ISSN 2250-3153

# Design and Simulation study of Electro-Mechanical Actuator for Missile Maneuvering

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DOI: 10.29322/IJSRP.10.07.2020.p10327
http://dx.doi.org/10.29322/IJSRP.10.07.2020.p10327

***Abstract-*** Electro-Mechanical Actuator (EMA) is the key component in the guidance systems of missiles to convert electrical power into mechanical power. EMAs have shown significant improvement in response times and are more reliable compared to other actuators. This paper proposes a Simulink model for linear electromechanical actuator which is very efficient and can withstand noise and disturbances. Electromechanical actuators are mechanical actuators where the control handle has been supplanted by an electric motor. This model is subjected to sudden loads and disturbances and the precise actuation is obtained within the specified settling time. The model is also subjected to nonlinearities and the results were found out to be competent.

***Index Terms***- Electromechanical Actuator, BLDC motor, Electric motor, Simulink, Non-Linearities.

## I. Introduction

A typical aerospace application involves a device or object which is able to change its direction and follow a desired path. The object is able to dynamically change its trajectory and moves from point A to point B. The object can change its direction with the help of fins, or flaps. These flaps/fins generate a torque due to aerodynamic friction present in the atmosphere and this torque rotates the object flying in the atmosphere. These fins are raised and lowered depending on the direction our object has to follow. The movement of flaps is done with the help of actuators.

In aerospace applications, precision and accuracy play a very important role. But there are many aerodynamic forces that affect the missile during its motion to the interception of the target. A slight error can cause adverse effects to the object. So, the integration of guidance system to a missile is to provide the required force for its propulsion, intelligence to evade targets and effective maneuvering which are the main features of the guided missile systems. In recent years, the requirements for the quality of automatic control increased significantly due to increased complexity of design of aerospace applications.

In the real time scenario, there are many factors that affect the precision and accuracy of the missile. When describing the action of forces, one must account for both the magnitude and the direction. In flight, a missile is subjected to four forces; weight, thrust, and the aerodynamic loading, lift and drag [1]. These forces account for deviation of the missile from its trajectory which can ruin the performance of the whole system as the missile fails to terminate the target. In order to avoid this, missiles are equipped with fins which helps us to steer the missile in such a way that the missile gets back into trajectory. So, the efficiency of the system depends on the efficiency of the fin actuators. In our project, we have developed a linear electromechanical actuator which is very efficient and this control system can withstand noise and disturbances. So, this paper emphasizes on the modelling of PMBLDC motor and controlling its position using PID Controller to suit all the aerospace application requirements which can withstand the effects of disturbances and non-linearities.

## II. ELECTRO-MECHANICAL ACTUATOR

The mechanical actuators where the control handle has been supplanted by an electric motor is Electro-Mechanical Actuator. The rotary motion of the BLDC motor is converted to linear motion. In the greater part of the electromechanical actuators, the principal activity depends on the inclined plane concept.

In order to achieve higher mechanical efficiency, speed operation, and increment load capacity, the variations of Electro-mechanical Actuators are devised.[2]

The main advantage of EMAs is that engineers have unlimited oversight over the motion profile. These are provided with encoders that can accurately control velocity and position. The ability to monitor and regulate torque is also provided by them resulting the amount of force applied. Electromechanical actuation systems can be programmed and reconfigured without shutting them down, which means the force and motion profile can be altered by the software while the device is still running.

Electromechanical actuators also offer critical cost savings since they possibly devour power when they are performing work. To maintain a position, the system stays in place while idle which makes it very efficient.

The operating costs are drastically reduced making them suitable to use in hazardous areas because of their high efficiencies, low maintenance, and increased up time.

Electromechanical actuators can disentangle the design procedure since they are simpler to indicate and design.

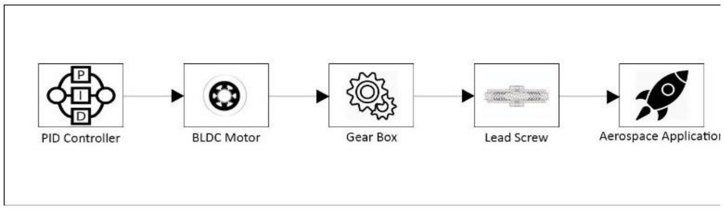


Figure 1. Electro-Mechanical Actuator

An EMA generally consists of a PID controller, a BLDC motor, a speed reduction gearbox, a lead or ball screw as shown in figure 1. All these blocks work in congruence and give an accurate actuation motion.

