as feedback device, which gives current positional data to controller system. A mathematical model of VCM is proposed by assuming some of its characteristic and its dynamics behavior and linear response is observed under different conditions.

Keywords: VCM, PID Controller, Linear Motion, LabVIEW, DAQ Modules, L298N Motor Driver, Linear Potentiometer.

INTRODUCTION
Nowadays the use of motor is almost every place or on any devices. Since it was invented, it is necessary to control and use them in efficient way. We can control the DC motor in aspect of speed, torque, position and acceleration. Since the application of DC motor is increasing day by day from aerospace to robotic manipulation precision control of DC motor have become unavoidable and necessary. A voice coil motor is termed as non-commutated Direct Current motor is a type of direct linear motor which works on Lorentz force principle. Voice coil motor consist of a permanent magnet and coil assembly, in this case a force vector is generated when a current carrying conductor i.e. coil of wire is placed in a magnetic field produced by permanent magnet. By changing the polarity of the applied current flowing across the coil, the produced force vector can be reversed. It means that the voice coil motor can give bi-directional linear movement by changing the polarity of applied current.

Fig.1. Voice Coil Motor

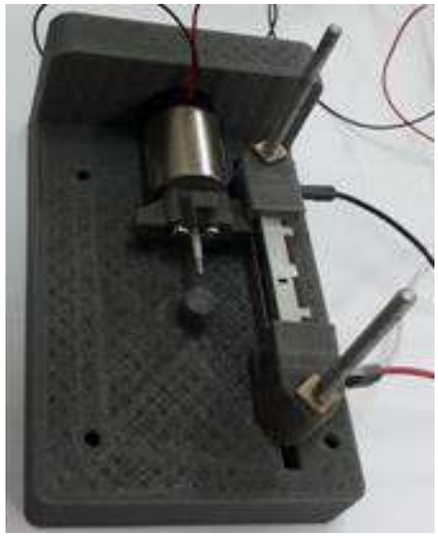


Fig. 2. Micro Positioning Actuator Assembly

Voice coil motor has constant force over its stroke, except at the beginning and end of the stroke. Voice coil motors are the devices which are used to provide high speed and highly accurate linear motion. Due to its compact size and light body weight, VCMs have capability to achieve micro positioning; hence we can use VCM for micro manufacturing and micro scanning, mirror tilting, automatic image focusing, integrated circuit, hard disk drive, robotic arm manipulation, in manufacturing process of integrated circuit designing, in additive manufacturing for upward and downward movement of bed and accurate positioning of nozzle. We can also use VCM in biomedical science for laser eye surgery [6]. Even in miniaturization device precision technology plays very important role [4,7]. Lately, precision and accurate positioning systems and technology has developed expeditiously. For fast, accurate and error- free product and system manufacturing technology required high speed and high precision manufacturing tools and equipment. For controlling angular position of stepper DC motor ATMEGA 2560 Microcontroller is used and they have designed their own fuzzy logic controller. This fuzzy logic consider the error as well as the change of error, and then gives the signal to the controller to control the DC motor. They have evaluated some graph and they come to the conclusion that the proposed hybrid controller, best performance controlling the position of the stepper motor [2]. Arduino ATmega328 microcontroller, Hall-effect Sensors, MOSFET Bridge and Optocoupler has been used to control the speed of brushless DC motor. Arduino ATMEGA328 microcontroller with 6 PWM is used to give the input voltage to BLDC motor and also used to take the feedback signal from the Hall-effect sensors. Position sensors such as Hall sensor are used to detect rotor position [9]. A PC based angular position control of Permanent Magnet DC Motor is controlled using Data Acquisition System. The comparator compares the set value and actual value and gives the error signal to the PID controller. Then the PID sends the controlled signal to the Data Acquisition System and then the Data Acquisition System sends signal to the Motor Driver. The Motor driver has H-bridge driver circuit which is used to change the polarity of voltage which causes the motor to rotate in clockwise and anticlockwise [3]. Design and fabrication of VCM with linear and Rotary movement on same shaft i.e. output shaft can rotate clockwise and anticlockwise and can translate to and fro position can be done. It can be equipped with inbuilt linear and rotary encoders. For controlling DSP (Digital Signal Processor) and improved PID controller is used. The result shows 5µm and 3’ steady state Error without overshoot with settling time as 48ms and 70.4ms respectively for linear and angular positioning when linear and angular position are set as 5mm and 15 degrees [4]. As we know VCM motor has low inertia, lightweight and fast response and due to its nonlinear electro-magneto-mechanical characteristics, it is very different to find out the exact VCM model parameters. To cope with this the author has developed his own perturbation wavelet neural sliding mode position control (PWSPC) system, which works on Type-2 Fuzzy Logic controller. The PWNN approximator uses perturbed wavelet functions to handle the rules uncertainties like interval type-2 fuzzy sets. The structure learning ability enables the PWNN approximator to evolve its structure online. Linear Encoder Sensor is used as feedback device and QEI (Quadrature Encoder Interface) is used to provide PWM (Pulse Width Modulation) signal [5]. In this study we have tried to design a controller which can control the linear motion of VCM in microns using PC based LabVIEW system, DAQ Modules, L298N motor controller and Linear potentiometer.

