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Impact of Injection Duration and Injection Timing Variations on Torque and Power Output of the Ken Arok Urban Car Utilizing E100 Ethanol

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ABSTRACT

State Polytechnic of Malang (Polinema) actively participated in the energy-efficient car competition. The Polinema team has developed an energy-efficient car called Ken Arok, which competes in the urban ethanol class (Internal Combustion Engine) concept. This class emphasizes using internal combustion engines as the driving force and ethanol as the fuel. Ken Arok won fifth place in the competition due to obstacles in the programmed ECU program, especially in the injection duration. This study examines the effect of the interaction between injection duration and injection time variations on the torque and power output of the Ken Arok urban car fueled by E100 ethanol. An experimental approach was used in this study. A modified motor, converted into an energy-efficient urban car, was tested. The injection duration mapping was varied in multiples of 2 ms, with values ranging from 2 ms less than the standard to 2 ms more than the standard. Likewise, the injection time was varied in multiples of 2 degrees, including 2 degrees less than the standard and 2 degrees more than the standard. The dyno tester measured the torque and power generated under these conditions. The main objective of this study was to identify the optimal torque and power settings for the Ken Arok energy-efficient engine. The highest torque value recorded was 10.13 N.m, achieved at 6000 rpm when using an injection duration of 2 ms more than the standard (9.06 ms) and an injection timing advanced by 2 degrees (3580). The peak power output reached 8.7 HP at 6000 rpm under compression injection duration plus 2 ms (9.06 ms), and when the injection was advanced by 20 (3580).

Keywords: power, injection duration, torque, injection timing.

ABSTRAK

Politeknik Negeri Malang (Polinema) turut berpartisipasi aktif dalam ajang kompetisi mobil hemat energi. Tim Polinema telah mengembangkan mobil hemat energi bernama Ken Arok, yang berkompetisi di kelas etanol urban concept (internal combustion engine). Kelas ini menekankan penggunaan internal combustion engine sebagai tenaga penggerak dan etanol sebagai bahan bakar. Ken Arok berhasil meraih juara ke-5 dalam kompetisi tersebut karena kendala yang dihadapi dalam pemetaan ECU terprogram, khususnya dalam pemetaan durasi injeksi. Penelitian ini mengkaji pengaruh interaksi antara durasi injeksi dan variasi waktu injeksi terhadap torsi dan daya keluaran mobil urban Ken Arok berbahan bakar etanol E100. Pendekatan eksperimental digunakan dalam penelitian ini. Motor yang dimodifikasi, diubah menjadi mobil urban hemat energi, diuji. Pemetaan durasi injeksi divariasikan dengan kelipatan 2 ms, dengan nilai berkisar antara 2 ms kurang dari standar hingga 2 ms lebih dari standar. Demikian pula, waktu injeksi divariasikan dengan kelipatan 2 derajat, meliputi 2 derajat kurang dari standar dan 2 derajat lebih dari standar. Alat uji dyno mengukur torsi dan daya yang dihasilkan dalam kondisi ini. Tujuan utama penelitian ini adalah untuk mengidentifikasi pengaturan torsi dan daya yang optimal untuk mesin hemat energi Ken Arok. Nilai torsi tertinggi yang tercatat adalah 10,13 N.m, dicapai pada 6000 rpm saat menggunakan pemetaan durasi injeksi 2 ms lebih dari standar (9,06 ms) dan waktu injeksi yang dimajukan 2 derajat (358 derajat). Output daya puncak mencapai 8,7 HP pada 6000 rpm di bawah pemetaan durasi injeksi ditambah 2 ms (9,06 ms) dan saat injeksi dimajukan 20 (3580).

