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Comparison of Swirl, Turbulence Generating Devices in Compression ignition Engine

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ABSTRACT

This paper deals with comparison of various swirl generating devices in single cylinder CI engine. Engine referred for this study is single cylinder, four stroke, Multi-fuel, research engine which has a capacity of 3.5 KW. Total four swirl generating devices are modeled and analyzed in ANSYS–Fluent. The swirl generating devices will be inserted inside the intake port of the Engine. The objective of this paper is to find the effect of swirl on the engine and to compare it with the existing base model. It is found that the swirl help in providing initial angular momentum to charge before entering cylinder and thus providing improved combustion phenomenon. With analysis it is found that six guide vane devices have added advantage of comparatively increased velocity and swirl motion at outlet, however actual strength of swirl generated will be precisely calculated only after actual installation of device.

Keywords: Swirl, turbulences, blade type vane, combustion

INTRODUCTION

Although there is rapid development in the diesel engine in last few decades it is still lagging in the performance in the sense of fuel economy & exhaust emission. It is due to the ineffective use of air in the engine causes improper atomization of the air-fuel mixture results in the poor combustion, which affects the engine performance characteristics in terms of fuel economy and emissions at part load conditions. So to improve the performance of engine better utilization of intake charge is necessary, different techniques are introduced in form of modification of intake manifold, development of swirl and tumble devices, modification of piston profile for efficient combustion of charge. In this paper different swirl generating devices are analyzed and their result is compared with base model without swirl device.

The organized rotational motion of the fluid mass with respect to the cylinder axis is called Swirl. Swirl significantly improves the mixing of fresh air and fuel to supply homogeneous mixture quickly. It's also a primary mechanism for extremely distributing of flame front during the combustion phenomenon. Swirl can be created in the suction stroke within the diesel engines through the intake valve and consequently by combustion chamber design in the compression process. Swirl intensity improves the tangential velocity component of the air within the engine cylinder, that assists in the mixing up with diesel and air, consequently has an effect on combustion and engines emission characteristics.

At part load operating conditions it is advantageous to dilute air fuel mixture with introduction of swirl for these reasons. [1].

a) Expansion stroke work is increased for given expansion result as result of change in thermodynamic properties.b) For given mean effective pressure, intake pressure increases with increase in mixture dilution, thus reduction in pumping works.

c) Heat losses to cylinder wall are reduced thus reducing the burned gas temperature and controlling exhaust emission parameters.

There are two ways of generating swirl in engine:

(i) BEFORE: Generate swirl within the intake manifold before entering charge in the cylinder; this is done generally with use of guide vanes.

(ii) AFTER: Generate swirl after entering the charge in the cylinder; this is generally done with intake modification development, changing piston profile

In this work we have developed different swirl generating devices to incorporate into intake manifold system. These devices are modeled in PRO-E and subsequent flow analysis is done in ANSYS- Fluent.

80 mm 48 mm

Overall length

Inner diameter

1.1 Device Specification

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Fig: 1 Location of Air Swirl Device

2. LITERATURE SURVEY:

[1] Sarang Rajabhau Bire, has modeled three different swirl generating devices compared with base line engine. With analysis he found that blade type device have added advantage of comparatively increased velocity and swirl motion at outlet, when compared with vane type and deflector type.

[2]Idris Saad & Saiful Bari has modeled the guide vane & tumble device for improving the air-fuel mixture for the highly viscous fuel in diesel engine. They have created a device with four & six number of vanes. Prime importance is given to improvement of the air flow & the effect of vane twist angle on the air flow characteristic. Finally it is found that with six number of vane device swirl generated is more than 4 vanes but the resistance in the flow way is increased on other hand.

The vane angle is varied from 3° to 60° it is found that with 35° vane angle in-cylinder air pressure increases by 0.02%, total kinetic energy of air by 2.7% & velocity of air by 1.7% compared to the unmodified diesel engine.

[3] A.K. Mohiuddin investigates the swirl effect on the engine performance by using insert swirl adapter. The testing has carried out on the protons CAMPRO engine model of 1.6 liter.

In swirl device adapter blade angle is maintained at 300 & is fitted in the intake port. Obtained results compared with the normal engine & it has found that at the full load condition the swirl generation is less but at the part load condition the swirl produce is effective. The BSFC reduces at part load condition but as the speed increases beyond 3500 rpm BSFC increases.

[4]Liu Shenghua investigates the effect of new swirl system & its effect on DI engine economy. In this ring type generator with four curvilinear blades used. The generator fitted in the intake air duct & the comparison is carried out, the result found out that with 1500 rpm effective swirl is generated and with reduced emissions.

[5] G .S .Gurudattatreya investigates the swirl effect on the engine performance by using whirl air fan with different inclinations placed before the intake manifold for effective air swirl motion. For this, the experiment is done on Kirloskar AV1 water cooled, natural aspirated direct injection diesel engine with pure diesel.

[6] Abhilash M Bharadwaj in his study he concerned on the swirl motion of inducted air during the suction stroke and during compression stroke. The results obtain from the numerical analysis can be employed to examine the homogeneity of air-fuel mixture structure for better combustion process and engine performance.

MATERIALS AND METHODS

Concept for different Swirl generating devices is developed taking into consideration turbulence, behaviors of air flow through pipes these devices are modeled taking into consideration their installation into intake air flow duct. Total four such devices are modeled and their flow performance is compared with base system (without any swirl device), All comparison is done in ANSYS–Fluent and compared on basis of outlet velocity, pressure drop across device and turbulence kinetic energy of device.

