Inlet System Optimization of a Four Strokes Mono-Cylinder Engine

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Key Words: Inlet System; Four-Strokes Engine; Motostudent; Optimization; Motorbike; Filling Coefficient; Inlet Trumpet; Torque; Power.

Abstract

Motostudent International Competition is a competition among university form all over the world. The aim is to build a prototype of pre-moto 3 category and race wheel to wheel in Aragon Motorland circuit in Spain. It is a complex and long process, and in this paper we are going to discuss the whole optimization process of the inlet system only. This process involves different field of physics, from the thermo-dynamics' behaviours of the flow in the duct, to the interaction with the structure of the engine. To properly study this phenomenon and understand the design process, it is needed to know how an engine works. This paper makes an overview of the engine, focusing on the main components that take part in the inlet process. Then the fluid behaviours are described, matching the two systems with a simulation software. The results obtained are analysed to find the optimal configuration and then refined to obtain the best output in terms of power and torque. Once found the best configuration, the inlet duct is realized and assembled on the prototype. At the end of the whole process the final motorbike has raced in Aragon Motorland with excellent results, gaining the 1st position in the rookies' cup and 9th overall. This provides a perfect base for studying some implementations in order to race the next edition with a more performant prototype.

1 - Introduction

In this report is presented one of the possible procedures for maximising the engine performance in a four strokes mono-cylindric bi-valve engine. In that specific case, it is related to the engine used in the Motostudent International Competition 2018, V edition.

The combustion engine is a complex system in which every component is strictly related to another. In order to increase its performances, there are a lot of different parameters that can be modified. This report focuses on the fluid-dynamics behaviours that govern the fresh air flow inside the inlet system.

The aim of the inlet design is to match the frequency of the pressure waves in the duct with the timing of the intake valves. This matching makes the pressure inside the cylinder increases and this pressure is transformed in horse power (HP) thanks to cinematic chain of the transmission shaft.

In order to find the best ratio of the section and the length of the duct, a mono-dimensional simulation software has been implemented in order to analyse the whole system. All the data that needs to be considered are from the literature (*"Motori a Combustione Interna" G. Ferrari*) and referred to the related KTM engine (*KTM RC 250 Service Manual*).

2 - Methodology

To optimise the sizes of the inlet system in order to maximise the output power and torque of the engine, it is needed to understand how these parameters depend on engine characteristics. Then a series of mono-dimensional simulations are needed to understand the behaviours of the component and refine the design of the component in order to realise it.

2.1 – How the Engine Works

The engine takes fresh air from the environment, mix it with the fuel sending this mixture into the combustion chamber (the cylinder).

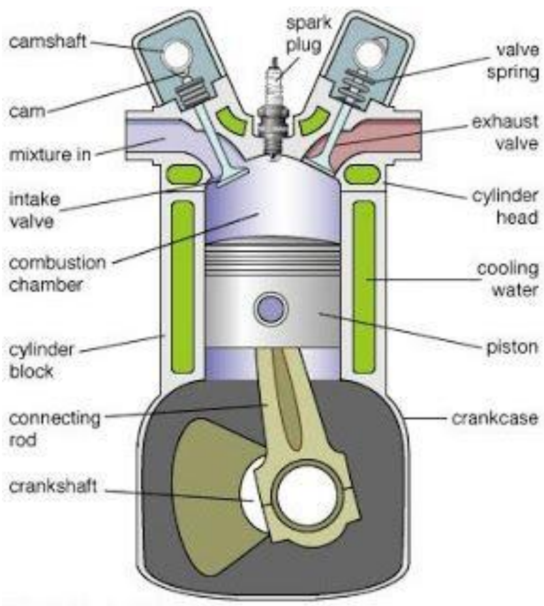
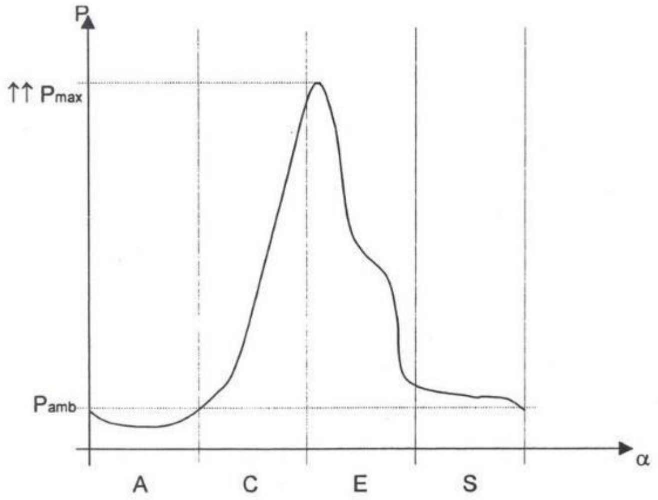


