Palestine Polytechnic University

College of Engineering

Mechanical Engineering Department

The Real Time Energy Management Of Electric Turbocharge

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Supervisor:

Dr. Iyad Hashlamon

Submitted to the College of Engineering
In partial fulfillment of the requirements for the
Bachelor's degree in Mechanical Engineering

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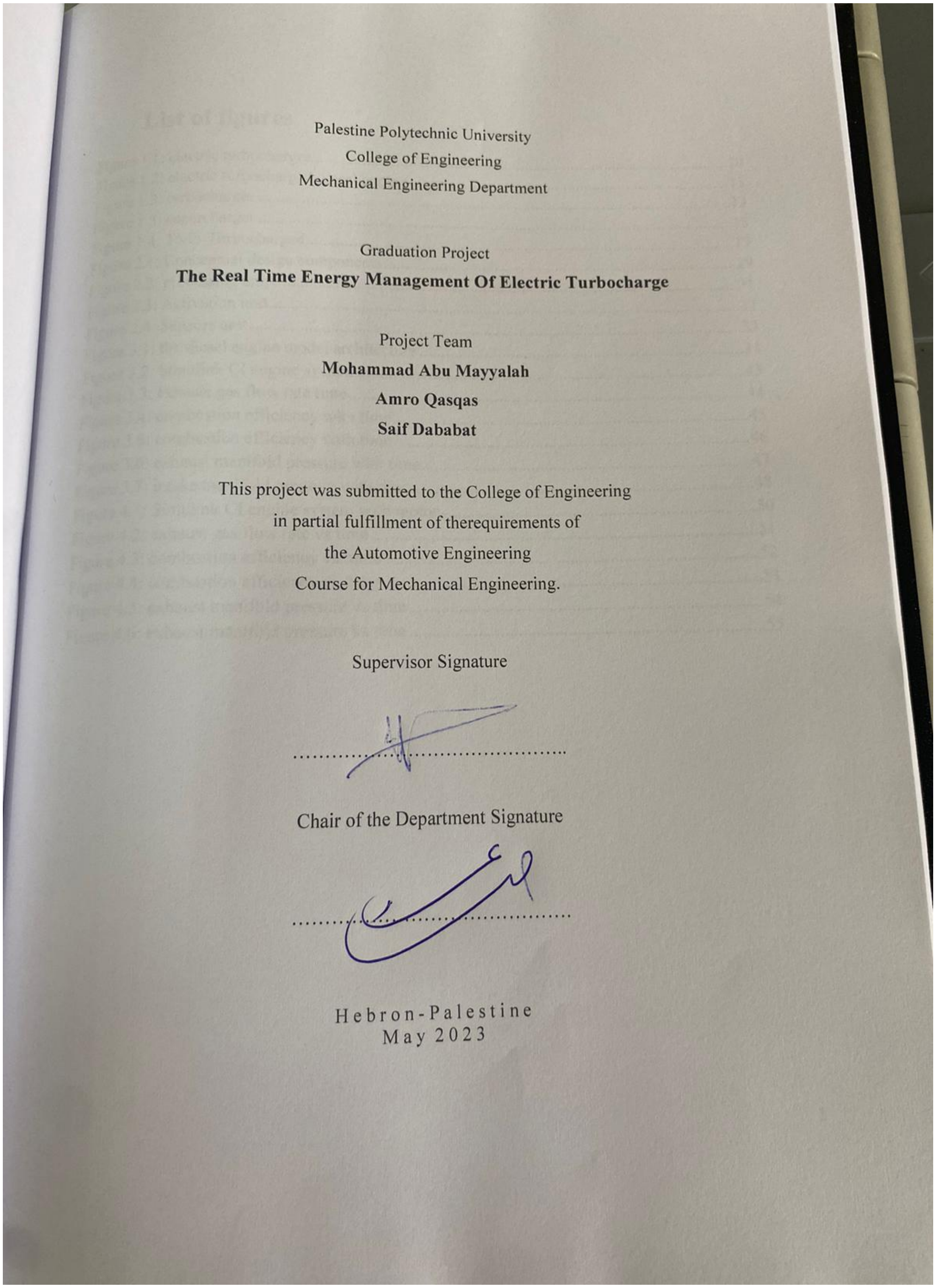

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Graduation Project

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Course for Mechanical Engineering.

Supervisor Signature

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Chair of the Department Signature

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Hebron-Palestine
May 2023

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الملخص:

يناقش هذا المشروع استخدام أنظمة الشاحن التوربيني الكهربائي في المركبات كوسيلة لتحسين كفاءة المحرك وتقليل حجم المحرك وزيادة الاقتصاد في استهلاك الوقود. يحدد المشروع وظيفة وتصميم الشواحن التوربينية ، وفوائدها وقيودها ، والحاجة إلى شاحن توربيني مدعوم كهربائيًا لتقليل وقت الاستجابة وزيادة الأداء. يستكشف المشروع أيضًا الأنواع المختلفة من الشواحن الفائقة وتشغيلها الميكانيكي. الهدف الرئيسي للمشروع هو زيادة سرعة الاستجابة ورفع كفاءة المحرك وتقليل أكاسيد النيتروجين. يتضمن الحل المقترح دمج وحدة إلكترونية مع محرك كهربائي فائق للتحكم في الشاحن التوربيني ، والذي يتم تنشيطه من خلال المعلومات التي تم الحصول عليها من أجهزة الاستشعار داخل نظام المحرك. يؤكد المشروع على أهمية تحسين خصائص الاستجابة السريعة وتحقيق المواصفات المطلوبة في تصميم التوربينات فائقة السرعة.

Abstract:

This project discusses the use of electric turbocharger systems in vehicles as a means of improving engine efficiency, reducing engine size, and increasing fuel economy. The article outlines the function and design of turbochargers, their benefits and limitations, and the need for an electrically assisted turbocharger to reduce response time and increase performance. The article also explores the different types of superchargers and their mechanical operation. The main goal of the project is to increase the speed of response, raise engine efficiency, and reduce exhaust NOx. The solution proposed involves integrating an electronic unit with a super electric motor to control the turbocharger, which is activated through information obtained from sensors within the engine system. The article emphasizes the importance of optimizing rapid response characteristics and attaining the required specifications in designing ultrafast turbines.

Dedication

We dedicate this project to Allah Almighty. It is with genuine gratitude and warm regard that we dedicate this research project to our family and friends.

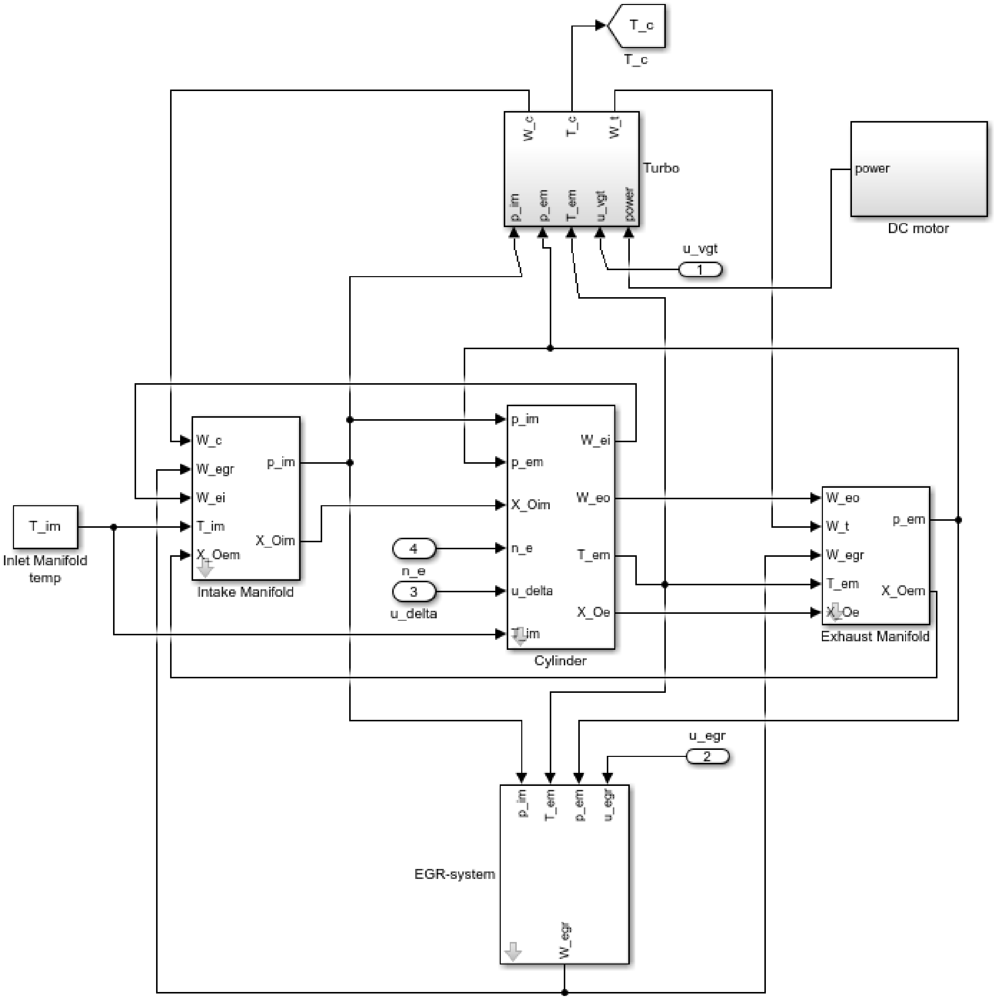
A special feeling of gratitude to our loving parents, whose words of encouragement and push for tenacity ring in my ears.

Acknowledgment

We wish to express our sincere gratitude to our supervisor Dr. Iyad Hashlamon for providing us all support and guidance, whose insightful leadership and knowledge benefited us to complete this project successfully. We are respectful of your continuous support and presence whenever needed.

We would like to express our deep appreciation and indebtedness to our teachers and supervisors for their endless support, and kindness. Last but not the least, we would like to thank everyone who is involved in the project and helped us with their suggestions to make the project better.

Content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Chapter 1

Introduction

Many systems in cars have been developed in order to increase engine efficiency, reduce engine size, improve exhaust gas handling and improve fuel economy. These include fuel injection systems, such as the direct injection system, and air supply systems to the engine, such as turbochargers and superchargers. In this study, we will explain the engine air supply system (turbocharger), the problems associated with this system and how to solve them.

The electric turbocharger system is used in cars, trucks, and heavy equipment equipped with a turbocharger, whether they are gasoline, diesel, or gas.

Turbochargers are commonly used in engine systems as a technological step to reduce engine size and increase engine efficiency. A conventional turbocharger takes its movement from the pressure of exhaust gases coming from the combustion chamber, and as a result of this movement, the air is charged into the inlet of the engine cylinder. One of the factors contributing to the poor performance of the car is the delayed response of the turbo due to the low number of engine revolution, as the low number of engine revolution results in a decrease in the flow rate of exhaust gases and thus a decrease in the speed of rotation of the turbine, which reduces the capacity of the turbocharger. To reduce this lag and delay in response and improve performance, we will develop a turbocharger with the help of a high-speed electric motor. [1]

There are different methods of integrating an assist feature into a turbocharger for improved performance. One approach is to incorporate an electric motor directly into the turbocharger.as shown in figure 1.1

Integrating the assist feature into the turbocharger offers several advantages, such as compact and flexible packaging. It also presents the opportunity to incorporate waste heat recovery through turbo compounding, utilizing hardware that is common to the assist function. By combining assist and turbo compound functions, a turbocharger can be controlled to have less speed variation across the engine's operating range. This allows for the inclusion of vanes in the compressor and turbine, which enhance efficiency. Typically, vanes are not used in conventional designs but can be utilized in turbochargers with both assist and turbo compound capabilities.

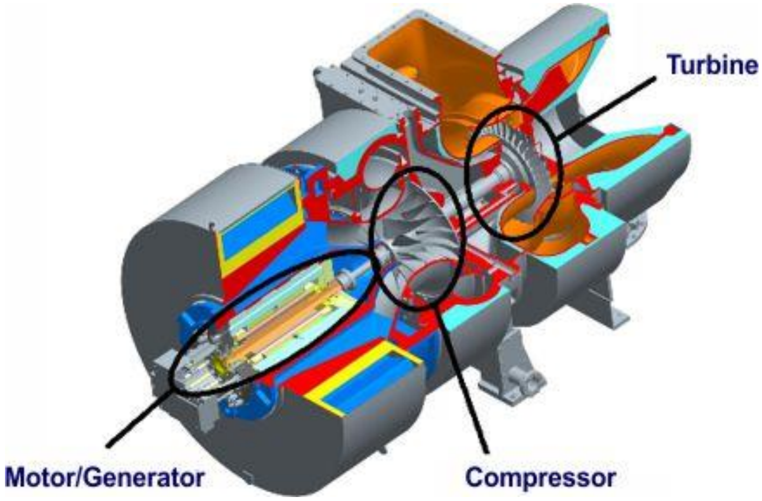


Figure 5.1: electric turbocharger

Additionally, as the response speed increases, the required volume will be reached in less time, eliminating turbo lag. One of the important issues in the design of turbochargers is to improve the characteristics of rapid response and achieve the required specifications.

The following diagram in Figure 1.2 shows a diesel engine with an electric turbocharger. The electric turbocharger works by compressing the exhaust gases, which move the turbine butterfly, which activates the compressor and compresses the air in the intake tracts. There are cases where a slow response occurs in the turbo action, so the electric turbo system is activated to improve the response speed.

The system is activated by a special electronic module that relies on a combination of information received from sensors within the engine system, intake and exhaust duct system.

