International Journal on Smart Material and Mechatronics
IJSMM Vol. 11 No. 2 2024 DOI. 10.20342/IJSMM.11.2. 299

p-ISSN: 2356-5314
e-ISSN: 2460-075X

Modeling and Simulation of Permanent Magnet DC Motors using LabView as a Teaching Aid

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***Abstract*— Manipulating materials, energy, and information is the function of the engineering profession, Laboratory practice is used as a tool in proving theoretical concepts taught in learning and promoting the development of skills required in engineering as independent learning and critical thinking analysis. Problems generally encountered in experimental activities, the number of students and the number of equipment and devices for experiment are not sufficient for individual use of each student with limited time duration to complete the entire job sheet. Our laboratory has developed modeling and simulation software to study the static and dynamic characteristics of permanent magnet DC motors using LabView as a teaching tool. By using this software, the learning process can be carried out independently by students and is expected to improve students' analytical skills.**

***Index Terms*— Permanent Magnet DC Motor, Modeling and Simulation, Teaching Aid, Labview.**

I. INTRODUCTION

Manipulating materials, energy, and information is the function of the engineering profession, so it benefits humanity. Knowledge of nature that goes beyond theory must be possessed by an engineer, knowledge that has traditionally been acquired in laboratory education and that over the years the nature of these laboratories has changed[1]. As one of the vocational education institutions, the Indorama Engineering Polytechnic requires a basic component in its engineering education, namely laboratory practice. Laboratory practice is used as a tool in proving theoretical concepts taught in learning and promoting the development of skills required in engineering as independent learning and critical thinking analysis[2].

Computing and communications technology has had a significant impact on the engineering education system, in the form of improving online and collaborative learning and student learning experiences with one of the distinguishing elements of engineering education being laboratory requirements. There are two types of laboratories being developed, namely: first, a simulation or virtual laboratory is a simplified version of the system, this type of laboratory is based on software to simulate a lab environment. Remote lab allows students to control and carry out trials or experiments via the internet using real components and instruments, thus providing the benefits of implementing a real hybrid laboratory and simulation. User interactivity is a factor in the effectiveness of this laboratory so the display must be made more realistic[3][4][5].

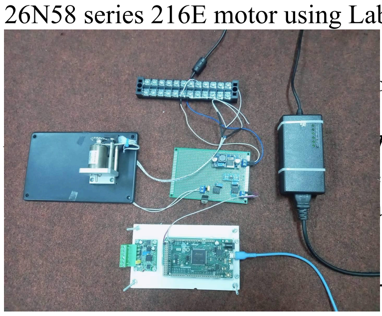
Experimental in laboratorium is a very important subject besides theoretical learning in technical and vocational education. Most lecturers agree that the learning process through practice is easier to remember than reading, so theoretical learning must be supported by practical learning in the laboratory[6][7]. Problems generally encountered in experimental activities, the number of students and the number of laboratory chairs, equipment and devices for experiment are not sufficient for individual use of each student with limited time duration to complete the entire job sheet, as well as the lack of teaching staff to provide adequate technical support can cause problems that important[8]. New methods of educational processes have been brought about by the modern world which influences the acquisition of theoretical and practical knowledge in laboratories. Students must have access to teaching materials and laboratories whenever and wherever they are, remote lab management allows the use of expensive and specialized laboratory equipment, easy management of experiments and exercises via the internet and significantly improves the quality of learning in general[9][10][11]. Making it possible to build virtual and remote lab learning systems creates new problems, namely the lack of student motivation in carrying out exploration so that the collaboration of direct laboratory, simulation and remote learning systems can make the learning process better[12].

DC (Direct Current) motors as a type of actuator are still widely used in control technology both in industry and in households, the advantage of DC motors is that they have a fast response but still have a steady state error. This deficiency can be corrected one way by using a PID (Proportional – Integral – Derivative) controller which has a fast response so it is suitable when used to control dc motors[13]. One of the stages in the analysis and design process is carrying out mathematical modeling of the plant which is then simulated to obtain the characteristics and responses of the plant, system models are usually represented in the form of block diagrams which are algebraic forms. systems represented in differential equations are difficult to model in the form of block diagrams, so laplace transformation is needed so that input, output and the system can be represented in the form of separate entities[14].

