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The Effect of EFI to the Carbureted Single Cylinder Four Stroke Engine

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ABSTRACT

The study is conducted to study the EFI system performance as compared to the carburetted system for a single cylinder 4 stroke engine. In this study, a modelling and simulation study on the engine performance with EFI system was investigated utilizing engine simulation software, GT POWER software. The first part of the study is developing the carburetted engine model and simulating it using the GT POWER software. The results are validated using the result of engine dyno testing as well as the result of simulation using WAVE software. Then, the validated carburetted model is converted to EFI model, and simulated to investigate the performance of the engine installed with EFI system especially at low speed range. The findings conclude that the application of the EFI system to the carburetted single cylinder 4 stroke engine does produces improved performance in term of engine torque and power generated. The result of this study will provide platform for further research related to the investigation of the effect of EFI on the performance of 4 stroke single cylinder engine against environmental changes, the emissions output, life cycle analysis, engine wear and degradation over time, fuel injection study, engine control and tuning and etc.

Keywords: *Carbureted Engine, Electronic Fuel Injection, GT Power, Air Fuel Ratio, Engine Torque*

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Introduction

Most of the single cylinder 4 stroke engines utilize carburetor instead of the Electronic Fuel Injection (EFI) in their fuel delivery system for simplicity and hence, reduces the overall production cost. These carbureted engines are usually used for motorcycle and karts. The examples of single cylinder 4 stroke engine are Brigss and Straton and GO-KART engine. It is a single cylinder, four stroke engine with carbureted fuel system used for the Go-Kart engine. The GO-KART engine is one of the engines produced by an undisclosed Manufacturer which is still under further development stage where the engine durability, functionality, emissions and performance are being further improved. Tuning of carburetor to get the right amount of fuel throughout its operating condition is exigent. Comparing to EFI fuel system, carburetor has high fuel consumption where the performance is also affected by the ambient condition. This leads to fuel delivery instability and affects drivability of the vehicle. When environmental factors change, the carburetors are less efficient. It produces less power, consume more fuel, or even damage the engine itself.

The objective of the work is to study the performance characteristics of a single cylinder 4 stroke engine equipped with an Electronic Fuel Injection (EFI) system as compared with that of the carbureted engines. Four parameters; torque and power generated, volumetric efficiency and brake specific fuel consumption, will be examined in this study. The study is conducted by using GT Power simulation software, Fluent [5, 6]. The simulation results are validated using the experimental data as well as using previous simulation results using WAVE simulation software (developed by Ricardo) which is obtained from the GO-KART manufacturer.

The result of this study will provide platform for further research related to the investigation of the effect of EFI on the performance of 4 stroke single cylinder engine against environmental changes, the emissions output, life cycle analysis, engine wear and degradation over time, fuel injection study, engine control and tuning and etc.

Research Approach

The first part of the study is developing the carburetted engine model and simulating it using the GT POWER software. The results are validated using the result of engine dyno testing as well as the result of simulation using WAVE software. Then, the validated carburetted model is converted to EFI model, and simulated to investigate the performance of the engine installed with EFI system especially at low speed range.

Modeling and Simulation of Carbureted Four Stroke Engine

Pragmatic approach is desirable to simulate the gas dynamic and thermodynamic within the engine cycles and the physical geometry of the engine should be defined to the finest detail, starting from the air entering the engine until the exhaust gas finally exits the engine. Computer modeling and simulation brings all theoretical model together and solve it on a digital computer. Sub model of engine i.e. intake manifold, cylinder, is brought together to illustrate the effectiveness of a complete simulation of the four stroke engine [2].

The carbureted model of the engine is developed using GT POWER software. The assumptions made for the development of model are; the piston modeled as mass less component, the effect of swirl and tumble are negligible, the intake runner, intake port, exhaust runner and exhaust port are assumed and modeled as a straight pipe and any restriction in the intake and exhaust system are neglected. The model was simulated based on steady state condition for the engine speed range of 3000 rpm to 10000 rpm. The result is validated using the simulation result using WAVE software and GO-KART engine experimental data obtained from an undisclosed manufacturing company. The technical data used to model and validate the carbureted model is shown in Table 1. This is a cyclic process and model is refined until the carbureted model is satisfied. The carbureted model of the engine is shown in Figure 1.

