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INVESTIGATION AND PROBABLE SOLUTION OF LOW END TORQUE DIP PROBLEM OF CAMPRO 1.6L ENGINE

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ABSTRACT

The main objective of this work is to perform an extensive study on the causes of the torque dip in CAMPRO engine and subsequently to provide the best solution that will improve the performance, reliability as well as production cost. CAMPRO engine is a basic Double Overhead Camshaft (DOHC) which has a capacity of 1597 cc and installed with a total of 16 valves developed by Malaysian car manufacturer PROTON. The CAMPRO engine experiences performance downfall when it reaches at certain rpm. The phenomenon is known as torque dip or torque loss where the output torque is not smooth, consequently formed a dip in the torque curve. The dip which occurs at 2500 – 3500 rpm is mainly influenced by the geometry of the designed intake manifold and valve timing. Analysis is mostly confined on the intake manifold geometry. From the analysis done, two possible solutions were provided viz., Natural Dual Intake Manifold and Continuous Variable Intake Manifold.

Keywords: Valve train, GT-Suite, GT-Vtrain, Backward solution, VT-Design.

INTRODUCTION

CAMPRO engine has been developed by Malaysian car manufacturer PROTON in 2000. The CAMPRO engine is a basic Double Overhead Camshaft (DOHC) which has a capacity of 1597 cc and installed with a total of 16 valves. The bore and stroke dimensions of each cylinder is 76 mm and 88 mm respectively. It is claimed to produce 110 bhp (82 kW) @ 6500 RPM and 148 Nm of torque (Proton, 2005). Despite of the great achievement, PROTON is facing a problem with the performance of its engine. In order to compromise the maximum torque and achieving the required emission level, PROTON engineers had to sacrifice the performance of the low-end torque of the engine. Therefore, unlike any other average performance engines, the CAMPRO engine experiences performance downfall when it reaches at certain rpm. The phenomenon is known as torque dip or torque loss where the output torque is not smooth, consequently formed a dip in the torque curve. The dip which occurs at 2500 – 3500 rpm is mainly influenced by the geometry of the designed intake manifold and valve timing. The main objective of this work is to perform an extensive study on the causes of the dip in CAMPRO engine and subsequently to provide the best solution that will improve the performance, reliability as well as production cost. The analysis is mostly confined on the intake manifold geometry and the valve timing. This is done by simulating similar model of CAMPRO in the GT SUITE software and acquired the results of changed intake geometry and valve timing on the output torque.

GT-SUITE is an integrated set of computer-aided engineering (CAE) tools developed by Gamma Technologies, Inc. to address engine and power train design (Gamma, 2004a). These tools are contained in a single executable form which is essential to its use in "Integrated Simulations". GT-SUITE comprised of six solvers (GT-Power, GT-Drive, GT-Vtrain, GT-Cool, GT-Fuel, and GT-Crank), a model-building interface (GT-ISE), a powerful post-processing package (GT-POST), and a collection of supporting tools (Gamma, 2004b). GT-ISE provides the user with the graphical user interface (GUI) that is used to build models as well as the means to run all GT-SUITE applications. GT-SUITE comes with an individual solver specifically to assist engineers in the design of valve trains which is called GT-VTRAIN. A useful tool included in GT-VTRAIN is the VT-Design. Valve train Design (VT-Design) is a stand-alone, interactive polynomial cam design/valve train mechanism design tool supplied with GT-SUITE that may be used as a pre-processor to the following applications: GT-POWER, GT-VTRAIN and GT-FUEL. Two distinct features of the tool are Cam Design and Valve Train Kinematics.

From the analysis it can be concluded that the torque dip phenomenon is caused by the pressure wave that is not coherent with the valve opening. The travelling pressure wave which is supposed to arrive at the time the intake valves are opening will be induced into the cylinder as a result of the vacuum effect created by piston's downward motion. The shape of the torque curve is largely dependent on the runner geometry, valve timing and pressure wave arrival.

GT-POWER: CAMPRO ENGINE MODEL

A GT-Model is created to model the CAMPRO engine. The model data were referred from PROTON Power train department database (Proton, 2005). Due to insufficient information, some data were taken from default value (Gamma, 2004a). Fig. 1 shows the model of the CAMPRO in

GT Power. Variation of torque with rpm for the CAMPRO 1.6L engine and its GT Power model is shown in Fig.2.

ANALYSIS

Intake manifold phenomenon

Intake manifold is a complex part of the engine. The pressure behavior is relatively complex due to the negative and positive pressure wave oscillation in the manifold. The intake system can be modeled as a spring-mass system. A series of pulsating waves of expansion and compression are occurring in the intake runner. The wave travels back and forth in the runner due to inertia. The pressure at the port builds up when the valve is closed (Fig.3). As it builds up, the pressure wave travels back and forth creating an oscillating wave. Theoretically, when the timing of the pressure wave is right, the pressure wave will travel towards the cylinder when the valve is open and the pressure at the port falls below atmospheric pressure. At the maximum opening of the valve, the positive pressure starts to drop as the valve starts to close. The pressure in the port will start to increase as the valve closes.

