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Design Optimization of Automotive Air Filter Housing for Minimum Pressure Drop

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***Abstract*— In spite the limitations of the space modern engines are designed to provide good performance with high efficiencies. Air intake system plays a vital role for an engine to perform efficiently by providing the clean air. Along with the filter, Air filter housing also restricts the air flow resulting in pressure drop, hence it is necessary to design the housing to provide optimum design for minimal pressure drop to increase the performance of engine by improving fuel economy, maintenance time, acoustic performance etc. This paper focuses study on design optimization of panel type air cleaner by adding guide vanes, inlet, outlet diameters and funnel at outlet section. This paper majorly focuses the study on variations in pressure drop by changing the cross- section shapes and varying in diameters & to design better air cleaner for minimum pressure drop with less turbulence& high efficiencies.**

***Key words*—Panel type air filter, Air flow restriction, Pressure drop, CFD analysis.**

I. INTRODUCTION

Earlier Air filter in automobile were not such highly efficient and were made of metal due to which their costs were high and took time for cleaning, As the years ahead innovation held lead to improved air filter technology which improved its efficiencies and its performance and material replaced by plastics which lead to cost reduction. Today's Air intake systems are highly efficient with the efficiencies of 99.8 %. The Air intake system consist of intake duct, air filter, outlet duct, air flow measurement (AFM) and resonators in some AIS system for noise damping. The function of air filter is to clean air coming from atmosphere and supply to engine with minimum air flow restriction. The filter has three basic components first dirty side case housing, clean side cover housing and filter. These housing and filter restricts the air flow which increase the pressure drop. The dirty side case consists intake duct through which the air enters the air filter and clean side consists of clean duct called outlet attached to the throttle of engine and supplies clean air for engine working. AFM are also attached to the outlet to measure the airflow and regulate the airflow required by the engine. The flow through the air filter is made smooth and streamlined flow to reduce the turbulence of flow.

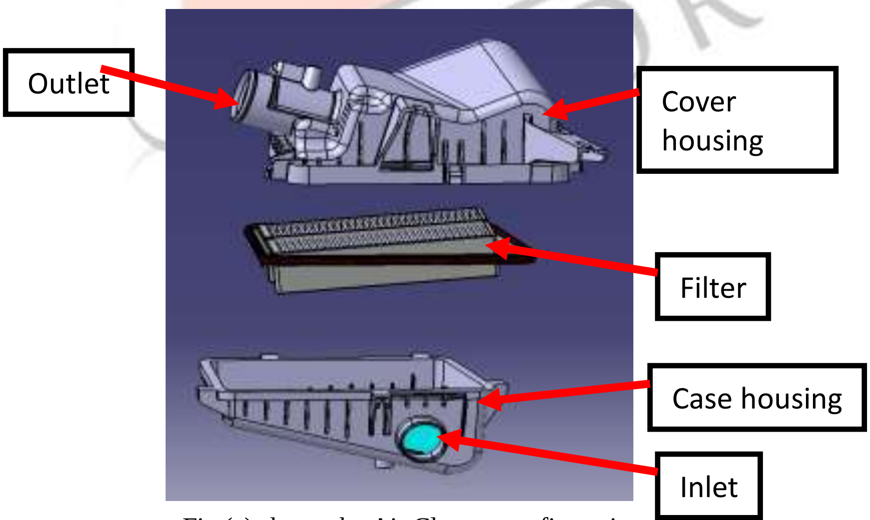

Fig (a) shows the Air Cleaner configuration

The Air from the atmosphere enters the air cleaner through intake duct and passes through fibrous filter and clean air enters the engine through outlet connected to throttle. The proper design of air filter is necessary for the good performance of the engine. The optimum design of the air cleaner improves the fuel economy by reducing the fuel consumption; it also reduces the maintenance cost and periodicity of the air filter.

The design of air cleaner must allow the air flow to flow uniformly with low speed on the air filter so that complete filter must be utilized top revent the clogging of the air filter at a small area resulting in pressure drop. If there is a large pressure drop downstream of the air cleaner then the supply of air to the engine is insufficient which will cause incomplete combustion leading to pass un burnt particles from the exhaust causing to air pollution.

II. LITERATURE SURVEY

Tadeusz Jaroszczyk, Byron A. Pardue, C.E Holm (2004) was focused their study on the gravimetric efficiencies and fractional efficiencies of panel and cylindrical type air filter. They also provided the acceptable limit of 2-3 % engine power loss due to air flow restrictions. The maximum air intake restriction for gasoline engine is 3.8- 5 kpa, 5-7.6 kpa for turbocharged diesel engine and 6.3 to 7.6 kpa for naturally aspirated diesel engines. **D.Ramasamy, Zamri.M, S.Mahendra ,S.vijayan (2010)** gave the explanation on reduction in pressured drop by adding the guide vanes. The pressure drop improvement with the different rpm of the engine was 12.01 %. The results were compared for 1.6L engine at different rpm with and without guide vanes. **M.R. Chopade, A.P. Valavade, S.H. Barhatte (2012)** studied on cylindrical air filter for design optimization to reduce the pressure drop and enhance the filter utilization area and explained the pressure drop with the variation of eccentricity of the filter element. While making the filter element eccentric to filter housing the pressure drop was improved by 10 %. It also explained the direct flow to the air filter can reduce the life of the air filter. **John Thomas, Brian west, Shean Huff (2013)** represented the experimental data and laboratory test for the improvement of fuel economy due to air filter replacement. The severe clogged air filter effects the acceleration & fuel economy and emission. They used air filter indicators to define the replacement period of air filter for a device equip with 6.7 l diesel engine indicates the replacement when indicator indicates the pressure drop of 3.6 kPa. **ShitalS.Thorat, D.N Kamble (2014)** studied a selection of Matrix approach is used for the optimal selection of the filter which enhances the performance like pressure drop, particle separation, filtration efficiency dust holding capacity etc. guidelines helped in reduction in design cycle time and cost. Analysis lead design approach is used as a methodology to optimize the design to reduce the pressure drop. **Sudarshan T A, Rajesh A (2016):** presented its analysis on pressured drop of intake manifold by changing the geometric of existing model by using CFD analysis. Air temperature sensors were used at the intake to measure the air temperature. Boundary conditions were taken at T 15°K, Density of 1.225 Kg/m^3.

