BACHELOR THESIS – ME141502

TURBOCHARGER CHARACTERISTICS ANALYSIS OF 93 kW MARINE DIESEL ENGINE

ARVIAN PRADANA
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DOUBLE DEGREE PROGRAM
MARINE ENGINEERING DEPARTMENT
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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ANALISA KARAKTERISTIK TURBOCHARGER PADA MESIN MARINE DIESEL 93 kW

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INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA 2016

APPROVAL FORM

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Bachelor Thesis
Submitted to Comply the Requirements to Obtain a Bachelor Engineering Degree
on
Laboratory of Marine Power Plant (MPP)
Bachelor Degree Program Department of Marine Engineering
Faculty of Marine Technology
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ABSTRACT

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Along with the developments of the maritime world, ship demand with the appropriate performance increase. At this time the ship with the size of 30 GT being crowded discussed. The way to improved it performance can be done from various aspects, one of it is by installed a turbocharger. The first step taken was to collect data specifications of the marine diesel engine. Performance predictions obtained by modeling the engine in simuation software. Simulation covers the entire engine from the dimensions, air flow in-out, fuel injection systems, etc. Engine performance predictions is done by installation of three turbocharger with different specifications. The simulation process was made into several cases based on the engine rotation 800, 1000, 1200, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2200 RPM. Simulation by software is made to obtained the characteristics of engine performance such as torque, power, fuel consumption, pressure, etc. Turbochargers used in the simulation are GT2052-3, GT2052-1, and GT1241. Highest brake power generated by the engine installed with GT2052-3 turbocharger is 129.824 HP with 61.4% compressor efficiency. Brake power engine installed with GT2052-1 turbocharger generated power for 125.549 HP with 73.9% compressor efficiency. Brake power engine installed with GT1241 generated power for 71.172 HP with 47.4% compressor efficiency.

Key Word *:Marine Diesel Engine, Performance, Matching, Turbocharger, Simulation, Modeling*

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ABSTRAK

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Seiring dengan perkembangan didunia maritim, permintaan akan kebutuhan kapal dengan performa yang sesuai semakin meningkat. Pada saat ini kapal dengan ukuran 30 tonasse sedang ramai dibahas. Peningkatan performa dapat dilakukan dari berbagai aspek, salah satunya dengan menggunakan *turbocharger*. Langkah pertama yang dilakukan adalah mengumpulkan spesifikasi data dari *marine diesel engine* tersebut. Prediksi performa mesin dilakukan dengan pemodelan rancangan mesin yang berbasis simulasi. Simulasi mencakup seluruh bagian mesin mulai dari dimensi, aliran udara masuk-keluar, bahan bakar, sistem injeksi, dsb. Prediksi performa mesin dilakukan dengan menggunakan tiga *turbocharger* dengan spesifikasi berbeda. Dalam menjalankan simulasi dibuat beberapa kasus berdasarkan putaran mesin 800 hingga 2200 RPM. Simulasi dengan *software* dilakukan untuk menghasilkan karakteristik dari performa mesin seperti torsi, daya, konsumsi bahan bakar, tekanan, dsb. *Turbocharger* yang digunakan pada simulasi yaitu GT2052-3, GT2052-1, dan GT1241. Brake power tertinggi dihasilkan oleh mesin dengan penggunaan turbocharger GT2052-3 menghasilkan daya sebesar 129.824 HP dengan efisiensi kompresor 61.4%. Brake power pada penggunaan turbocharger GT2052-1 menghasilkan daya sebesar 125.549 HP dengan efisiensi kompresor 73.9%. Brake power pada penggunaan GT1241 menghasilkan daya 71.172 HP dengan efisiensi kompresor 47.4%.

Kata Kunci *: Marine Diesel Engine, Performance, Matching, Turbocharger, Simulation, Modeling*

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PREFACE

Praise and great gratitude submitted to Almighty God, Allah SWT who always gives her gracious mercy and tremendous blessing that has helped the writer finishing this Bachelor Thesis entitled: ***Turbocharger Characteristics Analysis of 93 kW Marine Diesel Engine***. This thesis is as a requirement in accomplishing the S-1 Degree at the Department of Marine Engineering, Faculty of Marine Technology in Institut Teknologi Sepuluh Nopember.

The writer would like to thank to all of those who have given the contribution so that this Bachelor Thesis can be finished. The writer would like to express his sincere gratitude and respect, appreciation, thankfulness, and gratefulness to:

1. The greatest thanks and appreciation dedicated to Mr. Ary Prasetyo and Mrs. Evi Suviati, the writer’s beloved parents. They always give the writer pray, encourage, love, spirit, motivation and patience to the writer during finishing this Bachelor Thesis and waiting for the writer’s graduation. Thank you so much for everything.
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Hopefully, this Bachelor Thesis would give a positive contribution to the educational development or those who want to carry out further research

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CHAPTER I
INTRODUCTION

1.1 Background

Indonesia is the world’s largest archipelago country with more than 17,000 islands. This is one of a potential source of enormous latent power to be developed. Maritime and fisheries sector is very necessary role to increase the economic growth which aims to improve the welfare of people, including fisherman and their families. The country has a vast 5.8 million km^2 Exclusive Economic Zone, as well as 81,000 km of maritime borders. The sea therefore holds considerable potential, on which a large part of the population depends. There are currently some 6 million Indonesian fishermen and fish farmers and 15 to 20% of the country’s population rely on the fisheries sector for their livelihood.

At this time, there are a lot of fishing vessels are currently under development in Indonesia. One of them which is under development are fishing vessels with a size of 30 Gross Tonnage. Development is carried out for fishing vessel is divided into a several aspects, the development of the vessel include; design, economical, and performance. In terms of performance improvement on a fishing vessel can be performed at the engine sector. Such improvements can be done by installation of turbocharger to the engine of the vessel. This improvement aim to increase the engine performance by maximized the power output and efficiency of the engine it self.

In order to increasing engine performance by using a turbocharger, required the right turbocharger according to the engine specification. Ussualy specification of turbocharger to be equip has been provided by engine builder in cooperation with engine turbomanufacturer. Turbocharger can also be selected with lower economic value. The matching process of turbochargers using the calculation process of related aspects, so the maximum performance and efficiency can be obtained. Therefore, a study of the performance improvement needs to be done for the further result.

1.2 Problem Formulation and Scope

Based on the description above, there is a few of problem formulation can be given:

1. How to select a turbocharger for marine diesel engine with 93 kW of power output?
2. How to match the engine with a turbocharger?

Scope of Problem

1. The simulation using simulation modeling software
2. Simulation The experiment will be done to compare the efficiency and performance of the engine which had been installed by turbocharger with a different specification

1.3 Research Objectives

This bachelor thesis have purposes to:

1. Knowing the right step to select turbocharger based on marine diesel engine specification basic performance
2. Simulation only used to find the performance of basic engine and engine installed by turbocharger
3. Knowing the selected turbocharger which had been installed is already match with the engine or not

1.4 Research Benefit

Benefit to be gained in tis bachelor thesis are:

1. Recommendation for user of application turbocharger in marine diesel engine to improve engine performance
2. Consideration of choosing turbocharger with best efficiency according to marine diesel engine basic specification and performance

CHAPTER II
LITERATURE STUDY

Combustion engine sources of power comes from mixture of air and fuel inside the combustion chamber. The result of the combustion process will produce heat, so that the air in the combustion chamber will expanded. Because the combustion occurred in isolated and narrow space, and also bordered by static objects like cylinder wall. This causes the piston pushed due to the gas expands as the combustion chamber insulated by the cylinder wall. Up and down movement of the piston raises the energy of mechanical work. Diesel engine is the one example of internal combustion engine, where fuel could be ignite due to the high temperature of gas which compressed, different with otto engine which use spark plugs as energy to start the ignition process of fuel. Diesel engine was found in 1892 by Rudolf Diesel.

Diesel engine characteristic that differentiates it from other combustion engine is the way of ignition process of fuel. In the diesel engine fuel is injected into the cylinder which contain a high-pressure air through the the injector. Compressed air in the cylinder resulted in increased air temperature (Peter Taylor: 1990). So when the fuel in form of a fine mist injected into the combustion chamber, it will burn without any ignition tools.

2.1 Turbocharger History

Forced induction dates from the late 19th century, when Gottlieb Daimler patented the technique of using a gear-driven pump to force air into an internal combustion engine in 1885. The turbocharger was invented by Swiss engineer Alfred Büchi (1879-1959), the head of Diesel engine research at Gebrüder Sulzer (now called Sulzer), engine manufacturing company in Winterthur, who received a patent in 1905 for using a compressor driven by exhaust gases to force air into an internal combustion engine to increase power output, but it took another 20 years for the idea to come to fruition. During World War I French engineer Auguste Rateau fitted turbochargers to Renault engines powering various French fighters with some success.

The first mass-produced turbochargers came out of the General Electric factory in the early 1900s. Interested in the possibility of aviation usage, the company's head engineer, Sanford Moss, conducted tests to produce and maintain boost pressure at the altitude of over 14,000 feet at the top of Pike's Peak in Colorado. His experiments paved the way for the usage of turbochargers in airplane engines. In 1920 the first turbocharged plane was tested. A LaPere bi-plane, fitted with a 12-cylinder Liberty engine managed to get up to 33,000 feet without any loss of boost. The tests were repeated over the next year with the highest recorded altitude of 40,000 feet. Turbocharging was about to take over the aviation industry. By the mid 1920s turbocharged diesel engines also started appearing on ships and locomotives. The turbo design and manufacturing technology advanced rapidly during the second World War. Numerous fighter and bomber planes were fitted with turbochargers to make them faster and more efficient.

One of the biggest names in the turbo world – the Garrett Corporation was formed in 1936 by J. C. "Cliff" Garrett. Teir first product was a charged air cooler for the B-17 bomber. Garrett's main products at that time were small gas turbine engines, it wasn't until 1954 that Cliff Garrett decided to split the growing turbocharger division from the gas turbine division. The newly formed turbocharger group would later be name Garrett Automotive.

By the time the first oil crisis came in 1973 however, the automotive turbocharging technology has evolved enough to make inroads within the commercial diesel market. As the emission standards became more stringent, turbocharging grew in popularity, becoming a virtual standard in the transport industry by the late 1980s. 1970s also mark the entry of turbochargers into motorsport, most notably into Formula 1. As with most automotive inventions, motorsport popularized turbocharging to the point where it became a familiar term to the general public.

2.2 Turbocharger Working Principle

A turbocharger is basically an air pump. Hot exhaust gases leaving the engine after combustion are routed directly to the turbine wheel side of the turbocharger to make it rotate. That turbine wheel is connected by a shaft to a compressor wheel. As the turbine wheel spins faster and faster, it causes the compressor wheel to also spin quickly. The rotation of the compressor wheel pulls in ambient air and compresses it before pumping it into the engine's chambers.

As it guessed, the compressed air leaving the compressor wheel housing is very hot as a result of both compression and friction. So what's needed is a way to cool that air down before it enters the chambers. That's where a charge-air cooler (or "heat exchanger") comes in. It reduces the temperature of the compressed air so that it is denser when it enters the chamber (heat causes things to expand, as we all learned in science class). The charge-air cooler also helps to keep the temperature down in the combustion chamber. All together, the engine, turbocharger and charge-air cooler form what is known as a "charge-air system".

Air is the major factor as well as supporting factor of combustion process. Initially air enters through the compressor, the impeller blades will continue the air flow at high speed towards the diffuser, via intercooler. After being discharged from intercooler the air will be compressed so the pressure will increase. The compressed air entered the combustion chamber and the combustion process occurs. The power used to turn the compressor must be equal to the power supplied by the turbine. The power required to rotate the compressor by turbine, is defined as:

$$P = m \cdot \Delta h$$
$$P = m \cdot Cp. \Delta T$$
$$P = m \cdot u \cdot va(\tan \sigma_1 - \tan \sigma_2)$$

m is the mass density of air (kg/m3), u is the specific heat of air (J/kg-K), va is the speed of air flow mass, and tan σ1 is the angle of air flow (Hamid Keshaverzi: 2005). From the formula above shows the relationship that the pressure drop depends on the mass flow of air to the turbine. As for the compressor, power input depends in the amount of pressure and air temperature.

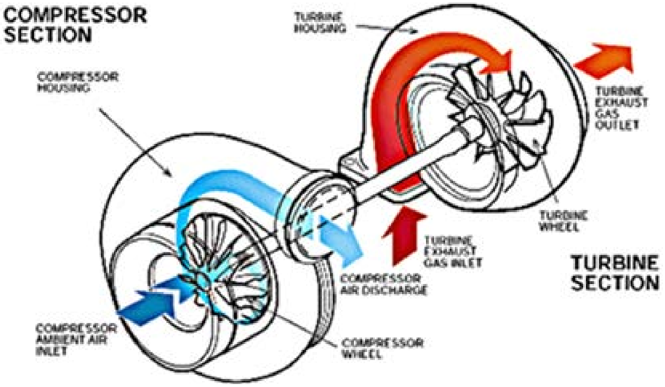


Figure 2.1 Turbocharger Components

Some systems also include a tip turbine fan which draws air across the charge-air cooler to further reduce the temperature of the compressed air generated by the turbocharger.

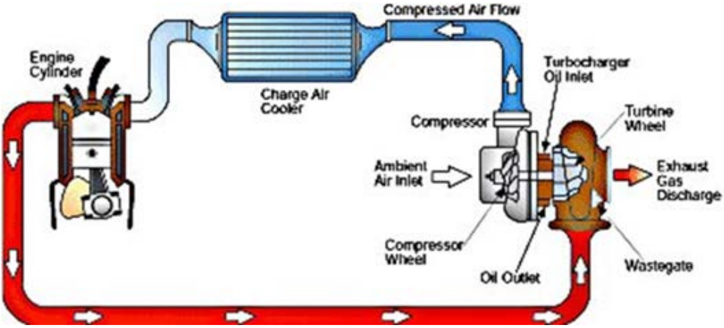


Figure 2.2 Turbocharger Flow System

The basic principal behind turbocharging is fairly simple, but a turbocharger is a very complex piece of machinery. Not only must the components within the turbocharger itself be precisely coordinated, but the turbocharger and the engine it services must also be exactly matched. If they're not, engine inefficiency and even damage can be the results. That's why it's important to follow correct installation, operating and preventative maintenance procedures.

2.3 Exhaust Gas Operation Method

In general, the manner in which the energy of exhaust gases is utilized to drive the turbocharger may be ascribed to:

2.3.1 Constant-Pressure

In constant pressure type turbocharger, the exhaust gases gets collected in a single exhaust gas reservoir, where the pressure is maintained constant so as to avoid any fluctuation in the exhaust gas energy pressure. The exhaust gas is introduced to the turbine side after maintaining the pressure inside the cylinder. Exhaust gas with constant pressure type allows for the concetration of all cylinder gas output, so as the result of such things make air mass flow fluctutations, low pressure in the manifold and relatively constant (Turbo Magazine I: 1993).

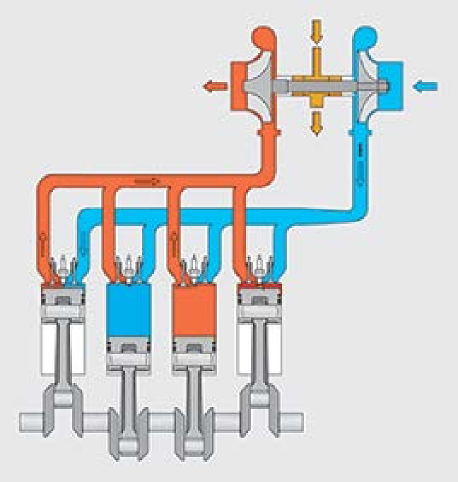


Figure 2.3 Constant Pressure Exhaust Gas

2.3.2 Pulse System

In pulse type turbocharger, the exhaust gas directly enters the turbine side and drives the turbine with the exhaust gas energy. The connection from the exhaust side of an engine is directly connected to the turbine side of a turbo charger. The pipe connections from the exhaust gas towards the turbine side are generally small in length and exhaust grouping is provided to prevent the blowback of gases from one cylinder to another.

Pulse system allows the size of the exhaust pipe that is relatively smaller, 1 to 3 of cylinder space accommodated by exhaust pipes which directly connected to the turbine, so that what makes the pulse system type has a smaller size of exhaust gas pipe.

The pressure that occurs in the manifold tends low, but this this is the one of advantages of this system related to the scavenging process. When the first cylinder in open condition, the exhaust gas pressure in the exhaust pipe will increase, and when the pressure value is greater than the air pressure into the engine can result in improved of turbine performance (Turbo Magazine: 1993)

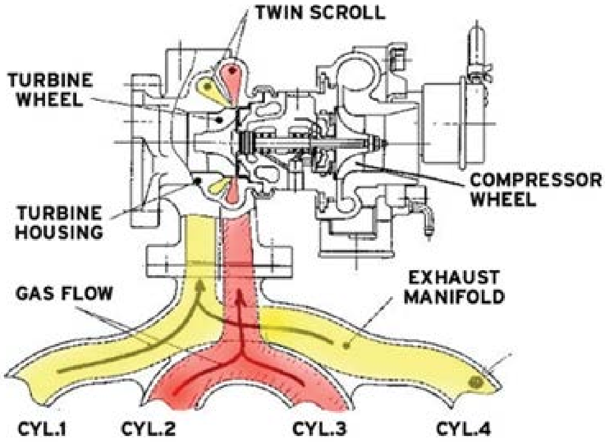


Figure 2.4 Pulse System Exhaust Gas

2.4 Turbocharger Effciency

The compression process in the compressor is a polytropic process with increasing entropy due to friction and losses in the compressor. Figure 2.5 shows the compression process of the intake air from the state 1 at the compressor inlet (p1, T1) to state 2 at the compressor outlet (p2, T2). The compressor efficiency ηC is defined as the ratio of the isentropic total enthalpy change from 1t to 2st to the polytropic total enthalpy change from 1t to 2t. In other words, the compressor needs more energy in the polytropic process (real process) than the possibly minimal required energy of the compressor stage in the isentropic process (ideal process). (Baines, Japikse, et al: 2005-1988-1994)

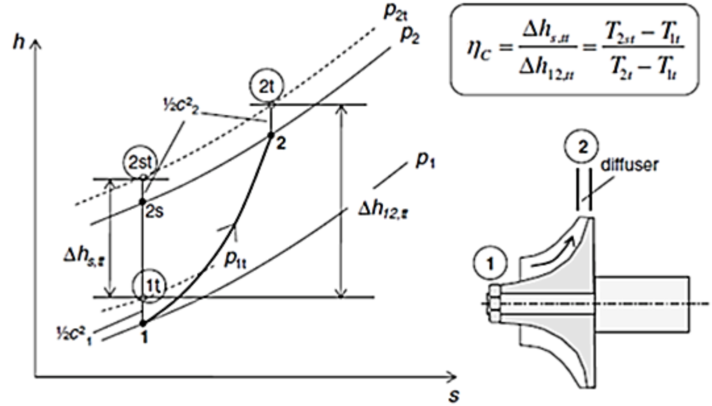


Figure 2.5 Compression process in the compressor stage in h-s diagram

The total–total isentropic efficiency of the compressor stage (further called compressor) consisting of the compressor wheel and diffuser is defined as:

$$\eta_C = \frac{\Delta h_{s,tt}}{\Delta h_{12,tt}} = \frac{T_{2st} - T_{1t}}{T_{2t} - T_{1t}} \dots (1)$$

The total–total isentropic efficiency is generally used in the compressor since the kinetic energy of gas in the state 2 could be transformed into the pressure energy in the diffuser. The process increases the charge-air pressure. Using thermodynamic equations for the isentropic process, the compressor efficiency is written in terms of the total pressures and temperatures at the inlet and outlet of the compressor, and the isentropic exponent of the charge air κa ≈ 1.4.

$$\eta_C = \frac{\left(\frac{p_{2t}}{p_{1t}}\right)^{\left(\frac{\kappa-1}{\kappa}\right)_a} - 1}{\left(\frac{T_{2t}}{T_{1t}}\right) - 1} \ldots (2)$$

The compressor efficiency is determined by measuring the total pressures and temperatures at the inlet and outlet of the compressor according to Eq. (2). The maximum total–total isentropic efficiency of the compressor η_C is normally between 70 and 80 % at the design point in the compressor performance map. Analogous to the compressor, the efficiency of turbine results from the polytropic expansion process of the exhaust gas from the state 3 at the turbine inlet (p3, T3) to state 4 at the turbine outlet (p4, T4), see Fig.2.6 The turbine efficiency η_T is defined as the ratio of the polytropic total enthalpy change from 3t to 4t to the isentropic total enthalpy change from 3t to 4s. Physically speaking, the turbine delivers less output energy due to friction and losses in the polytropic expansion process than the possibly maximum energy given in the isentropic process.

