Progress in Engineering Application and Technology Vol. 2 No. 2 (2021) 866–877

PEAT

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

The Effect of Camshaft Degreeing Towards Performance of a Passenger Car

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DOI: https://doi.org/10.30880/peat.2021.02.02.078
Received 13 January 2021; Accepted 01 March 2021; Available online 02 December 2021

Abstract: The word "Degreeing Camshaft" means ensuring that the position of the camshaft in the engine coincides with that of the crankshaft, in order to synchronize their rotation. A procedure known as camshaft "degreeing" is employed to determine if a camshaft meets the manufacturer's specifications. This research was conducted with laboratory setup to analyze the performance of power and torque produced from each advance and retard exhaust timing of the passenger vehicle using Mustang Chassis Dynamometer. The test is conducted using 1.3 L engine of Proton Saga FLX which has been changed to adjustable cam pulley for the exhaust. In addition, two types of tests conducted which are full load test and part load test. For full load test, each of the exhaust cam pulley adjustment tested on wide open throttle using 4th gear on dynamometer. For part load test, each of the exhaust cam pulley adjustment tested on dynamometer to record the torque produced using 4th and 5th gear at 2000 rpm and 2500 rpm. Generally, advancing the exhaust cam pulley results the exhaust valve to opened and closed sooner while retarding the exhaust cam pulley will results the exhaust valve to opened and closed later. The result indicated that the later the exhaust valve open, the more torque and power gained at low RPM, while the sooner the exhaust valve open, the higher RPM power and torque gained. It is confirmed that the objectives of this study were achieved, the vehicle tested on the power curve test was identified and the amount of power and torque produced by the effect of exhaust cam pulley adjustment were studied.

Keywords: Degreeing Camshaft, Exhaust Timing, Performance

1. Introduction

A procedure known as camshaft "degreeing" is employed to determine if a camshaft meets the manufacturer's specifications. The method determines whether the valves are opened and closed in the same, defined manner. It is especially important when it comes to competition engines because cylinder pressures / volumes are vital to engine efficiency. Inaccurate camshafts can rob these engines of much-

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needed horsepower, placing the driver at an actual competitive disadvantage. The question occurs because camshafts may not always follow the requirements for manufacture. However, cam timing may be affected negatively by tolerance stacking, and/or the decisions of the manufacturer to aim overall performance as a goal rather than racing performance [1-2]

The word "Degreeing Camshaft" means ensuring that the position of the camshaft in the engine coincides with that of the crankshaft, in order to synchronize their rotation. It is the only way to know whether the piston rise, and fall matches the valve opening and closing correctly, so that the engine works properly. A few degrees of misalignment can have a dramatic effect on engine operation. If the conditions were fine, it would only be necessary to line up the marks on the sprockets of the timing chain, and degreed the cam. In fact, it deals with a component group (camshaft, crankshaft, timing chain / timing belt, and sprockets), all with their own tolerances and standards. It can never be sure that the parts are in the appropriate place without degreeing the cam [3]. The relative position of the camshaft to top dead center (TDC) affects the valve timing events across the entire firing order, which can have substantial effects on the resulting horsepower and torque curves. Degreeing the cam not only ensures that can account for manufacturing tolerances, but also allows a builder to adjust the cam timing for performance.

2. Literature Review

The main function of an engine valve actuation system is to control the flow of gas in and out of a combustion chamber through intake and exhaust valves, respectively. The related valve lift or travel is generally shown in a valve timing diagram in Figure 1, where valve timing, valve lift and valve duration are set. A valve lift profile describes a valve lift as a function of the camshaft angle between its opening and closing. The opening and closing points decide the valve timing in the crank angle area, and hence the relationship between the lift profile and the rest of the engine components and events such as piston motion and ignition. The valve lifting mechanism is also equipped for minimal pumping failure. Intake and exhaust valve lifts are almost the same, but the diameter of the intake valve is greater than the exhaust one to ensure that fresh air can be pumped into the cylinder quickly. However, this involves very tight regulation of the lift to match changes in engine speed and load conditions that have yet to be completely demonstrated. The difference between opening the intake valve and closing the exhaust valve is an important secondary parameter that greatly impacts combustion efficiency. The region underneath a lift profile reflects the efficiency of gas exchange. For valve actuation systems classification the following descriptions are given:

i. Valve lift refers to the amplitude of the valve lift profile, and in particular the peak value.
ii. Valve timing refers to the phase change of the valve lift profile in the crank angle domain, in particular the valve opening and closing events such as EO, EC, IO and IC.
iii. Duration of the valve refers to the duration of the valve being held open, i.e. , the time between the opening and closing events.