Engine Data

The GO-KART engine data gathered to model and validate the engine model are; the engine parameters such as dimension of engine parts, lift arrays and flow arrays of the valves and the simulation result using WAVE software and experimental data such as torque curve and power curve. The accuracy of the data is extremely important in modeling, simulation and validation of the carbureted model.

Table 1: General Technical Specification of GO-KART Engine [9]

Type	Specifications	Current Fuel System	Carburetor
Displacement	199 cm^3	Max. Power	13.8 kW at 9000 RPM
Bore x Stroke (mm)	70 x 51.8	Max. Torque	16.5 Nm at 7000 RPM
Valve train system	2 valves SOHC	Cooling System	Air Cooled
Compression Ratio	10.0	Lubrication System	Dry Sump

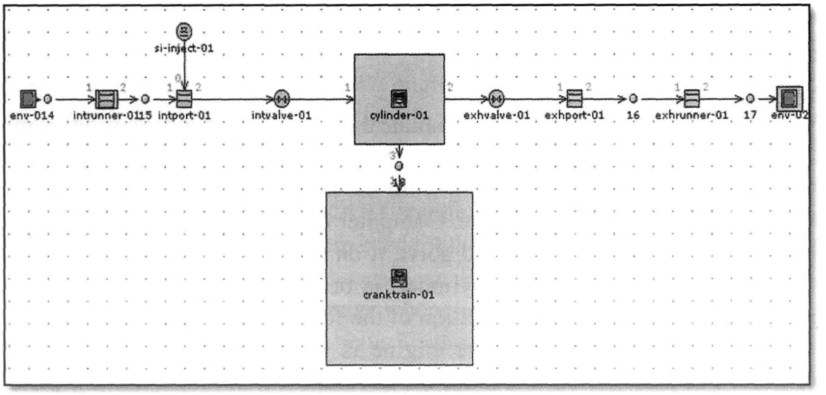

Figure 1: Carbureted Engine Model in GT POWER Software

Conversion of Carbureted Model to EFI Model

The conversion of the carbureted model is carried out by changing the fuel supply system whereby the carburetor part in the model is replaced with Electronic Fuel Injection. In reality, the replacement will require the carburetor to be replaced with the fuel injector and the intake pipe because of the unavailability of an injector port in the intake pipe of the carbureted fuel system. But the fuel injector selection and the intake pipe replacement will not be considered at this point of the study. Nevertheless, the location of the injector on the intake pipe will be specified in the injector part in the EFI model. For this conversion, the AFR values over the speed ranges for wide open throttle condition that has been used for carburetor model simulation as shown in Table 2 are also being adopted for the EFI model simulation. The EFI engine model will then be simulated and analyzed. Both simulations results of the carbureted and EFI models will be measured and analyzed.

Table 2: AFR Value Throughout Engine Speed

Engine Speed (RPM)	Air Fuel Ratio (AFR)
4000	11.8
5000	11.8
6000	11.8
7000	11.2
8000	11.0
9000	10.8
10000	10.3

Table 3 shows the initial condition of the EFI System which is specifically the initial condition of the injector. The injector delivery rate is assumed to be 5.5 which are based on the value in the GT Power software database for the 4 cylinder port injected gasoline [5, 6]. The vaporized fuel fraction is 0.3 in accordance to GT-ISE version 6.1 Help Navigator that states 0.3 is a typical value for port injected gasoline engine [5, 6].

Table 3: Initial Condition of EFI System in GT POWER [5, 6]

Parameter	Value
Injector delivery rate	5.5 g/s
Fuel ratio	As specified in Table 2.
Injection timing angle (crank angle relative to the TDC firing)	360° (at the start of intake stroke)
Injector location	Middle of intake pipe
Vaporized fuel fraction	0.3

Results and Discussions

Modeling, Simulation and Validation of Carbureted Model

Modeling simulation and analysis are done on carbureted engine model using GT POWER. For the purpose of validation, the torque, power, volumetric efficiency and BSFC of the GT carbureted model are compared with the previous WAVE simulation and testing data as shown in Figures 2 to 5 respectively.

