KTO KARATAY UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF MECHATRONICS ENGINEERING

MEM524 SYSTEM DYNAMICS

PROJECT REPORT

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PROJECT SUMMARY

This project is a project named Shaft Starting with Electric Rotor. The system can be defined as an electromechanical system by establishing an electrical circuit and starting a motor with armature current and connecting a shaft to this motor, and it deals with an understandable engineering application with a mathematical modelling approach and simulation through MATLAB program.

1. INTRODUCTION

In this project, the mathematical model of an electromechanical system is designed through MATLAB Simulink and MATLAB Simscape.

1.1 Project Purpose

The aim of the project is to create a mathematical model of the theoretical knowledge seen in the course in engineering terms, to make a simulation in MATLAB Simulink and Simscape environments and to analyse the results obtained.

1.2 Project Objectives

Creation of the Mathematical Model: The system was converted into a mathematical model using differential equations. This model is detailed to explain the behaviour of the system.

MATLAB Simulink Model: The mathematical model is converted into a simulation model in MATLAB Simulink environment. This model will be used to simulate the dynamic behaviour of the system over time.

MATLAB Simscape Model: Using MATLAB Simscape, a model of the system with mechanical, electrical and physical properties was created.

Simulation and Analysis: Various simulations were performed on the models and the results obtained were analysed. This analysis is performed to evaluate the performance, stability and other important features of the system.

Reporting of Results: The results obtained were reported in detail with graphs, tables and explanations. The report clearly shows whether the objectives of the project have been achieved or not. It includes the mathematical modelling and simulation part of the Shaft Starting with Electric Rotor project. These results will form the basis for system design, optimisation or improvement for future work.

2. PROJECT

A commonly used actuator in control systems is a DC motor. It provides direct rotary motion and can provide translational motion when coupled with wheels or drums and cables. The electrical equivalent circuit of the armature and the free body diagram of the rotor are shown in figure 1 below.

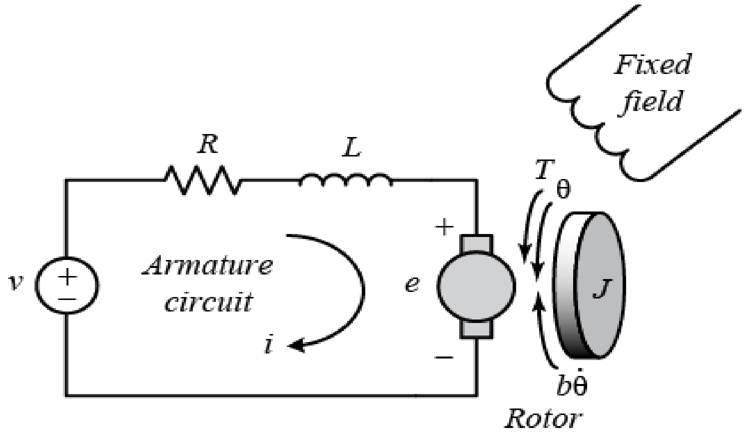

Figure 1. Armature Electrical Circuit

For this project, we will assume that the input of the system is the voltage source (V) applied to the armature of the motor and the output is the rotational speed θ of the shaft. The rotor and PTO shaft are assumed to be rigid. A viscous friction model is also assumed, i.e. the friction torque is proportional to the shaft angular velocity to be added at its end. The rotor in the electrical model actually behaves like a shaft. But in the figure, the rotor is designed as a rigid rod.

The mechanical part of the project consists of one shaft. This shaft is preferred as Flexible shaft from MATLAB Simscape library. The reason for using Flexible shaft is that there is a Torsional Stiffness value from MATLAB Simscape feature. Because this value indicates the stiffness value of the spring in the mechanical drawing on our theory. Thus, by connecting our motor, rotor and shaft in Simscape environment, we can get our output speed in rad/s again and have the ability to analyse it by connecting the scope. In addition, this Torsional Stiffness value was taken into consideration in MATLAB Simulink. The project was made on this logic in general terms. The project consists of two stages. The first stage consists of electrical and the second stage consists of mechanical parts. The mathematical model of these two stages was prepared and Simulink and Simscape simulations were drawn based on this model.

2.1 System Definition

This mechatronic system includes a DC motor and a spring-damper system with two masses (represented by moment of inertia) on the shaft. The system aims to control the two masses on the shaft using the output of the motor. In addition, the system provides information about the speed and position of the system using an ideal rotational motion sensor and a motion sensor.

2.1.1 Motor

Electric motors are devices that convert electrical energy into mechanical energy. In general, the electric motor structure consists of two basic components, a rotor (rotating part) and a stator (stationary part). The rotor provides motion by rotating in a magnetic field and is usually located on a shaft. The stator consists of magnetic coils that surround the rotor and create a magnetic field. Armature current enters this magnetic field and moves the rotor.[1] Rotor is the name given to a rotating component used as part of mechanical devices.[2] The motor is a DC motor and the moment of its rotor is expressed in Ja. The motor has a viscous friction coefficient B and an electromotive force constant Ka. There is also a torque constant, electrical resistance R and electrical inductance L, which relates the torque of the motor to the current.