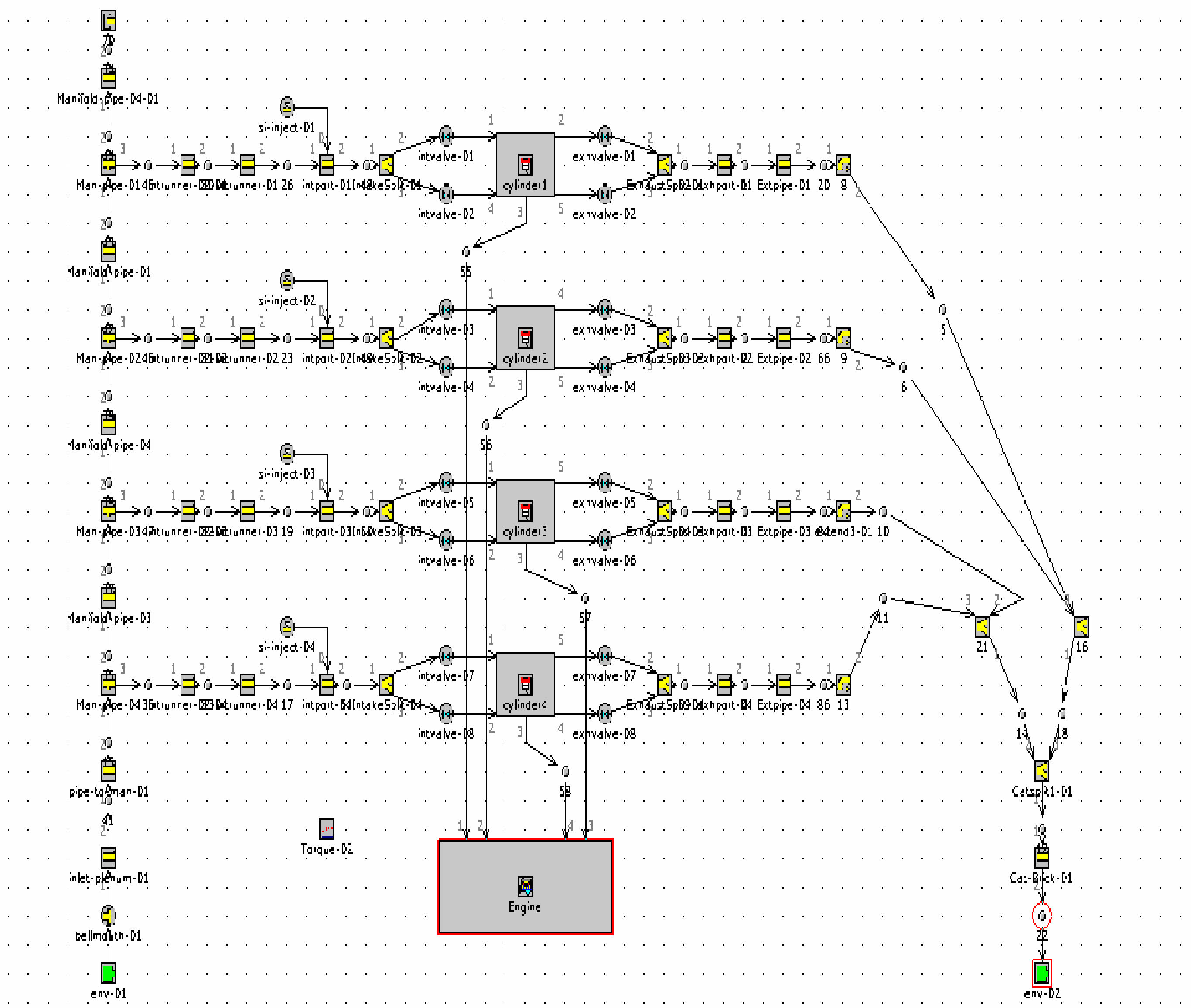

Fig. 1. CAMPRO Model in GT Power

When the valve is fully closed, the pressure wave travels backward as a negative start to increase as the valve closes. When the valve is fully closed, the pressure wave travels backward as a negative pressure wave. Then, the pressure wave travels back to the valve again until the valve is open for the next cycle. According to Lumley (2000), as seen in the pressure graph in Fig. 4, the pressure in the intake manifold can be modelled as a loaded spring and is released.

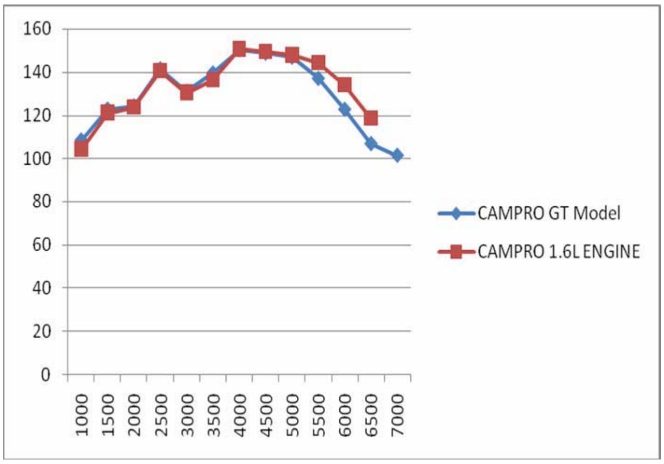

Fig. 2. Torque vs RPM for the CAMPRO 1.6L Engine and its GT Model

The fluid in the runner oscillates in similar manner as the spring-mass system. The oscillations dampen until the valves open again. Referring at crank angle where the valve is at its maximum opening in Fig.5, the pressure for the operating range other than 3000 rpm is much lower.

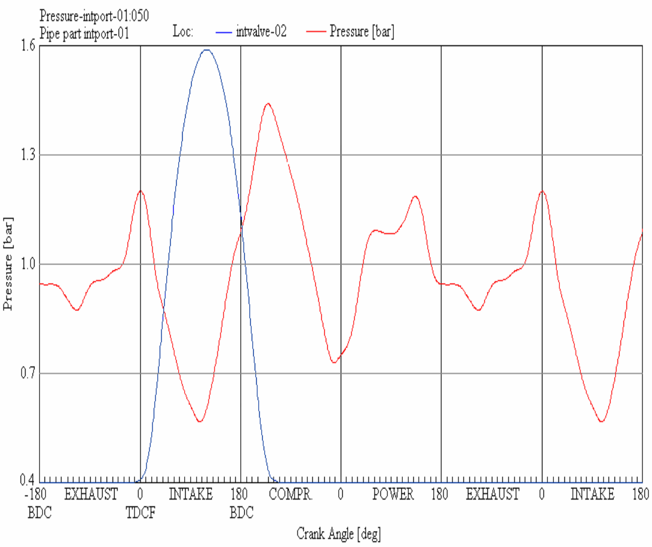

Fig. 3. Intake Port Pressure vs. Crank Angle at 6000 rpm

Low pressure at the port when the valve is opening indicates pressure flowing into the cylinder. Therefore the pressure at 3000 rpm during valve opening is higher in magnitude than the pressure at 2500 rpm during valve opening.

