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Performance of A Small Diesel Engine by Experimental and Numerical Simulation Analysis

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Abstract. A single cylinder diesel engine is an internal combustion engine; this machine is typically a compression ignition engine, fuel ignition through a high one made for compression of fuel and air mixtures. This study conducts a modelling with one dimension on a single cylinder four-stroke diesel engine and analyses the simulation results with experimental data. The simulation model covers the entire engine cycle consisting of compression, power, intake, and disposal for different engine speeds such as 1000, 2000, 3000, 4000, 5000, and 6000 rpm. Simulation modelling was done for the development of computation using software GT-POWER. The result of this modelling measures the accuracy level of machine parameter data from the modelled simulation. Based on the simulation results with modelling the machine, the data accuracy rate reached 90% in various cases tested with different engine speeds. Furthermore, the results also show that the modelling provides accurate data and can be used in the industry as a tool for development of different machines in the future.

Keyword : *single cylinder direct injection, in-cylinder heat transfer, performance*

1. Introduction

A single cylinder diesel engine is an internal combustion engine; this machine is typically a compression ignition engine, which fuel ignition through a high one made for compression of fuel and air mixtures [1-6]. The engine operating system uses a cycle on a diesel engine. Unlike the petrol machine, the incoming air does not throttle so the engine will experience over speed if not immediately done. The engine wheel system will encourage older injection [7-8].

The modelling of direct injection diesel engines in this study was measured using four distinctive steps. The modelling of the diesel engine with the GT-POWER simulation shown for this four-cylinder engine. The GT-POWER liner device is a very prominent simulation tool that can be used for the manufacture of vehicle engines and suitable to analyse various problems found on the machine [9]. Designing models for steady state and transient simulations using GT-POWER can be used as an analysis tool on engine control and powertrain. These are all for internal combustion engines, and many components are provided to users as advanced modelling concepts. GT-POWER software is based on the dynamics of gas for one dimension, beginning with heat transfer and flow into piping in other



components found on the system machine. GT-POWER software is a typical one-dimensional tool of the GT-SUITE family [10-14].

The details contained in the diesel engine design have many significant variations in the size range and performance on the machine. In particular, the geometry of the combustion chamber is very different from the required fuel injection characteristics, which can greatly enhance possibility to solve the problem of large diesel engine designs that can achieve rapid fuel blending speed in the process of available time completion for fuel combustion in the engine [1], [15-19]. Types of geometry contained in inlet port, piston shape, cylinder head, and pattern on fuel injection that can be used over a diesel size range.

A high increase in engine strength can be shown where their products can be expected by the manufacturer to provide strength, reliability, resilience, and economics that can be satisfactory below service situations. Generally, the maximum torque velocity at which it should reach is also provided. According to [20-22], machine performance parameters are the most important one in geometric properties, engine performance parameters, and of the engine efficiency. Engine efficiency includes thermal, mechanical, relative, brake heat, and volumetric efficiencies. Parameters related to engine performance are average effective pressure, specific power output, engine intake valve index, average piston speed, fuel-air, air-fuel ratio, specific fuel consumption, and the calorific value contained in the fuel.

Internal combustion [22-24] investigating the importance of performance parameters on diesel engines such as efficient terms, machine performance parameters, and other related geometric properties. Thermal efficiency can show machine, mechanical, brake heat, relative, and volumetric efficiencies. The parameters contained in the performance of other related machines are the effects of average pressure, specific power consumption for fuel output, the average speed of piston, fuel, intake valve match index, and air at fuel output or air-fuel ratio. Designs built on the geometry of a four-cylinder diesel engine, the compression ratio of a diesel engine is the maximum volume of the cylinder as well as the displaced volume cylinder (V_d) and cylinder volume demand (V_c) as in the division for lowest cylinder volume (V_c). The measurement of the compression ratio contained in a four-cylinder diesel engine can be done using Equation (1).

$$r_c = \frac{V_d + V_c}{V_c} \quad (1)$$

The power delivered by the diesel engine and absorbed by the dynamometer is the torque product and the angular velocity. The power of a diesel engine can be defined by Equation (2).

