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Performance Enhancement Of Petrol Engines At High Engine Speeds Using Variable Intake And Exhaust Valves Duration

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Abstract

The study was conducted in order to investigate the influence of different engine valve duration on engine brake power (BP), brake specific fuel consumption (Bsfc), and brake thermal efficiency (BTE). In this study, eight different valve durations were considered and compared with the engine of fixed valve duration. Intake valve opening time (IVO) and exhaust valve closing time (EVC) are taken 10° crank angle (CA) before top dead center (bTDC) and 5° CA after top dead center (aTDC) respectively, these are the same valve timings as the fixed-timing engine. Different valve opening duration depends on changing the intake valve closing time (IVC) and the exhaust valve opening timing (EVO). The IVO duration changes from 200° to 250° CA, while the EVO duration is from 210° to 240° CA. Whenever both valves (intake and exhaust) opening duration increased, the engine performance in terms of BP, Bsfc, and BTE are improved significantly particularly at high engine speeds. After analyzing the data by using simulation software, the best valve opening duration was selected according to the engine each speed. For 2000, 3000, and 4000rpm, the best intake and exhaust opening duration is 225° and 240° CA respectively, whereas at 5000 and 6000rpm were 250° and 240° CA respectively is the best duration, when compared to the fixed-timing engine. At 6000rpm, at the best intake and exhaust opening duration (250° and 240° CA), the brake power is 70.7kW, while at the fixed-timing engine, the brake power is 42.6kW, a significant increase of about 66%. The Bsfc at the same condition are equal to 0.29 and 0.325kg/kW.h respectively, so around 11% of the reduction ratio is achieved. Lastly, the BTE at same valves duration are equal to 27.2 and 24.6% respectively, an increase of about 11% when compared to the fixed-timing engine.

Keywords Variable Intake and Exhaust Duration, Engine Performance, Petrol Engine, High Engine Speeds.

1.Introduction

A four-stroke engine's piston moves from Top Dead Center (TDC) to Bottom Dead Center (BDC) when the intake valve is opened, a process referred to as the suction stroke (Figure 1-1). When the intake valve closes, the mixture in case of petrol engines (air-fuel) above the piston is trapped. Compression occurs when the piston moves up, causing the mixture to be compressed (Figure 1-2). Spark plugs cause instantaneous combustion, causing an explosion, during the combustion process. Due to the release of heat, the piston expands, resulting in a power stroke (Figure 1-3). As soon as the power stroke is completed, the exhaust valve is opened to expel the exhaust gasses generated during the combustion process. the exhausts stroke is the final phase in a four-stroke engine (Figure 1-4) [1].

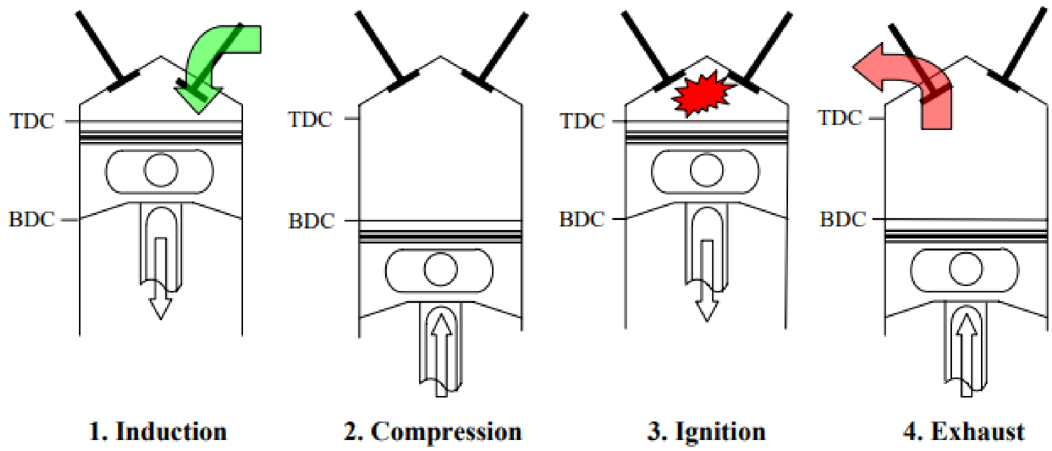

Figure 1, Four-stroke Petrol engine mechanism [2].

2. Literature Review

An engine's valves timing is defined as the particular timing of the valves operative (opening and closing). In four-stroke and some two-stroke engines, camshafts control valve timing. The valve overlap occurs when both the intake and exhaust valves are open at the end of the exhaust stroke of both a fixed valve timing engine and a variable valve timing engine. Before the exhaust gases leave the cylinder completely, the intake valve opens. Crankshaft Degree is used to designate the events that occur in the engine such as sparking, Piston Position, valve opening, and closing [2].
The intake valve opens at 10° - 20° crank angle (CA) before Top Dead Center (bTDC) and closes at 30° - 40° CA after Bottom Dead Center (aBDC). The total duration of intake valve opening is between 220° - 240° CA. The interval between an intake or exhaust valve opening and closing is called the valve duration, and it is measured by the angle of rotation of the crankshaft. Exhaust valve opens at 30° - 40° CA before Bottom Dead Center (bBDC) and closes at 10° - 15° CA after Top Dead Center (aTDC). The total duration is 220° - 235° of crankshaft angle Figure 2, shows the polar valve timing diagram of the individual stroke degrees for a four-cycle petrol engine. It can be seen from the polar diagram that both intake and exhaust valves are open for a period of 10° bTDC and 20° aTDC, a condition known as valve overlap [3].

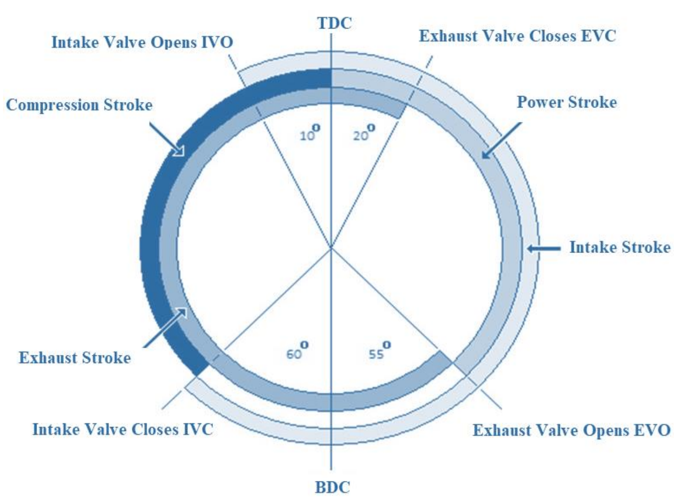

Figure 2, the polar valve timing diagram [4].

The variable valve timing (VVT) method in internal combustion engines adjusts the valve timing, and it is often used to increase fuel economy, performance, or emissions. The engine's valves act as a breathing system, the crankshaft's phase angle controls the timing of that breathing, i.e., how much air is sucked in and exhaled. The duration of intake and exhaust strokes decreases as engine speed increases, so enough fresh air cannot enter the combustion chamber as quickly as before at low engine speeds, in which the engine performance decreases. Furthermore, the exhaust no longer exists the combustion chamber fast enough [5]. Therefore, the most effective way to increase engine performance at high engine speeds would be by opening the intake valves earlier and closing the exhaust valves later. Thus, as the engine speed increases, the overlap between intake and exhaust periods should increase, Figure 3, shows the overlap duration for petrol engine at low and high engine speeds [6].