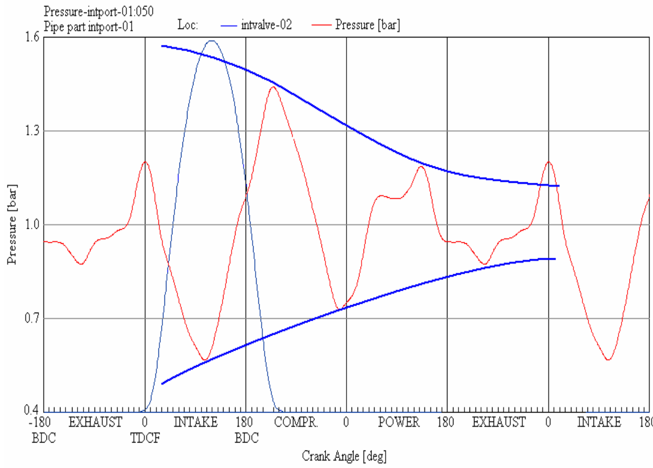

Fig. 4. Valve Timing and Pressure Oscillation in Intake Manifold

It shows that the pressure wave that sucked into the cylinder is lower at 3000 rpm than at 2500 rpm, consequently producing less torque and power. This is where the torque dip occurs. This happens mainly because of the timing the pressure arrives at the valve.

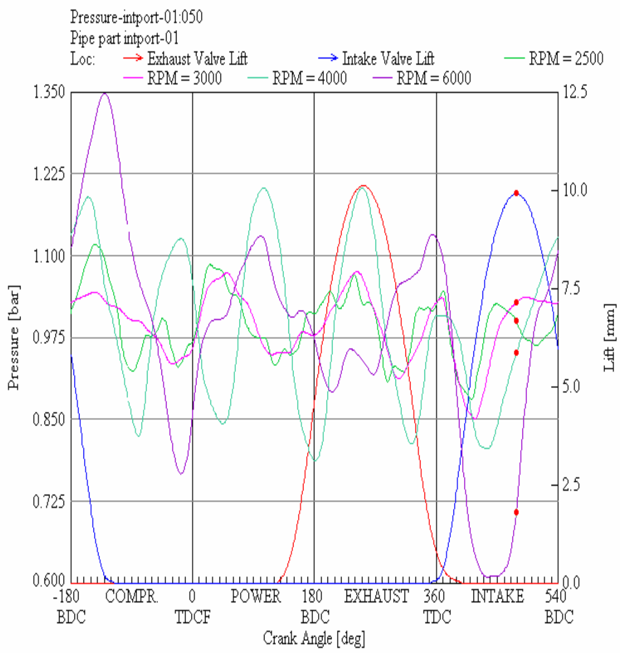

Fig. 5. Intake Port Pressure and Intake Valve Lift vs. Crank Angle

If the pressure wave arrives later than it supposes to be, then the pressure at 3000 rpm can be lowered and more pressure may enter the cylinder. To make the pressure at 3000 rpm arrives later; the length of the runner has to be changed so that the pressure of 3000 rpm at maximum opening of valve is lower than the pressure of 2500 rpm at maximum opening. Then, it will have higher cylinder pressure at maximum valve opening. It is important to tune the length (Hartman, 2003) accordingly, so that maximum cylinder pressure at the maximum valve opening can be achieved.

The runner length of the CAMPRO engine is optimized for higher torque at high rpm. So, the length is much shorter than other manufacturer's intake runner design. The low end torque is sacrificed and the torque dip occurs between 2500 and 3500 rpm (Fig. 6). The torque dip occurs only at this particular range because the valve timing and the pressure wave arrival time is not coherent at this range. The pressure wave arrives too early before the valve opens. The pressure arrival time at 3000 RPM is earlier than the opening of the valve. So, less pressure enters the cylinder. The oscillation at low rpm is more than the oscillation of higher rpm. At low engine speed, the valve opens and closes at a lower speed. So, the pressure wave formed in the intake runner bounces back and forth much more until the valve reopens. This explains why the oscillation at lower rpm is more than that at higher rpm. The more oscillations, the unstable the pressure forms at the intake port. The number of effective pressure wave assisting the fluid flow is higher. So, the study of the pressure wave effects is only limited to rpm higher than 2500. Referring to Fig. 7, the torque dip at rpm less than 2500 is not significant because the number of oscillations is more than that at other rpm. As the rpm increases the number of pressure wave oscillations is reduced per stroke. And the pressure wave arrives earlier. It is to be noted that the oscillations for different rpm is running at different phases. Coincidently, the pressure wave at higher rpm arrives later than at lower rpm. The pressure wave is much affected by the intake manifold design itself. The waves from other cylinders runner can cause interferences that reduce or increase the pressure wave.

AFFECTING PARAMETERS

It is evident from the performance curve of the CAMPRO 1.6L engine that at the point where the dip occurs; a downfall of the volumetric efficiency also occurs at that point (Fig. 8). The volumetric efficiency is influenced by many factors such as the density of the fresh charge, the amount of exhaust gas in the clearance volume, the design of the intake and exhaust manifold and also the valve timing (Ganesan, 2004). The volumetric efficiency is the breathing capacity of the engine during the opening and closing of the intake and exhaust valves. Therefore the volumetric efficiency is inter-related with the pressure wave (Ohata, 1982). In order to enhance the volumetric efficiency and to eliminate the torque dip, two parameters are considered, viz., runner length and diameter, and also the valve timing.