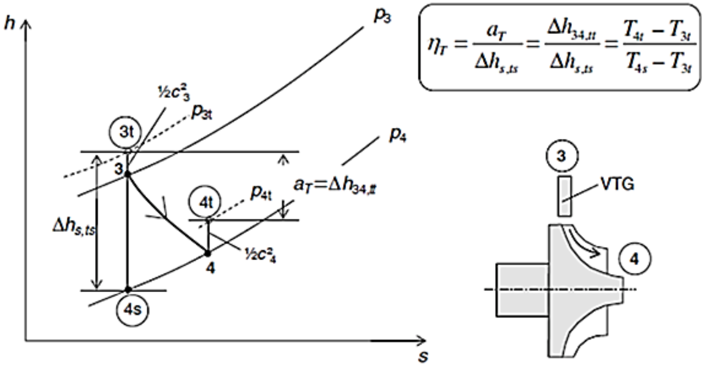


Figure 2.6 Expansion process in the turbine stage in h-s diagram

The total-static isentropic efficiency of the turbine stage (further called turbine) consisting of the turbine wheel and variable turbine geometry (VTG) or waste gate (WG). (Aungier and Cumpsty: 2006-2004)

$$\eta_T = \frac{\Delta h_{34,tt}}{\Delta h_{s,ts}} = \frac{T_{4t} - T_{3t}}{T_{4s} - T_{3t}} \ldots (3)$$

The total-static isentropic efficiency is normally used in the turbine since the kinetic energy of the exhaust gas in the state 4 does not generate any additional power for the turbine. Applying thermodynamic equations to the isentropic process, the turbine efficiency is expressed in terms of the total pressure and temperature at the turbine inlet and outlet and the isentropic exponent of the exhaust gas κg ≈ 1.32.

$$\eta_T = \frac{1 - \left(\frac{T_{4t}}{T_{3t}}\right)}{1 - \left(\frac{p_{4s}}{p_{3t}}\right)^{\left(\frac{\kappa-1}{\kappa}\right)_g}} \ldots (4)$$

The turbine efficiency is determined by measuring the total pressure and temperature at the turbine inlet and outlet according to Eq. (4). The maximum total-static isentropic efficiency of the turbine ηT is normally between 65 and 70 % at the design point of the turbine performance map. (Japikse, and Whitfield: 1990-2003)

2.5 Compressor

2.5.1 Design and Function

Turbocharger compressors are generally centrifugal compressors consisting of three essential components: compressor wheel (inducer dan impeller), rotor, compressor shaft, diffuser, silencer – filter, air intake casing, and housing. With the rotational speed of the wheel, air is drawn in axially, accelerated to high velocity and then expelled in a radial direction (Hamid Keshaverzi: 2005)

The diffuser slows down the high-velocity air, largely without losses, so that both pressure and temperature rise. The diffuser is formed by the compressor backplate and a part of the volute housing, which in its turn collects the air and slows it down further before it reaches the compressor exit.

2.5.2 Operating Characteristics

The compressor operating behaviour is generally defined by maps showing the relationship between pressure ratio and volume or mass flow rate. The useable section of the map relating to centrifugal compressors is limited by the surge and choke lines and the maximum permissible compressor speed.

2.5.3 Surge Line

The map width is limited on the left by the surge line. This is basically "stalling" of the air flow at the compressor inlet. With too small a volume flow and too high a pressure ratio, the flow can no longer adhere to the suction side of the blades, with the result that the discharge process is interrupted. The air flow through the compressor is reversed until a stable pressure ratio with positive volume flow rate is reached, the pressure builds up again and the cycle repeats. This flow instability continues at a fixed frequency and the resultant noise is known as "surging".

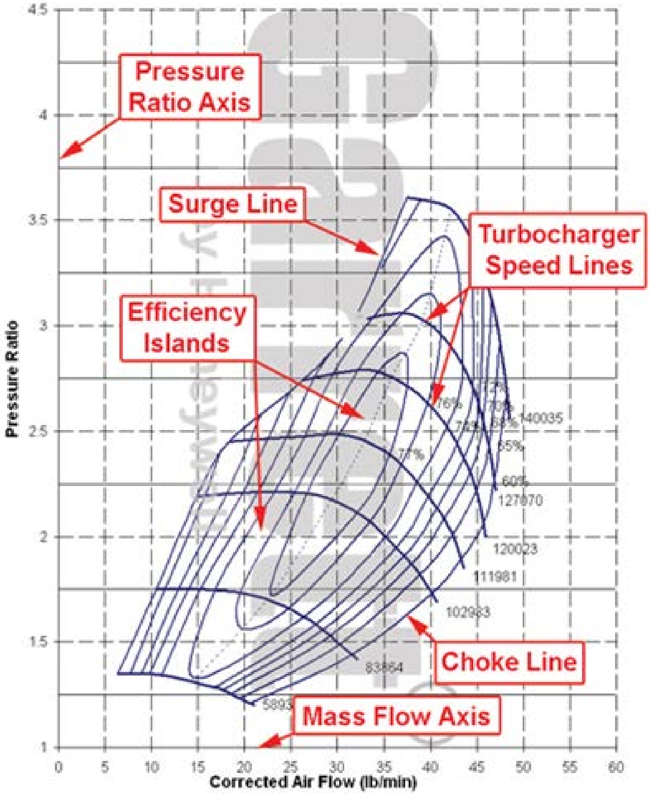


Figure 2.7 Compressor Map Line Definition
Source: www.turbobygarrett.com/turbobygarrett/compressor_maps

2.5.4 Choke Line

The maximum centrifugal compressor volume flow rate is normally limited by the cross-section at the compressor inlet. When the flow at the wheel inlet reaches sonic velocity, no further flow rate increase is possible. The choke line can be recognised by the steeply descending speed lines at the right on the compressor map.

2.6 Turbine

2.6.1 Design and Fuction

The turbocharger turbine, which consists of a turbine wheel and a turbine housing, converts the engine exhaust gas into mechanical energy to drive the compressor. The gas, which is restricted by the turbine's flow cross-sectional area, results in a pressure and temperature drop between the inlet and outlet. This pressure drop is converted by the turbine into kinetic energy to drive the turbine wheel.

There are two main turbine types: axial and radial flow. In the axial-flow type, flow through the wheel is only in the axial direction. In radial-flow turbines, gas inflow is centripetal, i.e. in a radial direction from the outside in, and gas outflow in an axial direction.

Up to a wheel diameter of about 160 mm, only radial-flow turbines are used. This corresponds to an engine power of approximately 1000 kW per turbocharger. From 300 mm onwards, only axial-flow turbines are used. Between these two values, both variants are possible.

As the radial-flow turbine is the most popular type for automotive applications, the following description is limited to the design and function of this turbine type. In the volute of such radial or centripetal turbines, exhaust gas pressure is converted into kinetic energy and the exhaust gas at the wheel circumference is directed at constant velocity to the turbine wheel. Energy transfer from kinetic energy into shaft power takes place in the turbine wheel, which is designed so that nearly all the kinetic energy is converted by the time the gas reaches the wheel outlet.

2.6.2 Operating Characteristic

The turbine performance increases as the pressure drop between the inlet and outlet increases, i.e. when more exhaust gas is dammed upstream of the turbine as a result of a higher engine speed, or in the case of an exhaust gas temperature rise due to higher exhaust gas energy.

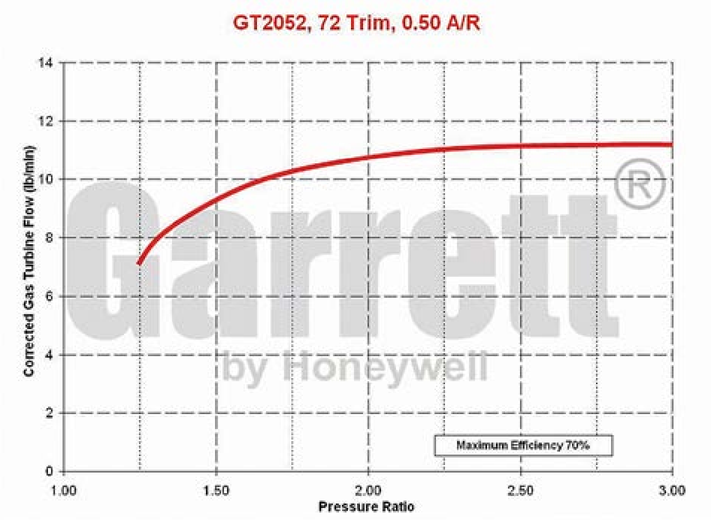


Figure 2.8 Turbine Map Example by Garrett

Source: www.turbobygarrett.com/turbobygarrett

The turbine's characteristic behaviour is determined by the specific flow cross-section, the throat cross-section, in the transition area of the inlet channel to the volute. By reducing this throat cross-section, more exhaust gas is dammed upstream of the turbine and the turbine performance increases as a result of the higher pressure ratio. A smaller flow cross-section therefore results in higher boost pressures.

The turbine's flow cross-sectional area can be easily varied by changing the turbine housing.

Besides the turbine housing flow cross-sectional area, the exit area at the wheel inlet also influences the turbine's mass flow capacity. The machining of a turbine wheel cast contour allows the cross-sectional area and, therefore, the boost pressure, to be adjusted. A contour enlargement results in a larger flow cross-sectional area of the turbine.

Turbines with variable turbine geometry change the flow cross-section between volute channel and wheel inlet. The exit area to the turbine wheel is changed by variable guide vanes or a variable sliding ring covering a part of the cross-section.

In practice, the operating characteristics of exhaust gas turbocharger turbines are described by maps showing the flow parameters plotted against the turbine pressure ratio. The turbine map shows the mass flow curves and the turbine efficiency for various speeds. To simplify the map, the mass flow curves, as well as the efficiency, can be shown by a mean curve.

For a high overall turbocharger efficiency, the co-ordination of compressor and turbine wheel diameters is of vital importance. The position of the operating point on the compressor map determines the turbocharger speed. The turbine wheel diameter has to be such that the turbine efficiency is maximised in this operating range.

2.7 State of the Art

The performance of turbochargers can be defined by the pressure ratio, mass flow rate and efficiency characteristics of the compressor and turbine, plus the mechanical efficiency of the bearing unit. (Vauxhaull: 2011)

One of the first studies of this phenomenon is Rautenberg's et al. in 1983. These authors emphasise the heat transfer influence on the turbine power and on the compressor outlet temperature. The increase of this temperature leads to a density decrease, which isn't favourable to the engine volumetric efficiency. The usual isentropic efficiency is wrongly used. It doesn't define the aerodynamical quality of the compression, because it considers the heat transfers between the turbine, the compressor and the surrounding area. Thanks to experimental tests, the authors note a strong dependence between turbine inlet temperature and compressor outlet temperature. The geometrical turbocharger characteristics, mainly the distance between compressor and turbine, appear to influence greatly the heat fluxes.

More recently, in 2002, Jung et al. suggest a parameterisation of turbine maps to obtain the behaviour of the turbine in its actual environment. They study heat losses considering the turbine as an exchanger which efficiency is derived from the manufacturers map. Aerodynamic and heat efficiencies are then added to obtain the global efficiency.

In 2003, Bohn et al. present a computational and experimental study of the internal turbocharger heat transfers. A three-dimensional calculation is performed on the center housing, the compressor and the turbine. The boundary conditions were derived from experimental test data. The temperature surface of the casing is measured with thermography- camera and resistance thermometers. This includes the aerothermal boundary conditions for the fluid at the inlet and outlet of the compressor and turbine. For the compressor, the transfer direction seems to change along the flow mean line. This transfer occurs from the flow to the wall for the first impeller part, and then reverses for the second part. This reversing limit is dependant on the compressor flow. From numerical simulation, the authors propose a heat transfer correlation based on inlet compressor and turbine temperature, on compressor flow and on geometrical and material characteristics of the turbocharger. The rotation speed doesn’t figure in this correlation. The compression process proposed by the authors is represented in Figure 9. The diabatic compression can be represented by a first heat transfer before the compression, then an adiabatic compression and a second heat transfer after the compression.

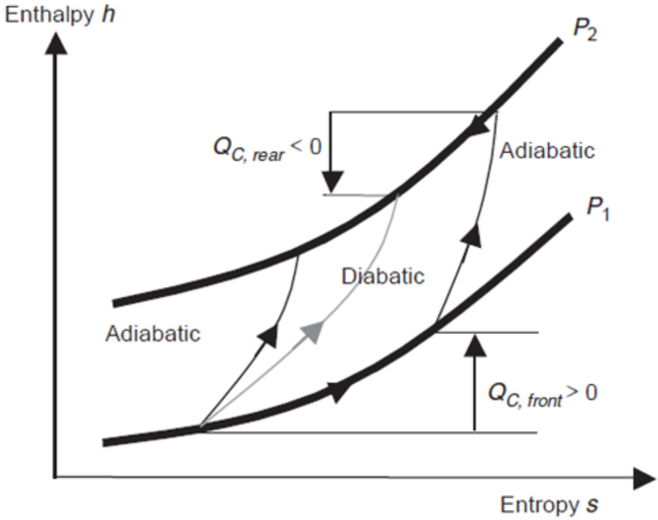


Figure 2.9 Compression Process Model

For slightly different turbomachinery, Riegler suggests an alternative technique to consider heat transfer in gas turbine performance calculations based on lumped capacitance method. The main idea is to consider only heat transfer effects on the working fluid properties changes. The heat transfers are calculated thanks to correlations which express the dependency on the most relevant parameters describing the influence of fluid flows, and in addition on time in transient operation. With this method, the calculations for the temperatures of the structures are not necessary. Another available study is Guzovic's et al. They propose different Nusselt correlation for flow/wall heat transfer in turbomachinery.

Even so this different studies are few, they all advance that the heat transfers cannot be neglected, more so between the compressor and the turbine. The heat transfers must be considered to simulate correctly a turbocharger.

CHAPTER III
METHODOLOGY

3.1 General

The methodology is a description of the steps carried out in a study. Methodology in this thesis include all activities carried out to solve a problem or process of analysis and evaluation of the problems this thesis.

3.2 Bachelor Thesis Methodology

In order to find the parameters of turbocharger output from the system, the data will be collected from many research related to the topic of this thesis. The methodology used in this thesis can be described as follows:

3.2.1 Indentification and Problem Formulation of the Problem

This thesis begins with indentif and formulating the problems regarding to the experiment to be carried as well limitation issue. It aims to simplify the problem, make it compact and easier in the final project.

3.2.2 Literature Study

Literature study conducted with collecting references to the turbocharger, the characteristics of turbocharger, and engine performance. The goal is to strengthen the basic theory problems as in the analysis. Literature used can be collected from websites, books, journals, papers, final project, and other related sources.

3.2.3 Data Collection

The data used in this bachelor thesis is the data of Marine Diesel Engine designed by Juniono Raharjo, student’s of Marine Engineering Department – ITS Surabaya. Data for this analysis will be collected from engine specification and turbocharger specification. The required data is as follows:

- Engine Specification
    - No. of Cylinder
    - Displacement
    - Bore
    - Stroke
    - Inlet Valve
    - Outlet Valve
    - Compression Ratio

- Turbocharger Specification
    - Brand
    - Model
    - Compressor
    - Turbine
    - Cooling
    - Dimension

- Engine Piping Installation System
    - Flow
    - Dimension (length, angel, diameter)
    - Material

3.2.4 Engine Modeling Using Engine Simulation Software

Analysis the characteristic of turbocharger based on engine performance parameter is done by using engine simulation software. The data collected will be used for making engine simulation. The simulation compared between three different turbocharger with the same engine specification. Result of the engine performance will be compared to analyze the characteristics every different turbocharger specification.

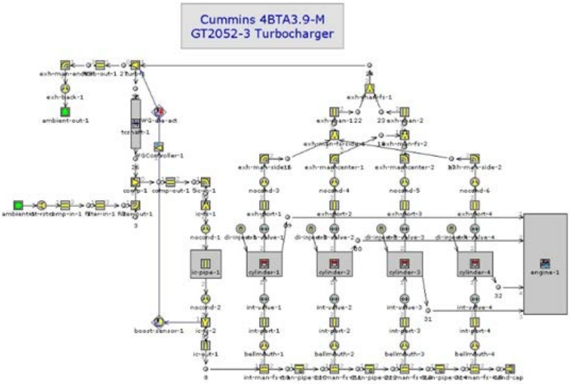


Figure 3.1 Engine Modeling Using Software

3.2.5 Engine Performance Data Output Validation

At this stage, the output data from simulation process not exactly resulted the correct data of engine performance. The output data obtained as a result from engine simulation might be had some of error. So we have to repeat the step of the simulation stage to find failures and corrected the input data. If the data has been obtained correctly, then we can go to the next step.

