IJFEAT
INTERNATIONAL JOURNAL FOR ENGINEERING APPLICATIONS AND TECHNOLOGY

Design, Development and Experimental Investigation of Voice Coil Actuator using Flexural Bearing

Sharad S. Mulik
Research Scholar,
Dept. of Mechanical Engineering,
Satyabhama University,
Chennai, India
sharadmulik@gmail.com

Suhas P. Deshmukh
Professor,
Dept. of Mechanical Engineering,
Sinhgad Academy of Engineering,
Pune, India
suhas.deshmukh@gmail.com

Mahesh S. Shewale
Assistant Professor,
Dept. of Mechanical Engineering,
Trinity Academy of Engineering,
Pune, India
mshewale802@gmail.com

***Abstract*— Flexural mechanisms are highly preferable over conventional rigid body mechanisms where highly accurate and precise motion is necessary in the range of microns. To achieve clean and precise motion, we propose a new design of voice coil actuator. Appropriate coil and magnet is selected considering the maximum force to be applied. CAD model is prepared and finite element analysis (FEA) is done to determine the stiffness. Voice coil motor (VCM) components are manufactured and assembled. This VCM is integrated with dSPACE DS1104 R&D controller to give desired amplitude and frequency of motion via linear current amplifier (LCAM). The displacement of output shaft of VCM is sensed by linear variable differential transformer (LVDT) which gives change in output voltage corresponding to the displacement of output shaft. The force deflection characteristics are noted down for FEA as well as experimental procedure and stiffness in both the cases is determined. It is observed that there is close agreement between FEA and experimental results.**

***Index Terms*— voice coil, Finite Element Analysis, system identification, dSPACE DS1104, flexure**

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 particular systems for industrial application is an inevitable criteria. Different type 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. AC or DC induction motors are utilized where speed of rotation is an essential criteria for example in lathe machines, drilling machines, etc. 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. Servo motors are similar to the above mentioned except they have a facility of feedback signal from the sensor mounted on output shaft. 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.

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. 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. 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.

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. 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. 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.

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 elaborates the force deflection characteristics through finite element analysis. Section IV describes the experimental layout necessary for the experimentation. Section V puts forward the experimental investigation of parameters of voice coil motor such as stiffness. Section VI summarizes the results and outcomes are discussed. Section VII concludes the research paper in accordance with the objectives.

II. Design of Voice Coil Actuator

Voice coil actuators arc direct drive, defined motion equipments 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.

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:

$$F = kBLIN$$

Where k – constant, B – magnetic flux density, I – current flowing through the coil, L – length of the conductor, N – number of conductors. Figure 2 shows a flexural hinges are building blocks. These hinges can be used as single axis hinge, multi-axis hinge as shown in Figure 2. Figure 3 shows a flexural mechanism where flexural hinge as building blocks. These mechanisms include 3DOF tripod mechanism, 2DOF motion stage for precision mechanism and six axis positioning stage.

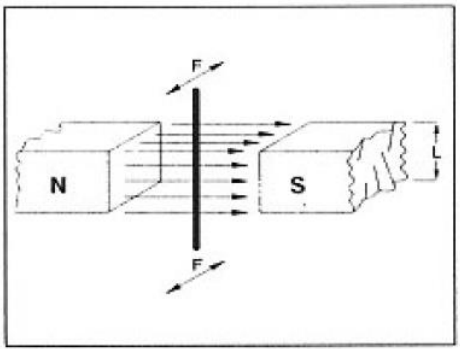


Fig. 1: Lorentz force principle

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. If the magnetic field and the conductor length are constant, as they arc in a voice coil actuator, then the generated force is directly proportional to the input current.

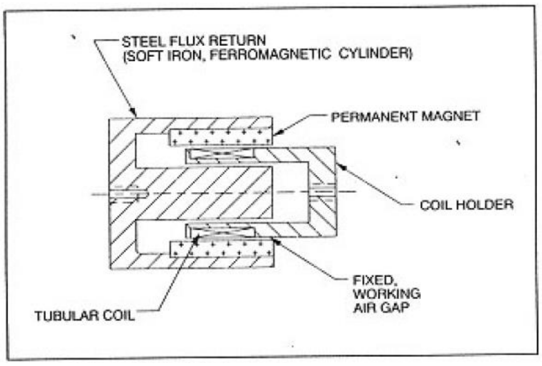


Fig. 2: Linear Voice Coil Actuator

In its simple manner, a linear voice coil actuator is a tubular coil of wire located within a radially occurring magnetic field, as shown in Figure 2. This field is developed by permanent magnets embedded on the inside diameter of a ferromagnetic cylinder, arranged so that the magnets "facing" the coil are all of the same polarity. An inner core of ferromagnetic material set along the axial centre line of the coil, joined at one end to the permanent magnet assembly, is used to complete the magnetic circuit. The force generated axially upon the coil when current flows through the coil produces relative motion between the field assembly and the coil, provided the force is large enough to overcome friction, inertia, and any other forces from loads attached to the coil.

