Design and Implementation of Position Estimator Algorithm on Voice Coil Motor

Mahesh S. Shewale  
Dept.of Mechanical Engineering,  
Purdue School of Engineering & Technology, IUPUI, Indianapolis,USA  
mshevale@iupui.edu

Dr. Ali Razban  
Dept.of Mechanical Engineering,  
Purdue School of Engineering & Technology, IUPUI, Indianapolis,USA  
arazban@iupui.edu

Dr. Suhas P. Deshmukh  
Dept.of Mechanical Engineering,  
Government College of Engineering,  
Chandrapur, India  
suhas.deshmukh@gmail.com

Sharad S. Mulik  
Dept.of Mechanical Engineering,  
G. H. Raisoni College of Engineering & Management, Pune, India  
sharadmulk@gmail.com

Hrishikesh B. Zambare  
Dept.of Mechanical Engineering,  
Purdue School of Engineering & Technology, IUPUI, Indianapolis,USA  
hzambare@umail.iu.edu

Abstract—Voice Coil Motors (VCMs) have been an inevitable element in the mechanisms that have been used for precise positioning in the applications like 3D printing, micro-stereolithography, etc. These voice coil motors translate in a linear direction and require a high accuracy position sensor that amounts for a major part in the budget. In this research work, an effort has been made to design and implement an algorithm that would predict the displacement of VCM and eliminate the need of high cost sensors. VCM was integrated with dSPACE DS1104 R&D controller via linear current amplifier (LCAM) which acts as a driver circuit for VCM. Sine input was given to VCM with various amplitude and frequency and the corresponding displacement is measured by using linear variable differential transformer (LVDT). The position estimator algorithm is also implemented at the same time on VCM and its output is compared with that of LVDT. It is observed that there is 97.8% accuracy in between algorithm output and LVDT output. Further, PID controller is used in integration with the novel algorithm to minimize the error. The estimator algorithm is tested for various amplitudes and frequencies and it is found that it has a very good agreement of 99.2% with the actual displacement measured with the help of LVDT.

Index Terms—LVDT, dSPACE DS1104, VCM, PID, position estimator

I. INTRODUCTION

In today’s industrial era where human workers are being replaced by highly intelligent automated systems, use of several types of sensors & actuators in these systems for industrial application is an inevitable criterion [1]. Different types of actuators are used for executing the actions in the industrial processes. Types of motors such as induction motors, stepper and servo motors are used for rotary actuation purposes i.e. to provide actuation in rotary motion [2]. AC or DC induction motors are utilized where speed of rotation is an essential criterion for example in lathe machines, drilling machines, etc. [3]. Stepper motors are used where the angular displacement of the rotating shaft is an important aspect to be considered. These motors can have high resolution in the range of 10000 pulses per revolution enabling them to achieve highly precise angular motion [4]. Servo motors are similar to the above mentioned except they have a facility of feedback signal from the sensor mounted on output shaft [5, 6]. This sensor can either be used to measure speed or angular displacement or both for a particular motor shaft. Therefore, several advancements in rotary actuators have been achieved till date [7].

However, if linear actuators are concerned, some devices are developed with the help of rotary actuators. Some traditional mechanisms are used for the application of linear or translatory motion such as lead screw, ball screw, hydraulic and pneumatic devices, etc. [8, 9]. But these mechanisms have some drawbacks such as friction, backlash and wear of components associated with the system. Also, these mechanisms need to be lubricated and they exhibit lot of hysteresis error [10-12]. As far as lead crews and ball screw mechanisms are concerned, they have very low speed of operation in translatory motion and low efficiency, whereas the possibility of leakages in hydraulic and pneumatic devices is a vital aspect to be considered. Gear trains like worm drive and rack & pinion need to be lubricated and wear out after certain amount of time [13].

To overcome these difficulties, we come up with a novel solution of voice coil actuators. Voice coil motors are linear motors basically used in speakers and headphones to convert electrical signals into appropriate vibrations and thus produce sound waves [14, 15]. Also, they are extensively utilized in motion head inside the hard disk drives which are used to store data in computers. These are light duty applications in which very less force is needed to be generated by voice coil motors [16]. In the industrial applications, large forces are needed to be generated. To achieve this, we need to make proper changes in the design of voice coil motor. This voice coil motor can be
widely used in the sectors where precise positioning is inevitable part in the range of microns[17-19].

In this paper, an effort has been made to elaborate the design procedure, finite element analysis, mechatronic integration and experimental investigation of voice coil motor. Section II describes design of voice coil motor based upon the requirements. Section III describes the experimental layout necessary for the experimentation. Section IV puts forward the design and implementation of position estimator algorithm in MATLAB Simulink. Section V displays the results and outcomes of this implementation. Section VI concludes the research paper in accordance with the objectives.

II. DESIGN OF VOICE COIL MOTOR

Voice coil actuators are direct drive, defined motion equipment which utilize a permanent magnet field and a coil winding or conductor to yield a force which is proportional to the current flowing through the coil. These non-commutated electromagnetic devices are utilized in translatory and rotary motion functions that require linear force output and high acceleration or high frequency operation [20].

The working principle of a voice coil motor is governed by the Lorentz Force Principle. This law of says that if a current carrying conductor is kept in a magnetic field, a force will act upon it. The magnitude of this force is given by:

$$ F = kBLI $$  

Where $k$ – constant, $B$ – magnetic flux density, $I$ – current flowing through the coil, $L$ – length of the conductor, $N$ – number of conductors [21].