The system consists of an electric motor integrated into the turbocharger, the electric motor providing additional power to enhance the performance of the turbocharger during lower engine speeds. It helps to increase air pressure, enhance acceleration, and reduce lag.

The system also consists of a turbocharger; the turbocharger consists of a compressor and a turbine. The compressor compresses the incoming air, increasing its density before it enters the engine. The turbine, driven by the exhaust gases, drives the compressor.

An intercooler is placed between the turbocharger and the engine's intake manifold to cool compressed air before it enters the combustion chamber. The intercooler lowers the temperature of the compressed air, increasing its density and oxygen content, resulting in better combustion and higher power output. By lowering the intake air temperature, the intercooler also helps prevent overheating and reduces the risk of engine knocking. [2]

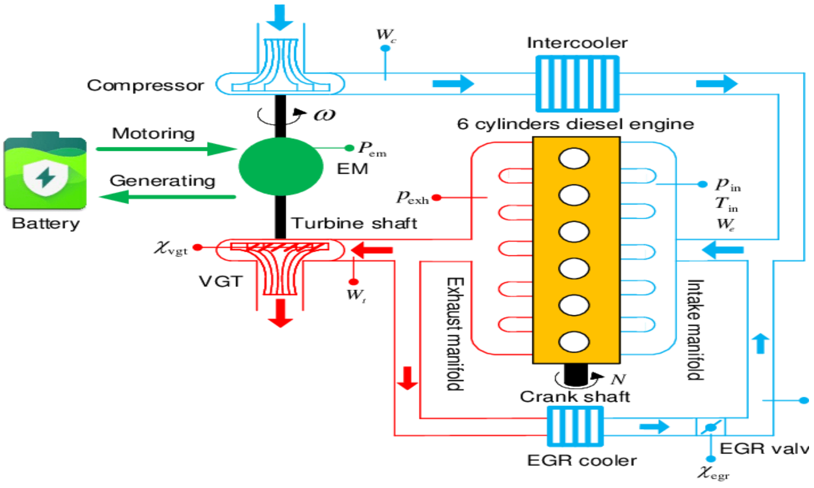


Figure 1.6: electric turbocharged diesel engine

1.1 Models of engine air supply systems

There are several models of engine air supply systems used in different types of engines. Some common models include:

1.1.1 Naturally Aspirated

Naturally aspirated engines, also known as non-turbocharged engines, rely on atmospheric pressure to supply air to the combustion chamber. This report aims to explore the advantages and disadvantages of naturally aspirated engines. [3]

1.1.2 Advantages:

1. Simplicity: Naturally aspirated engines are simpler in design compared to their turbocharged counterparts. They do not require additional components such as turbochargers or superchargers, leading to reduced complexity and potentially lower maintenance costs.

2. Immediate Throttle Response: Since there is no turbo lag associated with a turbocharger, naturally aspirated engines typically provide immediate throttle response. This can be advantageous in applications that require instant power delivery, such as motorsports or high-performance driving.

3. Lower Manufacturing Costs: The absence of a turbocharger or supercharger in the engine design can result in lower manufacturing costs. Fewer components and simpler systems contribute to a more cost-effective production process.

4. Reliability: Naturally aspirated engines are generally considered more reliable due to their simpler design and reduced complexity. They may have fewer points of failure compared to turbocharged engines, potentially resulting in lower maintenance and repair costs.

1.1.3 Disadvantages:

1. Lower Power Output: One significant disadvantage of naturally aspirated engines is their relatively lower power output compared to turbocharged engines. Without forced induction, the amount of air and fuel mixture that can be drawn into the combustion chamber is limited, resulting in reduced power potential.

2. Reduced Torque at Low RPM: Naturally aspirated engines often exhibit lower torque output at low engine speeds. The absence of forced induction makes it challenging to generate substantial torque at low revolutions per minute (RPM), which can impact acceleration and towing capabilities.

3. Limited Altitude Performance: At higher altitudes where the air density is lower, naturally aspirated engines can experience a significant reduction in power output. The decrease in atmospheric pressure negatively affects engine performance, which can be a drawback in mountainous or high-altitude regions.

4. Limited Fuel Efficiency: Due to their lower power output, naturally aspirated engines may exhibit higher fuel consumption compared to turbocharged engines. They might require higher RPMs to achieve similar performance, resulting in increased fuel usage.

1.1.4 Conclusion:

Naturally aspirated engines offer simplicity, immediate throttle response, and potential cost savings. However, they have limitations in terms of power output, torque at low RPMs, altitude performance, and fuel efficiency. The choice between a naturally aspirated engine and a turbocharged engine depends on specific application requirements, desired performance characteristics, and efficiency goals. Manufacturers and consumers need to consider these factors when selecting the appropriate engine type for a particular vehicle or application.

1.2 Turbocharger

Turbochargers are a popular component in automotive engines, designed to increase power output and efficiency by utilizing exhaust gas energy.

A turbocharger is a device fitted to a vehicle's engine that is designed to improve overall efficiency and increase performance. This is the reason why many auto manufacturers are choosing to turbocharger their vehicles.

The turbo consists as shown in Figure 1.3 of two halves connected to each other by a shaft. On one side, the gases resulting from the reactions inside the combustion chamber rotate a turbine connected to another turbine that sucks in air and compresses it into the engine. Where this pressure results in additional power and efficiency of the engine because the greater the amount of compressed air inside the combustion chamber, the greater the efficiency and power of the engine. [4]

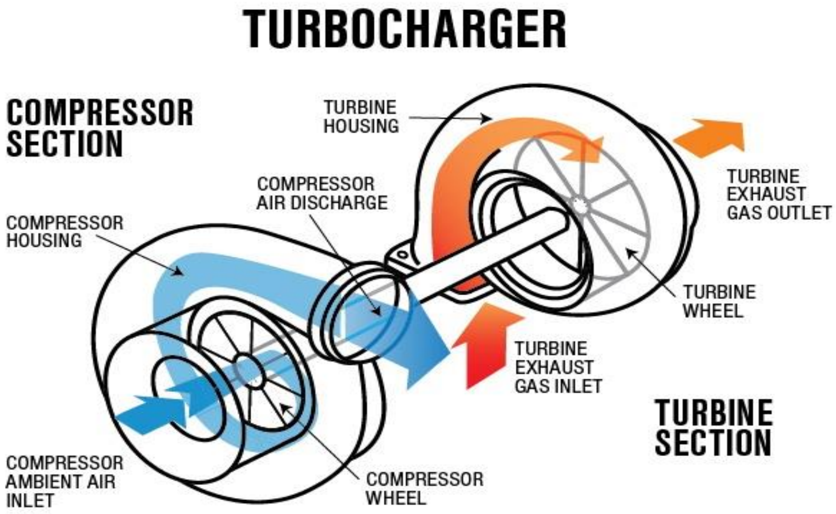


Figure 1.7: turbocharger

1.2.1 Advantages:

1. Increased Power Output: Turbochargers effectively increase the power output of an engine by compressing the incoming air. The compressed air allows for a greater amount of fuel to be burned in the combustion chamber, resulting in improved engine performance and higher power output.

2. Improved Fuel Efficiency: By increasing the air density entering the combustion chamber, turbochargers enhance the combustion process, leading to improved fuel efficiency. This means that the engine can produce more power with a smaller amount of fuel, resulting in reduced fuel consumption.

3. Enhanced Torque: Turbochargers provide a significant boost in torque, especially at low engine speeds. This is advantageous for tasks requiring high pulling power, such as towing or climbing steep gradients.

4. Downsizing Potential: Turbocharging allows manufacturers to downsize the engine without sacrificing performance. A smaller, turbocharged engine can deliver similar power outputs to larger naturally aspirated engines, resulting in weight savings and improved overall vehicle efficiency.

1.2.3 Disadvantages:

1. Turbo Lag: Turbochargers can experience a delay in power delivery known as "turbo lag." This lag occurs due to the time required for the turbocharger to spool up and reach optimal operating speed. It can result in a momentary lack of power when the accelerator pedal is pressed, especially at low RPMs.

2. Increased Complexity and Cost: Turbocharging adds complexity to the engine system, requiring additional components such as the turbocharger itself, intercoolers, and associated plumbing. This complexity can result in higher manufacturing costs and potentially increased maintenance and repair expenses.

3. Heat Build-up: Turbochargers generate heat as they compress the intake air. This can result in increased underwood temperatures and require additional cooling measures to manage the heat generated. Overheating can affect engine performance and longevity if not properly addressed.

4. Reliability Concerns: The increased stress and operating conditions placed on turbocharged engines can potentially lead to reduced long-term reliability compared to naturally aspirated engines. Components such as the turbocharger itself and associated intercoolers may require periodic maintenance or replacement

1.2.4 Conclusion:

Turbochargers provide numerous advantages, including increased power output, improved fuel efficiency, enhanced torque, and downsizing potential. However, they also present challenges such as turbo lag, increased complexity, heat build-up, and potential reliability concerns. Manufacturers and consumers need to carefully consider these factors when choosing to implement turbocharging in an engine. Proper design, maintenance, and consideration of the specific application requirements are crucial to maximizing the benefits and mitigating the disadvantages associated with turbochargers.

1.3 Supercharger

Superchargers are a popular component used in automotive engines to increase power output and enhance performance, supercharger is a mechanical air compressor that is bolted onto the engine and is used to force more air into the combustion chamber, mechanical supercharger can be driven by a belt, shaft, or chain attached to the crankshaft. As shown in Figure 1.4 the belt connects to a pulley to provide more or less thrust as the engine revs increase. This pulley turns the shafts, or gears, inside the supercharger, which in turn compresses the air entering the engine, centrifugal supercharger also runs off a belt that is driven by the engine but instead of the pulley turning screws or shafts, it rotates a gear system which in turn rotates the turbine that compresses the air through centrifugal forces, unlike a turbocharger, a mechanical supercharger will always require a physical link between itself and the engine to provide a boost. [5]

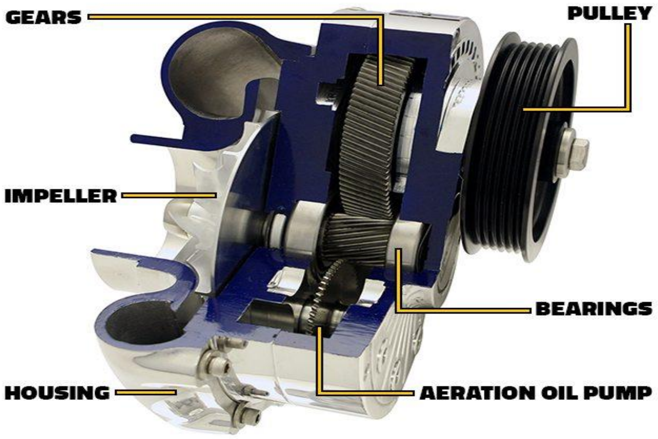


Figure 1.8: supercharger

1.2.3.1Advantages:

1. Increased Power Output: Superchargers provide a significant increase in engine power by forcing more air into the combustion chamber. The compressed air allows for a greater amount of fuel to be burned, resulting in improved engine performance and higher power output.

2. Immediate Throttle Response: Unlike turbochargers, superchargers operate directly from the engine's crankshaft, providing immediate power delivery. This eliminates the lag commonly associated with turbochargers, resulting in enhanced throttle response and acceleration.

3. Improved Torque: Superchargers generate substantial low-end torque, ensuring robust acceleration from low RPMs. This makes them particularly beneficial for applications that require high low-end pulling power, such as towing or heavy-duty vehicles.

4. Compact Design: Superchargers are generally more compact and lighter than turbochargers, allowing for easier installation in engine compartments with limited space. Their compact design also contributes to better weight distribution in the vehicle.

1.2.3.2 Disadvantages:

1. Increased Engine Load and Fuel Consumption: Superchargers consume engine power to operate, placing an additional load on the engine. This increased load results in higher fuel consumption compared to naturally aspirated engines, especially during high-performance driving.

2. Reduced Efficiency: Superchargers, being directly driven by the engine, consume energy that could otherwise be used to drive the wheels. This can lead to reduced overall engine efficiency compared to non-supercharged engines.

3. Limited Altitude Performance: Superchargers rely on engine RPM to operate effectively. At higher altitudes, where the air density is lower, superchargers may struggle to provide the same level of boost, resulting in reduced power output.

4. Potential Belt or Drive System Issues: Superchargers require a belt or drive system to connect them to the engine. This introduces additional components that can fail or require regular maintenance and adjustment.

1.2.3.3 Conclusion:

Superchargers offer several advantages, including increased power output, immediate throttle response, improved low-end torque, and compact design. However, they also come with certain disadvantages, such as increased engine load and fuel consumption, reduced efficiency, limited altitude performance, and potential belt or drive system issues. The decision to implement a supercharger should be based on specific performance requirements, desired power characteristics, and application considerations. Proper design, maintenance, and tuning are crucial to maximize the benefits and mitigate the disadvantages associated with superchargers.