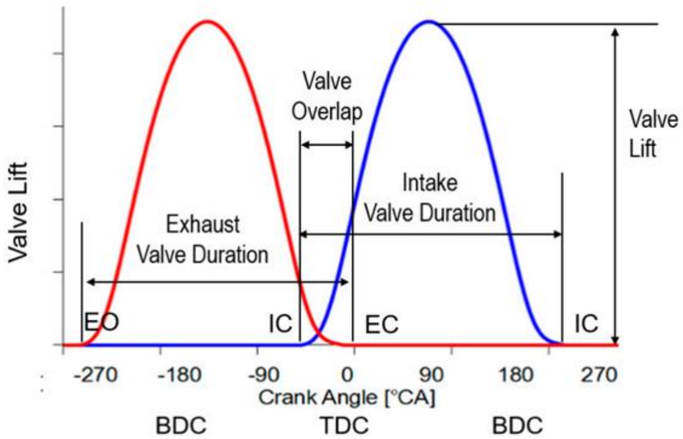

Figure 1: Regular valve timing diagram for naturally aspirated engines, defining valve lift, timing, and duration [4]

The timing (or phase) of the intake and exhaust valve opening, and closing is determined by the valve lift profiles shown in Figure 2. This timing is set in a traditional engine at a value that represents the best balance between competing demands for idle speed efficiency, fuel economy, low speed torque and power.

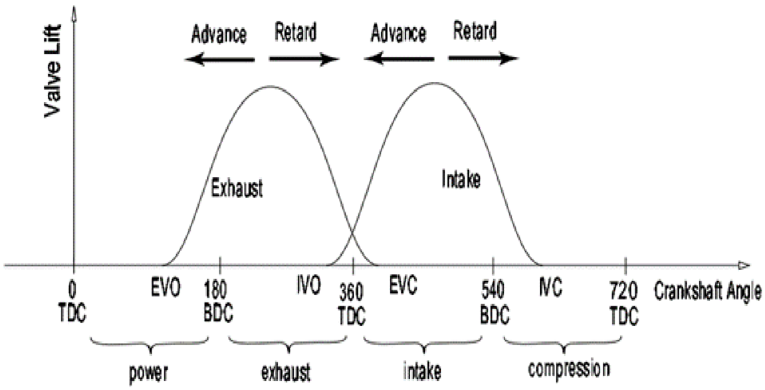

Figure 2: Profiles of intake and exhaust valve lifts versus crank angle [5]

The exhaust valve opening (EVO) usually occurs before power stroke finishes. This allows earlier release of the hot exhaust gas during the subsequent exhaust stroke resulting in reduced pumping losses. The exhaust valve closes at the end of the exhaust stroke, just after the cylinder hits the TDC. The slight angle (5-15 degrees) the EVC follows the TDC allows the exhaust gas to clear the cylinder beyond what otherwise would be achieved. Closing it earlier or later would increase the quantity of exhaust gas retained in the cylinder, especially at lower speeds.

Some of the feature tradeoffs can be avoided with adjusting the cam timing with the operating conditions by retard and/or advance the intake, exhaust, or both cams, depending on the cam-shaft actuated. Advancing cam timing results in faster opening and closing of the valves (in crankshaft degrees) while retarding results in subsequent opening and closing. Note that cam phasing doesn't adjust the length of the open valve intervals [5].

3. Materials and Methods

This section demonstrates the methods used in conducting the experiment to gather the data and the validity of the intended process. This experiment's approach would require the use of the chassis dynamometer to achieve the results for the experiment. The method used in this study was discussed in detail in this chapter.

3.1 Test Vehicle

The Proton Saga second generation is a subcompact car B-segment sedan manufactured by the manufacturer Proton of Malaysia since 2008 as shown in Figure 3 below. This car has a body style 5 door sedan, with a front mounted engine driving the front wheels. The 1.3 liter engine is a naturally aspirated, double overhead camshaft, 4 cylinder unit [6]. Table 1 shows the specifications of the test vehicle.