As shown in Figure 3, the CAD model for voice coil motor is created using ProE Creo 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.

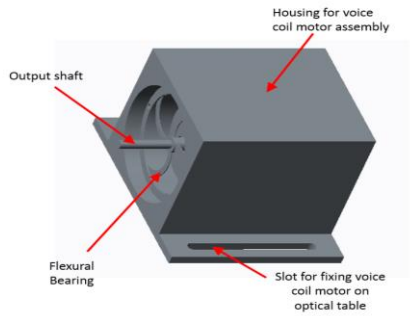


Fig. 3: CAD model assembly of the voice coil actuator

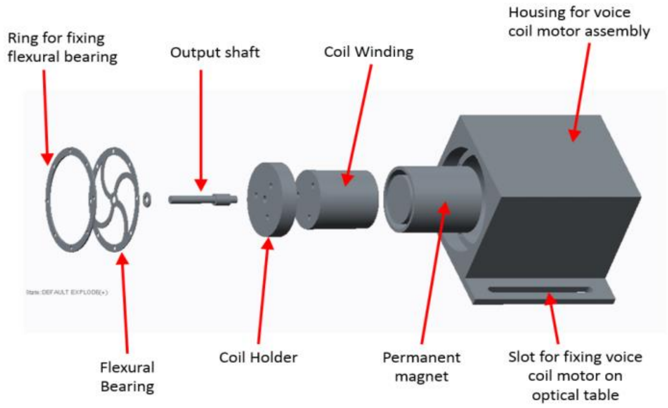


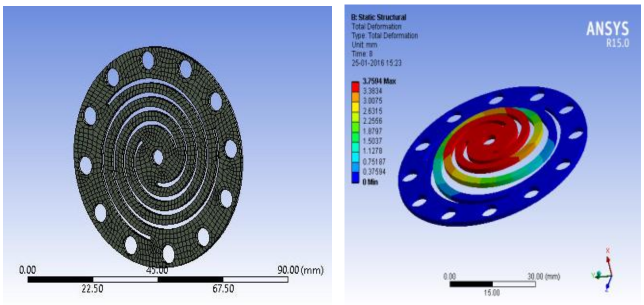
Fig. 4: Exploded view of voice coil motor assembly

III. Finite Element Analysis of Flexural Bearing

FEA is a computerized technique for the prediction of behavior of a particular product to real world disturbances, vibrations, temperature changes, fluid flow and other physical quantities. It is a numerical method which is a branch of solid mechanics and nowadays a generally used method to solve multiphysics problems.

In our particular work, we use FEA software like ANSYS to estimate the variation of displacement of flexural bearing for various forces. Prepared CAD model is imported in ANSYS workbench and meshed to create small elements as shown in Figure 5(a).

The boundary constraints are applied on the outer periphery of flexural spring and force is applied in axial direction. The variation of deflection of flexural spring is noticed as shown in Figure 5(b) and stiffness is determined. These results are mentioned below in Table No. 1.



(a) (b)

Fig. 5: Finite Element Analysis of Flexural Bearing

IV. 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.

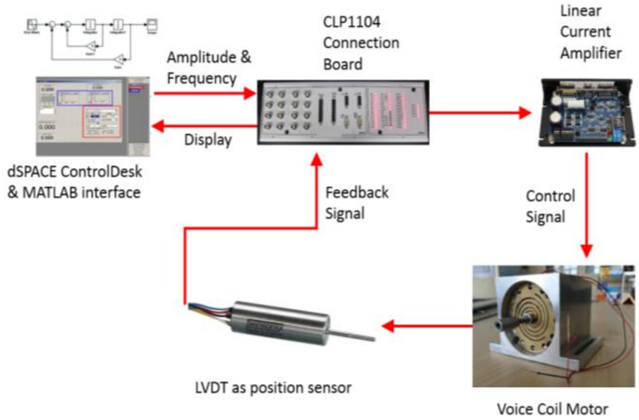


Fig. 6: Layout of Experimental Setup

V. Experimental Investigation and Results

Results are obtained for variation of displacement of voice coil motor with the change in amplitude i.e. force. Stiffness of flexural bearing is estimated experimentally and it is compared with FEA results as shown in Table 1.