1.4 Twin-Turbocharged

Twin-turbocharged engines utilize two turbochargers to provide increased airflow and improved power delivery.as shown in figure 1.5. A twin-turbocharger works by using two turbochargers of the same size to force air into the engine’s cylinders to add extra horsepower. The exhaust gases are recycled, split between the two turbo, and usually combined in a shared inlet before entering cylinders. This forces a greater volume of air into the induction chamber, allowing the engine to create more powerful combustion strokes. This type of setup is known as a parallel twin-turbo system. [6]

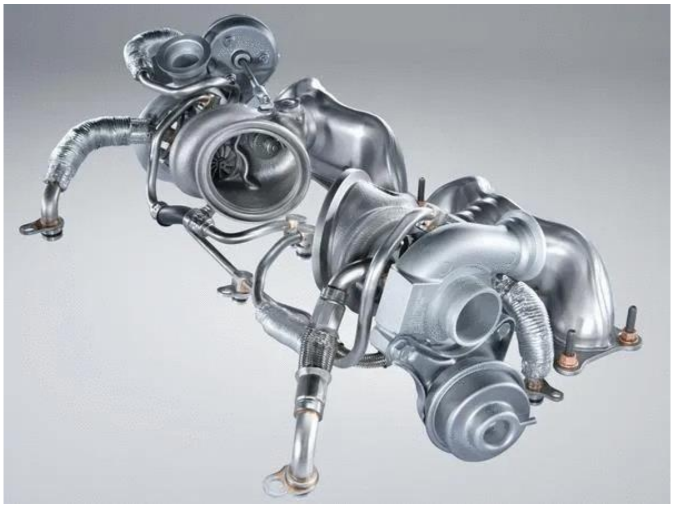


Figure 1.9: Twin-Turbocharged

1.4.1 Advantages:

1. Enhanced Power Output: Twin-turbocharging enables engines to produce significantly higher power outputs compared to naturally aspirated or single-turbocharged engines. The presence of two turbochargers allows for a greater volume of air to be compressed and delivered to the combustion chamber, resulting in improved engine performance.

2. Broad Power Band: Twin-turbocharged engines exhibit excellent power delivery across a wide range of engine speeds. The combination of two turbochargers typically arranged in parallel or sequentially, provides a consistent boost throughout the RPM range, ensuring strong acceleration and responsiveness.

3. Reduced Turbo Lag: By utilizing two turbochargers, twin-turbocharged engines can minimize or eliminate turbo lag. The presence of a smaller turbocharger often referred to as a "low-pressure" or "smaller" turbo, helps to overcome lag at lower RPMs, while a larger turbocharger takes over at higher RPMs, providing sustained power.

4. Improved Efficiency: Twin-turbocharging can enhance the overall efficiency of the engine. By using two turbochargers to distribute the workload, each turbocharger can operate more efficiently within its optimal operating range, resulting in improved fuel efficiency and reduced emissions.

1.4.2 Disadvantages:

1. Increased Complexity and Cost: Twin-turbocharged engines are more complex in design and require additional components such as intercoolers, plumbing, and control systems. This complexity can result in higher manufacturing costs and potentially increased maintenance and repair expenses.

2. Packaging Challenges: The presence of two turbochargers requires careful consideration of packaging constraints within the engine compartment. The additional components may occupy more space, potentially leading to challenges in fitting the engine into certain vehicle platforms or designs.

3. Potential Heat Build-up: Twin-turbocharged engines generate more heat compared to naturally aspirated engines due to the increased compression and air intake. This necessitates the use of effective cooling systems to manage heat build-up and prevent overheating, which can impact engine performance and reliability.

4. Higher Maintenance Requirements: With twin-turbocharged engines, there are more components that require regular inspection, maintenance, and potential replacement. The turbochargers themselves, intercoolers, and associated plumbing systems may need periodic attention to ensure optimal performance and reliability.

1.4.3 Conclusion:

Twin-turbocharged engines offer significant advantages, including enhanced power output, broad power band, reduced turbo lag, and improved efficiency. However, they also present challenges such as increased complexity and cost, packaging constraints, potential heat build-up, and higher maintenance requirements. Manufacturers and consumers need to carefully consider these factors when opting for twin-turbocharged engines. Proper design, maintenance, and consideration of the specific application requirements are crucial to maximizing the benefits and mitigating the disadvantages associated with twin-turbocharging.

1.5 The problem formulation:

Turbo Lag phenomenon. Through our visit to the maintenance centers, the solutions to this problem have been known.

Turbo lag is a phenomenon that occurs in turbocharged engines when there is a delay in the delivery of power after the driver presses the accelerator pedal. It is a result of the time it takes for the turbocharger to spool up and provide the engine with the boost it needs to generate power. This delay can vary in duration and intensity, depending on the specific engine and turbocharger design.

Turbo lag, a prevalent problem in older turbocharged engines, arises due to the presence of larger turbochargers that require more time to reach optimal speeds. Modern turbocharged engines, on the other hand, incorporate smaller turbochargers and advanced technology to minimize turbo lag. Despite these advancements, turbo lag can still be observed in certain high-performance vehicles, especially during low-speed driving or when initiating acceleration from a stationary position.

There are several ways to reduce turbo lag, such as using a smaller turbocharger, reducing the weight of the turbocharger, or using advanced technology to spool up the turbocharger more quickly. Additionally, some drivers may modify their engines with aftermarket parts to reduce turbo lag.

Overall, turbo lag is a trade-off for the benefits of a turbocharged engine, which include improved fuel efficiency and increased power. While it can be frustrating for some drivers, it is a manageable issue that can be addressed through engineering design and modification.

1.6 The influencers and those affected by the problem:

- ✓ The influencers are design companies.
- ✓ Those affected are the environment and society

1.7 problem formulation

1.5.1 The cusses of problem.

Table 1.1 : causes of the turbo lag phenomenon

Inertia	Boost Threshold	Compressor Efficiency
Piping and Intercoolers	Problem name: Turbo lag phenomenon	Westgate Operation
Turbocharger Size and Design		

1. Inertia: Turbochargers rely on exhaust gases to spin the turbine, which in turn drives the compressor to provide compressed air to the engine. At low engine speeds, there may not be sufficient exhaust gas flow to spin the turbine quickly. The turbine's inertia, combined with the time required for the exhaust gases to reach the turbine, leads to a delay in power delivery, resulting in turbo lag.
2. Boost Threshold: Turbochargers have a specific boost threshold, which is the minimum level of exhaust gas flow required to generate enough power to spin the turbine effectively. Until the engine reaches the boost threshold, the turbocharger may not provide significant boost pressure, leading to a delay in power delivery and turbo lag.
3. Compressor Efficiency: The efficiency of the compressor in compressing the incoming air affects the occurrence of turbo lag. If the compressor is not optimized for low-speed operation, it may struggle to provide sufficient airflow and boost pressure at low engine speeds, resulting in turbo lag.
4. Piping and Intercoolers: The length, diameter, and design of the intake and intercooler piping can also contribute to turbo lag. Longer or narrower piping can introduce additional airflow restrictions and increase the time it takes for compressed air to reach the engine cylinders, causing turbo lag.

5. Westgate Operation: The wastegate is a component that regulates the boost pressure generated by the turbocharger. It opens to bypass excess exhaust gas flow, preventing

over boost. However, if the wastegate is not properly calibrated or if it opens too early, it can limit the turbocharger's performance and contribute to turbo lag.

6. Turbocharger Size and Design: The size and design of the turbocharger itself play a role in turbo lag. Smaller turbochargers tend to spool up faster, but they may have limitations in terms of maximum boost pressure. Larger turbochargers can provide higher boost pressure but may suffer from slower spool-up times, resulting in turbo lag.

1.5.2 Suggest solution

Table1 .2 : Suggest solution for turbo lag phenomenon

Twin-scroll Turbochargers	Sequential Turbocharging	Boost Control Systems
Variable Geometry Turbo (VGT)	Suggest solution for Turbo lag phenomenon	Intercooler Efficiency
Electric Turbocharging		

1. Twin-scroll Turbochargers: Twin-scroll turbochargers feature divided exhaust passages that direct exhaust gases to separate turbine scrolls. This design reduces turbo lag by optimizing exhaust gas flow and maximizing energy extraction from the exhaust, resulting in quicker spool-up and improved throttle response.
2. Variable Geometry Turbo (VGT): VGT systems adjust the turbine's geometry to optimize performance across different engine speeds. By altering the size and angle of the turbine vanes, VGT mitigates turbo lag and provides better boost control at low RPMs, enhancing overall engine response.
3. Electric Turbocharging: Electric turbochargers utilize an electric motor to assist the turbocharger's spool-up. By providing instant boost pressure during low RPMs, electric turbocharging effectively eliminates turbo lag and enhances throttle response.
4. Sequential Turbocharging: Sequential turbocharging involves using two or more turbochargers of different sizes. Smaller turbo are responsible for providing immediate

boost at low RPMs, while larger turbo take over at higher RPMs. This setup reduces turbo lag and ensures continuous power delivery across the engine's operating range.

5. Boost Control Systems: Advanced boost control systems, such as electronic wastegate and advanced engine management systems, can optimize the turbocharger's response and regulate boost pressure more precisely. These systems help reduce turbo lag and improve throttle response.
6. Intercooler Efficiency: Upgrading the intercooler to a more efficient design can reduce the intake air temperature, enhancing overall engine performance and reducing turbo lag.

1.5.3 The feasible solution

Table 1.3: Twin-scroll Turbochargers

Complexity and Cost	Packaging Constraints	Increased Exhaust Backpressure
Limited Benefits at Low Engine Loads	Twin-scroll Turbochargers	
Higher Exhaust Gas Temperatures		

Table 1.4 : Variable Geometry Turbo (VGT)

Complexity and Cost	Potential for Increased Wear and Failure	Higher Backpressure at High RPM
Limited Benefits at Low Engine Loads	Variable Geometry Turbo (VGT)	
Packaging Constraints		

Table 1.5 : Sequential Turbocharging

Increased Complexity and Cost	Complexity of Control Systems	Costly Maintenance and Repairs
Packaging Constraints	Sequential Turbocharging	Potential for Increased Heat Generation
Increased Weight		

Table 1.6 : Boost Control Systems.

Increased Complexity and Cost	Compatibility and Integration	Increased Complexity of Troubleshooting
Reliability and Durability Concerns	Boost Control Systems	Limited Benefits at Low Engine Loads
Tuning Challenges		

Table 1.7 : Intercooler Efficiency

Increased Pressure Drop	Limited Cooling Capacity	Cost and Complexity
Increased Weight and Size	Intercooler Efficiency	
Potential for Heat Soak		

Table 1.8 : Electric Turbocharging

Flexibility and Tunability	Enhanced Power Output	
Reduced Dependency on Exhaust Gas Energy	Electric Turbocharging	
Improved Packaging and Design Options		

- **After studying the suggested solutions, we have found that the best solution to this problem is to add an electric motor connected to the turbo. It was chosen to combine the electric motor with the turbocharger as the best possible solution, because some other solutions have disadvantages as indicated in the above tables.**

1.8 Steps to work on the optimal solution:

1. Determine the type of vehicle
2. Identify sensors and actuators in the system
3. Determine the special variables in the operation of the system
4. Collect the special equations in the system and install them on MATLAB
5. Building simulations in the MATLAB program

1.9 Project objectives:

1. Increasing the speed of the turbo response, so there is a high quantity and higher pressure in the combustion chamber to a certain extent, and thus increasing the efficiency of combustion and the engine.

2. Reducing fuel consumption and exhaust emissions.

1.10 Literature review

This section focuses on presenting previous research and researchers' work that focus on this problem, as well as presenting and discussion their solutions and results. Here is some of the literature that was considered.

The electric turbocharger (ET) shows promise in improving vehicle fuel efficiency by enabling engine downsizing. However, integrating ET into engine systems poses challenges in energy management and control. This paper proposes a real-time energy management strategy that updates and tracks the optimal exhaust pressure set point. The study analyzes the impact of ET on engine response and exhaust emissions, and designs a multivariable explicit model predictive controller to regulate key variables in the engine air system. A high-level controller generates optimal set points for these variables, ensuring efficient energy management. The proposed method is validated through physical simulations and experimental testing, demonstrating effective tracking performance and sustainable energy management. [1]

The electrical turbocharger assist is a crucial technology for enhancing the fuel efficiency of conventional powertrain vehicles. However, effectively operating this complex device presents significant challenges. This paper presents an integrated framework that encompasses the characterization, control, and testing of the electrical turbocharger assist. The research begins with a thorough physical characterization of the engine, followed by an analysis of the device's controllability and its impact on fuel economy and exhaust emissions. A multivariable robust controller is then designed to systematically regulate the dynamics of the electrified turbocharged engine. Additionally, a supervisory level controller is developed to optimize the set points of key controlled variables in real-time, thereby minimizing fuel consumption .An experimental platform based on a heavy-duty diesel engine is constructed to validate the proposed framework through simulations, physical simulations, and experiments. The results showcase exceptional tracking performance, high robustness, and the potential for significant improvements in fuel efficiency. [2]

This paper deals with description of the use of electrically powered compressor for a turbocharged internal combustion engine. The main purpose for use of electrically powered compressor is an improvement of transient engine behavior and increase of the boost pressure at low engine speeds. The compressor is driven by high speed switched reluctance machine, while in this paper the control scheme is described together with its simulation and experimental verification. [7]

This paper presents a design methodology and analysis for an ultra-high-speed surface-mounted permanent-magnet synchronous motor (SPMSM) with a power rating of 4 kW and a speed of 150 krpm. The motor is designed to electrically assist a turbocharger, aiming to achieve the required torque and speed while eliminating turbo lag effectively. The existing prototype that does not meet the target performance is analyzed, and the experimentally obtained losses are considered in the design process. The speed response characteristics of the motor are analyzed using electromechanical undamped natural frequency and damping ratio. Design parameters such as the permanent-magnet grade, coil turn number, and axial length of the motor are optimized. The resulting improved motor demonstrates higher power density and faster speed response compared to the prototype. Experimental tests validate the effectiveness of the motor in electrically assisting the turbocharger. System experiments with the turbocharger show a 44.9% improvement in the rising speed of the boost pressure due to the designed motor. [8]

Achieving system requirements

Once the system requirements are thoroughly understood, the existing solutions are analytically studied to determine a suitable solution to the project problem. In this case, the solution to the problem is to add an electronic unit that controls a super electric motor integrated with the turbocharger. This unit is activated through information obtained from sensors such as the exhaust pressure sensor, the engine speed sensor, and the intake duct pressure sensor. Through this system, the response delay is overcome.