3.3 Conclusions and Recommendations

Conclusions are expected in this thesis is able to answer the problem. This thesis aims to know the main characteristics of turbocharger system. Written advice based on data from the discussion well as the fact that there is, and given to the improvement of this bachelor thesis in order to become better.

3.4 Flowchart Thesis

The methodology is a description of the steps carried out in a study. Methodology in this thesis include all of activities carried out to solve the problem or process of analysis and also to evaluate thesis problems. Methodology of this thesis can be viewed trough flowcharts final project below.

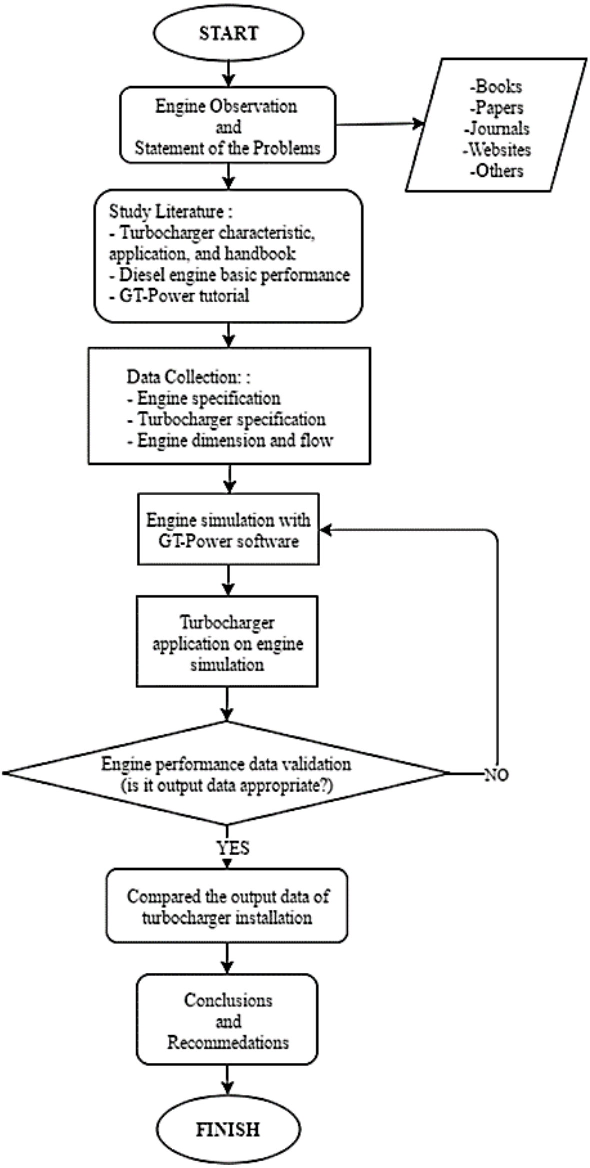


Figure 3.2 Research Methodology Flowchart

CHAPTER IV
DISCUSSION AND RESULTS

4.1 Engine Specification Data Used

Simulation done by marine diesel engine which has been design in previous study. The following is a specification of the engine data used in the simulation.

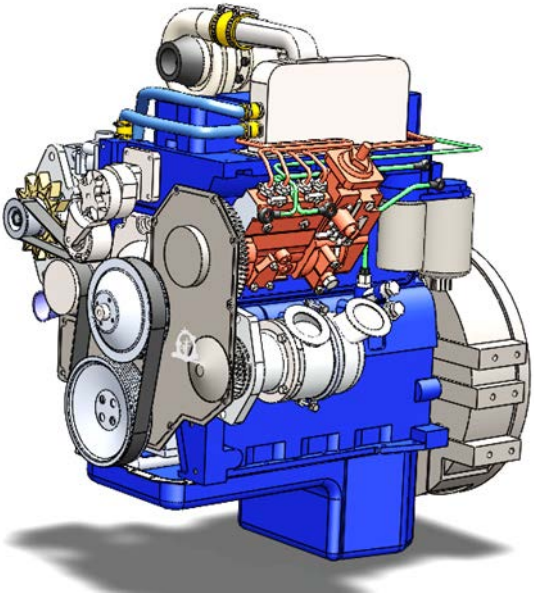


Figure 4.1 4-Stroke Diesel Engine Designed by Rahrjo (2015)

Table 4.1 Engine Specification Data

Engine Type	Diesel Engine
Stroke Type	4-stroke
Number of Cylinder	4
Displacement	3.9 Litre
Bore	102 mm
Stroke	120mm

Inlet Valve	45 mm (clearance= 0.25)
Outlet Valve	43 mm (clearance= 0.51)
Compression Ratio	16.5
Firing Order	1-3-4-2

From the simulation process, simulator generates a multiple output file containing simulation results in a various format. The result output used for performance analysis of the engine. At the end of simulation process, report that summarizes the simulation result can be made. This report contain the important information about simulation and simulation results in the form of graph and table.

The simulation conducted in several different cases. The installation of three different turbocharger done in simulation process. This simulation process has been run at speeds (RPM) 800, 1000, 1200, 1400, 1600, 1700, 1800, 2000, 2200 respectively. From the simulation result, the data has been analyzed to know the details on engine characteristic performance based on turbocharger installation.

4.2 Turbocharger I (GT2052-3)

The following is a specification data of first turbocharger to be input in the simulation process. Data collected such as compressor specification, turbine specification, and dimension of the turbocharger.

Figure 4.2 Turbocharger Garrett GT2052-3

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT2052 (3)

4.2.1 Turbocharger GT2052-3 Specification

- ✓ Brand : Garrett by Honeywell
- ✓ Model : GT2502 (727264-3)
- ✓ CHRA PN : 451298-44
- ✓ Bearing : Journal
- ✓ Cooling : Oil
- ✓ Compressor
  - Inducer : 36.1 mm
  - Exducer : 52.2 mm
  - Trim : 48
  - A/R : 0.51

✓ Turbine
    ▪ Wheel : 47.0 mm
    ▪ Trim : 72
    ▪ A/R : 0.50
✓ Housing inlet : Single
✓ Wastegate : Internal
✓ Water Cooled : No
✓ Ball Bearing : No
✓ Compressor Map

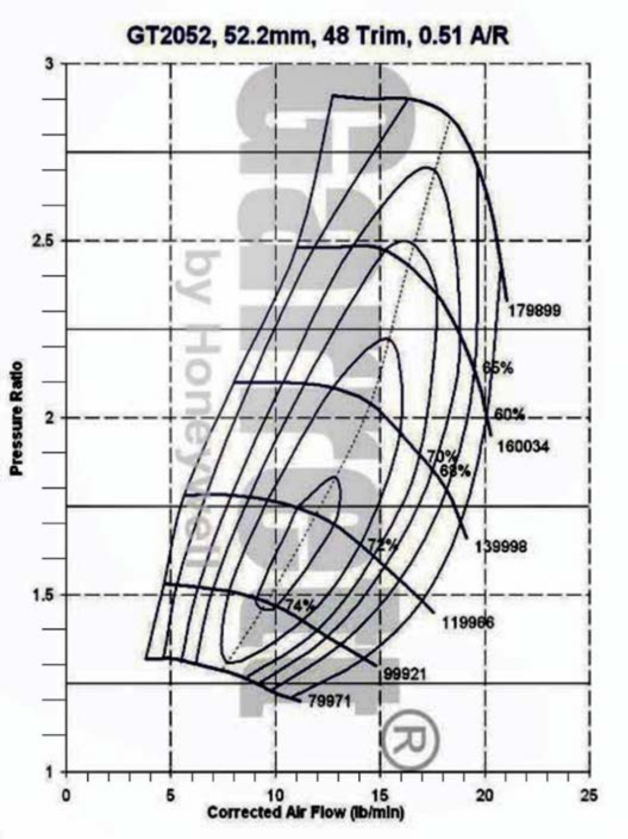


Figure 4.3 GT2052-3 Compressor Map

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT2052 (3)

- ✓ Turbocharger Dimension

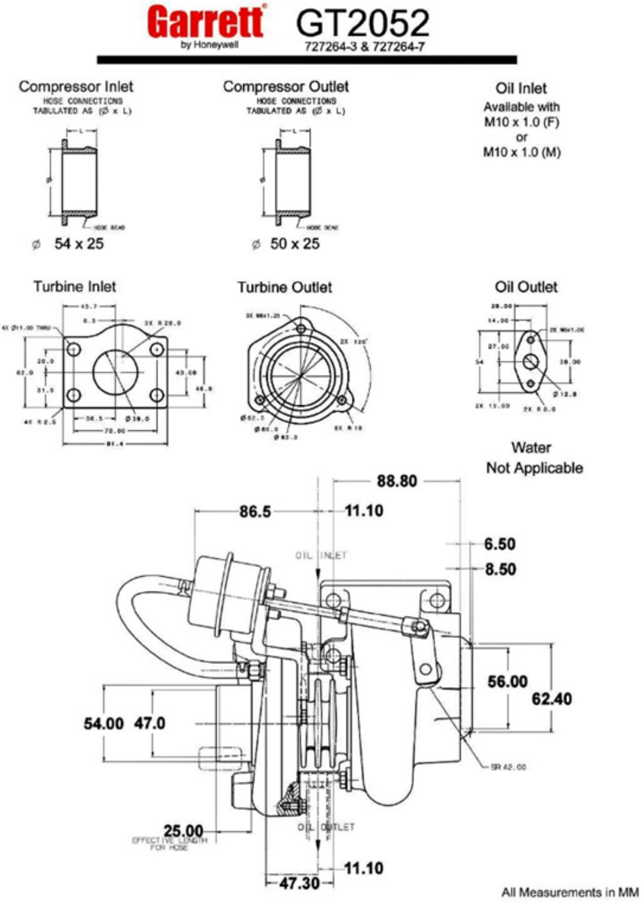


Figure 4.4 Garrett GT2052-3 Dimension

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT2052 (3)

4.2.2 Operating Line Compressor – Engine (GT2052-3)

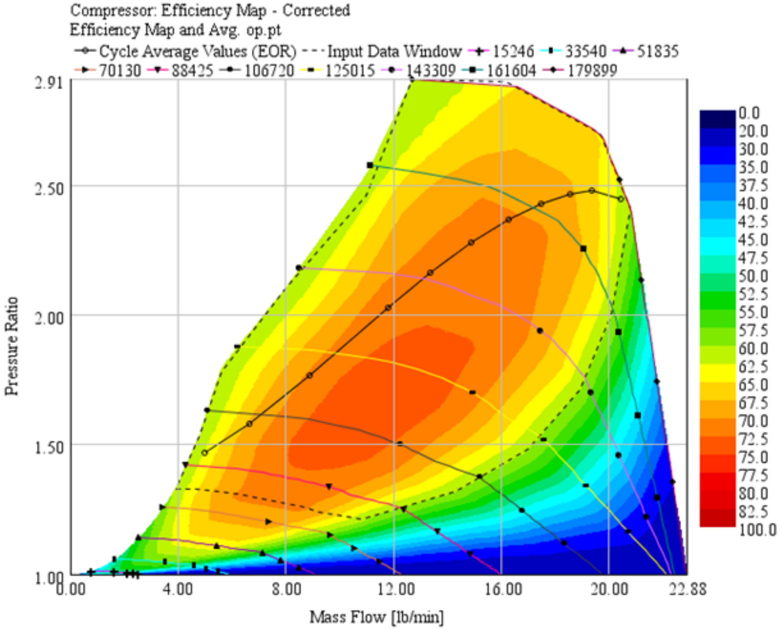


Figure 4.5 Operating Line Compressor - Engine (GT2052-3)

From the figure above shown the operating line of turbocharger compressor to the engine. Operating line turbocharger compressor to the engine data is used to prove the installation of the turbocharger on the specific engine is appropriate, in the sense that is no surge and stall . Surging is the complete breakdown of steady through flow, affecting the whole machine, in other words, when stalling takes place on all the blades simultaneously. This leads to choking of the flow. The color from compressor map shows the efficiency area of the compressor it self. At the 2200 RPM pressure ratio result is 2.447 bar, compressor outlet pressure 2.335 bar, compressor outlet temperature 437.356 K, mass flow rate 19.598 lb/min, and compressor efficiency at 61.413%.

4.2.3 Operating Line Turbine – Engine (GT2052-3)

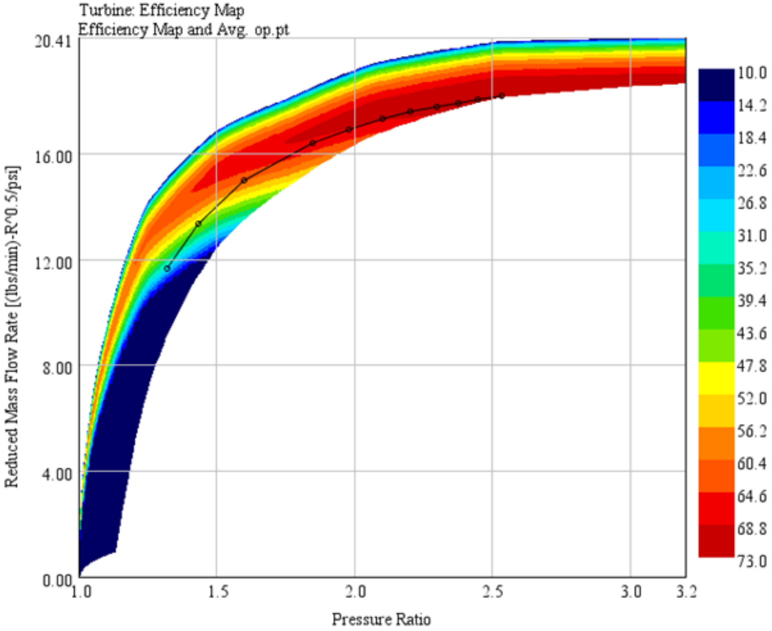
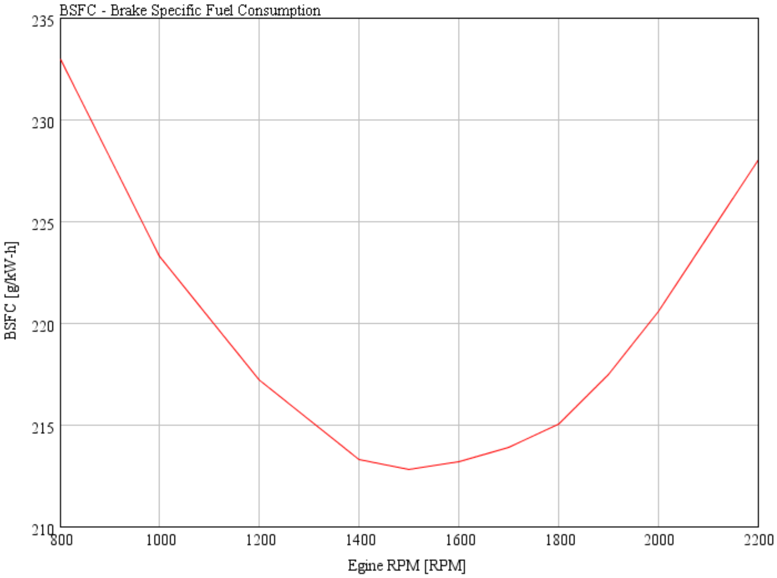


Figure 4.6 Operating Line Turbine - Engine (GT2502-3)

From the graph above shown the operating line turbocharger turbine to the engine. The color from the turbine map show the efficiency area of the turbine. The line on the map shows the performance done by the engine. At the highest point (2200 RPM) pressure ratio result is 2.482 bar, turbine outlet pressure at 1.212 bar, turbine outlet temperature at 765.811 K, mass flow rate at 20.065 lb/min, and turbine efficiency 72.076%.

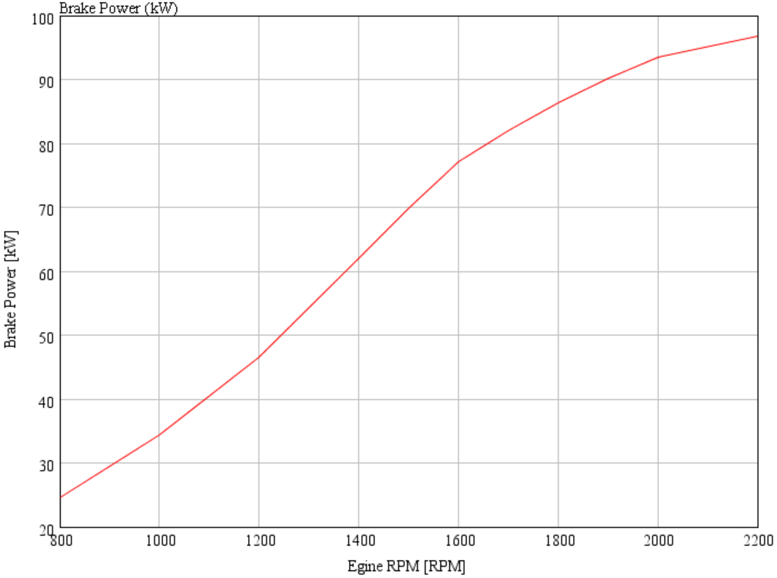
4.2.4 Engine BSFC (GT2052-3)



Graph 4.1 Brake Specific Fuel Consumption (GT2052-3)

Brake specific fuel consumption (BSFC) is is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft, power. The result from the graph shown the fuel consumption in every engine rotational speed. From the graph of simulation output result above obtained the highest fuel consumption at 800 RPM by 232.956 g/kWh and continue to decrease until RPM 1500. At this point (1500 RPM) is the point of the lowest fuel consumption by 212.806 g/kWh. The fuel consumption increased again in the next higher revolution after 1500 RPM of the engine.