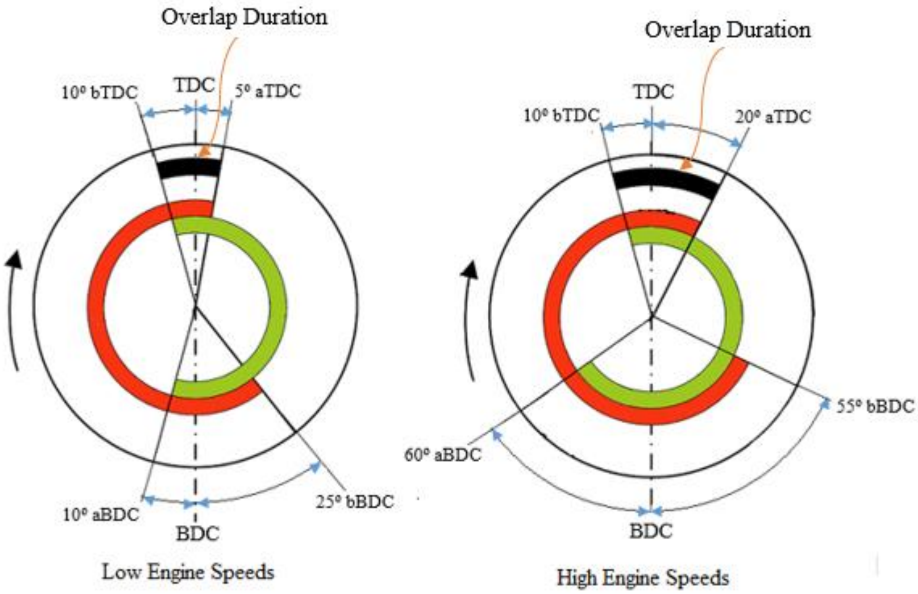

Figure 3, overlap duration for petrol engine at low and high engine speeds [5].

If VVT does not exist, the engine will operate with fixed valve timing at all engine speeds, therefore new arrangements are necessary to improve the engine performance. As a result of using the VVT system, the engine performance will improve over a wide range of operating conditions, particularly at high engine speeds. When an engine operates at high speeds, it requires a large amount of air [6]. Nevertheless, the intake valves closed before sufficient air has entered the combustion chamber, decreasing engine performance. As opposed to this, if the camshaft opens the valves for long periods of time, such as with a racing engine, problems will begin to appear at lower engine speeds. Unburnt fuel may exit the engine if the intake valve is opened with the exhaust valve still open, resulting in decreased engine performance and increased emissions (Figure 4) [7].

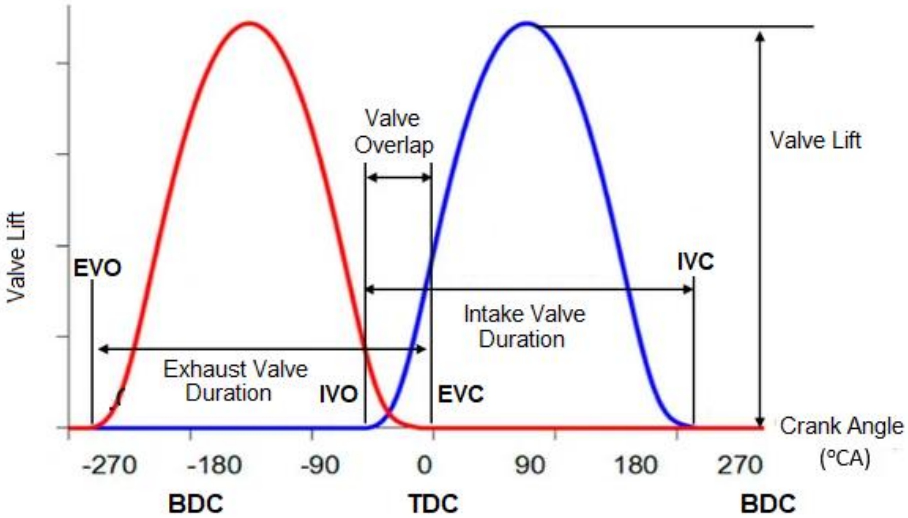

Figure 4, valve overlap diagram [6].

The pressure of the gases resulting from combustion inside the cylinder could be released when the exhaust valve opened. So as to gain the greatest output power from the piston expansion, it might be preferable not to open the exhaust valve before the piston reaches the BDC. However, it is also important for the pressure (exhaust backpressure) in the cylinder to decrease to the minimum possible value before the piston starts to move up [7] [8]. This reduces the power used to expel the combustion products. In other words, the choice of exhaust valve opening timing, therefore, is a comparison between the power lost by permitting the burned gases to escape before it is fully expanded (Exhaust valve opens before BDC), and the power needed to raise the piston (Exhaust valve opens after BDC). Typically, exhaust valve opening time is in the range of 50 - 60° bBDC for a petrol engine (Figure 5) [8].

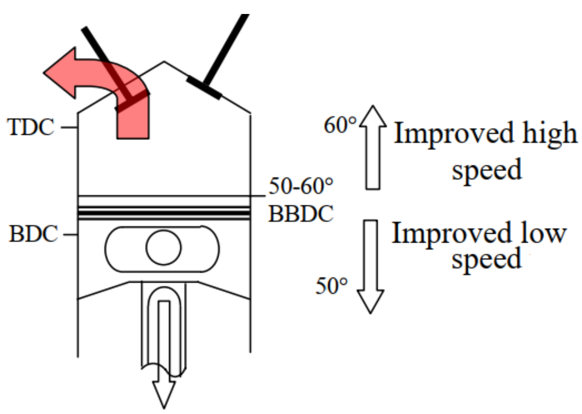

Figure 5, EVO timing range [8].

At part-load conditions and low engine speeds, it would be better if the EVO be closer to the BDC because the cylinder pressure is much closer to the exhaust backpressure and requires less work to flow through the exhaust valve. Alternatively, when an engine operating at full load or at high speeds, the engine has a tendency to result in an early opening of the exhaust valve as a result of the amount of time it takes for the exhaust back pressure to reach the cylinder pressure [8].

When the intake valve is opened, the intake manifold allows the mixture to enter the cylinder, a direct-injection engine only uses the intake valve to allow air into the cylinder. Another parameter affecting valve overlap is the opening time of the intake valve. This is typically the most significant factor when working out which timing is optimal for a given engine. Normally, exhaust gasses flow out of the cylinder through the exhaust valve, but if the intake valve is opened before TDC, they will flow into the intake manifold instead. A delayed intake valve opening tends to limit the flow of air-fuel mixture from the manifold and resulting in-cylinder pressure fall when the piston starts to move down after TDC. As a result, there will be Exhaust Gas Recirculation EGR if the exhaust valve remains open, as gases are drawn back into the cylinder (mixture of exhaust gases and fresh charge). When the exhaust valve is closed, the lag of IVO is not significant, since it does not affect how much fresh charge is trapped in the cylinder. IVO timing is typically between 0° and 10° before TDC, resulting in the valve overlap being relatively symmetrical around TDC. This timing is typically set to optimize the full load and, thus, is designed to prevent internal exhaust gas recirculation (Figure 6) [8].

