Variable Countercurrent Distribution Control (VCDC) System in IC Diesel Engine

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***Abstract*—A diesel engine requires close tolerances to achieve its compression ratio. The air entering the engine must be clean, free of debris and as cool as possible. Also to improve engine's efficiency, the compressed air must be cooled after being compressed. Development of Variable Countercurrent Distribution Control (VCDC) technology ensures proper air intake and exhaust system. In this regard, design of valve controller and most importantly valve mixer mechanism with fin arrangements has taken into consideration. Valve controller controls the intake airflow at a significant level and the valve mixture distributes the air to a form of streamline through the fin arrangements. There is no possibility of vortex generation which is important for smooth and linear flow of air inside the engine cylinder. A swirl combustion inside the combustion chamber take place that results uniform combustion, increase the flame propagation speed, overcoming the differences of turbulent flow, reduce the flame to burn, improves the function of the flame diffusion and serves to reduce the airflow noise. Pressure distribution ensures greater combustion pressure that results higher compression ratio as the air is compressed first and then the fuel injected which allow the IC diesel engine to be efficient.**

***Index Terms*— Swirl combustion, Variable Countercurrent Distribution Control (VCDC), Valve mixer, Vortex generation.**

I. INTRODUCTION

A diesel is an internal combustion engine that burns the air-fuel mixture within the cylinders. Diesel engine is a reciprocating engine that driven by pistons moving laterally in two directions. It is ponderous due to stronger and heavier materials used to withstand the greater dynamic forces from the higher combustion pressures present in the diesel engine. In a diesel engine the fuel is injected into the cylinder as the piston comes to the top of its compression stroke. When fuel is injected, it vaporizes and ignites due to the heat created by the compression of the air in the cylinder. The greater combustion pressure is the result of the higher compression ratio. The compression ratio is a measure of how much the engine compresses the gasses in the engine cylinders. In a diesel engine, compression ratio ranging from 14:1 to as high as 24:1 are commonly used. Diesel engine could be as efficient as here before the fuel injected, air is compressed by which it is possible to get higher compression ratio. Diesel engines are not self speed limiting because the air (oxygen) entering the engine is always the maximum amount. Therefore, the engine speed is limited solely by the amount of fuel injected into the engine cylinders. Therefore, the engine always has sufficient oxygen to burn and the engine is attempted to accelerate to meet the new fuel injection rate. That's why; a manual fuel control is not possible because diesel engines in an unloaded condition can accelerate at a rate more than 2000 revolutions per second. Diesel engines require a speed limiter commonly called governor to control the amount of fuel being injected into the engine [1].

II. AIR INTAKE IN DIESEL ENGINE

In a diesel engine, to achieve its compression ratio (the ratio between the volume of the cylinder and combustion chamber when the piston is at the bottom of its stroke and the volume of the combustion chamber when the piston is at the top of its stroke), the engine requires close tolerances. The compression ratio is a single number that can be used to predict the performance of any engine [2]. As because most diesel engines are either turbocharged or supercharged, the air entering the engine must be clean, free of debris and as cool as possible. The compressed air must be cooled after being compressed to improve a turbocharged or supercharged engine's efficiency. The air intake system is designed to perform these tasks.

In dry air intake (filter) system, paper, cloth or a metal screen material is used to catch and trap dirt before it enters the automobile engine. In addition to clean the air, the intake system is usually designed to take fresh air from as far away from the engine as practicable which provides the engine with a supply of air that has not been heated by the engine's own waste heat. The reason for ensuring that an engine's air supply is as cool as possible is that cool air has more density than hot air. This means that per unit volume cool air has more oxygen than hot air. Thus, cool air provides more oxygen per cylinder charge than less dense hot air. More oxygen means a more efficient fuel burn and more power (or speed). After being filtered, the air is routed by the intake system into the engine's intake manifold or air box. The manifold or air box is the component that directs the fresh air to each of the engine's intake valves or ports. If the engine is turbocharged or supercharged, the fresh air will be

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compressed with a blower and possibly cooled before entering the intake manifold or air box. The intake system also serves to reduce the air flow noise.