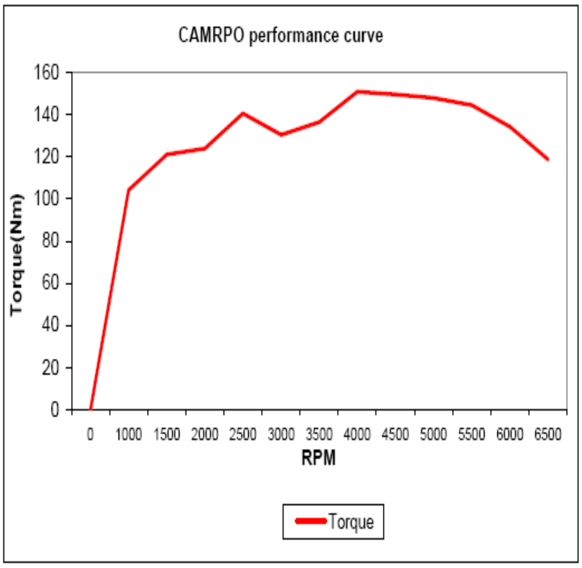

Fig. 6. CAMPRO Torque Curve

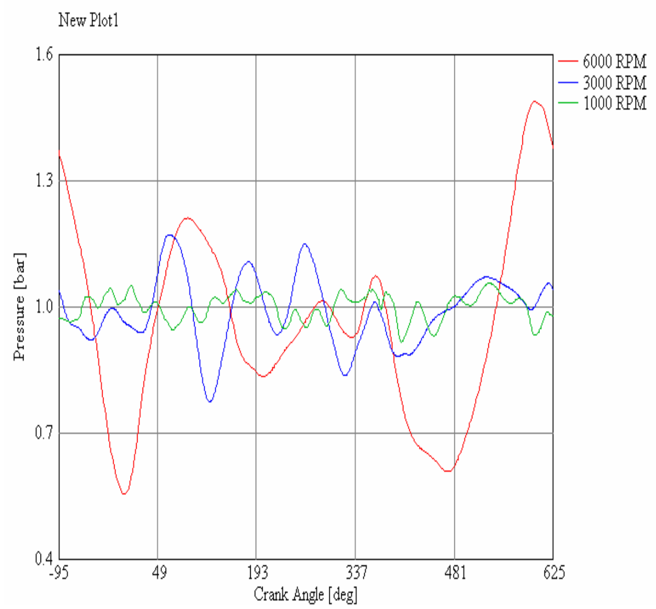

Fig. 7. Intake port pressure vs. crank angle

INTAKE RUNNER LENGTH

For optimum performance result, an appropriate length and diameter of the manifold should be used to get as much as possible of air/fuel mixture into the cylinder in time. The main key of the design of intake manifold is to provide maximum possible fresh charge during the intake stroke (Shinichi, 2003). In addition, by moving the air as fast as possible into the cylinder, we can increase the turbulence. Thus the mixing operation will be accelerated. The runner length controls the timing of the returning waves. With correct length of intake runner, it helps the wave in the runner to return at the port at correct time. But with the valve closing, the air cannot go anywhere and it piles up and became compressed.

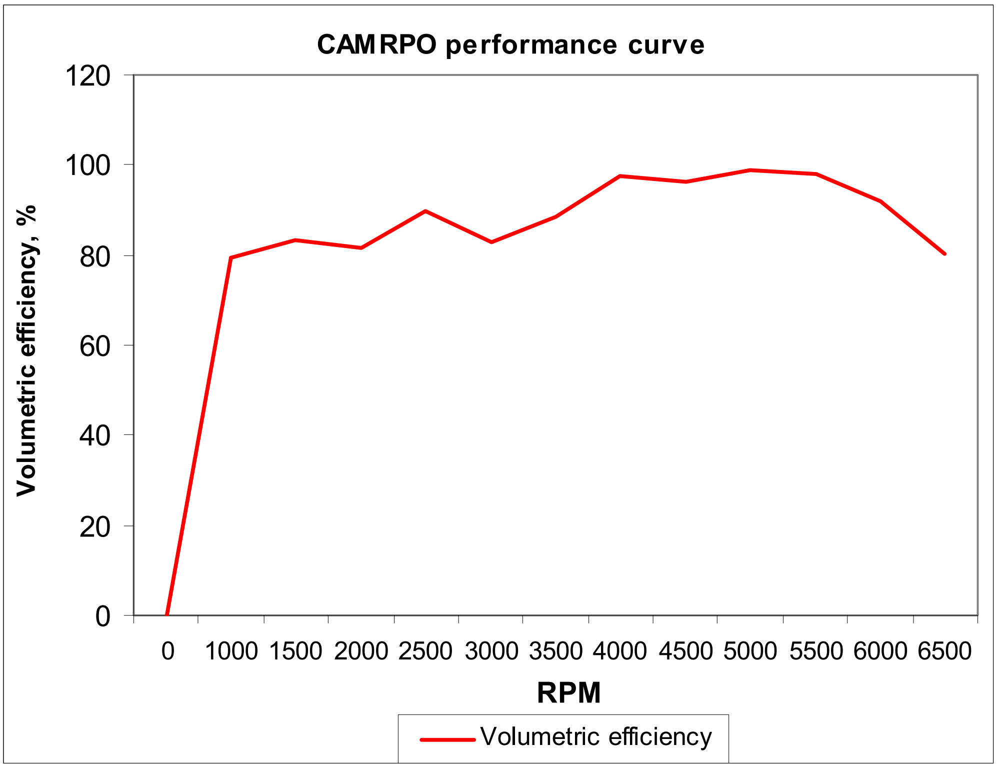

Fig. 8. CAMPRO volumetric efficiency curve

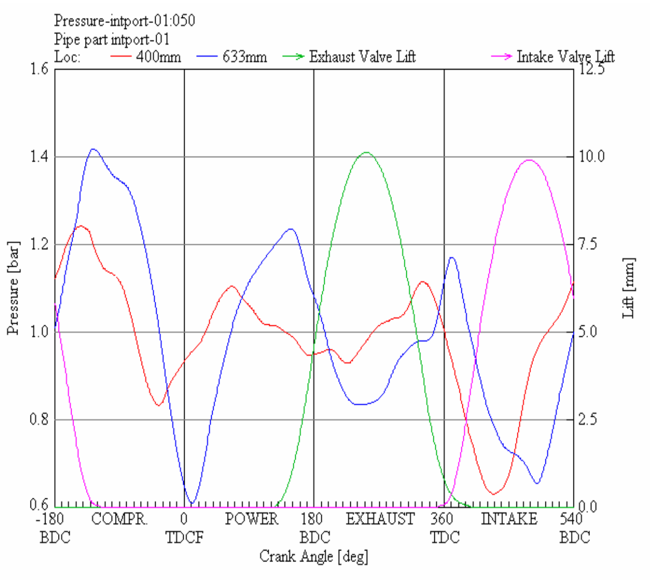

Fig. 9. Intake Port Pressure for 400 mm and 633 mm at 6000 rpm

The compressed air must be diverted so that it turns around it and will flow back through the intake runner in the form of pressure wave (manifold pressure) at the time when the valve is opened and bounces back and forth. If timed properly, it will arrive at the port when the valve is opened again and the extra pressure can force extra air drawn into the engine thus increasing the volumetric efficiency. The amplitude of the pressure wave i.e., nearest to the maximum valve opening is the main concern. The pressure wave arrival time can be controlled by increasing or decreasing the length. By increasing the length, we can increase the travel duration, thus later arrival and vice versa. A simulation using GT Power is conducted to validate this behavior of the fluid in the intake manifold. A series of test were conducted with two different runner lengths of 400 mm and 633 mm. The intake port pressure plotted for 6000 rpm is shown in Fig. 9.