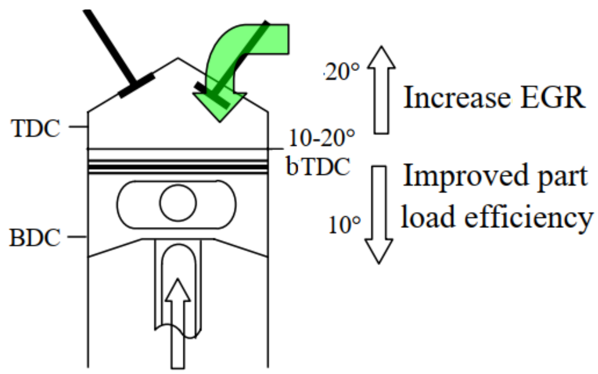

Figure 6, IVO timing range [8]

According to the previous discussion, the intake and exhaust valves overlap when the intake and exhaust valves are open. Basically, this allows for intake flow and the exhaust gas flow without interfering with one another. Overlap is only meaningful measured when considered in association with any given engine speed and load, pressure waves are generated in the intake and exhaust systems. Ideally, the valve overlap would permit the exhaust gases to pull the intake charge into the combustion chamber with no intake charge flowing to the exhaust. The intake charge will be replaced, causing its amount to be greater than that which can be obtained from the swept volume of the piston only [8].

Unfortunately, a given amount of overlap is optimal only for some engine speeds and loads. In general, the combustion process under high loads and higher engine speeds is assisted by overlapping caused by pressure waves in the exhaust manifold allowing fresh charge to enter the combustion chamber. The presence of a large amount of overlap duration leads to emissions when the engine is running at lower speeds due to fuel flowing directly into the exhaust [9].

In recent years, many engine manufacturers have turned to variable valve timing as a means of avoiding some of the drawbacks attached to fixed valve timing. A system that was completely flexible, allowing for the adjustment of intake and exhaust valve timings individually for different engine speeds and load conditions, generally, variable valve timing systems are more complex and, therefore, more expensive the more flexible they are. There are multiple variable valve timing systems, which are currently available and being developed, that allow different valve timing parameters to be controlled such as Phase Changing Systems, Profile Switching Systems, Variable Event Timing Systems, Variable Lift Systems, and Electromagnetic Valve Actuation Systems [10].

2.1 Problem Statements

Therefore, in this paper, different intake and exhaust valve timing (VVT) is used to optimize the engine performance and NOx emissions at high engine speeds comparing with the engine running on a constant valve timing. Many benefits come with using VVT compared to its disadvantages. One of the benefits is an increase in brake power (BP) at high engine speeds of up to 25% improvement. Brake Power at low engine speeds has also been increased, resulting in improved handling and drivability.

2.2 Objectives

The objective of this study is to optimize the engine performance and emissions at variable valve timing (VVT). The engine performance is concerned with Brake Power (BP), Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency ($\eta_{B.\ Th}$), and Nitrogen Oxides Emissions (NOx). Optimization is carried out by comparing the performance of the constant valve timing engine.

2.3. Research Approach

The study was conducted by using simulation software (Diesel-RK). The engine operating conditions are as follow;

1- At high Engine speeds (2000, 3000, 4000, and 5000rpm)
2- Intake valve opening time at 10° Crank Angle CA bTDC.
3- Variable Intake valve closing time 10°, 35°, and 60° CA aBDC.
4- Variable Exhaust valve opening time 25°, 40°, and 55° CA aBDC.
5- Exhaust valve closing time (average) at 5° CA aTDC.
6- Overlap duration 15° CA

Note: The engine design valves timing is IVO at 10° CA bTDC and closes at 10° CA aBDC (200° CA duration). The EVO at 25° CA bBDC and closes at 5° CA aTDC (210° CA duration). While the variable valves timing that under study are shown in Table 1.

Table 1. Valve Durations at Different Valve Timings

Setup No.	Intake Variable Valve Timing	Duration °CA	Exhaust Variable Valve Timing	Duration °CA
1	IVO 10° bTDC & IVC 10° aBDC	200	EVO 25° bBDC & EVC 5° aTDC	210
2	IVO 10° bTDC & IVC 10° aBDC	200	EVO 40° bBDC & EVC 5° aTDC	225
3	IVO 10° bTDC & IVC 10° aBDC	200	EVO 55° bBDC & EVC 5° aTDC	240
4	IVO 10° bTDC & IVC 35° aBDC	225	EVO 25° bBDC & EVC 5° aTDC	210
5	IVO 10° bTDC & IVC 35° aBDC	225	EVO 40° bBDC & EVC 5° aTDC	225
6	IVO 10° bTDC & IVC 35° aBDC	225	EVO 55° bBDC & EVC 5° aTDC	240
7	IVO 10° bTDC & IVC 60° aBDC	250	EVO 25° bBDC & EVC 5° aTDC	210
8	IVO 10° bTDC & IVC 60° aBDC	250	EVO 40° bBDC & EVC 5° aTDC	225
9	IVO 10° bTDC & IVC 60° aBDC	250	EVO 55° bBDC & EVC 5° aTDC	240

3. Methodology

Simulation software developed by the department of Internal Combustion Engines (Piston Engines) at Bauman Moscow State Technical University (MSTU) in 1982. The software was developed for use in internal combustion engine research. A number of computational improvements were made in the software to make it more powerful, based on requests from manufacturing enterprises, including the largest IC engine manufacturers in Russia. Researchers and graduate students can use Diesel-RK effectively because it is a professional software product. Advanced mathematical models of diesel engine combustion have been used to continuously develop the software [10]. The Diesel-RK calculates specific injection parameters and fuel injection quality, develops dynamics of diesel fuel injection developments and analyzes spray interaction with air swirl and cylinder walls, as well as spray direction in the combustion chamber. Some types of engines are supported by Diesel-RK software, including DI Diesel engines, SI petrol engines, SI gas engines, Two-stroke engines, and Dual fuel engines. Diesel-RK also simulates combustion chamber shape and injection location (central or non-central), number, bore, and direction of injection, fuels including biofuels and biofuel-diesel mixture, character of injection shape, and sprays interaction with the cylinder wall. A variable valve timing can be simulated using diesel – RK. It possible to configure and optimize a valve lift diagram with variable valve actuation individually [11].

The engine performance (BP, BSFC, and $\eta_{B.\ Th}$) and NOx emissions data, as determined by computer simulation processes, are provided in Appendix A. To calculate engine performance and NOx emissions, the simulation program was run on the 2ZR-FXE petrol engine at different intake and exhaust valve timings.

3.1 Petrol Engine Specifications

Toyota Motor Corporation introduced the ZR gasoline-engine family in 2007 with a DOHC 16-valve cylinder head and 4-cylinder die-cast block. The engines are either 1.6 liters, 1.8 liters, or 2.0 liter. Toyota's Dual VVT-i technology is common on engines in this family, which helps optimize the intake and exhaust valve timing. Table 2 presents the specifications of a 2ZR-FXE engine used in this study.