Figure 1: Engine Components

Once inside the cylinder, a spark light on the fuel and it comes the explosion. The explosion increases the pressure and temperature inside the cylinder that load the engine shaft in order to convey the pressure to the rear wheel through the crankshaft and the secondary transmission. Then the exhaust gas inside the chamber comes out through the outlet system to the environment again.

2.2 – Pressure Inside the Cylinder and Output Power

Inside the cylinder, the pressure increases and decreases depending on the crank angle and the timing of the inlet and outlet valves.



Graph 1: Pressure inside the cylinder

As shown in G*raph 1*, the pressure increases while the inlet valve is closed, and the piston is going to compress the mass inside the cylinder. The output power is strictly related to this pressure considering the efficiency of the transmission and the engine. The value of this power, related to the pressure, depends on several parameters:

$$P_e = \eta_g \frac{H_i}{\alpha} \lambda_v V \rho_a \frac{n}{\varepsilon}$$

Due to the competition constraints, it is possible to work only on two main parameters: $\boldsymbol{\lambda_v}$ and ***n***.

'***n***' is the number of rounds per minute (rpm). It means that the output power depends on the engine speed. Therefore, the engine performance will be set on one configuration. This configuration depends from the shape of the circuit and, in this case, the configuration chosen is 9000 rpm because of the long turns of Aragon Motorland circuit and its two one-kilometres straights.

'$\boldsymbol{\lambda_v}$' is the filling coefficient. This coefficient is defined by:

$$\lambda_v = \frac{m_a}{\rho V} \frac{\varepsilon}{n}$$

As shown in the formula it represents the quantity of fresh air entering in the cylinder before a thermodynamic cycle in a prescribed configuration. It considers all the effects acting on the pressure inside of the cylinder.

ε is equal to two because it is a complete round of the Otto cycle that is equal to two complete loops of the engine shaft. *n* is the configuration chosen before, and ρ is the air density referred to the atmospheric thermodynamic state.

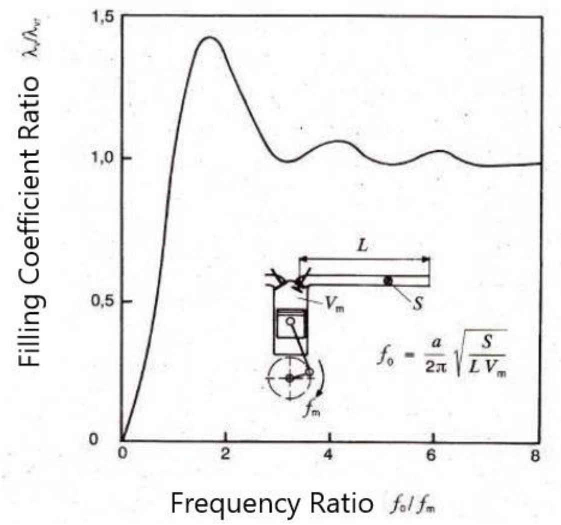
2.3 – Pressure Waves

In order to understand how to maximise the filling coefficient, it is needed to know the phenomena that act on this parameter. While in the inlet duct, before the valve, the mass of air behaves like a damper spring mass system going from the valve to the environment with its own frequency. When this mass arrives to the open inlet valve, it pushes the fresh air inside the cylinder with a positive peak of pressure.

Therefore, due to the inertial forces, the depression inside the cylinder takes more mass even if the air mass is starting to come back towards the beginning of the inlet duct.

To study its motion, two characteristics parameters are prescribed to the system: the elasticity and the viscosity. These parameters can be considered as one constant k_0.

Thanks to this simplification, the frequency of this mass can be computed, and the fluid motion is described. The frequency of the system depends on the ratio of the length and the section of the inlet pipe. Comparing it to the engine frequency, the optimal length and area that match these peaks can be found.