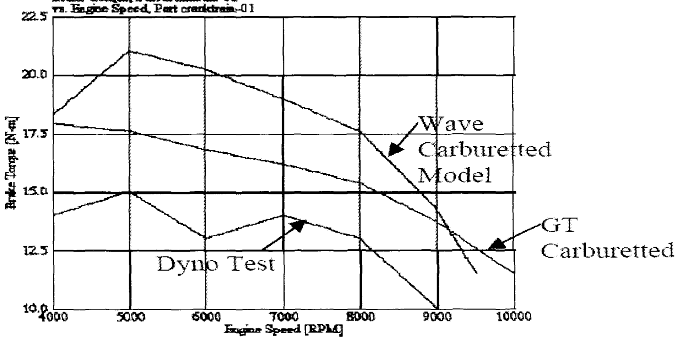

Figure 2: Torque Validation

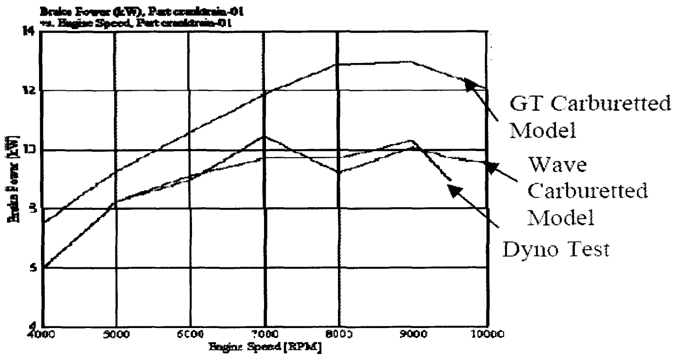

Figure 3: Power Validation

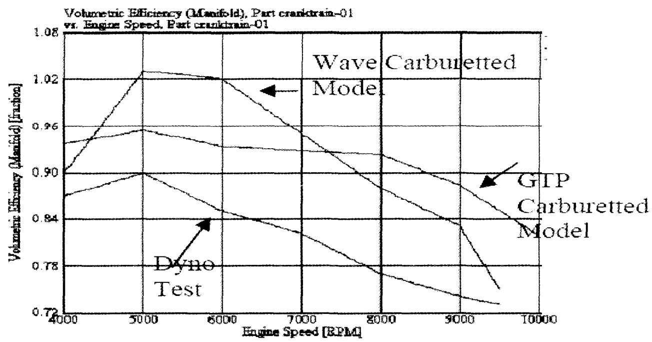

Figure 4: Volumetric Efficiency Validation

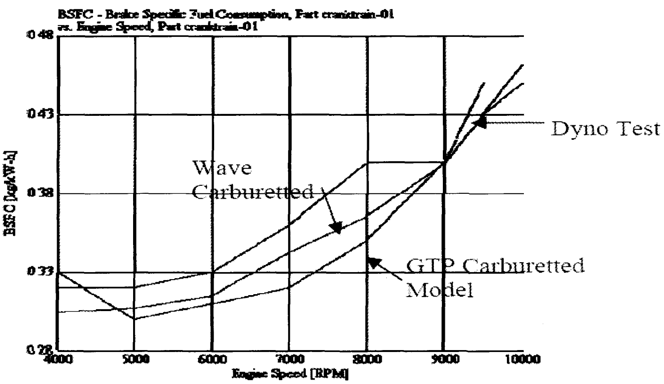

Figure 5: Brake Specific Fuel Consumption Validation

Apart from the power curve, it can be seen that the results of the simulation using GT Power are in between the results of the previous dynamometer testing and modeling using WAVE software. The torque curve resulting from the GT POWER simulations show decreasing trend all the way through from the engine speed of 4000 rpm to 10000 rpm. The trend follows the result based on WAVE software simulation for the engine speed of 5000 rpm and above. The result from the dynamometer testing shows the same trend except for speed range 6000 rpm to 7000 rpm where the torque of the dynamometer increases a little which is in contrary to the result of the GT POWER simulation result that shows decreasing trend.

