MODELING AND ANALYSIS OF FIELD OF EXHAUST MANIFOLD DESIGN

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Abstract - *In the current century, spark ignition engines have become an isolated part of society, and are used in many fields of energy. They act as the backbone for transport systems, but, as a bitter truth they behave like a major source of air pollution. There are basically three types of emissions, one emerged from an SI engine; Exhaust emissions, evaporative emissions and crankcase emissions, and the major pollutants emitted from these engines are CO, CO2, SOX, NOx. The current work aims to reduce emissions. It is a well-established fact that smooth combustion reduces emissions, and the exhaust process greatly contributes to completing the smooth combustion process. In the present work, multiple designs of exhaust for a multi-cylinder spark ignition engine are optimized to reduce emissions, by evaluating back pressure. For this purpose, four different designs, such as, short bend center exit, short bend side exit, long bend center exit with reducer, and long bend side exit with reducer are considered, and their performance is evaluated separately. Loading conditions are performed. The resulting performance scores of various models are evaluated based on back pressure, and based on these scores; the overall performance score is examined. In the next step, different models are ranked based on the overall performance score.*

Key Words: Exhaust manifold, back pressure, exhaust velocity, CATIA v5, ANSYS workbench

1. INTRODUCTION

Air pollution can be defined as an addition of any material which will deleterious effect on the life on the earth. The main pollutants contributed by IC engines are carbon monoxide, nitrogen oxides, unburned hydrocarbons, and other particulate emissions. In addition to this, different fuels used in engines also emit carbon dioxide in large quantities, which is more concerned to greenhouse effect. A renounced meteorologist recently predicted that polluted air can put an end to life on the earth within a century. This, in turn, will reduce the emissions of carbon dioxide. A viable alternative to IC engines or alternative fuels is not likely to be available within the next few decades. Therefore, all efforts should be made to develop better engines, and methods to reduce the pollution from IC engines.

1.1 THEORETICAL CONSIDERATIONS

In an internal combustion (IC) engine, combustion of fuel takes place inside the engine cylinder in the presence of oxygen (present in air), and a large amount of mechanical energy is obtained. For the purpose of combustion, either petrol is used along with air in case of spark ignition engines, or compressed air is used and diesel is sprayed in diesel engines. This process generates tremendous mechanical energy. Inside the engine cylinder, the piston power is transmitted to a shaft known as crank shaft, which converts reciprocating motion of the piston into rotary motion. Today's IC engines can be classified in many ways. Internal combustion (IC) engine rankings in some of the following methods:

1. Based on request

a) Automobile engine;

b) Aircraft engines;

c) Locomotive Engine;

d) Marine engines; and

e) Stationary engines.

2. Based on the basic engine design

a) Single cylinder engine,

b) Multi-cylinder line engine,

c) V-engine,

d) Radial engine,

e) Opposed piston opposed cylinder engine, and

f) Rotatory engine.

3. Based on Operating Cycle

a) Atkinson (full extension SI engine);

b) Diesel (e.g. diesel engine);

c) Dual (original diesel engine);

d) Miller (early / late inlet valve closing type SI engine); and

e) Otto (Convectional for SI engine).

4. On the basis of the working cycle

a) Four stroke cycle;

b) Two-stroke cycle;

c) Clean, straight / crankcase / cross-flow, back flow / loop, uniform flow; and

d) Naturally Aspirated or Turbocharged.

5. Based on the valve / port design

a) Poppet valve; and

b) Rotatory Valve.

6. Based on location Valve / port

c) Head T- type;

d) Head L- type;

e) France head

7. Based on fuels used

a) Convectional

b) Oil derivatives, petrol, diesel

c) Other sources, coal, standing biomass, tar, rock

d) Substitute

e) Petroleum derivatives CNG, LPG

f) Biomass derived: alcohol, vegetable oil, producer gas, biogas and hydrogen

g)Blending

h)Two fuel and dual-fuel

8. Based on Composition Preparation

a) Carburetion; and

b) Fuel Injection.

9. Based on ignition type

a) Spark ignition (SI); and

b) Compression ignition (CI).

2. LITERATURE REVIEW

Present chapter tells about the opinions of different researchers on pollutants form SI engines, and exhaust manifold designs, and finds the gaps found during the survey of literature, which constitute the objectives of the research, and concludes with the summary.

2.1 REVIEWS OF RELATED LITERATURE

A summary of literature based on different approaches adopted by researchers in the field of exhaust manifold design is present as follows:

1. Arcoumanis C (1994)

The researcher adopted a modelling approach for investigating flow distribution in exhaust manifold by modifying inlet and exhaust manifolds. Research also conducted experimentations for investigating the emission conditions for the engine.