Graph 2: Frequency – Filling Coefficient

As shown in *Image 1* the best configuration is when the frequency ratio is odd.

2.4 – Simulation and Test

Knowing all the phenomena that govern the inlet process in a mono-cylindric four strokes engine, it is possible to design the duct. As expected, there are several different optimal configurations. In order to find the best one, a series of simulation must be done.

The software used for this last part of the design process, is a mono-dimensional software that reproduces the engine at every configuration (rpm). The software takes in input a txt sheet with all the boundaries condition and the characteristics sizes of the system. In this study case all the engine sizes are taken from the *"KTM RC 250 Service Manual"* and the boundary conditions taken into account are the ones referred to that specific circuit (in the desert of Spain).

The software solves all the governing equations of that system in each part of the duct, discretized with a step of one mm. The output is an excel file with all the data of the engine, from the power, torque to the specific consumption per cycle.

Each run of that software was launched with different values of length and section of the duct in order to find the best solution.

3 – Results

After running different simulations of different configurations, the best solution chosen is the duct with the size in *Table 1*.

rpm	9600
Total lenght (m)	329,879
Area duct (m²)	917
Maximum area of the trumpet	1833
Mouthpiece area	3666
Lenght duct	263,903
Lenght trumpet	65,976

Table 1 – Trumpet Size in millimetres

The engine regime chosen is 9600 rpm. Based on this data, the total length of the duct is 329,879 mm. the duct is composed by three different parts: the first one is locked because of the engine case, the second one is the one with the throttle body and the last one is the trumpet.

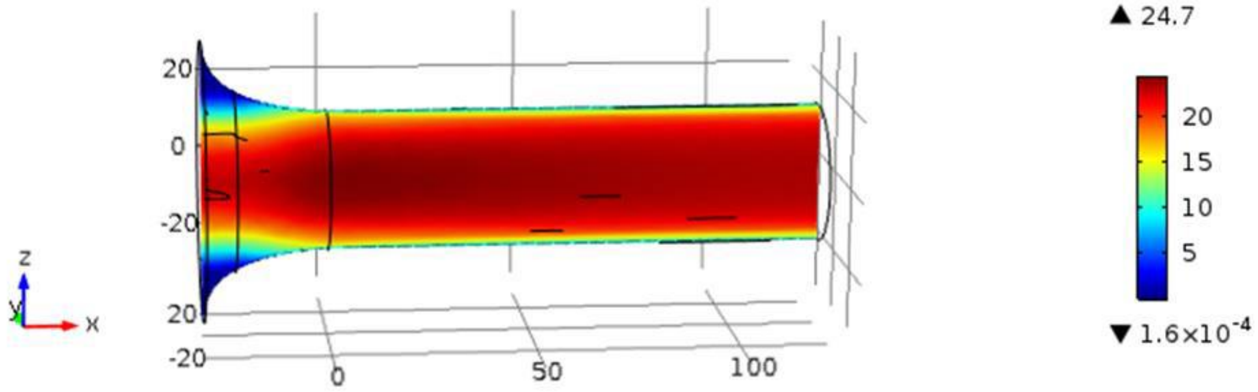
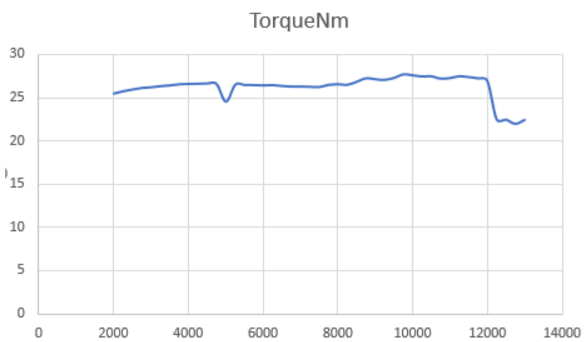


Figure 2: Trumpet CFD

Image 2 shows how the fluid behaves inside the whole duct before the cylinder and as expected it reaches the maximum values of pressure just before the inlet valve in order to maximise λ_v.