III. DETAILED PROCEDURE

The efforts are made to reduce the air flow restrictions and pressure drop. Using the 3D software CATIA V5 and benchmarking of available air cleaner of the vehicle (mini truck) the available space was created in the form of cocoon to develop the design for air cleaner. Using that cocoon as the available space and surrounding connection datum's an air cleaner was designed with best design. CFD analysis was done to get the initial results which were not satisfactory to meet the engine performance; hence the model was optimized to improve the pressure drop.

$$\text{Reynolds number} = \frac{\text{Inertial forces}}{\text{Viscous forces}}$$

$$Re = \frac{vd\rho}{\mu}$$

For high velocities Reynolds's number is higher, Increase in Reynolds number increase in turbulent flow, hence efforts are made to make flow less turbulent by compromising the other factor like diameter of inlet duct as, density is constant at standard temperature as flow is incompressible. Limitations exists in order to decrease the diameter as decrease in cross section increases the air flow restrictions and decrease the mass flow rate.

$$Q = A.V$$

Where Q = volumetric flow rate
A= area of inlet/outlet
V = velocity at inlet/outlet

From the engine specification maximum Volumetric flow rate required by the engine was calculated at full throttle.
Volumetric flow rate = 2.3 m^3 /min

Darcy equation was applicable for the flow with low Reynolds number to calculate the pressure drop. But for the turbulent flow **Non-Darcy** Equation was used for high Reynolds number. These equations were corrected by Forchheimer so called **Forchheimer equations**. The total pressure drop through the air cleaner via porous air filter medium (non-woven) was calculated by Non-Darcy Flow - Forchheimer Equation.

CFD governing equations:

$$\frac{\partial}{\partial t}\int \rho \emptyset dV + \oint \rho \emptyset V.dA = \oint \Gamma \nabla \emptyset .dA + \int S_{\emptyset} dV$$

Where first term is unsteady,
Second term is convection
Third term is diffusion
Last term is source term

In above equation Ø= any flow parameter like velocity, temperature, pressure.
If Ø=1 in above equation, then equation become **continuity equation**

Ø= u (velocity) then **Momentum equation.**
Ø= h (enthalpy) then **energy equation**

For the pressure drop through filter sheet was calculated by:

$$\frac{\Delta P}{L} = \frac{\mu}{k} V \quad \text{(For flat sheet)}$$

But Forchheimer proposed a flow equation to account for the non-linear effect of turbulence by adding a second order termβ

$$\frac{\Delta P}{L} = \frac{\mu}{k} V + \beta \rho V^2 \quad \text{(For pleated sheet)}$$

Where,

μ= Dynamic viscosity
K= media permeability
V= flow velocity
β= inertial coefficient
L= pleat Height.

1) For pleated element because of its geometry inertial term addedβ

IV. RESULT AND DISCUSSIONS

Boundary conditions are to be considered at 298 K.
Inlet conditions pressure – 1 atm
Temp - 298 K
Density - 1.184 Kg/m^3
Mass flow rate required – 2.8 m^3/min
Flow is to be considered as unsteady, incompressible, no diffusion factor considered in this analysis.

Iterations	Geometric changes	Diameter(mm)		Max. flow over filter (m/s)	Pressure drop(kpa)
		previous	changed to		
	OUTLET SHAPE	variable diameter			1.34
1	OUTLET DIAMETER	68	56.5	13.4	1.36
2	ADDING OF GUIDE VANES	………..	………..	10.5	1.24
3	ADDING OF FUNNEL SHAPE PROTUDING INWARD	………..	……………	12.5	1.15
4	OUTLET SHAPE	variable diameter	uniform diameter	12	1.12
5	INLET DIAMETER	41	43	12.5	1.08
		43	44	10	1.02
		44	46	9.6	0.94

V. CONCLUSIONS

OUTLET SHAPE with when variable diameters pressure drop was high, Again when **OUTLET DIAMETER** was decreased the pressure drop increased, this conclude that decrease in area increases pressure drop and change increment w.r.t to previous study was 0.02 kpa. **GUIDE VANES** prevent mixing of flow at greater extent, due to which pressure drop improves by 8.8%. **FUNNEL SHAPE** at the outlet entry section make flow smooth which improves pressure drop and was analyzed improvement of 1.24-1.15=0.09kpa. **UNIFORM OUTLET SHAPE** was made by removing the converging shape flow was streamlined more as compared to previous study and pressure drop improved by 0.03kpa. **INLET DIAMETER** increase improved the pressure drop by large extent up to (1.12-0.94) 16%.Guide vanes also increase the inertance of the air cleaner housing studied from inertance reports. Hence the for a 2.3m^3/min volumetric air flow diesel engine with the volume of 540ccthe optimum design parameter are

Inlet: 44mm
Outlet: 56.5 mm with funnel shape radius 7 mm

While optimization of air filter housing and air filter using above methodologies, it can be seen that total pressure drop is greatly improved of about $\frac{1.34-0.94}{1.34} = 30\%$.Hence housing topology plays an important role in pressure drop.

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