Chapter 2

Conceptual design

2.1 Introduction

This section shows the conceptual design of an electrically assisted turbocharger, which consists of subsystems, components, functions, the relationship between elements, and functional specifications. The function of the electric turbocharger is through its ability to overcome the phenomenon of delayed response in the turbo (Turbo Lag). The electric turbocharger contains fins (butterflies) on both sides, the first side where the butterflies move as a result of the flow and pressure of exhaust gases, on the other side the butterflies move and compress the air inside the intake ducts, it also contains a permanent magnetic motor (PM). the system is activated based on accurate information from the sensors, and this information is processed by a special control unit, and the system is activated if necessary.

2.2 Conceptual Design Schematic

This section describes the workflow of an electrically assisted turbocharger, including system components, parts functions, and the relationships between elements. An electrically assisted turbocharger relies on a combination of information obtained from sensors in the engine system. Among these sensors is the exhaust gas pressure sensor. This sensor measures the pressure of the exhaust gases and sends it to the control unit, turbo pressure sensor, this sensor measures the amount of pressure produced by the turbo and sends it to the control unit, based on this information, and the electric actuator booster supercharger activates the turbo.

2.3 Conceptual design components:

An electric turbine is a type of forced induction system that uses an electric motor to compress air and increase engine power. Here is a conceptual design of an electrically assisted turbocharged internal combustion engine as shown in figure 2.1

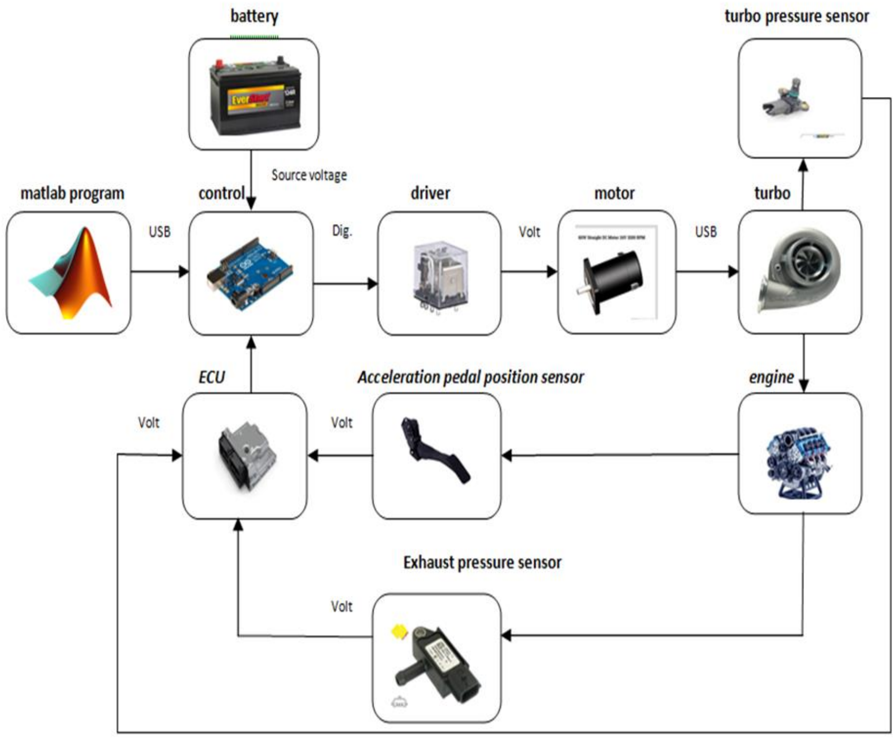


Figure 2.1: Conceptual design components

1. Electric motor: The electric motor is the heart of the electric turbo. It is typically a small, high-speed motor that is mounted on the air intake side of the engine.
2. Compressor wheel: The compressor wheel is similar to the compressor wheel in a traditional turbocharger. It is responsible for compressing the incoming air before it is fed into the engine.
3. Compressor housing: The compressor housing is part of the electric turbo that houses the compressor wheel. It is typically made of aluminum or other lightweight material.
4. Air filter: The air filter is an important component that cleans the incoming air before it is compressed by the electric turbo.
5. The electronic control unit (ECU): The ECU is responsible for controlling the electric turbo. It receives input from various sensors, including the throttle position sensor and the air intake temperature sensor, and adjusts the speed of the electric motor to optimize performance.

6. Power source: The power source for the electric turbo is typically the vehicle's battery. However, some designs may include a dedicated battery or another power source to ensure consistent performance.
7. Relay: An electrical relay is a type of switch that is used to control the flow of electricity in a circuit. It is an electromechanical device that consists of a coil, an armature, and a set of contacts.
8. Arduino: is an open-source electronics platform that is designed for creating interactive projects. It consists of a physical computing board, a programming environment, and a community of users and developers.
9. MATLAB: is a numerical computing and programming language that is widely used in engineering, science, and mathematics. It allows users to perform complex calculations, analyze data, and develop algorithms.
10. An exhaust pressure sensor: is a type of sensor used in modern automotive engines to measure the pressure of exhaust gases. The sensor is typically located in the exhaust system, either in the exhaust manifold or in the exhaust pipe downstream from the manifold.
11. A pedal position sensor: also known as an accelerator pedal position sensor (APPS) is a type of sensor used in modern automotive engines to measure the position of the accelerator pedal. The sensor is typically located on the accelerator pedal assembly and is used to provide input to the engine control module (ECM), which then adjusts the throttle position accordingly.

Unit (1)

Processing unit

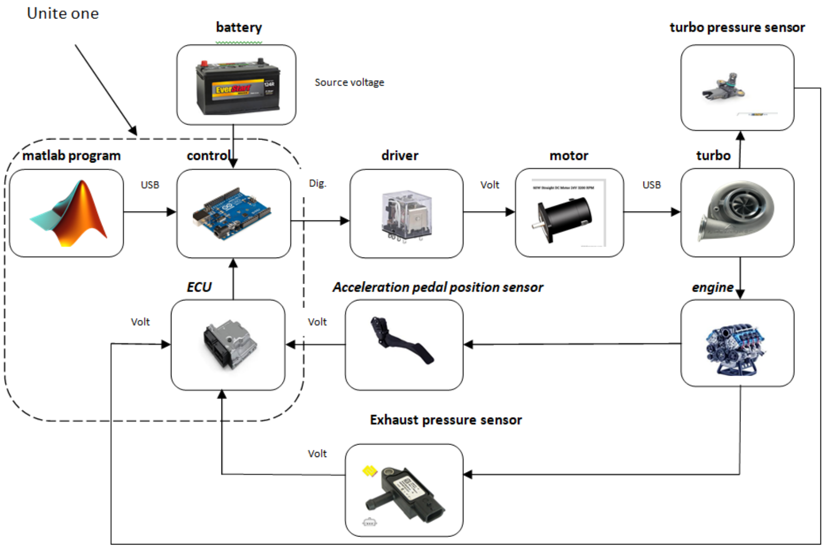


Figure 2.2: processing unit

✓ The aim:

This unit consists of a Matlab program, ECU, and Arduino as shown in figure 2.2 where Matlab consists of computerized algorithms and equations that are stored on ,Arduino the controller receives a set of information from the central control unit ECU and works to process and compare the information and then send a signal to the activation key If necessary, the central control unit sends basic information to the controller.

✓ Input:

1- Acceleration pedal sensor

2- Exhaust pressure sensor

3- Source power

4- Turbo pressure sensor

✓ output:

1-digital signal (on-off)

Unit (2)

Activation unit

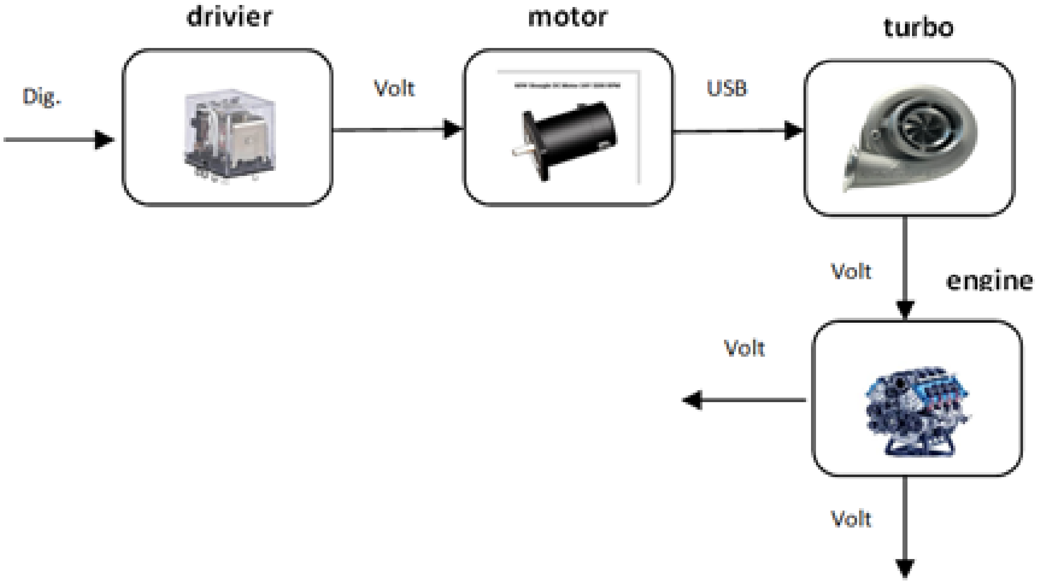


Figure 2.3: Activation unit

- ✓ The aim:

This unit consists of a relay switch, an electric motor as shown in figure 2.3, and a turbocharger where the relay receives a signal to deliver electric current to the electric motor to energize the turbine for the supercharger.

- ✓ (input):

Voltage

- ✓ (output):

1- Mechanical energy

Unit (3)

Sensors unit

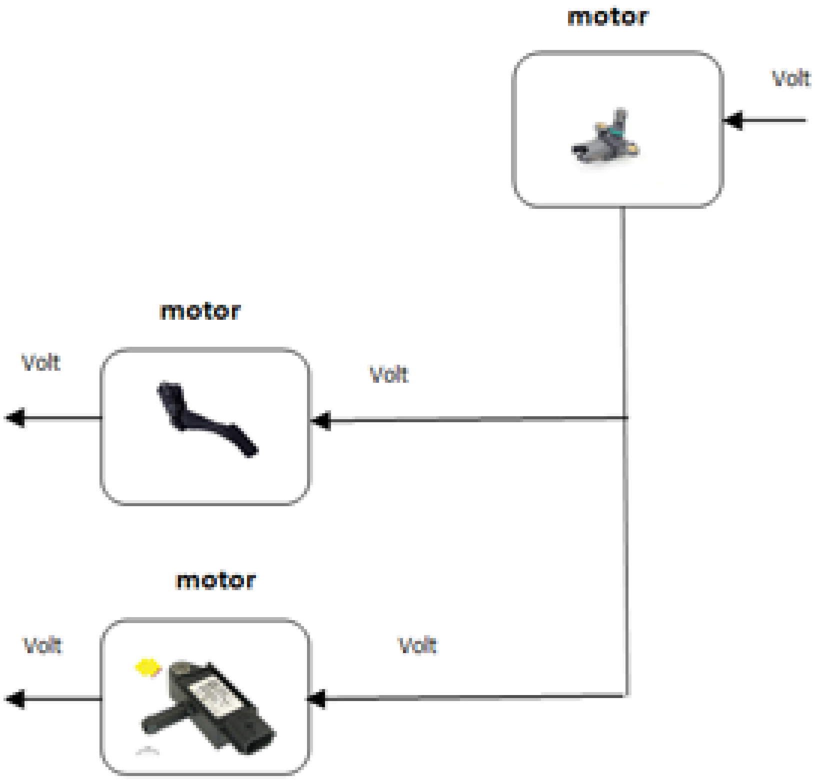


Figure 2.4: Sensors unit

- ✓ The aim:

This unit contains a set of sensors, including an Acceleration pedal position sensor as shown in figure 2.4, and this sensor knows the amount of load on the engine, aturbo pressure sensor, this sensor knows the amount of turbo pressure, and anExhaust pressure sensor, this sensor knows the amount of exhaust pressure.

- ✓ (Input):

  Voltage

- ✓ (output):

1. Change in the resistance

Chapter 3

Simulation system

3.1 Introduction

The purpose of this report is to discuss the simulation of a turbocharged diesel engine with turbo lag using MATLAB. Turbo lag is a common issue in turbocharged engines, which is the delay between the time the driver presses the accelerator and the time the turbocharger produces enough boost to provide a noticeable increase in power. This lag can result in decreased performance and fuel efficiency. Therefore, it is essential to study and simulate the behavior of a turbocharged diesel engine with turbo lag to optimize its performance.