Transfer Function

By applying Kirchhoff's voltage law to VCM Circuit

$$V_{in} - L\frac{di}{dt} - i\,R - \mathcal{E} = 0 \tag{1}$$

Here, V_{in} = Applied voltage, L = Armature inductance,

R = Armature resistance and $\mathcal{E}$ = Back EMF

By Newton's second Law

$$\left.\begin{aligned} M\ddot{x} &= F - b\dot{x} \\ M\ddot{x} + b\dot{x} &= F \end{aligned}\right\} \tag{2}$$

Now,

$$\text{Power} = F\dot{x} = \mathcal{E}\, i \tag{3}$$

Since F=ki and $\mathcal{E}$ =k$\dot{x}$ (4)

$$M\ddot{x} + b\dot{x} = k\,i \tag{5}$$

Here, M = mass of VCM, i = armature current, k = motor force constant and b= damping coefficient

By taking Laplace of (5)

$$Ms^2X + bsX = kI \tag{6}$$

$$I = \frac{(Ms^2 + bs)}{k} X \tag{7}$$

Now from (

$$V_{in} - L\frac{di}{dt} - iR - k\dot{x} = 0 \tag{8}$$

By taking Laplace of (8)

$$\left.\begin{aligned} V_{in} - LsI - IR - ksX &= 0 \\ V_{in} = LsI + IR + ksX &= I\,[\,Ls + R\,] + ksX \end{aligned}\right\} \tag{9}$$

By substituting value of I in (9)

$$V_{in} = \frac{(Ms^2 + bs)}{k} X\,(Ls + R) + ksX = X\left[\frac{(Ms^2 + bs)(Ls + R)}{k} + ks\right]$$

$$\frac{X}{V_{in}} = \frac{k}{(Ms^2 + bs)(Ls + R) + k^2 s} \tag{10}$$

Now,

M = Total mass of VCM = Body mass of VCM + Coil assy mass of VCM + mass of coupler

= 17 (gms) + 9 (gms) + 1.99 (gms) = 27.99 (gms) = 0.028 kg

k = Force constant = 1.7 N/A , Coil Inductance L = 0.8 mH

Case 1: Assuming inductance L<<< R, therefore neglecting L (L=0) and damping force bs = 0.2 N

$$\frac{X}{V_{in}} = \frac{k}{(Ms^2+bs)(Ls+R)+k^2\,s} = \frac{k}{(Ms^2+0.2)(0+R)+k^2\,s} = \frac{1.7}{0.1288\,s^2+2.89\,s+0.92} \quad (11)$$