***Kata Kunci** : daya,* injection duration, torsi, injection timing.

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INTRODUCTION

Diversifying energy sources, particularly renewable ones, is crucial to maximizing Indonesia's available energy resources [1]. For this reason, transitioning towards renewable alternative fuels, e.g. biofuels, is essential to mitigate environmental and economic impacts of fossil fuel consumption. Ethanol, a type of biofuel, holds promise as a viable transportation fuel [2]. Ethanol is an alcohol that contains hydrogen, oxygen, and carbon [3]. The function of ethanol is as an octane booster, which means that alcohol can increase the octane number with a positive impact on fuel efficiency and is expected to improve the engine's performance [4]. Several studies support the benefits of using ethanol in vehicles. E100 bioethanol from tapioca wastewater significantly impacts engine performance. The power generated using bioethanol from tapioca wastewater is 9.39 Hp at 7000 rpm. The maximum torque obtained from using ethanol from tapioca wastewater is 9.51 N.m at 7000 rpm, while 95% bioethanol only produces 9.49 N.m of torque at 7000 rpm [7]. Premium fuels were mixed with 96% ethanol, resulting in power, torque, and brake mean effective pressure (BMEP) changes. The highest power and torque were achieved with a 25% ethanol blend, reaching 6.27 HP and 5.26 N.m, respectively [8].

Nowadays, many universities in Indonesia compete to create fuel-efficient vehicles and replace gasoline with the latest fuels. They also frequently organize competitions such as energy-efficient car races. Politeknik Negeri Malang (Polinema) is also participating in these competitions. Students and lecturers from the Department of Mechanical Engineering have created an energy-efficient car named Ken Arok. Ken Arok competes in the urban concept MPD (internal combustion engine) ethanol class, a category in the energy-efficient car competition that uses an internal combustion engine as the driving force and ethanol as the fuel. Ken Arok has a 114 cc engine with an injection fuel system, making the electronic control unit (ECU) a crucial component. The ECU in a car's engine is a primary component that functions as an electronic circuit that controls and regulates various systems within the vehicle [5]. In the energy-efficient car competition held in 2022, the regulations prohibited using electric fuel pumps. Therefore, an external pneumatic pump was utilized to replace the electric pump. Politeknik Negeri Malang (Polinema) secured fifth place due to ongoing challenges with mapping the programmable ECU, particularly regarding injection duration and timing mapping [6]. In the energy-efficient car competition, the vehicles did not reprogram the ECU, so the injection time and duration settings still used the vehicle's standard settings.

ECU reprogramming will affect engine performance. Previous research concluded that the highest power achieved using the Bintang Racing Team (BRT) ECU (reprogramming) is 8.0 HP at 6,318 rpm. When the timing is advanced by 2°, the injection duration is reduced by 2 ms (3.10 ms) [9]. Based on previous research, there is a promising opportunity to identify the optimal influence point of the duration and injection time variation on E100 114 CC ethanol-fuelled vehicles to achieve maximum power and torque on the Ken Arok car. This study combines the duration and injection timing variables for testing to overcome these limitations.

Furthermore, this study will use the BRT ECU setting with standard injection timing, advanced by 2° from the standard and retarded by 2° from the standard. The standard BRT ECU setting will be used to set the injection duration, advanced by 2 ms from the standard and advanced by 2 ms from the standard. As informed by previous studies, this BRT ECU setting was chosen to identify the optimal combination of injection duration and timing variation that produces maximum power and torque for the Ken Arok car fuelled with E100 ethanol. This study hypothesizes that there is an influence between injection time and injection duration on torque and power. This study focuses on determining torque and power.

METHOD

The research methodology includes several stages. This study has six stages as shown in Figure 1. A literature review collects information and knowledge from credible scientific works and contemporary media. In addition to obtaining scientific knowledge, a literature review serves as a tool to identify new aspects of current research compared to previous research. This research was conducted in 2023 at the Mechanical Engineering Workshop of the Malang State Polytechnic,

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precisely at the Tunas Autron workshop. Dynamometer testing was conducted at the RAT Motorsport Indonesia workshop. The Ken Arok car uses a 2015 Honda Beat EFI engine base, modified with a dome-type piston to increase the cylinder capacity to 114 CC. The compression ratio is set at 14.5: 1 to meet fuel specifications. Because it follows the regulations of the energy-efficient car competition, the Ken Arok urban car uses an external pneumatic fuel tank [6].