Table 2. Specifications of 2ZR-FXE Petrol Engine

<table>
<tr><th colspan="3">Engine code</th><th>2ZR-FXE</th></tr>
<tr><td colspan="3">No. of cylinder. & Arrangement</td><td>4-cylinder, In-line</td></tr>
<tr><td colspan="3">Valve Mechanism</td><td>16-valve , Chain Drive</td></tr>
<tr><td colspan="3">Combustion Chamber</td><td>Pent roof Type</td></tr>
<tr><td colspan="3">Fuel System</td><td>SFI</td></tr>
<tr><td colspan="3">Displacement cm^3</td><td>1798 (1.8 liters)</td></tr>
<tr><td colspan="3">Bore × Stroke mm.</td><td>80.5 × 88.3</td></tr>
<tr><td colspan="3">Compression Ratio</td><td>13 : 1</td></tr>
<tr><td colspan="3">Max Output</td><td>72 kW at 5200 rpm</td></tr>
<tr><td colspan="3">Max Torque</td><td>142 Nm at 3600 rpm</td></tr>
<tr><td rowspan="4">Valve Timing</td><td rowspan="2">Intake</td><td>Open</td><td>10^o bTDC</td></tr>
<tr><td>Close</td><td>10^o aBDC</td></tr>
<tr><td rowspan="2">Exhaust</td><td>Open</td><td>25º bBDC</td></tr>
<tr><td>Close</td><td>5º aTDC</td></tr>
<tr><td colspan="3">Overlap duration</td><td>15^o CA</td></tr>
<tr><td colspan="3">Firing Order</td><td>1 – 3 – 4 – 2</td></tr>
</table>

Table 2. Properties of Petrol Fuel.

Table 3. Properties of Petrol Fuel

S/No.	Quantity	Value
1	Composition (mass fraction)	C = 0.885, and H = 0.145

2	Low heating value (MJ/kg)	44
3	Cetane Number	00
4	Density at 323K (kg/m^3)	720
5	Surface tension factor at 323K (N/m)	00
6	Specific vaporization heat (kJ/kg)	230
7	Fuel thermal specific capacity (J/kg. K)	2500
8	Molecular mass	115
9	Sulphur content	00

4. Results and Discussions

4.1. Brake Power (BP)

This part discusses the engine Brake Power (bp), the most important parameter of an internal combustion engine. The brake power is the net power output of an engine after considering friction losses from the operation of engine parts and auxiliary devices such as gearboxes, alternators, water pumps, differentials, etc. After the earlier literature review in this study, it is well recognized that valves timing and duration affects significantly the engine performance. Valve duration is defined as follow, in reciprocating engines, an intake or exhaust valve is open for a certain amount of time, measured in degrees of crankshaft rotation. Figures 7 show the brake power at different intake and exhaust timings. Based on Figure 7, braking power generally increased with an increase in engine speed at the different valve timings and valve opening durations. At a speed greater than 6000rpm, brake power began to decline because of many factors, the most important of which is the decrease of volumetric efficiency and the lack of time for complete combustion at high speeds (see Figure 7).

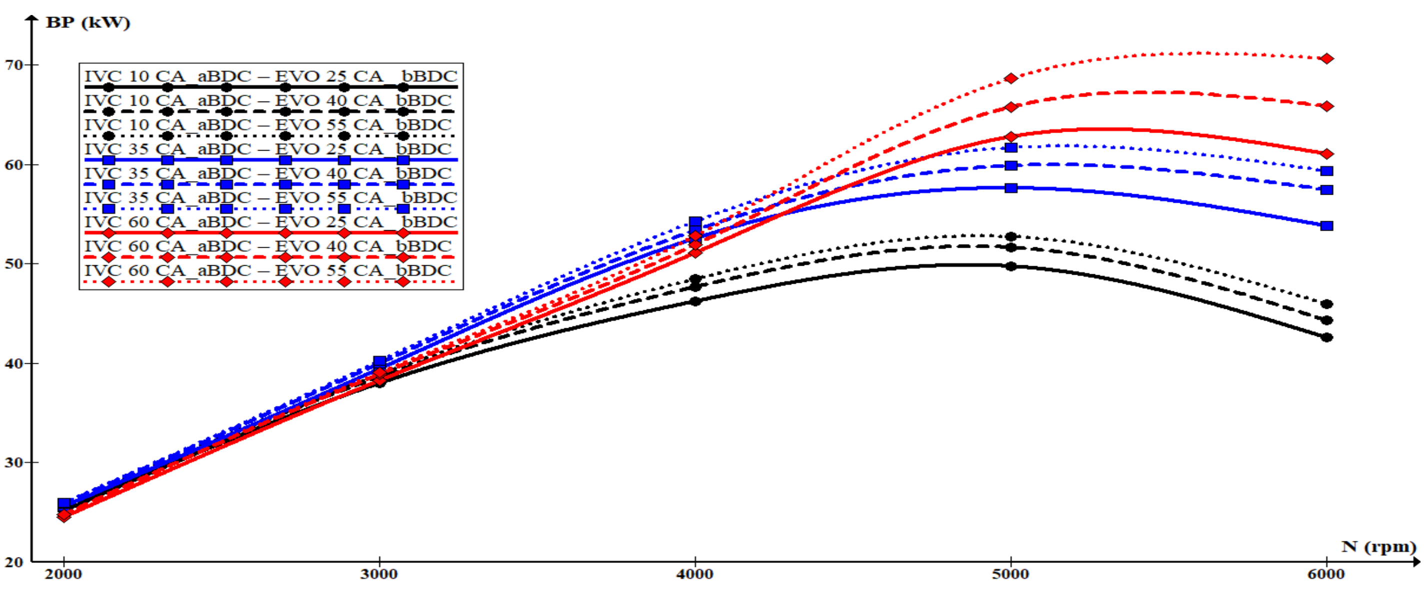

Figure 7. Brake power vs engine speeds at different valves timing and different valve durations

As shown in the Figure 7 and Table 1, the brake power increased as the valves (intake and exhaust) opening duration increased, especially at high engine speeds (greater than 3000 rpm). At low engine speeds, the different valve timings have little impact on brake power. At the greatest valve duration, the maximum brake power can be obtained (see Figure 7). For example, at 5000rpm and setup of intake and exhaust valve duration, 200 and 210^o CA respectively, the brake power is found to be 49.8kW. at the same engine speed and setup of intake and exhaust valve duration, 225 and 210° CA respectively, the brake power increased to 57.6kW. The increase in power is 14% as a result of increasing the duration of the intake valve by 25° CA (delay in intake valve closing), whereas the duration of the exhaust valve remains unchanged. When the setup was changed to 250° (intake) and 240° (exhaust) CA, the brake power rose to 68.6kW at the same engine speed. About 38% of the brake power is increased by increasing the valve duration (intake and exhaust), compared with the engine's fixed design duration of 200° (intake) and 210° (exhaust). The increase in valve duration at high engine speeds increased engine brake power.

Now proceeding from Appendix A and Figure 7, to select the variable valve duration that is appropriate for the high-speed engine (greater than 300 rpm). This selection is based on the best valve duration individually at all high engine speeds. The variable valve timing is shown in Table 4 and Figure 8 for the best valve duration to maximize brake power for all high engine speeds. Table 4 summarizes the effect of increased brake power due to increased intake valve duration, at the maximum duration of the exhaust valve (240° CA).