*A. PID Controller*

PID control represents a proportional–integral–derivative control. PID control is a feedback mechanism utilized in a control system. By ascertaining and controlling three boundaries – the proportional, integral, and derivative of how much a procedure variable veers off from the ideal set-point esteem – we can accomplish diverse control actions for specific work. The error between the actuator position and the input signal is given to the PID controller. The PID controller used in this simulation uses the compensator formula as shown in equation (1). The block output is a weighted sum of the input signal, the integral of the input signal, and the derivative of the input signal [3].
The PID position controller has the following parameters:

$$S = P + I\frac{1}{s} + D\frac{N}{1 + N\frac{1}{s}} \tag{1}$$

Where,

S: Speed at an instant

P: Proportional gain

I: Integral gain

D: Derivative gain

N: Filter co-efficient.

*B. BLDC Motor*

EMA typically employs a BLDC motor because of its high efficiency, high reliability, increased lifespan, better speed-torque characteristics, and low electromagnetic interference. The stator windings should be energized in a sequence to rotate the BLDC motor. It is essential to realize the rotor position to comprehend energized winding following the energizing sequence.

| HALL POSITION | PHASE A | PHASE B | PHASE C | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|---|---|---|
| 000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 001 | -1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 010 | 0 | 1 | -1 | 0 | 1 | 1 | 0 | 0 | 0 |
| 011 | -1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 100 | 1 | -1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 101 | 0 | -1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| 110 | 1 | 0 | -1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 2. Switching Sequence

Rotor position is sensed using Hall Effect sensors embedded into the stator. Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor [4]. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. A commutation logic specifies correct phases to be excited to the 3-phase inverter. This block represents how a motor would spin (at a constant speed) depending upon the position of the rotor. There are totally six switches from $S_1$ to $S_6$ on the 3-phase inverter which forms the commutation circuit. Process of switching ON and switching OFF the switches in the inverter arms is based on the predefined pattern or sequence depending on hall sensor values as shown in the fig.2.

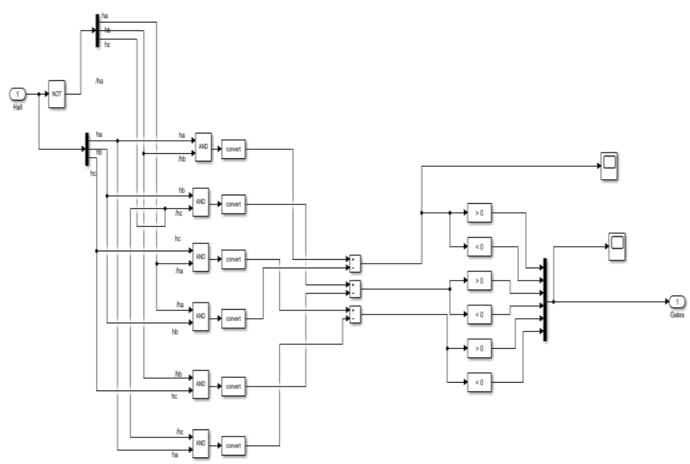

Figure 3. Decoder Implementation

The decoder logic for the above switching sequence is implemented in Simulink as shown in figure 3.

The output of this implementation is given as gate pulse inputs to the 3-phase inverter. A gearbox is used to reduce the shaft speed of the motor while increasing the output torque. It also helps in reducing the size of the motor there by reducing the form factor of EMA. Backlash affects almost each mechanical system and ignoring its presence during control design causes a severe deterioration of system performance which can even lead to instability [5]. This non- linearity increases with wear of the systems. When backlash is traversed, there is no torque transmitted through the shaft and when sudden contact is established, the resulted impact can destroy the gear and it causes a high frequency noise.

