Experimental Investigation and PID Control Implementation on Voice Coil Actuator using Flexural Bearing

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Abstract*- Flexural mechanisms are highly advantageous as compared to traditional rigid body structures where point accuracy and precision positioning is inevitable ranging in microns. To accomplish clear and to the point movement, we develop a new mechanism of voice coil motor. Proper coil and magnet is picked up by taking into account the maximum force to be provided to the further mechanism. Voice coil motor (VCM) elements are manufactured and assembled. Mechatronic integration is achieved by connecting VCM to dSPACE DS1104 R&D microcontroller to apply expected amplitude and frequency of motion with the help of linear current amplifier (LCAM) which works as driver circuit for VCM. Movement of output shaft of VCM is detected with the help of linear variable differential transformer (LVDT) that gives analog voltage output proportional to the movement of output shaft. PID control algorithm is developed in MATLAB Simulink and it is implemented on VCM to minimize the error in displacement of output shaft. The error observed after implementation of PID control was accurate upto 1.5µm at an amplitude of 100µm.*

Keywords- Voice coil, Finite Element Analysis, system identification, dSPACE DS1104, flexure

I. INTRODUCTION

In recent years where manpower is being substituted by highly perceptive robotic systems, usage of different forms of sensors & actuators in these distinct arrangements for industrial utilization is an inevitable aspect [1]. Several actuators are utilized to work out the sequence of operations in the industrial processes. Types of motors like induction motors, stepper and servo motors are needed for rotary movement applications i.e. to facilitate movement in rotational direction. AC or DC induction motors are used in case of rotation speed plays an important role for example in milling machines, lathe machines, etc. Stepper motors are applied where we need precise angular positioning of the shaft which is an important criteria to be taken into account. These motors possess high degrees of resolution ranging 10000 pulses per revolution which facilitate them in achieving accurate angular position [2-5]. Servo motors are same as above mentioned excepting they facilitate a feedback signal with the help of sensor located on output shaft. This sensor can be used for measuring speed as well as angular position. Therefore, many advanced techniques in rotary motors have been implemented till date [6-8].

Besides, if linear motors are considered, several equipments are manufactured by using rotary motors. Many conventional structures are utilized for utilization of linear or translatory movement like lead screw, ball screw, hydraulic and pneumatic devices, etc. However, these mechanisms possess some disadvantages like friction, backlash and wear of elements involved in system [1, 9, 12]. Further, these equipments need lubrication and they have huge hysteresis. As far as mechanisms made of lead crews and ball screw are considered, their speed of operation is very low in linear motion which is a function of pitch. They have less efficiency and risk of leakages in hydraulic and pneumatic equipments is a serious condition to be taken care of. Gear mechanisms like worm drive and rack & pinion are needed to be lubricated and pitting failure occurs after particular number of cycles [14-17].

To rectify these problems, we developed a new solution of voice coil actuators. Voice coil actuators are linear actuators which are utilized in speakers and headphones for conversion of electrical signals in proper vibrations and they generate sound waves [19-20]. Besides, they are broadly used in motion head in hard disk drives that are utilized to store data in computers. These are low load applications in which lesser actuation force is essential to be developed by voice coil motors. In industrial practices, huge forces are required to be generated. To attain this, we are required to make appropriate corrections in the design of voice coil motor. This voice coil motor can be extensively applied in the fields where precise and accurate movement in the range of microns is irresistive aspect [21].

In this research work, an attempt has been made to discuss the working of voice coil actuator, mechatronic integration and PID control implementation on voice coil motor. Section II mentions the working principle and design of voice coil motor as per the required specifications. Section III describes the experimental setup required for the experimental investigation. Section IV discusses the development and implementation of PID control algorithm on the mechanism. Section V summarizes the results and outcomes are discussed. Section VI concludes the research paper in accordance with the objectives.

II. VOICE COIL ACTUATOR

Voice coil actuators arc direct drive, limited movement devices that use a permanent magnet field and copper coil winding or conductor to develop a force that is equivalent to the current flowing through the conductor. These electromagnetic appliances are applied in linear and rotary movement functions which need single vector force output and tremendous acceleration or large frequency operation.