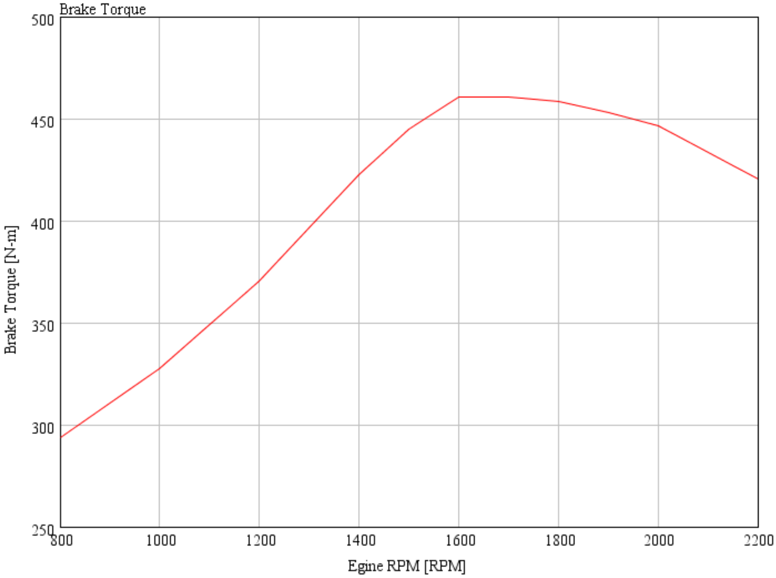
4.2.5 Engine Brake Power (GT2052-3)



Graph 4.2 Engine Brake Power in kW (GT2052-3)

From the graph above shown the power output of installation GT2052-3 turbocharger to the engine. This is the power output measured at the engine’s flywheel. (A flywheel is a disc with teeth on it. It's connected to the rear of the engine and its purpose is for the smooth transfer of power to the transmission from the engine.) Brake horsepower (bhp) is the measure of an engine's horsepower without the loss in power caused by the gearbox, generator, differential, water pump and other auxiliaries. Brake power result obtained from the simulation is 24.607 kW at 800 RPM. The highest power generated at 2200 RPM with a value of 96.823 kW. As the increases of engine revolution, power generated will be increased until certain point and the the power will decreased again.

4.2.6 Engine Brake Torque (GT2052-3)



Graph 4.3 Engine brake torque (GT2502-3)

Measurments on engine brake torque is normally done by using a dynamometer. From the graph above shown brake power result of the engine in various case of RPM. The maximum brake torque located at 1600 RPM with a value of 460.34 Nm. The lowest torque is at 800 RPM with a value of 293.735 Nm, and continued to increase until 1600 RPM. After it reach the highest torque at 1600 RPM then the torque decreased again to maximum revolution of the engine.

4.3 Turbocharger II (GT2502-1)

The following is a specification data of second turbocharger to be input in the simulation process. Data collected such as compressor specification, turbine specification, and dimension of the turbocharger.

Figure 4.7 Turbocharger Garrett GT2052-1
Source: turbobygarrett.com/turbobygarrett/turbocharger#GT2052 (1)

4.3.1 Turbocharger GT2052-1 Specification

- ✓ Brand : Garrett by Honeywell
- ✓ Model : GT2502 (727264-1)
- ✓ CHRA PN : 451298-45
- ✓ Bearing : Journal
- ✓ Cooling : Oil
- ✓ Compressor
    - Inducer : 37.6 mm
    - Exducer : 52.2 mm
    - Trim : 52
    - A/R : 0.51

- Turbine
  - Wheel : 47.0 mm
  - Trim : 72
  - A/R : 0.50
- Housing inlet : Single
- Wastegate : Internal
- Water Cooled : No
- Ball Bearing : No
- Compressor Map

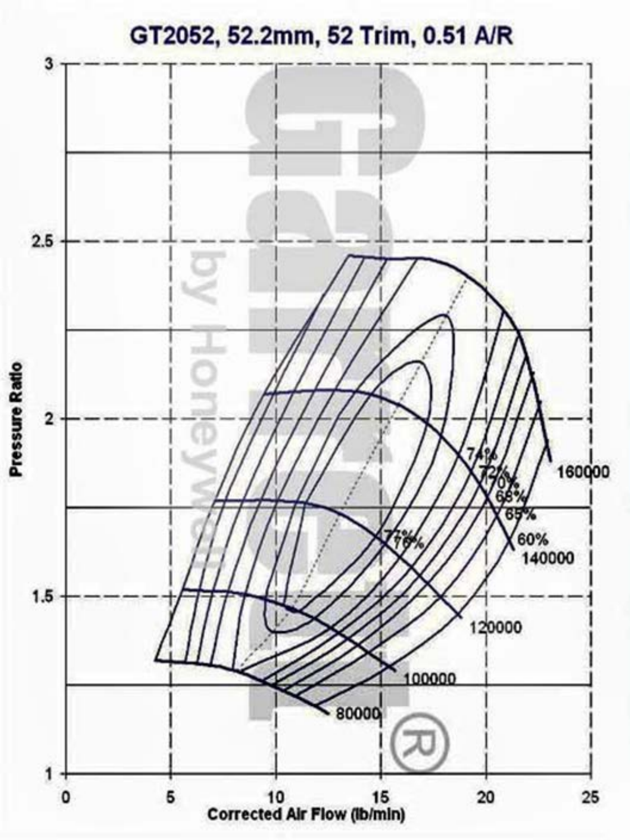


Figure 4.8 GT2052-1 Compressor Map

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT2052 (1)

- ✓ Turbocharger Dimension

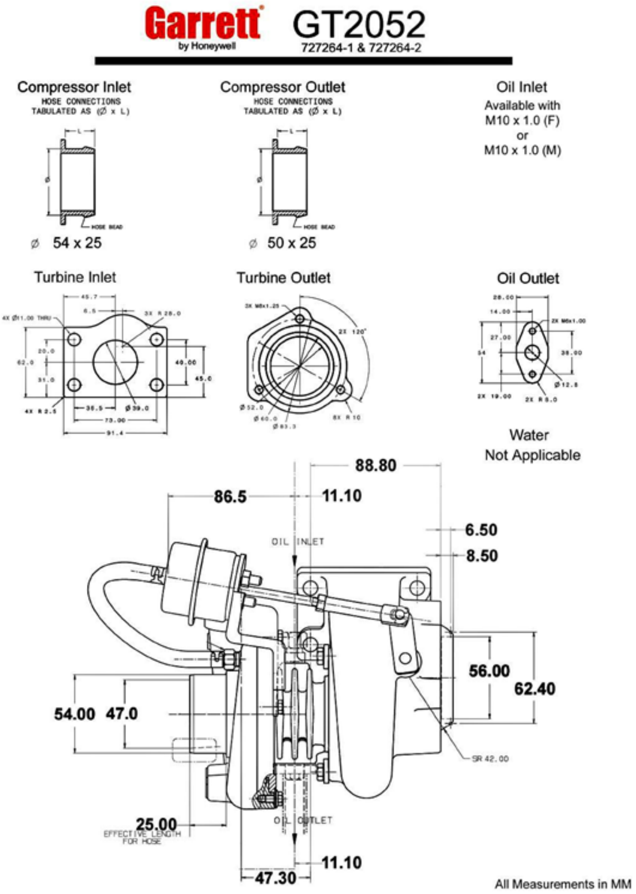


Figure 4.9 Garrett GT2052-1 Dimension

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT2052 (1)

4.3.2 Operating Line Compressor – Engine (GT2052-1)

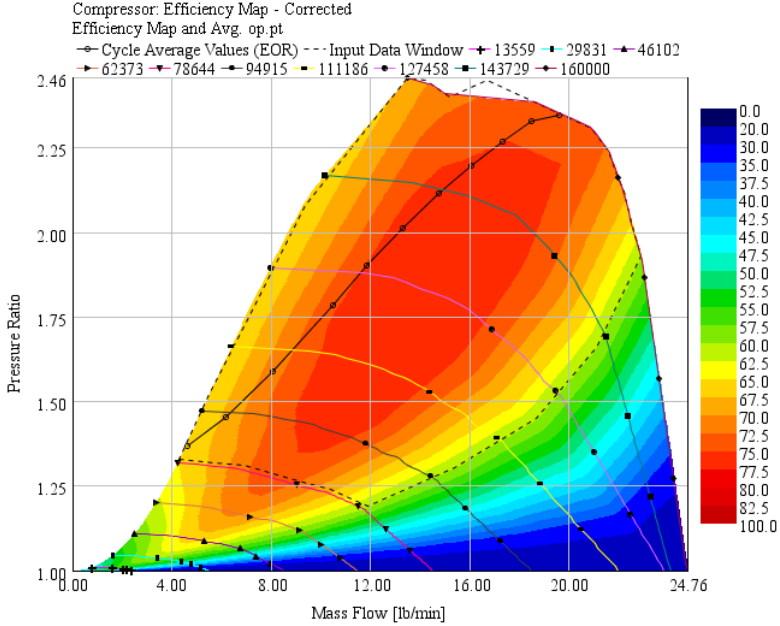


Figure 4.10 Operating Line Compressor – Engine (GT2052-1)

From the figure above shown the operating line of turbocharger compressor to the engine. Operating line turbocharger compressor to the engine data is used to prove the installation of the turbocharger on the specific engine is appropriate, in the sense that is no surge and stall . Surging is the complete breakdown of steady through flow, affecting the whole machine, in other words, when stalling takes place on all the blades simultaneously. This leads to choking of the flow. The color from compressor map shows the efficiency area of the compressor it self. At the 2200 RPM pressure ratio result is 2.376 bar, compressor outlet pressure 2.247 bar, compressor outlet temperature 408.01 K, mass flow rate 18.847 lb/min, and compressor efficiency at 73.933%.

4.3.3 Operating Line Turbine - Engine (GT2052-1)

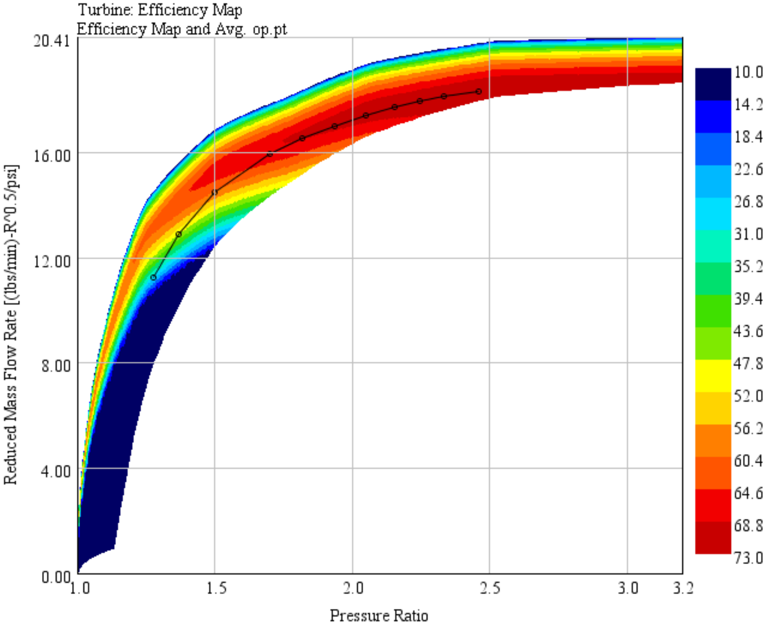
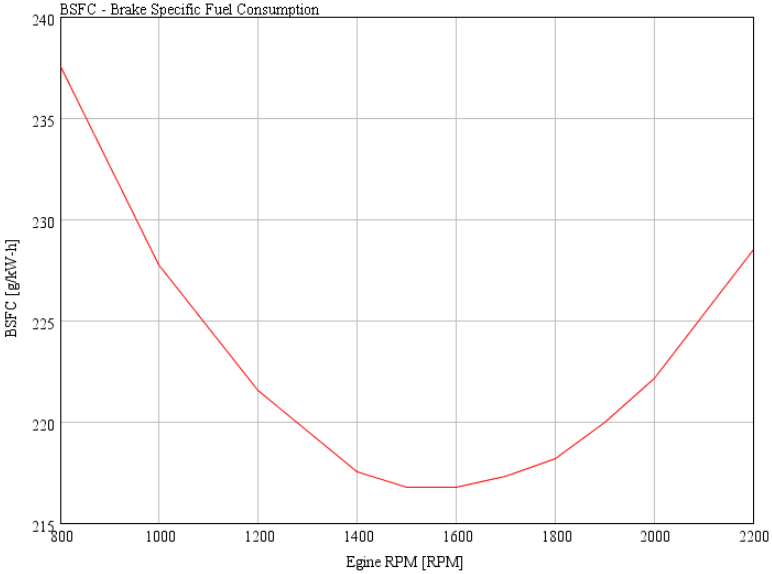


Figure 4.11 Operating Line Turbine - Engine (GT2502-1)

From the graph above shown the operating line turbocharger turbine to the engine. The color from the turbine map show the efficiency area of the turbine. The line on the map shows the performance done by the engine. The line At the highest point (2200 RPM) pressure ratio result is 2.408 bar, turbine outlet pressure at 1.2 bar, turbine outlet temperature at 767.855 K, mass flow rate at 19.459 lb/min, and turbine efficiency 72.022%.

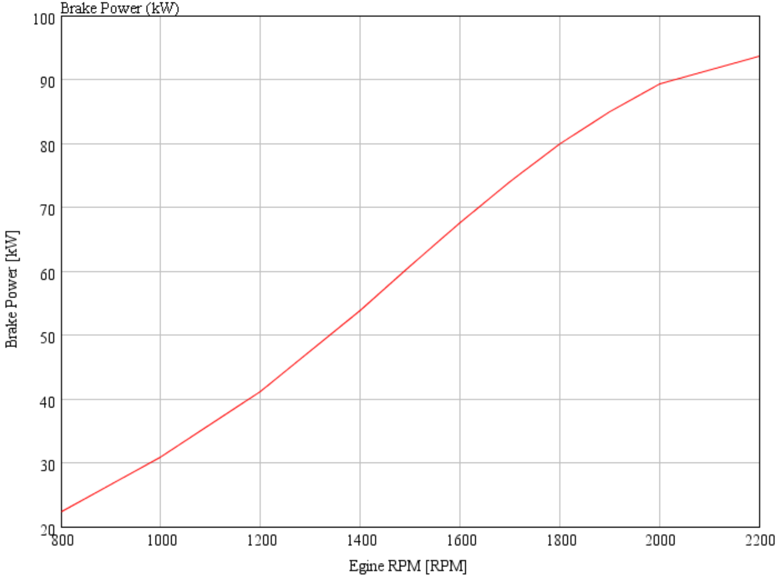
4.3.4 Engine BSFC (GT2052-1)



Graph 4.4 Brake Specific Fuel Consumption (GT2052-1)

Brake specific fuel consumption (BSFC) is is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft, power. The result from the graph shown the fuel consumption in every engine rotational speed. From the graph of simulation output result above obtained the highest fuel consumption at 800 RPM by 237.547 g/kWh and continue to decrease until RPM 1600. At this point (1600 RPM) is the point of the lowest fuel consumption by 216.746 g/kWh. The fuel consumption increased again in the next higher revolution after 1600 RPM of the engine.

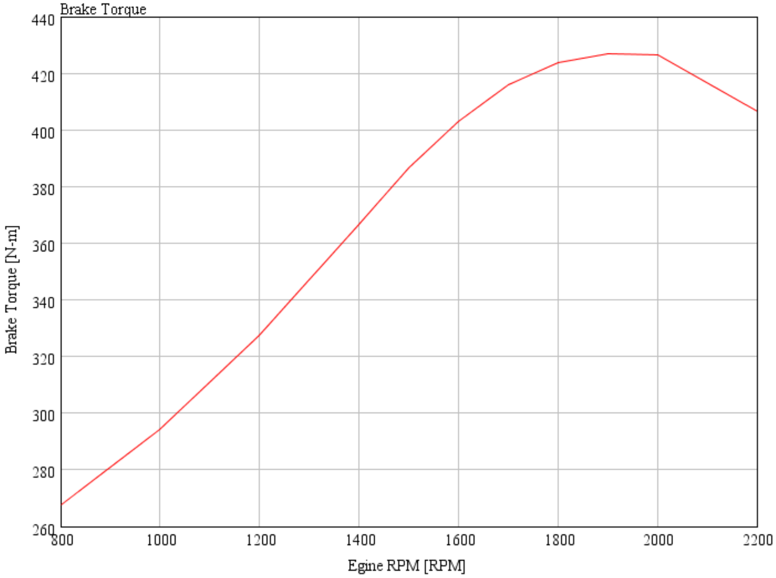
4.3.5 Engine Brake Power (GT2052-1)



Graph 4.5 Engine Brake Power in kW (GT2052-1)

From the graph above shown the power output of installation GT2052-1 turbocharger to the engine. This is the power output measured at the engine’s flywheel. (A flywheel is a disc with teeth on it. It's connected to the rear of the engine and its purpose is for the smooth transfer of power to the transmission from the engine.) Brake horsepower (bhp) is the measure of an engine's horsepower without the loss in power caused by the gearbox, generator, differential, water pump and other auxiliaries. Brake power result obtained from the simulation is 22.407 kW at 800 RPM. The higest power generated at 2200 RPM with a value of 93.622 kW. As the increases of engine revolution, power generated will be increased until certain point and the the power will decreased again.

4.3.6 Engine Brake Torque (GT2052-1)



Graph 4.6 Engine Brake Torque (GT2502-1)

Measurments on engine brake torque is normally done by using a dynamometer. From the graph above shown brake power result of the engine in various case of RPM. The maximum brake torque located at 1900 RPM with a value of 427.028 Nm. The lowest torque is at 800 RPM with a value of 267.469 Nm, and continued to increase until 1900 RPM. After it reach the highest torque at 1900 RPM then the torque decreased again to maximum revolution of the engine.

4.4 Turbocharger III (GT1241)

The following is a specification data of second turbocharger to be input in the simulation process. Data collected such as compressor specification, turbine specification, and dimension of the turbocharger.