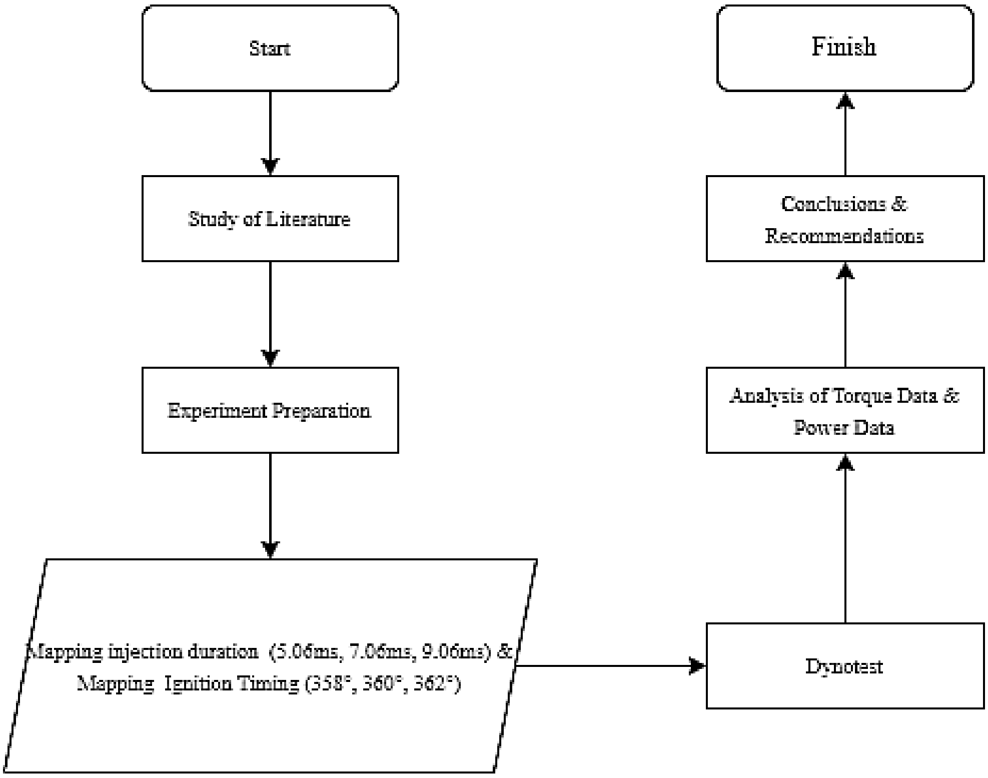

Figure 1. Research Flow

In order for the ECU to be reprogrammed, a programmable ECU type is used, i.e. the BRT Programmable ECU, which is an electronic control unit that regulates a series of actuators in an internal combustion engine, including ignition and injection [10]. The BRT Programmable ECU is the computerized brain of a modern vehicle engine [11]. The BRT Programmable ECU used in this study is the BRT Juken 5 with dual-band capabilities. The BRT Juken 5 ECU can interpret data using multidimensional performance maps and adjust engine actuators. An actuator is a device that utilizes electrical energy and engine vacuum, pressure, or a combination of both to do work. An actuator uses electric current in a computer network to move [12]. A laptop enters mapping data for injection duration and time into the ECU. The laptop has specifications including 8 GB of RAM, a 300 GB hard drive, a Windows 10 operating system, and an AMD A9 processor.