VALVE TIMING

Valve timing is the regulation of the points in the cycle at which the valves are set to open and close. The CAMPRO valve timing is used as reference to understand the standard values used by car manufacturers. The exhaust valve is open

45° before the exhaust stroke. The exhaust valve is open early so that the cylinder pressure will help the exhaust gas move out of the cylinder quickly. Then, the intake valve opens 12° before TDC. Both the intake and exhaust valves are open during the period known as "Valve Overlap". Valve overlap helps to pull the air into the cylinder by the suction effect created by the exiting exhaust gases. This helps to increase the volumetric efficiency of the engine. The intake valve is kept open until 48° after BDC. Due to inertia the air continues to flow even when the piston is moving upwards during the compression stroke. When the valve is opened, it creates vacuum and the pressure wave is theoretically minimum before the valves reach its maximum opening. Fig. 10 shows the pressure wave for 2000, 2500 and 3500 rpm which is not coherent with the maximum opening as in the other engine speeds. This is the cause of the torque dip. Changing the valve timing changes the opening and closing angle of the valves and thus changes the overlap angle. During the valve overlap, the intake and exhaust valves are open simultaneously creating a path for the fresh charges to flow into the exhaust. But a well designed engine can minimize the flow. The main objective of this work is to eliminate the torque dip at the 2500 – 3500 rpm range. According to Lumley (2000), improvement of the low-speed torque of an engine can be achieved by advancing the intake valve opening.

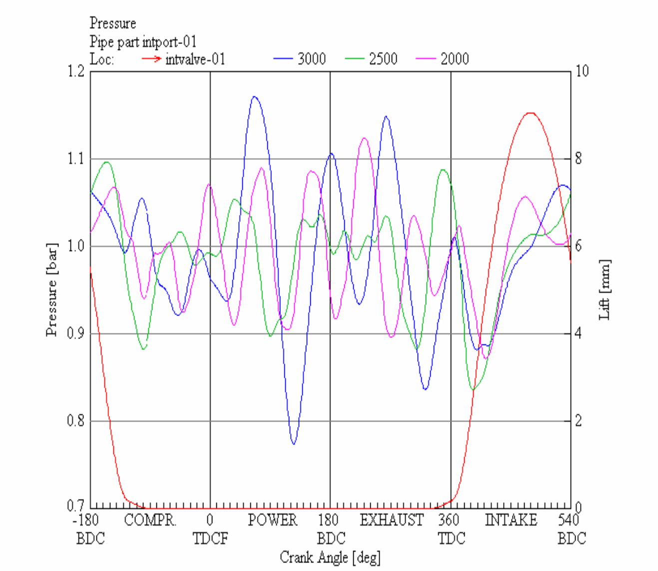

Fig. 10. Intake Port Pressure at 2000, 2500 and 3000 rpm

POSSIBLE SOLUTION

Analysis shows that at the point of dip; a downfall of the volumetric efficiency also occurs. The volumetric efficiency is influenced by many factors such as the density of the fresh charge, the amount of exhaust gas in the clearance volume, the design of the intake and exhaust manifold and also the valve timing. The volumetric efficiency is inter-related with the pressure wave. In order to enhance the volumetric efficiency and to eliminate the torque dip, two parameters are considered, viz., runner length & diameter and valve timing. In this paper focus will be given on the length of intake manifold. Therefore two types of intake manifold; Natural Dual Intake Manifold (NDIM) and Continuously Variable Intake Manifold (CVIM) are analyzed.

NATURAL DUAL INTAKE MANIFOLD

The Natural Dual Length Intake Manifold (NDIM) is a manifold having two different paths internally with different diameters; small diameter and large diameter. Referring to Figure 11, the inlet, center and the outlet diameter of each pipe are different. The pipe is designed to have venturi in the middle of its length. The objective of having the venturi is to create a venturi effect on the air flow.

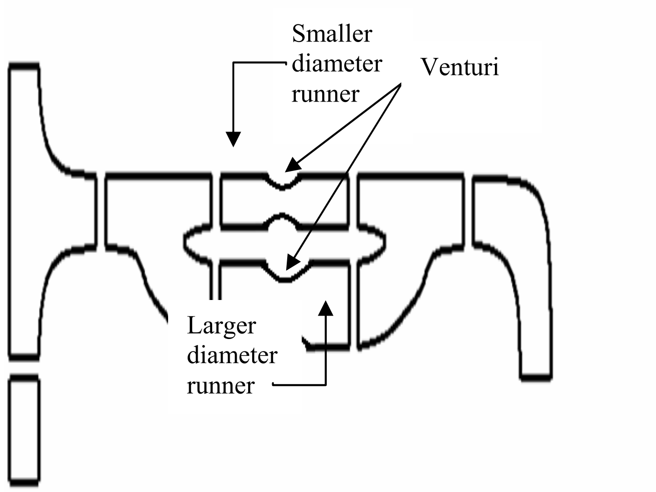

Fig. 11. Intake Runner of NDIM Model

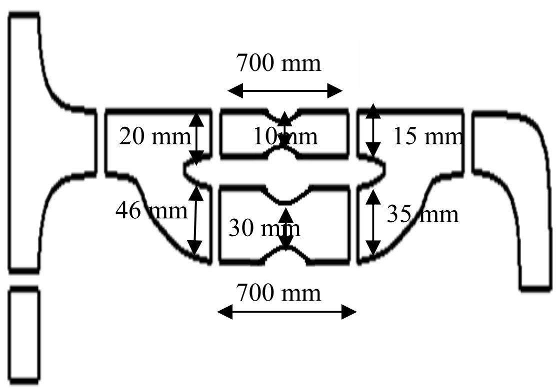

Fig. 12. Dimensions of the NDIM Model

The venturi effect is described as the drop in fluid pressure that results when a fluid flows through a constricted section of pipe. Both pipes are designed to have the same length. The intake runner dimensions of NDIM are shown in Figure 12. The hypothesis made is that during the low end speed, the air will utilize the small diameter passage.