*C. Lead Screw*

A lead screw converts rotational motion of the motor into linear motion which is the most essential part of a linear actuator. The ratio of linear to rotational motion is called the lead of the screw. The pitch of the screw determines the amount of distance the actuator advances per one rotation of the screw.

As we have considered a missile as our aerospace application, the EMA is connected to the fins of the missile. The linear motion of the lead screw results in the angular rotation of the fin which changes the direction of the missile.

## III. DESIGN IMPLEMENTATION IN SIMULINK

The designed model in SIMULINK software is shown in figure 4. The voltage demanded by this design is limited to 180V as most of the missile electrical systems work within this limit. This voltage is supplied to a 3-Phase inverter which controls the speed of the BLDC motor which is driven by the commutation sequence provided by the decoder. Now the rotational motion of the BLDC motor is converted into linear motion by the lead screw. The mathematical representation of the lead screw is given by eq-2.

$$TF = \frac{P}{2 * \pi * s} \quad (2)$$

Where,

TF: Transfer function of the Lead screw

P: Pitch of the Screw

As the lead screw is attached to the fin of the missile, the linear motion is converted to angular motion of the fin. The pitch of the screw determines the distance travelled by the screw for one rotation. The pitch of the screw used in our design is taken as 3 millimeters. We have designed the model considering that our fin shifts by $4^0$ in position for every 5-millimeter displacement in the lead screw. So, if the desired fin movement is $50^0$, the actuator should give a linear displacement of 62.5-millimeters.

In a control system, generally there are many unwanted inputs which will affect the output of control system resulting in the increase of system error [6]. These unwanted signals are disturbance signals. So, in order to eliminate these disturbances from the system, we use the system feedback to enable the control system to monitor and process them to minimize these disturbances to reach a state of stability. The model is designed to resist these unwanted signals dynamically. Also, the control systems are susceptible to the non- linearities (static or dynamic). A motor that does not react to very low input voltages due to frictional forces shows a nonlinearity called dead zone. Gears that do not fit perfectly exhibit a nonlinearity called backlash [7]. This model is designed in such a way to withstand them to certain acceptable range.

## IV. RESULTS AND DISCUSSION

The system requirements and system parameters used in this design are shown tables 1 and 2. The input signal and the actuator response are shown in the figure 5,6. The error signal which is the difference between input signal and feedback decreases with time as shown in figure 12. The demanded speed S by the BLDC motor is shown in figure 7**.** This assumes that the motor initially demands high speed and once the desired actuation output is achieved, the motor stops spinning. Also, it is observed that when a sudden load is acted on the motor (at 0.5 sec), the motor tries to counteract the load and the desired actuation is achieved with some delay as shown in figure 8. The demanded voltage by the EMA is shown in figure 9. It is observed that initially 180V is demanded by the actuator and the demand correspondingly reduces as the fin approaches the desired position. Stator currents and Hall sensor outputs are shown in figures 10, 11**.** The PID controller is tuned in such a way that if a backlash nonlinearity with a dead band value of 60 is applied, the system is still able to achieve the desired actuation within specified time of 2 seconds as shown in figure 13. The model is also tuned to withstand a dead zone nonlinearity with a band value ranging from -30 to +30 as shown in the figure 14.

Table 1. System Requirements

| **Parameter** | **Value** |
|---|---|
| Settling time | 2 seconds |
| Peak overshoot | <10% |
| Maximum input voltage | 180 volts |

Table 2. System Parameters

| **Parameter** | **Value** |
|---|---|
| Power Supply | 180V DC |
| Number of phases | 3 |
| Back EMF waveform | Trapezoidal |
| Mechanical Input | Torque |
| Stator phase resistance Rs (ohm) | 0.2 |
| Stator phase inductance Ls (H) | 8.5e-3 |
| Flux linkage | 0.175 |
| Motor Current | 15A |
| Inertia (J(kg.$m^2$)) | 0.6e-3 |
| Viscous damping (F(N.m.s)) | 1e-3 |
| Screw (displacement per revolution) | 3 mm |

Table 3. Various PID values

| **Sl. No** | **Kp** | **Ki** | **Kd** |
|---|---|---|---|
| 1 | 10 | 0.0001 | 0.005 |
| 2 | 25 | 0.02 | 0.000001 |
| 3 | 50 | 10 | 0.5 |
| 4 | 70 | 20 | 0 |
| 5 | 90 | 1 | 1 |

| | | | |
|---|---|---|---|
| 6 | 90 | 0.1 | 40 |

The fin response to various PID values as in table 3 are shown in figure 15.