Ethanol was used as vehicle fuel in this study. Ethanol, also known as ethyl alcohol, can be used as vehicle fuel and potentially replace gasoline as the main fuel source for cars. Ethanol has the chemical formula C_3H_5OH and is liquid at room temperature. Ethanol shows a high-octane rating of around 108 (RON), making it suitable for engines with high compression ratios [13]. The fuel used in this study was ethanol, with an alcohol content of 96%. In the context of this study, E100 ethanol refers to pure ethanol fuel without any additives or mixtures. The measuring instrument for torque and power uses a dynamometer. A dynamometer is an instrument used to measure engine output power, including power and torque produced by the engine [14]. The dynamometer used is the Sportdyno V3.3 model with an ISO 1585 correction factor. This dynamometer has a maximum load capacity of 450 kg, a maximum output power of 200 HP and a maximum speed of 300 km/h.

The independent variables in this study are injection time and injection duration. There are two dependent variables, which are torque and power. The control variable in this study is the fuel

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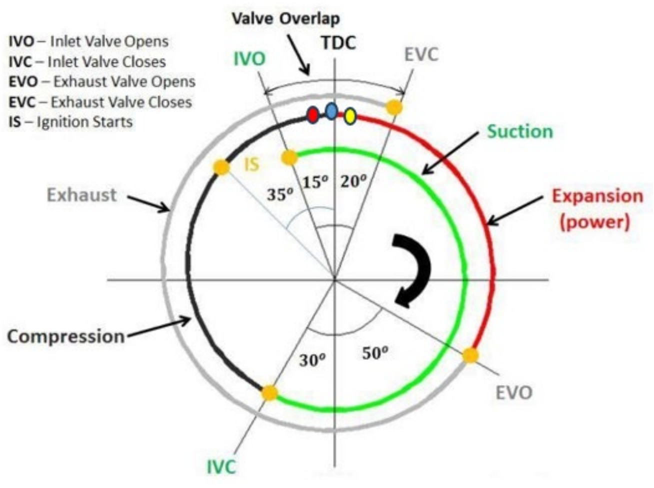
used, which is E100 ethanol or pure ethanol without any other fuel additives with a concentration of 96%. Injection duration refers to when the fuel injector remains open, allowing fuel to be sprayed into the combustion chamber [15]. The injection pulse duration determines the amount of fuel sprayed into the combustion chamber. The ECU controls the injection duration based on input from various sensors, including the intake air mass sensor, air temperature sensor, engine speed sensor, engine temperature sensor, throttle position sensor (TPS), and exhaust emission sensor. Sensors are electrical devices that change resistance or voltage in a circuit due to changes in engine conditions such as temperature, pressure, component position, and others [16]. The ECU will use voltage and electrical resistance changes to calculate variations in each sensor-detected component.

Meanwhile, injection timing refers to when the fuel injector sprays fuel into the intake manifold. This occurs during the piston's upward stroke from bottom dead center (BDC) to top dead center (TDC), exactly 60° before TDC (Figure 2). The fuel spray creates a mixture that enters the combustion chamber during the intake stroke [17]. The researchers will use three injection duration settings during the dyno testing: 5.07 ms (-2 ms), 7.09 ms (standard), and 9.07 ms (+2 ms). In addition, they will use three injection timing settings: 358° (2° BTDC), 360° TDC (standard), and 362° (2° ATDC).

Analyze the torque and power output of the Ken Arok vehicle using the dyno test results. Before dyno testing, a preparatory process must be carried out to ensure optimal torque and power test results. The preparatory steps include:
1. Checking lubricant viscosity and volume.
2. Inspecting the Ken Arok vehicle's electrical system.
3. Examining the fuel system.
4. Checking the vehicle's drive system.

Following the preparatory checks, the dyno test setup involves setting up various testing components, including the laptop, BRP ECU, Ken Arok vehicle, dynamometer, and dynamometer monitor. Figure 3 illustrates the test component setup for this study.



: Injection setting in 358° (2° BTDC)
: Injection setting in 360° TDC (standard)
: Injection setting in 362° (2° ATDC).

