Study of intake manifold for Universiti Malaysia Perlis automotive racing team formula student race car

A Norizan, M T A Rahman, N A M Amin, M H Basha, M H N Ismail and A F A Hamid

School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.

tasyrif@unimap.edu.my

Abstract. This paper describes the design differences between the intake manifold and restrictor used in racing cars that participate in the Formula Student (FSAE) competition. To fulfil the criteria of rules and regulation of the race, each race car must have a restriction device that has a maximum diameter of 20 mm installed between the throttle body and intake manifold. To overcome these problems, a restrictor has been designed and analysed using the steady state analysis, to reduce the loss of pressure in the restrictor. Design of the restrictor has a fixed parameter of the maximum diameter of 20mm. There are some differences that have been taken to make the comparison between the design of the restrictor, the diameter of the inlet and outlet, the curvature of the surface, convergence and divergence angle and length of the restrictor. Intake manifold was designed based on the design of the chassis, which shall not exceed the envelope defined by the FSAE competition. A good intake manifold design will affect the performance of the engine. Each design have made an analysis designed to ensure that each cylinder engine gets its air evenly. To verify the design, steady state analysis was made for a total mass flow rate and the velocity of air leaving a runner in each engine. Data such as the engine MAP reading was recorded by using Haltech ECU Management Software as reference purposes.

1. Introduction

UniART is Universiti Malaysia Perlis Automotive Racing Team has established in 2009 under the School of Mechatronics Engineering, Universiti Malaysia Perlis. The main objective is to nurture student’s automotive and technical skills, to prepare the student for new challenges in the industry. UniART has participating many event including FSAE-Asean. The formula car has developed by using Suzuki GSX-R 600 2005 engine model. FSAE regulation mentioned that all internal combustion formula car must use a single throttle body to operate the engine and must have a restrictor between throttle body and intake manifold. The maximum throat of restrictor is 20mm diameter. During FSAE-Asean competition, the UniART race car have a problem where the engine cannot idle below the 2000 RPM. The car need 4000 RPM to maintain idle speed. This problem will cause high fuel consumption because of the high RPM when idle. The team has investigated this issue and found that this problem is from the 20mm restrictor. To overcome this problem, the team has decided to redesign the 20mm restrictor and the intake manifold system. The 20mm restrictor needs to redesign before proceeding with the design of the intake manifold. To understand the design consideration, the research has been made to study the behaviour of the air flow pattern when entering the restrictor and the intake
The design has been made by drawing in CAD software, CATIA V5R21. The computational fluid dynamic (CFD) simulation was conducted by using ANSYS Workbench 15, CFX. CFD has a very important role in all analyses of fluid prior to producing the actual product in addition to reducing the cost of manufacture [1].

2. Design of Restrictor
In order to comply the FSAE rules and regulations, a single 20mm diameter of restrictor must be placed between the throttle body and the intake manifold inlet. The air flow must be passed through this restrictor before entering the intake manifold. Restrictor main purpose is to limit the power produced by the engine of a vehicle [2].

2.1. Venturi Restrictor and Calculation
The venturi tube or simply a venturi is a tubular setup of varying pipe diameter through which the fluid flows. Venturi effect is when the fluid through the shrinking surface area, it will increase the speed of the fluid and the fluid pressure is reduced. [3]. Based on governing fluid dynamics law, a fluid’s velocity must increase as it passes through a constriction to fulfil the principle of conservation of mechanical energy. An equation for the drop in pressure due to the venturi effect may be derived from a combination of Bernoulli’s principle and the continuity equation. It generally has a coefficient of drag around 0.85 [4]. The equation 1 show below is related with the mass flow rate to the flow area, $A$, total pressure, $P_t$, and temperature, $T$ of the flow, $M$, Mach number, $\gamma$, ratio of specific heats of the gas, and $R$, the gas constant [5]. By taking a Mach number is 1, so the maximum flow rate can be achieved. [6]

$$ m = \frac{AP_t}{\sqrt{TR}} \sqrt{\frac{\gamma}{R} \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{\gamma+1}{2(\gamma-1)}}} \quad (1) $$

2.2. Calculations
The values taken for substitution in Equation 1 are:

$P_t = 101325$ Pa
$T = 300K$
$\gamma = 1.4$
$R$ (air) = 0.286 kJ/Kg.K
$A = 0.001256$ m$^2$
$M = 1$ (Choking Conditions)

With the value shown above in Equation 1, the result of the calculation at choking is $= 0.0703$ kg/s. The results will be used in the output and the pressure at the inlet is ambient. The goal of this analysis is to maximize pressure recovery in output.

