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Optimising Intake Manifold to Increase the Efficiency of I.C. Engine

Aditya Chauhan, Anikait Arya, Ayush Bhatnagar, M. Zunaid*

Delhi Technological University, New Delhi – 110042, Delhi, India; mzunaid3k@gmail.com

Abstract

The intake manifold in an automotive engine is responsible for delivering the air-fuel mixture to the engine cylinders. Its primary aim is to ensure that the mixture is distributed evenly among each of the engine's intake ports, thus improving combustion efficiency. Our study aims to improve the mixing capabilities of the intake manifold first by analyzing various intake manifold shapes such as convergent, straight, and convergent-divergent and choosing the most optimal shape by comparing the velocity and turbulent kinetic energy, and second by attaching a vortex generator in the most optimal shape to increase the turbulence and create a swirl. The increased turbulence and swirl will help mix the fuel in a better way. These changes can lead to improved engine efficiency and reduced carbon emissions.

Keywords: *Ansys, Intake Manifold Geometries, Vortex Generator*

1.0 Introduction

In the field of automobile technology, an engine's intake manifold is the part that carries the fuel air combination to the cylinders of the engine. The term "manifold" is derived from the ancient word in English "manigfeald" and refers to the combining of different inputs and outputs. (from the Anglo-Saxon roots "many" and "fold")[1]. The intake manifold's major job, unless the engine has direct injection, is to create the air-fuel combination and distribute the combustion mixture to each of the cylinder's intake ports[2,3]. Uniform distribution is critical for optimizing volumetric efficiency and performance in engines. Intake manifold design and variable valve timing technology for intake and exhaust valves were identified to be the two best approaches for boosting volumetric efficiency but variable valve timing technology is hard and expensive to create, hence practically all researchers and the automobile industry are focused on upgrading the intake manifold. Most of the research undertaken by researchers (such as Mazda, BMW, Audi, Ford, Renault, and others) has been concentrated on the air intake system, which has gone through multiple revisions and advancements in recent years. Engine power can be increased while using less fuel and emitting fewer pollutants by modifying the dimensions and design of the intake manifold[3]. Porsche developed an intake system in the 1980s for their automobiles that could be lengthened by switching between a longer and shorter set of tubes using a butterfly valve, which led to positive pressure and improved engine performance[4]. Audi and Ford Motor Company began utilizing a similar technology in some of their vehicles in the 1990s[4,5]. IC engines generate air pollution due to the unequal distribution the engine's supply of combustible air and the incomplete combustion of the air-fuel combination. Carbon dioxide, sulphur and some unburned hydrocarbons are the principal byproducts of the process, which are created as a result of the engine getting a lower air-to-fuel ratio. Nitrogen oxides are another byproduct of the combustion process

*Author for correspondence

that are formed as a result of the engine obtaining more air fuel ratio than is required. The amount of air is one of the major aspect that influences emissions. As such, the intake manifold must be designed to distribute the volume of air entering the combustion chamber effectively[5]. The intake manifold lies between the engine cylinders and the throttle body. As stated earlier the primary function of the intake manifold in a multi-cylinder engine is transporting combustion air into cylinder of engine to create fuel air mixture. The intake manifold regulates the volume of air that may be sucked through, its impact under steady state and transient conditions, its speed, and how effectively it can mix with fuel. The amount of mass that may flow inside engine cylinders is determined by a constraint of 20 mm. Important phenomenon related to intake manifold include:

1.1 Passage of Fluid Via a Pipe and a Duct

An intake manifold is a network of ducts and pipes that deliver air to the combustion chamber of an engine. As a result, it can be analyzed and optimized in the same way that any other network of pipes and ducts can. The head loss, or pressure loss produced by certain internal geometries, has been widely investigated and theorized in pipe flows[6,7].

1.2 Pipe Pressure Losses

In pipes, there are two different forms of pressure losses: major and small. Major losses are caused by the physical length of the pipe as well as by viscous losses i.e. losses caused by friction between the fluid and the wall. Small losses occur as a result of differences in pipe geometry such as bends, elbows, valves, entrances, and re-entrances[8].
Nomenclature of intake is as follows

a. Plenum

Between the throttle valve and the cylinder runner lies this storage component. It can also serve as an acoustic suppressor device. On the basis of manifold dimension, there are two types of intake manifolds: fixed length intake manifolds and variable length intake manifold[9,10].

b. Restrictor

A restrictor is an intake manifold component that functions like a critical nozzle, critical flow venturi, or sonic choke. In industry, such components are widely utilized as basic control devices to manage the mass flow rate.

c. Cylinder runners

Cylinder runners are air intake system components that convey air from the plenum to the combustion chamber. The cylinder runner's function is air distribution. Acoustic waves are the primary phenomena that determines each runner's performance[11,12].

