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Analysis of Effect of Throttle Shaft on a Fuel Injection System for ICES

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Abstract

The development of fuel injection systems today, depend over various factors. The fuel injection system controls all the other parameters by measuring the amount of air entering the throttle body. The amount of fuel to be injected is dependent upon and proportional in ideal cases to the amount of air entering the throttle body. Hence, to study the effect of throttle body to the incoming air forms an important part of a fuel injection system. In this paper, the effect of the throttle shaft to the air entering the throttle body is discussed and in turn how it affects the amount of fuel to be injected into the cylinders. The engine is modeled in SIMULINK following the mean-engine model and effects on injected fuel are observed over varying throttle angle.

1. Introduction

Since, most of the automobiles today are Electronically Fuel injected, i.e., it employs various electronic equipments to sense the various parameters of the working conditions of an internal combustion engine and then an Engine Control Unit performs the necessary calculations and injects the fuel accordingly. The fuel is injected according to a particular ratio, (ideal ratio for petrol engines is 14.7:1) also known as the air to fuel ratio. When the driver demands throttle, air is sucked into the throttle body and then a proportional amount of fuel is calculated which would help in the complete combustion according to the air-to-fuel ratio. A throttle shaft is present over which a butterfly cap is mounted which allows or cuts of air depending upon the throttle demand of the driver. The throttle shaft provides restriction to the flow of air and hence, reduces the amount of air entering the throttle body, thus reducing the performance of the engine.

2. Background

The engine is modeled in SIMULINK using the mean-value engine model. As informed by [1], the complete engine model is composed of throttle subsystem, Intake manifold subsystem and engine power generation subsystem. To calculate the amount of air inside the throttle body, it is important to calculate the effective throttle area i.e., area available for flow of air as mentioned in [2]. The effective throttle area is dependent upon the throttle angle. Let "α" be the throttle angle then the relationship between the effective throttle area and throttle angle can be expressed as:

$$A_{et} = \frac{-dD}{2}(1-a^2)^{1/2} + \frac{dD}{2}\left(1-\left(\left(a\frac{\cos\alpha}{\cos\varphi}\right)^2\right)\right)^{1/2} + \frac{D^2}{2}\sin^{-1}(1a^2)^2 - \frac{D^2}{2}\frac{\cos\alpha}{\cos\varphi}\sin^{-1}\left(1-\left(\left(a\frac{\cos\alpha}{\cos\varphi}\right)^2\right)\right)^{1/2}$$

If throttle shaft is neglected then the effective throttle area is:

$$A_{et} = \frac{\pi}{4}d^2\left(1-\frac{\cos\alpha}{\cos\varphi}\right)$$

Critical Pressure P_c is calculated by the expression:

$$Pc = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

The ratio of Pm to Pc is calculated and is compared with the critical pressure values. The mass flow rate through the throttle body is calculated according to the relationship between Pc and ratio of Pm/Pc as:

If $P_c > P_m$

$$M_{th} = \frac{C_d A_{et} P_0}{(RT_0)^{1/2}}\left(\frac{P_m}{P_0}\right)^{\frac{1}{\gamma}}\left\{\frac{2\gamma}{\gamma-1}\left[1-\left(\frac{P_m}{P_0}\right)^{\frac{\gamma-1}{\gamma}}\right]\right\}^{\frac{1}{2}}$$

If $P_c \le P_m$

$$M_{th} = \frac{C_d A_{et} P_0}{(RT_0)^{1/2}}\gamma^{1/2}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

Once, the amount of air through the throttle body is obtained, the amount of fuel to be injected

Table 1: List of Symbols.