Figure 4.12 Turbocharger Garrett GT1241

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT1241

4.4.1 Turbocharger GT1241 Specification

- ✓ Brand : Garrett by Honeywell
- ✓ Model : GT1241 (756068-1)
- ✓ CHRA PN : 757864-1
- ✓ Bearing : Journal
- ✓ Cooling : Oil & Water
- ✓ Compressor
  - ▪ Inducer : 29 mm
  - ▪ Exducer : 41 mm
  - ▪ Trim : 50
  - ▪ A/R : 0.33

- ✓ Turbine
  - Wheel : 35.5 mm
  - Trim : 72
  - A/R : 0.43
- ✓ Housing inlet : Single
- ✓ Wastegate : Internal
- ✓ Water Cooled : Yes
- ✓ Ball Bearing : No
- ✓ Compressor Map

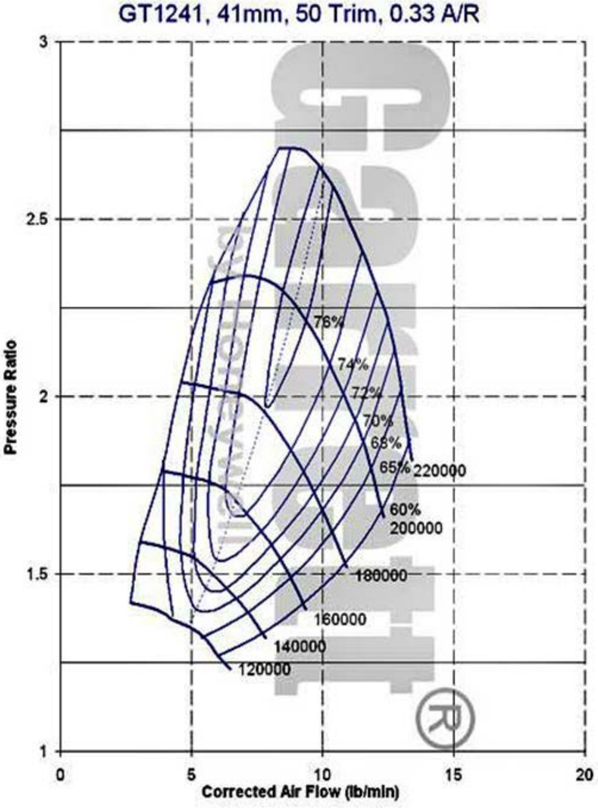


Figure 4.13 GT1241 Compressor Map

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT1241

- ✓ Turbocharger Dimension

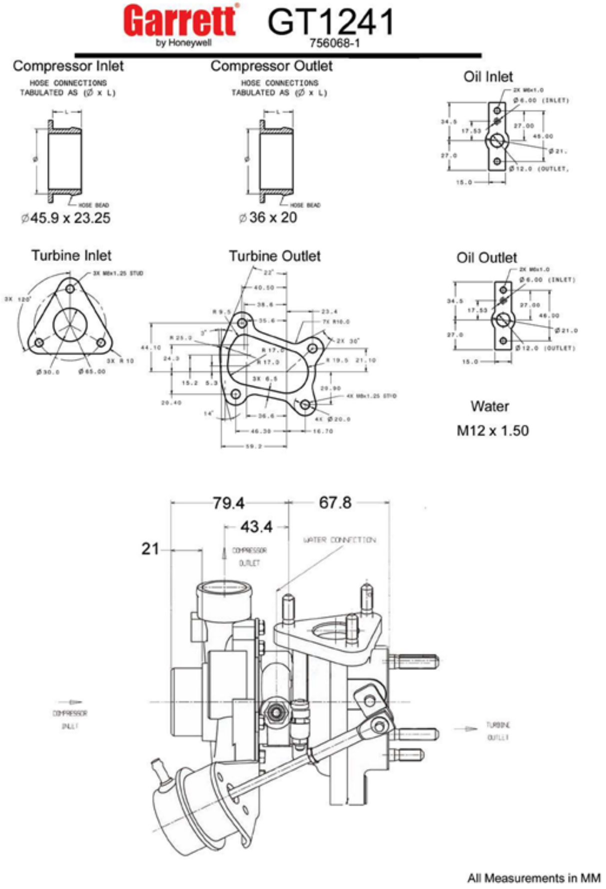


Figure 4.14 Garrett GT1241 Dimension

Source: turbobygarrett.com/turbobygarrett/turbocharger#GT1241

4.4.2 Operating Line Compressor - Engine (GT1241)

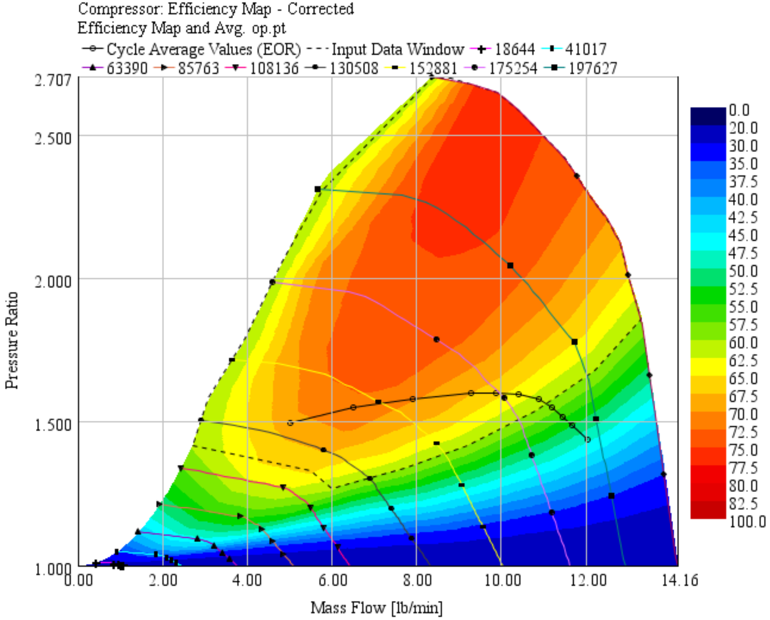


Figure 4.15 Operating Line Compressor – Engine (GT1241)

Surging is the complete breakdown of steady through flow, affecting the whole machine, in other words, when stalling takes place on all the blades simultaneously. This leads to choking of the flow. The operating line of turbocharger compressor above is exceeded the choke line of compressor map. The choke line is typically defined by the point where the efficiency drops below 58%. In addition to the rapid drop of compressor efficiency past this point, the turbo speed will also be approaching or exceeding the allowable limit. The color from compressor map shows the efficiency area of the compressor it self. The line exceeded compressor map at 1700 RPM. At the 2200 RPM pressure ratio result is 1.426 bar, compressor outlet pressure 1.377 bar, compressor outlet temperature 364.767 K, mass flow rate 12.04 lb/min, and compressor efficiency at 47.444%.

4.4.3 Operating Line Turbine - Engine (GT1241)

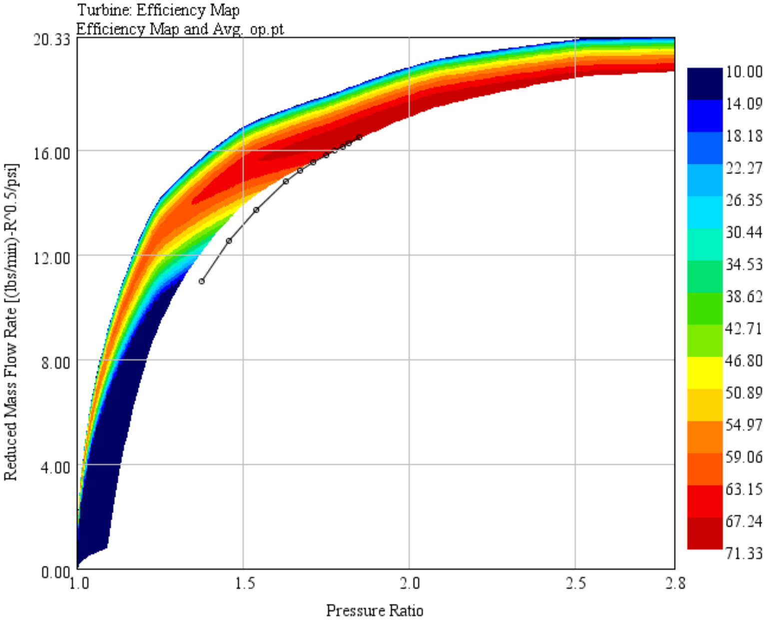
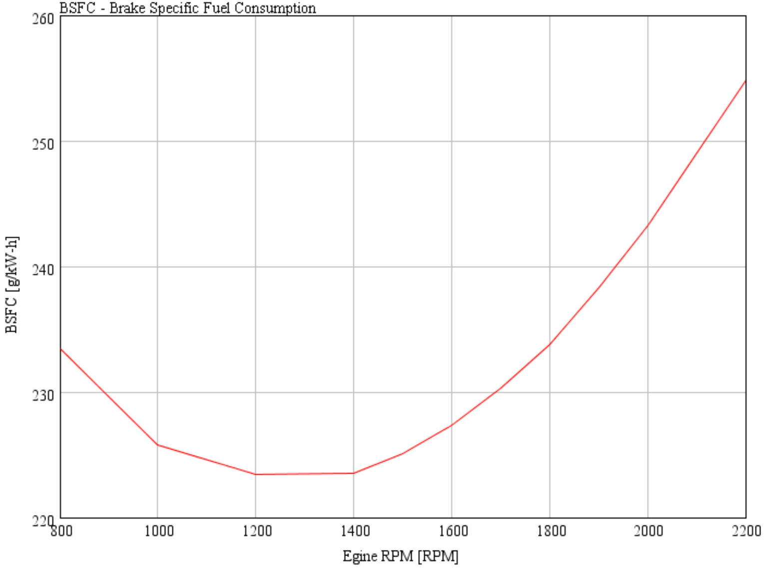


Figure 4.16 Operating Line Turbine - Engine (GT1241)

From the graph above shown the operating line turbocharger turbine to the engine. The color from the turbine map show the efficiency area of the turbine. The line on the map shows the performance done by the engine. Operating line turbocharger turbine to engine above is exceeded the efficiency map of the turbine efficiency map. The line At the highest point (2200 RPM) pressure ratio result is 1.82 bar, turbine outlet pressure at 1.084 bar, turbine outlet temperature at 792.976 K, mass flow rate at 12.018 lb/min, and turbine efficiency 67.691%.

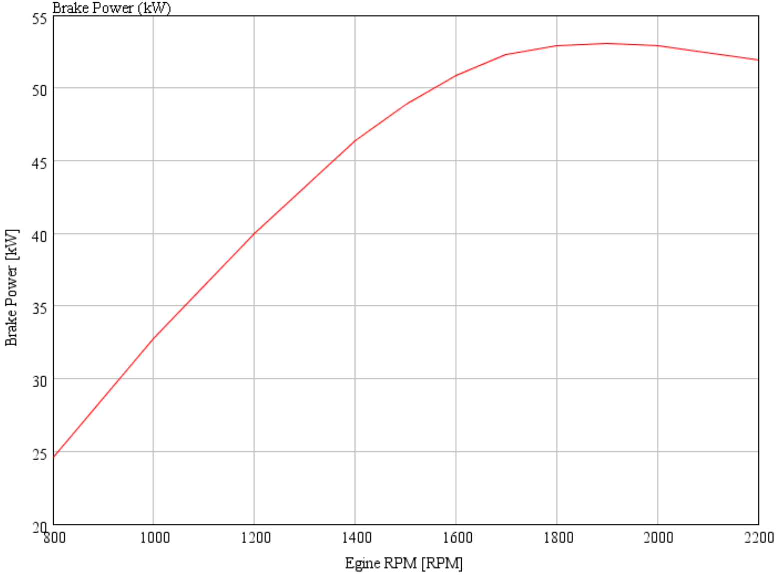
4.4.4 Engine BSFC (GT1241)



Graph 4.7 Brake Specific Fuel Consumption (GT1241)

Brake specific fuel consumption (BSFC) is is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft, power. The result from the graph shown the fuel consumption in every engine rotational speed. From the graph of simulation output result above obtained the highest fuel consumption at 800 RPM by 233.463 g/kWh and continue to decrease until RPM 1200. At this point (1200 RPM) is the point of the lowest fuel consumption by 223.464 g/kWh. The fuel consumption increased again in the next higher revolution after 1200 RPM of the engine.

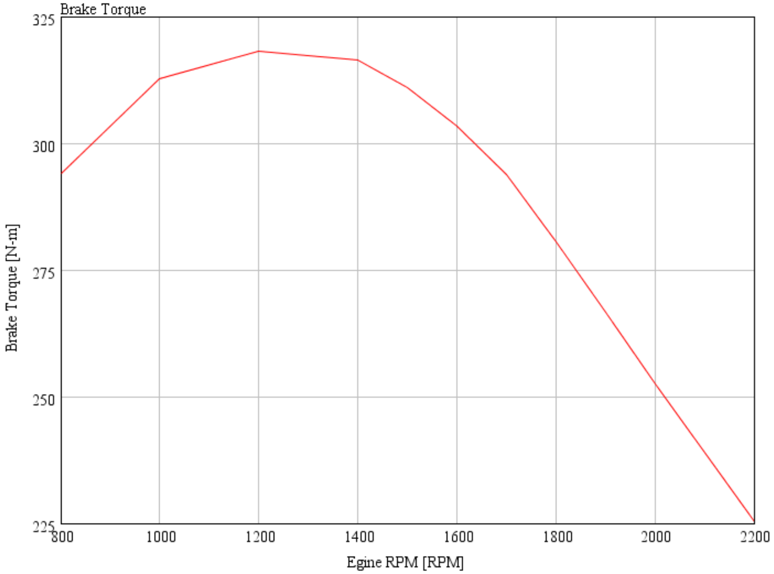
4.4.5 Engine Brake Power (GT1241)



Graph 4.8 Engine brake power in HP (GT1241)

From the graph above shown the power output of installation GT1241 turbocharger to the engine. This is the power output measured at the engine’s flywheel. (A flywheel is a disc with teeth on it. It's connected to the rear of the engine and its purpose is for the smooth transfer of power to the transmission from the engine.) Brake horsepower (bhp) is the measure of an engine's horsepower without the loss in power caused by the gearbox, generator, differential, water pump and other auxiliaries. Brake power result obtained from the simulation is 24.639 at 800 RPM. The higest power generated at 1900 RPM with a value of 53.032 kW. As the increases of engine revolution, power generated will be increased until certain point and the the power will decreased again.

4.4.6 Engine Brake Torque (GT1241)



Graph 4.9 Engine brake torque (GT1241)

Measurments on engine brake torque is normally done by using a dynamometer. From the graph above shown brake power result of the engine in various case of RPM. The maximum brake torque located at 1200 RPM with a value of 316.988 Nm. The lowest torque is at 2200 RPM with a value of 226.269 Nm. From 800 RPM of the engine, brake torque output continued to increase until 1200 RPM. After it reach the highest torque at 1200 RPM then the torque decreased again to maximum revolution of the engine. At 2200 RPM shows the lowest torque with a value of 225.401 Nm.

4.5 Turbocharger – Engine Matching Comparison

Evaluated from the existing results of engine operation line at compressor map, there are difference in the compressor map efficiency efficiency value.

4.5.1 Engine installed with GT2052-3 Turbocharger

Table 4.2 Turbine and Compressor output GT2052-3

Type of Device	Compressor	Turbine
Speed [RPM]	178662	178662
Pressure Ratio (static)	2.48	2.48
Pressure Ratio	2.45	2.54
Mass Flow Rate [kg/s]	0.15	0.15
Power [kW]	21.1	23.6
Efficiency [%]	61.4	72.1
Inlet Pressure [bar]	0.94	3.01
Outlet Pressure [bar]	2.34	1.21
Inlet Temperature [K]	297	898
Outlet Temperature [K]	437	766
Map PR Exceeded/Stalled ?	NO	NO
PR less than 1.0 ?	NO	NO

Table 4.3 Turbocharger – Engine matching output GT2052-3

RPM	Brake Power (kW)	SFOC (g/kWh)	TORQUE (Nm)
2200	96.823	228.023	420.269

Based on the trendline performance output on GT2502-3 compressor and turbine map obtained the data output as shown above. Table above is the output results of engine performance to turbocharger at 100% load. Turbocharger shaft speed is 178662 RPM at maximum load. Turbocharger compressor generates power by 21.1 kW , and turbine by 23.6 kW. Average efficiency engine performance to turbocharger is 61.4%, with turbine efficiency

72.1%. The power generated at 2200 RPM of the engine is 96.823 kW. Fuel consumptios used by 228.023 g/kWh, with torque value of 420.629 Nm. From trendline performance output on turbocharger compressor map, the trendline position looks to be in the middle of the map. But as it shows the trendline tend to be closer to the surge line with the top of trend line almost approach the boundary of the choke line. Based on theory of turbochargers and turbocharging, ideal trendline operation is located in a region that is almost approaching the surge line with efficiency level turbocharger >80%.

4.5.2 Engine installed with GT2052-1 Turbocharger

Table 4.4 Turbine and Compressor output GT2052-1

Type of Device	Compressor	Turbine
Speed [RPM]	165365	165365
Pressure Ratio (static)	2.38	2.41
Pressure Ratio	2.35	2.46
Mass Flow Rate [kg/s]	0.14	0.15
Power [kW]	16	22.1
Efficiency [%]	73.9	72
Inlet Pressure [bar]	0.95	2.89
Outlet Pressure [bar]	2.25	1.2
Inlet Temperature [K]	297	896
Outlet Temperature [K]	408	768
Map PR Exceeded/Stalled ?	NO	NO
PR less than 1.0 ?	NO	NO

Table 4.5 Turbocharger – Engine matching output GT2052-1

RPM	Brake Power (kW)	SFOC (g/kWh)	TORQUE (Nm)
2200	93.622	228.489	406.374

Based on the trendline performance output on GT2502-1 compressor and turbine map obtained the data output as shown above. Table above is the output results of engine performance to turbocharger at 100% load. Turbocharger shaft speed is 165365 RPM at maximum load. Turbocharger compressor generates power by 16 kW, and turbine by 22.1 kW. Average efficiency engine performance to turbocharger is 73.9%, with turbine efficiency 72%. The power generated at 2200 RPM of the engine is 93.622 kW. Fuel consumptios used by 228.489 g/kWh, with torque value of 406.374 Nm. From trendline performance output on turbocharger compressor map, the trendline position looks to be in the middle of the map. But as it shows the trendline tend to be closer to the surge line. Based on theory of turbochargers and turbocharging, ideal trendline operation is located in a region that is almost approaching the surge line with efficiency level turbocharger >80%.