The work investigates various methods to optimize the intake manifold so that the efficiency of the engine can be improved

1. Designing various shapes of intake manifold in solidworks and finding the most optimum shape using ansys CFD analysis
2. Designing and fitting a vortex generator in the intake manifold to analyze the effect it has on outlet velocity and turbulence

2.0 Intake Designs and Analysis

2.1 Designs

- Dimensions of straight manifold are: length-358 mm and radii-11 mm.
- Dimensions of convergent divergent manifold: length- 288 mm and radii-11 mm (Straight part),

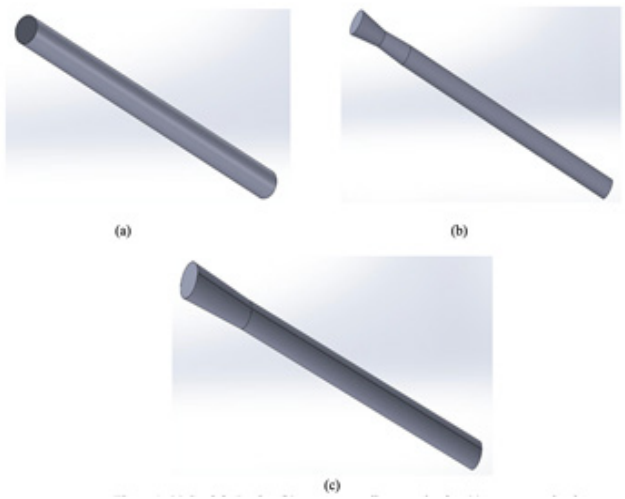


Figure 1. **(a)** Straight intake, **(b)** Convergent-divergent intake and **(c)** Convergent intake.

length-35 mm and radii-9 mm (Divergent part), length-35 mm andradii-14 mm (Convergent part).

- Dimensions of convergent manifold: length-288 mm and radii-11 mm (Straight part), length-70 mm and radii-14 mm (Convergent part). Figure 1 shows the intake systems, a) Straight Intake, (b) convergent-divergent intake, (c) convergent intake.

2.2 Meshing

We used default mesh settings to create a fine automated mesh of element size 10^{-3} m. The element order was set to linear and solver preference was fluent. The rest of the settings such as growth rate, max size was kept at default values.

2.3 Boundary Conditions

Modal considered for the analysis is viscous-laminar (k-epsilon).

For inlet: Inlet is pressure inlet in this case having turbulence length scale equal to 7 percent of inlet diameter and turbulence intensity equal to the default one. Inlet pressure equal to 0 pa as we are considering pressure relative to atmospheric pressure.

For outlet: Outlet is pressure outlet in this case having turbulence length scale equal to the default one and turbulence intensity equal to 4.2 percent. Outlet pressure equal to 101325 pa as we are considering pressure relative to atmospheric pressure.

2.4 Results

The main aspects for our aim are outlet velocity as more outlet velocity signifies more air entering the combustion chamber and turbulent kinetic energy as more turbulent kinetic energy signifies better mixing of fuel.

Outlet velocity: On examining outlet velocity we can see that convergent-divergent manifold is having the largest velocity among all.

Turbulent kinetic energy: On examining turbulent kinetic energy we can see that convergent-divergent manifold is also having the largest kinetic energy among all grid independent test values of outlet velocity and turbulent K.E.

Table 1. Straight intake manifold grid values

Name	P9 - Mesh Element Size [m]	P4 - out-val [m s^{-1}]	P5 - out-tur-ke [J kg^{-1}]	P7 - Mesh Nodes	P8 - Mesh Elements
DP 0	0.002	361.35576	185.88938	56730	53690
DP 1	0.0019	372.96441	194.85578	59784	56848
DP 2	0.0018	373.89257	176.81025	71874	68359
DP 3	0.0017	371.83286	189.63081	85814	81579
DP 4	0.0016	372.03336	181.84248	99904	94775
DP 5	0.0015	370.52198	193.24465	101520	96317
DP 6	0.0013	370.06169	180.44152	160356	153450
DP 7	0.0012	371.14017	170.39864	210192	201670
DP 8	0.0011	369.44685	174.50004	270272	260619
DP 9	0.001	369.66497	169.6267	351102	338310

