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SIMULATION OF INTAKE AND EXHAUST VALVE TIMING ON INTERNAL COMBUSTION ENGINE

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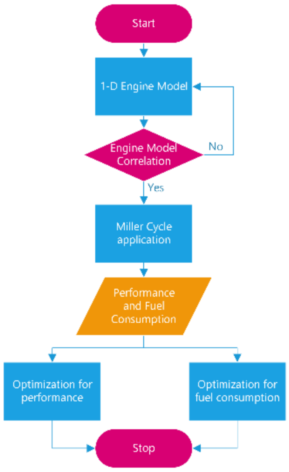
Graphical abstract



Abstract

Internal combustion engine in automotive industry is widely researched to increase its efficiency and power output. Valve system in modern internal combustion engine controls the opening and closing timing of intake and exhaust stroke. Its duration affects the performance of the engine at both power output and fuel efficiency. Therefore, this study discusses about the Miller cycle concept that alters the duration of both intake and exhaust valve opening and closing characteristics. The study focuses mainly on finding the optimum timing characteristics on Proton Iriz gasoline engine. A 1-dimensional model has been built using a commercial software called GT-POWER for engine simulation purpose. The engine is then calibrated with the simulation model. The optimization was run in this software to find the best optimum timing of intake and exhaust valve for two categories which are targeting performance and fuel consumption. The results show positive trends in the BSFC results with the maximum percentage difference of 26.27% at 6,250 rpm. The average percentage difference in the BSFC results is 14.12%. For targeting performance, the overall results show an increasing trend in the brake torque curves with maximum percentage difference is 9.83%. The average percentage difference in brake torque is found to be 3.12%. Therefore, this paper concludes that Miller cycle implementation gives minimal performance increment. The targeting performance and fuel consumption optimization can also be implemented for changing mode of driving. However, the increase compression ratio would also give adverse effects on engine performance and endurance. The Miller cycle is also more suitable to be implemented on force induction system.

Keywords: Miller cycle, intake valve, exhaust valve, optimization, targeting performance

1.0 INTRODUCTION

In the world of automotive industry, the application of internal combustion engine (ICE) in vehicle is extensive worldwide. All automotive engineers in this world continue to work on improving the technologies and their application in ICE to increase its efficiency but in 1973, the world oil crisis emerged and caused a drastic increase in the price of fuel [1]. After the crisis, all automotive industries feel that this problem will affect the market sales of vehicles. By considering the emissions problems, all automotive industries seem to take up the challenge to develop the ICE that consumes less fuel but produces more power and higher efficiency. Among the efforts made by the automotive engineers are downsizing the engine, improving the Atkinson and Miller cycles and forcing the use of induction system (turbocharged and supercharged) [2-13].

The technology keeps on improving from year to year to solve the existing problems in ensuring the market sales of vehicles are always better or on the rise. Among the problems encountered are the growing population of the vehicles worldwide, continuing exhaust emission from the passenger vehicles, increasing manufacturing costs and dynamic market demands. Because of these persisted issues, there are several researches done worldwide to produce technologies that give better fuel consumption in ICE such as variable valve timing (VVT), exhaust gas recirculation (EGR), valve timing electronic Control (VTEC) and others [14 & 15]. In Malaysia, the national automotive industry, Proton also takes up the challenge to keep on improving their technology. Currently, Proton has utilised and embraced the application of VVT technology in their vehicle makes and models, namely the Proton Iriz, Proton Saga and Proton Persona.

The aim of this study is to investigate the potential application of Atkinson and Miller cycles in dual variable valve timing (Dual-VVT) based on the 1.6 litre VVT Proton Iriz engine. The study was carried out considering a 1D simulation analysis to produce the potential use of its application and determine the efficiency results from the simulation are compared with those of the current and standard 1.6-litre VVT Proton Iriz engine.

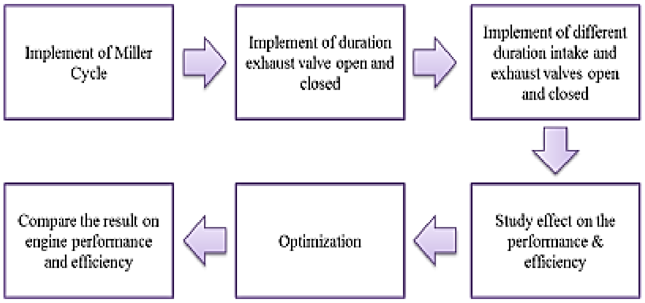


Figure 1 Steps showing various stages in the project

2.0 METHODOLOGY

This project focuses on the studying the effect of implementing the Miller cycle duration for the opening and closing of the intake and exhaust valve on the engine performance. The engine modelling as based on the Proton Iriz engine and its model correlation was done based on the previous study pertaining to looking at the effect of the intake valve timing on the engine using cylinder deactivation technique via simulation.