Case 2: Assuming inductance L<<< R, therefore neglecting L (L=0) and damping force bs = 1.2 N

$$\frac{X}{V_{in}} = \frac{k}{(Ms^2+bs)(Ls+R)+k^2\,s} = \frac{k}{(Ms^2+1.2)(0+R)+k^2 s} = \frac{1.7}{0.1288\,s^2+2.89\,s+5.52} \quad (12)$$

Case 3: Taking inductance L = 0.8 mH and damping force bs = 0.2 N

$$\frac{X}{V_{in}} = \frac{k}{(Ms^2+bs)(Ls+R)+k^2\,s} = \frac{k}{(Ms^2+0.2)(Ls+R)+k^2\,s} = \frac{1.7}{0.0000224s^3+0.1288\,s^2+2.8916s+0.92} \quad (13)$$

Case 4: Taking inductance L = 0.8 mH and damping force bs = 1.2 N

$$\frac{X}{V_{in}} = \frac{k}{(Ms^2+bs)(Ls+R)+k^2\,s} = \frac{k}{(Ms^2+1.2)(Ls+R)+k^2\,s} = \frac{1.7}{0.0000224\,s^3+0.1288\,s^2+2.89112s+5.52} \quad (14)$$

Case 5: Taking inductance L = 0.8 mH and damping coefficient b= 0.1Nms

$$\frac{X}{V_{in}} = \frac{k}{(Ms^2+bs)(Ls+R)+k^2\,s} = \frac{k}{(MLs^3+bLs+MRs^2+bRs)+k^2\,s} = \frac{1.7}{0.0000224\,s^3+0.12888\,s^2+3.35s} \quad (15)$$

Control System Algorithms and Simulation

With the help of Control Design and Simulation module available in LabVIEW, user can easily simulate dynamic systems, can design sophisticated controller and can derive certain dynamic characteristics of that system and deploy it to Real-Time hardware. LabVIEW Control Design is a systematic process that involves deriving mathematical models of certain physical systems, and to learn about their dynamic characteristic by analyzing the models and finding of certain dynamic characteristics. With the application of LabVIEW Control Design and Simulation Module, user can construct plant of a dynamic system using Transfer Function, Zero-Pole gain or State Space Equation. By using Simulation Module of LabVIEW we can insight into the behavior of dynamic system and analyze system performance by using tools such as Step Response, Bode Plot and Pole-Zero mapping/Plotting. Control Design and Simulation module help us to analyze behavior of Linear, Nonlinear and discrete system with Open Loop or Closed Loop controller and conduct physical implementations according to simulation Data. To control any system first, we need to know the transfer function model of that system. Hence we have obtained theoretical transfer function model of Micro Actuator Systems. During this we have assumed some of the characteristics of voice coil motor and linear potentiometer and got 5 different cases. After that we used PID controller to control our system, since PID controller needs PID gains to control it, now with the help Control Design and Simulation module available in LabVIEW software we have constructed Control and Simulation program for our theoretical Transfer Function. This Control Design and Simulation Program consist of step input, PID Controller with advanced autotuning VI, Transfer Function of system and Input and Output response graph here we are giving step signal to our Transfer Function and with the help of advanced autotuning feature we are analyzing at what values of PID gains we are getting output response with no or less error and over shoot.