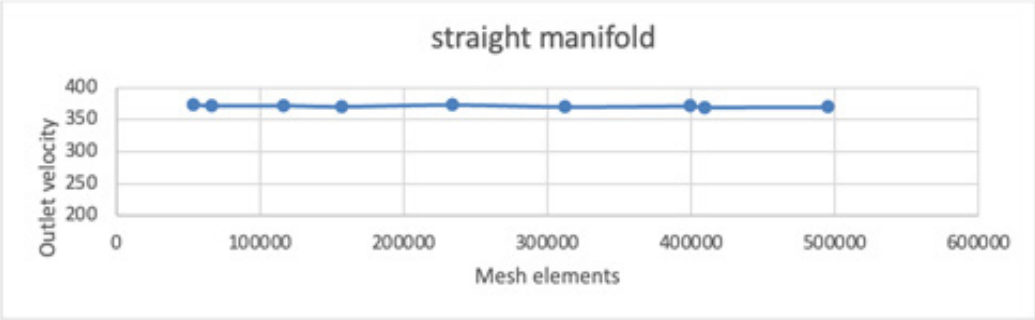


Figure 2. Straight intake manifold outlet velocity vs number of mesh elements.

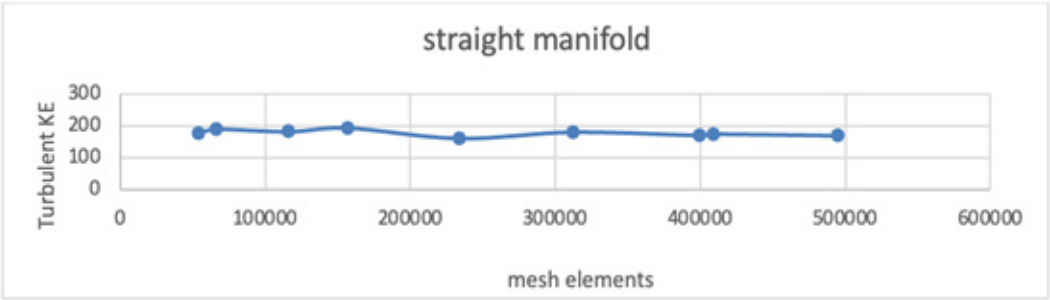


Figure 3. Straight intake manifolds turbulent kinetic energy vs number of mesh elements.

For grid independence test we use the facet average values at outlet for both turbulent kinetic energy and velocity. After examining all the results, we can see that convergent-divergent manifold is the best design among all in both aspects outlet velocity and turbulence. Table 1 shows the Straight intake manifold grid values, Table

Table 2. Convergent intake manifold grid values

Name	P6 - Mesh Element Size	P1 - Mesh Nodes	P2 - Mesh Elements	P4 - tur-ke	P5 - out-vel
Units	m			J kg^{-1}	m s^{-1}
DP 0	0.00175	95850	90736	151.1424	348.2731
DP 1	0.0017	111826	106700	133.7306	350.7773
DP 2	0.0016	141984	136059	119.2709	352.7735
DP 3	0.0015	140368	133380	131.4377	349.6721
DP 4	0.0014	155760	148332	142.4281	347.2759
DP 5	0.0012	296949	287364	112.5209	350.9544
DP 6	0.0011	317791	305424	136.4936	346.1285
DP 7	0.00105	383711	371008	125.8907	347.9044
DP 8	0.001	404410	390033	135.1465	346.3066

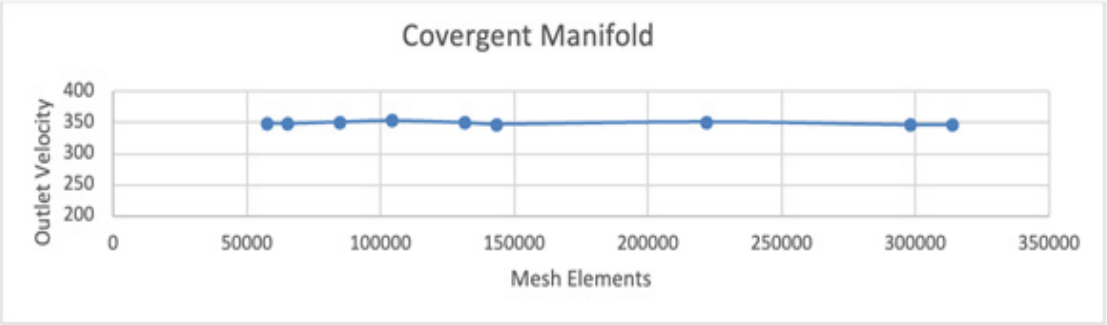


Figure 4. Convergent intake manifold outlet velocity vs number of mesh elements.