As shown in Figure 1, the project starts with the implementation of Miller cycle, during the opening and closing of the exhaust valve and its duration. After that, the optimization was run via simulation to find the optimum timing of the intake and exhaust valves. The results of the optimization will be compared with the standard results of the Iriz engine with reference to the brake power, brake torque, brake specific fuel consumption, volumetric and thermal efficiencies and burnt residuals.

2.1 Implementation of the Miller Cycle

The concept of the Miller cycle is to let the intake valve closed late after BDC to reduce the compression ratio so that the expansion ratio in the engine is greater than that of the compression ratio [2]. This idea was implemented on the engine model to observe the effect on the performance and efficiency of the engine by letting the intake parameter to approach late closing of the valve after BDC. But, the opening of intake valve was set at an angle like the one in the standard engine model for each speed. Thus, the implementation was designed to get the compression ratio lower than the standard Iriz engine. Table 1 shows the different intake timing maximum operating point (MOP) for the implemented Miller cycle and the standard Iriz engine considering various engine speed. It was set up based on the engine modelling and then the simulation was executed to obtain the engine performance results.

Table 1 Different intake timing for the implemented Miller cycle and standard Iriz engine

Engine Speed [RPM]	**Intake timing (MOP) Crank Angle [°]**	
	Implement Miller Cycle	Standard Engine Iriz
1000	249.38	239.25
1500	240.18	230.05
2000	235.28	225.15
2500	235.28	225.15
3000	235.28	225.15
3500	238.28	228.15
4000	243.38	233.25
4500	245.43	235.30
5000	247.13	237.00
5500	249.18	239.05
5750	249.18	239.05
6000	249.18	239.05
6250	249.18	239.05

2.2 Opening and Closing of the Exhaust Valve

For implementing the duration of the exhaust valve opening and closing, different exhaust timing parameters were set to get the results of the engine performance which will be compared with the standard Iriz engine. Four different cases of exhaust timing were considered, and the results presented in Figure 2.

2.3 Duration of Exhaust and Intake Valve Opening and Closing

For the implementation of exhaust and intake duration related to the opening and closing of the valves, pre-optimization was done to study its effect on the engine performance and efficiency. An optimization method was used to employ a direct optimizer. Thus, the maximum and the minimum conditions for the intake and exhaust timing parameters were set in the direct optimizer mode. To perform the pre-optimization, the volumetric efficiency was set as the maximum target to get the duration of the intake and exhaust timing parameters for each speed. Table 2 shows the range for the intake and exhaust timing conditions.

Table 2 The range for intake and exhaust timing

Exhaust timing MOP	(250 ° - 290 °) CA
Intake timing MOP	(430 ° - 470 °) CA

2.4 Final Optimization

2.4.1 Targeting Performance

To find the best optimum timing, targeting performance was used. The parameters selected to be optimized are intake and exhaust timing parameters. The range for these parameters was assigned for the maximum and minimum conditions and the resolution (% of range) was set in the direct optimizer.

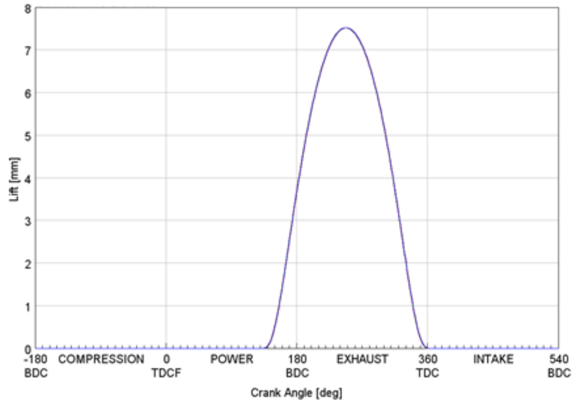
Intake timing	: (420° CA – 480° CA)
Exhaust timing	: (240° CA – 300° CA)
Resolution (% of range)	: 1

To get the optimum timing for targeting good engine performance, the brake torque was prescribed as the maximum target. Thus, the direct optimizer will optimize the optimum intake and exhaust timing parameters to achieve the maximum brake torque using the discrete grid method that will reduce the search range into smaller interval that is half of the range until the optimum condition is found.

