Design, Optimisation and Testing of a 200CC Single Cylinder Petrol Engine for FHSAE Car for Mid-Range Torque Improvement

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Abstract
The present work aims to optimize the intake manifold design suitable of a 200cc KTM engine, in order to get the best power and torque output from the engine in the mid RPM range. Currently this engine produce majority of its power output at very high RPM, design will be such that it performs best at mid-range, this will increase the drivability of the vehicle as the engine will not need to be revved hard to accelerate, thus increasing fuel efficiency of the vehicle. After necessary calculations has been carried out for the size and shape of the manifold, the same has been modeled using Solidworks and subsequently flow analysis was carried out using ANSYS. With a preliminary design is finalized, after several steps of iteration, a prototype was created using Rapid Prototyping Technique (RPT), for experimental validation with the engine. Its performance was evaluated to make further changes in the final design and thereon the final product has been manufactured using 3D printing technology. Performance characteristics assessment with the optimized design was performed to assess the torque and volumetric efficiency. With the optimized design, an increase in volumetric efficiency by 6.1 % at the desired RPM range and an increase of torque by 1.1 Nm respectively, has been achieved.

Keywords: Intake manifold: resonator: torque improvement: rpm range: frequency

1. Introduction:
Breathing of air is an important factor for an engine, if the breathing of the engine is proper the overall performance of the engine is good, Intake manifold is responsible for the proper breathing of the engine, any changes and advancement in the intake system will lead to more good breathe ability and
hence good performance. Peak power from an engine is usually achieved at higher RPM, though the engine is normally used at mid-range RPM. The power created by the engine is directly proportional to the torque and the power increment at mid-range RPM is related to the air intake and combustion inside the cylinder, more air means good combustion and an ability to increase the amount of fuel that can be burned which means more power.

The objective of the work is to design, analyze and manufacture the intake system for 200 cc single cylinder petrol engine of FHSAE car. FHSAE is a formula hybrid car made by students; the vehicle is equipped with a hybrid power train that is an electric motor and an engine. The main objective is to increase the drivability at mid-range of the vehicle. The target is mid-range RPM because at the lower RPM electric motor will work and the peak power arrives at very high RPM in the stock engine but at mid-range RPM, performance of the engine may not be good. Therefore, for better drivability strong mid-range is required. This can be done by increasing the torque of the engine at mid-range of the vehicle and this can be achieved if more amount of air can enter at the mid-range RPM, which leads to increase the volumetric efficiency of the engine and hence performance and drive ability of the vehicle at mid-range. This can be achieved by designing intake in such a way that it sucks more amount of air at mid-range RPM. The aim of the work is to perform different set of calculation to design the air intake manifold suitable for a 200cc KTM engine, to get the best power and torque output from the engine in mid-RPM range. Currently the engine produce majority of its power output at very high RPM. The modified design is expected to perform best at mid-range. This will increase the drivability of the vehicle as the engine will not need to be revved hard to accelerate, thus increasing fuel efficiency of the vehicle. We will prepare the design on CAD modelling software, then analysis of the design will be done on ANSYS to perform further modification in the design. After a preliminary design is finalized, a sample model will be prepared using RPT, this sample model will be tested with the engine. Its performance will be evaluated to make further changes in the final design. Final product will be manufactured using 3D printing technology, this model will be tested to examine the final improvement in the volumetric efficiency.

2. Pressure wave tuning

The intake system of a four-stroke engine has one main goal, to get as much air-fuel mixture into the cylinder as possible. One way to get more amount of air-fuel mixture is tuning the lengths of the pipes of the intake manifold of the engine. When the intake valve is opened, air is being sucked into the engine rapidly so the air in the intake runner is moving rapidly towards the cylinder. Now when the intake valve closes suddenly, the air slams to a stop and stacks up on itself and leads to forming an area of high pressure. This high-pressure wave now propagates in
opposite direction to the cylinder and when this high-pressure wave reaches at the end of the intake runner, where the runner connects to the intake manifold, the pressure wave bounces back down the intake runner. If the intake runner length is just the right length then the high pressure wave will arrives back to the intake valve just as it opens for the next cycle. This extra pressure helps more air-fuel mixture in the cylinder which increases the performance of engine. It acts like a supercharging but the problem with this technique is that it only provides benefit in a fairly narrow speed range.

2.1 Helmholtz resonator:

The purpose of a resonator when used with an air intake system is to increase the volumetric efficiency of the engine. Any hollow container of any size with an opening can be termed as a resonator, Helmholtz resonator is a spherical shaped container with an opening, the hollow area in the container is filled with air, tends to have springiness effect. When the air enters the resonator from one opening due to already present air inside the resonator a pressure is created, and the air tends to normalize the pressure, in order to do so the a lump of air is pushed out, which also creates a suction and new air enters and the cycles keep on repeating, entering and exiting of the air have a particular frequency which depends on the shape and volume of the resonator. When attached with the runner of the intake the air coming from the runner gets into the resonator and due to spring effect of the inside present air it is pushed back again towards the same path with increment in the pressure. To use a Helmholtz resonator in an air intake system the frequency of the resonator should match with the engine in order to do so the RPM of the engine is converted into RPS and half is taken as the matching frequency. Once the frequency of the resonator is matched with the engine the volume of the resonator can be calculated using a formula for frequency calculation. Formula uses length of the neck, shorter the neck of the length bigger will be the resonator, so the length of the neck needs be in such a way that both the resonator and neck length fits into the profile of the vehicle.