2.1.2 Spring-Damper Shaft System

On the shaft there is a moment of inertia J1 of the first mass and a moment of inertia J2 of the second mass. A spring (with stiffness K) and a damper (with damping coefficient B1) are connected to the first mass, and a damper (with damping coefficient B2) is connected to the second mass. While theoretically designing this project on paper, it was prepared by utilising the flexible shaft element in MATLAB Simscape library.

2.1.3 Used Sensors

In the project, Current Sensor was used to measure current, Ideal Motion Sensor and Motion Sensor were used to measure motion on MATLAB Simscape.

2.1.4 Joints

The motor controls the first mass on the shaft, where the output generates the forces affecting the spring-damper system. The movement of the mass on the shaft is determined by the elasticity of the spring and the damping effect of the dampers.

2.1.5 Objective

This system is designed to control the masses on the shaft using the output of the motor. Spring and damper elements are used to control the vibrations in the system and provide the desired performance. It also aims to improve ourselves on the applicability of the theory and mathematical equations seen in the course.

2.1.6 Simulation and Analysis

This system is modelled using MATLAB Simulink or a similar simulation tool. Simulations are used to understand the system behaviour and to evaluate the interaction between the motor and the loads on the shaft. The simulation results are analysed to evaluate the stability, response times and overall performance of the system.

2.2 Electric Model

The electrical model of the project was prepared in MATLAB Simulink and Simscape environment.

2.2.1 MATLAB Simulink

Figure 2 shows the MATLAB Simulink simulation of the electrical part of the project. This model was calculated according to the theory seen in the course and the block diagram was prepared in MATLAB Simulink environment.

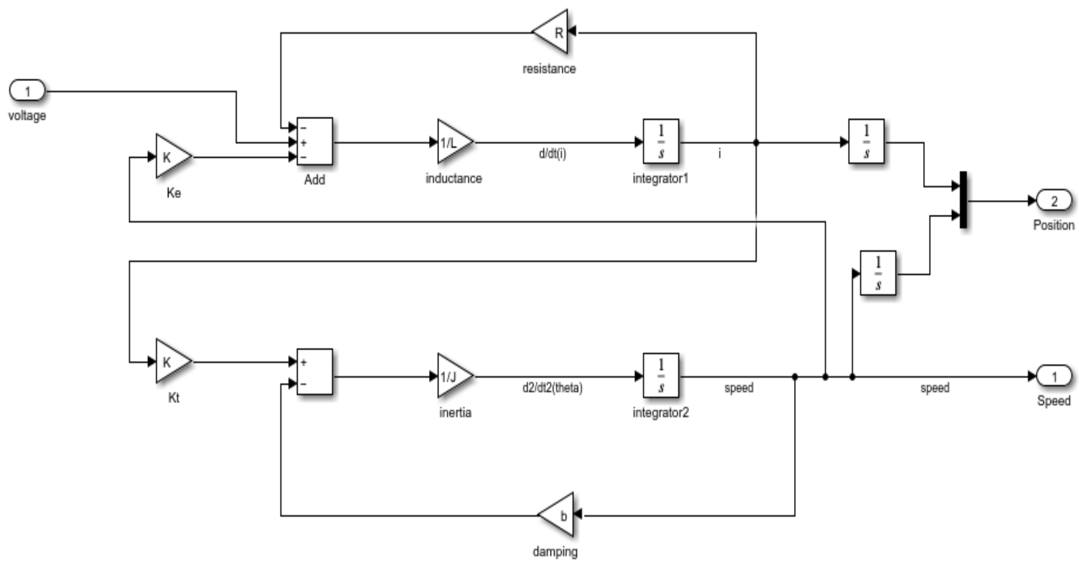

Figure 2. MATLAB Simulink Electric Model

2.2.2 MATLAB Simscape

Figure 2 shows the MATLAB Simscape simulation of the electrical part of the project. This model was prepared by researching according to the theory of modelling electrical systems seen in the course and prepared in MATLAB Simscape environment.