$$P = 2\pi NT \quad (2)$$

Every engine efficiency is as predetermined by [20]. The energy ratio (E) is the measured indicated thermal efficiency (π_{ith}) of the indicated power (ip) with the energy at the fuel input. The ratio of energy in brake power (bp) is the efficiency of the brake thermal efficiency (π_{bth}), the ratio of braking power (bp) or power delivery to indicated power as shown by the indicated power or also the power supplied to the piston is defined by mechanical efficiency (π_m) which also can be defined as the efficiency ratio for brake heat and thermal efficiency. The thermal efficiency ratio of the actual cycle has an ideal cycle which is the relative efficiency or efficiency ratio (π_{rel}). The efficiency ratio is very necessary to be used in the criteria for the level of engine development used. One of the most important parameters in determining the performance of the four-stroke engine is volumetric efficiency (π_v). This is because in the four-stroke machine, there is a difference of suction stroke and therefore volumetric efficiency can show the machine respiration ability. The volume rate into the shared intake system is the volumetric efficiency at a rate at which the system removes volume. The normal volumetric efficiency range is about 85%–90% when at full speed for the CI machine and 80%–85% for the SI machine [24], [25].

$$\Pi_{ith} = \frac{ip}{E} \quad (3)$$

$$\Pi_{ith} = \frac{bp}{E} \quad (4)$$

$$\Pi_m = \frac{bp}{ip} \quad (5)$$

$$\Pi_v = \frac{m_a}{P_n V_{dip} N/2} \quad (6)$$

$$\Pi_{rel} = \frac{\text{Actual therm efficiency}}{\text{Air-standar efficiency}} \quad (7)$$

The research related to machine performance has been done by [20], [26-27]. Mean effective pressure (*mep*) is where number of crank revolutions per power stroke (n_R) is the sum of all crank turns for each power on the cylinder (one for two-stroke and two for four-stroke per cycles) as shown in Equation (8).

$$mep = \frac{P n_R}{V_d N} \quad (8)$$

The efficiency of a given fuel conversion is an efficient measure of the engine as mentioned by [1]:

$$\eta_f = \frac{W_c}{m_f Q_{HV}} = \frac{(P n_R / N)}{(m_f n_R / N) Q_{HV}} = \frac{P}{m_f Q_{HV}} \quad (9)$$

Specific fuel consumption as:

$$sfc = \frac{m_f}{P} \quad (10)$$

In testing this modelled engine, both the fuel mass flow rate (m_f) and the mass flow rate (m_a) were measured. The use of the flow rate ratio to define the conditions in engine operation is the fuel or air ratio (A/F) and also the water ratio (F/A). Development of parameters of machine performance can be correlated using the following Equations (11) and (12).

For power P:

$$P = \frac{n_f m_a N Q_{HV} (F/A)}{n_R} \quad (11)$$

$$P = \frac{n_f n_v N V_d Q_{HV} P_{a,i} (F/A)}{2} \quad (12)$$

The torque (T) measurement used Equation (13). Where power per piston crown area is fuel conversion efficiency (η_f), volumetric efficiency (η_v), (N_d) fuel heating value (Q_{HV}), ($P_{a,i}$), and (F/A) divided by 4π .

$$P = \frac{n_f n_v N_d Q_{HV} P_{a,i} (F/A)}{4 \pi} \quad (13)$$

For mean effective pressure measurement, Equation (14) was used.

$$mep = n_f n_v Q_{HV} P_{a,i} (F/A) \quad (14)$$

The specific strength of each piston unit is a success in measuring and designing the engine used in the existing piston area regardless of the available cylinder size. Specific power can be measured using Equation (15). Where power per piston crown area is fuel conversion efficiency (η_f), volumetric efficiency (η_v), fuel heating value (NLQ_{HV}) ($P_{a,i}$), and (F/A) divided by two.

