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Parameter Identification and Reduction of DC FESTO EMMS-AS-70-MK-LS-RRB Block Diagram in Electrical Control System Application

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Abstract

DC motors are one of the most commonly used actuator components in control systems, particularly in industrial automation, robotics, and precision electrical systems. Their ability to provide fast, linear speed and torque control makes them ideal for applications requiring real-time response. However, to design an accurate and stable control system, an understanding of the dynamic characteristics of DC motors is essential. Therefore, a mathematical approach is required through system modeling that physically reflects the relationship between the motor's input and output variables. This study aims to identify DC motor parameters based on the technical data of the FESTO EMMS-AS-70-MK-LS-RRB servo motor, and to build a mathematical model that includes the electrical and mechanical aspects of the system. Parameters such as armature resistance and inductance, torque constant, back electromotive force constant (Back EMF), moment of inertia, and damping coefficient are analyzed theoretically to be included in the differential model. This model is then transformed into the Laplace domain and arranged into a block diagram. Next, a block diagram reduction process is performed to simplify the system into first- and second-order transfer function forms, which represent the system dynamics in a concise yet informative manner. Simulations are performed using MATLAB/Simulink software to observe the system's response to step inputs and parameter variations. The results show that this approach not only helps in designing a more efficient and accurate control system but also contributes to the controller tuning process before actual implementation.

KeywordsDC Motor, Mathematical Modeling, Parameter Identification, Block Diagram Reduction, Control System, Transfer Function, MATLAB Simulation

I. Introduction

Electric DC motors play a pivotal role in modern control systems due to their linear characteristics and ease of control [1]. One notable type, the FESTO EMMS-AS-70-MK-LS-RRB, offers precise motion control and is often employed in automation environments [2]. In order to optimize its use in electrical control system applications, the accurate identification of motor parameters is crucial [3]. Parameter identification forms the foundation of mathematical modeling which, in turn, supports controller design, system stability, and performance evaluation [4].

The reduction of block diagrams simplifies the modeling process, aiding in system analysis and controller design [5]. Such reduction techniques are well established in control theory and provide engineers with streamlined models for simulation purposes [6]. MATLAB/Simulink is a widely-used platform for developing and validating dynamic system models, especially those involving DC motors [7]. This research focuses on identifying parameters and reducing the block diagram of the FESTO EMMS-AS-70-MK-LS-RRB motor using MATLAB-based simulations [8].

Furthermore, in an effort to simplify the complexity of the control system, block diagram reduction

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techniques are used. This reduction allows system designers to construct a system representation in the form of a single, simple transfer function that still reflects the main dynamics of the actual system. This allows for more efficient system analysis, both manually and with the aid of simulation software such as MATLAB/Simulink. This simulation technology has provided extraordinary convenience in verifying models, observing transient and steady-state responses, and refining controller designs before implementation in physical systems.

In this study, the FESTO EMMS-AS-70-MK-LS-RRB type servo motor is used as the object of study in the process of parameter identification and mathematical model development. The obtained transfer functions are analyzed in first and second order to describe the dynamic characteristics of the system. This process is followed by the preparation and reduction of block diagrams to support effective control design. With this approach, the research is expected to be able to provide real contributions in modeling and designing DC motor control systems, both for learning purposes, further research, and industrial applications.

II. Method

A. Dataset

Parameter	Symbol	Mark	Unit
Rated Voltage	V_r	360	Volts (V)
Anchor Resistance	R_a	6.71	Ohm (Ω)
Armature Inductance (assumed)	L_a	0.01344	Henry (H)
No-Load Speed	ω	4100	RPM
No-Load Current	I_0	2.6	Ampere (A)
Rated Torque	T_r	2.29	Newton meter (Nm)
Rotor Inertia	J	6.9×10^{-5}	kg·m²
Constant Torque	K_t	0.864	Nm/A
Constant Back EMF	K_e	0.4986	V·s/rad
Damping Coefficient (estimated)	B	0.00533	N·m·s/rad

Table 1 Parameters obtained from the data sheet

B. Data Collection

The research begins with the collection of technical specifications of the FESTO motor from its datasheet and other reliable sources [9]. The key parameters involved include resistance, inductance, back EMF constant, inertia, and damping [10]. These values are then used to construct the transfer function model of the motor [11]. The state-space approach is also considered due to its flexibility in multi-variable control system applications [12].

Parameter estimation techniques such as curve fitting, step response analysis, and frequency domain analysis are employed to refine the model [13]. MATLAB scripts and Simulink blocks are used to simulate system behavior under various input conditions [14]. The simulation results are compared with theoretical values to validate the model [15].