Common software in the process of analyzing, designing, building, simulating and implementing control systems is MATLAB, with LABVIEW we have another alternative and it even collaborates with MATLAB. Labview requires the Control design and simulation toolkit and mathscript RT to carry out control system analysis, design and simulation functions. The control design and simulation toolkit is divided into two palette subsections: the Control Design subpalette is used for the analysis and design process, and the Simulation subpalette is used for the simulation process of system modeling results to determine the dynamic characteristics of the system[15]. Labview's capabilities in the form of extensive support for accessing instrumentation hardware, drivers and abstraction layers for various types of instruments and buses are Labview's advantages compared to other development software.

II. PERMANENT MAGNET DC MOTOR

The appearance of the permanent magnet DC motor control learning media developed by our laboratory is as shown in Fig. 1. The hardware module built consists of an Arduino controller based on the Atmel SAM3X8E ARM Cortex-M3 microcontroller, Portescap Type 26N58 DC Motor 216E series with incremental encoder, frequency converter to the voltage and DC motor driver. This research focuses on creating virtual learning media for the DC Portescap Type 26N58 series 216E motor using Labview.



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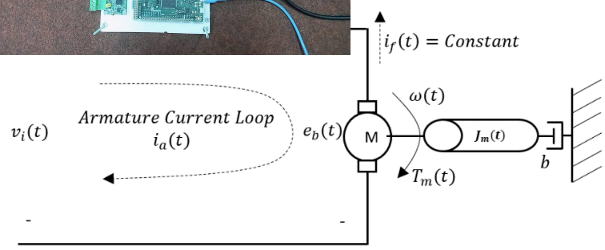

Fig. 2. Schematic diagram of Permanent Magnet DC Motor

Fig. 1 shows that a DC motor is an electromechanical component, there are electrical and mechanical parts that are connected by a torque component that arises when the armature current flows when a voltage v_i (t) is applied. In general, the motor torque is directly proportional to the armature current and magnetic field strength, because DC motors are permanent magnets, the magnetic field strength is constant so that the DC motor torque is only influenced by the armature current and the torque is formulated as in equation 1.

$$T_m(t)=K_t\, i_a(t)$$

When the DC motor armature rotates, the coil of wire in the armature moves perpendicular to the magnetic field, thus producing a voltage at the terminals which is directly proportional to the rotation speed of the motor as stated in equation 2.

$$e_b(t)=K_b\ \omega(t) = K_b(d\Theta(t)/dt)$$

DC motors have electrical parts that can be analyzed using Kirchoff's voltage law, as shown in equation 3.

$$v_i(t) - e_b(t) = R_a\, i_a(t) + L_a\ (di_a(t))/dt$$

The mechanical part of the DC motor is obtained by considering the moment of inertia that arises in the anchor rotor and the viscous damping caused by the anchor rotor bearing, so that it meets equation 4.

$$T_m\,(t) = J_m\ (d\omega(t)/dt) + b\omega(t) + T_L\,(t)$$

The transfer function of a permanent magnet DC motor can be obtained by carrying out the Laplace transformation of equations 1 to 4 to obtain the equation 5 to 8.

$$T_m\,(s) = K_t\, I_a\,(s) = (T_m\,(s))/(I_a\,(s)) = K_t$$

$$E_b\,(s) = K_b\, \omega(s) = (E_b\,(s))/(\omega(s)) = K_b$$

$$V_i\,(s) - E_b\,(s) = R_a\, I_a\,(s) + L_a\, s\, I_a\,(s)$$

$$(I_a\,(s))/(V_i\,(s)-E_b\,(s)) = 1/(L_a\, s + R_a\,)$$

$$T_m\,(s) - T_L\,(s) = J_m\, s\, \omega(s) + b\, \omega(s)$$

$$(\omega(s))/(T_m\,(s) - T_L\,(s)) = 1/(J_m\, s + b)$$

The transfer function method is used to describe equations 5 to 8 in block diagram form as in Fig. 3(a) or can also be simplified into one block with input voltage V_i (s) and output ω(s) as in Fig. 3(b).