Figure 2. Injection Timing

After configuring the testing equipment, the next step is to perform testing using the notes tool and collect data. The data collected during the testing phase includes torque and power data generated by the Ken Arok car. In the first stage, Ken Arok is lifted onto the dynamometer, and the front part is secured with a rope. Additionally, the right side of the Ken Arok car needs to be propped up because only the left wheel rotates to prevent Ken Arok from jumping during data collection. The second stage involves starting the engine until it reaches the operating temperature of 75°C to 80°C. The engine temperature can be read from the Engine Oil Temperature (EOT) sensor and observed through the BRT ECU programmable application. In the third stage, Ken Arok is run to collect dyno test data using the standard ECU mapping. This running process is repeated three times. The fourth stage involves mapping the data into the programmable ECU.

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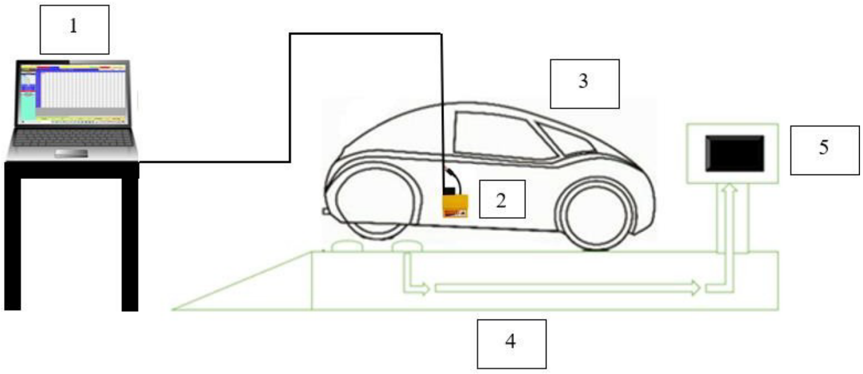
The fifth stage focuses on collecting torque and power data for each pattern. Ken Arok is run on the dynamometer using either the complete throttle method or the dyno data collection method by fully opening the throttle from the initial position of 0° to 90°. The engine speed ranges from 2000 to 7000 rpm, using ethanol E100 as the fuel. Finally, the power values produced in the sixth stage are observed on the dynamometer monitor. The research conclusions and recommendations will be presented at the end of the study. The conclusions contain answers to the research objectives. The research recommendations will focus on two objectives, i.e. suggestions for future research and tips for implementing the research results.



1. Laptop for the ECU remapping process
2. ECU BRT Juken 5+
3. Ken Arok Urban Car
4. Dynamometer
5. Dynamometer Monitor

Figure 3. Illustration of Test Component Setup

RESULTS AND DISCUSSION

The interaction effect of injection duration on torque will be analyzed and presented as a line graph, as shown in Figure 4. Injection duration mapping pattern of 7.06 ms (standard) and injection duration of 9.06 ms, there is an increase in torque compared to the injection duration of 5.06 ms. The average torque value from an engine speed of 2000 to 7000 rpm is the largest in the injection duration mapping pattern of 9.06 ms, which is 9.98 N.m at an engine speed of 5000 rpm; this can happen because by increasing the duration of fuel injection, the volume of fuel entering the combustion chamber is increasing (rich), so that the power generated from combustion is greater.