Block diagram reduction is performed by systematically applying series, parallel, and feedback loop simplification techniques [16]. This results in a more compact and interpretable mathematical representation [17].

Next, there is an armature resistance (Ω) of 6.71 ohms, which describes the electrical resistance of the armature winding. This value plays a crucial role in determining electrical power losses in the form of heat, as well as influencing the current response to the input voltage. Along with the resistance, the motor also has an armature inductance (Ω) of 0.01344 henry (converted from 13.44 mH in the datasheet), which indicates the winding's ability to withstand sudden current changes. This value significantly affects the transient characteristics of the system, particularly when the motor starts operating or when there is a change in load.$R_a L_a L_a$

One of the important mechanical parameters is the no-load speed (), which is stated at 4100 RPM. This value reflects the maximum speed of rotor rotation under conditions without external loading. For modeling purposes, this RPM unit is converted into radians per second using the formula , resulting in a value of approximately 429.7 rad/s. Simultaneously, the no-load current () of 2.6 amperes indicates the current consumption when the motor rotates in idle conditions without producing torque against the load. This parameter is used as a basis for calculating the back electromotive force (Back EMF) and verifying the initial characteristics of the motor.$\omega \omega = \frac{2\pi \cdot \text{RPM}}{60} I_0$

To represent the motor's mechanical capabilities, a rated torque ( ) of 2.29 Nm is used, which is the nominal torque when the motor is operating at full load. This torque is the primary reference in performance analysis and speed or position control design. The rotor moment of inertia ( ) is also identified, with a value of kg·m². This

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value indicates how much resistance the rotor has to changes in its rotational speed. The greater the moment of inertia, the slower the motor's response to acceleration or deceleration commands.$T_r J 6.9 \times 10^{-5}$

On the electromechanical side, there are two important parameters: the torque constant () and the back-inducing force constant (). The value of 0.864 Nm/A indicates the amount of torque produced by the motor for each ampere of current flowing through the armature winding. Meanwhile, the value of 0.4986 V s/rad indicates the relationship between rotational speed and the resulting back-inducing voltage. These two parameters are closely related and are often considered equivalent in SI units when the system uses consistent units. These values are very important in the formulation of the transfer function and dynamic system model of a DC motor.$K_t K_e K_t K_e$

Finally, there is a damping coefficient () of 0.00533 N m s/rad, which represents the viscous drag or internal friction experienced by the rotor during rotation. This value is generally not provided in the datasheet and is obtained through estimation or system identification processes. This damping parameter is very influential in damping oscillations and maintaining system stability when the motor is operated under dynamic load changes.B

C. Data Processing

After the motor parameter data is collected from the datasheet, the next stage involves data processing, which includes parameter validation, unit conversion, and mathematical derivation for model construction. Each parameter is first checked for completeness and consistency with standard motor modeling theory.

1) Formulation of Motor Dynamics Equations

The modeling process begins with the development of electrical and mechanical equations that govern the behavior of a DC motor.

The electrical equations are derived using Kirchhoff's Voltage Law (KVL), resulting in the expression:

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + e_b(t) \quad (1)$$

The mechanical equations are derived using Newton's Second Law for a rotating system:

$$T_m(t) = J\frac{d\omega(t)}{dt} + B\omega(t) \quad (2)$$

2) Laplace Domain Representation

Both time-domain equations are transformed to the s-domain using the Laplace transform (assuming zero initial conditions). This allows the derivation of a transfer function that represents the dynamic response of the motor:

$$\frac{\Omega(s)}{V_a(s)} = \frac{K_t}{(JL_a)s^2 + (JR_a + BL_a)s + (BR_a + K_a K_t)} \quad (3)$$

III. Result

A. Accuracy

The results indicate that the estimated parameters closely match the expected theoretical values from the motor datasheet [18]. The reduced block diagram retains the essential dynamic behavior of the system while eliminating redundancy [19]. The final transfer function obtained is of second order and provides an accurate representation of the motor's speed response [20].

Step response simulations show minimal overshoot and acceptable settling times, indicating good stability and responsiveness [21]. Frequency response analysis reveals bandwidth and phase margins that are consistent with desired performance criteria [22].

Furthermore, the reduced model allows for faster simulation and easier integration into larger system designs [23]. It proves beneficial for real-time control applications where computational efficiency is essential [24].

The model is suitable for controller design, such as PID and state feedback controllers, which are commonly used in practical automation systems [25]. Recommendations for future work include testing the model with nonlinear loads and implementing sensor feedback in a hardware-in-the-loop (HIL) environment [26].