Figure 1 is a simplified example of this law. Here, the direction of the force generated depends on the direction of current and magnetic field vectors. Especially, it is the cross-product of the two vectors. If current flow is reversed, the direction of the force on the conductor will also reverse. Produced force is proportionate to input current, if the magnetic field strength and conductor length are unchanged, as they are in a voice coil motor.

![Fig. 1. Linear Voice Coil Actuator](image)

As shown in Figure 3, the CAD model for voice coil motor is created using ProECreo modelling software. Figure 4 shows the exploded view of voice coil motor assembly in which all the components of voice coil motor are shown. Initially, permanent magnet is placed inside the housing made of aluminum and it is fixed to the housing with the help of alan screws. One end of bobbin on which a coil made of copper is wound and it is enclosed in the magnet. Other end of cylindrical bobbin is connected to the output shaft through coil holder. To maintain the bobbin exactly at the center, we use flexural spring made of beryllium copper. To fix this flexural bearing to the housing, we use a ring on which holes are made at its periphery to facilitate insertion of screws for fixing. Horizontal slots are made at the extended base of the housing in order to attach it to the optical table.

![Fig. 2: Linear Voice Coil Actuator](image)

![Fig. 3: CAD model assembly of the voice coil actuator](image)
Figure 5 shows the manufactured voice coil motor along with its output shaft and LVDT core is connected to it for displacement measurement purpose.

III. MECHATRONIC INTEGRATION

It is essential for voice coil motor that it should be operated through controller. We use dSPACE DS1104 R&D controller to provide amplitude and frequency of voice coil actuation. When we provide amplitude and frequency in ControlDesk GUI, the control logic in Simulink converts it into appropriate voltage signal which is given to linear current amplifier (LCAM) through CLP1104 connection board. This connection board facilitates receiving and sending analog, digital, PWM and serial communication to the controller. The voltage signal from dSPACE is converted into current with the help of LCAM. It works as a driver circuit for voice coil motor. VCM gives out desired linear displacement at the output shaft as per the provided amplitude and frequency. This displacement is measured with the help of linear variable differential transformer (LVDT) which has resolution in microns. LVDT generates a voltage proportional to the displacement of core of LVDT and this feedback voltage signal is given to dSPACE controller through CLP1104 connection board. This mechatronic integration is explained in Figure 6 below.

IV. DESIGN & IMPLEMENTATION OF POSITION ESTIMATOR ALGORITHM

VCM used in this research work consists of permanent magnet and current carrying coil. Principle of working of linear motor is similar to voice coil used in speakers. As current passes through coil, mechanical force is generated, and direction of force depends on the direction of current. Construction of linear voice coil motor is shown in Figure 7 and also equivalent circuit diagram is shown as subfigure.

Equation of electrical circuit is given by relation,

$$V_{ss} = R_i I_a + L_i \frac{dI_a}{dt} + \alpha \frac{dx}{dt} \quad (2)$$

Where, $V_{ss}$ is supply voltage, $R_i$ is resistance of coil, $L_i$ is inductance of coil, $\alpha$ is motor constant, $I_a$ is current drawn by coil, and $dx/dt$ is velocity of coil.

Linear voice coil actuator can be further used as velocity sensor and above equation can be further simplified as velocity sensor as below,

$$\frac{dx}{dt} = \frac{1}{\alpha} \left( V_{ss} - R_i I_a - L_i \frac{dI_a}{dt} \right) \quad (3)$$

Integrating above equation we can easily estimate position of coil and position estimator equation can be given by relation,

$$x = \frac{1}{\alpha} \int \left( V_{ss} - R_i I_a - L_i \frac{dI_a}{dt} \right) dt \quad (4)$$
Thus, from above we can easily adopt this algorithm for measurement of displacement of motion stage which is shown in figure 8 below.

![Figure 8: Position Estimator Algorithm in MATLAB Simulink](image)

Similar sort of concept is used for stroke estimation in DFM. Here we need to accurately measure current and voltage drawn by coil in real time. Above discussion shows that linear voice coil actuator can work as displacement sensor to obtain the position information without any extra sensor is adopted.

Figure 9 shows the mechatronic interface done for implementation of position estimator algorithm. Additional circuit is integrated to VCM for sensing current and voltage drawn by VCM.

![Figure 9: Voltage and Current Monitoring System](image)

This concept is used in present research work for sensor-less measurement of position of motion stage of flexural mechanism. Measurement of voltage and current across coil is experimentally carried out using suitable sensing circuit and these collected data is further processed. Position estimator algorithm needs a current & voltage signal. Estimated position from position estimator is compared with actual position of motion stage.

V. RESULTS & DISCUSSION

The actual position output from output encoder and predicted position by algorithm is compared with the input reference signal provided and the difference between both is determined to verify the accuracy of the developed position estimator algorithm with the position optical encoder.

From figures 10 and 11, it has been observed that scanning speed achieved is 0.6 mm/sec at 1 Hz frequency. It shows error to 25 μm. whatever error is present is because of noise present in the electrical systems.

VII. CONCLUSION

Voice coil motor for high precision applications is successfully designed and fabricated. Further it is integrated with dSPACE DS1104 R&D controller and LVDT for
calibration purpose. The position estimator algorithm is developed in Simulink in integration with PID controller to obtain minimum error. Due experimentation shows there is a very good agreement of 99.2% in between the measured LVDT output and predicted position by algorithm. Further experimentation can be carried out based on varying the type of input such as step input, ramp input, etc. A generic algorithm can be developed further which can work under any type of input signal.

REFERENCES