![Figure 1. Restrictor Parameter.](image-url)
Figure 1 shows the parameters that will be used to determine the differences between the designs made for the pressure loss at the restrictor outlet. (A) is the inlet restrictor, (B) is a choke diameter of 20mm maximum. (C) is the output and (D) is the divergence angle of the restrictor, while the (E) is type of shape, either from a convergence angle or using a curve of the restrictor. Table 1 below shows the values used to design the restrictor.

| Table 1. Restrictor Design Parameter. |
|---------------------------------------|
| A(mm) | B(mm) | C(mm) | D(°) | E(°) | Length(mm) |
|-------|-------|-------|------|------|-------------|
| Design 1 | 38 | 18 | 50 | 10 | 14 | 192 |
| Design 2 | 38 | 20 | 38 | 7 | - | 178.47 |
| Design 3 | 38 | 20 | 38 | 7 | - | 180.8 |
| Design 4 | 40 | 20 | 40 | 10 | - | 167 |

Figure 2 shows the design of a different restrictor. (A) choke with a diameter of 18mm and a convergence angle of 14 degrees and an angle of divergence is 10 degrees. (B) is the choke area 20mm diameter and divergence angle is 7 degrees. At the inlet, oval-shaped curve is connecting to the choke and continue to the point of divergence area. (C) choke area 20mm diameter and divergence angle is 7 degrees. At the inlet, in the form of semi-circular curve and straight to the point of divergence. (D) the choke area 20mm diameter and divergence angle is 10 degrees. At the inlet, the curve is semi-circular shape and has a smooth curve that is connected to the choke and continue to the point of divergence area.

3. Design of Intake Manifold
The function of the intake manifold is to distribute the air enters the engine evenly. Evenly distribution is very important for better engine performance and optimum efficiency [7]. The design of the intake manifold is very important for better engine performance. The length and diameter of the runner, the total volume of the intake manifold plenum, and shape runner is among the factors to be considered in the design of the intake manifold. some improvements that can be made in the intake manifold is to direct the airflow straight towards the runner. [8]. Intake manifold geometric design greatly affects the volumetric efficiency of an engine, therefore directly impacts on the performance of the vehicle. [9]. Better understanding of the flow, inlet velocity and pressure loss through the intake manifold system is very important to optimize the flow in the intake manifold, [10].
3.1. Intake Manifold Data Value.
The engine reading has been recorded using Haltech Engine Management ECU Software. The map reading has been recorded to make a reference when analyze the intake manifold design. Table 2 shows the data that has been recorded by using Haltech Engine Management ECU software, when the data is retrieved, the engine speed to idle speed, 3300RPM where the main problems that need to be repaired. Vacuum value during idling is -42,300 Pascal, total pressure at the inlet is fixed which is at ambient pressure, and the amount of 101325 Pascal outlet pressure is 59,025 Pascal.

Table 2. Engine Data Value.

|                      |             |
|----------------------|-------------|
| Engine Speed         | 3300 RPM    |
| Vacuum Level         | -42300 Pa   |
| Pressure Inlet       | 101325 Pa   |
| Pressure Outlet      | 59025 Pa    |

(a) Intake Manifold Design 1

(b) Intake Manifold Design 2

(c) Intake Manifold Design 3

(d) Intake Manifold Design 4

Figure 3. Variation of Intake Manifold Design.

Figure 3 shows the various types of the intake manifold without restrictor. (a) The intake manifold has two branch paths after the inlet. Shaped plenum box and quarter round. (b) The inlet of the intake manifold edges, shape longitudinal and tapered at the ends. (c) The intake manifold inlet of the central and symmetrical. (d) The intake manifold inlet of the central and symmetrical but having additional fins at the inlet of the intake manifold.
4. Data Collection and Analysis

4.1. Restrictor Design Result.
By simulating the design of restrictor and intake manifold, the restrictor design result comparison has been made with comparing the pressure at the outlet. Table 3 shows the results of the analysis carried out using Ansys. Analysis performed on each design using same parameters as the inlet pressure is equal to ambient pressure, 101325 Pascal and the outlet is as it has been calculated that 0.0703 kg/s. The Design 1 has the more pressure loss while the Design 4 pressure loss at least when compared with all four of the design.

| Restrictor | Inlet(Pa) | Outlet(Pa) | Pressure Drop(Pa) |
|------------|-----------|------------|-------------------|
| Design 1   | 101325    | 95062      | 6263              |
| Design 2   | 101325    | 91739      | 9586              |
| Design 3   | 101325    | 93721      | 7604              |
| Design 4   | 101325    | 98286      | 3039              |

From Table 3, the contour of the pressure has been shown in Figure 4 below. Figure 4 shows the change in pressure contour analysis results based on the mass flow rate that has been calculated. Therefore, the restrictor that have a low pressure loss have been selected to proceed with the analysis of the intake manifold as well.