2. Ahmed and Gowreesh (2015)

This research work consists of application of different CFD techniques to identify the optimum exhaust manifold for a 4-cylinder, 4-stroke petrol engine. In the research work, five variants of header based on manifold pipe geometry, namely, convergent inlet pipe, reduced convergent length, divergent-straight-convergent, reduced, divergent length, and enhanced convergent length, ideal divergent and convergent, and reduced straight length, are considered. The simulations were carried out with the help of simulation and analysis software ANSYS FLUENT using unstructured meshes. In the research work, boundary condition used was mass flow inlet. On the basis of results obtained, researchers reported that the minimum back-pressure at the exhaust manifold outlet can be achieved with the help of reducers.

3. Amruthraj, et al. (2012)

In the present work, researchers have studied the exhaust when a additive (brown gas) is mixed with air and petrol in 4 stroke SI engine. Results of the analysis show that with this combination, percentage of hydrocarbon emissions has reduced by 99.92%, and CO emissions are reduced by 98.668%.

4. Bafghi (2013)

In his research work, researcher analyzed the effect of exhaust gas to air manifold on NOX on different loads, the smoke temperature at exhaust, bsfc, vol. efficiency, and changes in thermal efficiency. Results of this research show that on increasing the exhaust temperature to the manifold, volumetric and thermal efficiency of the engine decreases.

5. Chi et al.(2012)

In this research work, performance of a single cylinder SI engine was estimated using 1-dimensional, GT-Power software. The virtually obtained power output, was then, compared against the experimental data. During the research work the considered parameters were the intake runner diameter, the position of restrictor, the exhaust runner lengths, and the sphere plenum diameter. For designing the plenum for both the manifolds Helmholtz theory was applied, and the optimization experimental study was conducted with the help of Orthogonal Array Testing Strategy (OATS). The results obtained from the experimental analysis show satisfactory level of similarity with results of GT-Power software predictions.

6. Chiavolaet al. (2001)

The researchers carried out the study of flow behaviour on intake and exhaust systems of an IC engine, and found that the phenomena of flow in ducts closely affects the volumetric efficiency of the engine.

7. Cho et al. (2013)

The researcher designs the exhaust manifold for a 4s- SI engine, to run at 700 – 1500 RPM, and with power output up to 600 kilowatts. In the research work, thermal expansion analysis, and vibration analysis of the exhaust manifold was carried out.

8. Choongsik and Junemo (2001)

The researchers performed the research to analyze the effect of exhaust gas re-circulation on combustion characteristics of a petrol engine.

9. Dattatrayet al. (2013)

The researchers focused on thermal analysis of exhaust system for a motor bike silencer for the purpose of reducing hot spot through design improvement, and suggest for improving life of the device. During the research, they used a customized power coating for making mufflers used in automotive applications. As a result they analyzed that modified design offers reduced hot spots.

10. Dattuet al. (2014)

In this research work, researchers carried out thermal analysis for the exhaust manifold of tubular type, for various operating conditions. In the research work, researchers considered four different types, namely, radius 48 mm exhaust valve at extremely left, radius 48 m exhaust valve at center, radius 100 mm exhaust valve at the extremely left, and radius 100 mm exhaust valve at the center. The materials used for this purpose were cast iron, and aluminium. On the basis of results obtained, researchers suggested that as a material aluminium shows better thermal performance as compared to cast iron, and the exhaust manifold with 48 mm radius with exhaust valve at the center, shows superior thermal properties as compared to the other options.

11. Duratet al. (2014)

The researchers carried out both computational fluid dynamics and experimental analysis for investigating thermal performance of exhaust system for a SI engine. For this purpose, an experimental study was conducted to analyze the behaviour of gas flowing in exhaust pipe. The result shows satisfactory values.

12. Ghazikhaniet al. (2014)

The researchers focused on exergy recovery for a diesel engine of direct injection type. In the research work investigations were performed for turbocharged diesel engines for different RPM and torque values. For this purpose, a double pipe heat exchanger with reversed flow conditions was used. The research shows that by increasing load and engine speed the recovered exergy of the system increases, while the bsfc reduces by approximately 10%.

2.2 GAPS IS THE LITERATURE

On the basis of above mentioned literature survey, following gaps are being identified:

There is a limited research available considering different geometries of exhaust manifold; there is a limited research conducted for analyzing pressure and velocity changes happening in the header and their effect on exhaust emission; and Comparative study of different geometries of exhaust manifold for reducing exhaust emission problem.

Based on the gaps noticed in literature, objectives for the present research work are targeted.

3. DESIGNING, MODELING AND ANALYSIS OF EXHAUST MANIFOLD

MODEL FORMULATION

In present research work CFD analysis of exhaust manifold of multi-cylinder SI engine is accomplished for determining optimal geometry for the purpose of reducing the emissions. For this purpose four manifolds chosen from the research work of Umeshet al. (2013) are compared at comparatively higher load values as compared with the research work of the previous researchers. Following are the physical details of models adopted for research.