Table 4. The Best Valves Duration (the engine with variable valve timing)

Engine Speed rpm	Best Intake Valve Timing	IV Duration	Best Exhaust Valve Timing	EV Duration	BP (kW)
2000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	25.9
3000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	40.3
4000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	54.3
5000	IVO 10° bTDC & IVC 60° aBDC	250°	EVO 55° bBDC & EVC 5° aTDC	240°	68.6
6000	IVO 10° bTDC & IVC 60° aBDC	250°	EVO 55° bBDC & EVC 5° aTDC	240°	70.7

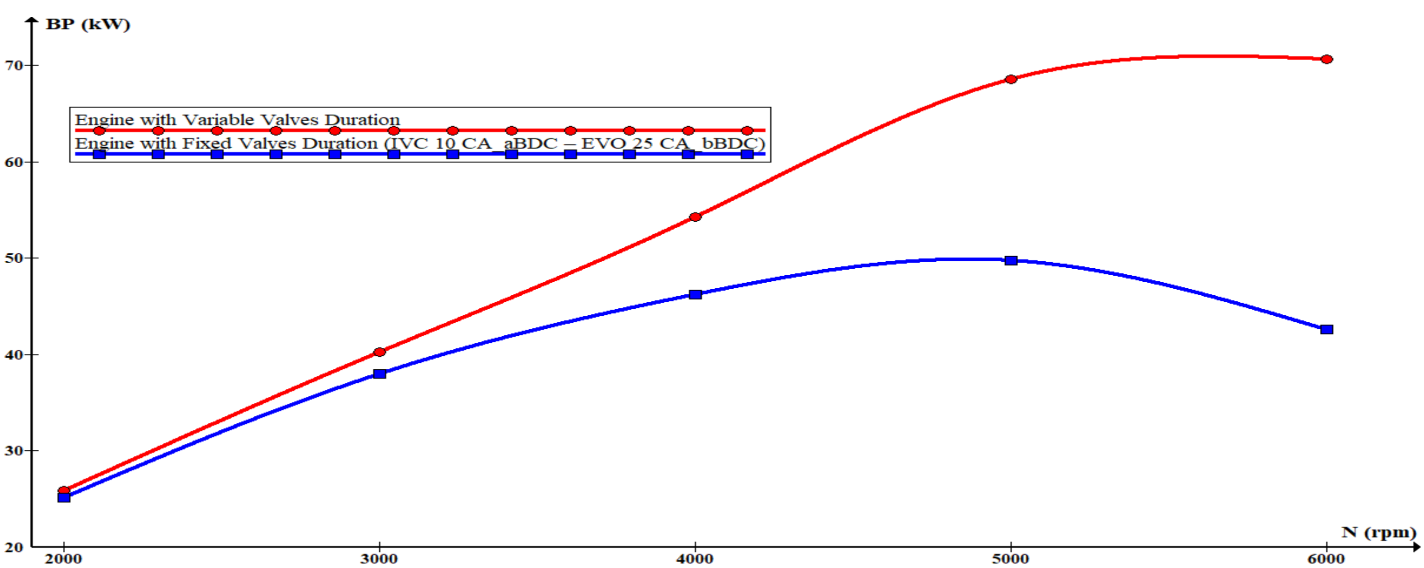

Figure 8. Comparison of the brake power of an engine with fixed valve duration and variable valve duration

As can be seen from the Figure 8, a variable valve duration engine has a much greater brake power than a fixed valve duration engine, particularly at high engine speeds. At 4000rpm, the brake power of the engine with fixed valve timing is equal to 46.3kW, but the brake power of the same engine with variable valve timing is 54.3kW. Therefore, the increase is about 17%. Similarly, at 6000rpm the engine with variable valve timing has a brake power of 70.7kW, whereas the engine with fixed valve timing it has a brake power of 42.6kW, therefore, the increase in brake power is about 66%. Analyzing the effect of the variable valve duration on the engine's braking power, we can conclude that an increase in the valve opening period (both intake and exhaust) leads to an increase in the engine's productive power.

4.2. Brake Specific Fuel Consumption (BSFC)

A study is presented here to determine how variable valve timing affects specific fuel consumption. Diesel-RK software first ran at engine with fixed valve timing, then changed valve timing according to engine setups shown in Figure 9 and Appendix A. For heat engines that use fuel and provide torque, brake specific fuel consumption (BSFC) is used to measure fuel efficiency. The measure is the ratio of fuel consumption to power output. Practically speaking, BSFC is a measurement of the efficiency with which gasoline converts into a certain amount of brake power. Alternatively, it can also be viewed as an indicator of combustion efficiency, which we will discuss in this article. Figure 9 and Appendix A show the impact of variable valve timing on BSFC, in general, the BSFC decreased as the engine speed increases till reached mid speed and tend to increased again as the engine speed increases at all engine setups that are simulated (see Figure 9). Essentially, the low brake power is the cause of the high BSFC at low and high speeds.