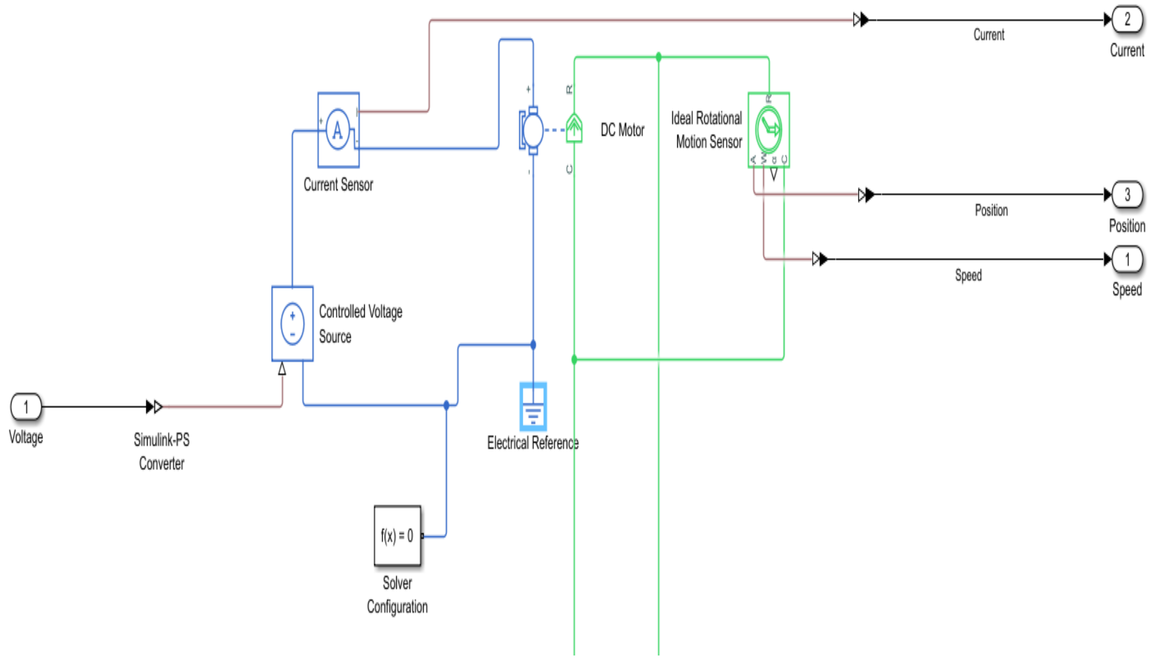

Figure 3. MATLAB Simscape Electric Model

2.3 Mechanical Model

The mechanical model of the project was prepared in MATLAB Simulink and Simscape environment.

2.3.1 MATLAB Simulink

Figure 4 shows the MATLAB Simulink simulation of the mechanical part of the project. This model was calculated according to the theory seen in the course and the block diagram was prepared in MATLAB Simulink environment.

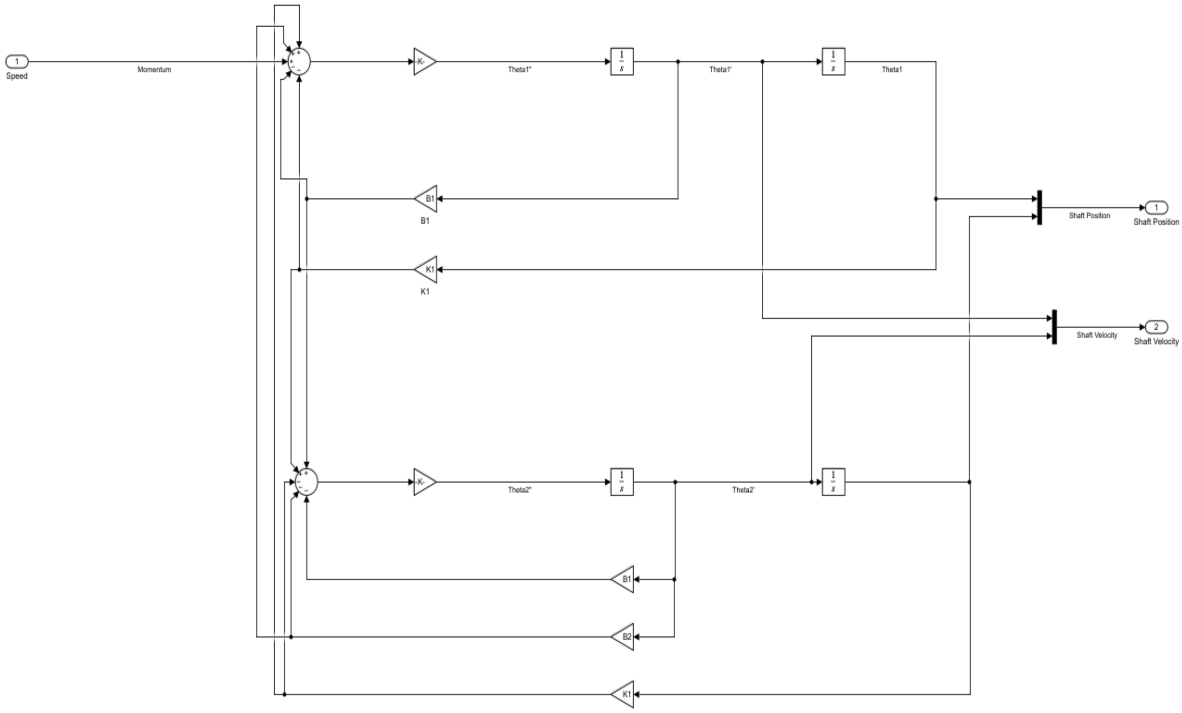

Figure 4. MATLAB Simulink Mechanical Model

2.3.2 MATLAB Simscape

Figure 5 shows the MATLAB Simscape simulation of the mechanical part of the project. This model was prepared by researching according to the theory of modelling rotational mechanical systems seen in the course and prepared in MATLAB Simscape environment.