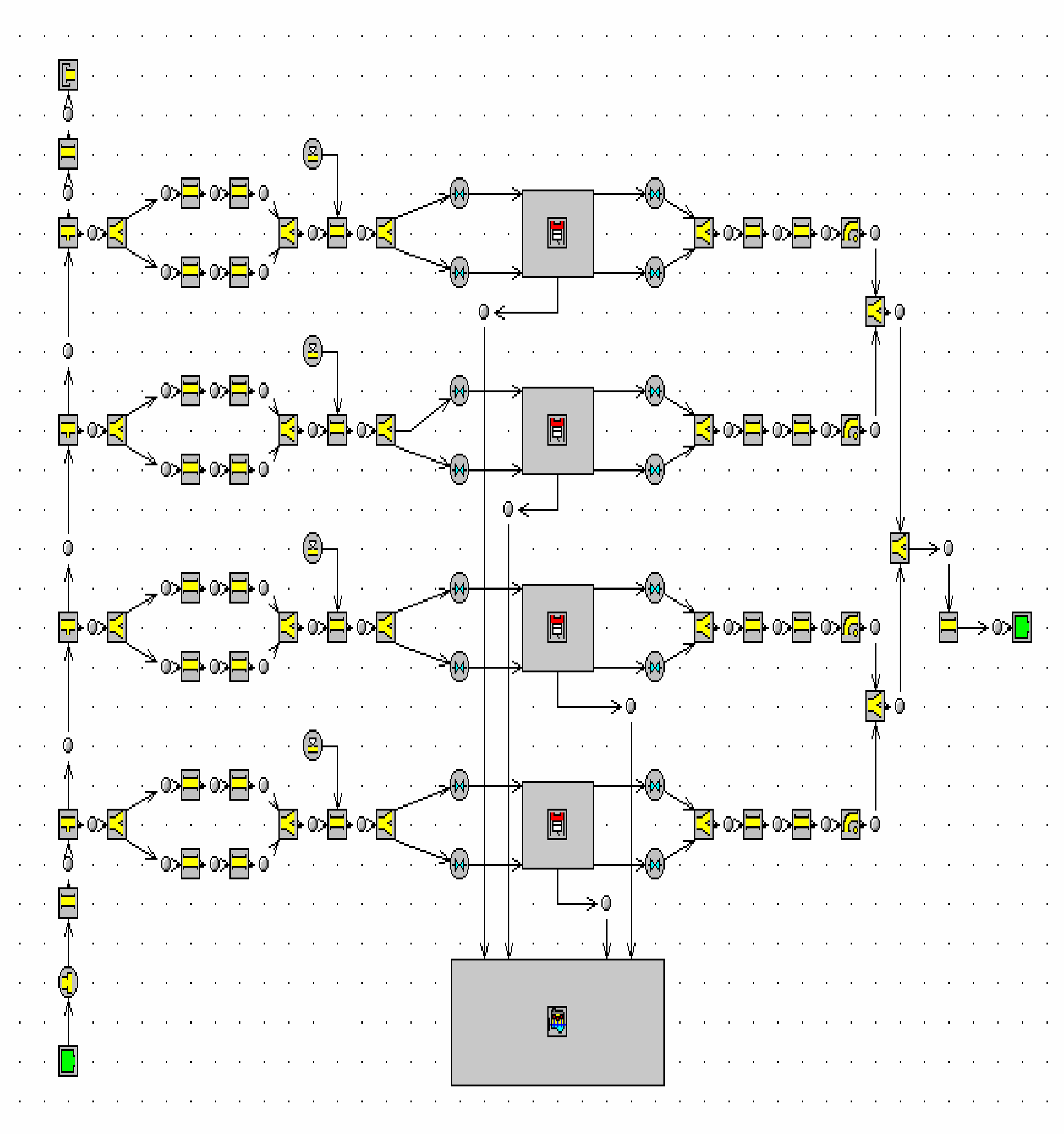

Fig. 13. NDIM GT Model

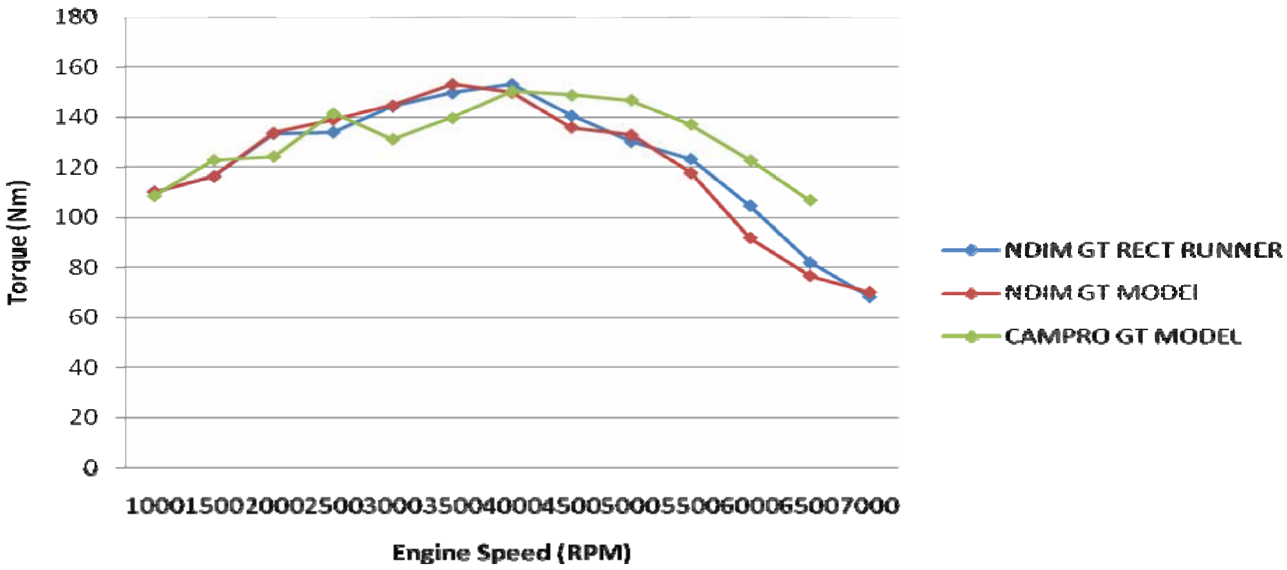

Fig. 14. Performance Test Result Comparison between CAMPRO, CAMPRO GT and NDIM GT Model - Torque

But later when the engine reaches higher speeds, the pressure increases and the small diameter passages are incapable of providing maximum flow, the pressure will be shifted to the big diameter runner passage.