The governing principle of voice coil actuator is controlled by the principle of Lorentz Force. This rule states that if a current carrying conductor is located in a magnetic field, a force will act upon the current carrying conductor. The magnitude of this force is given by:

$$F = kBLIN$$

Where k – motor constant, B – magnetic flux density in tesla, I – current flowing through the conductor in amperes, L – length of the conductor in m, N – number of conductors.

In this case, the direction of the force developed relies on the direction of current and magnetic field vectors. Especially, it is the cross-product of the two vectors. If the polarity of current flow is reversed, the direction of the force on the conductor is also opposed. If magnetic field and the conductor length are kept constant, as they have been kept constant in a voice coil actuator, then the developed force is directly proportional to the input current.

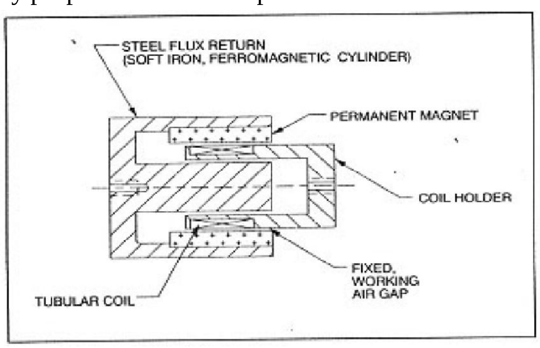


Fig. 1: Linear Voice Coil Actuator

In simple words, a linear voice coil motor is a cylindrical wire coil placed in a radially generated magnetic field, as shown in Figure 1. This field is developed by permanent magnets enclosed in a ferromagnetic cylinder, arranged so that the magnets “facing” the coil are of the same polarity. An inside core of ferromagnetic material is aligned along the centre axis of the coil, joined at one end to the permanent magnet assembly, is used to complete the magnetic circuit. The force developed axially on coil when current flows through the coil generates a relative translatory motion in between the permanent magnet and the coil, added that the generated force is huge enough to overcome friction, inertia, and any other forces from loads attached to the coil.

As shown in Figure 2, the CAD model for voice coil actuator is developed with the help of ProE Creo modelling software. Figure 2 elaborates the exploded view of voice coil motor assembly. At the initial stage, permanent magnet is kept in the aluminum housing block and it is attached to block by using alan screws. Copper wire is wound on a bobbin, one end which is enclosed in the magnet. The other end of cylindrical bobbin is attached to the output shaft with the help of coil holder. We utilize flexural bearing made of beryllium copper for maintaining the bobbin exactly at the center in axial as well as radial orientation. To constrain this flexural bearing to the housing block, we use a ring on which holes are made at its periphery for insertion of screws for fixing. Horizontal slots are provided at the expanded base of the housing to fix it to the optical table. Figure 3 shows the finally manufactured and assembled voice coil motor.