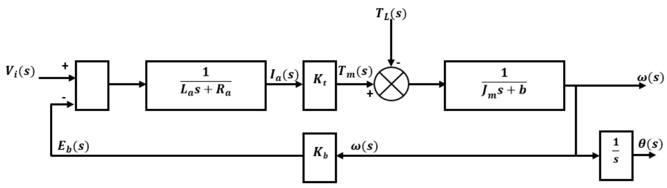

Fig. 3. Modeling of Permanent Magnet DC Motor

Based on Figure 3, assuming T_L=0 Nm, the transfer function equation can be obtained as equation 9.

$$\omega(s) / V_i\,(s) =$$

$$K_t / (J_m L_a s^2 + (bL_a + J_m\, R_a)s + (bR_a + K_t\, K_b)$$

Figure 3 shows that the permanent magnet dc motor model consists of an electrical part with an input of armature voltage difference (V_i) and back emf voltage (E_b) which is influenced by angular velocity (ω), the output is an armature current (I_a). The mechanical part consists of an input of mechanical torque difference (T_m) whose value depends on the magnitude of the armature current (I_a), and load torque (T_L) which is influenced by the mass of the load, the output of the mechanical part is the angular displacement (Θ)and angular velocity (ω) of the motor.

B. Labview Simulation Implementation

This experiment, the modeling performances are compared between permanent magnet DC motor datasheet and modeling

 p-ISSN: 2356-5314
e-ISSN: 2460-075X

and simulation labview. This research uses a Portescap Type 26N58 series 216E DC motor. Based on the datasheet from the official website, the parameter data obtained from the DC motor is shown in Table 1

TABLE I. PORTESCAP 26N58 216E SERIES DC MOTOR PARAMETER

Description	Value	Unit
Terminal Resistance (Ra)	10	Ω
Rotor Inductance (La)	0,0008	H
Nominal Voltage (Vi)	12	Volt
Back-EMF Constant (Kb)	0,0238732	V.s/rad
Torque Constant (Kt)	0,0239	N.m/A
Friction Torque (Tf)	0,00038	N.m
Mechanical Time Constant (τm)	0,0105	s
Rotor Inertia (Jm)	0,0000006	Kg-m2
Viscouse damper (bm)	0,0000007664	N.m.s/rad
No-load speed (ωm)	495.848	rad/s
No-load current (ia)	16	mA

Based on the selected motor specifications in Table 1, the equation for the transfer function of the motor speed to the given input voltage, assuming the load torque T_L=0 Nm.

$$\omega(s) / V_i(s) =$$

$$49791666{,}67 / (s^2 + 12501{,}27733s + 1204653{,}083)$$

Equation 10 is the transfer function of the permanent magnet DC motor Portescap Series 26N58-216E, and the analysis by giving a unit step signal to the transfer function of the permanent magnet DC motor using the Labview Control Design Subpalette. Assuming the initial condition of the system is equal to zero.

C. Experimental results and considerations

The experimental results are shown in Fig. 4 and Fig.7, Figure 4 shows the system analysis using the Control Design Subpalette and Figure 7 shows the results of the system simulation using the Simulation Subpalette.

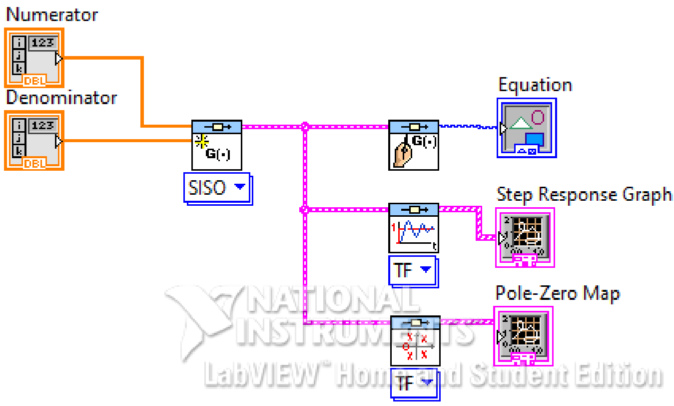

Fig. 4. Diagram Block VI Step Response

Figure 4 shows the Labview block diagram for the analysis of the step response transfer function of a permanent magnet DC motor, involving the CD Construct Transfer Function Model.vi which is responsible for creating a transfer function representation using sampling time, Numerator, Denominator and Delay. The CD Draw Transfer Function Equation.vi functions to display the transfer function equation of the model and the CD Step Response.vi functions to calculate the output of the system when given a unit step signal by assuming the initial condition of the system is zero. The CD Pole-Zero Map.vi functions to display the poles and zeros plots of the system model using an XY graph that states the complex axis.