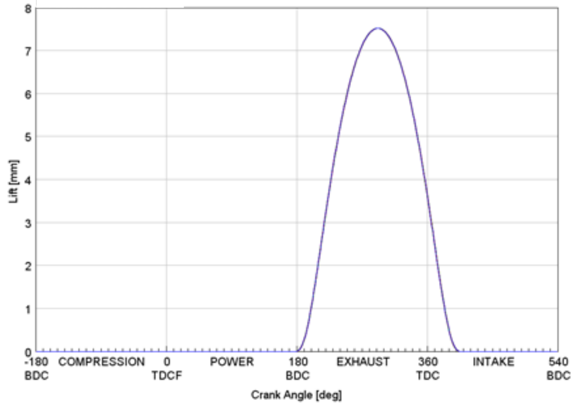
2.4.2 Fuel Consumption

The best optimum timing for the intake and exhaust valves targeting low fuel consumption was optimized using the Design of Experiment (DOE) method via the GT-POWER software [16 & 17]. The range for the intake and exhaust timing parameters was set for the maximum and the minimum conditions and the number of experiments for DOE.

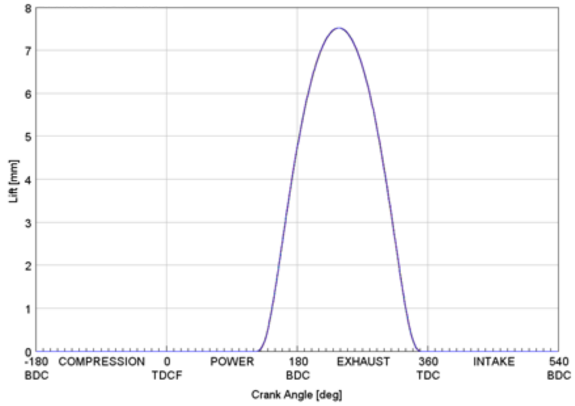
Intake timing	: (410° CA – 490° CA)
Exhaust timing	: (230° CA – 310° CA)
Resolution (% of range)	: 625



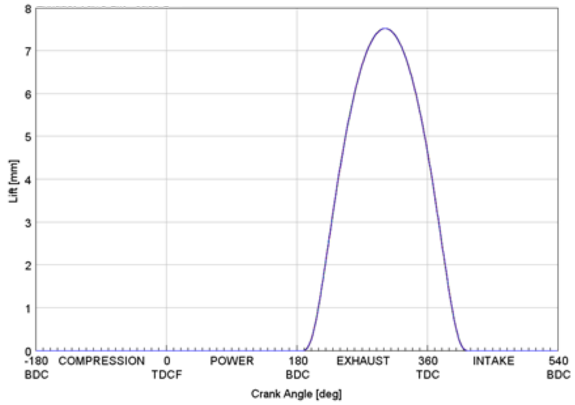
Case A (Exh_MOP : 247.8 °)



Case B (Exh_MOP : 292.0 °)



Case C (Exh_MOP : 237.8 °)



Case D (Exh_MOP : 302.0 °)

Figure 2 Four cases of exhaust timing

In addition to the above, the brake specific fuel consumption (BSFC) was set as the minimum target, also to achieve the best optimum timing for the intake and exhaust valves targeting low fuel consumption. Thus, the DOE involves 625 experiments for each point of the range of the intake and exhaust timing using full-factorial method in which all combination factors will be included in the simulation using DOE. Then, the optimization acquires the lower (minimum) value in BSFC using the interpolation between two target points until the data is converged.

3.0 RESULTS AND DISCUSSIONS

The results from the optimization technique for targeting performance and those targeting fuel consumption will be plotted in the same graph and compared to the standard Iriz engine results.

3.1 Final Optimization

3.1.1 Brake Torque

Figure 3 shows the brake torque results and the percentage different of brake torque. In targeting performance, results show the increasing value in brake torque compared to the standard result with maximum percentage difference of 9.83% at 6,000rpm. There is the wide range at 3,000 rpm, the maximum torque occurs because there is no overlap in the valve profile at 3,000 rpm.