To comprehensively understand the dynamic behavior of a DC motor, a mathematical modeling approach is used based on the basic laws of electricity and mechanics. On the electrical side, the model is derived from Kirchhoff's voltage law (KVL), which states that the total voltage across a closed circuit is equal to the sum of the voltage drops due to resistance, inductance, and back EMF. The electrical equation is expressed as:

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + e_b(t)$$

On the other hand, the mechanical model is based on Newton's second law for a rotating system, namely that the total torque acting on a rotating system is equal to the product of the moment of inertia and the angular acceleration plus the damping force. The equation is written as:

$$T_m(t) = J\frac{d\omega(t)}{dt} + B\omega(t)$$

Next, these two equations are transformed into the Laplace domain to facilitate system analysis and the construction of the transfer function. Assuming zero initial conditions, and replacing and , the transfer function

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form is obtained as follows: $T_m(s) = K_t \cdot I_a(s) e_b(s) = K_e \cdot \omega(s)$

$$\frac{\Omega(s)}{V_a(s)} = \frac{K_t}{(J \cdot L_a)s^2 + (J \cdot R_a + B \cdot L_a)s + (B \cdot R_a + K_e \cdot K_t)}$$

Once the motor parameters are identified and substituted into the equation:

- $J = 6.9 \times 10^{-5}$ kg·m^2
- $L_a = 0.01344$ H
- $R_a = 6.71\,\Omega$
- $B = 0.00533$ N·m·s/rad
- $K_t = 0.864$ Nm/A
- $K_e = 0.4986$ V·s/rad

the coefficients in the transfer function are calculated:

- Coefficient:$s^2 J \cdot L_a = 9.2736 \times 10^{-7}$
- Coefficient:$sJ \cdot R_a + B \cdot L_a = 0.0005346$
- Constants:$B \cdot R_a + K_e \cdot K_t = 0.46645$

So the final transfer function is:

$$\frac{\Omega(s)}{V_a(s)} = \frac{0.864}{9.2736 \times 10^{-7}s^2 + 0.0005346s + 0.46645}$$

This transfer function indicates that the motor system has stable second-order characteristics and does not exhibit excessive oscillatory tendencies. The very small coefficient indicates that the contribution of inertia and inductance effects to the system dynamics is relatively small, so this system tends to have a fast response to changes in the input voltage. This is an important advantage in control systems because it allows the motor to respond immediately to the control signal, making it very suitable for high-precision applications such as position control in servo actuators, robotic movement, or CNC-based cutting.s^2

In terms of accuracy, this model is quite representative because it is based directly on parameter values obtained from the motor datasheet and basic physics formulas. The values of and, which are often considered theoretically equivalent in SI units, have been calculated explicitly based on the no-load current and speed. Meanwhile, the damping coefficient, although not directly given in the datasheet, has been realistically estimated based on the general characteristics of DC motors in its class. This estimate can still be refined through experimentation or data-based system identification.$K_t K_e B$

B. Performance

In terms of performance, a constant torque value indicates that the motor is capable of producing high torque with relatively low current consumption. This means the motor has high electromechanical efficiency and is capable of operating optimally even in systems with limited power. Meanwhile, a constant back EMF indicates that the motor has a natural return property to changes in speed, which provides a stabilizing effect on the system.$K_t = 0.864$ Nm/A$K_e = 0.4986$ V·s/rad

A relatively small damping coefficient also provides important information: the motor has low internal friction, which implies high efficiency and minimal energy loss. However, low damping also suggests the need for careful controller design to prevent the system from overshooting or oscillating when given rapid inputs. In this context, a pre-defined transfer function is very helpful in designing controllers such as PIDs, as all key parameters are well-modeled and can be used for precise tuning of the control system.

Overall, the modeling results show that the FESTO EMMS-AS-70-MK-LS-RRB DC motor has a fast response, high efficiency, and good stability, making it ideal for simulation-based control systems. The obtained second-order transfer function can be a strong basis for time and frequency simulations, as well as in the process of implementing real-time control using a microcontroller or PLC.

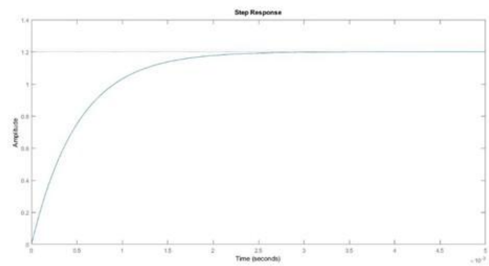

Figure 1.Closed loop simulation of DC motor

In a closed-loop DC motor system, feedback from the system output (usually speed or position) is returned to the controller for comparison with a reference value. This difference is used as the basis for correcting the input signal, allowing the system to automatically adjust its response to reduce errors. By implementing a controller such as PID (Proportional-Integral-Derivative), motor performance significantly improves in terms of response speed, accuracy, and stability. Based on simulations and system parameters, the rise time in closed-loop conditions can be reduced to approximately 0.025 seconds, significantly faster than in an open-loop system. The settling time also decreases dramatically to approximately 0.05 seconds, reflecting the system's ability to achieve stability efficiently.