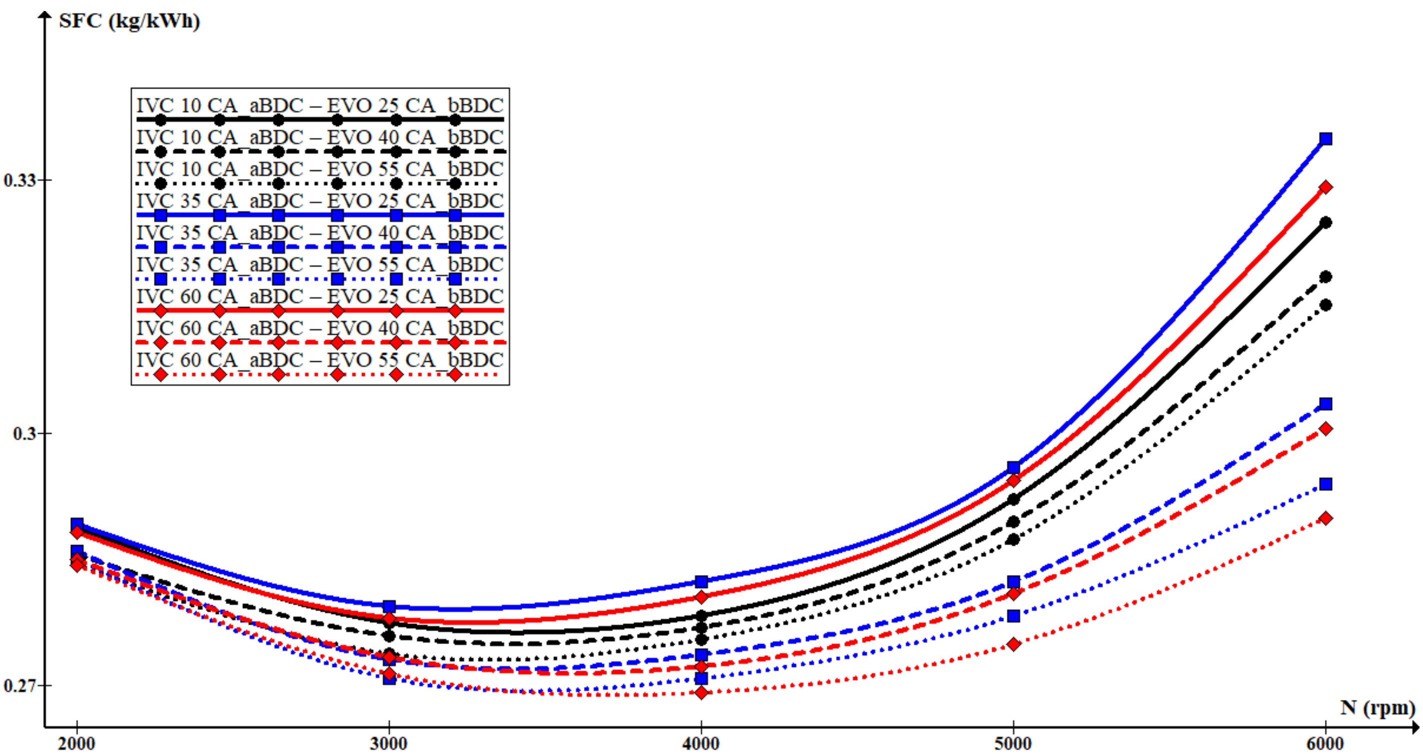

Figure 9. BSFC vs engine speeds at different valves timing and different valve durations

Low specific fuel consumption values are good indicators of engine efficiency. The ratio indicates low fuel consumption (numerator) and higher brake power (denominator). BSFC values are less in engines with variable valve timing and different valve duration setups than in those with fixed valve timing (IVO 10^o bTDC & IVC 10^o aBDC – EVO 25^o bBDC & EVC 5^o aTDC), due to the higher brake power with variable valve timing setup (see Figure 9). For example, at 5000rpm and fixed valve setup, it is found that the BSFC is 0.2921kg/kWh, and at the intake and exhaust durations of 225^o, the BSFC is equal to 0.2737kg/kWh the rate of decrease was 6.7%, when compared to the fixed duration. In contrast, BSFC is equal to 0.274966 kg/kWh at maximum intake duration of 250^o CA and exhaust valve duration of 225^o.

Now, let's examine the impact of valve duration that are chosen in Table 4 in terms of BSFC. Table 5 and Figure 10 show BSFC values versus engine speeds according to the variable valve duration in Table 4.

Table 5. BSFC in terms of brake power, BSFC at Best Valves Duration

Engine Speed rpm	Best Intake Valve Timing	IV Duration	Best Exhaust Valve Timing	EV Duration	BSFC (kg/kWh)
2000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	0.28494
3000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	0.27093
4000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	0.27093
5000	IVO 10° bTDC & IVC 60° aBDC	250°	EVO 55° bBDC & EVC 5° aTDC	240°	0.27496
6000	IVO 10° bTDC & IVC 60° aBDC	250°	EVO 55° bBDC & EVC 5° aTDC	240°	0.28991

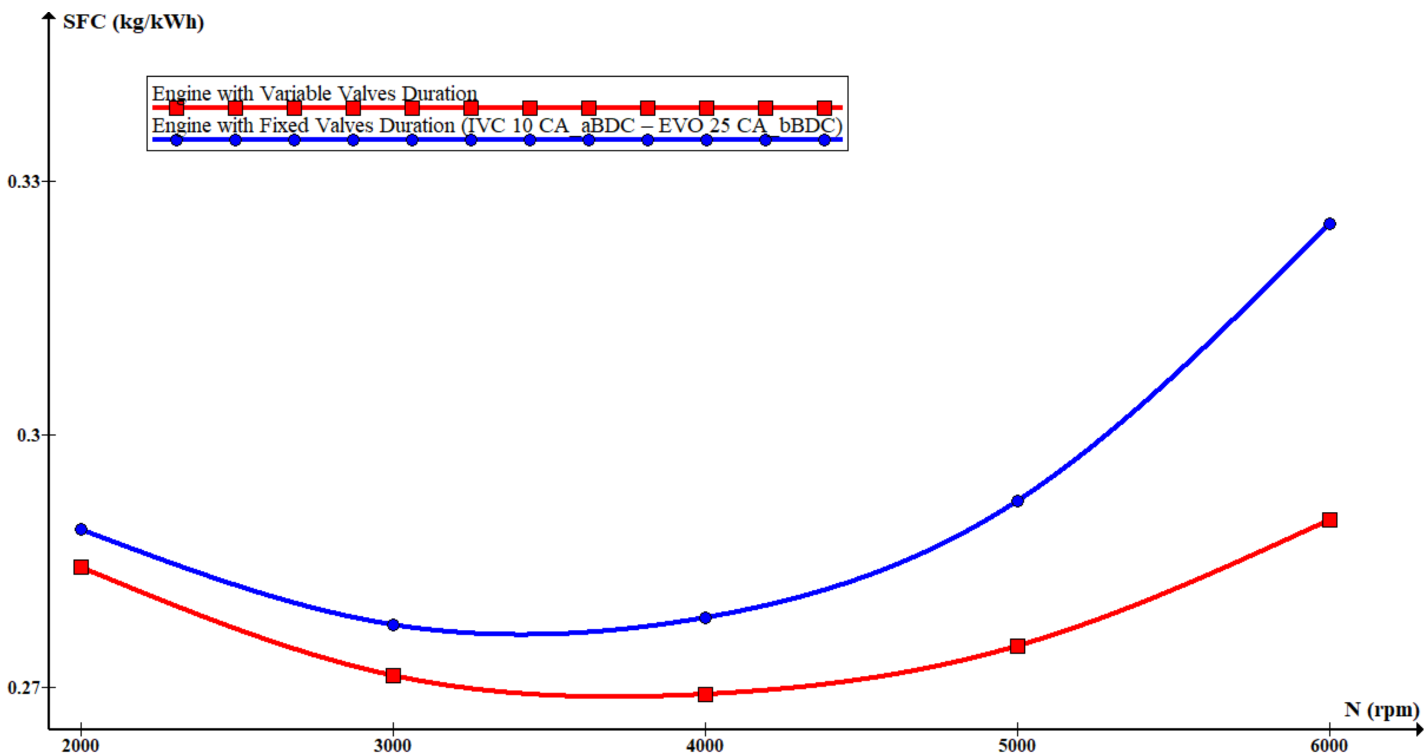

Figure 10. Comparison of the BSFC of the engine with fixed valve duration and variable valve duration

Figure 10 shows that the variable valve duration engine has a much lower BSFC compared to the fixed valve duration engine, especially when running at high speeds. The BSFC of the engine with fixed valve timing is 0.32499kg/kWh at 6000rpm, while the BSFC at the same engine with variable valve timing is 0.28991kg/kWh, Therefore, the decrease is about 12%. Referring to the effect of the variable valve duration on the engine's BSFC shown in the Figure 10, an increase in valves opening time (both intake and exhaust) reduces the engine's BSFC.

4.3. Brake Thermal Efficiency ($\eta_{B.\,Th}$)

The brake thermal efficiency of an internal combustion engine is another indicator of its fuel efficiency. It measures how much brake power you get compared to how much fuel you use. In other words, it is how well the engine is able to convert heat into work. As brake thermal efficiency increases, fuel consumption decreases and brake power increases.