Symbol	Meaning and Measurement
d	Throttle shaft Diameter (m),0.005m
D	Throttle Bore Diameter(m),0.035m
a	d/D , Diameter ratio

α	Throttle angle(deg), (5° to 90°)
φ	Minimum angle at which the throttle remains open (deg), 5°
C_d	Throttle discharge coefficient
A_{et}	Effective Area of Throttle body
P_0	Ambient Pressure (1bar)
T_0	Ambient temperature, 278.15K
R	Gas constant,287Kj/Kg
P_m	Manifold Pressure (bar), 0.9 bar
γ	Specific Heat Ratio ,1.401
P_c	Critical pressure
M_{th}	Throttle mass flow
F_{cy}	Fuel Injected

The dimensions used are of a Royal Enfield Bullet 500cc engine (version may vary) having a single cylinder, Electronically fuel injected (EFI) engine. These equations are combined in SIMULINK. Firstly the effective throttle area is calculated as a part of the throttle subsystem. After the Effective throttle area is calculated based on the throttle angle the mass air flow equations are modeled to obtain the value of air into the throttle body. For the mass air flow, the value of pressure of intake manifold is required. This value is provided by the Manifold Air Pressure of MAP sensor to the Engine Control Unit. The output is the mass of air flow through the throttle body according to which the fuel is injected. The amount of fuel to be injected is calculated by considering the ideal air-to-fuel ratio of 14.7:1 (for a petrol engine). Graphs of amount of fuel injected with changing throttle angle is obtained for both the conditions (i) when throttle shaft is considered and (ii) when throttle shaft is not considered. Also, for ideal conditions the power delivered by the engine can be calculated and observed for the change in power.

3. Simulation and Results

The SIMULINK model is as follows:

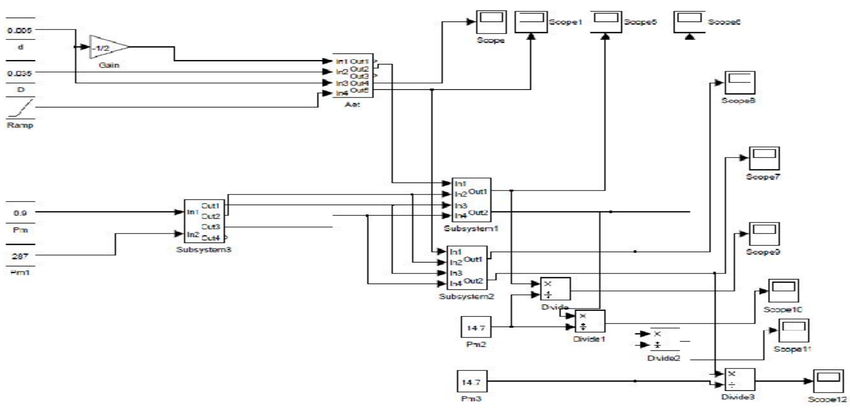

Fig. 1: SIMULINK Model

The throttle angle is increased from 0 to pi/2 (90°)and is thus calculated as a function of cosine angle.

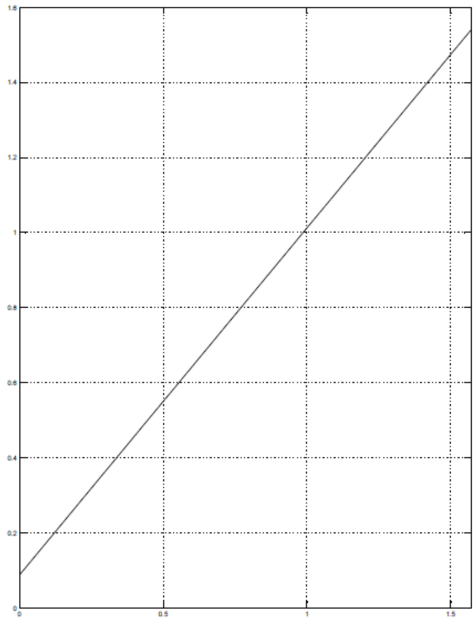

Fig. 2: Throttle angle from 0 to pi/2

The Mass of air through the throttle body for this varying throttle angle is as:

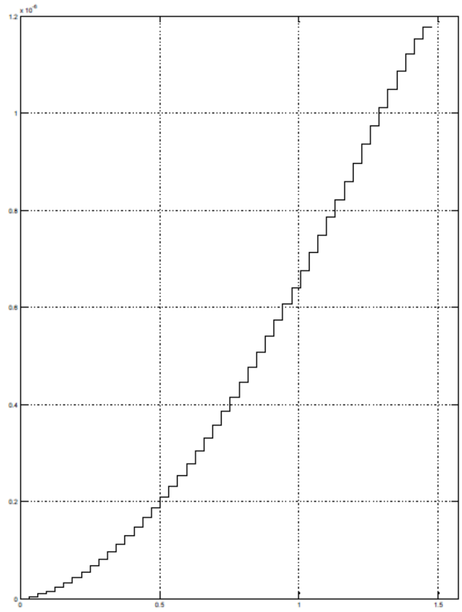

Fig. 3: Mass of air trough throttle body when shaft effect if not neglected

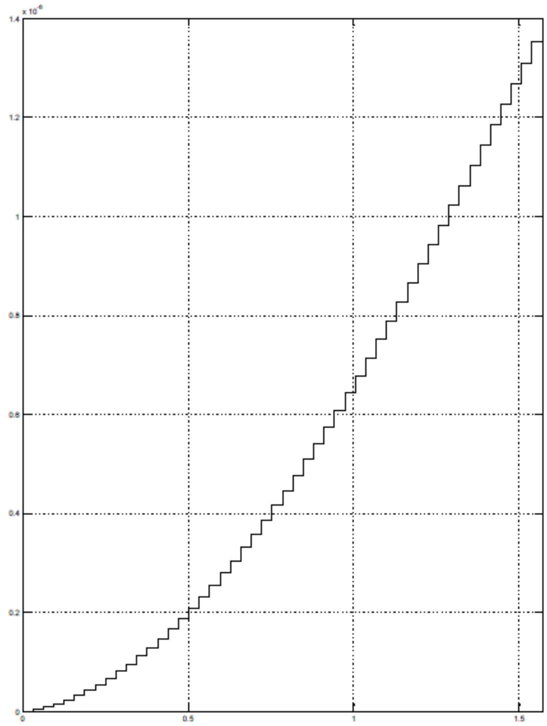

Fig. 4: Mass of air trough throttle body when shaft effect is neglected

The value of mass of air through the throttle body, neglecting the throttle shaft is given in fig. and with the throttle shaft is in figure. The maximum values obtained when shaft is neglected is more than the value obtained when the shaft effects are considered. As a result it also affects the amount of fuel to be injected.

Fig. 5: Maximum mass of air when shaft effect is not neglected.

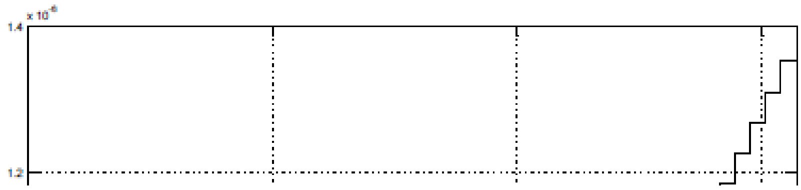

Fig. 6: Maximum mass of air when shaft effect is neglected.

The amount of fuel injected into the cylinder is as follows:

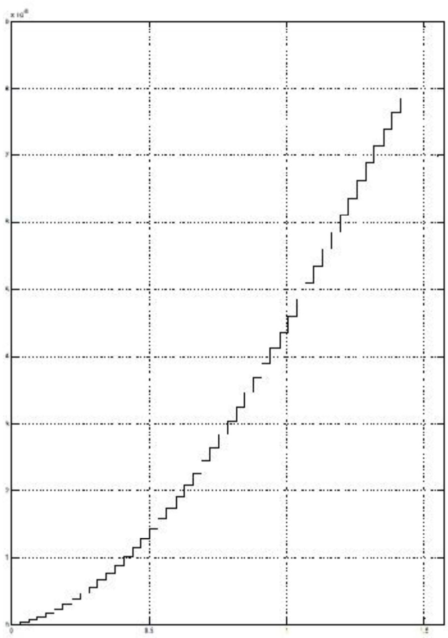

Fig. 7: Mass of fuel injected when shaft effect is not neglected.