Developed swirl device can be inserted into intake duct of engine as mentioned in Fig.1. Capability of device to produce variable swirl is also explored. On basis of device geometry devices are named as Three guide vane, four guide vane, five guide vane and six guide vane devices as shown in Fig:2,Fig:3, Fig:4, and Fig:5. Prime importance is given to improvement of the air flow & the effect of vane twist angle on the air flow characteristic. The vane angle is varied from 0° to 40°.

The shape of the geometry is modeled like that it should give efficient angular momentum to the charge but without affecting to the volume flow rate so less resistance to the charge. Devices are shown in following Fig.

Swirl Generation: In this flow rate of charge is held constant, with known velocity and pressure conditions at inlet. With some modifications in inlet duct swirl device is introduce. The geometry of devise is made such that it will offer minimum resistance to flow and minimum vortex are generated after air pass through device.



Fig: 2 three guide vane device Fig: 3 four guide vane device



Fig: 4 five guide vane device Fig: 5 six guide vane device

Resistance offered by device to flow is prime factor. Since volumetric efficiency of CI engine is always a critical parameter due to numerous component in intake system. Addition of swirl generating device should not develop more resistance to flow. Requirement of swirl is also varying in engine and is not constant at all loading conditions. At cold start conditions and part load conditions engine require slightly rich mixture. Geometry of device is maintained in such a way that it should allow max air to flow inside it will affect volumetric efficiency of engine as low as possible. In case of uniform flow device the volumetric efficiency is more because resistance in the flow way is less. By considering this factor the geometry has created. The geometry has curvature like that flow gets deflected into angular momentum.

3.1 ANSYS–Fluent 14.0 Analyses:

Three main steps are involved in the solving of any flow domain problem are 1) Geometry 2) Meshing 3) CFD Problem set up and solution.

1) Geometry Setup: The devices are modeled in PRO-E and then imported in DESIGN MODELER in ANSYS 14.0. Fluid domain inside domain is developed in order to simulate fluid flow problem.

2) Meshing: Meshing is necessary to simulate the moving boundary technique. Mesh quality has major influence on the results. Element size should be small. Poor mesh affects numerical accuracy & convergence. First aspect ratio describes the width & height of element.

3) CFD Problem set up and solution: Initial boundary conditions are set up in problem considering inlet as Velocity inlet with velocity keeping at 35m/s and pressure of 100Kpa. Problem is solved taking 1000 iterations and final values of pressure, Pressure based solution method is followed and K-Epsilon Model is followed for Turbulence flow. Cell zone conditions are specified with diesel.

RESULTS AND DISCUSSION

Modeled devices are compared on basis of outlet velocity, swirl flow at outlet. Plots and counter across each device are plotted in ANSYS and shown in following section. With values of pressure drop and tangential velocity we can conclude on ability of device to generate swirl motion at intake of cylinder.

Outlet Velocity Vector: Direction of velocity vector is important factor to determine strength of swirl created at inlet of cylinder. In case of base model there is no tangential vector found. Thus we can determine that swirl generated inside cylinder will be very less.

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Fig: 4.1 Velocity Vectors of Base Model



Fig: 4.2 Velocity Vectors of Three Guide Vane Model



Fig: 4.3 Velocity Vectors of Four Guide Vane Model









Velocity Vectors: We get increased velocity at outlet of swirl devices as compared to base model maximum outlet velocity is obtained in cases of vane type geometry.

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Fig: 4.8 Velocity Contour of four guide vane model

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Fig: 4.10 Velocity Contour of Six guide vane model

Pressure Drop: Ideally there should be no pressure drop across inlet and outlet studied system, addition device into intake duct will increase pressure drop, maximum pressure drop is found in case of blade type device.







Fig: 4.12 Pressure contour three guide vane model

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Fig: 4.13 Pressure contour of four guide vane model







Fig: 4.15 Pressure contour six guide vane model

Evaluated values for all devices after analysis is found out and tabulated below

S. No	Model	Pressure Drop (KPa)	Outlet Velocity (m/s)	Strength of Swirl generated
1	Base Model	10	108	Very Less
2	Three Vane guide blade	14	141	less
3	Four Vane guide blade	15	160	medium
4	Five vane guide blade	16	165	High
5	Six vane guide blade	16	168	Very High

Table: 2 Evaluated values for all devices.

CONCLUSION

Thus from above values we can conclude that Six guide vane geometry generates high swirl as compared to others, also we can explore the possibility of variable swirl in this device. Pressure drop across this device is less as compared to other and thus its implementation in intake duct of engine is justified. This study gives us which device is more effective in swirl generation, however actual strength of swirl generated will be validated precisely only after the implementation of device in intake manifold.

REFERENCES

[1] Sarang Rajabhau Bire, International Journal of Applied Engineering Research, ISSN 0973-4562, 2013, Vol. 8, No. 19

[2] Idris Saad & Saiful Bari, SAE International Technical paper, 2013, Vol.10, No. 10.

[3] A.K.M. Mohiuddin, , *IIUM Engineering Journal*, **2011**, Vol.12, No. 3.

[4] Liu Shenghua, SAE Technical paper, 1999, Vol.01.No. 6.

[5] Sihun Lee, Kun Tong, SAE International Technical paper, 2000, No. 16.

[6] Abhilash M Bharadwaj, International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME) ISSN: 2319–3182, 2013, Volume-2, Issue-1, No. 10.