4.5.3 Engine installed with GT1241 Turbocharger

Table 4.6 Turbine and Compressor output GT1241

Type of Device	Compressor	Turbine	
Speed [RPM]	194046	194046	
Pressure Ratio (static)	1.43	1.82	
Pressure Ratio	1.44	1.85	
Mass Flow Rate [kg/s]	0.09	0.09	
Power [kW]	6.2	8.9	
Efficiency [%]	47.4	67.7	
Inlet Pressure [bar]	0.97	1.97	
Outlet Pressure [bar]	1.38	1.08	
Inlet Temperature [K]	298	879	
Outlet Temperature [K]	365	793	
Map PR Exceeded/Stalled ?	NO	NO	
PR less than 1.0 ?	NO	NO	

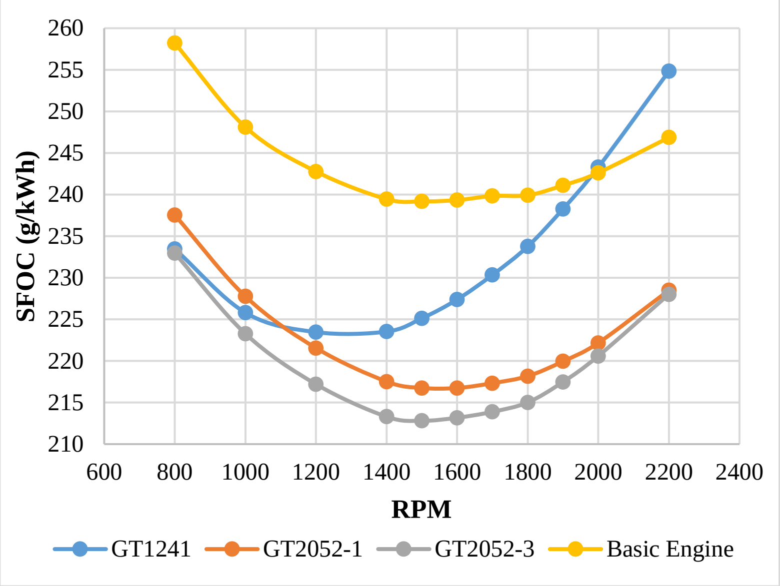
Table 4.7 Turbocharger – Engine matching output GT1241

RPM	Brake Power (kW)	SFOC (g/kWh)	TORQUE (Nm)
2200	51.929	254.828	225.401

Based on the trendline performance output on GT1241 compressor and turbine map obtained the data output as shown above. Table above is the output results of engine performance to turbocharger at 100% load. Turbocharger shaft speed is 194046 RPM at maximum load. Turbocharger compressor generates power by 6.2 kW , and turbine by 8.9 kW. Average efficiency engine performance to turbocharger is 47.4%, with turbine efficiency 67.7%. The power generated at 2200 RPM of the engine is 51.929 kW. Fuel consumptios used by 254.828 g/kWh, with torque value of 225.401 Nm. From trendline performance output on turbocharger compressor map, the trendline position looks linear from the midle of the map to the area outside the choke line. Based on theory of turbochargers and turbocharging, ideal trendline operation is located in a region that is almost approaching the surge line with efficiency level turbocharger >80%.

4.6 Specific Fuel Oil Consumption Comparison

Evaluated from the existing results of engine specific fuel oil consumption, there are difference in basic engine specification and engine installed with turbocharger.

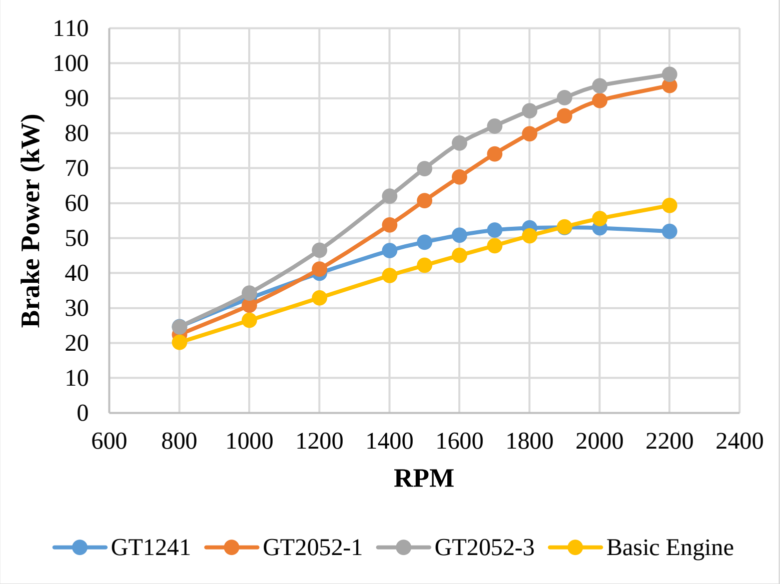


Graph 4.10 SFOC Comparison

From the graph above shown the line of engine specific fuel oil consumption. The yellow line is the line of basic engine fuel consumption without any turbocharger. And another color of the line shows the engine fuel consumption installed by different turbocharger specification. From the graph above the lowest fuel consumption shown in gray line with GT2052-3 turbocharger installed. The value obtained is 212.806 g/kWh at 1500 RPM.

4.7 Brake Power in kW Comparison

Evaluated from the existing results of engine brake power, there are difference in basic engine specification and engine installed with turbocharger.

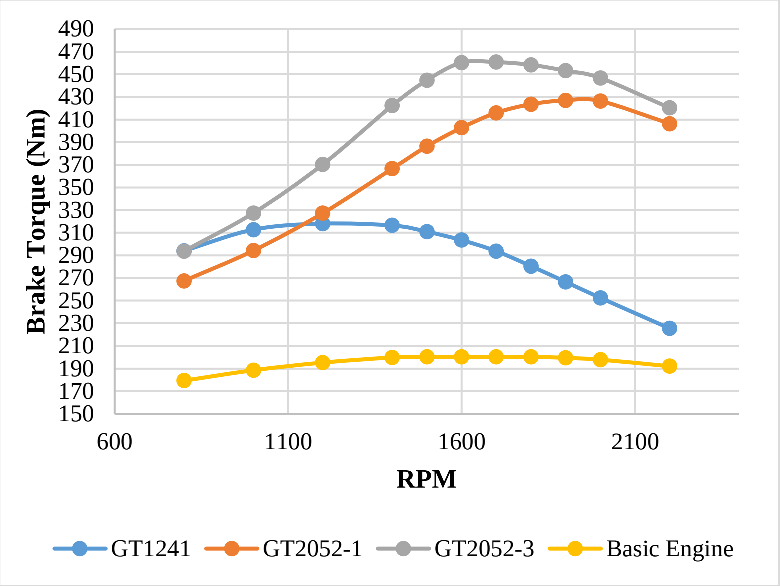


Graph 4.11 Brake Power (kW) Comparison

From the graph above shown the line of engine brake power in kW. The yellow line is the line of basic engine brake power without any turbocharger. And another color of the line shows the engine brake power installed by different turbocharger specification. From the graph above the highest power generated shown in gray line with GT2052-3 turbocharger installed. The value obtained is 96.823 kw at 2200 RPM.

4.8 Brake Torque Comparison

Evaluated from the existing results of engine brake torque, there are difference in basic engine specification and engine installed with turbocharger.



Graph 4.12 Brake Torque Comparison

From the graph above shown the line of engine brake torque. The yellow line is the line of basic engine brake power without any turbocharger. And another color of the line shows the engine brake torque installed by different turbocharger specification. From the graph above the highest torque generated shown in gray line with GT2052-3 turbocharger installed. The value obtained is 460.761 Nm at 1700 RPM.

4.9 Turbocharger – Engine Matching Discussion

Based on the performance of the engine which had been installed by a different turbocharger, there are differences between every engine power output results:

4.9.1 Turbocharger GT2052-3 output result

The first turbocharger installed resulted compressor efficiency of 61.412% with turbine efficiency of 72.076%. Maximum power output of the engine which installed with GT2502-3 turbocharger is equal to 96.823 kW or 129.842 HP at 2200 RPM. Boost pressure value at this point is 2.336 bar with a temperature of 437.356 K. This turbocharger generated high power, but the weakness lies in the efficiency of compressor map at this rated point.

4.9.2 Turbocharger GT2052-1 output result

The second turbocharger installed resulted compressor efficiency of 73.933% with turbine efficiency of 72.022%. Maximum power output of the engine which installed with GT2502-3 turbocharger is equal to 93.622 kW or 125.549 HP at 2200 RPM. Boost pressure value at this point is 2.247 bar with a temperature of 408.01 K. This turbocharger generated power not as high as first turbocharger installed, but the efficiency of the compressor is greater.

4.9.3 Turbocharger GT1241 output result

The third turbocharger installed resulted compressor efficiency of 47.444% with turbine efficiency of 67.691%. Maximum power output of the engine which installed with GT2502-3 turbocharger is equal to 51.929 kW or 69.638 HP at 2200 RPM. Boost pressure value at this point is 1.377 bar with a temperature of 364.767 K. this turbocharger generated low power with low efficiency of turbocharger. More higher turbocharger specification is recommended to replace this turbocharger.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the simulation results analysis that has been done, obtain some conclusions, there are:

1. Turbocharger match results known from operating line turbocharger to the engine performance. From the first turbocharger (GT2052-3), maximum power output value is 96.823 kW at 2200 RPM. Obtained torque value by 420.269 Nm, with a specific fuel oil consumption by 228.02 g/kWh. The second turbocharger (GT2052-1), maximum power output value is 93.622 kW at 2200 RPM. Obtained torque value by 406.374 Nm, with a specific fuel oil consumption by 228.389 g/kWh. The third turbocharger (GT1241), maximum power output value is 51.929 kW at 2200 RPM. Obtained torque value by 225.401 Nm, with a specific fuel oil consumption by 254.828 g/kWh. So turbocharger selected for the main engine is GT2502-3 with lowest SFOC, highest power, and highest torque generated.

2. Maximum load of the engine at 2200 RPM installed with GT2502-3 turbocharger, power generated value is 96.823 kW. Efficiency of the selected turbocharger compressor map is 61.4%, and turbine efficiency map 72%. Compressor and turbine revolution is at 178662 RPM. Boost pressure generated at highest point of this turbocharger used is 2.379 bar, with a temperature of 431.306 K.

5.2 Recommendation

Based on simulation results there are a few recommendation for the next research, such as:

1. Installation another specification of turbocharger to the engine to get higher power possible to be a subject for further research.
2. Material selection for the engine to fit the turbocharger compression pressure can be a subject for further research.

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APPENDIX

Basic Engine Performance

Engine Speed (cycle average)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
Engine Speed (end of cycle)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
BMEP - Brake Mean Effective Pressure	bar	6.1525	6.3386	6.39	6.421	6.4182	6.422	6.4175	6.4003	6.2564	6.0396	5.7448
IMEP720 - Net Indicated Mean Effective Pressure	bar	7.6535	7.7626	7.7737	7.7635	7.7262	7.6883	7.6419	7.5827	7.3579	7.052	6.6689
IMEP360 - Gross Indicated Mean Effective Pressure	bar	8.1278	8.1569	8.1289	8.081	8.0075	7.9356	7.8575	7.7686	7.4906	7.1411	6.725
FMEP - Friction Mean Effective Pressure	bar	1.501	1.424	1.3837	1.3426	1.308	1.2662	1.2244	1.1825	1.1015	1.0124	0.9241
PMEP - Pumping Mean Effective Pressure	bar	-0.474	-0.394	-0.355	-0.317	-0.281	-0.247	-0.216	-0.186	-0.133	-0.089	-0.056
BSFC - Brake Specific Fuel Consumption	g/kW-h	246.86	242.62	241.1	239.92	239.83	239.34	239.18	239.46	242.77	248.11	258.2
ISFC - Indicated Specific Fuel Consumption	g/kW-h	198.45	198.11	198.19	198.43	199.23	199.92	200.86	202.12	206.43	212.49	222.43
BSAC - Brake Specific Air Consumption	g/kW-h	5924.5	5822.8	5786.3	5757.8	5755.8	5744	5740.2	5746.8	5826.4	5954.5	6196.7
ISAC - Indicated Specific Air Consumption	g/kW-h	4762.6	4754.6	4756.4	4762.1	4781.4	4798	4820.5	4850.7	4954.2	5099.7	5338
FMEP-PMEP	bar	1.9753	1.8183	1.7389	1.66	1.5894	1.5136	1.44	1.3683	1.2342	1.1015	0.9802
Shaft MEP	bar	6.1525	6.3386	6.39	6.421	6.4182	6.422	6.4175	6.4003	6.2564	6.0396	5.7448
Attachment MEP	bar	0	0	0	0	0	0	0	0	0	0	0
Crank Pin MEP	bar	7.6535	7.7626	7.7737	7.7636	7.7262	7.6883	7.642	7.5827	7.3579	7.052	6.6689
Average of Maximum Cylinder Pressures	bar	74.217	74.815	74.748	74.516	75.609	75.248	74.881	74.488	74.286	72.481	70.811
Percent Load	%	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
FMEP - Cylinder (if 'EngFrictionDetail' used)	bar	1.501	1.424	1.3837	1.3426	1.308	1.2662	1.2244	1.1825	1.1015	1.0124	0.9241
FMEP - Crankshaft (if 'EngFrictionDetail' used)	bar	0	0	0	0	0	0	0	0	0	0	0
FMEP - Valvetrain (if 'EngFrictionDetail used)	bar	0	0	0	0	0	0	0	0	0	0	0

Basic Engine Energy

Indicated Efficiency	%	42.188	42.259	42.243	42.193	42.023	41.877	41.682	41.422	40.556	39.399	37.64
Indicated Efficiency - Gross (360)	%	44.802	44.405	44.174	43.918	43.553	43.225	42.857	42.438	41.288	39.897	37.957
Brake Efficiency	%	33.914	34.507	34.724	34.896	34.908	34.98	35.003	34.963	34.485	33.743	32.424
Fuel Power	kW	130.45	120.08	114.28	108.26	102.16	96.012	89.889	83.768	71.159	58.503	46.329
Fuel Power, Useful Portion	kW	130.45	120.08	114.28	108.26	102.16	96.012	89.889	83.768	71.159	58.503	46.329
In-Cylinder Heat Transfer	kW	28.043	26.778	26.03	25.228	24.769	23.917	23.057	22.189	20.568	18.504	16.385
Total Exhaust Energy Percentage	%	36.315	35.441	34.98	34.503	33.733	33.212	32.668	32.089	30.54	28.973	26.995
Useful Exhaust Energy Percentage	%	36.315	35.441	34.98	34.503	33.733	33.212	32.668	32.089	30.54	28.973	26.995
Exhaust Energy Percentage (MeanV)	%	--	--	--	--	--	--	--	--	--	--	--

Basic Engine Torque – Power

Brake Torque	N-m	192.03	197.84	199.45	200.42	200.33	200.45	200.31	199.77	195.28	188.51	179.31
Indicated Torque	N-m	238.88	242.29	242.64	242.32	241.15	239.97	238.52	236.68	229.66	220.11	208.15
Friction Torque	N-m	46.851	44.448	43.189	41.905	40.827	39.522	38.217	36.907	34.379	31.6	28.843
Attachment Torque	N-m	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Torque	N-m	238.89	242.29	242.64	242.32	241.15	239.97	238.52	236.68	229.66	220.11	208.15
Shaft Torque	N-m	192.03	197.84	199.45	200.42	200.33	200.45	200.31	199.77	195.28	188.51	179.31
Brake Power (HP)	HP	59.329	55.567	53.216	50.66	47.825	45.039	42.194	39.275	32.908	26.473	20.145
Brake Power (kW)	kW	44.242	41.436	39.683	37.777	35.663	33.585	31.464	29.288	24.539	19.741	15.022
Indicated Power	kW	55.035	50.745	48.277	45.676	42.931	40.207	37.467	34.699	28.86	23.05	17.438
Friction Power	kW	10.794	9.3092	8.5932	7.8989	7.2682	6.6221	6.0031	5.4109	4.3202	3.3092	2.4163
Attachment Power	kW	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Power	kW	55.035	50.745	48.277	45.676	42.931	40.207	37.467	34.699	28.86	23.05	17.438
Shaft Power	kW	44.242	41.436	39.683	37.777	35.663	33.585	31.464	29.288	24.539	19.741	15.022

Basic Engine Flow

Volumetric Efficiency, Air	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.8679	0.8563	0.8476
Volumetric Efficiency, Trapped Air	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.8679	0.8563	0.8476
Volumetric Efficiency, Air+Burned Gas	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.868	0.8563	0.8476
Volumetric Efficiency, Air+Fuel Vapor	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.8679	0.8563	0.8476
Volumetric Efficiency, All Gases	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.868	0.8563	0.8476
Volumetric Efficiency (Manifold), Air	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.8679	0.8563	0.8476
Volumetric Efficiency (Manifold), Trapped Air	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.8679	0.8563	0.8476
Volumetric Efficiency (Manifold), Air+Burned Gas	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.868	0.8563	0.8476
Volumetric Efficiency (Manifold), Air+Fuel Vapor	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.8679	0.8563	0.8476
Volumetric Efficiency (Manifold), All Gases	fraction	0.8679	0.8788	0.8804	0.8803	0.8796	0.8783	0.8771	0.8758	0.868	0.8563	0.8476
Air Flow	kg/hr	262.11	241.27	229.62	217.52	205.27	192.91	180.61	168.31	142.98	117.55	93.085
Fuel Flow	kg/hr	10.922	10.053	9.5678	9.0633	8.5531	8.0382	7.5256	7.0132	5.9575	4.898	3.8787
EGR Percentage (normalized by Air+Burned Gas)	%	0	0	0	0	0	0	0	0	0	0	0
Trapping Ratio		1	1	1	1	1	1	1	1	1	1	1
Air-Fuel Ratio (Inducted Air/Total Fuel)		23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999
Air-Fuel Ratio (Trapped Air/Total Fuel)		23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999	23.999
Percent Burned Mass at Cycle Start	%	3.8465	3.782	3.7765	3.787	3.825	3.8498	3.8799	3.9113	4.0295	4.1908	4.3835

GT2052-3 Performance

Engine Speed (cycle average)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
Engine Speed (end of cycle)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
BMEP - Brake Mean Effective Pressure	bar	13.465	14.313	14.518	14.685	14.762	14.749	14.251	13.534	11.868	10.491	9.4108
IMEP720 - Net Indicated Mean Effective Pressure	bar	15.379	16.176	16.346	16.469	16.512	16.439	15.87	15.072	13.253	11.73	10.526
IMEP360 - Gross Indicated Mean Effective Pressure	bar	16.925	17.378	17.354	17.283	17.137	16.893	16.165	15.231	13.211	11.577	10.31
FMEP - Friction Mean Effective Pressure	bar	1.9173	1.8662	1.8299	1.7867	1.751	1.6918	1.6184	1.5363	1.3795	1.2327	1.1078
PMEP - Pumping Mean Effective Pressure	bar	-1.547	-1.202	-1.008	-0.814	-0.625	-0.454	-0.295	-0.159	0.0417	0.1539	0.2152
BSFC - Brake Specific Fuel Consumption	g/kW-h	228.02	220.6	217.47	215.01	213.88	213.17	212.81	213.3	217.2	223.27	232.96
ISFC - Indicated Specific Fuel Consumption	g/kW-h	199.65	195.19	193.16	191.71	191.22	191.25	191.1	191.53	194.51	199.68	208.28
BSAC - Brake Specific Air Consumption	g/kW-h	5479.6	5398.6	5380.5	5320.5	5232.3	5118.9	5107.5	5116.1	5201.6	5339.7	5568.8
ISAC - Indicated Specific Air Consumption	g/kW-h	4797.7	4776.7	4779	4744	4678	4592.5	4586.5	4593.9	4658.1	4775.4	4979
FMEP-PMEP	bar	3.4642	3.0678	2.8383	2.6007	2.3764	2.1456	1.9137	1.6954	1.3377	1.0788	0.8926
Shaft MEP	bar	13.465	14.313	14.518	14.685	14.762	14.749	14.251	13.534	11.868	10.491	9.4108
Attachment MEP	bar	0	0	0	0	0	0	0	0	0	0	0
Crank Pin MEP	bar	15.379	16.176	16.346	16.469	16.512	16.439	15.87	15.072	13.253	11.73	10.526
Average of Maximum Cylinder Pressures	bar	157.45	163.23	163.99	163.34	164.21	160.36	153.67	145.25	129.89	116.54	107.56
Percent Load	%	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
FMEP - Cylinder (if 'EngFrictionDetail' used)	bar	1.9173	1.8662	1.8299	1.7867	1.751	1.6918	1.6184	1.5363	1.3795	1.2327	1.1078
FMEP - Crankshaft (if 'EngFrictionDetail' used)	bar	0	0	0	0	0	0	0	0	0	0	0
FMEP - Valvetrain (if 'EngFrictionDetail used)	bar	0	0	0	0	0	0	0	0	0	0	0