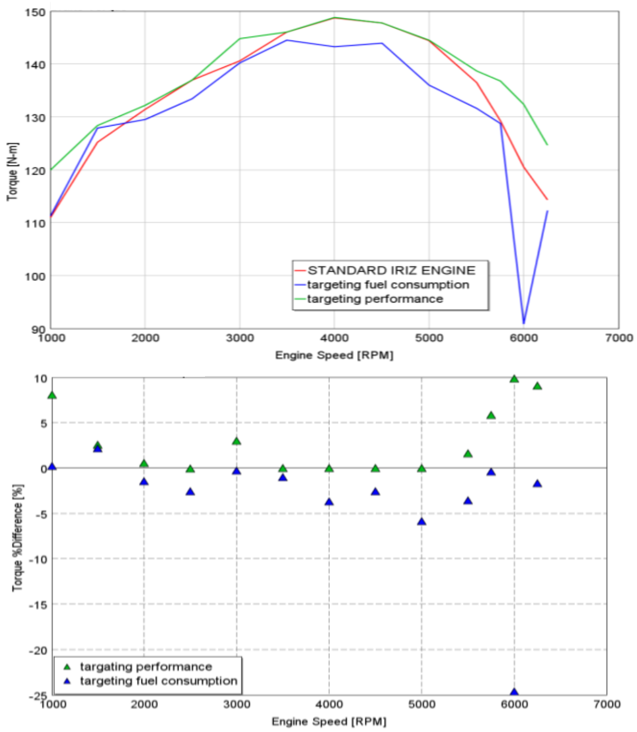


Figure 3 Brake torque and percentage difference of brake torque

No overlap will cause the exhaust gas in cylinder not to enter into the intake system during intake stroke. No exhaust gas return to intake system will cause the air mixture from intake to enter properly into the cylinder without less mix with exhaust gas. The high amount of air mixture enters to the cylinder will combust and produce high torque. In targeting fuel consumption, the overall brake torque result in optimization is low when compared to the standard Iriz engine result. There is slight increase in brake torque at 1,500 rpm when compared to the standard results. The overall brake torque decreases because on order to reduce the fuel consumption, the performance will decrease.

3.1.2 Brake Power

Figure 4 shows the brake power results and the percentage different in brake power. The percentage difference of brake power has the same pattern and same amount with the percentage difference in brake torque. This is because brake torque was directly proportional to the brake power. In the targeting performance, there is a significant difference in brake power at high rpm. This is because, at 6,000 rpm, the intake valve was closed late and allows longer time for air mixture to enter the cylinder. While, targeting fuel consumption shows wider range between 5,000 rpm and 6,000 rpm. This is due to reducing the fuel consumption, the brake power must decrease.

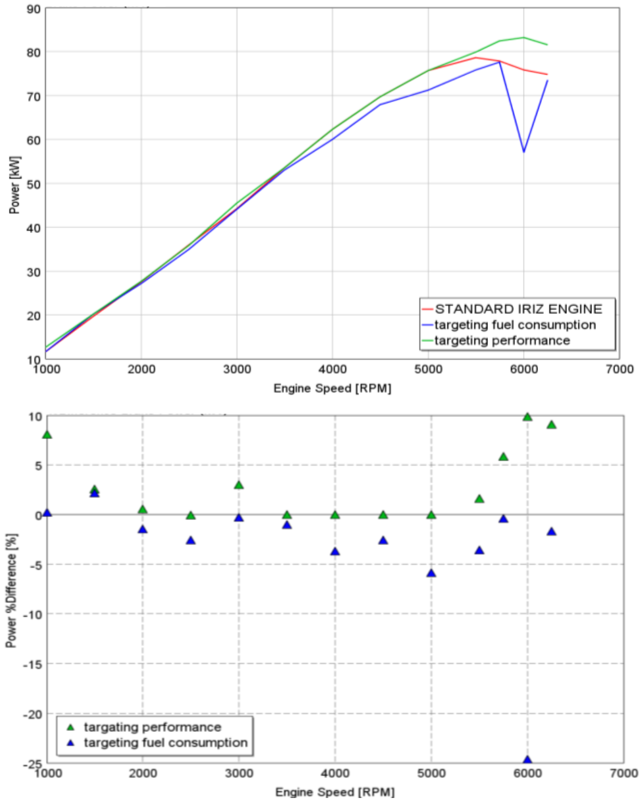


Figure 4 Brake power and percentage difference of brake power

3.1.3 Brake Specific Fuel Consumption

Figure 5 shows the result comparing between targeting performance and fuel consumption in BSFC results. For the targeting performance, there is a slight increase of BSFC in middle range rpm compared to the standard Iriz engine.