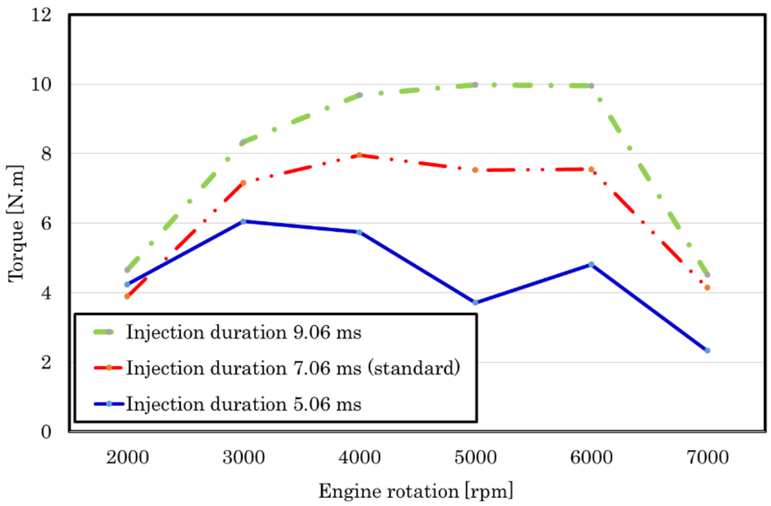


Figure 4. Influence of Engine Rotation and Injection Duration on Torque

The results of the effect of injection duration on power are processed into a graph, which can be seen in Figure 5. At the time of 360˚ injection (standard), the highest power is generated by mapping the injection duration of 9.06 ms at an engine speed of 6000 rpm of 8.5 HP, then decreases at an injection duration of 7.06 ms (standard) at 6.4 HP. The smallest generated power is at an injection duration of 5.06 ms of 3.8 HP. When viewed from the relationship between the power results and the engine speed, the power will increase according to the size of the engine speed and will decrease after passing the peak. This is because the engine speed is too high, so the engine

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work cycle becomes fast, especially in the valve work cycle that does not close perfectly so that the fuel and air mixture does not burn perfectly. The results of the effect of injection time on torque are processed into a graph, which can be seen in Figure 6. At an injection duration of 7.06 ms (standard) at an engine speed of 4000 rpm, the highest torque is produced at 362˚ injection of 8.66 N.m, then decreases at 360˚ injection (standard) to 7.96 N.m and the lowest at 362˚ injection of 7.24 N.m at the same engine speed of 4000 rpm. This is because the mixing of air with fuel in the intake manifold becomes faster by delaying the injection time. Fuel and air can be mixed better because there is not much fuel sticking to the intake manifold wall.