Table - 1. Data Result for CAMPRO, CAMPRO GT Model and NDIM GT Model – Torque

	Torque		
RPM	**CAMPRO**	**CAMPRO GT**	**NDIM GT**
1000	104.19	102.381	110.106
1500	121.1	112.506	116.159
2000	123.9	121.265	133.572
2500	140.6	135.858	138.939
3000	130.5	124.614	144.58
3500	136.5	138.626	153.065
4000	150.9	144.375	149.821
4500	149.6	145.425	135.825
5000	147.9	154.057	132.795
5500	144.54	151.705	117.577
6000	134.1	140.373	91.7144
6500	118.7	122.566	76.4596
7000			69.9043

This will in some way create the dual diameter intake manifold effect. It is believed that the solution is a unique design and never been used in the automotive field. Therefore, it has a wide potential for further development. To test the hypothesis, NDIM GT Model was created and simulated in the GT-POWER. The intake manifold of CAMPRO GT model was replaced by the split pipe having small diameter and large diameter for each cylinder.

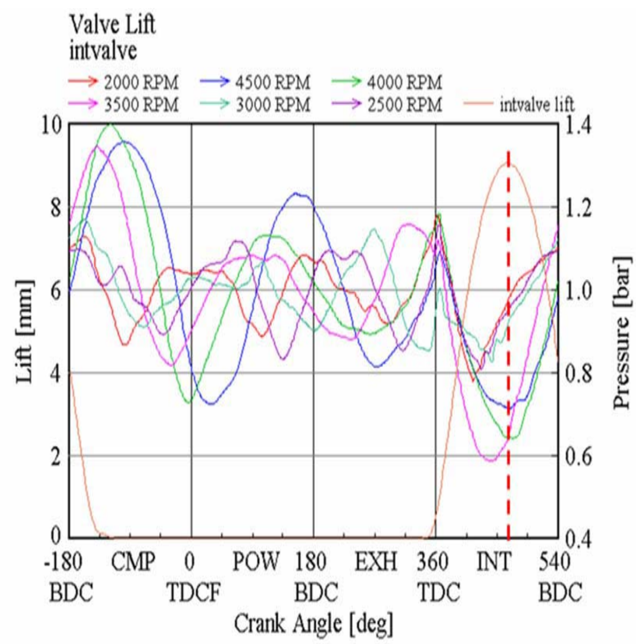

Fig. 15. The pressure wave of 2000 RPM – 4500 RPM

Comprehensive simulations are done by varying different parameters; diameter and length to get the appropriate diameter and length for each pipe that give the best performance. The final length, inlet, center and the outlet diameter of each pipe is shown in Figure 12 and the NDIM GT model is shown in Figure 13. As stated earlier in the hypothesis, the air will utilize the small diameter passage during the low end speed. But later when the engine reaches higher speeds, the pressure increases and the small diameter passages are incapable of providing maximum flow, so the pressure is shifted to the big diameter runner passage. This will in some way create the dual diameter intake manifold effect. In order to verify the hypothesis made, the NDIM GT model was simulated and the pressure of each runner is compared.

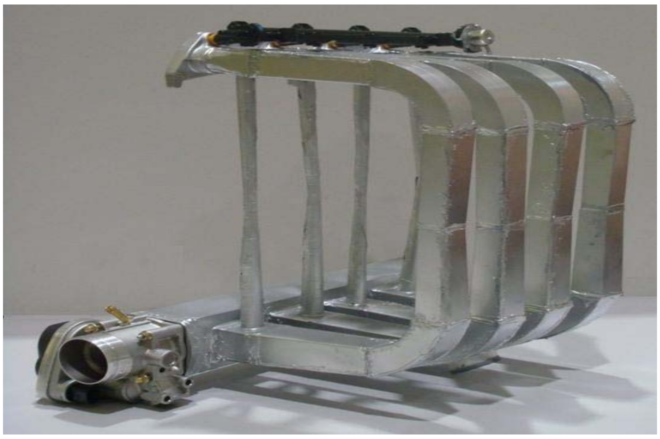

Fig. 16. Fabricated NDIM

With higher speed, the pressure in the larger diameter runner will increase thus acting as a dual diameter intake manifold. The operation is similar to the dual diameter intake that uses the butterfly valve except that this system is self-actuated depending on the maximum pressure at the small runner. This design is still in the conceptual stage and can be further revised. The effects of changing the diameter and length will cause unpredictable behavior of pressure and torque. From the result of the simulation, it is observed that a promising outcome is achieved. Figure 14 and Table 1 are showing the comparison of the output torque between CAMPRO engine, CAMPRO GT model and NDIM GT model. It shows that with NDIM, the output is smoother compared to the CAMPRO torque. The NDIM torque has eliminated the torque dip that occurs at 3000 rpm. The low end torque is higher than the torque in the CAMPRO engine. However the high end torque in NDIM GT model is lower than the CAMPRO low end torque. Referring to Figure 15, the pressure wave of 2000 RPM to 4000 RPM is decreasing at the maximum opening of intake valve which indicates that greater air is induced in the cylinder as the speed is increasing and thus producing higher output torque. Therefore, the output torque at 3000 RPM is eliminated. But at 4500 RPM, the pressure wave is greater than the pressure wave at 4000 RPM which explains the decreasing output toque at that speed. With NDIM, it is effective most when used in low engine speeds. It is rather difficult to have the best of both worlds as at higher engine speeds, the split runner may create lag and incapable of supplying enough air needed at the right time in the higher engine speeds. But the main key here is that the torque dip is eliminated when using NDIM. In Table - 1, the data show the torque comparison of the CAMPRO engine, CAMPRO GT model and NDIM GT model at engine speed with increment of 500 rpm. The fabricated prototype of the NDIM is shown in Figure 16.

CONTINUOUSLY VARIABLE INTAKE MANIFOLD

An intake manifold based on the CAMPRO intake manifold is modified to have the varying runner length effect. A manifold that can vary its runner length at specific engine speed advantage the high pressure in the intake manifold at all engine operating range.