## V. CONCLUSION

The design and simulation study of Electro-Mechanical Actuator using MATLAB Simulink software has been executed and is validated. The model is developed towards high reliability and high-power efficiency. The effects of parameters variations on system's stability and performance were also analyzed. The model can handle the disturbances and non-linearities to a great extent. This model can also thwart the effect of sudden load on the motor and can achieve desired actuation within a very short settling time. The maximum tolerable range for nonlinearities has been found out. The model stands out to be very reliable even when acted upon with disturbances and high amounts of non-linearities the outcomes acquired from this simulation study are satisfactory and experimental validations are presented.

## VI. REFERENCES


1. https://www.grc.nasa.gov/WWW/K-12/rocket/rktfor.html#:~:text=In%20flight%2C%20a%20rocket%20is,the%20parts%20of%20the%20rocket.
2. https://www.machinedesign.com/mechanical-motion-systems/article/21836654/engineering-refresher-the-basics-and-benefits-of-electromechanical-actuators
3. MathWorks Help : https://in.mathworks.com/help/simulink/slref/pidcontroller.html
4. https://shodhganga.inflibnet.ac.in/bitstream/10603/141533/10/10_chapter%202.pdf
5. M. L. Corradini, G. Orlando, G. Parlangeli: *Robust control of nonlinear uncertain systems with sandwiched backlash*, 44th IEEE Conference on Decision and Control, 2006.
6. Ashraf Abd Almageed Ahmad, Dr.Eltahar Mohammed Hussein: *Effect of Disturbance on Closed-Loop Control System*, ISSN: 2319-8753, Vol. 3, Issue 8, August 2014.
7. Norman.Nise - "Control.Systems.Engineering"-6th.Edition.