GT2052-3 Energy

Indicated Efficiency	%	41.935	42.893	43.343	43.67	43.782	43.775	43.81	43.713	43.042	41.928	40.196
Indicated Efficiency - Gross (360)	%	46.153	46.079	46.017	45.828	45.44	44.984	44.626	44.174	42.907	41.378	39.374
Brake Efficiency	%	36.717	37.952	38.497	38.938	39.144	39.274	39.341	39.251	38.545	37.497	35.939
Fuel Power	kW	263.7	246.53	234.21	221.88	209.55	196.39	177.6	157.78	120.77	91.446	68.472
Fuel Power, Useful Portion	kW	263.7	246.53	234.21	221.88	209.55	196.39	177.6	157.78	120.77	91.446	68.472
In-Cylinder Heat Transfer	kW	49.422	47.242	45.568	44.046	43.32	41.845	39.207	36.317	31.085	26.315	22.358
Total Exhaust Energy Percentage	%	39.324	37.945	37.201	36.479	35.546	34.918	34.114	33.27	31.218	29.296	27.152
Useful Exhaust Energy Percentage	%	39.324	37.945	37.201	36.479	35.546	34.918	34.114	33.27	31.218	29.296	27.152
Exhaust Energy Percentage (MeanV)	%	--	--	--	--	--	--	--	--	--	--	--

GT2052-3 Torque – Power

Brake Torque	N-m	420.27	446.74	453.15	458.34	460.76	460.34	444.81	422.43	370.43	327.44	293.74
Indicated Torque	N-m	480	504.9	510.19	514.04	515.36	513.11	495.34	470.44	413.65	366.14	328.53
Friction Torque	N-m	59.842	58.247	57.117	55.768	54.654	52.806	50.514	47.951	43.057	38.476	34.578
Attachment Torque	N-m	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Torque	N-m	480	504.9	510.19	514.04	515.36	513.11	495.34	470.44	413.65	366.14	328.53
Shaft Torque	N-m	420.27	446.74	453.15	458.34	460.76	460.34	444.81	422.43	370.43	327.44	293.74
Brake Power (HP)	HP	129.84	125.47	120.91	115.86	110	103.43	93.698	83.051	62.424	45.983	33
Brake Power (kW)	kW	96.823	93.565	90.163	86.395	82.026	77.131	69.871	61.931	46.55	34.29	24.608
Indicated Power	kW	110.58	105.75	101.51	96.894	91.747	85.972	77.807	68.97	51.981	38.342	27.523
Friction Power	kW	13.787	12.199	11.364	10.512	9.7298	8.8477	7.9346	7.03	5.4106	4.0292	2.8968
Attachment Power	kW	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Power	kW	110.58	105.75	101.51	96.894	91.747	85.972	77.807	68.97	51.981	38.342	27.523
Shaft Power	kW	96.823	93.565	90.163	86.395	82.026	77.131	69.871	61.931	46.55	34.29	24.608

GT2052-3 Flow

Volumetric Efficiency, Air	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2478
Volumetric Efficiency, Trapped Air	fraction	1.7545	1.8374	1.8578	1.8584	1.8376	1.7966	1.733	1.6496	1.4731	1.3385	1.2528
Volumetric Efficiency, Air+Burned Gas	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2479
Volumetric Efficiency, Air+Fuel Vapor	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2478
Volumetric Efficiency, All Gases	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2479
Volumetric Efficiency (Manifold), Air	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2478
Volumetric Efficiency (Manifold), Trapped Air	fraction	1.7545	1.8374	1.8578	1.8584	1.8376	1.7966	1.733	1.6496	1.4731	1.3385	1.2528
Volumetric Efficiency (Manifold), Air+Burned Gas	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2479
Volumetric Efficiency (Manifold), Air+Fuel Vapor	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2478
Volumetric Efficiency (Manifold), All Gases	fraction	1.7568	1.8398	1.86	1.8603	1.8391	1.7976	1.7331	1.6487	1.4699	1.3338	1.2479
Air Flow	kg/hr	530.55	505.11	485.12	459.66	429.19	394.83	356.86	316.85	242.13	183.1	137.04
Fuel Flow	kg/hr	22.078	20.64	19.608	18.576	17.544	16.442	14.869	13.21	10.111	7.656	5.7326
EGR Percentage (normalized by Air+Burned Gas)	%	0	0	0	0	0	0	0	0	0	0	0
Trapping Ratio		0.9987	0.9987	0.9988	0.999	0.9992	0.9995	1	1	1	1	1
Air-Fuel Ratio (Inducted Air/Total Fuel)		24.031	24.473	24.741	24.745	24.464	24.013	24.001	23.986	23.948	23.916	23.905
Air-Fuel Ratio (Trapped Air/Total Fuel)		24	24.441	24.712	24.719	24.444	24	24	24	24	24	24
Percent Burned Mass at Cycle Start	%	4.6082	4.2476	4.0884	3.9209	3.7723	3.5998	3.4749	3.3876	3.4074	3.6416	3.9037

GT2052-3 Compressor

Average Speed	RPM	178662	172532	168254	163417	158095	152204	145363	137433	119800	104636	94224.5
Average Map Pressure Ratio		2.44735	2.48058	2.46698	2.42959	2.36722	2.28041	2.16435	2.02724	1.76484	1.57999	1.46906
Average Static Pressure Ratio		2.48077	2.51151	2.49507	2.45394	2.38725	2.29602	2.17573	2.03501	1.76803	1.5813	1.46966
Average Inlet Pressure	bar	0.941546	0.947192	0.951422	0.956513	0.96224	0.968138	0.973986	0.97935	0.987693	0.992457	0.995084
Average Outlet Pressure	bar	2.33576	2.37888	2.37387	2.34723	2.29711	2.22286	2.11913	1.99299	1.74627	1.56937	1.46244
Average Inlet Temperature	K	297.079	297.226	297.336	297.467	297.613	297.763	297.911	298.048	298.265	298.4	298.487
Average Outlet Temperature	K	437.356	431.306	426.542	421.061	415.305	409.077	401.181	392.154	373.126	359.53	350.53
Average Mass Flow Rate	lb/min	19.59809	18.65879	17.91116	16.96021	15.8213	14.53583	13.10333	11.60114	8.808101	6.62932	4.953312
Average Efficiency	%	61.4125	65.3824	67.3971	69.1145	70.1785	70.5816	70.7284	70.4144	69.864	67.9925	66.4772
Average Power	kW	21.133	19.2206	17.7758	16.0994	14.3013	12.429	10.3943	8.38524	5.06107	3.109	1.97701
Average Reduced Speed	RPM/K^0.5	10336	9981.81	9734.65	9455.18	9147.66	8807.15	8411.61	7952.98	6932.83	6055.28	5452.61
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	32.68353	30.99478	29.66555	27.99136	26.00781	23.79745	21.3658	18.84644	14.22719	10.67305	7.960537
Rack Position		0	0	0	0	0	0	0	0	0	0	0
Average Corrected Speed	RPM	178426	172313	168046	163222	157913	152035	145207	137290	119679	104530	94126.7
Average Corrected Mass Flow	lb/min	20.42707	19.37163	18.54093	17.49448	16.25478	14.8734	13.35354	11.77903	8.891939	6.670644	4.975324
Average Tip Speed	m/s	488.316	471.562	459.87	446.649	432.103	416.001	397.303	375.629	327.436	285.99	257.533

GT2052-3 Turbine

Average Speed	RPM	178662	172532	168254	163417	158095	152204	145363	137433	119800	104636	94224.5
Average Map Pressure Ratio		2.53568	2.44745	2.3788	2.29692	2.20338	2.1027	1.98193	1.84881	1.60175	1.43379	1.32176
Average Static Pressure Ratio		2.48246	2.39681	2.33008	2.25047	2.15969	2.06207	1.9452	1.81635	1.57759	1.41598	1.30827
Average Inlet Pressure	bar	3.00769	2.85171	2.73678	2.60612	2.46246	2.31501	2.14547	1.9688	1.66261	1.46712	1.34198
Average Outlet Pressure	bar	1.21158	1.1898	1.17454	1.15803	1.14019	1.12266	1.10295	1.08393	1.05389	1.03612	1.02577
Average Inlet Temperature	K	898.041	873.064	857.899	847.939	839.751	837.543	825.43	812.362	780.727	750.902	718.393
Average Outlet Temperature	K	765.811	749.866	740.93	737.52	736.633	741.669	739.409	737.606	728.596	714.242	691.187
Average Mass Flow Rate	lb/min	20.06582	19.08353	18.32677	17.37265	16.23838	14.96309	13.54349	12.04313	9.233426	7.065108	5.289377
Average Efficiency	%	72.0759	71.2697	70.7227	70.0415	69.1632	68.1786	66.7005	64.4465	56.8061	46.9236	41.0592
Average Power	kW	23.6029	20.8495	18.9705	16.9678	14.8173	12.7113	10.3116	7.95341	4.21027	2.19857	1.18139
Average Reduced Speed	RPM/K^0.5	5946.72	5824.39	5730.07	5598.09	5442.4	5246.86	5048.16	4811.59	4279.72	3812.78	3511.15
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	18.1718	18.00861	17.88885	17.73704	17.50217	17.18338	16.71009	16.1146	14.41961	12.29256	9.828739
Wastegate Mass Flow Rate	lb/min	0.166839	0.16011	0.154782	0.147911	0.139895	0.130754	0.120707	0.109473	0.087167	0	0
Wastegate Diameter	mm	2	2	2	2	2	2	2	2	2	0	0
Rack Position		0	0	0	0	0	0	0	0	0	0	0
Average Blade Speed Ratio		0.78651	0.786798	0.787588	0.787016	0.787459	0.786953	0.79488	0.808621	0.859154	0.944029	1.07854
Average Tip Speed	m/s	512.847	495.251	482.971	469.087	453.81	436.899	417.262	394.499	343.885	300.357	270.47

GT2052-1 Performance

Engine Speed (cycle average)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
Engine Speed (end of cycle)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
BMEP - Brake Mean Effective Pressure	bar	13.02	13.66	13.681	13.571	13.328	12.906	12.38	11.748	10.487	9.4276	8.5693
IMEP720 - Net Indicated Mean Effective Pressure	bar	14.909	15.47	15.443	15.278	14.99	14.501	13.903	13.196	11.802	10.614	9.6426
IMEP360 - Gross Indicated Mean Effective Pressure	bar	16.389	16.586	16.378	16.036	15.579	14.936	14.202	13.381	11.814	10.526	9.4954
FMEP - Friction Mean Effective Pressure	bar	1.8907	1.8207	1.771	1.7152	1.6689	1.5993	1.5259	1.4495	1.3132	1.1831	1.0687
PMEP - Pumping Mean Effective Pressure	bar	-1.48	-1.116	-0.935	-0.758	-0.589	-0.435	-0.299	-0.184	-0.012	0.0878	0.1472
BSFC - Brake Specific Fuel Consumption	g/kW-h	228.49	222.17	219.95	218.17	217.33	216.75	216.75	217.52	221.56	227.77	237.55
ISFC - Indicated Specific Fuel Consumption	g/kW-h	199.54	196.17	194.86	193.8	193.23	192.92	193.01	193.65	196.86	202.3	211.11
BSAC - Brake Specific Air Consumption	g/kW-h	5483.6	5354.1	5299	5254.3	5230.7	5213.6	5210.2	5224.6	5312	5456.1	5684.6
ISAC - Indicated Specific Air Consumption	g/kW-h	4788.8	4727.5	4694.6	4667.3	4650.8	4640.3	4639.5	4651.2	4719.9	4846.1	5051.8
FMEP-PMEP	bar	3.371	2.9365	2.7061	2.4731	2.258	2.0343	1.8245	1.6338	1.3248	1.0953	0.9216
Shaft MEP	bar	13.02	13.66	13.681	13.571	13.328	12.906	12.38	11.748	10.487	9.4276	8.5693
Attachment MEP	bar	0	0	0	0	0	0	0	0	0	0	0
Crank Pin MEP	bar	14.909	15.47	15.443	15.278	14.99	14.501	13.903	13.196	11.802	10.614	9.6426
Average of Maximum Cylinder Pressures	bar	152.14	154.15	152.19	149.04	147.77	141.85	135.17	127.89	116.64	106.62	99.744
Percent Load	%	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
FMEP - Cylinder (if 'EngFrictionDetail' used)	bar	1.8907	1.8207	1.771	1.7152	1.6689	1.5993	1.5259	1.4495	1.3132	1.1831	1.0687
FMEP - Crankshaft (if 'EngFrictionDetail' used)	bar	0	0	0	0	0	0	0	0	0	0	0
FMEP - Valvetrain (if 'EngFrictionDetail used)	bar	0	0	0	0	0	0	0	0	0	0	0

GT2052-1 Energy

Indicated Efficiency	%	41.958	42.678	42.965	43.2	43.327	43.398	43.377	43.233	42.528	41.384	39.658
Indicated Efficiency - Gross (360)	%	46.124	45.756	45.566	45.344	45.03	44.7	44.308	43.837	42.57	41.041	39.053
Brake Efficiency	%	36.641	37.684	38.064	38.374	38.523	38.626	38.626	38.488	37.788	36.757	35.244
Fuel Power	kW	255.51	236.96	223.22	208.07	192.24	174.74	157.15	139.67	108.85	83.832	63.578
Fuel Power, Useful Portion	kW	255.51	236.96	223.22	208.07	192.24	174.74	157.15	139.67	108.85	83.832	63.578
In-Cylinder Heat Transfer	kW	48.127	45.911	44.16	42.169	40.668	38.202	35.653	33.062	28.719	24.648	21.142
Total Exhaust Energy Percentage	%	39.207	37.948	37.252	36.533	35.519	34.741	33.936	33.096	31.087	29.214	27.088
Useful Exhaust Energy Percentage	%	39.207	37.948	37.252	36.533	35.519	34.741	33.936	33.096	31.087	29.214	27.088
Exhaust Energy Percentage (MeanV)	%	--	--	--	--	--	--	--	--	--	--	--

GT2052-1 Torque – Power

Brake Torque	N-m	406.37	426.36	427.03	423.59	416	402.84	386.42	366.68	327.31	294.26	267.47
Indicated Torque	N-m	465.34	482.86	482.01	476.87	467.88	452.6	433.95	411.88	368.37	331.29	300.97
Friction Torque	N-m	59.013	56.83	55.276	53.535	52.089	49.917	47.626	45.242	40.988	36.927	33.358
Attachment Torque	N-m	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Torque	N-m	465.34	482.86	482.01	476.87	467.88	452.6	433.95	411.88	368.37	331.29	300.97
Shaft Torque	N-m	406.37	426.36	427.03	423.59	416	402.84	386.42	366.68	327.31	294.26	267.47
Brake Power (HP)	HP	125.55	119.75	113.94	107.07	99.314	90.514	81.397	72.09	55.157	41.323	30.049
Brake Power (kW)	kW	93.622	89.296	84.965	79.845	74.058	67.497	60.698	53.758	41.131	30.815	22.407
Indicated Power	kW	107.21	101.13	95.904	89.887	83.293	75.834	68.164	60.385	46.291	34.693	25.214
Friction Power	kW	13.596	11.902	10.998	10.091	9.2731	8.3636	7.4811	6.6328	5.1507	3.867	2.7946
Attachment Power	kW	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Power	kW	107.21	101.13	95.904	89.887	83.293	75.834	68.164	60.385	46.291	34.693	25.214
Shaft Power	kW	93.622	89.296	84.965	79.845	74.058	67.497	60.698	53.758	41.131	30.815	22.407

GT2052-1 Flow

Volumetric Efficiency, Air	fraction	1.6999	1.7414	1.7262	1.6978	1.6599	1.6022	1.5358	1.4614	1.3263	1.2247	1.1599
Volumetric Efficiency, Trapped Air	fraction	1.7	1.7342	1.7196	1.692	1.6552	1.5986	1.5334	1.4603	1.3277	1.227	1.1632
Volumetric Efficiency, Air+Burned Gas	fraction	1.6999	1.7414	1.7262	1.6978	1.66	1.6022	1.5358	1.4614	1.3263	1.2248	1.1599
Volumetric Efficiency, Air+Fuel Vapor	fraction	1.6999	1.7414	1.7262	1.6978	1.6599	1.6022	1.5358	1.4614	1.3263	1.2247	1.1599
Volumetric Efficiency, All Gases	fraction	1.6999	1.7414	1.7262	1.6978	1.66	1.6022	1.5358	1.4614	1.3263	1.2248	1.1599
Volumetric Efficiency (Manifold), Air	fraction	1.6999	1.7414	1.7262	1.6978	1.6599	1.6022	1.5358	1.4614	1.3263	1.2247	1.1599
Volumetric Efficiency (Manifold), Trapped Air	fraction	1.7	1.7342	1.7196	1.692	1.6552	1.5986	1.5334	1.4603	1.3277	1.227	1.1632
Volumetric Efficiency (Manifold), Air+Burned Gas	fraction	1.6999	1.7414	1.7262	1.6978	1.66	1.6022	1.5358	1.4614	1.3263	1.2248	1.1599
Volumetric Efficiency (Manifold), Air+Fuel Vapor	fraction	1.6999	1.7414	1.7262	1.6978	1.6599	1.6022	1.5358	1.4614	1.3263	1.2247	1.1599
Volumetric Efficiency (Manifold), All Gases	fraction	1.6999	1.7414	1.7262	1.6978	1.66	1.6022	1.5358	1.4614	1.3263	1.2248	1.1599
Air Flow	kg/hr	513.38	478.1	450.23	419.53	387.38	351.9	316.25	280.86	218.49	168.13	127.38
Fuel Flow	kg/hr	21.392	19.839	18.688	17.42	16.095	14.63	13.156	11.694	9.1128	7.0185	5.3228
EGR Percentage (normalized by Air+Burned Gas)	%	0	0	0	0	0	0	0	0	0	0	0
Trapping Ratio		1	0.9959	0.9962	0.9965	0.9972	0.9978	0.9984	0.9992	1	1	1
Air-Fuel Ratio (Inducted Air/Total Fuel)		23.999	24.099	24.092	24.083	24.068	24.054	24.038	24.019	23.976	23.955	23.93
Air-Fuel Ratio (Trapped Air/Total Fuel)		24	24	24	24	24	24	24	24	24	24	23.999
Percent Burned Mass at Cycle Start	%	4.5791	4.1804	4.0318	3.9086	3.8192	3.7212	3.6163	3.5726	3.6479	3.9325	4.2097

