Overview on Turbocharging of Single Cylinder Gasoline Engine for Formula Student Race Car

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ABSTRACT

A Turbocharger is a turbine driven forced induction device that increases an internal combustion engines efficiency and power output by forcing extra air into the combustion chamber. This improvement over a naturally aspirated engine's power output is due to the fact that the compressor can force more air and proportionately more fuel into the combustion chamber than atmospheric pressure alone.
Our goal is to determine the performance gains associated with adding a turbocharger to a naturally aspirated engine, used in formula SAE race car. This involves selecting the correct turbocharger for the engine,choosing an appropriate engine management system, tuning various engine variables and performing before and after tests to determineany performance gains.This project is meant to provide future teams with design information to help them determine whether or not using a turbocharger is a viable design consideration.

Keywords*: forced induction, compression ratio, Air to Air cooler,Riccardo software, simulation etc.*

1. INTRODUCTION

There are ways to work around displacement limitations. If more air/fuel mixture is forced in during the intake cycle, higher power output numbers can be achieved. The process of creating a high pressure area outside of the intake valve so more mixture can be forced in during the intake stroke is called forced induction. The two main methods of forced induction are turbocharging and supercharging. Both methods use compressors, creating more pressure inside the intake manifold, but the main difference is how they are driven. A supercharger is mechanically driven by a belt connected to the crankshaft; while a turbocharger uses exhaust gases to power a turbine, which shares a shaft with the compressor.
For combustion, the only necessary ingredients are fuel and an oxidizer (air in our case). With gasoline, a complete combustion is achieved when the air to fuel ratio (AFR) is stoichiometric, or approximately 14.7:1. Keep in mind that this is a mass ratio, meaning that for every 1-unit mass of fuel, 14.7-unit mass of air are needed for complete combustion. Complete combustion is an ideal case, however, and doesn't necessarily produce the most power. Increasing the fuel slightly (~10%) so the AFR is nearly 13:1 has experimentally produced more power than the stoichiometric AFR.

1.1 Literature review

Turbocharging of an engine requires meticulous selection of parameters so that the system operates perfectly, else it can result in an underperforming choked engine or can cause serious damage to the engine. [1] Mike Kojima presented a very simple method of turbo-matching. Although more precise methods exist for selection of compressor pressure ratio, this article from Turbotech magazine sets you in the right ballpark. [2] Maximum Boost by Corky Bell is an excellent book for beginners and briefly explains you the do's and don'ts rather than the more tangible calculations part. It also provided us the most necessary intercooler core sizing calculations. [3] This forum has very helpful information and it helped us in Intake runner sizing, bell mouth shaped inlet duct design and plenum design. [4] Presented all the relevant guidelines since it is a project on similar grounds. It helped us in deciding flow of work and warned us of the possible mistakes.

1.2 Objectives

1. To increase engine power output by 80% to 90%.
2. Keeping the weight of whole assembly as low as possible below 10 kg.
3. To reduce brake specific fuel consumption.
4. To increase thermal efficiency.
5. To reduce emissions by achieving complete combustion.

1.3 Turbocharger selection

It is the process of selecting right turbocharger for the engine which will provide the appropriate amount of air at variable load and speed. This process of selecting a right turbocharger is called turbo-matching. A compressor map is the most important element in this process. It has corrected engine air flow on X axis while compressor's pressure generating capacity on Y axis. On the plot there are uniform efficiency circles called as efficiency islands. If the engines operating points lie in the highest efficiency islands, then the turbo is said to be a good match.

With numerous manufacturers and multiple types of turbochargers, this seemed like it would be the major part of the project. However, our task was made simpler after the discovery of Honeywell's FSAE Sponsorship program. Honeywell would provide a turbocharger free of charge to any FSAE team that would want to implement forced induction. All we had to do was to provide supporting calculations to show that the turbocharger would in fact increase our performance. Honeywell provided us with two options: the GT1241 and the GT0632. When engine's operating points were plotted on each of the respective compressor maps it seemed to be a good match for GT0632, while GT1241 was showing surging tendency. After matching the characteristics of our engine with the compressor maps, we decided to finalize on the GT0632.

Fig-1: Compressor map and acquired Turbocharger from Honeywell

2. DESIGN DEVELOPMENT

2.1 Simulation – Ricardo Wave

In order to determine the optimum design for the intake and exhaust components we used a program called Ricardo WAVE. From Ricardo's website: "WAVE is the market-leading ISO approved 1D engine & gas dynamics simulation software package from Ricardo Software. WAVE enables performance simulations to be carried out based on virtually any intake, combustion and exhaust system configuration, and includes a drivetrain model to allow complete vehiclesimulation. However, we did not use the drivetrain model in our simulation.