The turbine assembly, consisting of a turbine wheel and housing, extracts energy from the exhaust gases, whiles the shaft and bearings transmit this power to drive auxiliary systems, necessitating sturdy bearings for smooth operation. In terms of exhaust gas flow, the exhaust manifold collects gases from the engine cylinders and directs them into the turbine assembly, where the turbine wheel, propelled by the exhaust gases, converts the energy into rotational motion. In the intake air system, the air filter plays a crucial role by removing contaminants from incoming air, safeguarding the engine and optimizing combustion, while the compressor wheel, driven by the turbine, compresses the intake air, thereby increasing its density to improve combustion efficiency. Additionally, the intercooler is responsible for reducing the temperature of the compressed intake air, resulting in increased density and enhanced combustion efficiency, as shown in figure 3.1

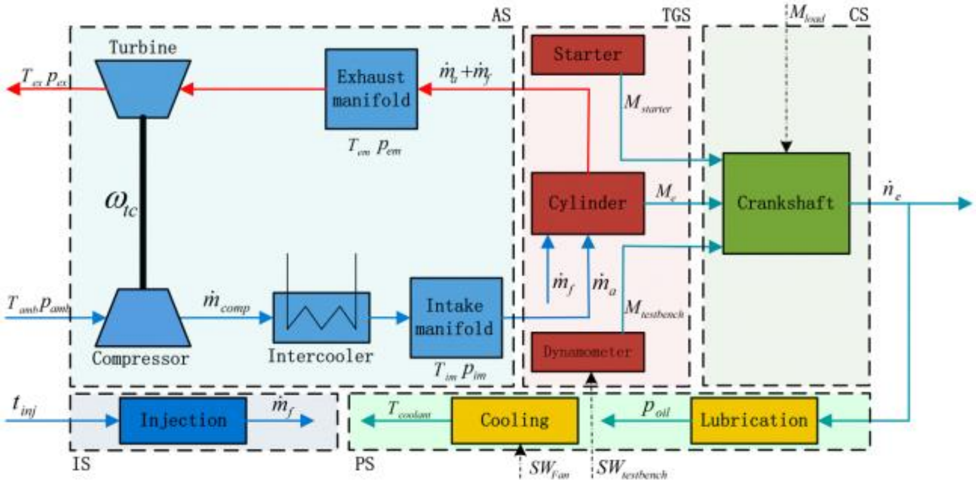


Figure 3.1: the diesel engine model architecture

The air block, which is composed of five sub-models (turbocharger, intercooler, intake manifold air mass into cylinder, and exhaust manifold), is described using dynamic differential equations.

3.2 Manifold

The intake and exhaust manifolds are modeled as dynamic systems with two states each and these are pressure and oxygen mass fraction. The standard isothermal model, which is based upon mass conservation, the ideal-gas law, and the fact that the manifold temperature is constant or varies slowly, gives the differential equations for the manifold pressures as: [9]

$$\frac{d}{dt} p_{im} = \frac{R_a T_{im}}{V_{im}} \left(W_c + W_{egr} - W_{ei} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

P_{im} : Intake manifold pressers (pa).

R_a : Specific gas constant of air ($J/(Kg.K)$)

T_{im} : Intake manifold temperature (K).

V_{im} : Intake manifold volume (L)

W_c : Compressor mass flow (Kg/s).

W_{egr} : Exhaust gas recirculation mass flow (Kg/s).

W_{ei} : Total Mass flow (kg/s).

$$\frac{d}{dt}p_{em}=\frac{R_eT_{em}}{V_{em}}\left(W_{eo}-W_t-W_{egr}\right)\ldots\ldots(2)$$

Where:

P_{em} : Exhaust manifold pressers (Pa).

R_e : Ideal gas constant ($J/(Kg/K)$).

T_{em} : Exhaust manifold temperature (K).

V_{em} : Exhaust manifold volume (L).

W_{eo} : Mass flow (kg/s).

W_t : mass flow (kg/s).

The EGR fraction in the intake manifold is calculated as:

$$X_{egr}=\frac{W_{egr}}{W_c+W_{egr}}\ldots\ldots(3)$$

$$X_{oim}=\frac{m_{oim}}{m_{totim}}\ldots\ldots(4)$$

$$X_{oem}=\frac{m_{oem}}{m_{totem}}\ldots\ldots(5)$$

Where:

X_{egr} : Exhaust gas recirculation friction.

X_{oim} : Oxygen concentration.

X_{oem} : Oxygen concentration.

m_{oim} : Oxygen masses in the intake manifold.

m_{totim} : Total masses in the intake manifold.

m_{oem} : Oxygen masses in the exhaust manifold.

m_{totem} : Total masses in the exhaust manifold.

Note that the EGR gas also contains oxygen which affects the oxygen-to-fuel ratio in the cylinder. This effect is considered by modelling the oxygen concentrations X_{oim} and X_{oem} in the control volumes. These concentrations are defined in the same way as in reference according to.

$$\frac{d}{dt}X_{Oim} = \frac{R_a T_{im}}{p_{im} V_{im}}\left(\left(X_{Oem} - X_{Oim}\right)W_{egr} + \left(X_{Oc} - X_{Oim}\right)W_c\right) \ldots\ldots (6)$$

$$\frac{d}{dt}X_{Oem} = \frac{R_e T_{em}}{p_{em} V_{em}}\left(X_{Oe} - X_{Oem}\right)W_{eo} \ldots\ldots (7)$$

Where:

X_{oc} : Constant oxygen concentration in compressor.

X_{oe} : Oxygen concentration in exhaust.

3.3 Cylinder:

$$W_{ei} = \frac{\eta_{vol} P_{im} n_e V_d}{120 R_a T_{im}} \ldots\ldots (8)$$

Where:

η_{vol} : Volumetric efficiency.

n_e : Rotational engine speed $(R/\min.)$.

V_d : Displaced volume (m^3).

Where p_{im} and T_{im} are the pressure and temperature respectively in the intake manifold, ne is the engine speed, and V_d is the displaced volume. The volumetric efficiency is in its turn modeled as:

$$\eta_{vol} = C_{vol1}\sqrt{P_{im}} + C_{vol2}\sqrt{n_e} + C_{vol3} \quad \text{.......} (9)$$

Where:

C_{vol} : Volumetric compressor.

The fuel mass flow W_f into the cylinders is controlled by ud , which gives the injected mass of fuel in milligrams per cycle and cylinder as:

$$W_f = \frac{10^{-6}}{120} u_\delta n_e n_{cyl} \quad \text{.......} (10)$$

Where:

W_f : Fuel mass flow (Kg/s).

u_δ : injected amount of fuel ($mg/cycle$).

Where n_{cyl} is the number of cylinders, the mass flow W_{eo} out from the cylinder is given by the mass balance as:

$$W_{eo} = W_f + W_{ei} \quad \text{.......} (11)$$

Where:

W_{eo} : Mass flow out the cylinder (kg/s).

W_{ei} : Mass flow in the cylinder (Kg/s).

The oxygen-to-fuel ratio T_t in the cylinder is defined as:

$$\lambda_o = \frac{W_{ei} X_{Oim}}{W_f (O/F)_s} \quad \text{.......} (12)$$

Where:

λ_o : Oxygen to fuel ratio.

$$X_{Oe} = \frac{W_{ei} X_{Oim} - W_f \, (O/F)_s}{W_{eo}} \quad \text{.....}(13)$$

3.4 Engine torque:

The torque M_e produced by the engine is modeled using three different engine components, namely the gross indicated torque M_{ig} the pumping torque M_p, and the friction torque M_{fric} according to:

$$M_e = M_{ig} - M_p - M_{fric} \quad \text{.....}(14)$$

Where:

M_e : Engine torque ($N.m$).

M_{ig} : Indicated torque ($N.m$).

M_{fric} : Friction torque ($N.m$).

M_p : pumping torque ($N.m$).

The pumping torque is modeled using the intake and exhaust manifold pressures, according to:

$$M_p = \frac{V_d}{4\pi}(P_{em} - P_{im}) \quad \text{.....}(15)$$

The gross indicated torque is coupled to the energy that comes from the fuel according to:

$$M_{ig} = \frac{u_\delta 10^{-6} n_{cyl} q_{HV} \eta_{ig}}{4\pi} \quad \text{.....}(16)$$

Where:

q_{HV} : Heating value of fuel (J/kg).

η_{ig} : Thermal indicated gross.

Assuming that the engine is always running at optimal injection timing, the gross indicated efficiency is modeled:

$$\eta_{ig} = \eta_{igch}\left(1-\frac{1}{r_c^{\gamma_{cyl}-1}}\right) \qquad (17)$$

The friction torque is assumed to be a quadratic polynomial in engine speed given by:

$$M_{fric} = \frac{V_d}{4\pi}10^5\left(c_{fric1}n^2_{eratio} + c_{fric2}n_{eratio} + c_{fric3}\right) \qquad (18)$$

$$n_{eratio} = \frac{n_e}{1000} \qquad (19)$$

3.5 EGR-valve actuator:

The EGR-valve actuator dynamics are modeled as a second order system with an overshoot and a time delay. This model consists of a subtraction between the two first order systems with different gains and time constants according to:

$$\tilde{u}_{egr} = K_{egr}\tilde{u}_{egr1} - \left(K_{egr}-1\right)\tilde{u}_{egr2} \qquad (20)$$

$$\frac{d}{dt}\tilde{u}_{egr1} = \frac{1}{\tau_{egr1}}\left[u_{egr}\left(t-\tau_{degr}\right) - \tilde{u}_{egr1}\right] \qquad (21)$$

$$\frac{d}{dt}\tilde{u}_{egr2} = \frac{1}{\tau_{egr2}}\left[u_{egr}\left(t-\tau_{degr}\right) - \tilde{u}_{egr2}\right] \qquad (22)$$

Where:

$\tilde{u}_{egr}$: EGR position (%).

K_{egr} : Affects the size of the overshoot.

3.6 Turbine:

One way to model the power P_t is to use the turbine efficiency h_t which is defined as:

$$\eta_t = \frac{P_t}{P_{t.s}} = \frac{T_{em} - T_t}{T_{em}\left(1-\Pi^{1-1/\gamma e}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(23)$$

Where:

η_t : Turbine efficiency.

P_t : Turbine power (W).

$P_{t.s}$: Power from the isentropic process.

T_t : Temperature after turbine (K).

Π : Pressure ratio.

γ^e : Specific heat capacity ratio exhaust.

Where T_t the temperature is after the turbine, P_t is the pressure ratio given by:

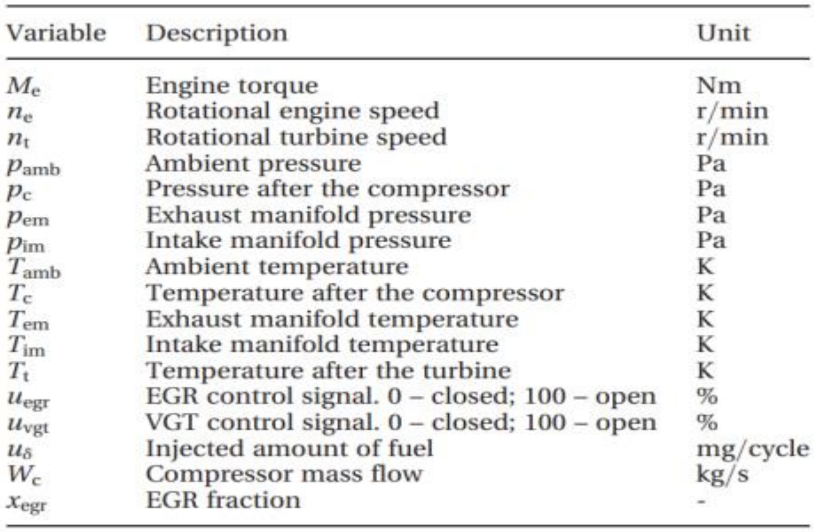
$$\Pi_t = \frac{P_{es}}{P_{em}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(24)$$

And $P_{t.s}$ is the power from the isentropic process

$$p_{t.s} = W_t C_{pe} T_{em}\left(1-\Pi_t^{1-1/\gamma_e}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(25)$$

Measured variables during stationary measurement

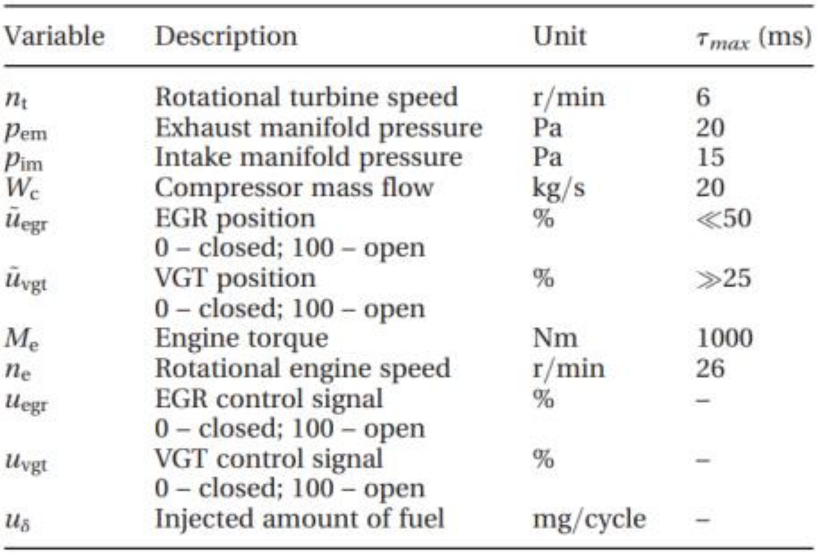
Table 3.1



Variable	Description	Unit
M_e	Engine torque	Nm
n_e	Rotational engine speed	r/min
n_t	Rotational turbine speed	r/min
p_{amb}	Ambient pressure	Pa
p_c	Pressure after the compressor	Pa
p_{em}	Exhaust manifold pressure	Pa
p_{im}	Intake manifold pressure	Pa
T_{amb}	Ambient temperature	K
T_c	Temperature after the compressor	K
T_{em}	Exhaust manifold temperature	K
T_{im}	Intake manifold temperature	K
T_t	Temperature after the turbine	K
u_{egr}	EGR control signal. 0 – closed; 100 – open	%
u_{vgt}	VGT control signal. 0 – closed; 100 – open	%
u_δ	Injected amount of fuel	mg/cycle
W_c	Compressor mass flow	kg/s
x_{egr}	EGR fraction	-

Measured variables during dynamic measurements and maximum sensor time constants $t_{\max}$.