$$\frac{P}{A_p} = \frac{n_f n_v N L Q_{HV} P_{a,i} (F/A)}{2} \quad (15)$$

Meanwhile, the piston velocity can be measured using Equation (16). Where power per piston crown area is fuel conversion efficiency (n_f), volumetric efficiency (n_v), fuel heating value (NS_p), (Q_{HV}), ($P_{a,i}$), and (F/A) divided by four.

$$\frac{P}{A_p} = \frac{n_f n_v N S_p Q_{HV} P_{a,i} (F/A)}{4} \quad (16)$$

Thus, the specific power is related to the product such as average piston velocity and average effective pressure [1]. This relationship has illustrated the importance of engine efficiency performance in high fuel conversion, high volumetric efficiency, can increase engine output at the time of displacement by growing the incoming air density, the maximum fuel ratio that can be used for the machine and the average speed pistons.

2. Experiment Setup

The modelling of diesel engine direct-injection (DI) four single cylinder strokes developed for the simulation is presented in this paper. The diesel engine specifications were modelled as shown in Table 1. Figure 1 shows the engine used in the experiment.

Table 1. Specifications diesel engine single cylinder

Model	Yanmar Model TF120M
Ratio Compression	17.7:1
Continuous output	10.5 HP @ 2400 rpm
Fuel tank capacity	11 L
Displace volume (cm ³)	638
Fuel injection type	Direct Injection
Bore (mm)	92
Maximum output	12.0 HP @ 2400 rpm
Type	Horizontal single-cylinder four-stroke engine diesel
Max power	7.7 kW @ 2400 rpm
Max torque	161 Nm @ 4500 rpm
Cooling system	Water-radiation
Stroke (mm)	96



Figure 1. Engine test

In the development of engine modelling in GT-POWER, the first step was to investigate and open the diesel engine to measure all components contained in the machine to be incorporated into the GT-POWER library. Then, for modelling machines in the GT-POWER, the window was selected at first and the title template was contained in the library menu. The GT-POWER in template library was placed on the left side of the screen. All templates were pre-loaded, and everything available on the menu were used for the machine modelling. To begin the modelling purposes, the icons listed in the template library were clicked and dragged into the project library. Among them was the required template and also some contained objects which were included in the GT-POWER library. Fuel injection systems and engine cylinders were focused on the engine cylinder performance with fuel support from fuel injection systems, exhaust gases, and systems on fresh air intake up to the exhaust system. In cylinders and fuel injection systems on diesel engines have several components, but all diesel engines have the same components. Components, data, and size were recorded and inserted into the GT-POWER library. All components of the system on fuel injection and engine cylinders were injectors, engines and cylinders. The exhaust system was the last system on the machine. This system started from the exhaust valve and ended in the environment. Exhaust system found on GT-POWER are exhaust port, muffler, exhaust valve, exhaust runner exit, exhaust runner, and environment.

Once the diesel engine system modelling was completed, the development of diesel engine model was done using GT-POWER software. GT-POWER computing was used for modelling diesel engines, engine cylinders, intake systems, and fuel injection systems as well as exhaust systems. Fuel injection systems, intake systems, and engine cylinder systems were connected to the involved in the engine and intake cylinder systems as well as the fuel injection system. Fuel injection systems and engine cylinders were connected into the exhaust system inside the cylinder and fuel injection system were located on exhvalve in the exhaust. Orificeconn connected all components contained in the diesel engine. Once the work was completed, diesel engine modelling was extended and developed using GT-POWER software. Modelling diesel engines were fired by GT-POWER as shown in Figure 2.