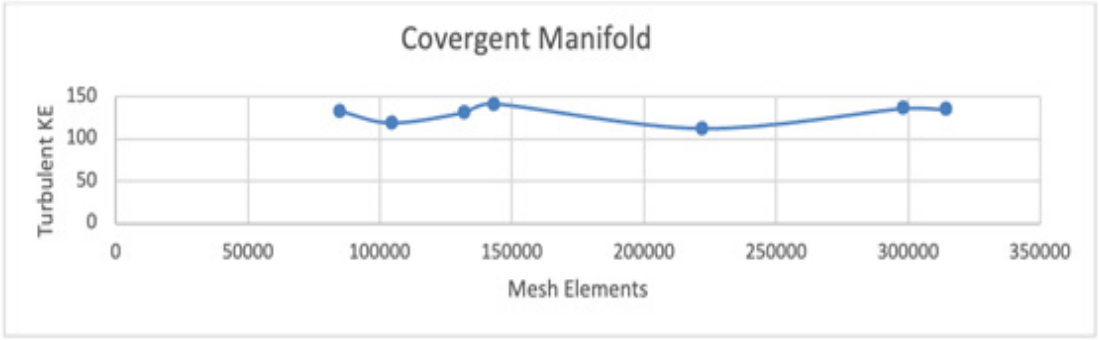


Figure 5. Convergent intake manifold turbulent kinetic energy vs number of mesh elements.

Table 3. Convergent-divergent intake manifold grid values

Name	P6 - Mesh Element Size	P2 - Mesh Nodes	P3 - Mesh Elements	P4 - outlet-velocity	P5 - tur-ke
Units	**m**			**m s^{-1}**	**J kg^{-1}**
DP 0 (Current)	0.002	72192	68442	375.7239	181.3995
DP 1	0.0019	73914	69673	378.201	219.8995
DP 2	0.0018	84048	79745	379.3083	212.101
DP 3	0.0017	111826	106700	381.085	194.3556
DP 4	0.0016	141984	136059	383.7054	169.6922
DP 5	0.0015	140368	133380	379.6989	203.5522
DP 6	0.0014	155760	148332	376.5744	229.2833
DP 7	0.0013	228800	221160	382.1914	178.5461
DP 8	0.0012	296949	287364	381.346	182.5778
DP 9	0.0011	317791	305424	375.2481	226.7948
DP 10	0.001	404410	390033	375.3381	222.2819

2 shows the Convergent intake manifold grid values and Table 3 shows the Convergent-divergent intake manifold grid values.

Moreover, Figure 2 shows the Straight intake manifold outlet velocity vs number of mesh elements, Figure 3. Shows the Straight intake manifolds turbulent kinetic energy vs number of mesh elements, Figure 4. Convergent intake manifold outlet velocity vs number of mesh elements and Figure 5 shows the Convergent intake manifold turbulent kinetic energy vs number of mesh elements.

2.5 Vortex Generator

The vortex generator alters the airflow over the bodywork, causing a swirl of air between the high energy and low energy streams. This increases the energy of the boundary layer by drawing a flow of highly energetic air into the boundary layer from the free stream. Air with high energy clings to the bodywork considerably more strongly, increasing the attached flow[13].

There has been considerable amount of work done that shows how vortex generators increase the turbulence of airflow. Work done in clearly explains the effect of vortex generators in creating turbulence. A turbulent boundary layer is later more resistant to an unfavorable pressure gradient that is responsible for promoting separation. The vortex created by the VG changes the boundary layer from laminar to turbulent[14].

Reports on experimental measurements of turbulence intensity and the rate of heat transfer in a concentric tube heat exchanger. The results show that the vortex generators increase the intensity of turbulence and the rate of heat transfer[15,16]. Shows how turbulence created by vortex generators can help in the separation of fine particles and proved to be effective in fine particle flotation. Figure 6 shows the Vortex Generator.

2.6 Meshing

For this geometry we use 2 different mesh sizes for creating a mesh here. Mesh elements of 10^{-3} m are used for the piped portion and $5*10^{-3}$ m are used for the vortex generator portion.