Table 3.2



Variable	Description	Unit	τ_{max} (ms)
n_t	Rotational turbine speed	r/min	6
p_{em}	Exhaust manifold pressure	Pa	20
p_{im}	Intake manifold pressure	Pa	15
W_c	Compressor mass flow	kg/s	20
$\tilde{u}_{egr}$	EGR position 0 – closed; 100 – open	%	$\ll$50
$\tilde{u}_{vgt}$	VGT position 0 – closed; 100 – open	%	$\gg$25
M_e	Engine torque	Nm	1000
n_e	Rotational engine speed	r/min	26
u_{egr}	EGR control signal 0 – closed; 100 – open	%	–
u_{vgt}	VGT control signal 0 – closed; 100 – open	%	–
u_δ	Injected amount of fuel	mg/cycle	–

The above-mentioned equations were programmed on the MATLAB program to simulate the dynamics of the engine, and a set of curvatures that are related to the work of the system were obtained within a short period.

3.7 Simulink

Simulink is a visual programming environment used for modeling, simulating, and analyzing dynamic systems. It's widely used in engineering and research.

In this part, the parts were combined with each other, where each part contains a set of equations for the system's work, as shown in the figure 3.2.

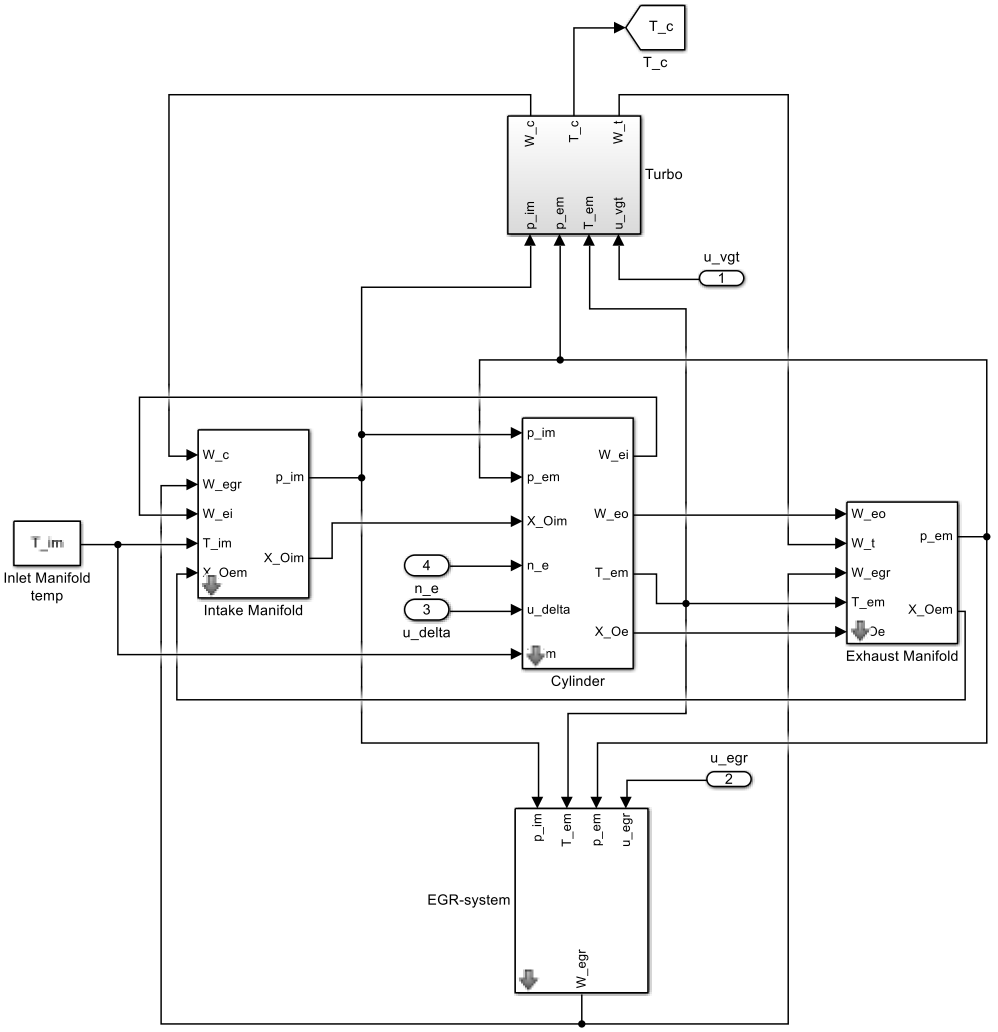


Figure 3.2: Simulink CI engine system

To study the exhaust gas flow rate vs time, a simulation system with special equations installed on MATLAB software was used for the purpose of displaying the system workflow for data acquisition. The system was operated at various speeds and loads, and the exhaust gas flow rate was measured in each case. The data was recorded for a period of time to capture the change in the exhaust gas flow rate over time.

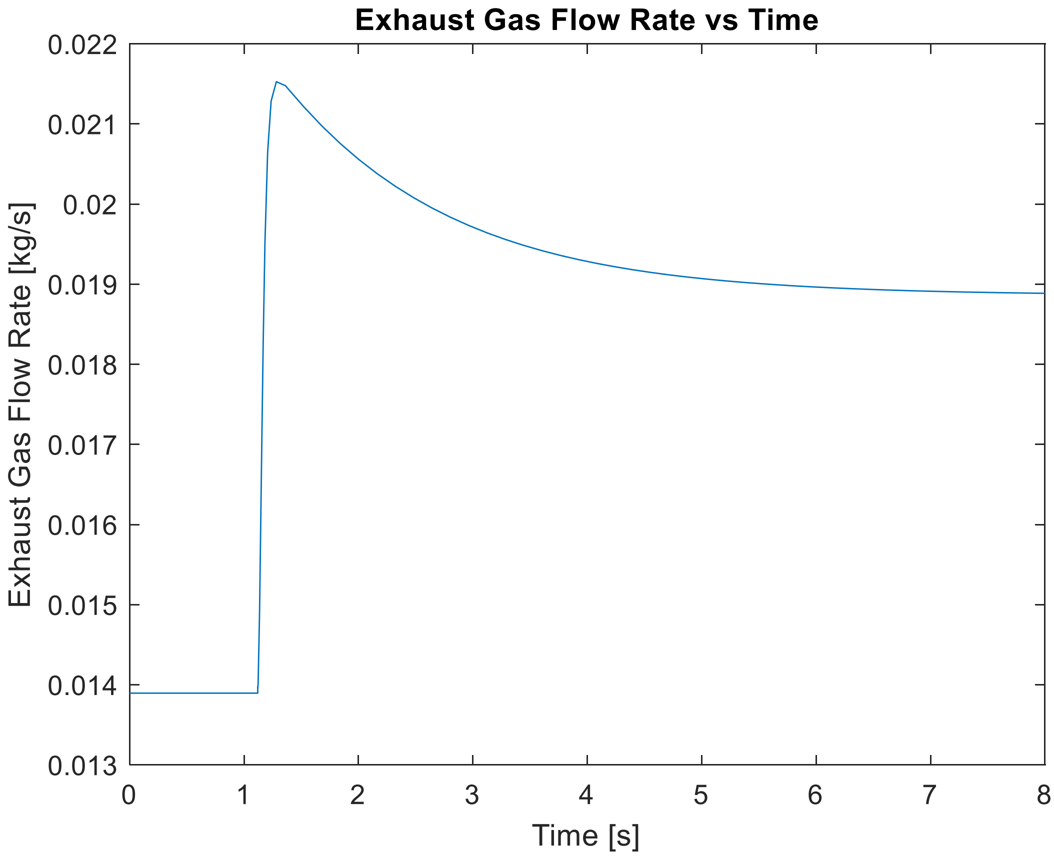


Figure 3.3: exhaust gas flow rate time

The combustion efficiency of an internal combustion engine is a critical factor that directly affects its performance, fuel economy, and emissions. In compression-ignition (CI) engines, which include diesel engines, achieving high combustion efficiency is essential for optimal operation. Figure 3.4 shows the relationship between combustion efficiency and time in (CI) engines.

To study combustion efficiency vs time in a CI engine, we conducted a series of experiments using a simulated system, running the system under various operating conditions, including variable engine loads, injection timing, and air-fuel ratios, while also measuring combustion efficiency and other engine parameters.

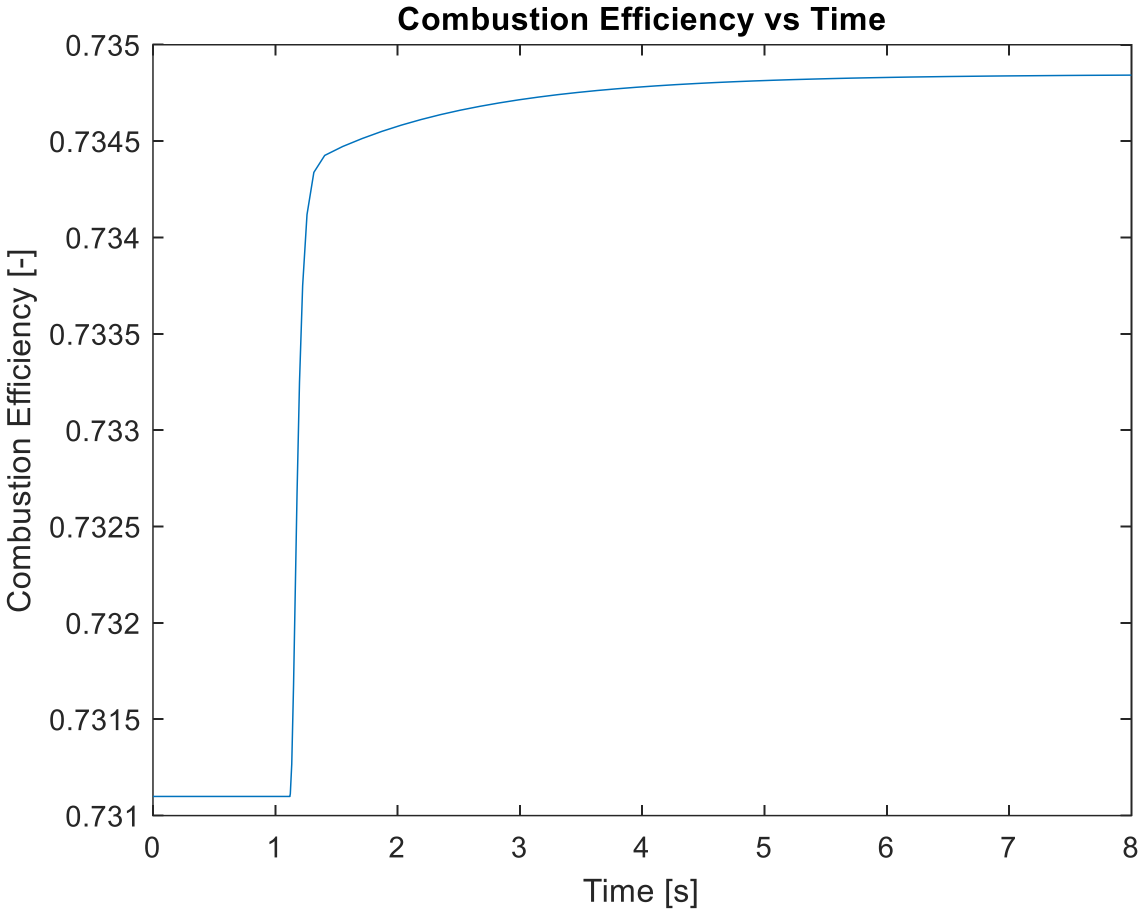


Figure 3.4: combustion efficiency with time

Cylinder pressure is an important parameter in the operation of compression ignition (CI) engines. Understanding the relationship between cylinder pressure and time provides valuable insights into the combustion process, engine performance, and emissions.

To study cylinder pressure versus time in a CI engine, we performed a series of experiments using a diesel engine. The system is equipped to show the cylinder pressure in different locations and obtain data to record the cylinder pressure data as shown in figure 3.5 The engine was run under various operating conditions, including variable engine loads, injection timing, and air-fuel ratios, with cylinder pressure and other engine parameters measured.