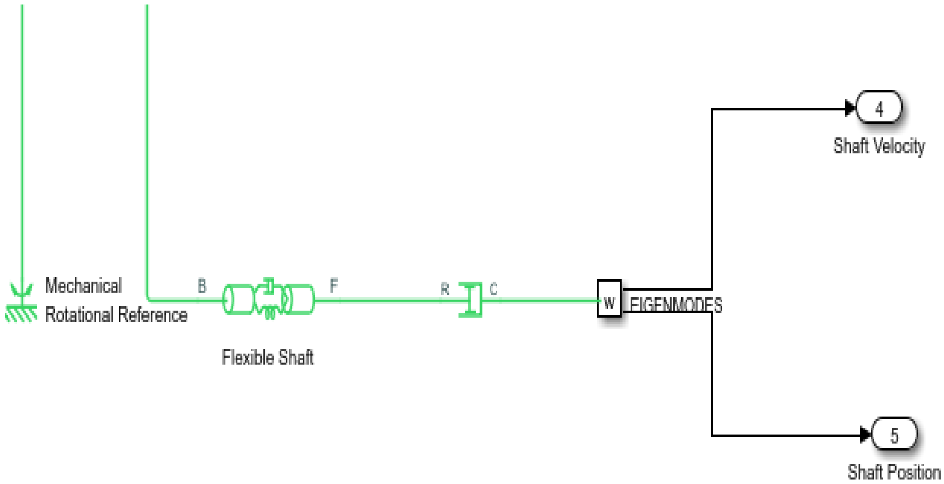

Figure 5. MATLAB Simscape Mechanical Model

2.4 Mathematical Calculations of the Project

The first step of the mathematical model of the system is prepared for the block diagrams used in MATLAB Simulink. Since the system is an electromechanical system, the mathematical calculations of the electrical and mechanical parts are handled separately. And thanks to these mathematical calculations, the block diagrams of the system were created and placed on MATLAB Simulink and the system was analysed. The drawing given in Figure 6 is the theoretical version of the project on paper.

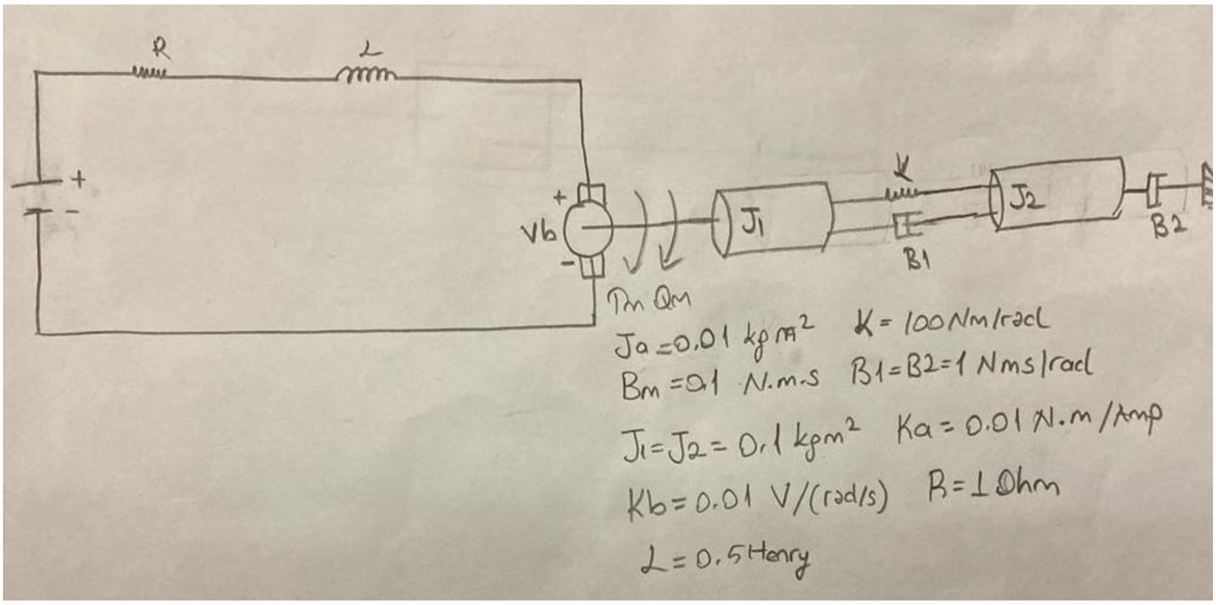

Figure 6. Theoretical Project

2.4.1 Mathematical Calculation Of The Electrical Section

At this stage of the project, calculations were made for the electrical section. Thanks to these calculations, the MATLAB Simulink block diagram given in Figure 2 was made.