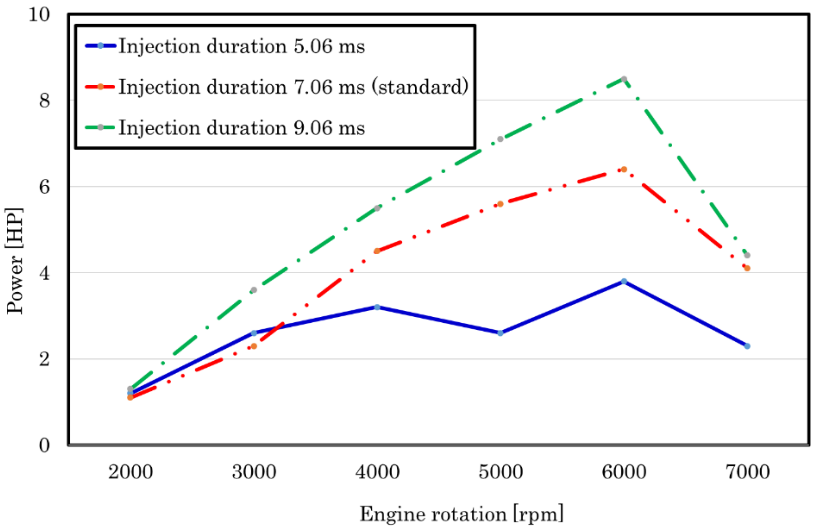

Figure 5. Influence of Engine Rotation and Injection Duration on Power

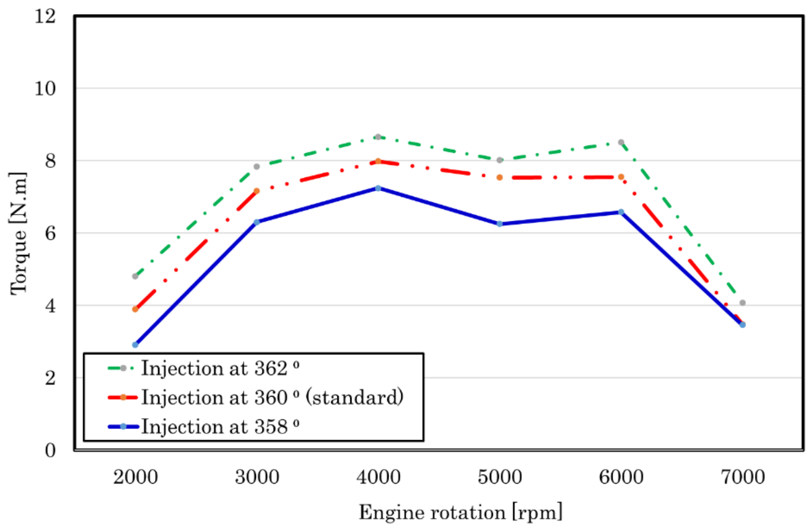

Figure 6. Influence of Engine Rotation and Injection Timing on Torque

The results of the effect of injection time on power are processed into a graph, which can be seen in Figure 7. The highest power at standard injection duration (7.06 ms) is at 6000 RPM with a 2-degree (362-degree) delayed injection time of 7.2 HP. The delayed injection time will result in increased power. This is because it shortens the time gap for the fuel to enter the cylinder. If the fuel's time in the cylinder is too long, the fuel may stick to the intake manifold wall, reducing the amount of fuel entering the combustion chamber. At 6000 rpm engine speed, the power generated tends to be higher than other engine speeds, and the lower the engine speed, the lower the power will be. When viewed from the relationship between power and engine speed, power will increase according to the size of the engine speed, and power will decrease after passing the highest power peak; this is because the engine speed is too high, causing the valve not to close perfectly or floating so that it causes air and fuel not to burn perfectly resulting in not producing maximum power.

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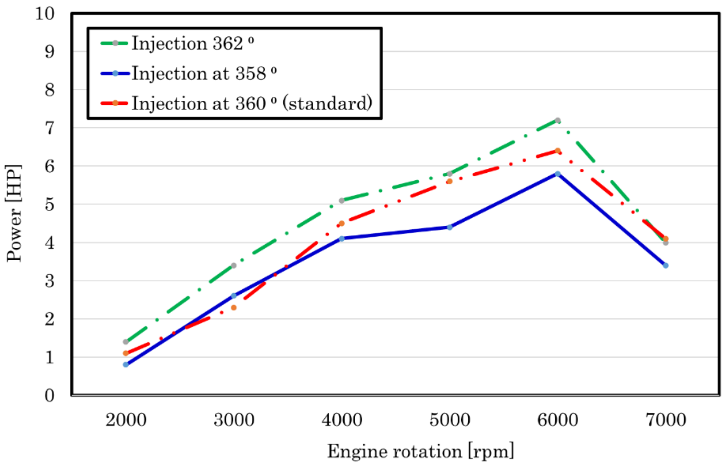

Figure 7. Influence of Engine Rotation and Injection Timing on Power

CONCLUSION

The injection duration added by 2 Ms (9.06 ms) is more optimal to produce the highest torque at 5000 rpm engine speed can produce a torque of 9.98 N.m, meaning there is a 25.38% increase in torque compared to the standard injection duration and power of 7.2 HP at 6000 rpm engine speed which tends to increase by 12.50% compared to the standard injection duration (7.06 ms). When the injection is delayed 2° ATDC (362°), it is more optimal to produce the highest torque and power; at 4000 rpm engine speed, it produces a torque of 8.66 N.m, meaning there is an 8.79% increase in torque compared to the standard injection and power of 7.3 HP at 6000 rpm engine speed which tends to increase by 14.06% from the standard injection (360°).

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