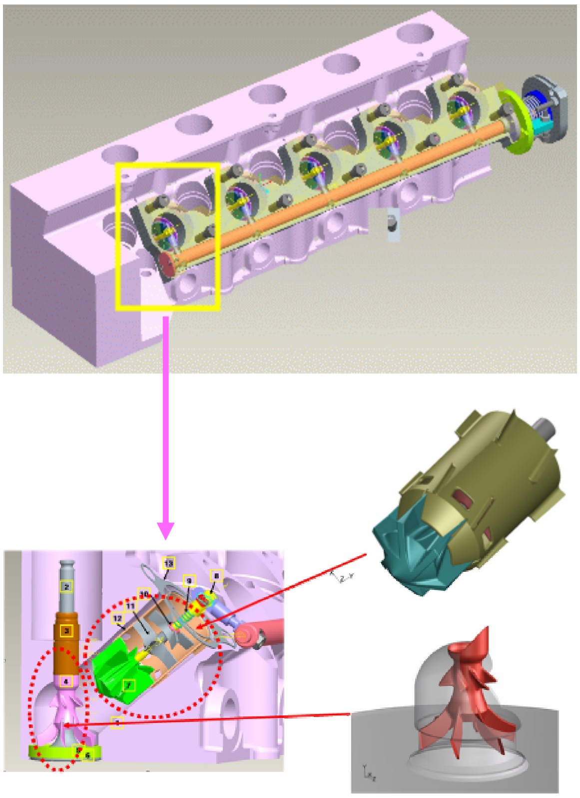
III. VALVE CONTROLLER AND MIXER

Variable Countercurrent Distribution Control (VCDC) system in the internal combustion diesel engine is specially developed by a newly modeled valve controller and valve mixer which control the entire system effectively. Figure-1 shows the valve controller, valve mixer and its set up arrangement.


(a) (b) (c)

Figure-1: (a) Valve controller (b) Valve mixer (c) Set up arrangement

Figure-2 refers the characteristics of the set up arrangement that shows different parts of the valve controller and valve mixer. The valve controller is designed in such a way that it supplies a required volume of air to the side downstream from the fully closed position of a valve body for control purposes. The arrangement supplies the volume of air that required for the travelling of a car [3].



(1) Engine head
(2) Valve
(3) Valve guide
(4) Valve mixer
(5) Valve mixer guide
(6) Case
(7) In-1
(8) Push rod
(9) Compression spring
(10) Compression spring guide
(11) In-2
(12) Out
(13) Bracket

Figure-2: Characteristics of the set up arrangement

On the other hand, valve mixer (made of STS 304) is designed with fin arrangements that ensure swirl flow of air inside the combustion chamber. The mixer is located on the valve's upper surface and it is surrounded by the valve mixer guide for smooth air flow. The mixer is supported by a fixed valve guide that is mounted on the valve body.

IV. COMPUTATIONAL ANALYSIS

A. *Pressure Distribution*

Pressure distribution is termed as the distribution of pressure at all points around an airfoil at a given angle of attack. Figure-3 shows the pressure distribution in different steps with respect to valve controller position.

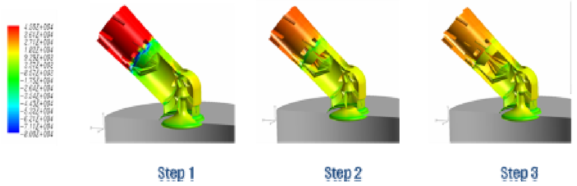


Figure-3: Pressure distribution in different steps

Typically, graphs of these distributions are drawn so that negative numbers are higher on the graph, as the C_p (pressure co-efficient) for the upper surface of the airfoil will usually be farther below zero and will hence be the top line on the graph [4]. Figure-4 shows the graphical representation of pressure distribution with respect to airfoil over the valve mixer. At the upper surface of the airfoil the pressure is about -50 Pa and it is the top line on the plot.