Figure 3: Proton Saga Second Generation (FLX 1.3 L)

Table 1: Vehicle Specification

Specifications	Descriptions
Wheelbase/length/width/height (mm)	2465/4278/1680/1520
Curb Weight (kg)	1080
Engine Type	Natural Aspirated Petrol
Cylinders	Straight 4
Capacity	1.3L (1298cc)
Fuel Tank Capacity (L)	40
Maximum Power Output	96 bhp/70 kW at 6000 rpm
Maximum Torque	120 Nm at 4000 rpm
Transmission	5 Speed Manual Transmission

3.2 Mustang Chassis Dynamometer

The Mustang Chassis Dynamometer is a robust device designed to apply load to the test vehicle. The Mustang Chassis Dynamometer is a consolidated assembly of electrical/electronic, mechanical and electromechanical sub-systems that work together to provide the ability to simulate real road conditions while testing the vehicle in a safe and confined space in the test centre.

Figure 4: Mustang Chassis Dynamometer (MD-AWD-500)

In addition, the Mustang Chassis Dynamometer shown in Figure 4 provides the performance information of the vehicle during the test, which will also enable the user to install test instruments and diagnostic equipment on the engine of the test vehicle to monitor the performance of the engine. In the fields of emission testing, fault diagnosis, performance engineering and test engineering around the world, the Chassis Dynamometer has become an important asset. Chassis Dynamometer can perform a wide variety of vehicle testing as follows:

i. Vehicle Heating & Cooling Systems
ii. Engine Performance and Evaluation
iii. Drive Train Component Evaluation
iv. Transmission Components
v. Tire Testing
vi. Fuel Efficiency
vii. Failure Analysis
viii. Auxiliary Components

3.3 Test Procedures

To create a consistent workflow while conducting the cam timing test, an experimental procedure for the experiment is set to be followed. The procedures for the experiment were conducted as follows:

3.3.1 Finding TDC

The important thing to do before starting the Dial Cam Shaft is to locate the Top Dead Center (TDC). The TDC is the position of piston number 1 at the top and the position of Valve in a closed state for Intake and Exhaust. This position is called Compression Stroke in the cycle of 4 stroke engine (Stroke). The degree wheel attached to the crank pulley and dial gauge needle were placed on top of the first piston as shown in Figure 5 below.

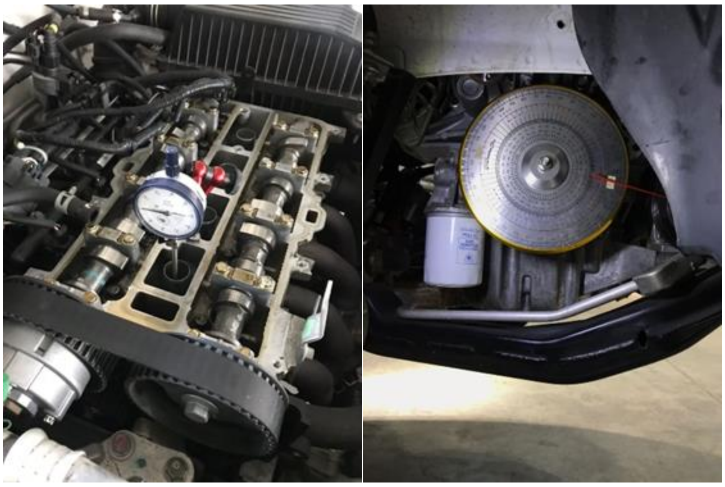

Figure 5: Dial gauge placed on piston surface and degree wheel attached on crank shaft pulley

i. Adjust the crankshaft pulley to the TDC position as the original TDC mark on the engine. Attach the degree wheel to the crankshaft pulley. Attach a pointer to indicate TDC on the degree wheel.
ii. Install dial gauge on piston (spark plug should all be detached) on retainer valve intake, and retainer valve exhaust.
iii. The dial gauge needs to be adjusted so that the dial gauge is in a state of pressure. As soon as there is a movement of the piston goes down or up from the TDC mark, it will be moving from the zero marks (on the dial gauge). From this point, slowly rotate clockwise and rotate anti-clockwise on the crankshaft pulley until the reading on the dial gauge in piston is at its highest reading (when turning the crank pulley, the reading on the dial gauge will fall).
iv. At this moment, move the marker on the degree wheel to show the actual TDC. This process is done because there are cases where the TDC mark on the crank pulley is not positioned correctly since the rubber damper on the crank pulley has moved from its original position.