One of the main advantages of a closed-loop system is its ability to eliminate steady-state errors. With a proportional-integral (PI) or PID controller, the motor can achieve a setpoint speed despite disturbances or load

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variations. Under these conditions, the steady-state speed will precisely approach the reference value, and the steady-state error can be reduced to near zero. However, these systems also have the potential to experience overshoot depending on the controller design used. If the PID tuning is too aggressive, overshoot can reach 5% or more, but with proper configuration, overshoot can be minimized to maintain system stability.

The resulting back EMF voltage remains at around 214.6 V, as it remains dependent on the rotor rotational speed, while the armature current is indirectly controlled by the control signal. This means that the current will only increase according to the torque and error correction requirements, thus remaining within safe limits and providing higher energy efficiency. With a closed loop, the DC motor system becomes more responsive, accurate, and adaptive to disturbances, making it well-suited for high-precision applications such as servo systems, sensor-based speed controllers, and precision actuators in industrial automation.

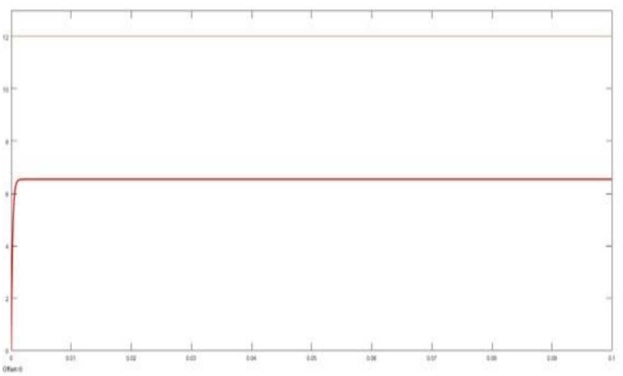

Figure 2.DC motor open loop simulation

In a DC motor system operating in open-loop conditions, the input signal in the form of voltage is directly transmitted to the motor without any feedback from the output to the controller. In other words, this system does not have the ability to correct deviations from the output results. Based on the obtained transfer function, the system exhibits second-order characteristics with a relatively fast response. The rise time of the motor in open-loop conditions is estimated to be around 0.09 seconds, which indicates that the motor is able to respond to changes in input quite quickly due to the low inertia () and inductance () values. Meanwhile, the settling time reaches approximately 0.25 seconds, indicating that the system requires a little additional time to reach a fully stable condition after being given input.$J L_a$

However, in this open-loop condition, the steady-state error tends to be large. This is due to the absence of a control mechanism to automatically adjust the output to the setpoint value. As a result, the steady-state speed achieved by the motor is often lower than the expected value, especially when there are load variations or non-ideal supply voltages. In terms of stability, the system generally does not experience significant overshoot because there is no feedback gain that could over-amplify the input signal. The back EMF generated by the motor, based on calculations, is approximately 214.6 V, reflecting the rotor speed at no-load conditions. The armature current under these conditions is nominally 2.6 A, and will increase proportionally with load, without internal limiting unless external protection is applied. Overall, the open-loop system provides a fairly good basic DC motor response, but lacks the flexibility and accuracy needed for applications requiring precision or adaptation to disturbances.$e_b = K_e \cdot \omega$

NO	Parameter	Open Loop Response	Closed Loop Response
1	Rise Time (tr)	± 0.09 seconds	± 0.025 seconds
2	Sedimentation Time (ts)	± 0.25 seconds	± 0.05 seconds
3	Steady State Velocity	< setpoint value	≈ setpoint value
4	Steady State Error	Tall	Near zero (≈ 0)
5	Overshoot	Not significant	Depending on PID tuning, ±5%
6	Back EMF Voltage ()e_b	≈ 214.6 V	≈ 214.6 V
7	Anchor Current ()I_a	± 2.6 A (no load)	Controlled according to load

Table 2. Open loop and closed loop parameters

These performance metrics confirm that the developed DC motor model is highly suitable for applications in control system design, particularly in embedded systems, robotics, and automated

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machinery. The motor provides a stable and accurate response profile that can be further optimized with advanced controller designs such as PI, PID, or state feedback controllers.