For the power curve, the GT POWER results shoot up an average of 25% from both dynamometer and WAVE results. Although the magnitude differs, the results follow the trend of the WAVE simulation and dynamometer testing results. From the volumetric efficiency perspective, the graph shows typical volumetric efficiency and the range of 0.8 to 1 efficiency value is also a typical value for a naturally aspirated engine. The results are again fall in between both the results of simulation using WAVE software and dynamometer testing. It does follow the trend of both results where it starts to increase from 4000 rpm to 5000 rpm and decrease from 5000 rpm onwards. From the BSFC, it can be seen that the GT POWER simulation results are nearly the average of both testing and WAVE result.

The simulation results vary with the previous simulation and testing result in terms of the values and the trending in certain speed range. For example, the trend in dyno torque in Figure 2 at speed range of 5000 rpm is different from the GT POWER result. However, the trending in the simulation result using WAVE software is similar to the simulation result using GT POWER simulation. The discrepancies in the magnitude of the results could possibly due to the assumptions made in developing the model as well as the inputs used in the simulation. The intake system used carburetor for fuel supply and this cannot be modeled accurately. There was also no input from carburetor to correlate the volume of fuel being supplied with respect to the pressure inside the venturi. Therefore, the values of AFR throughout the speed range at wide open throttle are being assumed so that the result as in Figures 2 to 5, will meet the previous testing and simulation data.

The values of AFR adopted for the GT POWER EFI model are shown in Table 2. The exhaust pipe, intake port, and exhaust port are modeled as straight pipes. Restrictions in the airflow on the intake side including air filter, throttle body, plenum and exhaust system including exhaust header, the catalyst converter, and the mufflers are neglected. Similarly, the other assumptions made are piston is modeled as mass less, and the effect of swirl and tumble are neglected. Other required parameters that are not available are obtained from database. Constant and some values used are through prediction based on typical value. For example, the friction mean effective pressure (FMEP) values used in the model are typical value obtained in the model example of GT POWER because the testing data is not available.

Figures 6 to 9 show the results after the conversion in terms of torque, power, volumetric efficiency and brake specific fuel consumption respectively. With the same air fuel ratio assumed in the carburetor model, it is proven that EFI improves the performance of the engine as can be clearly seen the graphs in Figures 6 to 9. For naturally aspirated engine, the volumetric efficiencies will always be less than 100% because the fuel vapor will displace some of the incoming air. Carburetor adds fuel early in the intake flow and generally has low volumetric efficiency. Fuel will start to evaporate immediately and its vapor will displace the incoming air. Fuel with high heat of evaporation will contribute to less loss of volumetric efficiency. The other factors that affect