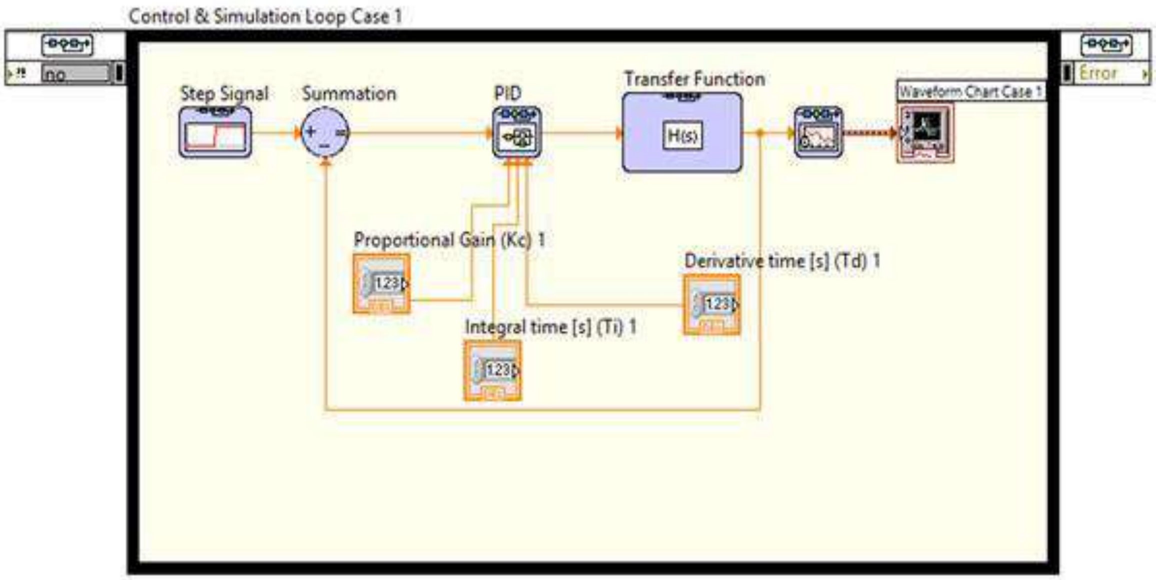


Fig.3: LabVIEW Control and Simulation Program

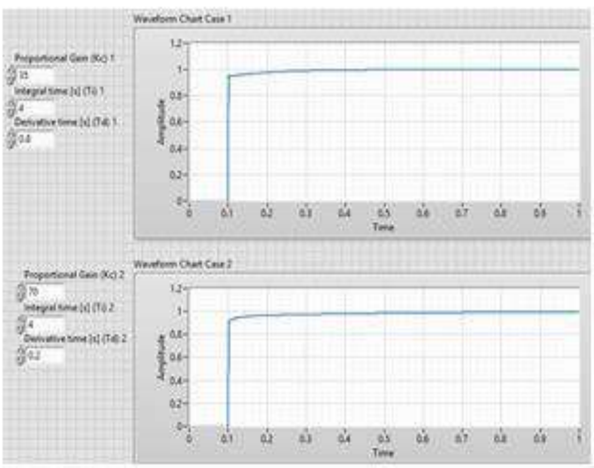


Fig.4: LabVIEW PID gains for Case 1 and Case 2

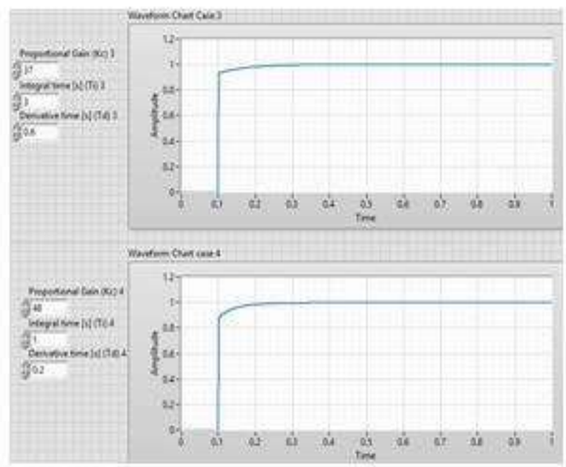


Fig.5: LabVIEW PID gains for Case 3 and Case 4

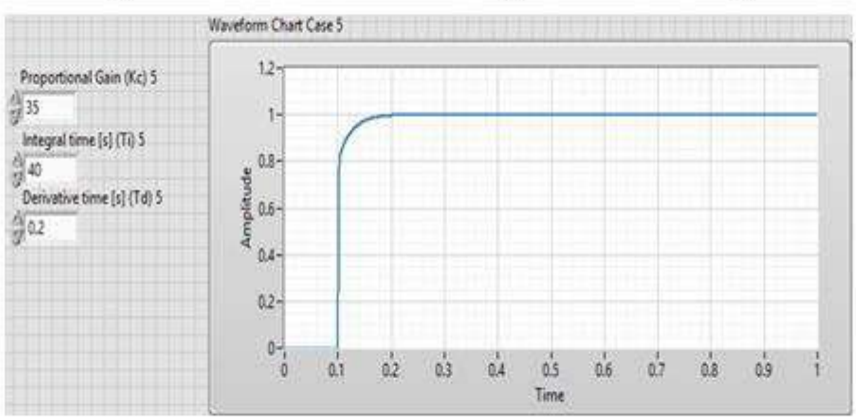


Fig.6: LabVIEW PID gains for Case 5

PID Controller Testing

We have designed closed loop PID controller in LabVIEW software and configured it to voice coil motor. This closed loop system consists of PC based PID controller LabVIEW program, DAQ Modules, L298N Motor Driver, VOICE COIL MOTOR and Potentiometer. All the programs and logic is written in LabVIEW software.