The data information was used to build diesel engine models included in the GT-POWER library. This modelling does not require all items, and only additional information may be required. However, this list is an excellent starting point. If the initial stage of model development is being done, the optimum value must be determined for some items on the list to which the simulation ends. In this case, the determination of the attribute must first be defined as a parameter to run a series of cases in determining the optimal value. The data from machine characteristics were compression ratio, inline or V configuration, combustion sequence, V-angle (optional), two or four strokes. While the data contained in the geometry of the cylinder were a stroke, pin offset, bore, high clearance TDC piston, length connecting rod, head area, piston area, and head of bowl geometry. All components in geometry were data in intake and exhaust systems. While the data on the throttle was a throttle location and coefficient for discharge with throttle angles in a two-way flow. Meanwhile, the data in fuel injector were some injector and location, nozzle diameter and a number of the nozzle hole, LVH, injection rate, and type of fuel. Data on the exhaust and intake valves were profiles of elevators, valve lashes, valve diameters, and discharge coefficients. For data on ambient conditions were temperature, humidity, and pressure. While for performance data is very used when setting up the model after the development has been completed.

These preparations such as reviewing the finished model, setting the case, making arrangements, plot settings, and plot requests need to be done. The parameters contained in the created model were listed automatically in each case, and case settings must be defined for the initial case of the simulation. Computational time can often be reduced to steady-state simulation systems in the planned sequence and take advantage of the initialisation state to be able to run the settings. Time plots and also cycles can be requested by selecting some appropriate plots to be used from the folders in the plot options for each section. Requests from all plots contained in individual sections will be automatically saved, the result of this plot regardless of the request selected.

When diesel engine modelling is ready, the simulation with GT-POWER can be started and run. Simulation progress was displayed in a window with a scrolling text form. After all, the data input was

successfully read, the simulation was run, and further developments in the form of reports were produced.

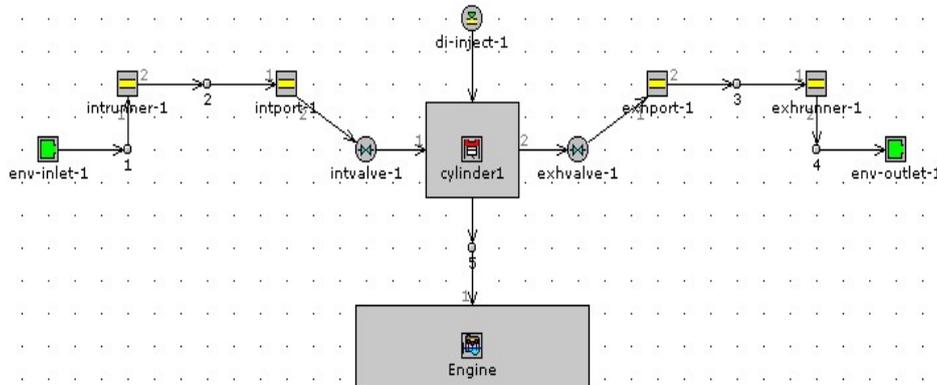


Figure 2. Single cylinder direct injection diesel engine on GT-POWER [28]

3. RESULTS AND DISCUSSION

Whenever a simulation is run, some output files will be generated from the GT-SUITE process which contains the report results in graphs and tables in various formats. The output is mostly available on GT-POST post-processing applications. This tool is very sophisticated as it can be used to display the animation and output of the analysis as it has been selected during the setup before simulation [2].

The results of all running simulations were all data from different engine performance and speed (rpm). The modelling of this machine was run at different engine speeds such as 1000, 2000, 3000, 4000, 5000, and 6000 rpm. Simulation results in this paper to produce engine performance such as brake specific CO, brake specific CO₂, brake power (kW), brake power (HP), and brake torque (bar).

The experimental results data needs to be verified in determining the accuracy of the data in the simulated model. The accuracy of the verified values in the modelling were compared with the data from the experimental results. Verification at the initial stage that the simulation results there are some differences in the results data from the experiment. Thus, this modelling requires calibration so that the simulation result will be close to the experiment result. Calibrated models include lifting at a crank angle with a value of 0.83 for the duration of a single cylinder diesel engine to obtain similarity to the engine specifications. Furthermore, the maximum coefficient number was 5 mm and advanced to 0.95. Hence, this model has a new array to be able to perform validation on the experimental data.