The accuracy of Wave is solely dependent on the accuracy of the computer model in relation to the actual engine.We measured Camshaft profiles using a dial indicator and a degree wheel. We measured many parameters of the KTM390 engine and used data given from Garrett to construct a reasonably accurate model. We obtained greater accuracy through the use of actual flow bench data from the cylinder heads instead of using default values within WAVE and through more time fine tuning the tube wall heat transfer and friction coefficients.Wave helped us to determine variables such as runner length, plenum volume, power figures and most importantly detonation characteristics.

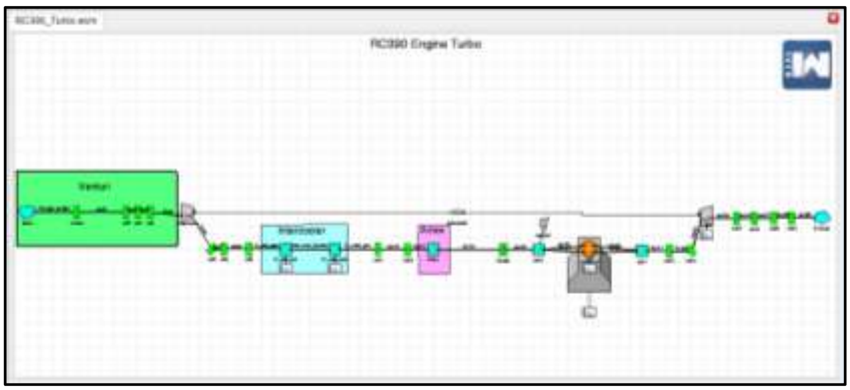

Fig-2: Wave Model

2.2 Intake and Exhaust System

The intake system consists of the air filter, restrictor, compressor, plenum, bell mouth, throttle body and fuel injector. The actual design process was required for components like intake runner, plenum, bell mouth and restrictor. Intake runner's length was determined based upon air density, speed of pressure waves, required rpm for peak power and runner diameter. Plenum was chiefly designed keeping in mind throttle resolution and peak power output. Bellmouth shaped inlet duct was necessary for proper suction and less pressure losses. Restrictor is designed to be converging – diverging nozzle. The exhaust system consists of turbocharger downpipe, wideband O2 sensor and the muffler. The downpipe is made from Stainless steel 304 and has bung made for accommodating wideband O2 sensor. The wideband O2 sensor is necessary for ECU tuning.

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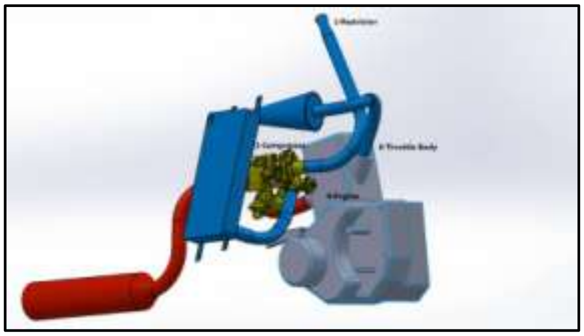

Fig-3: Intake and Exhaust system

2.3 Lubrication System

For the oiling system of the turbocharger, oil has to be teed off from a suitable location of the engine where there is adequate pressure for the oil to flow through the turbocharger bearings. The oil must be below the maximum temperature specified by Honeywell. According to “Maximum Boost,” a good rule of thumb is to have a minimum oil pressure of 5 psi (0.34 bars) at 0.1 gal/min at idle and 25 psi (1.72 bars) at 0.5 gal/min at maximum load going into the turbo. Oil temperature is usually one of the biggest issues that would cause turbocharger failure as coking occurs due to insufficient flow. This usually happens when the engine is shut off immediately after a very long, hot run and oil flow is stopped.Another failure in the oiling system can happen when the oil returning enters below the oil level in the case. This can cause oil to back up into the turbocharger, heat up, and coke up the bearings. If it is not possible to return the oil above the engine oil level, a scavenging pump will be required to ensure that the oil will not back up into the turbocharger.