3.3.2 Find Open and Close Exhaust Valve

The dial gauge was taken out and attached to the exhaust section where the needle of the dial gauge was placed on the exhaust valve tappet as shown in Figure 6 below.

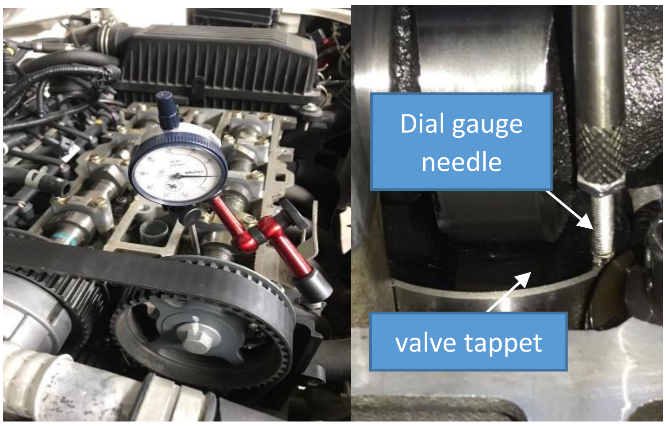

Figure 6: Dial gauge attached and needle placed above exhaust valve tappet

i. Rotate the crankshaft pulley clockwise rotation until the dial gauge of the exhaust section begins to move from the mark 0. Take a movement in the count of 0.05 mm dial gauge movement from 0, then stop. Look at the degree wheel and note down the degree value for 0.05 mm exhaust open.

ii. Rotate the crankshaft pulley anti-clockwise so that the dial gauge returns to 0 mm, then rotates the engine in a clockwise direction, and takes the reading at 1.00 mm and stops. Look at the degree wheel and note down the degree value for 1.00 mm exhaust open.

iii. Continue to rotate the crankshaft pulley following the engine rotation until the exhaust valve is closed. It can be known by looking at the dial gauge return to the reading of 0. To get the exhaust closed reading, turn the crankshaft pulley anti-clockwise. Then, will be able to see the dial gauge start moving from the mark 0. Take a move in the count of 0.05 mm movement of the dial gauge from 0, then stop. Look at the degree wheel and note down the degree value for 0.05 mm exhaust closed.

iv. Rotate the crankshaft pulley clockwise so that the dial gauge returns to 0 mm. Then rotates the engine anti-clockwise and takes the reading at 1.00 mm, then stops. Look at the degree wheel and note down the degree value for 1.00 mm exhaust closed.

3.3.3 Find Open and Close Intake Valve

The dial gauge was taken out from the exhaust section and attached to the intake section where the needle of the dial gauge was placed on the intake valve tappet as shown in Figure 7 below.

Figure 7: Dial gauge attached, and needle placed above inlet valve tappet

i. Rotate the crankshaft pulley clockwise rotation until the dial gauge of the intake section begins to move from the sign of 0. Take a move in the count of 0.05 mm movement of the dial gauge from 0 and stop. Look at the degree wheel and note down the degree value for 0.05 mm intake open.

ii. Rotate the crankshaft pulley anti-clockwise so that the dial gauge returns to 0 mm then rotates the engine clockwise and takes the reading at 1.00 mm and stops. Look at the degree wheel and note down the degree value for 1.00 mm intake open.

iii. Continue to rotate the crankshaft pulley following the engine rotation until the intake valve is closed. It can be known by looking at the dial gauge return to the reading of 0. To get the reading for intake closed, turn the crankshaft pulley anti-clockwise. Then, will be able to see the dial gauge start moving from the 0 marks. Take a move in the count of 0.05 mm movement of the dial gauge from 0, and then stop. Look at the degree wheel and note down the degree value for 0.05 mm intake close.

iv. Rotate the crankshaft pulley clockwise so that the dial gauge returns to 0 mm. Then rotates the engine anti-clockwise and takes the reading at 1.00 mm, then stops. Look at the degree wheel and note down the degree value for 1.00 mm intake close.

3.3.4 Engine Testing – Full Load and Part Load

The procedures for this experiment were conducted starting with turn power up the dyne panel and computer system, turn the isolators on. Launch Software for PowerDynePC. Click the 'lift' menu to form the software menu bar shown in Figure 8 and select the 'up' option to raise the platform and restrain the roller.