At high rpm, there is a decreasing value of BSFC compared to the standard Iriz engine because at high rpm speed, the intake valve was closed late and cause the returning of air mixture back to the intake system and caused the lack of fuel combust during the combustion process. In the targeting fuel consumption, the overall BSFC result is lower than the result of standard Iriz engine. The wide ranges occur at 6,000 rpm with the maximum percentage difference which is 73.65%. This is because the computational error during the simulation running at this speed that the result could not converge.

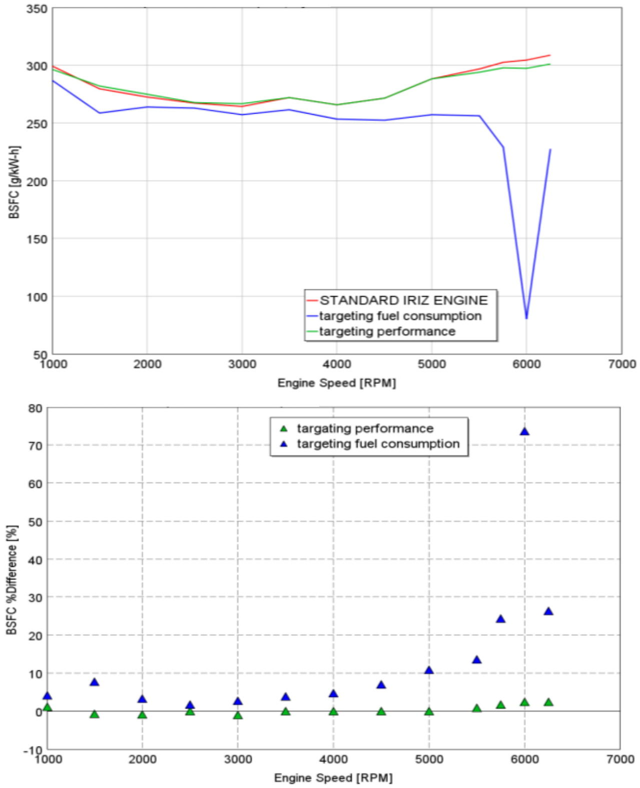


Figure 5 BSFC and percentage difference of BSFC

3.1.4 Volumetric Efficiency

Figure 6 shows the result of the volumetric efficiency. In targeting the performance results, the maximum percentage difference in volumetric efficiency is 7.23% at 6,000 rpm. Overall, it was shown that there is an increasing trend in the volumetric efficiency compared to the standard Iriz engine result. The average percentage difference in volumetric efficiency is 2.63%. at the lower rpm. The wide range of intake valve will cause a large amount of mass air flow rate to enter to the cylinder and will increase the volumetric efficiency.

In the targeting fuel consumption, overall shows the decreasing value in volumetric efficiency compared to the standard Iriz engine result. The average of percentage difference in volumetric efficiency is -2.88%. At the lower rpm which is 1,500 rpm, there is an increasing value in volumetric efficiency when compared to the standard Iriz engine result. This is because the wide range of intake valve at 1,500 rpm causes the large amount of mass air flow rate enters to the cylinder.