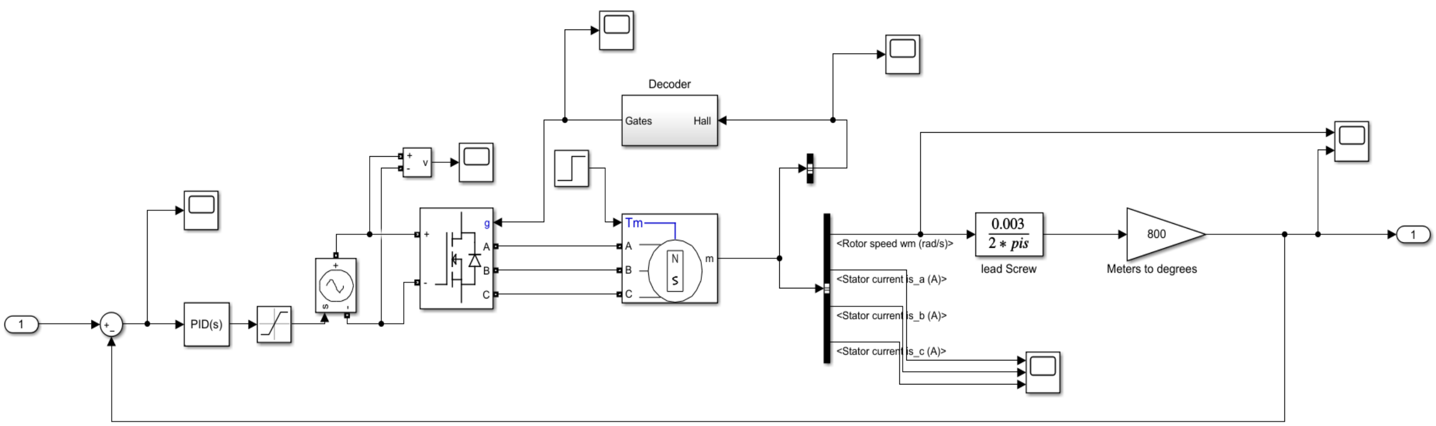


Figure.4. Electromechanical Actuator Subsystem

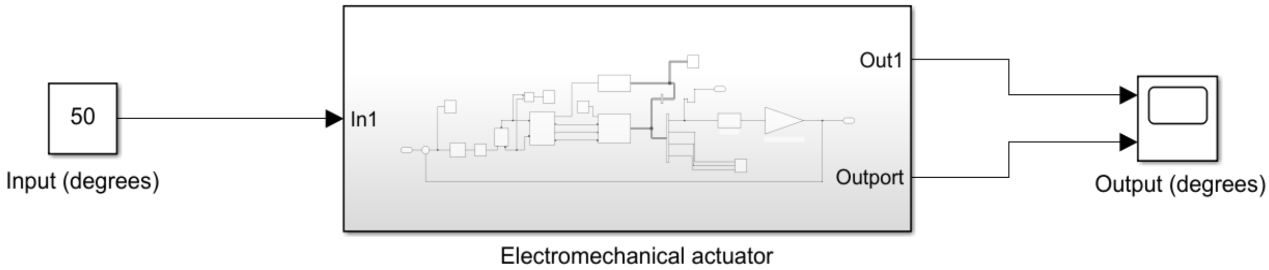


Figure 5. Model input-output

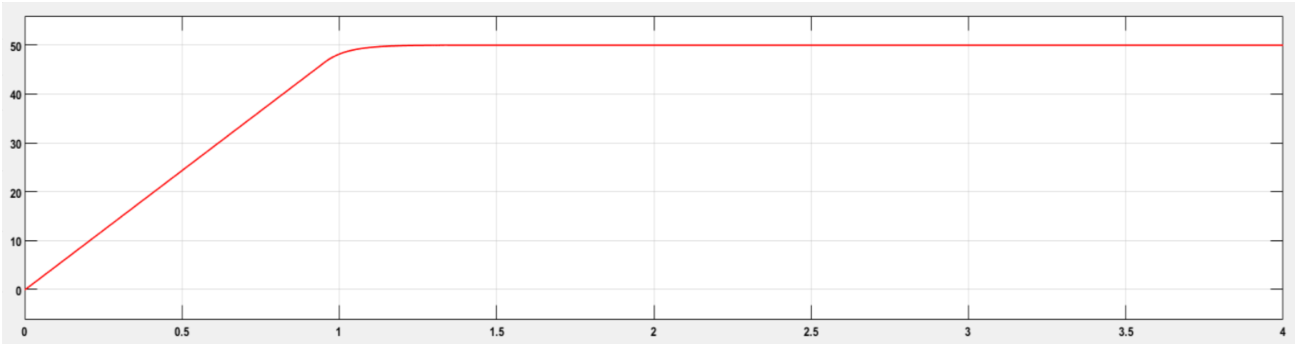

Figure 6. Fin response

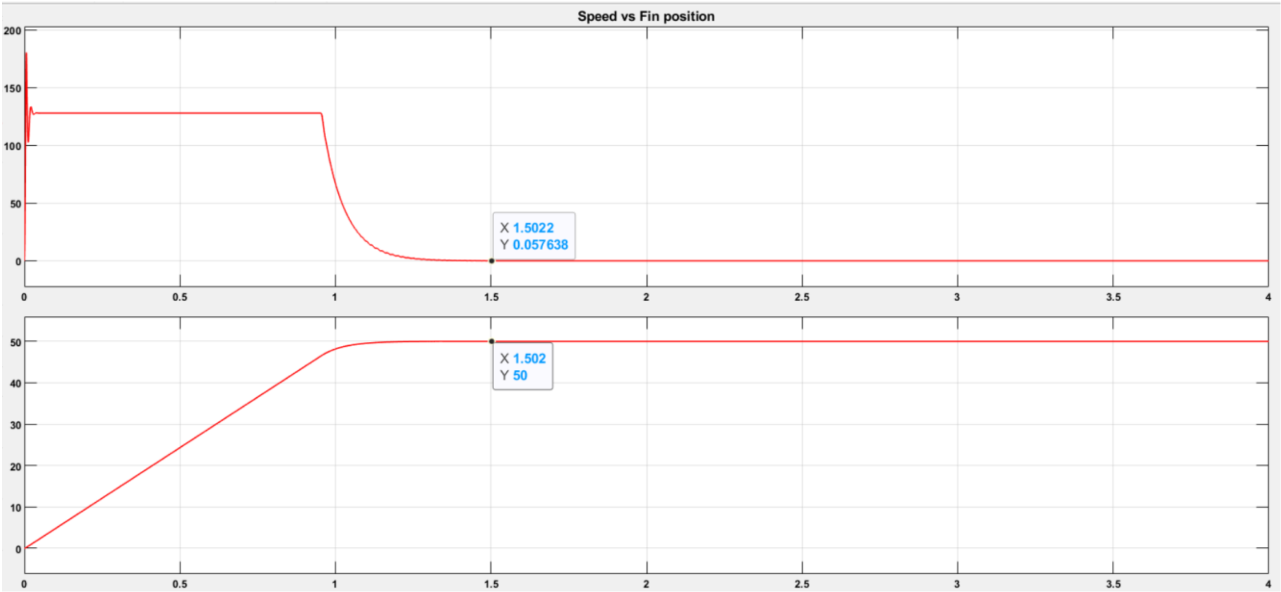