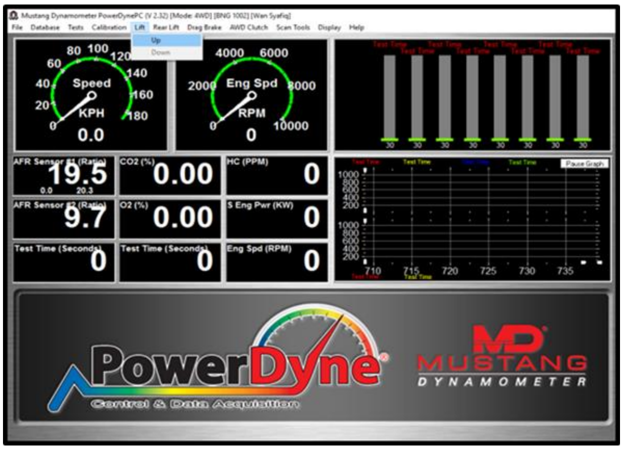

Figure 8: PowerDyne PC's software homepage

Drive the test vehicle to the dynamometer and make sure that the drive wheels are properly positioned between the rollers. Select the 'lift' menu again from the software and click on the 'down' option to release the restrain platform. Assemble the four restraining belt sets. Attach two belts to the front of the test vehicle (cross-over) and two belts to the rear of the vehicle (cross-over or parallel), as shown in Figure 9.

Figure 9: Front and Rear Vehicle Setup on Dynamometer

After engaging them in the vehicle, the belt tightens slightly. Rotate the roller at a minimum speed by pressing the throttle. The vehicle should be aligned in a balanced position. Then tighten the restraining belts and use the locks to secure them properly. From the PowerDynePC's menu bar, click on the 'test' menu. Select the 'performance' option and go to 'power curve' option. Click on the 'Start Test' to run the power curve test from the PowerDynePC's software. Drive the vehicle from 1st gear to 4^{th} gear until engine speed shows around 3000rpm and release the throttle pedal until it reaches 1500-2000 rpm and click 'start test' go for wide open throttle (WOT) until 4000 rpm. The test displays the power and torque produced from the power curve WOT test. There are total of four WOT test, that is the standard exhaust camshaft setup, advance 5 ° exhaust, retard 5 ° exhaust and retard 10 ° exhaust. For part load test, drive the vehicle to 4^{th} gear maintain it for 2000 rpm and 2500 rpm. Then drive the vehicle to 5^{th} gear maintain it for 2000 rpm and 2500 rpm. The test displays the torque produced from each of the part load test. The test repeated in each advance and retard of the exhaust camshaft.

To collect the data from camshaft centerline, experimental procedures were carried out. In each advance and retard of the exhaust camshaft, the vehicle test is then collected in the full load and part load test. The torque and power produced by the test vehicle are collected by the end of this experiment.

4. Results and Discussion

The result will be divided into three sections which are camshaft centerline data and calculations, power and torque produced from dynamometer by exhaust cam pulley adjustment and torque produced from dynamometer by maintaining 4th gear 2000 rpm -2500 rpm and 5th gear 2000 rpm-2500 rpm (each of exhaust cam pulley adjustment). All the data collected were analyzed and discussed.

4.1 Saga FLX Camshaft Centerline Data

Table 2 below shows the result of camshaft centerline after dial. The main purpose of dial cam in this experiment is to know the original centerline camshaft. This is because when the original cam pulley is changed to adjustable cam pulley, it is likely that the centerline will slightly not follow the original spec. In this experiment, after being converted to adjustable cam pulley, the dial cam process was re-run to ensure the centerline camshaft was as original. After the installation of the adjustable cam pulley, the data centerline on the camshaft was found to be unchanged from the original. Therefore, this vehicle is allowed and ready for the next experiment which is dynamometer power curve test.

Table 2: Camshaft Centerline Data

	Calculation (mm)	Open (°)	Close (°)	Duration (°)	Centerline (°)
Exhaust	0.05	34	19	233	97.5
Exhaust	1.00	12	-6	186	99
Intake	0.05	6	70	256	122
Intake	1.00	-28	30	182	119

4.2 Power Curve (Full Load)

This experiment was performed using the Mustang Chassis Dynamometer to measure the quantity of torque and power generated by the full load test vehicle engine when driving with wide open throttle (WOT) different types of exhaust camshaft timing, which are standard setup, 5-degree advance, 5 degree retard and 10 degree retard. The data collected from all four different adjustable cam pulley adjustment were discussed for the power and torque produced. Experiments were conducted with the same engine condition for the RON 95 fuel gasoline fuel engine. This section will show the comparison average data recorded.