From figure 7, it is observed that there is close agreement between FEA and experimental results. As we increase the force we notice increase in variation because of the progressive error. The variation of between FEA and experimental results is well within the acceptable limits.

Force	Actual Displ.	FEA Displ.	Actual Stiffness	FEA Stiffness	Error
N	±mm	mm	N/mm	N/mm	%
4.52	0.492	0.50125	9.18699187	9.01745636	1.845
9.04	1.077	1.0025	8.39368617	9.01745636	7.431
13.56	1.654	1.5037	8.20078621	9.0177562	9.962
18.08	2.212	2.005	8.17544653	9.01745636	10.299
22.6	2.767	2.5062	8.16916682	9.01763626	10.386
27.12	3.222	3.0075	8.41843862	9.01745636	7.1155
31.64	3.768	3.5087	8.3970276	9.01758486	7.3902
33.9	3.993	3.7594	8.49092048	9.01739639	6.2004

Table 1: Determination of actual and FEA stiffness

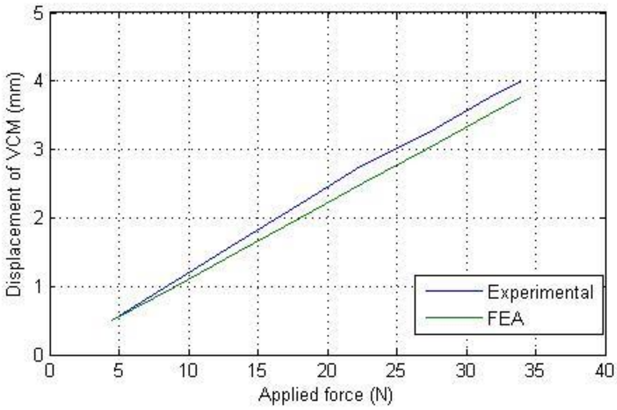


Fig. 7: Force deflection characteristics of VCM

VI. CONCLUSION

Voice coil motor for high precision applications is successfully designed and fabricated. Further it is integrated with dSPACE DS1104 R&D controller. The force deflection characteristics show linear output behavior. Static characterization is carried out and experimental & theoretical observations are compared and prove to be in good agreement.

ACKNOWLEDGMENT

This work was financially supported by a grant from the Department of Science and Technology, HRD Ministry, Govt of India. The authors thank to management of Sinhgad Academy of Engineering Kondhwa, Pune for providing technical and managerial support to execute research work.

REFERENCES

[1] Shuichi Dejima, Wei Gao, Hiroki Shimizu,Satoshi Kiyono , Yoshiyuki Tomita, Precision positioning of a five degree-of-freedom planar motion stage, Mechatronics 15 (2005) 969–987.

[2] S. Awatar, Synthesis and analysis of parallel kinematic xy flexure mechanism, PhD Thesis, Massachusetts Institute of Technology, Cambridge, MA, see also URL http://web.mit.edu/~shorya/www/PHD/Thesis/Introduction.pdf (2004).

[3] S. Awtar, A. H. Slocum, Design of parallel kinematic XY flexural mechanism, Proceedings of IDETC/CIE 2005 ASME 2005 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Long Beach, California, USA.

[4] Lobontiu N., 2003, Compliant Mechanisms: Design of Flexure Hinges, CRC Press.

[5] Qing Yao, J. Dong, P.M. Ferreira, Design, analysis, fabrication and testing of a parallel-kinematic micropositioning XY stage, International Journal of Machine Tools & Manufacture 47 (2007) 946–961.

[6] Hwa Soo Kim, Young Man Cho, Design and modeling of a novel 3-DOF precision micro-stage, Mechatronics 19 (2009) 598–608.

[7] Yangmin Li, Qingsong Xu, Modeling aand performance evalutrion of a flexure-based XY parallel micromanipulator, Mechanism and machine Theory, 44 (2009) 2127-2152.

[8] Y. Tian, B. Shirinzadeh, D. Zhang, X. Liu, D. Chetwynd, Design and forward kinematics of the compliant micro-manipulator with leaver mechanisms, Precision Engineering 33 (2009) 466-475.

[9] Ranier Clement, J. L. Huang, Z. H. Sun, J. Z. Wang, W. J. Zhang, Motion and stress analysis of direct-driven compliant mechanisms with general-purpose finite element software, The International Journal of Advanced Manufacturing Technology, April 2013, Volume 65, Issue 9-12, pp 1409-1421