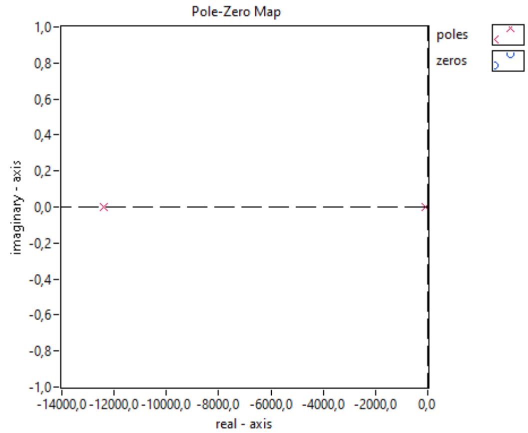

Fig. 5. Poles – Zeros Map

Figure 5 shows the system has two different negative real roots with values x_1 = -12404.2 and x_2 = -97.1 located on the left side of the imaginary axis. The input pole at the origin produces a constant forced response, each pole of the system on the real axis produces an exponential natural response whose exponential frequency is the same as the location of the pole. This response is called an overdamped response referring to the large amount of energy absorption in the system, which inhibits the transient response from overshooting and oscillating, if the energy absorption is reduced then it will change to underdamped and overshoot occurs.

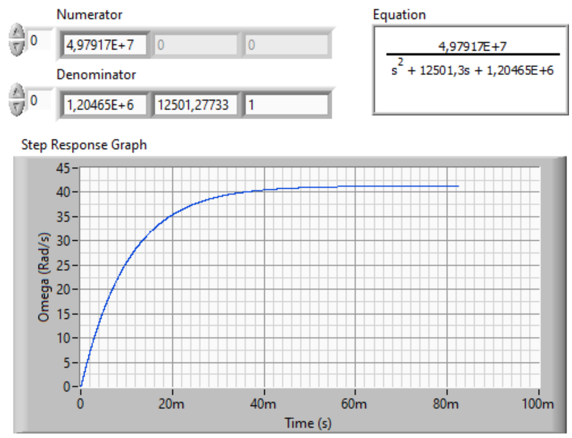

Fig. 6. Step Response Permanent Magnet DC Motor

Figure 6 shows that when 1Volt is given to the system, the motor will reach a maximum speed of 41.32 rad/s with a time of 79.91ms to reach its stable speed. The mechanical time constant value is obtained by taking 63.2% of the maximum value obtained at 26.11 rad/s which takes 10.37ms.

Based on Table 1, the block diagram in Figure 3 is then implemented into the LabView programming environment using the control and simulation toolkit, as shown in Figure 7.

p-ISSN: 2356-5314
e-ISSN: 2460-075X

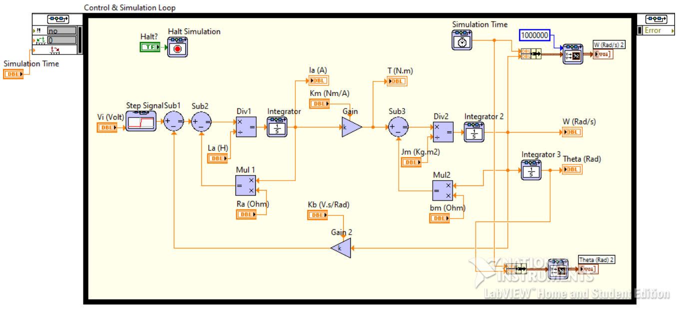

Fig. 7. Block Diagram of Permanent Magnet DC Motor

To generate the Labview model at steady state, the functions can be defined in a Labview Simulation or in the Labview Control Design Palette, Figure 7 shows the modeling and simulation of a permanent magnet DC motor using the Labview Simulation palette which is similar to Simulink in MATLAB. After defining functions and gains, Labview Simulation model can be generate at different values for $V_i(s)$ and T_L was zero.