Figure 10 below shows graph of power against engine speed at full load conditions. At low engine speed to 3250 rpm, the power increased by an average of 4.70 % for advance 5 degree and it shows no power improvement from 3250 rpm to 4000 rpm compared to standard exhaust setup. This is due to valves overlap were reduced. Retard 5 degree has little improvement of power at low engine speed and significantly increased at middle range RPM compared to standard exhaust setup. This is due to valves overlap increased, it induced more air inside the combustion chamber, thus produced more power. Meanwhile, for retard 10-degree experienced power drop significantly at low to middle RPM compared to the standard exhaust setup as the valves overlap goes further increased. This possibly due to excessive exhaust residual inside the combustion chamber due to bigger overlap. Higher residual will lead to lower combustion efficiency therefore the power reduced.

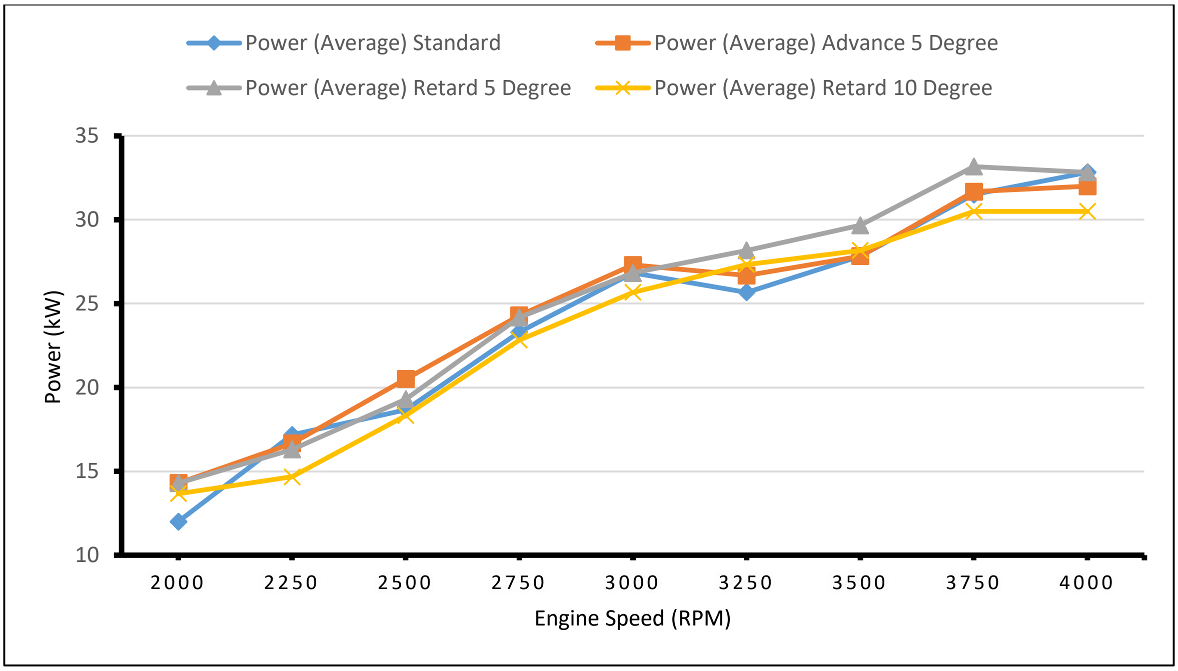

Figure 10: Graph of Power (kW) against Engine Speed (RPM) Average (full load)

Figure 11 below shows graph of torque against engine speed at full load conditions. During low engine speed to 3250 rpm, the torque increased by an average of 5.0 % for advance 5 degree and it shows no power improvement from 3250 rpm to 4000 rpm compared to standard exhaust setup. This is due to valves overlap were reduced as it improved low-end response due to less reversion of the exhaust gasses back up the intake port. Retard 5 degree has little improvement of torque at low engine speed and significantly increased at middle range RPM compared to standard exhaust setup. This is due to valves overlap increased as it manages to cram more intake charge into the cylinder, thus produced more torque. On the other hand, retard 10-degree experienced torque drop significantly at low to middle RPM compared to the standard exhaust setup as the valves overlap goes further increased. This possibly due to exhaust gas manages to preserve the intake manifold, dilute the incoming charge of air/fuel, and create soot on the intake runners. Due to the lack of vacuum produced in the manifold, many valves overlap appear to result in rougher idling.