Figure 7. Demanded Speed by the motor

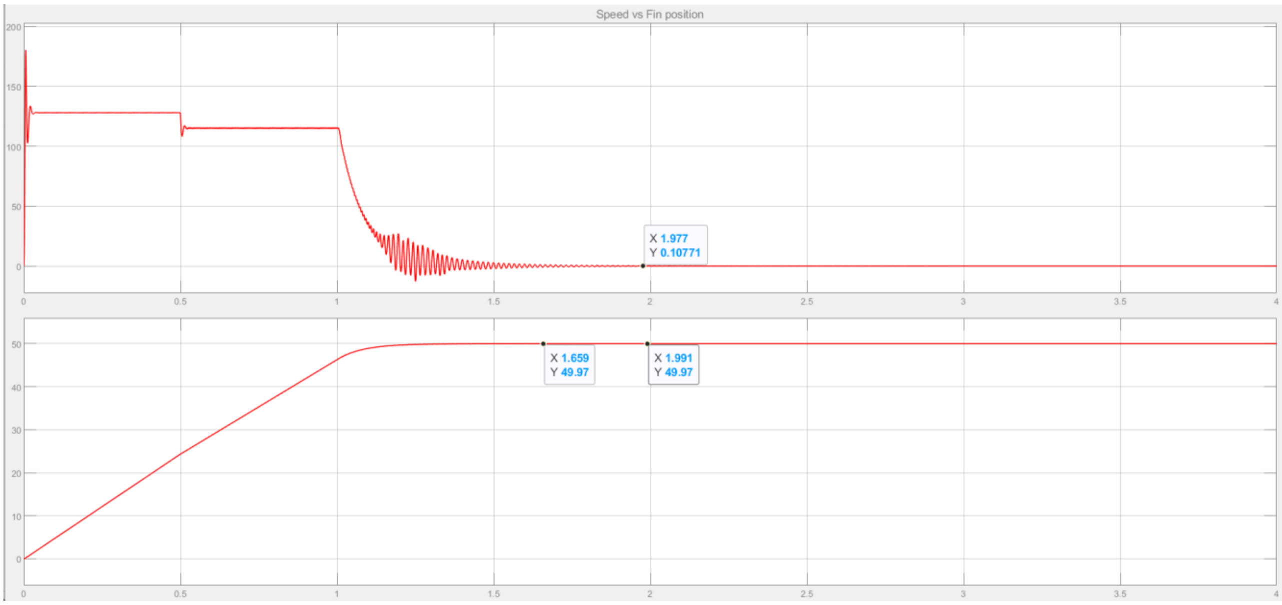


Figure 8. Motor response for sudden load at 0.5 sec

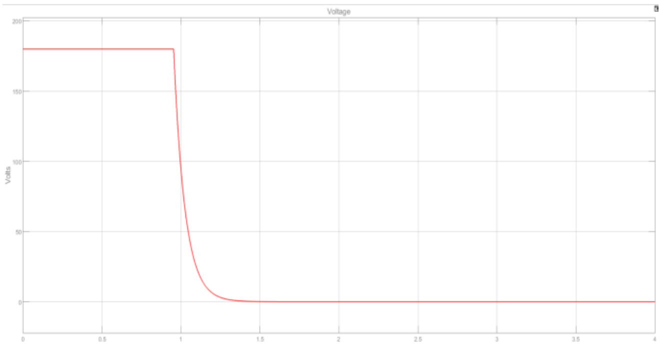

Figure.9 Demanded Voltage

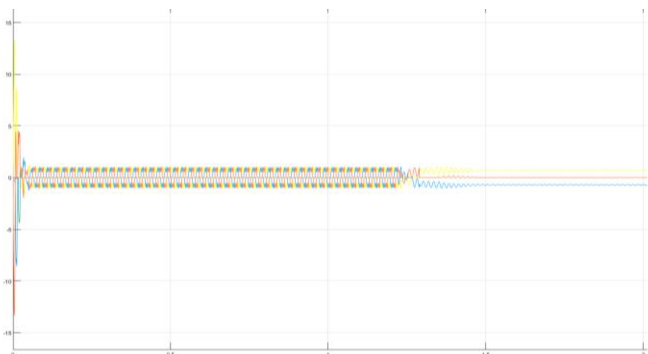