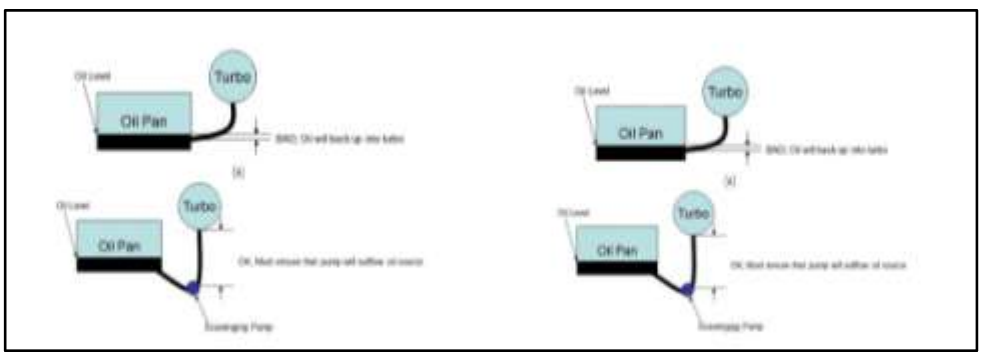

Fig-4:Lubrication conditions

2.4Air-to-Air cooler

An air to air cooler or most commonly known as charge air cooler is any mechanical device used to cool a fluid, including liquid or gases, between stages of multistage compression process, typically a heat exchanger that removes waste heat in a gas compressor. They are mainly used to improve their volumetric efficiency by increasing intake air charge density through nearly isobaric cooling.

A decrease in intake air charge temperature sustains use of a more dense intake charge into the engine, as a result of forced induction. The lowering of intake charge air temperature also eliminates the danger of pre-detonation(knock) of the fuel/air charge prior to timed spark ignition. This preserves the benefits of more fuel/air burn per engine cycle, increasing the output of the engine. Intercoolers can vary dramatically in size, shape and design, depending on the performance and space requirements of the entire turbocharged system. common spatial designs are air-to-air cooler and air-to-water cooler. we have choosen air-to-air cooler because it is satisfying efficiency, weight, compactness criterions.

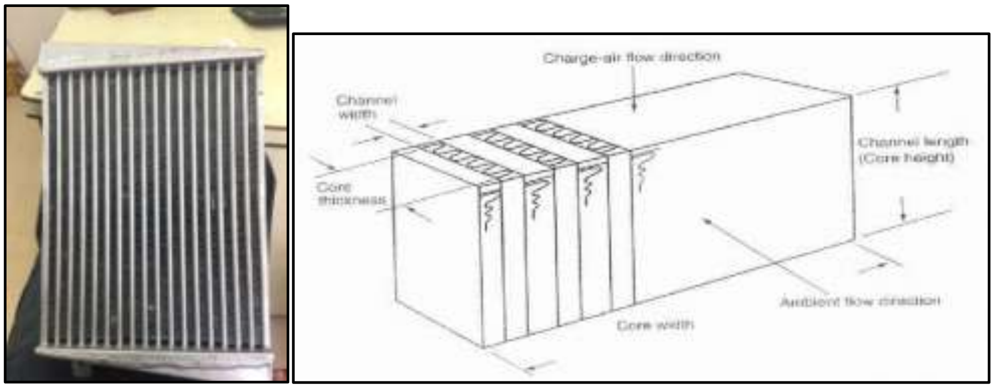

Fig-5:Manufactured component and Nomenclature of air-to-air cooler

Important formulae incorporated with air-to-air cooler are as follows:

Temperature rise through the compressor is compressor outlet temperature (Tco) and the air exciting the intercooler (Ta)

Temperature rise = Tco – Ta

Heat removed by the intercooler is the temperature difference between air exciting the compressor(Tco) and the air exiting the intercooler(Tio)

Temperature removed = Tco – Tio

Intercooler efficiency (Ei) is then temperature removed to the temperature rise:

Ei = (Tco – Tio) / (Tco – Ta).

3.CONCLUSION

The addition of the turbocharger system onto the Stallion Motorsport 2017 car proved its worth that year at the Indian FSAE competition, particularly in the acceleration event where the 2017 car completed the run in 5.25 sec compared to 6.45 sec for the previous year's car. This was despite the car being marginally heavier than its predecessor, and resulted in a net increase in the acceleration event alone. There were also significant gains in the autocross and endurance events. From test bench data, the addition of the turbocharger resulted in a peak power to weight ratio increase of 52 % and average torque increase of 35 % across the operating range. The team was extremely pleased with the outcome of the turbocharger project, and many of the rumoured difficulties associated with the turbocharging of a single-cylinder engine proved to be misconceptions. Nonetheless, there were numerous problems encountered from the initial design phase to a fully-working system on the car, particularly with the oil system and minimising oil accumulation in the intake system of the engine. Future improvements to the system will focus on tailoring the engine to better suit the change in utilised operating range with the turbocharger system, as well as enhanced integration of the turbocharger package within the car.

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