Figure 3 shows the results after tuning and calibration of the data. The difference between the simulation results and the experimental data was 7%–10%. Thus, the newly completed model can be optimised and used in the next simulation phase. The average percentage of simulation difference with the experiments of all cases tested was about 7%. Hence, the modelling with GT-POWER software has been successful. This result is a development of real research experimental data.

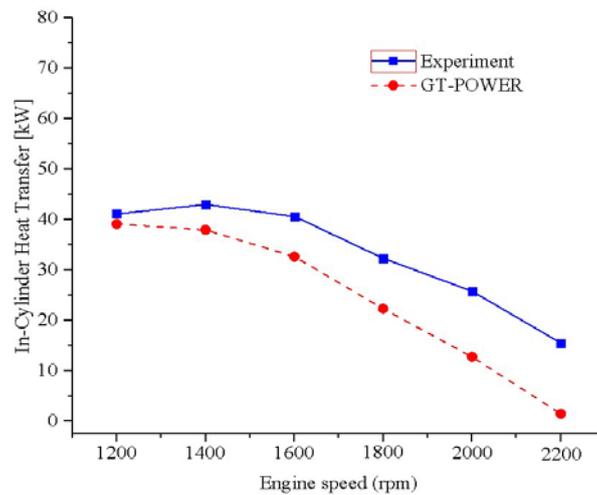


Figure 3. In-Cylinder Heat Transfer for different speed

Variations of brake efficiency with different engine speeds and loads are as shown in Figure 4. Different ratios of results between experimental data developed and simulations of models made using GT-Power with different engine speeds and loads was only about 7%. Thus, the level of accuracy of simulation data with built models can be trusted and can be used for engine development in automotive industry [29].

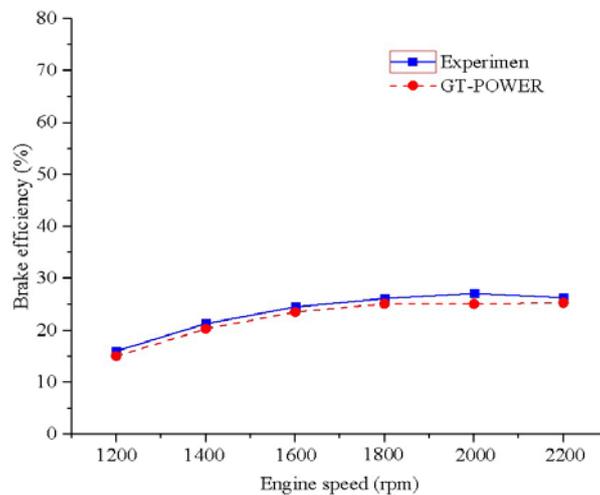


Figure 4. Brake specific for different speed

A measurement of the accuracy of the engine modelling built to verify the experimental data is required. The model was built, and its accuracy was verified by comparing experimental engine performance with modelling. Of the two results, the value was correlated based on the trend. The initial stage of verification shows a very significant difference when compared with the experimental results. Thus, this model needs to be calibrated so that the results will be able to resemble experimental data. In order to calibrate the model, some parameters must be adjusted such as the angle multiplier is set so that the duration of the simulation is the same as that on the machine. The forward coefficient was also adjusted, and the maximum number was made to 5 mm to generate new array numbers which can be

used in the valve model. The result of experimental validation data with model simulation is as shown in Figure 5.