GT2052-1 Compressor

Average Speed	RPM	165365	158134	153932	149007	143623	136837	129566	122103	106678	94167.6	85239.7
Average Map Pressure Ratio		2.34623	2.33094	2.27067	2.19805	2.11768	2.01485	1.90323	1.78626	1.58904	1.45257	1.36983
Average Static Pressure Ratio		2.37557	2.35669	2.29213	2.21531	2.13113	2.02471	1.91015	1.79087	1.59096	1.45336	1.37018
Average Inlet Pressure	bar	0.945667	0.951255	0.956955	0.962793	0.968442	0.973949	0.978868	0.983158	0.989431	0.993245	0.995407
Average Outlet Pressure	bar	2.2465	2.24181	2.19346	2.13289	2.06387	1.97196	1.86978	1.76071	1.57415	1.44354	1.36389
Average Inlet Temperature	K	297.192	297.329	297.477	297.625	297.768	297.909	298.035	298.145	298.313	298.425	298.5
Average Outlet Temperature	K	408.01	406.79	402.42	397.25	391.829	385.39	378.548	370.835	356.834	346.118	339.19
Average Mass Flow Rate	lb/min	18.874	17.87108	16.80426	15.63215	14.39853	13.04615	11.68736	10.34288	7.989	6.128624	4.626601
Average Efficiency	%	73.9329	74.1068	74.5878	75.0742	75.3363	75.1062	74.3754	73.6263	71.8486	70.1423	68.7052
Average Power	kW	16.0111	14.9934	13.5206	11.943	10.3889	8.75619	7.22036	5.76853	3.58567	2.24091	1.44274
Average Reduced Speed	RPM/K^0.5	9566.94	9149.18	8906.49	8621.89	8310.69	7918.3	7497.76	7066	6173.49	5449.43	4932.64
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	31.38868	29.60635	27.7286	25.68902	23.56894	21.27405	18.99348	16.75878	12.88891	9.861732	7.433924
Rack Position		0	0	0	0	0	0	0	0	0	0	0
Average Corrected Speed	RPM	165151	157939	153750	148837	143465	136691	129431	121978	106571	94071.7	85150.6
Average Corrected Mass Flow	lb/min	19.6178	18.50389	17.33032	16.05557	14.73054	13.29626	11.87087	10.47422	8.055549	6.163559	4.646191
Average Tip Speed	m/s	451.972	432.209	420.726	407.264	392.548	374.001	354.129	333.73	291.572	257.377	232.976

GT2052-1 Turbine

Average Speed	RPM	165365	158134	153932	149007	143623	136837	129566	122103	106678	94167.6	85239.7
Average Map Pressure Ratio		2.46048	2.33318	2.24728	2.15255	2.0513	1.93736	1.81785	1.70012	1.50032	1.36868	1.27676
Average Static Pressure Ratio		2.40798	2.28427	2.20099	2.10928	2.01144	1.90124	1.78562	1.67186	1.47912	1.35278	1.26462
Average Inlet Pressure	bar	2.88973	2.67571	2.53826	2.39341	2.24543	2.08795	1.93107	1.78296	1.54468	1.39464	1.29309
Average Outlet Pressure	bar	1.20007	1.17137	1.15324	1.1347	1.11633	1.0982	1.08146	1.06645	1.04432	1.03094	1.02251
Average Inlet Temperature	K	895.601	878.437	868.732	858.473	844.072	832.412	820.071	807.044	776.44	747.816	716.009
Average Outlet Temperature	K	767.855	761.216	758.36	755.736	749.958	747.778	745.66	743.214	731.885	715.954	692.179
Average Mass Flow Rate	lb/min	19.45986	17.9515	16.92145	15.78334	14.59562	13.27959	11.95568	10.6389	8.30792	6.463524	4.904462
Average Efficiency	%	72.022	71.1358	70.5353	69.787	68.8671	67.6291	65.9882	63.6047	56.2044	46.7283	40.3545
Average Power	kW	22.1277	18.7108	16.5978	14.4011	12.1814	9.95337	7.86249	5.98056	3.21371	1.72631	0.941624
Average Reduced Speed	RPM/K^0.5	5511.38	5321.83	5209.52	5073.17	4931.79	4732.03	4514.69	4289.42	3821.9	3438.71	3181.88
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	18.31272	18.11112	17.92592	17.66157	17.29886	16.85004	16.32562	15.65317	13.90033	11.77421	9.420223
Wastegate Mass Flow Rate	lb/min	0.160524	0.14968	0.142505	0.134713	0.126724	0.117406	0.107427	0.09711	0.07784	0	0
Wastegate Diameter	mm	2	2	2	2	2	2	2	2	2	0	0
Rack Position		0	0	0	0	0	0	0	0	0	0	0
Average Blade Speed Ratio		0.740001	0.73772	0.739607	0.741773	0.747197	0.751137	0.760452	0.777659	0.833456	0.917814	1.05125
Average Tip Speed	m/s	474.677	453.921	441.861	427.723	412.268	392.789	371.918	350.494	306.219	270.307	244.679

GT1241 Performance

Engine Speed (cycle average)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
Engine Speed (end of cycle)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
BMEP - Brake Mean Effective Pressure	bar	7.2215	8.089	8.5394	8.9875	9.4104	9.722	9.963	10.139	10.19	10.021	9.4227
IMEP720 - Net Indicated Mean Effective Pressure	bar	8.8115	9.6282	10.054	10.477	10.885	11.166	11.374	11.515	11.495	11.238	10.539
IMEP360 - Gross Indicated Mean Effective Pressure	bar	9.9075	10.548	10.876	11.195	11.49	11.658	11.753	11.785	11.568	11.152	10.354
FMEP - Friction Mean Effective Pressure	bar	1.5924	1.5416	1.5168	1.4918	1.4767	1.4457	1.4118	1.3756	1.3023	1.2135	1.1112
PMEP - Pumping Mean Effective Pressure	bar	-1.096	-0.92	-0.822	-0.718	-0.605	-0.491	-0.379	-0.27	-0.073	0.0862	0.1848
BSFC - Brake Specific Fuel Consumption	g/kW-h	254.83	243.29	238.27	233.76	230.34	227.38	225.12	223.53	223.46	225.81	233.46
ISFC - Indicated Specific Fuel Consumption	g/kW-h	208.85	204.4	202.38	200.53	199.13	197.97	197.2	196.82	198.11	201.35	208.74
BSAC - Brake Specific Air Consumption	g/kW-h	6125.8	5847.8	5726.8	5617.8	5534.5	5461.8	5405.4	5364.5	5357.2	5407.9	5587.4
ISAC - Indicated Specific Air Consumption	g/kW-h	5020.4	4912.9	4864.1	4819.1	4784.7	4755.4	4734.8	4723.6	4749.3	4822.2	4995.6
FMEP-PMEP	bar	2.6884	2.4617	2.3391	2.2094	2.0819	1.9371	1.7905	1.6455	1.3751	1.1273	0.9265
Shaft MEP	bar	7.2215	8.089	8.5394	8.9875	9.4104	9.722	9.963	10.139	10.19	10.021	9.4227
Attachment MEP	bar	0	0	0	0	0	0	0	0	0	0	0
Crank Pin MEP	bar	8.8116	9.6282	10.054	10.477	10.885	11.166	11.374	11.515	11.495	11.238	10.539
Average of Maximum Cylinder Pressures	bar	92.475	98.319	101.36	104.35	109.34	111.13	112.36	113.12	114.46	112.69	108.24
Percent Load	%	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
FMEP - Cylinder (if 'EngFrictionDetail' used)	bar	1.5924	1.5416	1.5168	1.4918	1.4767	1.4457	1.4118	1.3756	1.3023	1.2135	1.1112
FMEP - Crankshaft (if 'EngFrictionDetail' used)	bar	0	0	0	0	0	0	0	0	0	0	0
FMEP - Valvetrain (if 'EngFrictionDetail used)	bar	0	0	0	0	0	0	0	0	0	0	0

GT1241 Energy

Indicated Efficiency	%	40.088	40.96	41.368	41.751	42.042	42.289	42.456	42.536	42.261	41.58	40.108
Indicated Efficiency - Gross (360)	%	45.074	44.874	44.752	44.61	44.38	44.15	43.87	43.533	42.528	41.262	39.405
Brake Efficiency	%	32.854	34.412	35.137	35.815	36.346	36.819	37.189	37.455	37.465	37.077	35.86
Fuel Power	kW	158.06	153.67	150.93	147.64	143.86	138.09	131.35	123.87	106.68	88.339	68.708
Fuel Power, Useful Portion	kW	158.06	153.67	150.93	147.64	143.86	138.09	131.35	123.87	106.68	88.339	68.708
In-Cylinder Heat Transfer	kW	33.575	33.137	32.872	32.541	32.644	31.961	31.136	30.196	28.296	25.634	22.408
Total Exhaust Energy Percentage	%	38.671	37.476	36.853	36.209	35.267	34.566	33.839	33.087	31.217	29.401	27.278
Useful Exhaust Energy Percentage	%	38.671	37.476	36.853	36.209	35.267	34.566	33.839	33.087	31.217	29.401	27.278
Exhaust Energy Percentage (MeanV)	%	--	--	--	--	--	--	--	--	--	--	--

GT1241 Torque – Power

Brake Torque	N-m	225.4	252.48	266.54	280.52	293.72	303.45	310.97	316.46	318.07	312.77	294.11
Indicated Torque	N-m	275.03	300.52	313.81	327.02	339.75	348.53	355.01	359.4	358.78	350.76	328.95
Friction Torque	N-m	49.702	48.117	47.344	46.562	46.091	45.123	44.066	42.937	40.648	37.876	34.684
Attachment Torque	N-m	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Torque	N-m	275.03	300.52	313.81	327.02	339.75	348.53	355.01	359.4	358.78	350.76	328.95
Shaft Torque	N-m	225.4	252.48	266.54	280.52	293.72	303.45	310.97	316.46	318.07	312.77	294.11
Brake Power (HP)	HP	69.638	70.911	71.117	70.909	70.121	68.182	65.505	62.217	53.6	43.922	33.042
Brake Power (kW)	kW	51.929	52.879	53.032	52.877	52.289	50.843	48.847	46.396	39.969	32.753	24.639
Indicated Power	kW	63.362	62.941	62.438	61.641	60.484	58.396	55.765	52.69	45.085	36.732	27.558
Friction Power	kW	11.451	10.078	9.4199	8.7767	8.2053	7.5604	6.9218	6.2949	5.108	3.9663	2.9056
Attachment Power	kW	0	0	0	0	0	0	0	0	0	0	0
Crank Pin Power	kW	63.362	62.941	62.438	61.641	60.484	58.396	55.765	52.69	45.085	36.732	27.558
Shaft Power	kW	51.929	52.879	53.032	52.877	52.289	50.843	48.847	46.396	39.969	32.753	24.639

GT1241 Flow

Volumetric Efficiency, Air	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Volumetric Efficiency, Trapped Air	fraction	1.0516	1.1246	1.1627	1.2005	1.2387	1.2632	1.2817	1.2951	1.3013	1.293	1.2571
Volumetric Efficiency, Air+Burned Gas	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Volumetric Efficiency, Air+Fuel Vapor	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Volumetric Efficiency, All Gases	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Volumetric Efficiency (Manifold), Air	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Volumetric Efficiency (Manifold), Trapped Air	fraction	1.0516	1.1246	1.1627	1.2005	1.2387	1.2632	1.2817	1.2951	1.3013	1.293	1.2571
Volumetric Efficiency (Manifold), Air+Burned Gas	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Volumetric Efficiency (Manifold), Air+Fuel Vapor	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Volumetric Efficiency (Manifold), All Gases	fraction	1.0533	1.1263	1.1644	1.2022	1.2401	1.2643	1.2823	1.2951	1.2998	1.2903	1.2536
Air Flow	kg/hr	318.11	309.22	303.7	297.05	289.4	277.7	264.04	248.89	214.12	177.13	137.67
Fuel Flow	kg/hr	13.233	12.865	12.636	12.361	12.044	11.561	10.997	10.371	8.9317	7.3958	5.7523
EGR Percentage (normalized by Air+Burned Gas)	%	0	0	0	0	0	0	0	0	0	0	0
Trapping Ratio		0.9984	0.9985	0.9985	0.9986	0.9988	0.9991	0.9995	1	1	1	1
Air-Fuel Ratio (Inducted Air/Total Fuel)		24.039	24.036	24.035	24.032	24.027	24.02	24.011	24	23.973	23.95	23.933
Air-Fuel Ratio (Trapped Air/Total Fuel)		24	23.999	23.999	23.999	24	24	24	24	24	24	24
Percent Burned Mass at Cycle Start	%	5.1685	4.8006	4.6334	4.4822	4.3549	4.2392	4.1388	4.0598	3.9659	4.0346	4.2567

GT1241 Compressor

Average Speed	RPM	194046	190320	188123	185620	183136	179355	174989	170165	158776	148310	137001
Average Map Pressure Ratio		1.4372	1.49016	1.51991	1.55038	1.58167	1.59571	1.60186	1.60207	1.57977	1.55049	1.49747
Average Static Pressure Ratio		1.42597	1.4813	1.5123	1.54401	1.57649	1.59136	1.59817	1.59891	1.57732	1.54866	1.49609
Average Inlet Pressure	bar	0.96599	0.967934	0.969112	0.970501	0.972073	0.974373	0.976929	0.9796	0.985031	0.989808	0.993709
Average Outlet Pressure	bar	1.37747	1.4338	1.46558	1.49846	1.53246	1.55058	1.56129	1.56629	1.55371	1.53288	1.48667
Average Inlet Temperature	K	297.648	297.703	297.736	297.775	297.819	297.884	297.956	298.032	298.187	298.329	298.454
Average Outlet Temperature	K	364.767	365.51	365.549	365.323	365.161	364.123	362.765	361.094	356.927	353.746	351.389
Average Mass Flow Rate	lb/min	11.77048	11.43553	11.22742	10.97619	10.68328	10.23865	9.719175	9.1448	7.83159	6.452823	5.002295
Average Efficiency	%	47.4439	52.0736	54.8866	57.9613	61.0457	63.4088	65.4385	67.3235	70.0842	71.1469	68.3659
Average Power	kW	6.15013	6.02009	5.90299	5.74077	5.56346	5.23915	4.86152	4.44729	3.54248	2.75044	2.03509
Average Reduced Speed	RPM/K^0.5	11226.2	11010.9	10883.9	10739.2	10595.7	10377.2	10124.8	9845.92	9187.35	8581.95	7927.55
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	19.26432	18.69292	18.3389	17.91271	17.41715	16.66789	15.79642	14.83773	12.66322	10.40235	8.044332
Rack Position		0	0	0	0	0	0	0	0	0	0	0
Average Corrected Speed	RPM	193795	190077	187886	185388	182910	179138	174781	169967	158598	148147	136851
Average Corrected Mass Flow	lb/min	12.04014	11.68301	11.46177	11.19538	10.8857	10.41739	9.872763	9.273533	7.914501	6.501461	5.027692
Average Tip Speed	m/s	416.569	408.569	403.855	398.481	393.148	385.031	375.658	365.303	340.854	318.385	294.107

GT1241 Turbine

Average Speed	RPM	194046	190320	188123	185620	183136	179355	174989	170165	158776	148310	137001
Average Map Pressure Ratio		1.85256	1.81973	1.80007	1.77746	1.75047	1.71383	1.67329	1.63141	1.54028	1.46022	1.37646
Average Static Pressure Ratio		1.82072	1.78918	1.77026	1.7485	1.72253	1.68728	1.64832	1.60816	1.52084	1.44453	1.36416
Average Inlet Pressure	bar	1.97434	1.9316	1.90641	1.87764	1.84355	1.79769	1.74755	1.69639	1.58746	1.49381	1.39931
Average Outlet Pressure	bar	1.08437	1.0796	1.07691	1.07386	1.07026	1.06544	1.0602	1.05487	1.0438	1.03411	1.02577
Average Inlet Temperature	K	879.027	863.393	855.211	846.693	834.212	824.657	814.604	804.122	777.766	751.449	720.135
Average Outlet Temperature	K	792.976	781.981	776.53	771.12	762.574	757.856	753.319	748.79	735.956	718.435	694.646
Average Mass Flow Rate	lb/min	12.01789	11.68531	11.47882	11.23025	10.94614	10.51054	10.00164	9.436393	8.135114	6.810051	5.299324
Average Efficiency	%	67.6913	66.7442	66.0572	65.1505	63.9212	61.9739	59.2165	55.4761	43.8615	36.0046	31.0934
Average Power	kW	8.92935	8.19617	7.77204	7.29329	6.72512	6.00919	5.2317	4.44007	2.85325	1.83512	1.06882
Average Reduced Speed	RPM/K^0.5	6531.25	6463.84	6419.91	6366.47	6328.32	6233.83	6119.94	5990.39	5684.56	5403.29	5099.76
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	16.44586	16.22029	16.0834	15.91667	15.70786	15.40852	15.02477	14.54475	13.2422	11.62586	9.456445
Wastegate Mass Flow Rate	lb/min	0.107805	0.105721	0.104333	0.102617	0.100677	0.09755	0.093915	0.089969	0.081	0	0
Wastegate Diameter	mm	2	2	2	2	2	2	2	2	2	0	0
Rack Position		0	0	0	0	0	0	0	0	0	0	0
Average Blade Speed Ratio		1.04225	1.05038	1.05578	1.06248	1.07563	1.08737	1.10199	1.11967	1.17113	1.25059	1.3557
Average Tip Speed	m/s	557.007	546.31	540.005	532.82	525.689	514.836	502.304	488.457	455.766	425.722	393.259