- $T_m = K_a * I_a \rightarrow I_a = T_m / K_a$
- $V_b(s) = K_b * s * \theta_{m1}(s)$

$$I_a R_a + I_a L_a + V_b = V_a \quad (1)$$

$$J_a \ddot{\theta}_{m1} + B_m \dot{\theta}_{m1} = K_a * I_a(s) \quad (2)$$

$$I_a(Ls + R) + K_b * s * Q_{m1}(s) = V_a(s) \quad (3)$$

$$Q_{m1}(s)(J_a s^2 + B_m s) = K_a * I_a(s) \quad (3.1)$$

$$Q_{m1}(s)[(J_a s^2 + B_m s)/(K_a) * (L_a * s + R) + K_b * s] = V_a(s) \quad (3.2)$$

2.4.2 Mathematical Calculation of the Mechanical Section

At this stage of the project, calculations were made for the mechanical part. Thanks to these calculations, the MATLAB Simulink block diagram given in Figure 4 was made. The action-response forces of the two masses according to the direction of rotation are given in Figure 7.

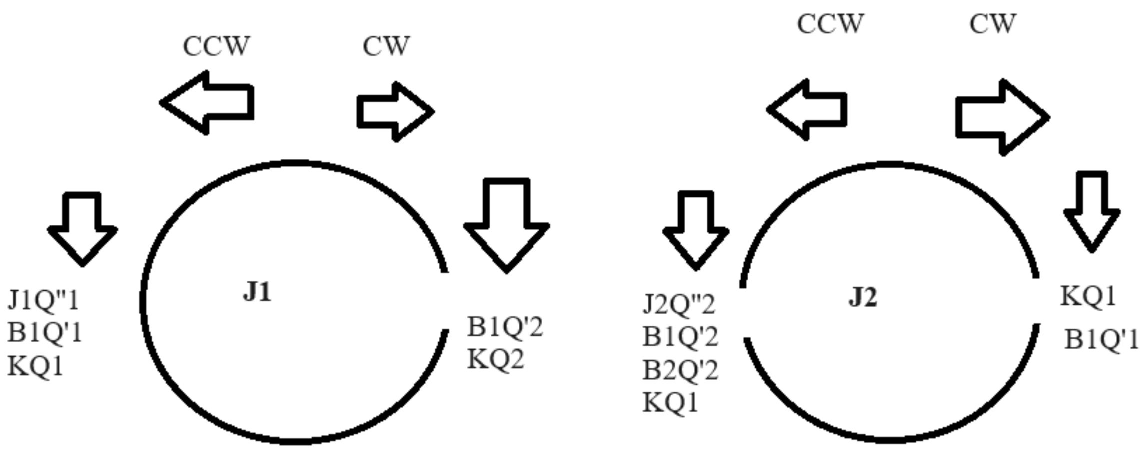

Figure 7. Impact-Response Forces of Mechanical Section

1. $J_1\ddot{\theta}_{m1} + B_1\dot{\theta}m_1 + K\theta_{m1} - B_1\dot{\theta}m_2 - K\theta_{m2} = T_m$ (1)
2. $J_2\ddot{\theta}_{m2} + (B_1+B2)\,\dot{\theta}m_1 + K\theta_{m2} - B_1\dot{\theta}m_1 - K\theta_{m1} = 0$ (2)
3. $\ddot{\theta}_{m1}\,[\,J_1 + B_1 + K] + \ddot{\theta}_{m2}\,[-B1 - K] = T_m$ (1.1)
4. $\ddot{\theta}_{m1}\,[\,-B1 - K] + \ddot{\theta}_{m2}\,[J_2 + (B_1 + B2) + K] = 0$ (2.1)

2.4.3 Transfer Function Calculation of the Project

The transfer function of the project is composed of two parts as seen in the last two sections. Since it is an electromechanical project, the transfer function of the electrical and mechanical parts are calculated separately and finally the transfer function of the electromechanical system is found by multiplying these two transfer functions. Calculations in the last two sections were made for block diagram and Simulink. The calculations in this section are the continuation of the last two calculations. In the calculations made in this section, the values are substituted.

Transfer function calculation for electrical section:

$\theta_{m1}(s) = [((0.005s^3 + 0.06 s^2 + 0.1001s) / 0.1) + ((0.0001s) / 0.01)] = V_a(s)$ (3.3)

$\theta_{m1}(s) = [((0.005s^3 + 0.06s^2 + 0.1001s) / 0.01)] = V_a(s)$ (3.4)

$(\theta_{m1}(s) / V_a(s)) = [(0.01) / (0.005s^3 + 0.06s^2 + 0.1001s)]$ (3.5)

Transfer function calculation for mechanical part:

$\theta_{m1}(s)\ [0.1s^2 + s + 100] + Q_{m2}(s)\ [-s - 100] = T_m$ (1.2)

$\theta_{m1}(s)\ [-s - 100] + Q_{m2}(s)\ [0.1s^2 + 2s + 100] = 0$ (2.2)

$$\begin{matrix} 0.1s^2+s+100 & -s-100 \\ -s-100 & 0.1s^2+2s+100 \end{matrix} \quad * \quad \begin{matrix} \theta m1(s) \\ \theta m2(s) \end{matrix} = \begin{matrix} Tm \\ 0 \end{matrix}$$

$\theta_{m1}(s) = [(T_m\ (0.1s^2 + 2s + 100)) / (0.01s^4 + 0.3s^3 + 19.01s^2 + 98s)]$ (1.3)

$\theta_{m2}(s) = [(T_m(s + 100)) / (0.01s^4 + 0.3 s^3 + 19.01s^2 + 98s)]$ (2.3)

$\theta_{m2}(s) / \theta_{m1}(s) = [(s + 100) / (0.1s^2 + 2s + 100)]$ (3)

Finally, to find the transfer function of the electromechanical section, the two transfer functions obtained are multiplied. And the result [θm2(s) / Va(s)] gives the transfer function.