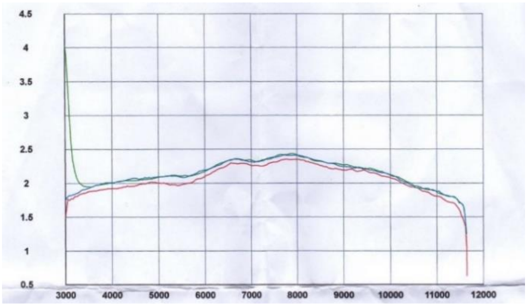


Graph 3: rpm – Torque

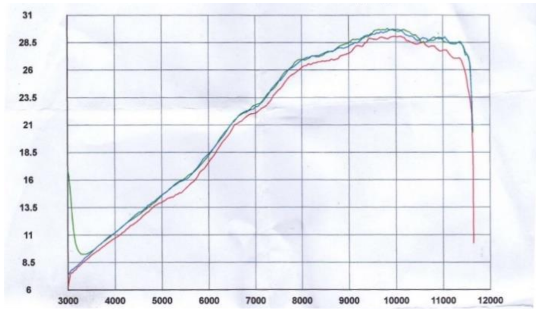
Graph 4: rpm - Power

In *Graph 3* and *4* are represented the torque and power graphs from the mono-dimensional simulator adapted to this engine.

As expected, the simulator worked very well. In *Graph 5* and *6* are shown the real power and torque graph after assembling the whole motorbike. When are considered all the efficiency losses due to the secondary transmission and the engine, the graph are less linear but the maximum values and the general behaviours of these values are coherent.



Graph 5: rpm – Torque



Graph 6: rpm - Power

3.1 – Final Design of the Inlet System

The final part of the duct (the one in the case) is 100 mm length with a section of 37 mm and it is locked and constant (par. 3). For the part containing the throttle body, a commercial component has been chosen with a length of 80 mm and a 40 mm diameter. The final trumpet has the following design:

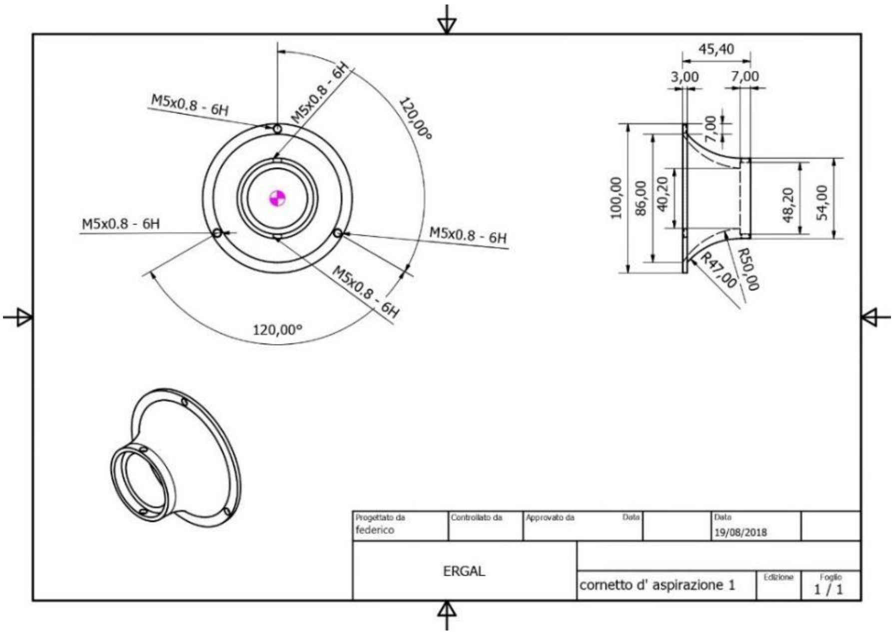


Image 4: Trumpet Drafting

The final configuration perfect fits with the engine system inside the motorbike chassis according with the overall spaces.

The final diameter is fixed by the commercial duct (second part) and is 40 mm. The largest section is the beginning of convergence and it is of 86 mm. The total length comes from the design, simulation and testing process. Considering the convergence behaviour of the fluid the total length has been calculated as

$$L_{tot} = L + \frac{D_{max}}{2}$$

3.2 – Race Results

From the 3rd to the 7th of October 2018 the Motostudent International Competition has taken place in Aragon Motorland. The prototype called "La Biga" behaves very well as it obtained the 1st place in the rookies' cup over 12 rookie teams and the 9th position in the overall ranking over 45 teams.