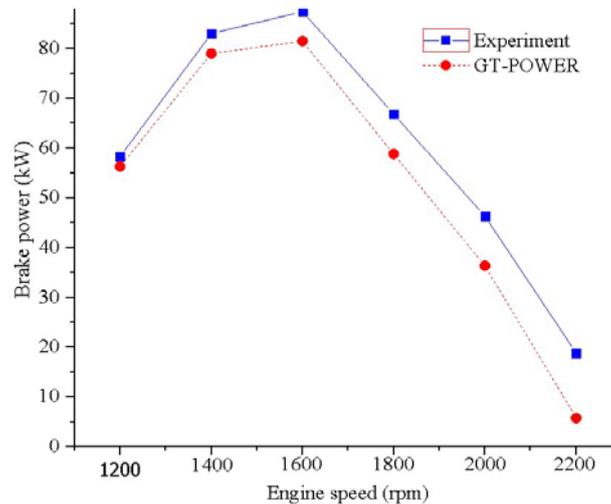


Figure 5. Brake power (kW) for different speed

The simulated results were validated based on the results data from experiments that have been performed to serve as practical data [30]. The graph of the comparative results modelled between the simulation results and the results of the experimental studies is as illustrated in Figure 6. The graph illustrates the brake power curves with full engine loads at different speeds. The percentage of the maximum and minimum deviations investigated that deviation was 5%–10%, respectively. From this result, it states that the level of accuracy of the simulation has achieved reliable results.

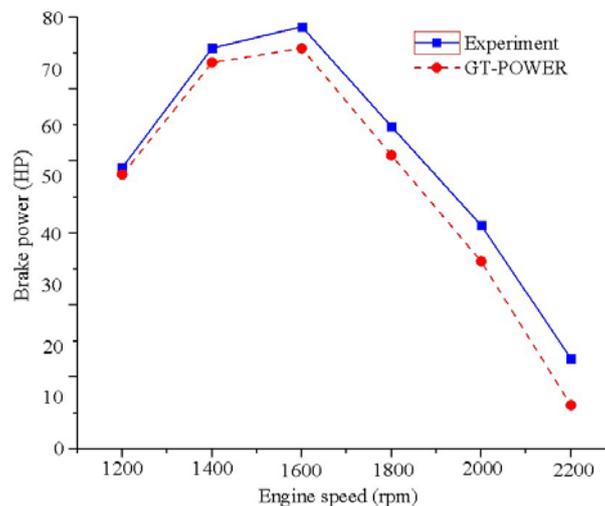


Figure 6. Brake power (HP) for different speed

The modelling machines built with GT-POWER software were evaluated with experimental data to calculate the accuracy of the data, and the results of experimental data were compared with the simulation results using GT-Power to be adjusted, as shown in Figure 7. The simulation results and experimental data got the deal which was excellent. This suitability can be seen at experimental and

simulated experimental error rate at only 3%, which was within the allowed distance range. Therefore, the results of calibration with GT-POWER modelling have a level of performance accuracy in the analysis and simulation modelled was relatively reliable.

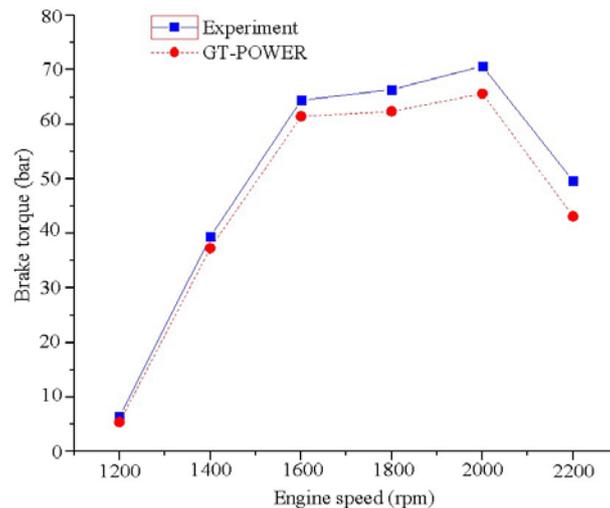


Figure 7. Brake torque (bar) for different speed

4. Conclusion

In this paper, the experimental data were compared with the simulation using GT-POWER software. The purpose of this simulation is to measure machine parameters with accuracy in the model simulation. Simulations were performed with different machine speeds (1000, 2000, 3000, 4000, 5000, and 6000 rpm). This simulation result can be used as a standard for machine in the future. Testing at different engine speeds indicates a level of data efficiency similar to that of experimental data. From the simulation results, it shows that the accuracy of the data in the simulation with experimental reached 90% for the entire tested case. Thus, the simulation of diesel engine modelling with GT-POWER software can be used for industry in the development of vehicle engines and other engines.

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