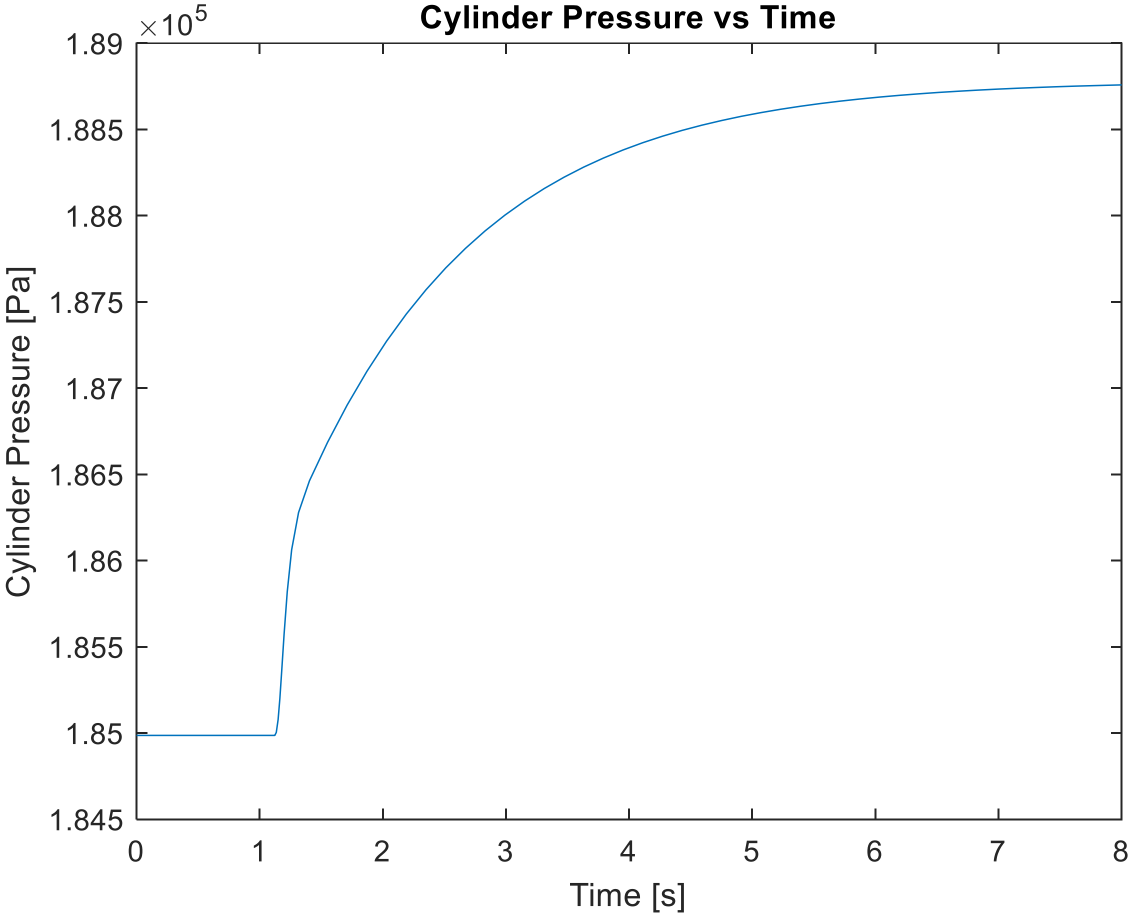


Figure 3.5: combustion efficiency with time

Our experimental results showed from figure 3.6 that the exhaust manifold pressure of a CI engine increases during high revs. Maximum exhaust manifold pressure is affected by several factors, including engine load, injection timing, and the air-to-fuel ratio. At higher engine loads, the exhaust manifold pressure increased due to increased combustion pressure, while the advanced injection timing and lean air and fuel ratios resulted in higher exhaust manifold pressures due to increased turbulence and reduced return pressure. Conversely, the delayed injection timing and rich air-fuel ratios resulted in lower exhaust manifold pressures due to lower combustion efficiency.

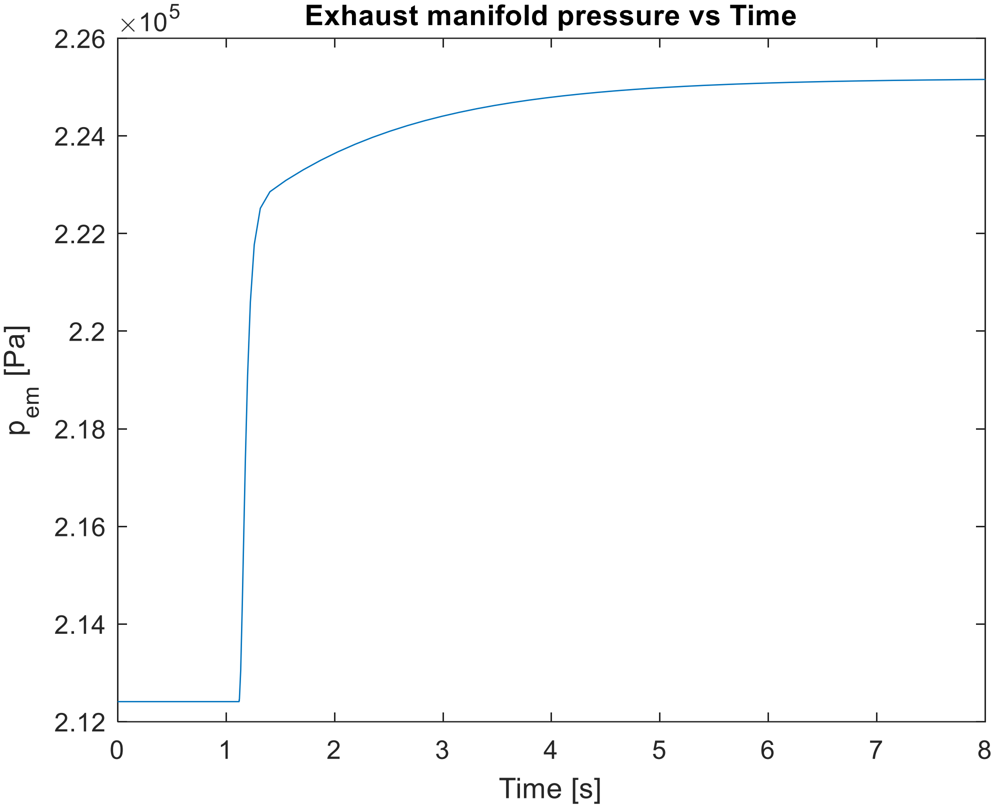


Figure 3.6: exhaust manifold pressure with time

Intake manifold pressure is a critical parameter in the operation of compression ignition (CI) engines. Understanding the variation of intake manifold pressure with time provides valuable insights into the engine's air supply, combustion process, and overall performance.

The results of the study revealed that the intake manifold pressure and flow rate varied with time, depending on the engine speed and load. At low speeds and loads, the intake manifold pressure and flow rate were relatively low and remained relatively constant. As the engine speed and load increased, the intake manifold pressure and flow rate exhibited a nonlinear relationship with time. The pressure increased with engine speed due to increased demand for air, while the flow rate increased linearly initially and then plateaued as it approached the maximum capacity of the intake system from figure 3.7

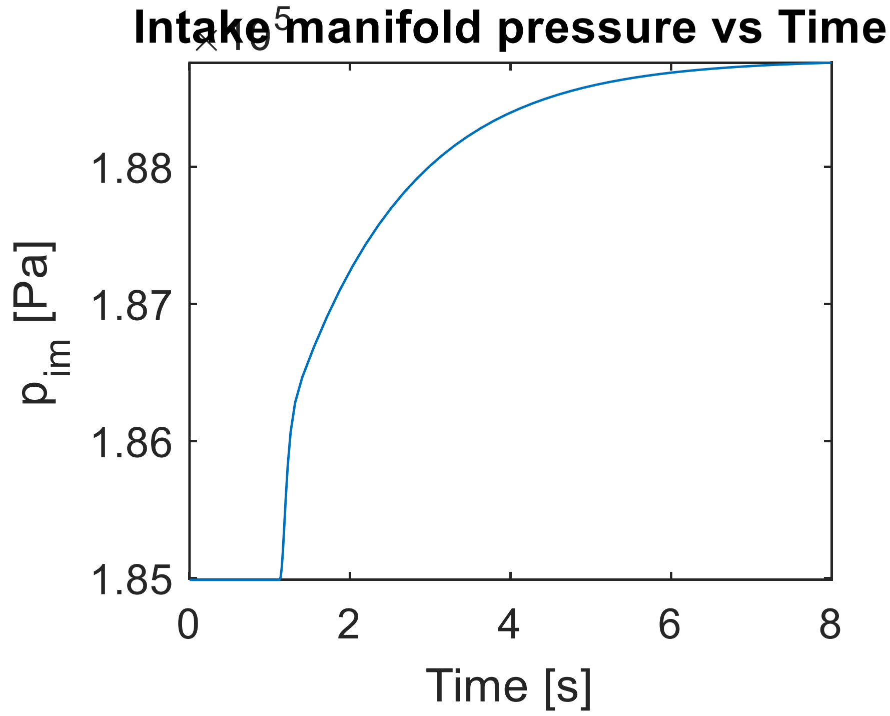


Figure 3.7: intake manifold pressure with time

Chapter 4

4.1 Introduction

The primary objective of this report is to delve into the intricacies of simulating a turbocharged diesel engine with turbo lag using the MATLAB software. Turbo lag represents a prevalent concern in turbocharged engines, characterizing the time delay between the moments the driver engages the accelerator and the subsequent period required by the turbocharger to generate sufficient boost for a perceptible surge in power. This lag inherently leads to diminished performance levels and compromised fuel efficiency. Consequently, a comprehensive study and simulation of the turbocharged diesel engine's behavior, encompassing the impact of turbo lag, become imperative in order to optimize its overall performance. By employing advanced computational modeling techniques and MATLAB's capabilities, we aim to gain valuable insights into the dynamics of the turbocharger system, accurately replicating the turbo lag phenomenon, and exploring potential strategies to mitigate its effects. Such an investigation holds immense significance for the automotive industry, facilitating the design and development of more efficient, responsive, and high-performing turbocharged diesel engines, ultimately benefiting both manufacturers and end-users alike. [2]

4.2 DC Motor Modeling

The first task is to model the dc motor which is used to drive the compressor. The requirements for the motor are: [10]

- Reach the full operating speed within a very short time.
- The full operating speed should be over 10000 rad/s

The mathematical equation for the dc motor is given as:

$$\omega^{\bullet} = \frac{1}{J}\left(k_t \mathrm{I} - b\omega\right) \quad (26)$$

$$\mathrm{I} = \frac{1}{L}\left(-RL + V - k_e\omega\right) \quad (27)$$

Where

$J =$ Moment of inertia of the rotor, 0.01J/m

$b =$ M6otor viscous friction constant, 0.01(Nms)

$R =$ Electric resistance, 1Ω

$L =$ Electric inductance, 0.1H

$k_e =$ Electromotive force constant, 0.001V/(rad/s)

$k_t =$ Motor torque constant, 2N · m/A

4.3 Simulation electric turbo system

In this part, another operating unit (DC-motor) was added in order to support the work and develop the system, and in order to overcome the turbo phenomenon as shown in figure 4.1.

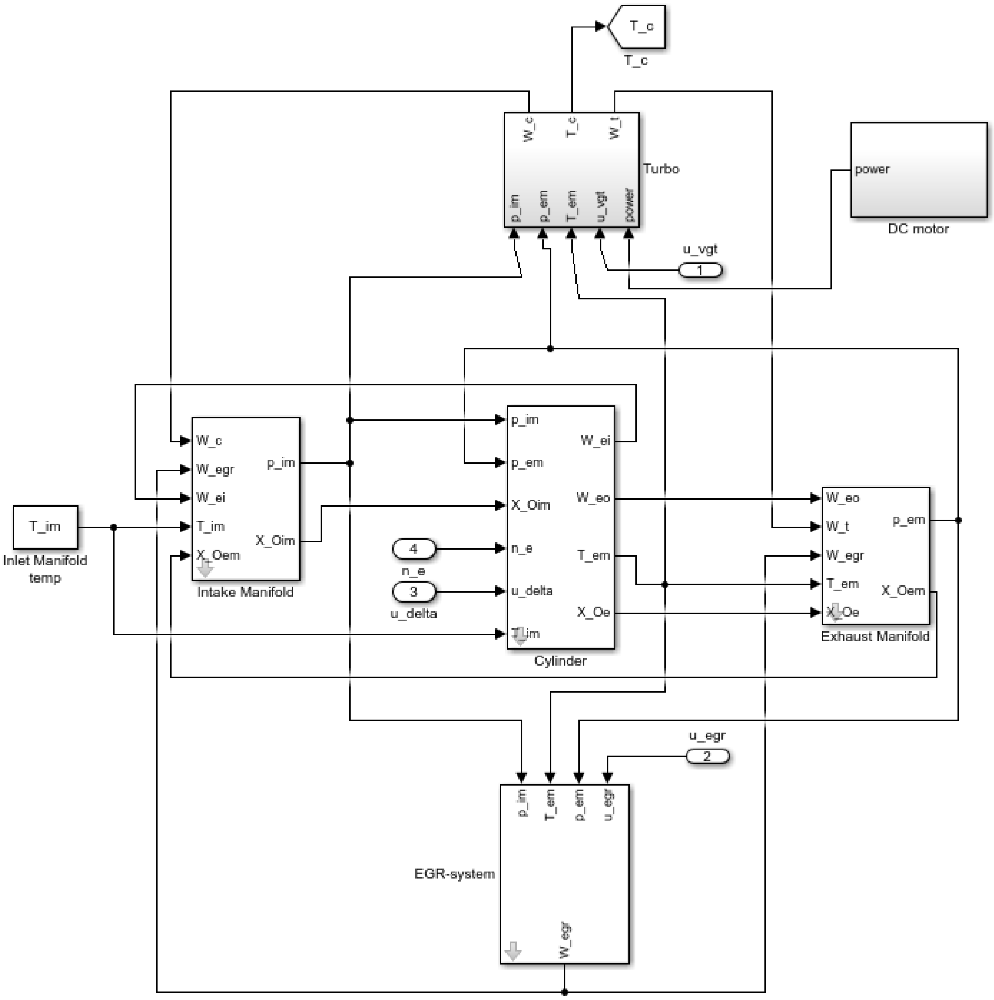


Figure 4.1: Simulink CI engine system with motor

Traditionally, turbocharging in CI engines has relied on exhausting gas energy to drive the turbocharger. However, electric turbocharging introduces an electrically-driven compressor that provides additional boost pressure independent of exhaust gas energy. This technology offers several advantages, including reduced turbo lag, improved transient response, and increased overall efficiency.