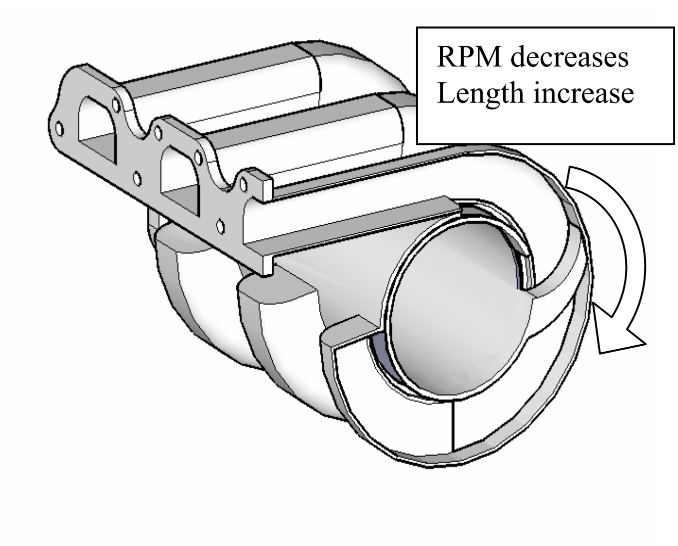

Fig. 17. Continuously Variable Intake Manifold Model

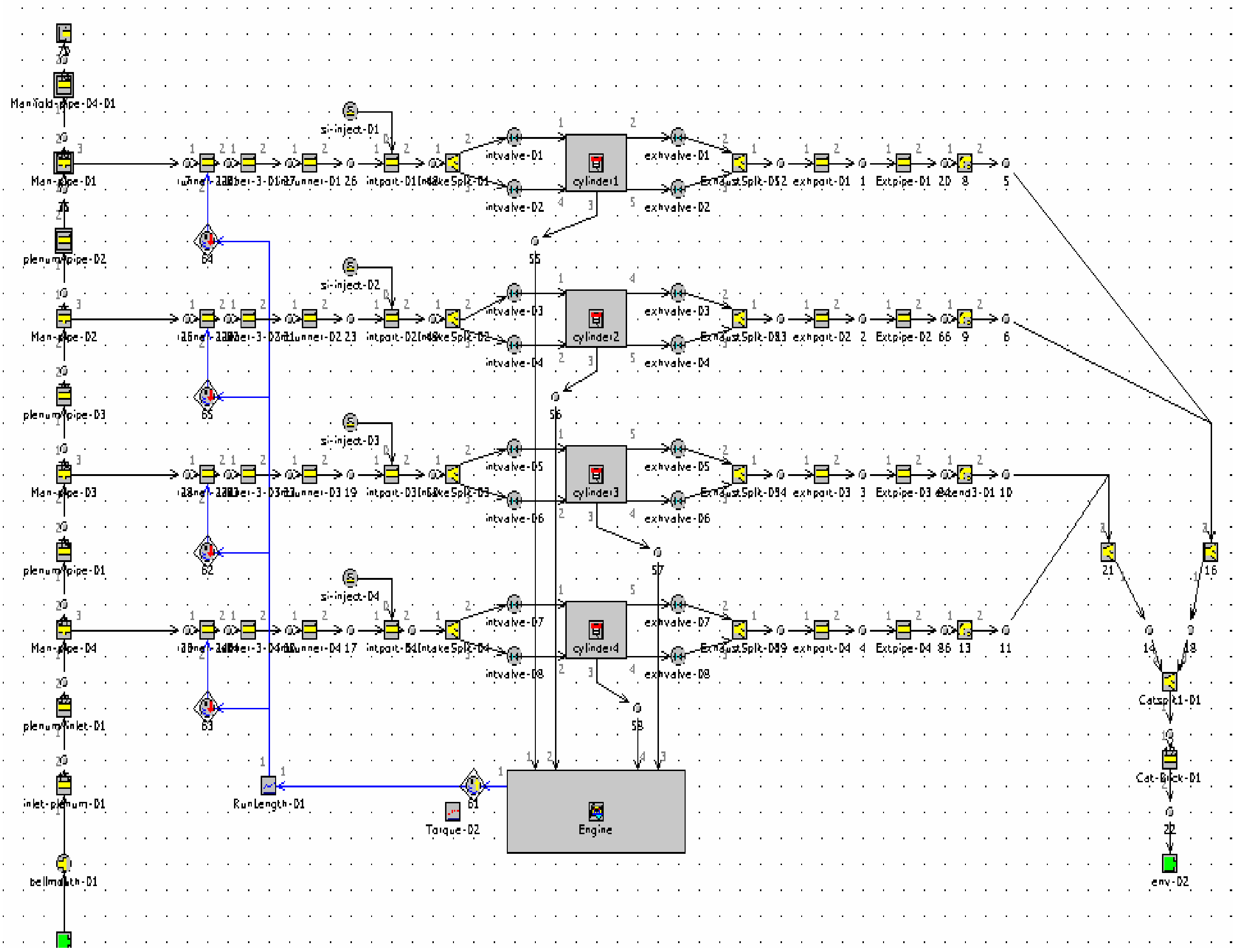

Fig. 18. Continuously Variable Intake Manifold GT Model

The runners are wrapped around a plenum housing which houses the rotating plenum. The plenum along with the inlet of the primary runners rotates along the primary runner creating the elongation of the runners. The Continuously Variable Intake Manifold is shown in Figure 17. A GT model of the CVIM which based on the CAMPRO is created with varying length of the primary runner and is shown in Figure 18. The length is determined by design of experiments (DOE) method. The length is determined from the pressure wave characteristics. It is possible to determine whether to decrease or increase the length of the runner based on the pressure wave. The length is varied from 130 mm to 600 mm. The length is adjusted so that the performance of the intake manifold is kept optimized every 500 RPM. FLUENT software is used to simulate the flow in the manifold. The results of the CVIM simulation show an increase of the low end torque by 12 Nm and the maximum torque by 5 Nm. The manifold can be easily adjusted to have the most optimized air flow to the engine. The difference between FLUENT and GT simulation averaged at 5% for each runners. This error is due to the design of the manifold itself. The manifold is fabricated with 1mm aluminum sheets.

CONCLUSION

The causes of occurrence of torque dip between the ranges of 2500 rpm – 3500 rpm are thoroughly investigated. It can be concluded that the torque dip phenomenon is caused by the pressure wave that is not coherent with the valve opening. The travelling pressure wave which is supposed to arrive at the time the intake valves are opening will be inducted into the cylinder as a result of the vacuum effect created by piston's downward motion. The shape of the torque curve can be optimized using different types of manifold. The NDIM and CVIM can increase the performance of the low end of engine. Both of the manifolds have their own advantages.

ACKNOWLEDGEMENT

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