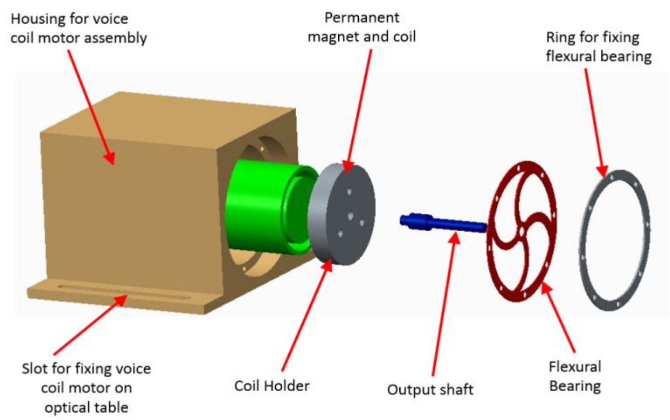


Fig. 2: Exploded view of voice coil motor assembly

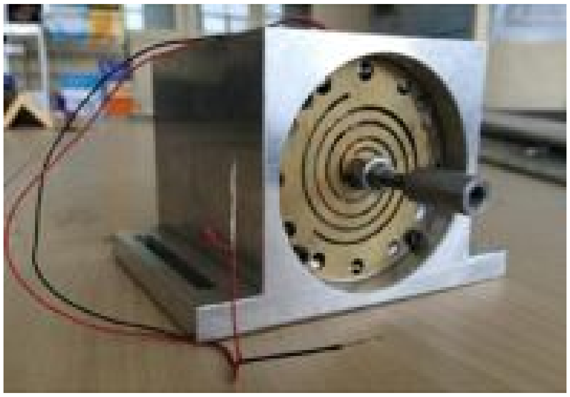


Fig. 3: Manufactured voice coil actuator

III. MECHATRONIC INTEGRATION

It is necessary for voice coil motor that it has to be run by using appropriate controller. We used dSPACE DS1104 R&D controller to give desired amplitude and frequency of operation of voice coil actuation signal. When we give amplitude and frequency in ControlDesk GUI which is a frontend platform for dSPACE controller, the control logic developed in Simulink converts it into appropriate voltage signal which is forwarded to linear current amplifier (LCAM) through ADC port of CLP1104 connection board. This connection board provides connections for receiving and sending analog, digital, PWM and serial communication to the controller. The voltage signal from dSPACE is converted into current by using LCAM. It works as a driver circuit for voice coil motor. Output of VCM results in expected linear motion at the output shaft with regards to the desired amplitude and frequency. This movement is measured by using linear variable differential transformer (LVDT) having resolution in microns. Output of LVDT is a voltage signal that is equivalent to the movement of core of LVDT and this feedback voltage signal is provided to DAC port of dSPACE controller through CLP1104 connection board. This mechatronic integration is denoted in Figure 6 below.

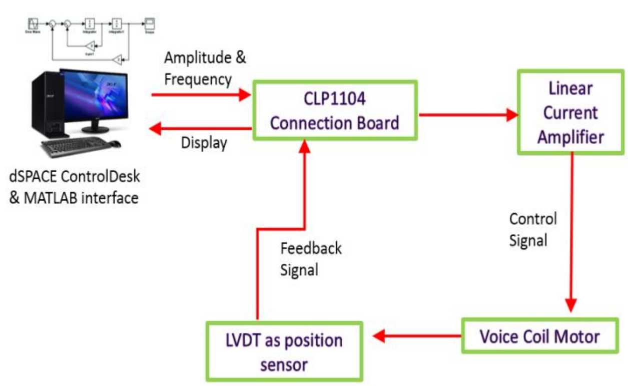


Fig. 4: Layout of Experimental Setup

IV. DEVELOPMENT AND IMPLEMENTATION OF PID CONTROL ALGORITHM ON VCM

A proportional-integral-derivative controller (PID controller) is a control loop feedback system (controller) broadly utilized in practical control systems (see Figure 10). A PID controller determines an error value i.e. difference between a measured process variable and a desired setpoint. The controller tries to minimize the error by adjusting the process through use of a manipulated variable.

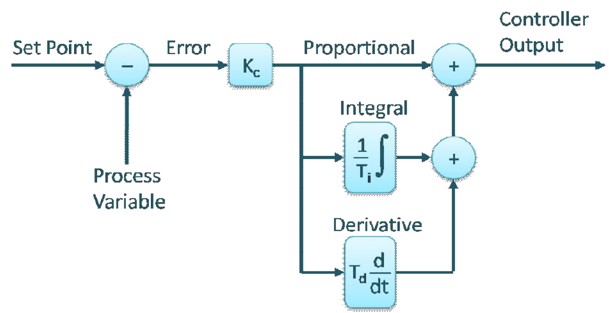


Fig. 5: PID Control System

The PID control algorithm includes three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted by P, I and D.

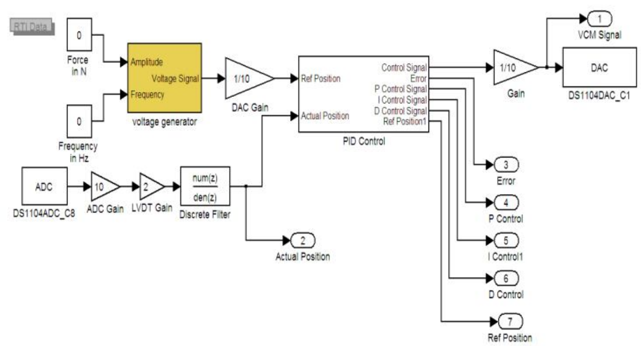
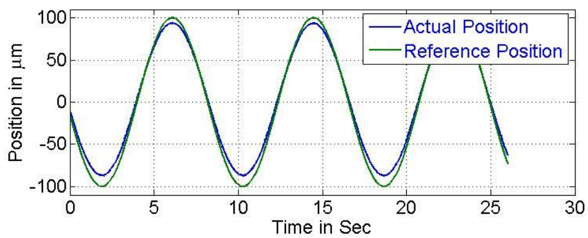