![Figure 1. Spring effect](image-url)
3. Analysis

To obtain an efficient design that did not create any obstruction in the flow and performed the function wanted, analyses of the design was done using Computational Fluid Dynamics (CFD). Before moving on to any analytic software the input values are required, that need to be input into the software to perform an accurate transient analysis within a complete cycle of the engine. To do that, a data log was included in the custom ECU to record the MAP sensor values with respect to the RPM and the value of the throttle position sensor. In order to obtain accurate values, engine had to run at full throttle on high load to keep the rate of increase in engine RPM slow enough to generate enough data points on the log, across the entire rev band of the engine. To obtain an efficient design that did not create any obstruction in the flow and performed the function wanted, analyses of the design was done using Computational Fluid Dynamics (CFD). Before moving on to any analytic software the input values are required, that need to be input into the software to perform an accurate transient analysis within a complete cycle of the engine. To do that data log was setuped in the custom ECU to record the MAP sensor values with respect to the RPM and the value of the throttle position sensor. In order to obtain accurate values, engine had to run at full throttle on high load to keep the rate of increase in engine RPM slow enough to generate enough data points on the log, across the entire rev band of the engine.

The testing was performed on FHSAE car with the stock throttle body without the air box or stock plenum from the motorcycle. The driver had to short-shift the engine into a higher gear at low speed and then performs a full throttle acceleration run from the lowest RPM possible to the reline. Doing this in higher gears was important so that we could generate maximum number of values at every RPM value as the maximum logging rate for the ECU was only 20000Hz. From the
data that was obtained, the range of data that does not have any major fluctuations in RPM were selected. The selected data will resemble the suction effect from the engine in the analysis software when the analysis was performed. To do the analysis, first a model of the fluid domain through which the air will pass with the fuel being injected in the end is needed. So various different designs were made adhering to the calculation values of the dimensions of the resonator and runner with slight modifications to determine the best suitable flow pathway. The design also had to adhere to the rules and regulations of the Formula Hybrid Competition for which the FHSAE car was made. The model created therefore had to stay inside the envelope formed by the outer edges of the tires and the main roll hoop when viewed from any side. Once the designs were finalized, CFD analysis on each design and comparing the behavior and output values of every individual design to obtain the best suitable iteration was done. ANSYS Workbench fluid flow CFX analysis system was selected for its accuracy; ease of use and due to our familiarity with the software. ANSYS is an industry leading analysis software package that can perform fluid dynamics, Structural mechanics, electromagnetic and multi physics engineering simulations to test individual properties of a product or system. The fluid volume geometry was imported from SOLIDWORKS into a STEP file for the ANSYS software to read. Since the geometry generation was out of the way as it had been completed in SOLIDWORKS itself.

4. Manufacturing and testing

Once the design was finalized the design prototype manufacturing was needed to test the design in real time condition with the engine at different engine speed. Today’s growing trend and feasibility of the 3D printing technology to manufacture the prototype components with desired material, made it the best choice for manufacturing the intake system. 3D printing technology is used to make three dimension components with various kinds of materials (depending on the equipment), without any requirement to make mold first. The process is an additive process since the object is manufactured layer by layer until the object is completed. After deciding the manufacturing method, the next step was to decide the material to manufacture the intake system, the intake material should be able to withstand the temp working ranges and should have enough strength to hold off during shocks and vibrations. On
the basis of the different properties of the materials and their cost of manufacturing, Acrylonitrile butadiene styrene (ABS) was used to manufacture the part as “Nylon” temperature range and yield strength are very high but not economically feasible, “PLA” is a biodegradable material having the ability to dispose completely or recycled but the temperature working range was not preferable, “HDPLA” is the best suited material for manufacturing but the availability of the material is hard to find and would take around 2 months to get the final product. Based on the above mentioned limitations of the other available materials, ABS was found to be the best suited option.

![Figure 3. Final model of the Helmholtz resonator](image1)

![Figure 3. Intake system manufactured using 3D printing](image2)
Table 1. The most suitable materials for manufacturing

| Material                                      | Temperature (°C) | Cost (Rs.) | Yield strength (Mpa) |
|-----------------------------------------------|------------------|------------|----------------------|
| Acrylonitrile butadiene styrene (ABS)         | 105              | 8000       | 45                   |
| Polylactic Acid (PLA)/Wood fill PLA           | 60-65            | 10000      | 55                   |
| High Density Polylactic Acid (HDPLA)          | 140              | 12000      | 65.5                 |
| Nylon                                         | 220              | 65000      | 82                   |

Summary/Conclusions
In summary, attempt has been made to improve the drivability of the hybrid power train by optimizing intake manifold of the engine with the specific objective of increasing the drivability at mid-range rpm of the vehicle. The simulation was carried out with four different manifold designs viz., with no fillet between neck and resonator, 15mm fillet between neck and resonator, fillet radius increased to a varying radius of 60mm and reducing gradually to 50mm along the flow of the air and finally with a resonator diameter of 61mm. Assessment was made between 1500 rpm to 8500 rpm for the best of the
above four designs. Among the above four designs simulated, the optimum design was found to be the 15mm fillet radius between neck and resonator. The simulation and testing results revealed an improvement in the mid-range drivability with a peak increase in volumetric efficiency amounting to 6.1 % at the desired RPM range with an increase of torque by 1.1 Nm. This nullifies the reason to keep engine in the higher RPM for acceleration, which may also result in increasing the fuel efficiency of the vehicle and eventually pollutant emissions.

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