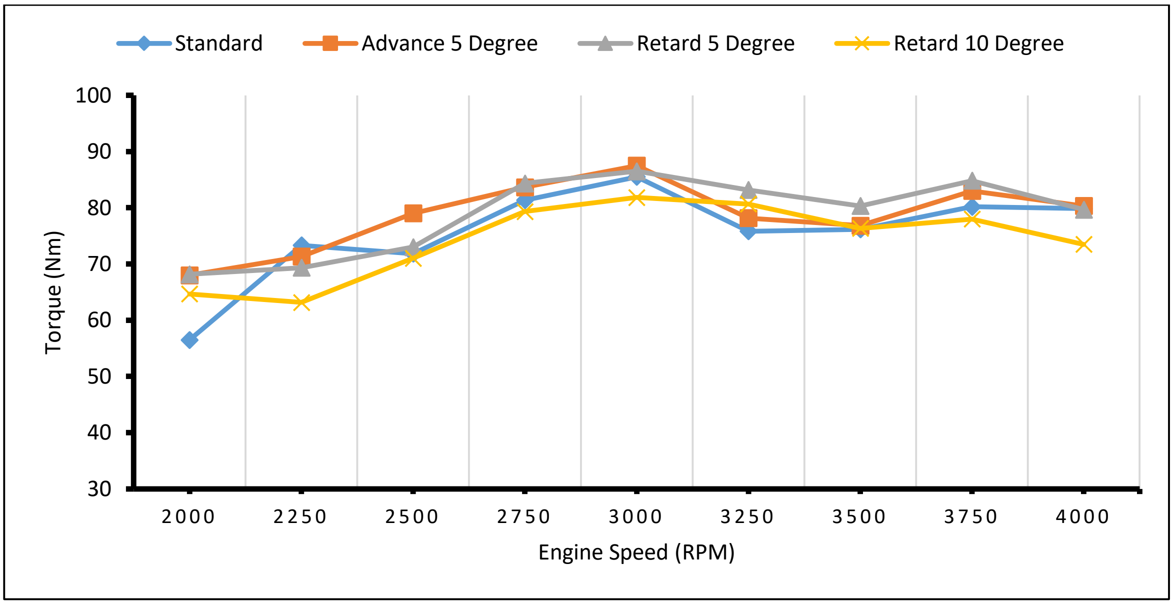

Figure 11: Graph of Torque (Nm) against Engine Speed (RPM) Average (full load)

4.3 Part Load Test

Part Load experiment purpose is to identify average torque being produced by car driven by most people. Usually, most people drive using fourth and fifth gear at 2000 and 2500 rpm. For this test, the vehicle was driven at 4th and 5th gear maintain it for 2000 rpm and 2500 rpm. The test displays the torque produced from each of the part load test. The test repeated in each advance and retard of the exhaust camshaft. Each of this test was conducted 3 times. The average data of the test are shown in Figure 12:

Figure 12 below shows the average difference of torque produced by the engine test vehicle with 4th and 5th gear at 2000 rpm and 2500 rpm. Based on the graph, the torque was directly proportional with the engine speed. From the graph, at 4th gear 2000 rpm and 2500 rpm shows that advance 5 degree produced 1.40 % higher torque than standard exhaust setup. It also shows that retard 5 degree produced 2.00 % lower torque than standard exhaust setup. Retard 10 degree produced the lowest torque among all exhaust setups. On the other hand, at 5th gear 2000 rpm show that advance and retard 5 degree significantly increased on torque and at 2500 rpm shows that standard exhaust setup were slightly highest among advance and retard 5-degree exhaust. Meanwhile, retard 10 degree produced the lowest torque among all the exhaust setup. Figure 12 below also illustrates that the larger the degree of overlap of the camshaft, the greater the power produced. But however, a lot of overlap may also make the engine run poorly at low RPM, this possibly due to exhaust gas manages to preserve the intake manifold, dilute the incoming charge of air/fuel, and create soot on the intake runners. This is because the amount of fuel and air mixture entered is increasing so that the combustion process can be powered during the compression cycle of work. The optimally used is fuel and air mixture during the combustion process. Due to the various properties that are trapped in the combustion chamber between the fuel-air mixture and the combustion product from each degree of camshaft overlap, it will be produced different force on piston.