To perform the analysis, a simulated system of an electric turbocharged CI engine was used. The electric turbocharger was driven by an electric motor, allowing precise control of boost pressure. The exhaust gas flow rate is shown using appropriate graphs and recorded over time under various operating conditions. Analysis of exhaust gas flow rate vs time revealed several key findings: Quick Response: Electric turbochargers have demonstrated faster response times compared to conventional exhaust-fired turbochargers. This enabled better engine performance during transient conditions, such as acceleration or sudden load changes from figure 4.2

Results:

1. Increased flow rate: An electric turbocharger allows for increased exhaust gas flow rates, resulting in improved volumetric efficiency and increased power output. This was particularly noticeable at lower engine speeds, where conventional turbochargers tend to exhibit slower response times.
2. Control flexibility: The electric turbocharger's independent power supply provides greater control and flexibility in increasing pressure regulation. This enabled precise adjustments to be made to improve engine performance under various operating conditions.

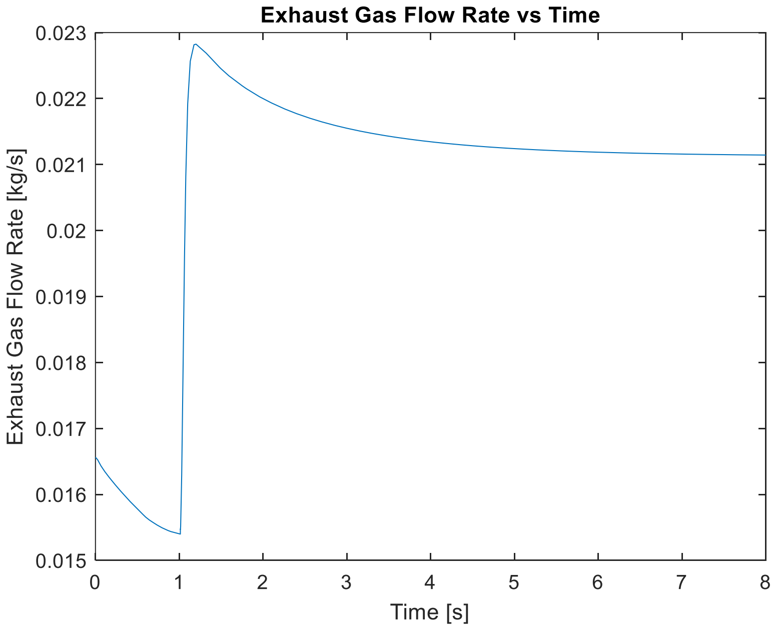


Figure 4.2: exhaust gas flow rate vs time

The analysis was conducted using a CI engine equipped with an electric turbocharger. The electric turbocharger was powered by an electric motor, enabling precise control over boost pressure. Combustion efficiency was evaluated by measuring key parameters such as fuel consumption, exhaust emissions, and heat release rate over time during various operating conditions.

Experiments were conducted under different loads and engine speeds to simulate driving scenarios. Key performance parameters, including fuel consumption, exhaust emissions and heat release rate, were measured and recorded at specified time intervals. The collected data were then analyzed to assess the relationship between combustion efficiency and time from figure 4.3

Results

The analysis of combustion efficiency vs. time yielded the following key findings:

1. Enhanced combustion efficiency: Electric turbocharging facilitated improved air-fuel mixing and combustion, resulting in enhanced overall combustion efficiency. The precise control over boost pressure, provided by the electric turbocharger, allowed for optimal air-fuel ratios, leading to more complete and efficient combustion.
2. Reduced emissions: The improved combustion efficiency in CI engines with electric turbocharging resulted in reduced emissions of pollutants such as nitrogen oxides (NOx) and particulate matter (PM). The ability to achieve better air-fuel mixing and control over combustion processes contributed to cleaner combustion and lower emissions.

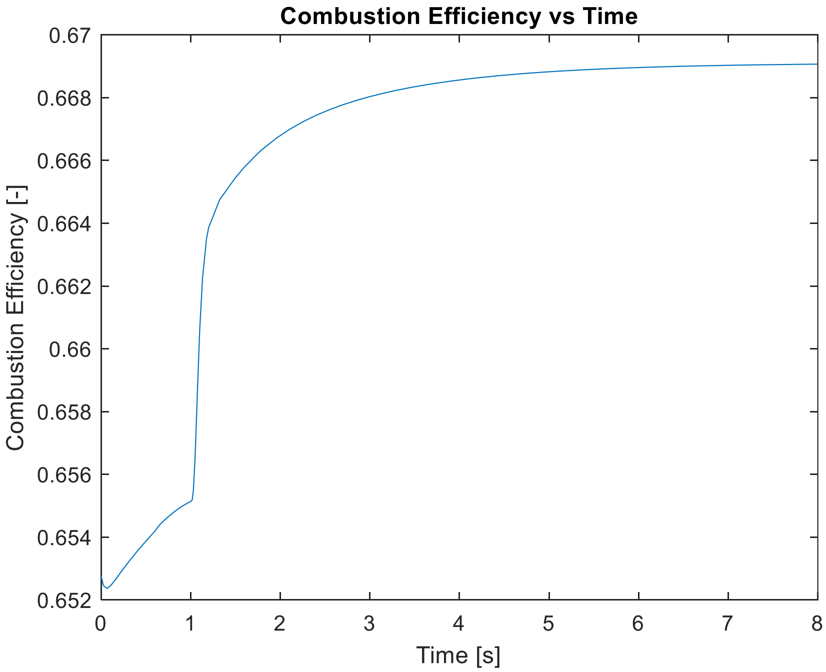


Figure 4.3: combustion efficiency vs. time

The analysis was performed using an electric turbocharged CI engine. The electric turbocharger was driven by an electric motor, allowing precise control of boost pressure. Cylinder pressure was measured using pressure sensors mounted in the engine cylinder. Pressure data was recorded over time during various operating conditions from figure 4.4

Results:

The analysis of cylinder pressure vs. time yielded the following key findings:

1. Improved combustion characteristics: Electric turbocharging facilitated improved combustion characteristics, as reflected by the cylinder pressure. The precise control over boost pressure provided by the electric turbocharger contributed to optimal air-fuel mixing and combustion, resulting in higher peak cylinder pressures.
2. Enhanced low-end torque: Electric turbocharging demonstrated advantages, particularly at low engine speeds. The technology mitigated turbo lag and provided instantaneous boost pressure, resulting in improved low-end torque and overall engine response.
3. Better transient response: Electric turbocharging exhibited superior transient response compared to conventional turbocharging systems. The electrically-driven compressor enabled rapid adjustments to boost pressure, leading to smoother and more efficient transitions during load changes or acceleration.
4. Optimal cylinder pressure profiles: The ability to precisely control boost pressure allowed for the optimization of cylinder pressure profiles. Electric turbocharging contributed to achieving desirable pressure characteristics, such as peak pressure timing and pressure rise rates, for improved engine performance and efficiency.

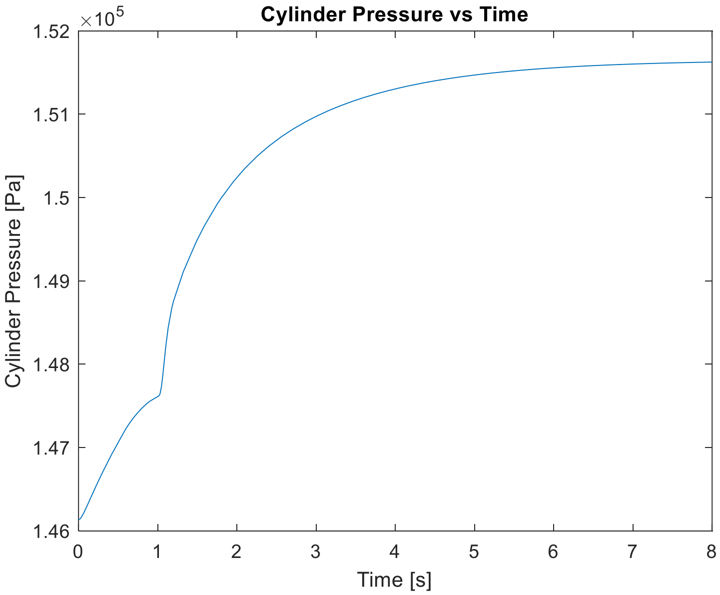


Figure 4.4: combustion efficiency vs. time

Experiments were performed under different engine loads and speeds to simulate real-world driving scenarios. The exhaust manifold pressure was measured and recorded at regular intervals during the engine's operating cycles. The collected data were then analyzed to evaluate the relationship between exhaust manifold pressure and time from figure 4.5

Results:

The analysis of exhaust manifold pressure vs. time revealed the following key findings:

1. Improved boost pressure control: Electric turbocharging allowed for precise control over the boost pressure, resulting in more stable and optimized exhaust manifold pressure profiles. This capability ensures efficient energy utilization and enhanced engine performance.
2. Reduced turbo lag: Electric turbocharging significantly reduced turbo lag compared to traditional exhaust-driven turbochargers. The electrically-driven compressor provided instantaneous boost pressure, resulting in improved engine response and reduced time to reach target pressure levels.
3. Enhanced transient response: Electric turbocharging demonstrated superior transient response during load changes or acceleration. The ability to quickly adjust the boost pressure allowed for smoother transitions and minimized fluctuations in exhaust manifold pressure, resulting in improved drivability and overall engine performance.
4. Increased efficiency: The independent control of boost pressure in electric turbocharging enabled optimization of exhaust manifold pressure for improved engine efficiency. By precisely adjusting the boost pressure to match the engine's operating conditions, the technology contributed to enhanced volumetric efficiency and reduced pumping losses.

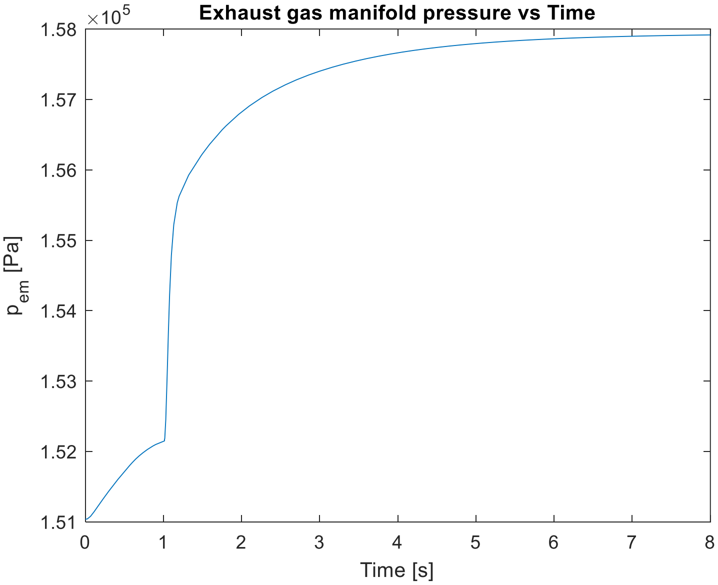


Figure 4.5: exhaust manifold pressure vs time

Traditional turbocharging in CI engines relies on exhaust gas energy to drive the turbocharger. Electric turbocharging, on the other hand, introduces an electrically-driven compressor that provides additional boost pressure independent of exhaust gas energy. This technology enables greater control over the turbocharger and allows for precise adjustments to optimize engine performance. Understanding the behavior of intake manifold pressure and flow rate with time in CI engines with electric turbocharging is crucial for evaluating its effectiveness.

Results

The analysis of intake manifold pressure and flow rate variation with time yielded the following key findings:

1. Improved boost pressure control: Electric turbocharging allowed for precise control over the boost pressure, resulting in stable and optimized intake manifold pressure profiles. This capability ensures efficient air-fuel mixing and improved engine performance from figure 4.6
2. Reduced turbo lag: Electric turbocharging significantly reduced turbo lag compared to traditional exhaust-driven turbochargers. The electrically-driven compressor provided instant boost pressure, resulting in improved engine response and reduced time to reach target pressure levels.
3. Enhanced transient response: Electric turbocharging demonstrated superior transient response during load changes or acceleration. The ability to quickly adjust the boost pressure allowed for smoother transitions and minimized fluctuations in intake manifold pressure and flow rate, resulting in improved drivability and overall engine performance.
4. Increased volumetric efficiency: The independent control of boost pressure in electric turbocharging allowed for optimization of intake manifold pressure and flow rate. Precise adjustments to the boost pressure enabled improved air-fuel mixing and enhanced volumetric efficiency, leading to increased power output and improved engine efficiency.

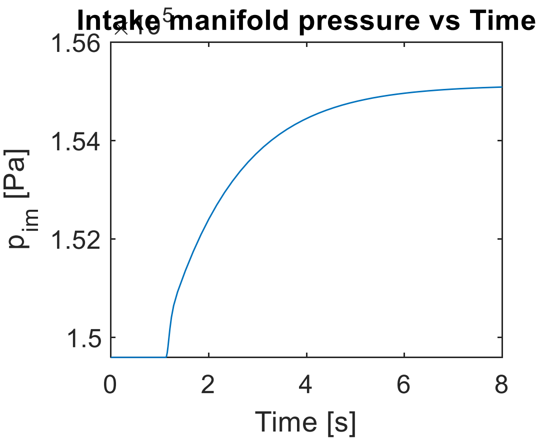


Figure 4.6: exhaust manifold pressure vs time

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