Fig. 6: Layout of Experimental Setup

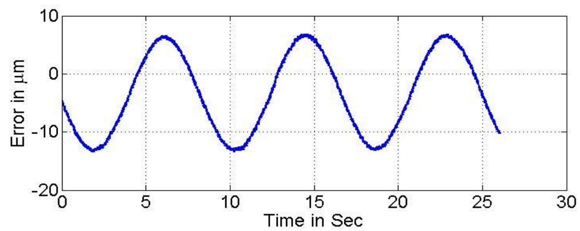
Figure 6 shows the Simulink block diagram for PID control implementation. A reference voltage signal is generated with the help of voltage generator logic. This reference signal is compared with the actual position signal generated by LVDT. This comparison produces error signal which is fed to the PID control block. Based on this error PID control logic tries to minimize it based on K_P, K_I and K_D.

V. EXPERIMENTAL INVESTIGATION AND RESULTS

Results are obtained for various amplitudes and frequencies as shown below.

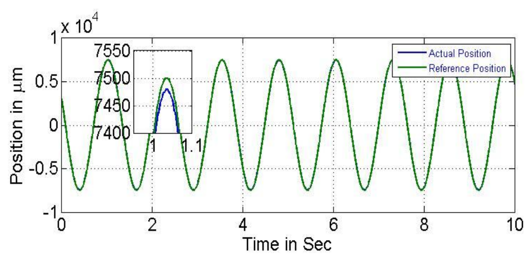


(a) Comparison between actual position and commanded reference position

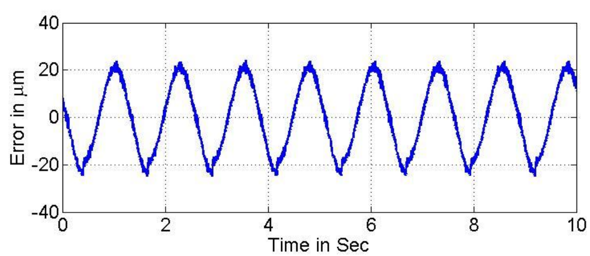


(b) Error in Real Time Precision Positioning

Fig. 6: Real Time PID Implementation on DFM at 100 µm Amplitude and 0.75 Hz Frequency



(a) Comparison between actual position and commanded reference position



(b) Error in Real Time Precision Positioning

Figure 6 shows a Real time PID implementation results on DFM at lower speed (0.75 Hz Average Speed = 400 µm/s) and small scan range (Amplitude = 100 µm) of motion stage. Position accuracy of less than 2.5 µm is achieved. Figure 12 shows a Real time PID implementation results on DFM at lower speed (0.75 Hz Average Speed = 2500 µm/s) and small scan range (Amplitude = 2500 µm) of motion stage. Position accuracy of less than 8 µm is achieved. The results achieved for variations in different amplitudes and frequencies are compiled below in Table 1.

Table I: Determination of Error for various Amplitude & Frequency

Sr. No.	Amplitude	Frequency	Scanning Speed	Error
	µm	Hz	mm/s	µm
1	1000	2	8	60
2	100	0.75	0.2	1.5
3	500	1	1	1.5
4	2500	5	50	5
5	2500	0.12	1.2	7
6	3500	5	70	7
7	3750	2.5	37.5	7
8	5000	0.8	8	14
9	5000	0.8	16	13
10	5000	3	60	5
11	7500	0.12	3.6	23
12	7500	0.8	24	20

VI. CONCLUSION

Voice coil motor for high precision applications is successfully designed and fabricated. Further it is integrated with dSPACE DS1104 R&D controller. PID Control algorithm is developed in MATLAB Simulink and it is applied on the voice coil motorz. PID parameters are tuned using Ziegler Nichols tuning method. Accuracy of less than 1.5 µm is achieved at low speeds and amplitude of 100µm. Further as we increase the amplitude and frequency of operation, error increases at it is a progressive error. Voice coil motor involves smooth and frictionless motion that can be further applied to laser scanner for different applications.

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