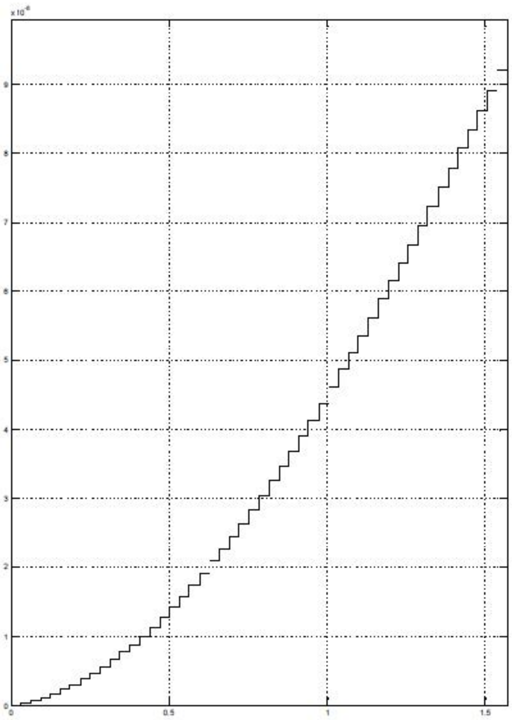

Fig. 8: Mass of fuel injected when shaft effect is neglected.

The amount of fuel injected incase of neglecting the shaft diameter is more than when the shaft is considered. This tells us that the power supplied by the engine would differ in both the cases. Power would be higher if the amount of fuel injected is higher. Thus, this tells us that to obtain the maximum power out of the engine the throttle shaft needs to be as small as possible so that its effect over the mass of air through throttle body can be minimized and more power can be extracted from the engine.

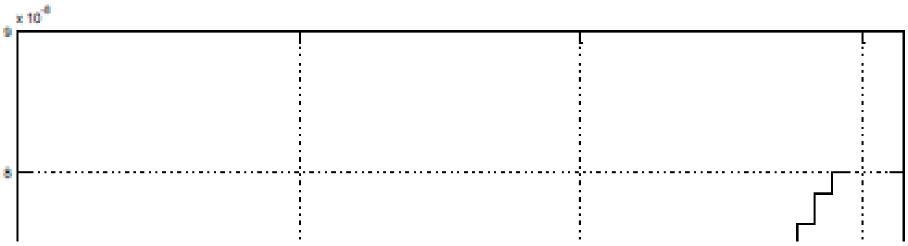

Fig. 9: Maximum mass of fuel when shaft effect is not neglected.

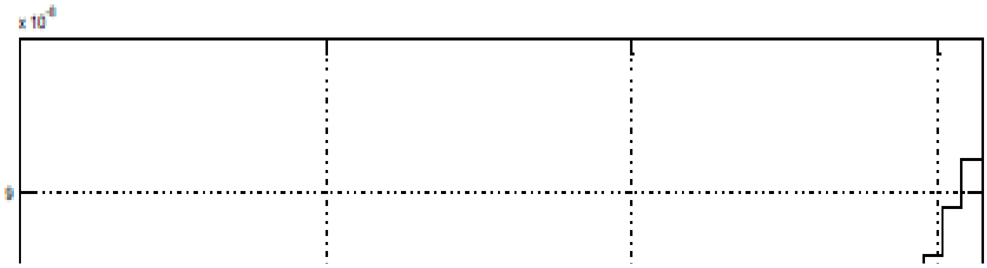

Fig. 10: Maximum mass of fuel when shaft effect is neglected.

4. Limitations and Drawbacks

The stepped output for mass of air and fuel is due to the small change in mass of air for small angular change of the throttle angle. That is due to the small size of the throttle body. If a throttle body with dimensions greater than the dimensions of the chosen throttle body (Bullet 500cc) is simulated, the graphs thus obtained would be smoother.

5. Conclusion

Hence, as observed the fuel injected decreases when the diameter of throttle shaft is considered. This states that in order to gain the maximum amount of power from an automobile the effect of throttle shaft should be minimized. Hence, for high performance applications, the components can be designed with precision and accuracy which have the minimum throttle shaft resistance.

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