$[\theta_{m1}(s) / V_a(s)] * [\theta_{m2}(s) / \theta_{m1}(s)] = [\theta_{m2}(s) / V_a(s)]$

$[\theta_{m2}(s) / V_a(s)] = [(0.01s + 1) / (0.0005s^5 + 0.1661s^4 + 1.9311s^3 + 3.2032s^2)]$

2.5 Result Graphs

MATLAB Simulink and Simscape graphs and calculated transfer function graphs are given in this section.

2.5.1 MATLAB Simulink Graph

The graph given in Figure 8 is the MATLAB Simulink simulation graph as a result of the mathematical calculations. In this graph; the position and velocity of the mass at the inlet and outlet of the shaft, the position and velocity of the motor are given. The motor and shaft speed rotate at a constant speed of 0.5 rad/s according to the calculated conditions. Likewise, the shaft and motor position increases linearly as calculated. The reason why the graph increases linearly although the shaft and motor movement is rotational is due to the MATLAB Simulink feature. Because the motor and shaft make rotational movement, it must return to the beginning at 6.283185 radians (360 degrees) in position. However, due to MATLAB Simulink solvers, this graph cannot be captured in Simulink simulation. But this graph was captured on Simscape simulation.

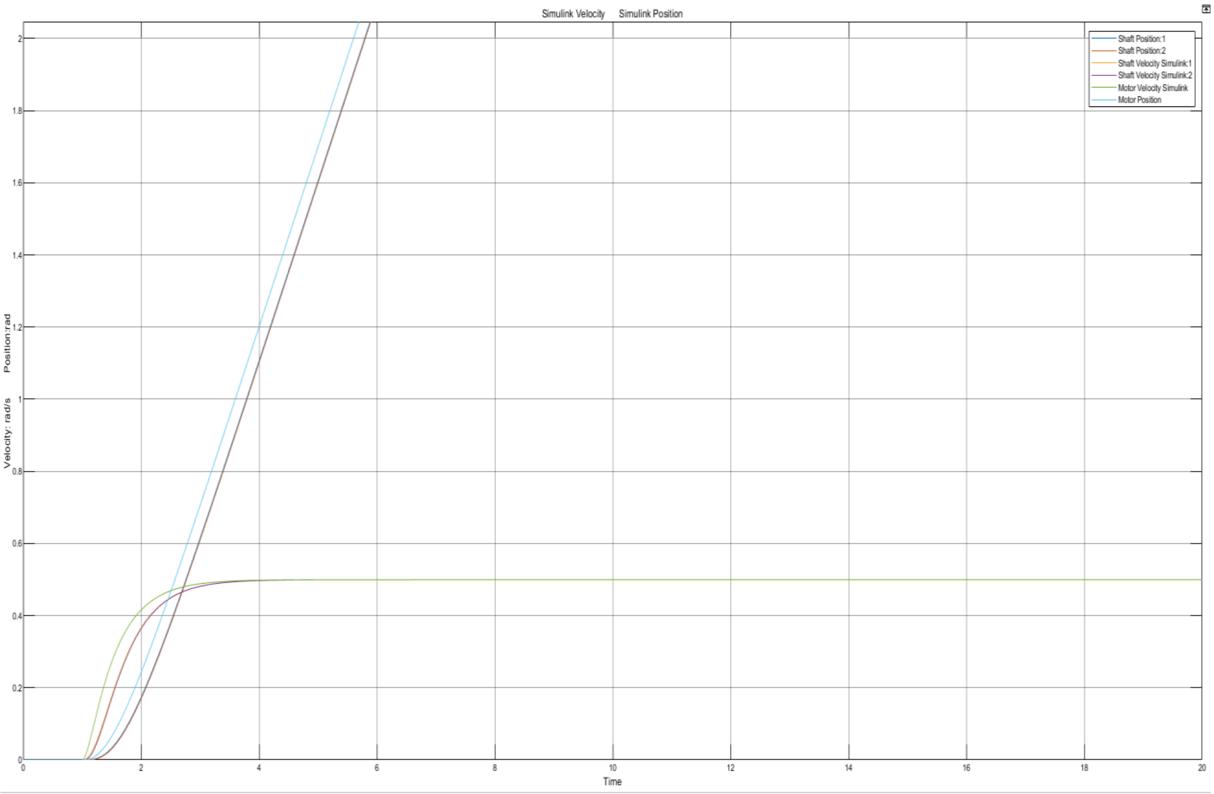

Figure 8. MATLAB Simulink Graph

2.5.2 MATLAB Simscape Graph

The graph given in Figure 9 is the graph of the simulation made as a result of the theory seen in the thesis, internet, MATLAB researches and lectures. In this graph, motor and shaft speed, motor and shaft position are shown. In addition, the current was measured with the ideal rotational motion sensor used. In the obtained graph; the motor and shaft speed makes rotational motion with 0.5 rad/s. The position graph, which could not be obtained in MATLAB Simulink, was captured here due to the Simscape feature. The motor and shaft positions fall to an initial position at 6.283185 radians (360 degrees) and logically work correctly.