![Figure 4. Variations of Pressure Contour in Each Restrictor Design.](image)

4.2. Intake Manifold Design Result
Based on the result in Table 3, the Design 4 has been selected. The results of the analysis of the intake manifold and restrictor were recorded as in the table below.
Table 4. Intake Manifold Mass Flow Rate Result.

| Cylinder | 1      | 2      | 3      | 4      |
|----------|--------|--------|--------|--------|
| Design 1 | 0.07883| 0.06659| 0.06862| 0.07827|
| Design 2 | 0.04241| 0.04186| 0.07784| 0.14447|
| Design 3 | 0.01330| 0.09130| 0.10160| 0.01490|
| Design 4 | 0.13085| 0.15248| 0.13999| 0.14159|

Figure 5. Mass Flow Rate Graph Plot Between 4 Design Result Analysis.

Figure 5 shows the results of the data that has been recorded in table 4. Based on observation, Design 1 has almost uniform mass flow rate value in each cylinder. From Design 2, Cylinder 3 and 4 only have high mass flow rate than Cylinder 1 and 2. Design 3, the cylinder closest to the inlet only will get the high mass flow rate high, the Cylinder 2 and 3. Design 4, the mass flow rate is almost evenly on all cylinders and is higher than the design. Table 5 shows the outlet velocity data sets obtained during the analysis is conducted.

Table 5. Intake Manifold Velocity Analysis Result.

| Intake Manifold | Velocity (m/s) |
|-----------------|----------------|
|                 | 1   | 2   | 3   | 4   |
| Design 1        | 97.63| 99.03| 98.93| 97.51|
| Design 2        | 33.00| 34.93| 61.76| 109.56|
| Design 3        | 10.76| 76.89| 83.73| 12.12|
| Design 4        | 103.73| 106.03| 105.26| 104.41|
Figure 6. Velocity Graph Plot Between 4 Design Result Analysis.

By referring to Table 5, plots graphs were shown as Figure 6. Design 4 shows a very high velocity and evenly on each cylinder followed by the velocity of the Design 1. Design 2 get a high velocity value only on the cylinder away from the inlet as it approaches the surface of the plenum wall. Design 3 is also just acquired a high velocity in the cylinder near the inlet for air flow directly toward the cylinder.

Figure 7. Variations of Velocity Streamline Pattern in Each Intake Manifold Design.
Figure 7 shows a variety streamline velocity in each intake manifold design. (a) Velocity streamline seems equally due to the inlet manifold has been split into two paths after the restrictor. (b) Velocity streamline at the end of the intake manifold higher than the cylinder near the inlet. (c) Velocity streamline is more focused on the area near the inlet compared to far away from the inlet. (d) Velocity streamline more evenly when added fins at the inlet of the intake manifold.

5. Conclusion
From the result of the study, the restrictor converging boundary must have smooth edge corner to make sure the air flow maintains with their flow path. The pressure recovery of restrictor must be maximum as much as possible to minimize the pressure drop. Based on simulation that has been made, to get a little pressure loss on the outlet restrictor, the restrictor design geometry must be focused to achieve the objective restrictor design. The air flow in the intake manifold must distributed evenly to improve the volumetric efficiency while improve the engine performance. It is necessary to determine the velocity of throttle body inlet and Manifold Air Pressure for another engine and intake system with sensitive experimental studies. For future validations, high calibrated sensors should be used to improve the accuracy of the experimental data obtained.

6. Acknowledgments
This work has been supported by the UniMAP Automotive Racing Team (UniART) and School of Mechatronic Engineering, Universiti Malaysia Perlis.

7. References

[1] P. A. Shinde, "Research and optimization of intake restrictor for Formula SAE car engine," International Journal of Scientific and Research Publications, vol. 4, 2014.

[2] N. Persaud, "DESIGN AND OPTIMIZATION OF A FORMULA SAE COOLING SYSTEM," Department of Mechanical and Industrial Engineering, University Of Toronto, 2007.

[3] ASME MFC-7M, Measurement of Gas Flow by Means of Critical Flow Venturi Nozzles, New York: American Society if Mechanical Engineers, 1987.

[4] "Venturi Description - Flow through a Venturi," [Online]. Available: en.wikipedia.org/wiki/Venturi_effect.

[5] National Aeronautics and Space Administration, [Online]. Available: https://www.grc.nasa.gov/www/k-12/airplane/mlchkl.html. [Accessed 17 March 2017].

[6] A. G. F. Y. a. A. B. Harry C. Watson, "Optimizing the Design of the Air Flow Orifice or Restrictor for Race Car Applications," SAE TECHNICAL PAPER SERIES, 2007.

[7] S. Singla, "Study of Design Improvement of Intake Manifold of Internal Combustion Engine," International Journal of Engineering Technology, Management and Applied Sciences www.ijetmas.com, 2015.

[8] M. &. K. P. Kumar, "CFD Simulation of Air Flow in Intake Manifold of SI Engine," 2013.

[9] C. B. W. Ryan Ilardo, "DESIGN AND MANUFACTURE OF A FORMULA SAE INTAKE SYSTEM USING," Design, Research, and Education for Additive Manufacturing Systems Laboratory, 2009.