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A Short Review on Factors that Impact the Backpressure of Exhaust Manifold of Spark Ignition Engine

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Abstract

Exhaust manifold serves as breathing equipment for internal combustion (IC) engine removing combustion products. Backpressure or pressure drop in exhaust manifold is one of the flow characteristic that gives various effect to IC engine. Current methods of estimating the backpressure are through computational fluid dynamic (CFD) analysis and experimental analysis. The effects of backpressure on spark ignition (SI) and compression ignition (CI) engine are usually severe which includes pumping loss, reduced thermal efficiency, increased brake specific fuel consumption (bsfc) and reduced brake power. This paper reviews the Various design parameters that cause backpressure in exhaust manifold such as diameter, shape, length and pipe bend.

Keywords

Exhaust manifold, Backpressure, Pressure drop, Internal combustion engine

Introduction

In every single spark ignition (SI) engine, a good exhaust system design is vital in order to maximize engine power and minimize fuel consumption. Exhaust system could be divided into two main components which are exhaust manifold and muffler. Poor exhaust system design can lead to unwanted engine power loss and can even cause engine failure (Hillier and Coombes, 2004). Poor exhaust design will cause poor exhaust discharge. The most influencing boundary condition that is affected by exhaust system is backpressure (Girase, 2017). In exhaust stroke, burnt product will be flowed out from the combustion chamber to the exhaust manifold. This process will happen due to the pressure difference where once the exhaust valve open, the pressure in the combustion chamber will be higher compared to the pressure in exhaust manifold. This will

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cause the exhaust gases to flow out from combustion chamber to exhaust manifold. The exhaust gas will flow out in pulses (R.Ramganesh and G.Devaradjane, 2015; Srinivas, Mamilla, Venkata, Rao,Moin Ahmed and Sowdager, 2016). The average pressure in exhaust pipe during exhaust stroke will be named as mean exhaust pressure. The difference between mean exhaust pressure and atmospheric pressure will be called as backpressure. Backpressure also could be defined as pressure that is exerted on mowing fluid due to obstruction against its flow of direction (Mohon Roy, Joardder and Md. Shazib, 2010; R.Ramganesh and G.Devaradjane, 2015; Puneetha, Manjunath and Shashidhar, 2015). Back pressure could be produced in two places. First will be when exhaust valve opens and second when cam overlap period taking place. Positive backpressure occurs when the exhaust valve opens and negative backpressure occurs during the valve overlap period, (Teja et al., 2016). Increase in backpressure in both situation will lead to reduced engine power and increase in fuel consumption (Hillier and Coombes, 2004; Aziz, Al-Kayiem and Wahhab, 2017), reduces the brake power and increases the pumping work (R.Ramganesh and G.Devaradjane, 2015).

Kanazaki, Masahiro & Morikawa, Masashi & Obayashi, Shigeru & Nakahashi, Kazuhiro (2002) optimized exhaust manifold design using Divided Range Multiobjective Genetic Algorithm (DRMOGA) to achieve more engine power by reducing backpressure. The aim of the design optimization was to increase temperature of exhaust gas at 1500 right per minute (RPM) and increase charging efficiency or the engine's power at 6000 rpm. It was found that longer the distance from exhaust manifold inlet to the merging point, better the gas flow as well as the charging efficiency. It was also documented that larger pipe radius improves the charging efficiency as well.

In contrast, A. Patil, Navale & Patil (2014) conducted experiment and Computational Fluid Dynamic (CFD) analysis on exhaust system of Compression Ignition (CI) engine to study the effect of backpressure on different shape of exhaust manifold. Three different diffuser shapes (diverging) for exhaust with 0, 45 and 90 degree angle were analysed. It was mentioned that when the angle of the diffuser increases, the backpressure increases and the brake thermal efficiency decreases at a constant load of 5kg. The maximum pressure at manifold for 0, 45 and 90 degree diffuser was observed to be 1650Pa, 188P0a and 1900Pa respectively. Diffuser shape with 0 degree angle was a straight manifold with constant diameter. It was observed that the pressure drop increases when the length increases. It was also tabulated that the brake thermal efficiency decreases with increase angle of the diffuser. Theoretically, Nakayama (2000) has stated that the pressure drop (backpressure) will increase when there is a sudden expansion along a pipe. The increase in expansion size and angle directly will increase the pressure drop. Therefore, the experiment and CFD analysis conducted by A. Patil et al. (2014) verifies the relationship between pressure losses (backpressure) to the sudden or gradual change in pipe's cross sectional area.

Moreover, G. Chaudhari, N.Borse and Y.Patil (2017) conducted experiments and CFD Analysis on exhaust manifold to improve performance of internal combustion (IC) engine. Effect of type of bending on backpressure on exhaust manifold was studied through this experiment. Three type of manifold bend were experimented which will be sharp bend, short bend and long bend. This experiment was conducted on a single cylinder CI engine with rpm of 1500. It was tabulated that when the load of engine increases, the backpressure and brake thermal efficiency increases. In addition, the backpressure and brake thermal efficiency was tabulated to be the lowest on smooth bend and highest on sharp bend.