Due to the increase in brake power as the valve duration increases and SFC decreases, the brake thermal efficiency increases. Figure 11 shows the BTE at different variable valve duration compared to design valve duration. A longer valve duration results in a higher BTE, according to Figure 11, the maximum BTE is obtained at 4000rpm, at all engine setups that understudy. In higher engine speeds, the BTE tends to decrease since the volumetric efficiency decreases. For example, at design setup and 5000rpm, the BTE is equal to 28%, while at 4000rpm the BTE is equal to 30%. By increasing the valve opening duration compared to the design duration, the brake thermal efficiency increases. For example, at 5000rpm and setup IVO 10° bTDC & IVC 60° aBDC – EVO 55° bBDC & EVC 5° aTDC (240° CA duration), the BTE is equal to 29.8%

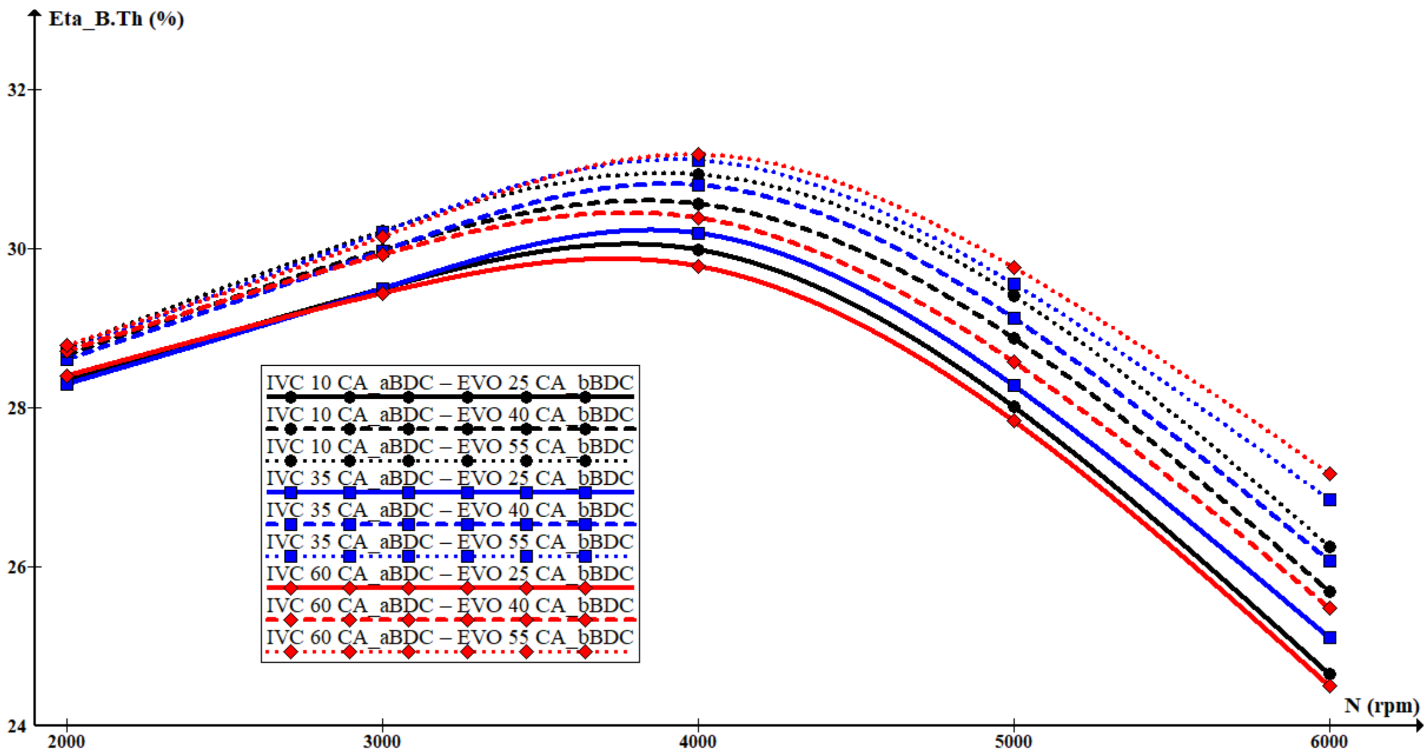

Figure 11. Brake thermal efficiency vs engine speeds at different valves timing and different valve durations

In the following subsection, we will examine the influence of the valve duration that is selected in Table 4 on BTE. Fig. 12 and Table 6 show the BTE values versus the engine speed based on the variable valve duration.

Table 6. BTE in terms of brake power, BTE at Best Valves Duration

Engine Speed rpm	Best Intake Valve Timing	IV Duration	Best Exhaust Valve Timing	EV Duration	BTE (%)
2000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	28.7
3000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	30.2
4000	IVO 10° bTDC & IVC 35° aBDC	225°	EVO 55° bBDC & EVC 5° aTDC	240°	31.1
5000	IVO 10° bTDC & IVC 60° aBDC	250°	EVO 55° bBDC & EVC 5° aTDC	240°	29.8
6000	IVO 10° bTDC & IVC 60° aBDC	250°	EVO 55° bBDC & EVC 5° aTDC	240°	27.2