2.7 Boundary Conditions

Modal considered for the analysis is viscous-laminar (k-epsilon).

For inlet: Inlet is pressure inlet in this case having turbulence length scale equal to 7 percent of inlet diameter and turbulence intensity equal to the default one. Inlet pressure equal to 0 pa as we are considering pressure relative to atmospheric pressure.

For outlet: Outlet is pressure outlet in this case having turbulence length scale equal to the default one and turbulence intensity equal to 4.2 percent. Outlet pressure equal to 101325 pa as we are considering pressure relative to atmospheric pressure. Figure 7 shows the Mesh for vortex generator applied intake manifold. Figure 8. Shows the Velocity of intake manifold with vortex generator and Figure 9 shows the Turbulent K.E. of intake manifold with vortex generator.

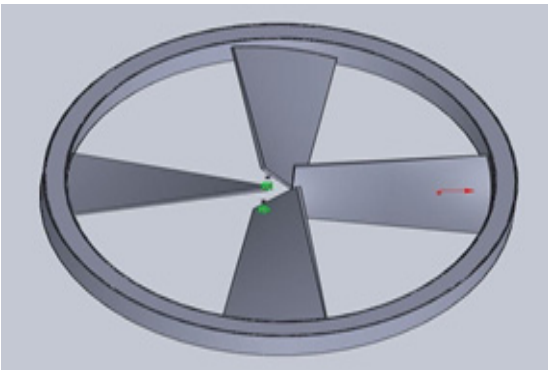


Figure 6. Vortex generator.

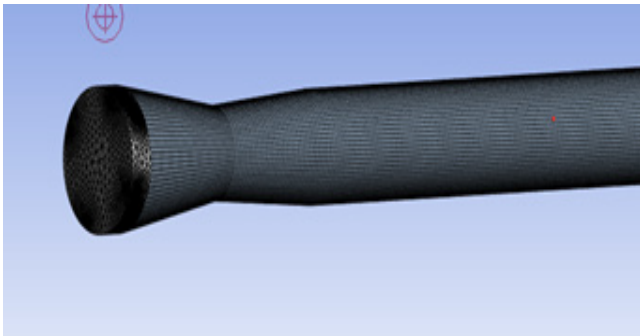


Figure 7. Mesh for vortex generator applied intake manifold.

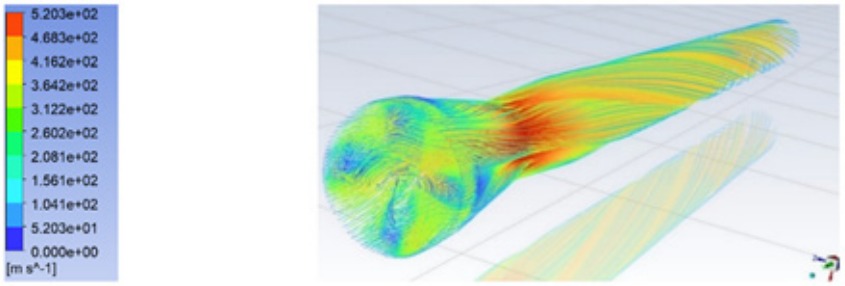


Figure 8. The velocity of the intake manifold with a vortex generator.

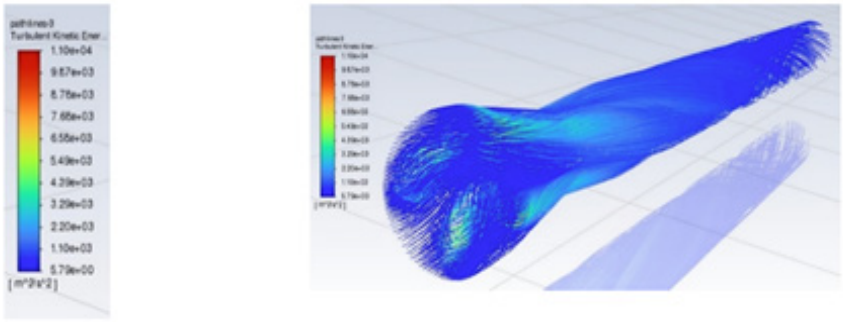


Figure 9. Turbulent K.E. of intake manifold with vortex generator.