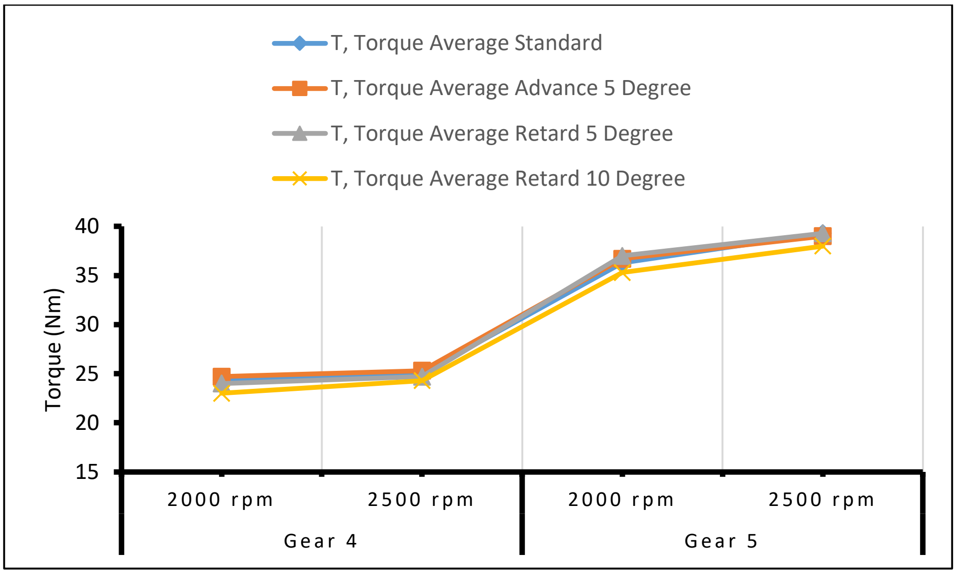

Figure 12: Graph of average Torque (Nm) against Engine Speed (RPM) at 4th and 5th gear at 2000 rpm and 2500 rpm (part load)

5. Conclusion

The aims of the effect of camshaft degreeing towards performance of a passenger car experiment were achieved. The experiment was carried out using a Proton Saga FLX 1.3L test vehicle with a spark ignition (SI) engine. Different adjustments to the exhaust cam pulley have shown that it affects the vehicle's engine performance by measuring the amount of torque and power generated by the engine. The test vehicle was tested on the dynamometer with 2 types of experiments, which were the full load and part load power curve test at 2000 rpm and 2500 rpm with different adjustments of the exhaust cam pulley. To detect the impact of the timing adjustment exhaust cam pulley on engine power and torque performance, the exhaust adjustable cam pulley was advanced 5 degrees, retarded 5 and 10 degrees.

There are several causes on this actual data testing results may differ from theory. This is due to several uncontrolled conditions such as, inconsistence driving by the dynamometer conductor on pedal progression behavior during data collection. Then, different data reading tolerance, data logger and sensors by the dynamometer machine will also affect actual testing results to be difference. The methods used for data testing also play a big role for the achievable results. Insufficient samples and testing may trigger the inaccuracy of results obtained. Therefore, the more testing samples generated, the more accurate the results may be. Finally, the environment is one of the many factors on getting the actual result. There are several uncontrollable environmental factors affecting the accuracy of results which can be listed such as ambient temperature, air humidity and wind conditions.

Exhaust opening occurs near the middle of power stroke, after the spark plug is fired and flame front expanded, and it pushes the piston downward. Once the exhaust valve opens, the exhaust begins exiting the chamber and cylinder pressure drops rapidly. Then the combustion chamber is now used to forces the burned mixture out of the exhaust. During the exhaust stroke, the remaining exhaust gasses will be pushed out by piston and making room for next charge of air and gas mixture. Thus, the later the exhaust valve open, the more torque gained on lower RPM. The sooner the exhaust valve opens, the more power curve will carry past the point of peak horsepower due both reduce exhaust pumping losses and the exhaust having more times to free itself of the chamber. In conclusion, the power and torque increase at high RPM when the exhaust cam pulley is advanced. Otherwise, if the exhaust cam pulley is retarded, at low to mid RPM range, the power and torque increase. It is confirmed that the objectives of this study were achieved because when the vehicle tested on the power curve test was identified and the amount of power and torque produced by the effect of exhaust cam pulley adjustment was studied.

Acknowledgement

The authors would like to thank Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

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