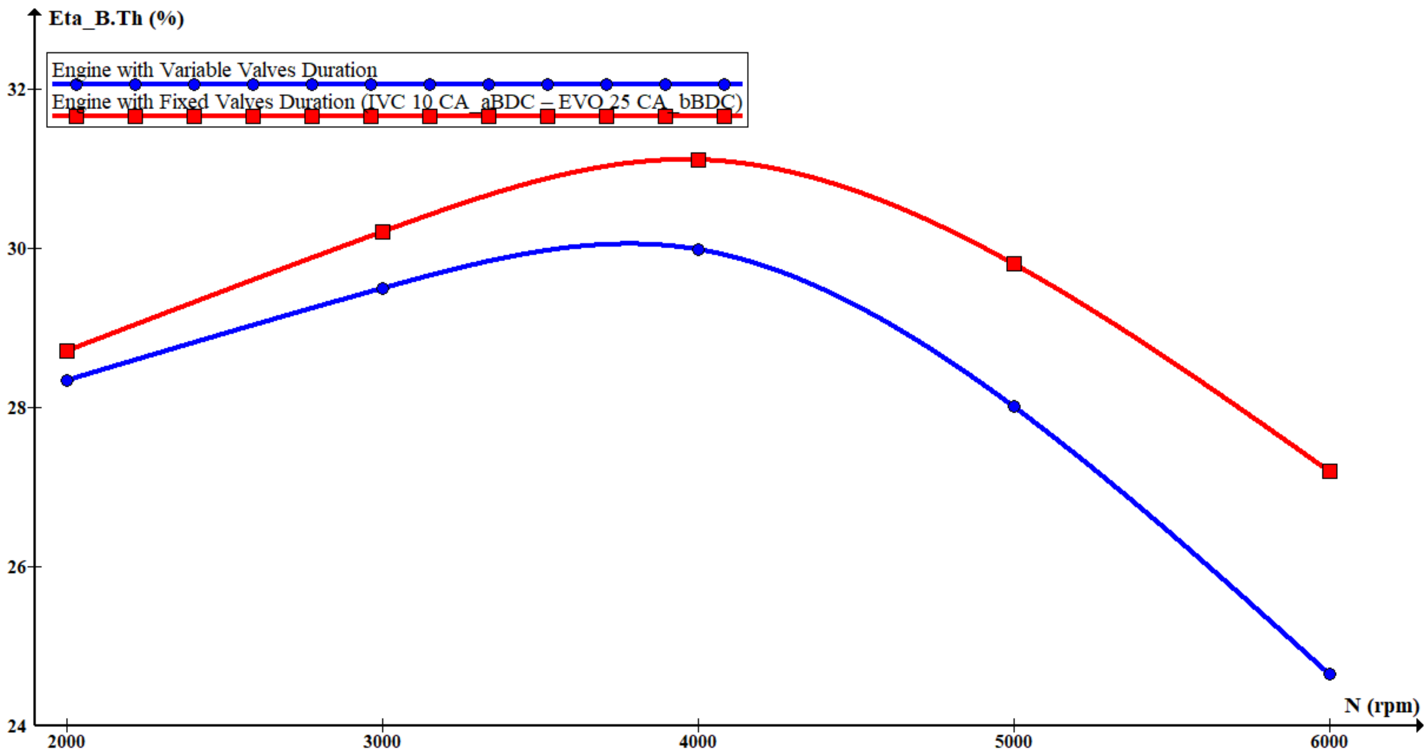

Figure 12. Comparison of the BTE of the engine with Fixed valve duration and variable valve duration

Figure 12 shows that the variable valve duration engine has a much BTE compared to the fixed valve duration engine, particularly when running at high speeds. The BTE of the engine with fixed valve timing is 24.7% at 6000rpm, while the BTE at the same engine with variable valve timing is 27.2%, Therefore, the increase is about 10.2%. Referring to the effect of the variable valve duration on the engine's BTE shown in the Figure 12, an increase in valves opening time (both intake and exhaust) reduces the engine's BTE.

5. Summary and Conclusion

In vehicles with high loads and high engine speeds, variable valve timing becomes more relevant. In IC engines, variable valve timing (VVT) improves performance and fuel economy. In the case of higher speeds, a large amount of air is needed, which requires the inlet valves to be open longer. Based on what was discussed previously, the intake valve should be positioned as follows; opens at 10° CA bTDC and closes between 35° and 60° CA aBDC, therefore the valve opening duration should fall between 225° and 250° CA. Whereas the best exhaust valve timing is defined as follow; opens at 55° CA bBDC and closes at 5° CA aTDC, exhaust valve opening duration is fixed at 240° CA. Variable valve timing engines have the following advantages over fixed valve timing (IVO 10° bTDC & IVC 10° aBDC – EVO 25° bBDC & EVC 5° aTDC) engines:

1- At high engine speeds (3000 to 6000 rpm), the brake power increased considerably from 17 to 66%. At low speeds, there is no significant effect.

2- The rate of improvement in specific fuel consumption has ranged between 12 to 21% at high engine speeds. The effect is negligible at low speeds.

3- The improvement is also associated with thermal efficiency at the same variable valve timing and the same high speeds, ranging between 10 to 21% when compared to the engine with fixed valve timing.

Nomenclatures:

aTDC	After Top Dead Center ° CA	CA	Crank Angles °
aBDC	After Bottom Dead Center ° CA	IC	Internal Combustion Engine
BDC	Bottom Dead Center	IVO	Intake Valve Opening
bp	Brake Power kW	IVC	Intake Valve Closing
bTDC	Before Top Dead Center ° CA	EVO	Exhaust Valve Opening
bBDC	Before Bottom Dead Center ° CA	EVC	Exhaust Valve Closing
Bsfc	Brake Specific Fuel Consumption	rpm	Revolution per Minute
BTE	Brake Thermal Efficiency	TDC	Top Dead Center

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Appendix (A)

IVO 10° bTDC & IVC 10° aBDC – EVO 25° bBDC & EVC 5° aTDC (Engine with Fixed valve Timing)				
Speed (rpm)	BP (kW)	SFC (kg/kWh)	η (%)	NOx (ppm)
2000	25.199	0.28875	28.336	4776.5
3000	37.974	0.27745	29.490	4797.3
4000	46.259	0.27832	29.980	4624.0
5000	49.776	0.29208	28.013	4287.8
6000	42.579	0.32499	24.645	3624.7
Engine with Variable valve Timing				
IVO 10° bTDC & IVC 10° aBDC – EVO 40° bBDC & EVC 5° aTDC				
2000	25.521	0.28551	28.657	4774.6
3000	38.623	0.27590	29.981	4792.8
4000	47.724	0.27684	30.554	4589.4
5000	51.701	0.28947	28.871	4230.7
6000	44.349	0.31857	25.683	3590.8
IVO 10° bTDC & IVC 10° aBDC – EVO 55° bBDC & EVC 5° aTDC				
2000	25.584	0.28450	28.758	4770.0
3000	38.865	0.27379	30.215	4789.2
4000	48.534	0.27542	30.925	4532.7
5000	52.734	0.28734	29.410	4182.4
6000	45.986	0.31522	26.256	3542.4
IVO 10° bTDC & IVC 35° aBDC – EVO 25° bBDC & EVC 5° aTDC				
2000	25.603	0.28918	28.294	4790.2
3000	39.431	0.27940	29.495	4834.0
4000	52.570	0.28228	30.181	4753.9
5000	57.623	0.29585	28.272	4519.4

6000	53.869	0.33490	25.117	4053.4
IVO 10º bTDC & IVC 35º aBDC – EVO 40º bBDC & EVC 5º aTDC				
2000	25.873	0.28597	28.610	4786.9
3000	39.998	0.27305	29.965	4829.0
4000	53.392	0.27365	30.790	4742.4
5000	59.925	0.28240	29.123	4495.9
6000	57.433	0.30339	26.068	4011.5
IVO 10º bTDC & IVC 35º aBDC – EVO 55º bBDC & EVC 5º aTDC				
2000	25.944	0.28494	28.714	4782.2
3000	40.252	0.27093	30.200	4825.5
4000	54.295	0.27093	31.103	4758.3
5000	61.728	0.27828	29.551	4468.6
6000	59.386	0.29387	26.841	3980.1
IVO 10º bTDC & IVC 60º aBDC – EVO 25º bBDC & EVC 5º aTDC				
2000	24.503	0.28817	28.392	4770.5
3000	38.286	0.27801	29.430	4817.0
4000	51.101	0.28049	29.769	4804.4
5000	62.773	0.29439	27.835	4618.0
6000	61.045	0.32914	24.507	4185.1
IVO 10º bTDC & IVC 60º aBDC – EVO 40º bBDC & EVC 5º aTDC				
2000	24.761	0.28501	28.707	4766.6
3000	38.866	0.27345	29.920	4845.8
4000	51.892	0.27227	30.384	4847.2
5000	65.787	0.28098	28.569	4666.3
6000	65.878	0.30057	25.481	4287.8
IVO 10º bTDC & IVC 60º aBDC – EVO 55º bBDC & EVC 5º aTDC				
2000	24.805	0.28423	28.786	4761.2
3000	39.113	0.27140	30.147	4876.4
4000	52.828	0.26913	31.177	4879.4
5000	68.626	0.27496	29.756	4713.3
6000	70.657	0.28991	27.168	4392.8