Similarly, Shekhar, Dhugga, and Malik (2016) has conducted similar CFD analysis on exhaust manifold to study the effect the bending to the backpressure. The platform on which the analysis conducted was ANSYS Fluent. From the analysis, it was observed the pressure drop significantly increases when the number of bend increases. It was stated that when exhaust gas exit the manifold, its velocity will reduced once it hits the bend. This will act as a resistance to the upcoming exhaust pulse and the pressure at inlet of exhaust manifold will increase. When backpressure increases, it will increase pumping work, decreases scavenging effect in engine and reduced intake manifold boost pressure.

In a research article by Mohon Roy, Joardder and Uddin (2010), it was stated that thermal efficiency decreases and brake specific fuel consumption (bsfc) increases when the backpressure increased on 1200 rpm. While on 600 rpm, the thermal efficiency and bsfc shows no significant changes when the backpressure is increased. On 950 rpm, thermal efficiency slightly decreased and bsfc slightly increased with increase of backpressure. The changes on 950 rpm was very less compared to 1200 rpm. Therefore, it could be said that too much backpressure on high speed will reduces engines' power as the thermal efficiency decreases and it will give fuel penalty to the engine.

Furthermore, Puneetha, Manjunath and Shashidhar (2015) has conducted CFD analysis on single cylinder CI engine to study the effect of backpressure to the engine. It was mentioned that, as the backpressure level increases, the engine has to do more pumping and mechanical work due to increased compression work in the engine. The performance of turbocharger will be affected as well as the backpressure will alter the air fuel ratio. However, increased backpressure will increase prevent some of the exhaust gases from leaving the combustion chamber and will cause the EGR exhaust gas recirculation (EGR) to further reduce the nitrogen oxide (NOx) usually limited to 2 to 3% of reduction.

Bhure (2018) has conducted an experiment to study the effect of backpressure on compression ignition (CI) engine's performance and exhaust gas characteristics. The exhaust system was equipped with diesel oxidation catalyst (DOC) and exhaust gas recirculation (EGR) to reduce the harmful emission. The experiment was conducted using manually controlled exhaust valve lift and exhaust brake pressure valve control (BPVC) fitting on a constant rpm of 1500. The BPVC lifts were set on 100%, 87.5% and 75%. The result for increasing backpressure shows decrease in thermal efficiency, fuel consumption and brake mean effective pressure (BMEP). This is due to pumping loss which leads to reduction in brake power. In contrast, increase in backpressure in CI engine increases the efficiency of DOC. Increased efficiency of DOC aid to reduce hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxide (NOx) emission to environment as the time of the oxidation will be higher. Similarly, Puneetha et el. (2015) mentioned increased backpressure will reduce NOx emission as well.

A computational analysis using FLUENT software of flow characteristics on exhaust manifold on spark ignition (SI) engine was conducted by Aziz, Al-Kayiem & Wahhab (2017). The boundary condition obtained from experiment test of SI engine on 2500 rpm was used on the CFD analysis. From the analysis, it is observed that the backpressure tries to push exhaust back to the engine. It was stated that in extreme situation too much of backpressure could damage the engine.

Thus, this analysis is useful for designers to optimize the exhaust manifold so that the backpressure will be as minimal as possible.

A similar computational fluid analysis was done by Akhil Teja, Ayyappa, Katam & Anusha (2016) to analyse flow characteristics of exhaust manifold. Four sets of simulation was conducted at 1200 rpm, 1300 rpm, 1400 rpm and 1500 rpm respectively. The static pressure of exhaust manifold on 1200, 1300, 1400 and 1500 rpm were 500kPa, 550kPa, 600kPa and 750kPa respectively. Therefore, it could be said that the static pressure on exhaust manifold increases with the rpm.

Girase (2017) has conducted geometry optimization by undergoing CFD analysis on exhaust manifold to reduce backpressure. The analysis was conducted on CI engine with a speed of 1500 rpm. The exhaust manifold has four inlet and two outlet. It was observed that the two middle inlet tubes have higher temperature compared to outer tubes. This is due to engine firing order that will discharge exhaust gas in sequence. It was suggested that internal surface of the pipe has to be made smoother for better discharge and sharp changes is suggested to be minimized to reduce pressure drop. After applying this suggestion the net decrease in pressure drop is documented to be 0.088kPa. This proves that smoother bend has lesser backpressure similar to experiment conducted by G. Chaudhari et el. (2017).

Conclusions

In a conclusion, it could be said that four important parameters affects the backpressure of exhaust manifold which will be manifold diameter, manifold shape, manifold length and manifold bend. The similarity with all these parameters will be characteristics of exhaust gas velocity. When exhaust gas velocity increases, the backpressure decreases. Backpressure give severe bad impact to both SI and CI engine in term of scavenging effect, thermal efficiency, bsfc and brake power. Therefore, a good exhaust manifold design need to be done by considering all the design parameters discussed in this paper in order to minimize the backpressure. While in CI engine, increased backpressure will reduce the harmful emission such as CO, HC and NOx.

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