Table 3.1: Values of back pressures for different models

S. No	Type	Load applied				
		5kg	10 kg	15 kg	20 kg	25 kg
1	Short Bend Center Exit	993	1079	1184	1204	1219
2	Short Bend Side Exit	1089	1132	1242	1262	1277
3	Long bend center exit with reducer	1099	1187	1302	1322	1337
4	Long bend side exit with reducer	1194	1276	1386	1411	1441

Graphical representation of above analysis is as follows.

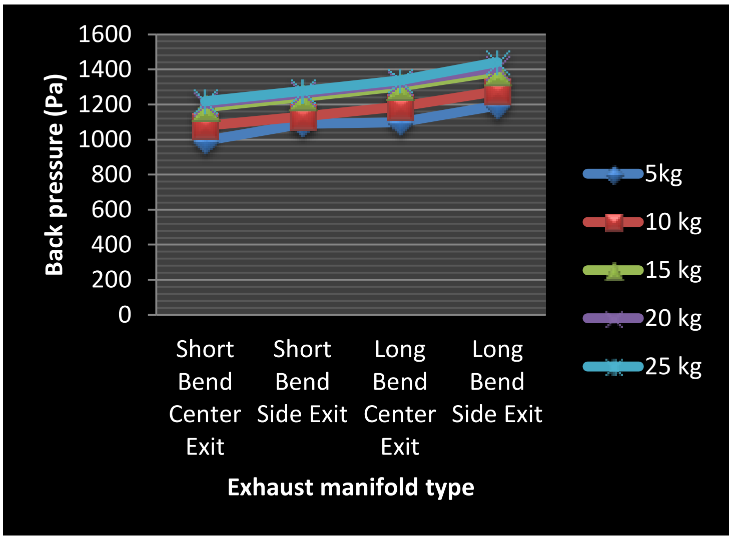

Figure3.1: Values of back pressures for different models

a) In next stage, exit velocities for different models in different loading conditions were calculated (please refer figure 5.3 to figure 5.6). Following are the results.

S.No	Type	Load applied				
		5kg	10 kg	15kg	20kg	25 kg
1	Short Bend Center Exit	18.41	21.45	24.39	27.43	30.37
2	Short Bend Side Exit	18.92	21.60	34.82	27.90	30.72
3	Long bend center exit with reducer	19.10	23.65	25.90	28.46	32.72
4	Long bend side exit with reducer	18.48	21.86	24.56	29.94	31.64

Table4.8: Values of exit velocities for different models

Graphical representation of above analysis is as follows.

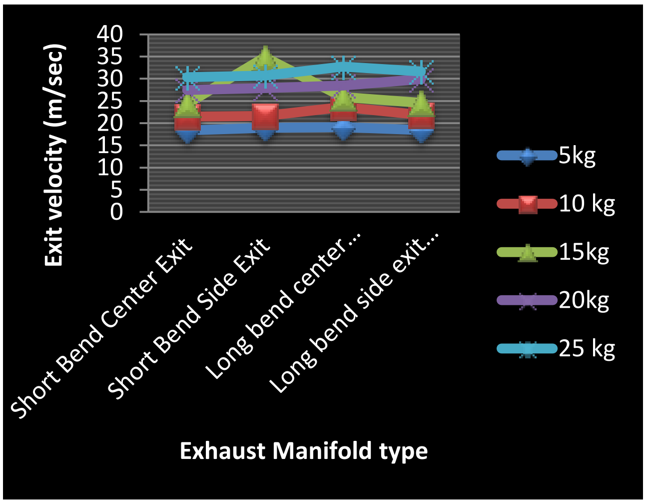

Figure 3.2: Values of Exit velocity for different models

Table4.9: Performance scores for Back Pressure

Graphical representation of above analysis is as fallows

S. No	Type	Load applied					Average perform-ance score
		5kg	10 kg	15 kg	20 kg	25 kg	
1	Short Bend Center Exit	1	1	1	1	1	100
2	Short Bend Side Exit	0.911846	0.953180	0.953301	0.954041	0.954581	94.53899
3	Long bend center exit with reducer	0.903549	0.909014	0.90937	0.910741	0.911743	90.88834
4	Long bend side exit with reducer	0.831658	0.845611	0.854257	0.853296	0.84594	84.61525