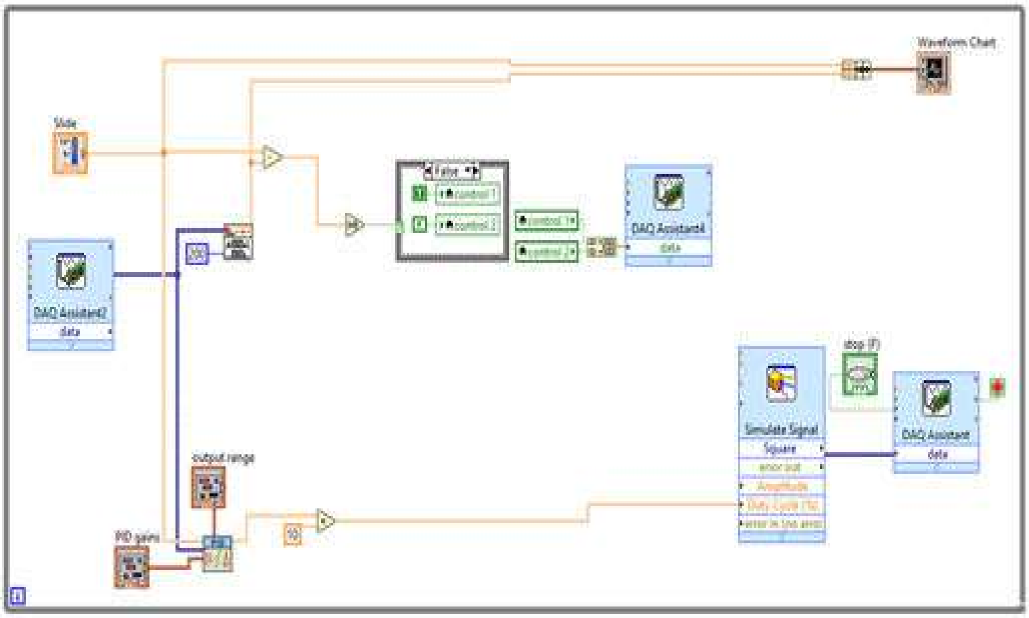


Fig.7. PID Controller Design

We are using 3 DAQ Modules: A. Ni 9401 DAQ Modules used to drive motor in forward and backwards direction B. Ni 9269 DAQ Modules used to control PWM signal and C. Ni 9205 DAQ Modules is used to acquire potentiometer and input signal data. We are using L298N motor driver which provides us both input voltage control and forward and backward directional control. We are using linear potentiometer connected with our Voice Coil Motor, which provides us linear positional data of voice coil motors at that instant. The working of this closed loop PID controller can be explains as it has 2 algorithms to control linear positions of voice coil motor. One algorithm decides the PWM signal by using PID controller and the another one is used to decides whether VCM has to go forward or backwards. When we give a set point to our controller it goes to PID controller and depending upon feedback data from potentiometer, PID controller