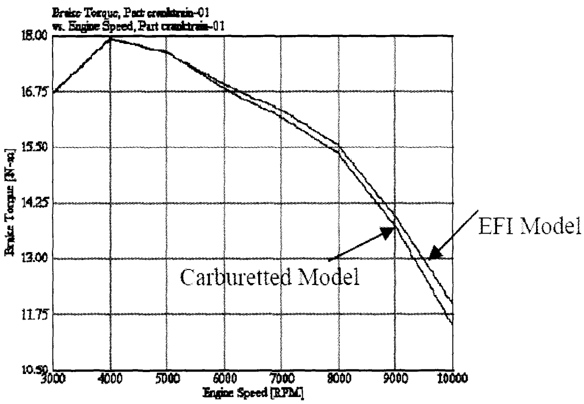

Figure 6: Torque Comparison

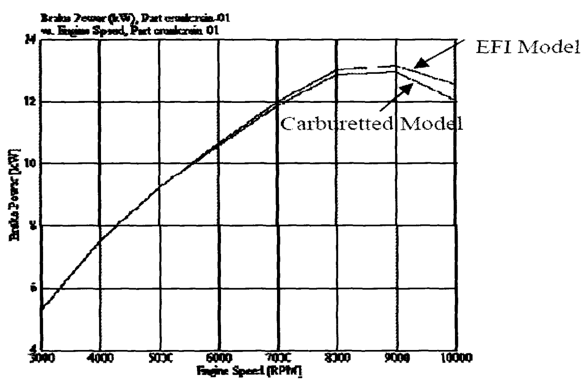

Figure 7: Power Comparison

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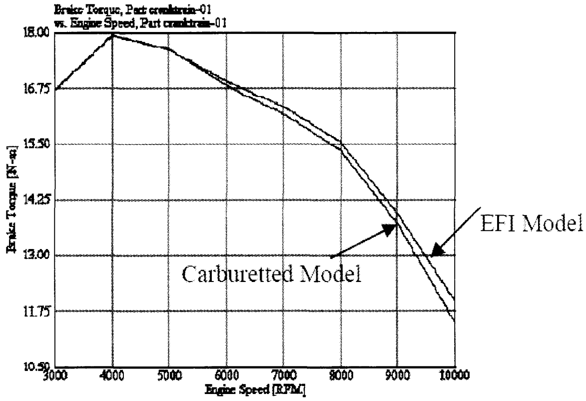

Figure 6: Torque Comparison

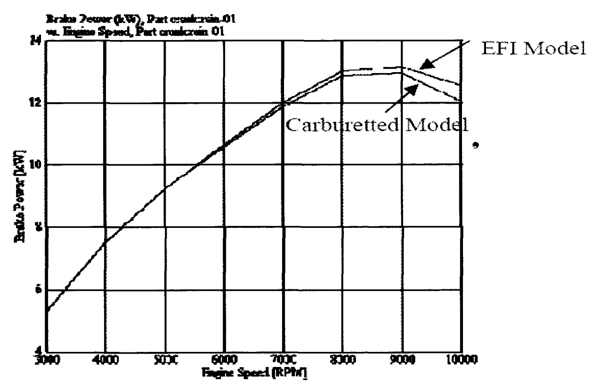

Figure 7: Power Comparison

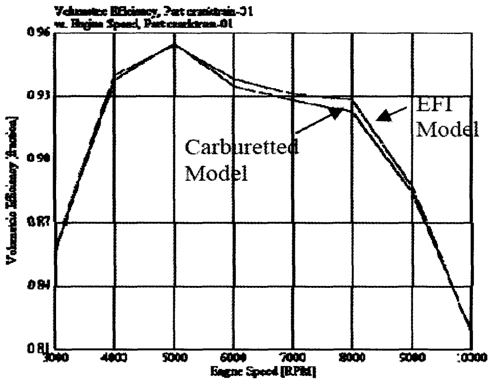

Figure 8: Volumetric Efficiency Comparison

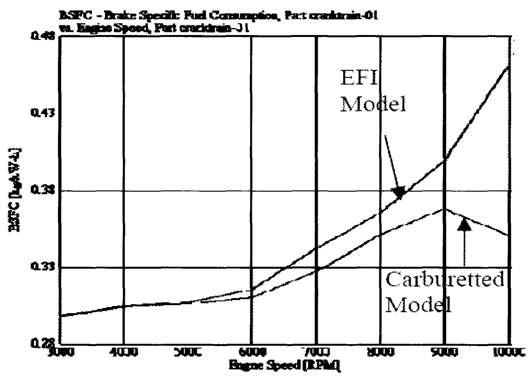

Figure 9: Brake Specific Fuel Consumption Comparison

volumetric efficiency are intake temperature and fluid friction losses. When the intake temperature is high, it will improve the fuel mixing but it will sacrifice the volumetric efficiency. Intake bends, sharp corners, and flow restriction cause pressure losses and viscous drag. These will contribute to decrease in volumetric efficiency.