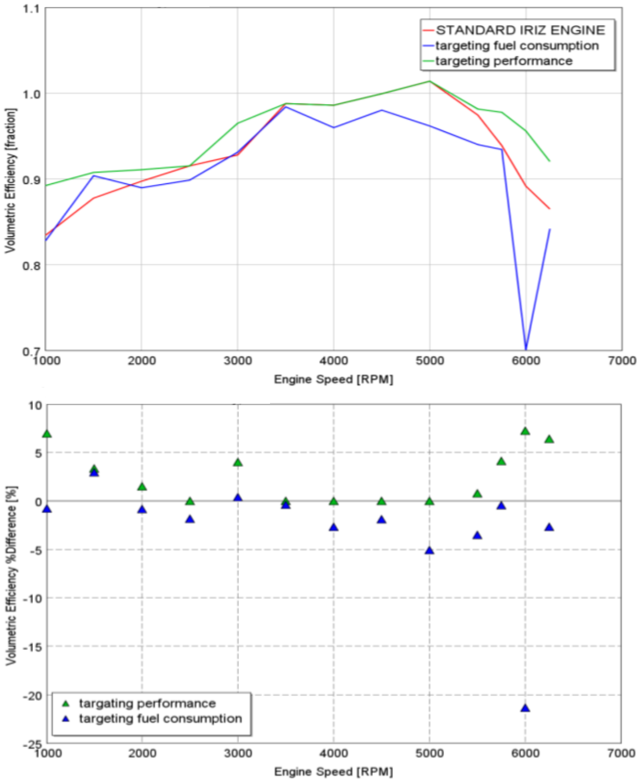


Figure 6 Volumetric efficiency and percentage difference of volumetric efficiency

3.1.5 Thermal Efficiency

Figure 7 shows the result in thermal efficiency. For targeting performance result, there was slightly different result when compared to the standard Iriz engine result. The wide range is at 6,250 rpm with the percentage difference is 2.51% and for the range of 5,000 rpm until 6,250 rpm, thermal efficiency was shown increasing than standard Iriz result. At 6,000 rpm, the exhaust valve was opened early before BDC. This allows the exhaust gas to move out from cylinder early and this will bring the temperature in the cylinder to move out to the exhaust system and will increase the thermal efficiency.

In the targeting fuel consumption, the result was higher when compared to the standard Iriz engine result. The wide range is at 6,250 rpm with the percentage difference is 5.74%. This is because the intake valve helps the temperature to move out during the air mixture entering the cylinder and move out of the exhaust system. Thus, the lack of overlapping will result in slightly higher temperature compared with the standard Iriz engine during each engine cycle.

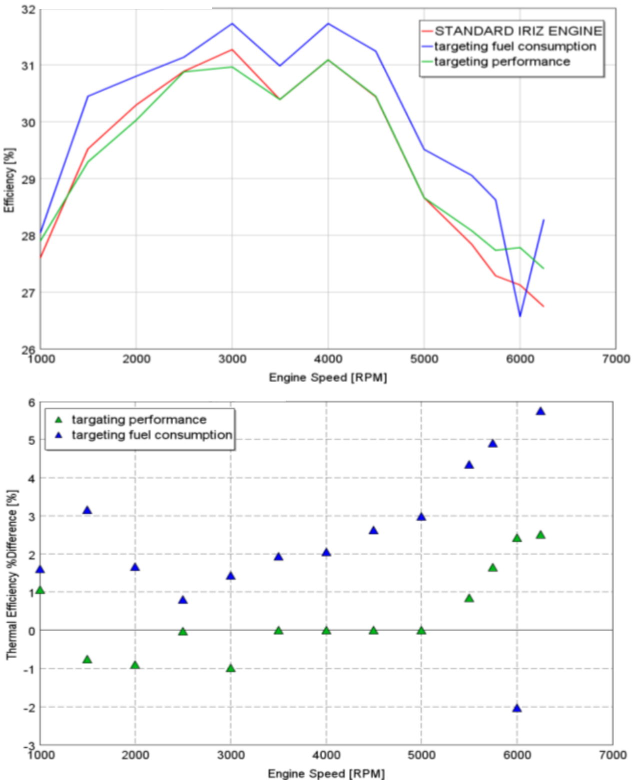


Figure 7 Thermal efficiency and percentage difference of thermal efficiency

4.0 CONCLUSION

A 1D simulation was carried out using the GT-POWER software to produce the optimum condition of the intake and exhaust timing to get the higher performance and reduced fuel consumption. The simulation was carried out to study the effect of implementing the duration of exhaust timing in the engine model. The concept of Miller cycle has been successfully applied to the engine model by adjusting the intake parameters prior to executing the simulation. The overall simulation result shows that the effect of implementing the Miller cycle concept is minimal compared to the standard Iriz engine, largely because too large a reduction in the compression ratio will cause an adverse effect on the engine performance. Other than that, the concept of the Miller cycle was more suitable to be implemented in the engine with the force induction system such as turbocharged and supercharged engines. The results also produce two types of optimum which is targeting the engine performance and fuel consumption, both the optimum timing can be used and installed in the Proton Iriz engine and tuning the valve to get targeting performance and fuel consumption. The timing can be categorized into two modes that are the sport mode for targeting performance and economy mode for targeting fuel consumption.

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