generates PWM signal for Voice Coil Motor. As we know L298N motor driver is capable to control both PWM signal as well as directional I.e. forward and backward control signal, hence we are using it to control VCM. And for directional control we have another algorithm which acquire set point data and potentiometer data, and if potentiometer data less than set point data it moves forward and if potentiometer data is greater than set point data it moves backward. The set point can be set by using slider available in front panel of LabVIEW software, set point and potentiometer response is acquiring by Ni 9205 DAQ module and displayed in waveform chart. To generate PWM signal ‘simulate square signal VI’ is used in LabVIEW and its duty cycle i.e. how much voltage is required to move VCM in forward or reverse direction to meet set point voltage is controlled by PID controller.

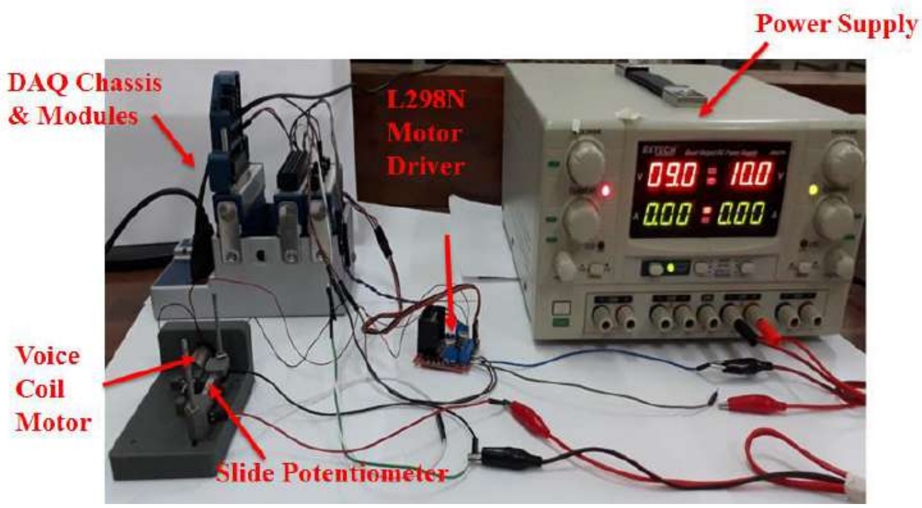
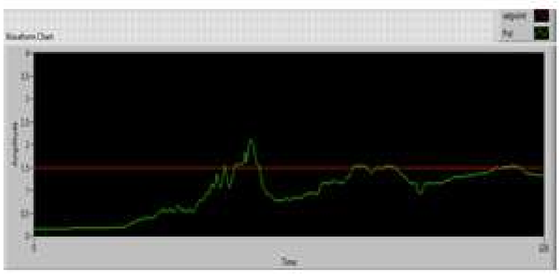
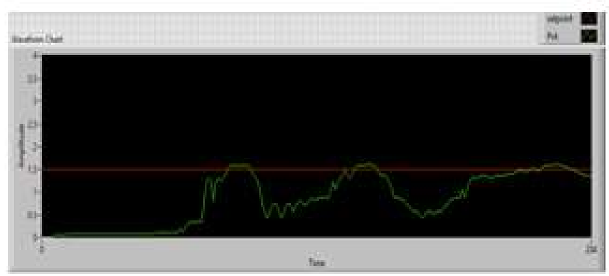