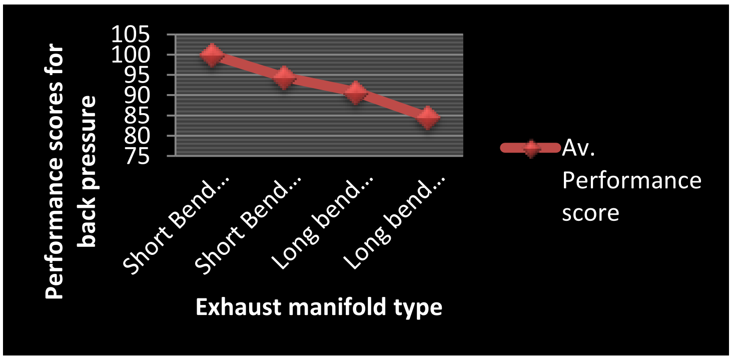

Figure 3.3: Average performance score based on Back Pressure

Table4.10: Performance scores for Exit Velocity

S. No	Type	Load applied					Average performance score (Σ)
		5kg	10 kg	15 kg	20 kg	25 kg	
1	Short Bend Centre Exit	0.963	0.90	0.700	0.916	0.928	88.313
2	Short Bend Side Exit	0.990	0.913	1	0.931	0.938	95.492

3	Long Bend Center Exit with Reducer	1	1	0.743	0.950	1	93.8
3	Long Bend Side Exit with Reducer	0.967	0.924	0.705	1	0.966	91.28

Graphical representations of above results are as follows.

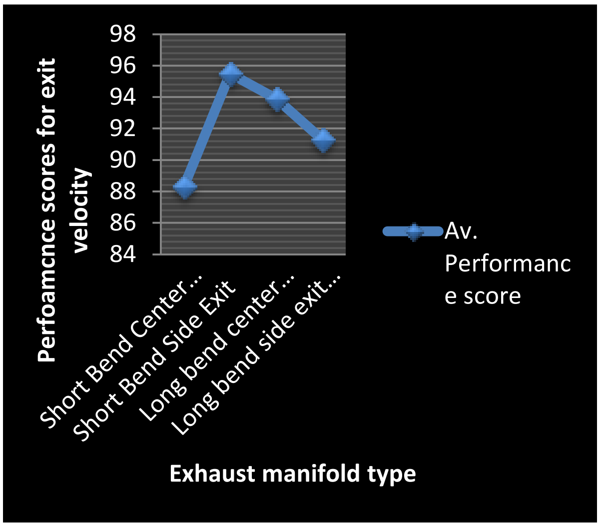

Figure3.4: Average performance score based on exit velocity

g) As the last stage of research, overall performance score for different manifold models was calculated, which was the average of average performance scores based on back pressure, and exit velocity values for models. Following are the details:

Table4.11: Overall performance score

A	B	C	D	E
S. No	Model type	Av. Performance score based on back pressure	Av. Performance score based on exhaust velocity	Overall performance score (= (C+D)/2)
1.	Short Bend Center Exit	100	88.31309	94.15655
2.	Short Bend Side Exit	94.53899	95.49268	95.01584
3.	Long bend center exit with reducer	90.88834	93.88786	92.3881
4.	Long bend side exit with reducer	84.61525	91.28373	87.94949

Graphical representations of above results are as follows

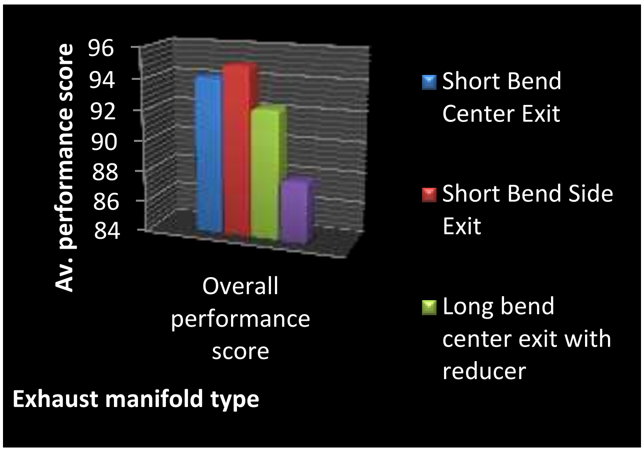

Figure5.1: Overall performance scores for different exhaust manifold models

4. CONCLUSIONS

1. Forces exerted by gas particles within the manifold effect the values of back pressure and exit velocity, thanks to which overall performance score on the idea of those two parameters changes;

2. Small bend models show better performance, as compared with long bend models;

3. thanks to increased length, differences in overall performance score in long bend models are greater than that of short bend models; and

4. Out of obtainable set of alternatives, short bend side exit model of manifold is that the best one because it's scored rank first for overall performance score. After this model, short bend center exit sort of manifold secures second rank. Proceeding within the same manner long bend centre exit model with reducer, and long bend side exit with reducer model has secured third, and forth ranks respectively.

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