V International Competition MotoStudent
3-7 October 2018 – MotorLand Aragón

MotoStudent Petrol
BEST ROOKIE TEAM

Ref	Bike Number	Team Name	Score	Position
002P	15	MariTeam Racing Stralsund	227	5
013P	46	REV MECHANICS - VIT	217	6
015P	69	Sapienza Gladiators RT	634	1
017P	17	DIFAMT by ITESM	16	10
018P	44	Panther Racing AUTh	509	2
019P	27	WUT SiMRacing Team	264	4
025P	29	TECNOCAMPUS RACING TEAM	-3	12
028P	88	SOLEMADE RACING INDIA-KR	5	11
029P	63	Chicane Racing India - SRM	62	9
034P	68	Galo de Campina - UFCG	181	8
044P	33	FIMUP	190	7
045P	41	ETH Moto Racing	421	3

Table 2: Rookie's Ranking

V International Competition MotoStudent
3-7 October 2018 – MotorLand Aragón

MotoStudent Petrol
BEST MOTOSTUDENT

Ref	Bike Number	Team Name	Score	Position
001P	22	FESB Racing team	485	20
002P	15	MariTeam Racing Stralsund	227	32
003P	4	UPM MotoStudent Petrol	754	3
004P	10	Polimi Motorcycle Factory	879	1
005P	89	MotoR-UPV moto3 team	287	27
006P	9	UniBS Motorsport	625	11
007P	1	ETSEIB Racing	751	5
008P	7	MotoUPCT	511	17
009P	11	Wolfast Uniovi	404	22
010P	26	ICAI Speed Club Petrol	263	30
011P	2	2WheelsPoliTO	216	34
012P	25	EPSEVG RACING TEAM	197	35
013P	46	REV MECHANICS - VIT	217	33
014P	3	Quartodilitro Unipd	756	2
015P	69	Sapienza Gladiators RT	634	9
016P	99	MOTOSTUDENT UNIZAR	511	18
017P	17	DIFAMT by ITESM	16	42
018P	44	Panther Racing AUTh	509	19
019P	27	WUT SiMRacing Team	264	29
020P	14	Sevilla Racing Team	554	15
021P	16	UAL Motorsport	-9	45
022P	8	FLORIDA MOTO TEAM	668	8
023P	39	EIG-EHU ENGINEERING	739	6

Table 3: Overall Ranking

The maximum speed reached is 188 km/h and the prototype became part of the top world racing motorbike of 2018's.

The inlet system and the engine behave very well as was considered in the top five engines of the competition.

4 – Conclusion

The results obtained are the consequence of a cooperation between all the units. There are some improvements that can be done in each component of the prototype, from the material chosen to the design process. This report is focused only on the design of the inlet system and here are presented some conclusion related only to that part.

The simulations were so coherent with the real performances of the prototype as shown in the graph tot and tot. This means that the code optimised for the KTM engine was very accurate. As said in paragraph 3 the software didn't consider the losses due to the transmission components. Comparing the two graphs obtained from the software with the real ones, it has been demonstrated that the part of the code linked to the engine is perfectly working. Next goal is to implement the code in order to avoid the cost related to the test bench.

The results in the competition showed that the design process has been carried on in a proper way. All the literature considered was enough for the whole design process and perfectly suits a possible improvement of the system.

It figured out that if the pressure at the beginning of the trumpet increases, all the graphs (from the pressure related to the crank angle, to the output power and torque) benefits from this phenomenon. In order to increase the pressure on the trumpet, it is needed to create a high-pressure environment from which the inlet system takes the fresh air. In order to achieve this, an airbox and a dynamic inlet in front of the motorbike. This system pre-pressurizes the air mass inside the airbox, so the starting pressure is higher than the atmospheric one.

The goal of the next engine unit is to implement the inlet system with the airbox and test it with the implemented software.

5 – Acknowledgments

The realization of this project was possible thanks to the whole team that cooperates in order to realise a well-working and performant prototype. A huge thanks to all the companies that funded the project believing in it, even if it was the first year. Among them, I want to name “IOLI IMPIANTI” that permits the team to work in his garage, “SPIN ITALIA” that has been the main sponsor and all the others that helped the project with funds and components or advices. A special mention to the professor Antonio Carcaterra and the “University of Rome – La Sapienza” that let us participate in the competition using his name.

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