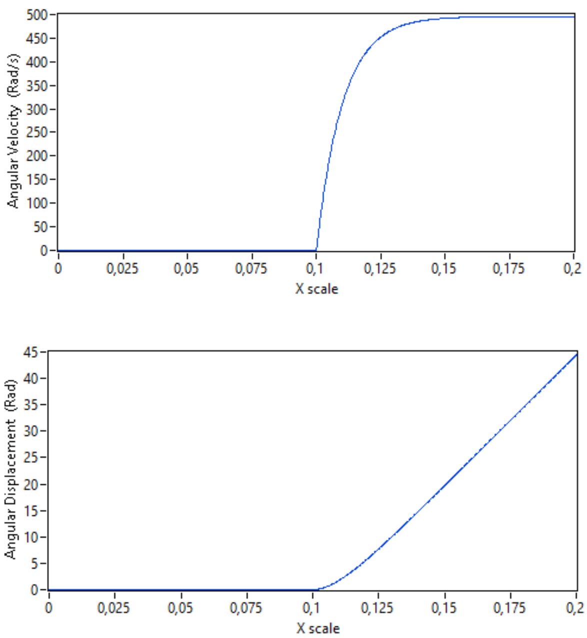

Fig. 8. Step Response Angular Velocity and Displacement

Figure 8 shows that when 12 Volt is given to the system at 0,1s, the motor will reach a maximum speed of 496 rad/s with a time of 0,196s to reach its stable speed. The mechanical time constant value is obtained by taking 63.2% of the maximum value obtained at 314,3 rad/s which takes 0,0104s. in a time span of 0.1 seconds the motorbike has also covered a distance of 44.45 rad.

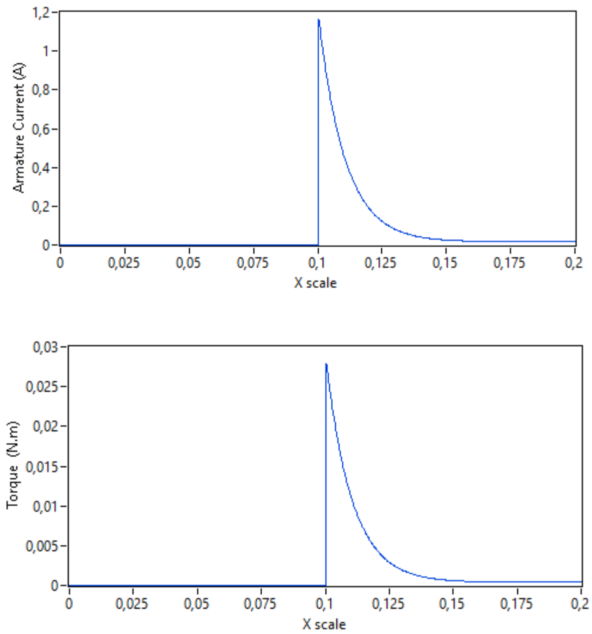

Fig. 9. Step Response Armature Current and Torque

Other parameters that need to be observed are the torque curve and armature current, in Figure 9 the curve shows the spike in armature current and torque that occurs as a result of inertia load and friction on the bearing causing the motor to require a stall current of 1.165A and reach a steady state condition at a current of 0.01596 A which also results in a spike in motor torque, Stall Torque of 0.02785 Nm and reaching a steady state condition at a Torque of 0.0003815 Nm.

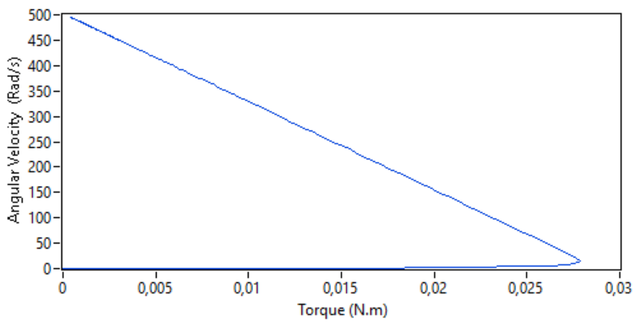

Fig. 10. Step Response Torque vs Angular Velocity

Through modeling and simulation using Labview, data acquisition process can be done on several variables which then display the results into an XY graph to get the correlation of two variables. Figure 10 shows the relationship between the torque curve and the angular velocity curve of the motor, at 0.1s the motor input voltage changes from 0 volts to 12 volts, because the motor rotor has inertia and friction on the bearing then the motor requires an initial torque of 0.02785Nm to be able to move the rotor to rotate by 15.89 rad / s which then the motor torque decreases and stabilizes at 0.0003815 Nm and the angular velocity increases and stabilizes at 496 rad / s linearly.

III. CONCLUSION

In this paper, we develop a teaching aid with the object of a permanent magnet DC motor which is widely used as a mechatronic actuator. The teaching aid created is in the form of modeling and simulation software for permanent magnet DC motors, experiments conducted by comparing the modeling and simulation made with the datasheet of permanent magnet DC motor components. The results ensure that the modeling and simulation made meet the datasheet standards for permanent magnet DC motor components. The next step that can be taken is to design a suitable speed and position control system.

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