An air fuel mixture that will produce a *complete combustion* is 14.7:1 or simply 14.7. At starting cold condition, the air fuel mixture is rich which is about 9:1 ratio. During idling, the mixture leans out to about 12:1 and at medium speed, it leans out to around 15:1. If the driver accelerates the engine, the mixture will be temporarily enriched. The mixture is also enriched at full throttle condition. Varying of the air-fuel ratio ensures that a combustible mixture always reaches the engine cylinders [3]. The difference between carburetor and EFI is that fuel supply (AFR) values of the carburetor are dependent on the ambient condition. This effect can be seen in the AFR equation. The AFR delivered by the carburetor is given by

$$AF = \frac{\dot{m}_a}{\dot{m}_f} = \frac{c_{DT}}{c_{DO}} \cdot \frac{A_T}{A_O} \cdot \sqrt{\left(\frac{\rho_{ao}}{\rho_f}\right)\frac{\Delta p_a}{p_a - p_f g z}} \cdot \Phi$$

and

$$\Phi = \left[\frac{\gamma}{\gamma - 1} \cdot \frac{\left(\frac{p_T}{p_o}\right)^{\frac{2}{\gamma}} - \left(\frac{p_T}{p_o}\right)^{\frac{\gamma-1}{\gamma}}}{1 - \left(\frac{p_T}{p_o}\right)} \right]^{1/2}$$

where $\dot{m}_a$ is the air mass flow rate, $\dot{m}_f$ is the fuel mass flow rate, c_{DT} is the throat discharge coefficient, c_{DO} is the throat discharge coefficient, A_T is the throat area, A_0 is the section A-A area, ρ_{ao} is the density of air at section A-A, ρ_f is the fuel density, Δp_0 is the pressure difference at the throat, p_o is the pressure at the throat, p_T is the pressure at the throat, g is the gravitational acceleration, z is the difference in elevation between fuel discharge nozzle and fuel level in float chamber and γ is the specific heat ratio. Φ is a flow compressible function where it accounts for the effect of compressibility. Relative mass flow rate and compressible flow function Φ as a function of nozzle or restriction pressure ratio for ideal gas with $\gamma = 1.4$ [7]. The density of air changes with the change of pressure, temperature and altitude of the ambient and hence, the AFR value changes when the air density changes. Carburetor delivers a mixture of increasing fuel to air ratio as the flow rate increase. Some of the carburetor deficiencies are the mixture cannot be enriched during the startup and warm up, unadaptive to changes in ambient air density which is primarily due to change in altitude, and as the air flow approaches the maximum wide open throttle, the equivalent ratio remains essentially constant.

As for the EFI system, the fuel injection system is controlled by the Engine Control Unit (ECU). The amount of fuel injected by the injector and the time it sprays the fuel is controlled by the ECU. Sensors for the measurement of engine speed, throttle position, manifold vacuum, coolant temperature, air intake temperature, and oxygen works as an input to the Electronic Control Module. The ECM then determines the amount of fuel needed and when to open the injectors to produce the desired air fuel ratio. The Electronic fuel injection system supplies the engine with a combustible air fuel mixture. It varies the richness of mixture to suit different operating conditions. When a cold engine starts, the fuel system delivers a very rich mixture. This has a high proportion of fuel. After the engine warms up the fuel system leans out the air fuel mixture.

For acceleration and high speed operation, the mixture is again, enriched [3]. With EFI, there's no venturi throat to create pressure drop as with a carburetor system. Because of little and no air fuel mixing occurs in the intake manifold, high velocity is not as important, and thus, larger diameter runners with less pressure loss can be used. There is also no displacement of incoming air with fuel vapor in the manifold [8]. Fuel injection is able to atomize fuel better than carburetor and thus improving fuel economy.

Conclusion

Based on the above, it is concluded that the results of the simulation model correlate with the previous testing and simulation result in terms of the trending. The discrepancies in the magnitude of the results could be due to the used of parameters taken from the database for simulation as well as the assumptions used in modeling. Although the results of the testing are limited, the correlation between the model and the testing results can be considered acceptable. Thus, the GT power model is valid for further analysis. In comparing with the EFI and carbureted system, the EFI system produce slightly better performance compared to that of the carbureted fuel system especially at higher engine speed. With the result of this study, further research could be conducted to investigate the effect of EFI on the engine performance against environmental changes, the emissions output, life cycle analysis, engine wear and degradation over time, fuel injection study, engine control, tuning and etc.

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