Fig.8. Experimental Setup of Micro Positioning Actuator

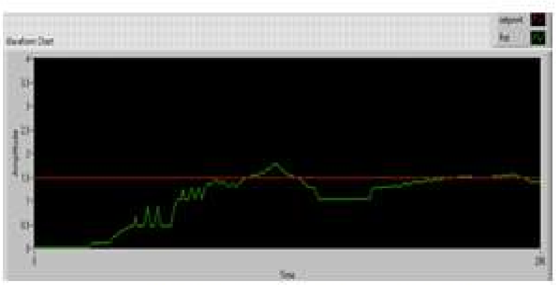
Experimental Result



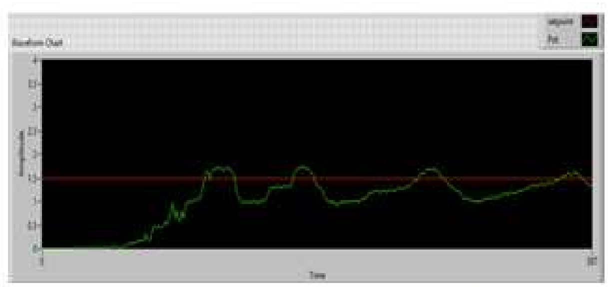
(a) : Case 1 and PID gains Kc= 35,Ti= 4, Td= 0.8



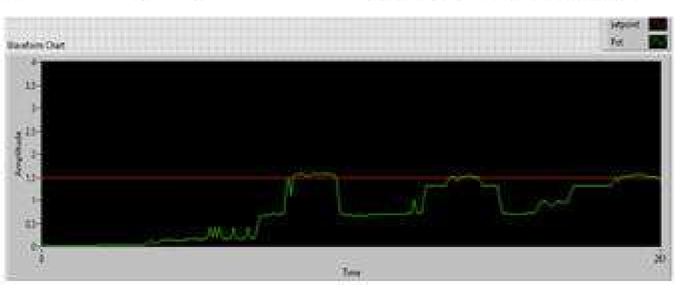
(b) : Case 2 and PID gains Kc= 70,Ti= 4, Td= 0.2



(c) : Case 3 and PID gains Kc= 37, Ti= 3, Td= 0.6



(d): Case 4 and PID gains Kc= 48, Ti= 1, Td= 0.2



(e) : Case 5 and PID gains Kc= 35,Ti= 40, Td= 0.2

Fig.9: VCM Response for different cases

From VCM response graph, it is observed that results are unstable the reasons are:

a. Potentiometer is nonlinear.

b. It's taking more current in forward motion and less current in backwards motion.

c. Potentiometer has lot of friction.

d. Right now we have theoretical Transfer function of VCM, which has lots of assumptions.

e. Don't have perfect PID gains.

CONCLUSION

The conclusion which we made from VCM response graph is the red line is our set point voltage and the green line is the voltage obtained by linear potentiometer when it moves back and forth. The controlling parameters are decided by the PID gains.

- **Case 1:** This graph shows high rise time and high overshoot, the two lines i.e. red and green are collinear for very short amount of time.
- **Case 2:** This graph shows high rise time, high peak time the overshoot is less as compared to case 1 and Steady state error is also present in this case.
- **Case 3:** This graph shows less rise time as compared to case 1 and case 2. It shows less overshoot as compared to case 1, but the two voltages are collinear for long time and steady state error is less compared to both case 1 and case 2.
- **Case 4:** This graph shows less rise time compared to case 1, but it has more numbers of overshoot compared to case 1, case 2 and case 3. Also the two voltages are collinear for very short amount of time.
- **Case 5:** This graph shows high rise time compared to case 1. It has little amount of overshoot but high setting time compared to case 3 and 4. It also shows high steady state error compared to case 3.

The final conclusion which can be made from all these 5 cases are Case 3 having PID gains values (Kc=37, Ti=3, Td=0.6) shows better performance as compared to other 4 cases.

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