Figure.10. Stator Currents

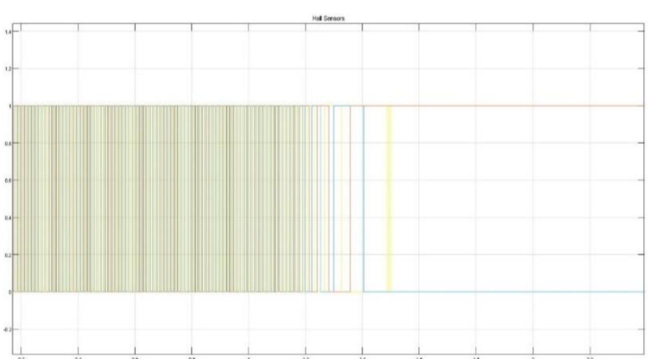

Figure 11. Hall Sensors

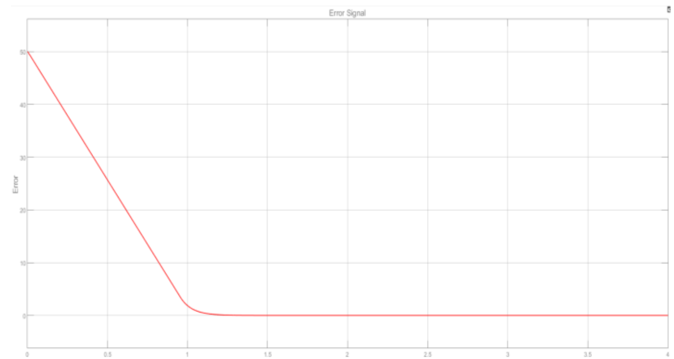

Figure 12. Error Signal

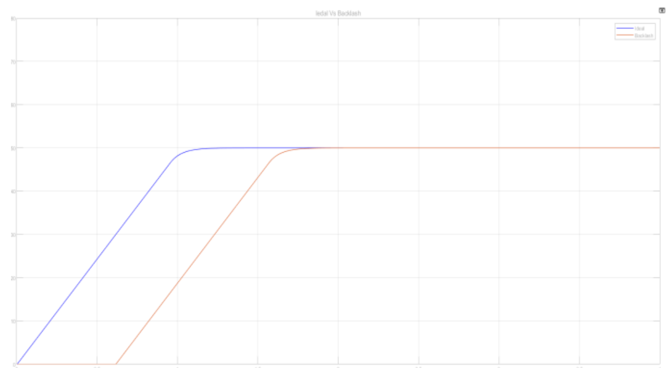
Figure.13 Introduction of Backlash nonlinearity