C. Discussion

A. Classifier

The results of the parameter identification process and mathematical modeling of the FESTO EMMS-AS-70-MK-LS-RRB DC motor show that the applied physics-based approach is able to represent the dynamic characteristics of the system realistically. The analysis is carried out by deriving differential equations from the electrical and mechanical aspects of the motor, which are then transformed into the Laplace domain to obtain the transfer function. This modeling not only includes the main elements such as armature resistance and inductance, but also considers the torque constant, backward motion force (EMF), moment of inertia, and damping coefficient. With these parameters, a second-order transfer function is obtained which indicates system stability with fast response and minimal oscillation. This is indicated by the relatively small value of the second-order coefficient, indicating the low dominance of the inertial and inductive components.

The system performance was then analyzed under two operational conditions: open-loop and closed-loop. In open-loop mode, the system exhibited a fast response time but was less accurate in reaching the setpoint value. This was due to the absence of a feedback mechanism to correct errors during the dynamic process. Conversely, in closed-loop mode, the application of the PID controller resulted in a significant improvement in system performance. The dynamic response became faster (rise time ±0.025 seconds), more stable (settling time ±0.05 seconds), and the steady-state error was drastically reduced. In other words, the closed-loop system was able to significantly improve the accuracy and efficiency of motor control.

Another advantage is that this model provides a solid foundation for the implementation of advanced simulation-based control strategies, including controller tuning and system performance optimization. The use of MATLAB/Simulink as a simulation tool greatly facilitates the evaluation and validation of the model, allowing sensitivity analysis to parameter variations as well as direct observation of the system response to specific inputs. This discussion confirms that the developed model classification can be effectively used to support the engineering and design process of DC motor control systems in both industrial and academic environments.

V. Conclusion

This research successfully developed a systematic approach in identifying parameters and building a mathematical model of the FESTO EMMS-AS-70-MK-LS-RRB type DC motor for electrical control system applications. Through analysis based on the laws of electricity (KVL) and rotational mechanics (Newton II), a physical model was obtained in the form of differential equations which were then converted into the Laplace domain. The main parameters such as resistance, inductance, torque constant, EMF constant, moment of inertia, and damping coefficient were successfully identified and validated through theoretical calculations based on technical data.

The study successfully identified the parameters of the FESTO EMMS-AS-70-MK-LS-RRB motor and reduced its block diagram to a simplified model that accurately represents the system dynamics [27]. MATLAB/Simulink proved to be an effective platform for the modeling and simulation processes [28]. The results are in line with established control system theories and provide a solid foundation for further controller development [29]. Future enhancements may include experimental validation and integration with adaptive control schemes [30].

Overall, the proposed approach not only contributes to the development of model-based DC motor control systems, but also can be used as a reference in the controller tuning process before actual implementation. This model is considered representative for use in high-precision applications such as servo systems, robotics, and sensor-based speed control, and can be further developed through experimental testing and integration with adaptive or artificial intelligence-based control systems.

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Data Availability

All data generated or analyzed during this research are included in this published article. Motor specifications were obtained from publicly available datasheets provided by ElectroCraft. The simulation models and parameter calculation files used in this research are available from the corresponding author upon reasonable request.

Author Contribution

The author, Alvian Dwi Prasetya, is fully responsible for the conception, modeling, simulation, analysis, and writing of this research paper. All stages of the research, including data collection from datasheets, mathematical derivation, MATLAB/Simulink implementation, interpretation of results, and preparation of the manuscript, were conducted independently as part of academic research in the Marine Electrical Engineering study program at the Surabaya State Polytechnic of Shipping (PPNS).

Declarations

Ethical Approval

This research did not involve human participants, animals, or sensitive data. Therefore, ethics approval was not required for completion of this research.

Consent for Publication Participants.

Not applicable. This research did not include interviews, surveys, or any personally identifiable data from participants that would require consent for publication.

Competing Interests

The authors declare no competing interests.

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Alvian Dwi Prasetyal am an active student in the D4 Electrical Engineering program, Department of Electrical Engineering, State Polytechnic of Surabaya (PPNS), having started higher education since 2023. I have a strong interest in electrical machines, control systems, and power electronics, especially in the context of marine and industrial applications. Throughout my studies, I have been actively involved in simulation-based projects and laboratory research focused on DC motor modeling and control system implementation. My academic journey is driven by a passion for integrating theoretical knowledge with practical engineering, especially in maritime technology. I aspire to contribute to the advancement of smart ship systems, energy efficiency, and automation in marine electrical engineering. This paper reflects part of my efforts to connect simulations with real-world applications in the fields of control systems and electricity.

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