2.8 Results

Air flow lines: In case of vortex generator the air flow lines are much more turbulent as compared to normal convergent-divergent manifold. Table 4 shows the Vortex generator intake manifold grid values. Figure 10 shows the Vortex generator intake manifold outlet velocity vs

Table 4. Vortex generator intake manifold grid values

Name	Mesh Element Size [m]	Face Sizing Element Size [m]	Mesh Nodes	Mesh Elements	tur ke	outlet- vel
DP 1	0.015	0.0013	170052	277263	994.4143	234.0888
DP 2	0.015	0.0012	181017	287587	1026.678	231.3342
DP 3	0.015	0.0011	225372	330112	923.4461	230.7782
DP 4	0.015	0.001	264503	367447	870.1869	228.4131
DP 5	0.015	0.00099	267572	370414	882.8249	227.1057
DP 6	0.015	0.00098	278316	381738	849.4961	228.4863
DP 7	0.015	0.00097	277704	379898	860.4743	227.6489
DP 8	0.015	0.00096	293979	397529	827.4258	228.2738
DP 10	0.015	0.00094	305004	405974	832.6904	227.1338
DP 11	0.015	0.00093	306352	407569	831.8916	226.8536

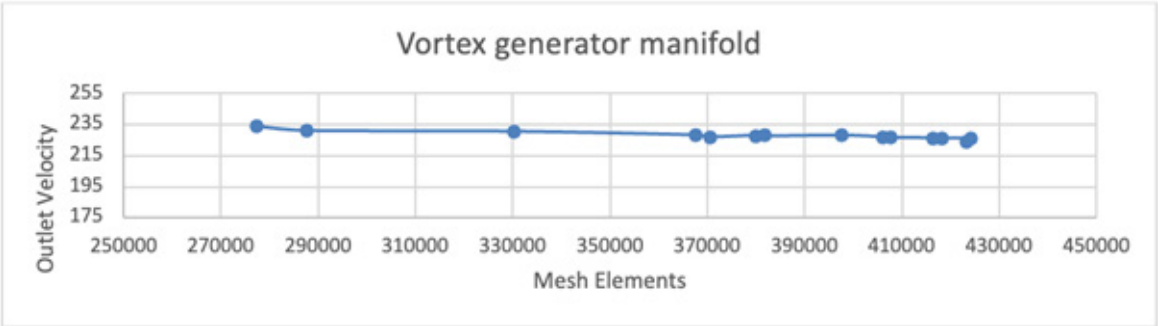


Figure 10. Vortex generator intake manifold outlet velocity vs number of mesh elements.

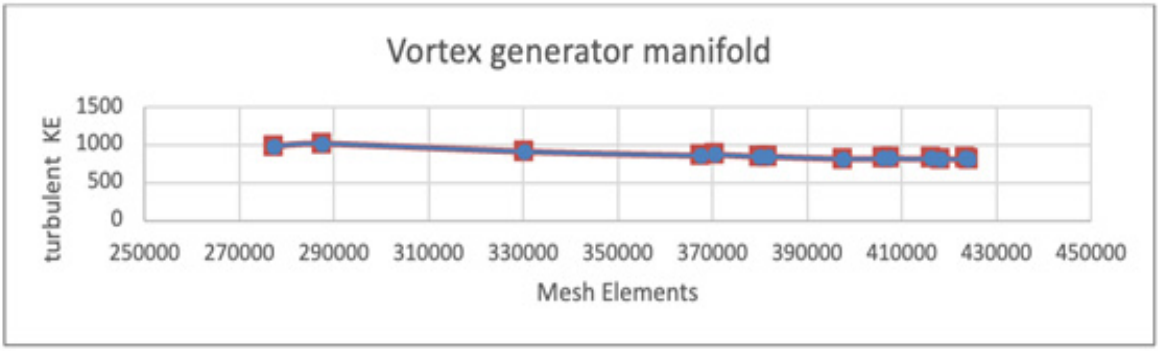


Figure 11. Vortex generator intake manifold turbulent kinetic energy vs number of mesh elements.

number of mesh elements and Figure 11 shows the Vortex generator intake manifold turbulent kinetic energy vs number of mesh elements.

3.0 Conclusion

From all our above analysis we find that convergent-divergent manifold generates the highest outlet velocity and turbulent kinetic energy. Vortex generator can increase the turbulent K.E. when compared to normal intake manifold. Further a vortex generator also creates a swirl. Hence such a setup can increase the efficiency of the entire engine and reduce carbon emissions by distributing the air-fuel mixture in a much better way. From the grid independent tests of all our designs we can see that the analysis is mesh independent and reliable. In the future work can be done to create better vortex generator designs for better motion of air using genetic algorithms. The length of the intake can also be optimized in future studies.

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