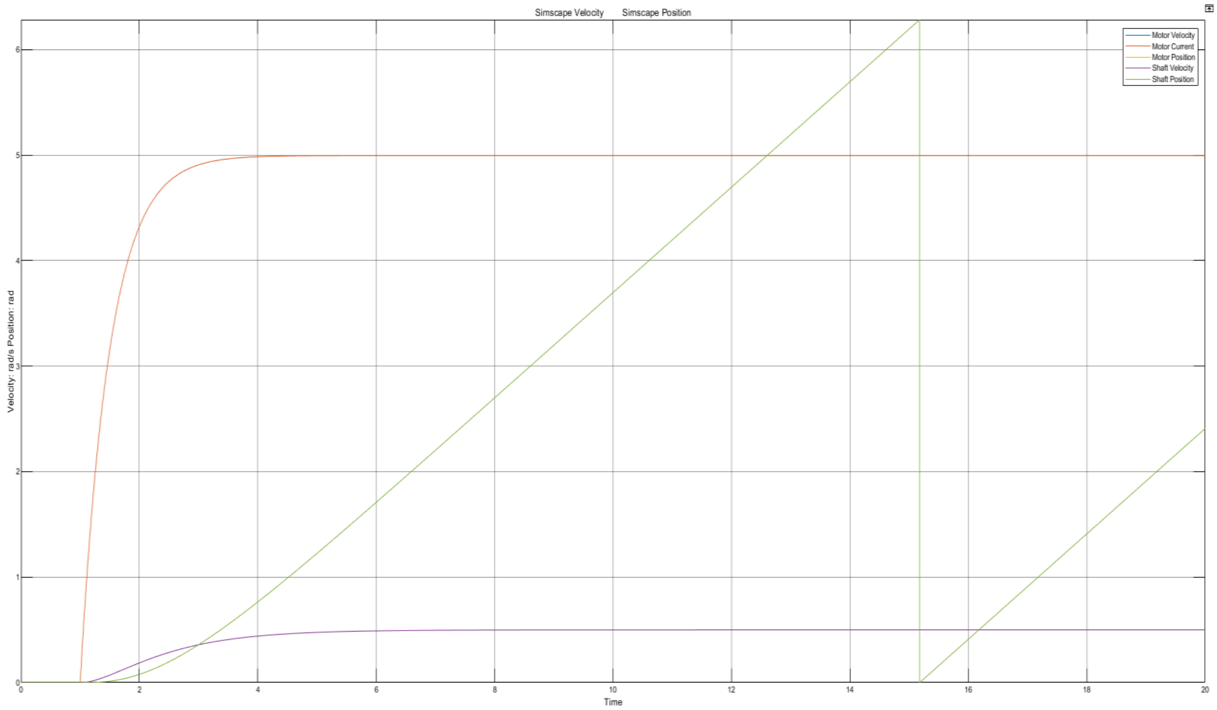

Figure 9. MATLAB Simscape Graph

2.5.3 Transfer Function Graph

The MATLAB Scope graph given in Figure 10 is the graph of the position and velocity obtained as a result of the transfer function calculated above. Again, this graph increases linearly due to MATLAB feature.