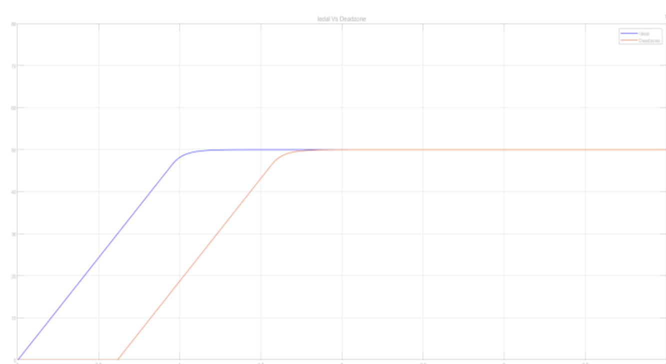
Figure.14 Introduction of Deadzone nonlinearity

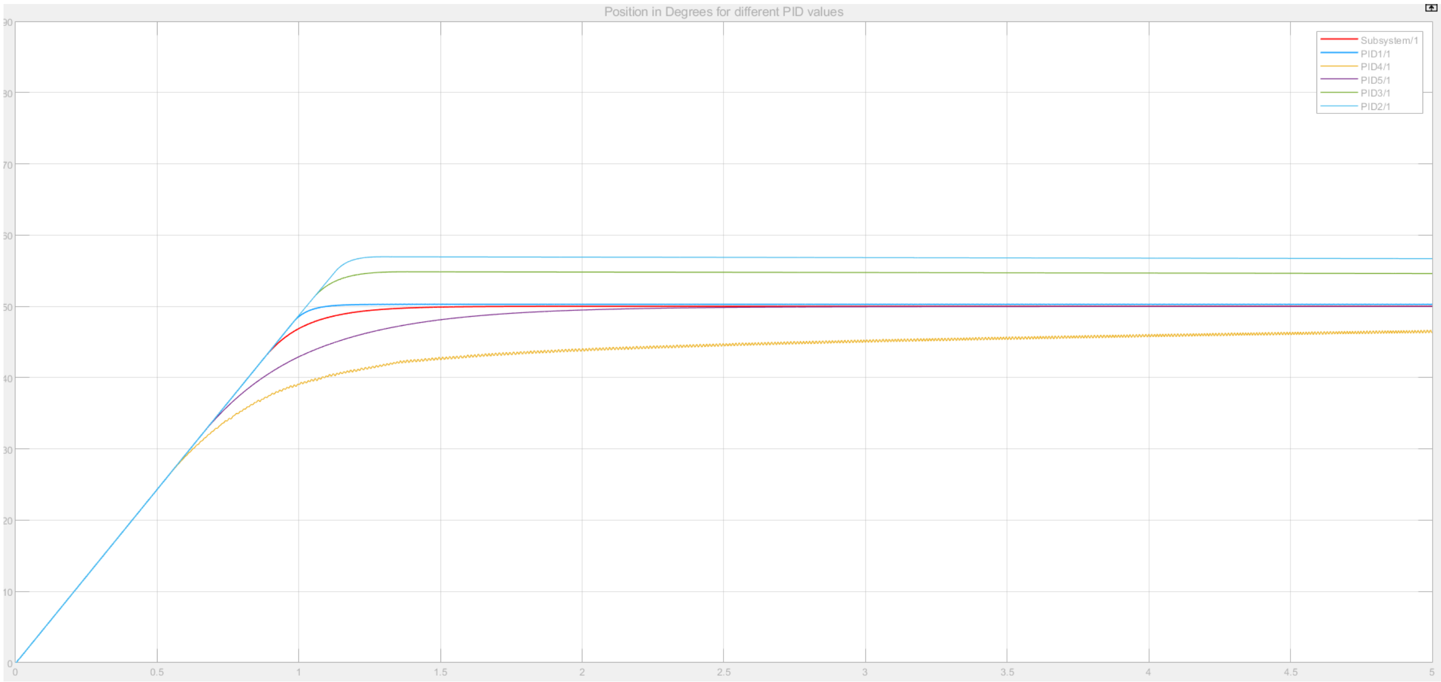


Figure 15. Fin response for different PID values