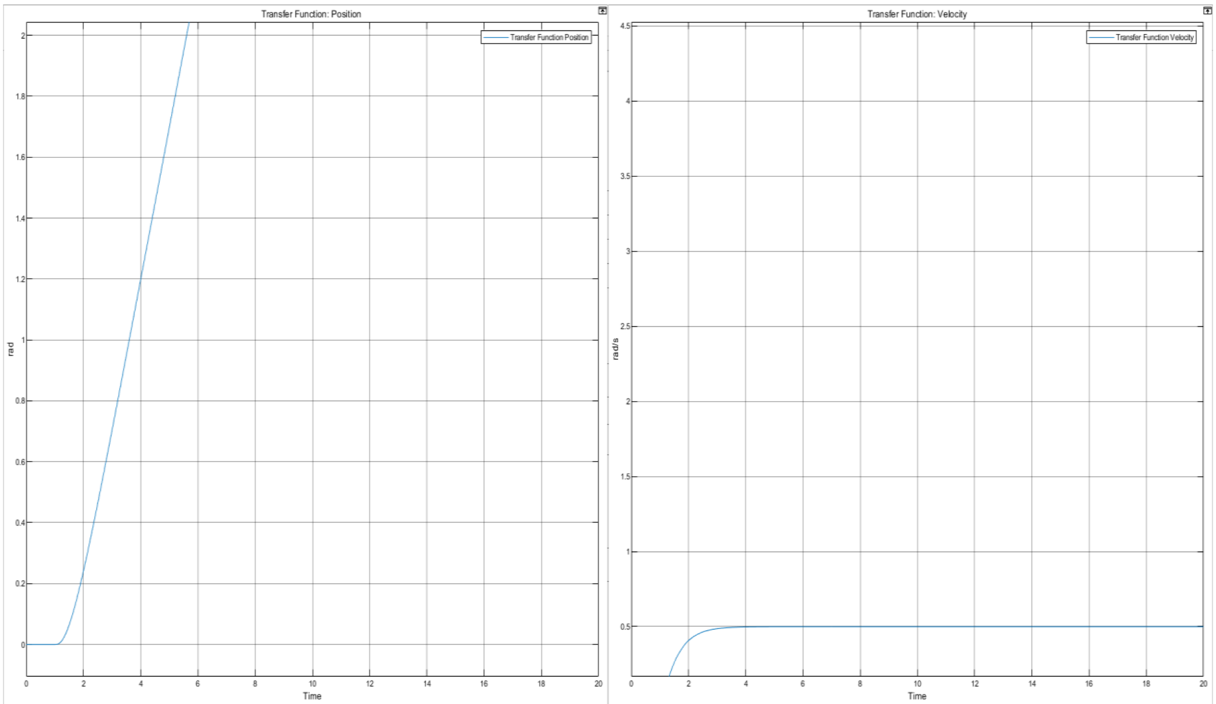

Figure 10. Transfer Function Position And Velocity Graph

2.5.4 General Scope

The important graphs of MATLAB Simulink, Simscape and transfer function graphs made in this section are connected on a scope and given in Figure 11.

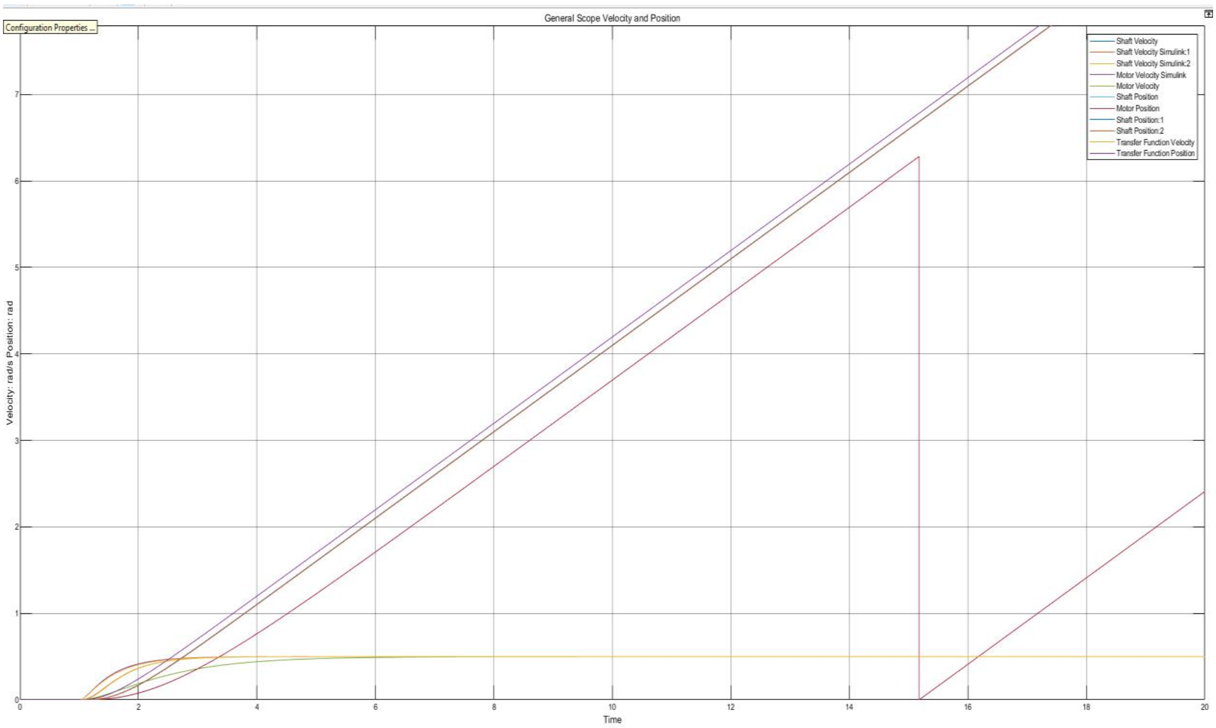

Figure 11. General Scope

3. CONCLUSION OF THE PROJECT

In this project, which was carried out in accordance with the course curriculum, it has added a lot to us in terms of engineering. Thanks to MATLAB Simulink and Simscape simulations made according to the mathematical calculations seen in the course, we are able to predict how a system should behave and have the ability to make comments according to the analysis and results. By learning a lot in terms of MATLAB, we have developed ourselves and learnt to integrate theoretical knowledge into a system in engineering terms and to simulate it.

4. REFERENCES

1. GAMAK (2023). Elektrik Motorlarının Yapısı. https://www.gamak.com/elektrik-motorlarinin-yapisi

2. GAMAK (2023). Rotor Nedir? https://www.gamak.com/rotor-nedir