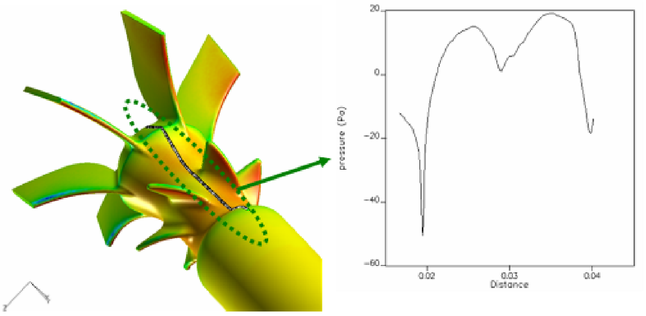


Figure-4: Graphical analysis of pressure distribution over mixer

B. *Velocity Vector*

For motion with constant velocity, the velocity vector is expressed as,

$$v = \frac{r}{t} \qquad (1)$$

The 'r' vector points in the direction of the motion and dividing it by the scalar 't' (only change of its length, not its direction) so the velocity vector points in the same direction as the motion [5]. Figure-5 shows different contact points of airflow on the valve mixer.

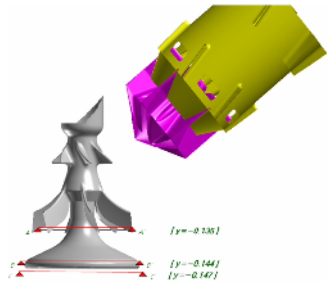
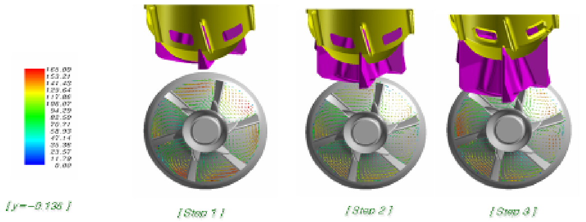


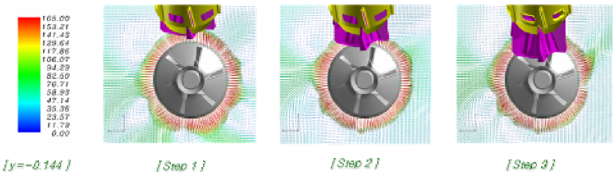
Figure-5: Different lift point (contact point) on valve mixer

Considering the lift point (contact point) y=0; figure-6 shows the velocity vectors at different contact points i.e. y= -0.135 (surface A-A′), y= -0.144 (surface B-B′) and y= -0.147 (surface C-C′) at maximum velocity of 165 m/s.

At surface "A-A′"



At surface "B-B′"



At surface "C-C′"

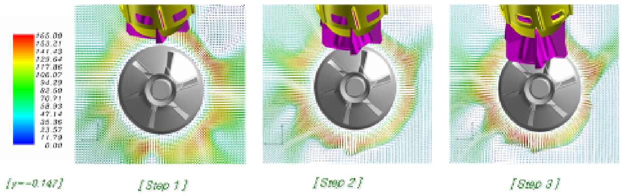


Figure-6: Vector distribution on different lift points

C. *Streamlines*

Stream lines are the family of curves that are instantaneously tangent to the velocity vector of the air flow. Mathematically,

$$\frac{d\vec{x}}{ds} = \vec{u}(\vec{x}) \qquad (2)$$

If the components of the velocity are written as $\vec{u} = (u, v, w)$. Therefore, by differentiation,

$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w} \qquad (3)$$

This shows that the curves are parallel to the velocity vector. Here 's' is a variable which parameterizes the curve as $s = \vec{x}(s)$. For streamlines there is no t (time) dependence. This is because they are calculated instantaneously meaning that at one instance of time they are calculated throughout the fluid [6].

Figure-7 refers to stream lines on the valve mixer. Due to the fin arrangements there is no possibility of vortex generation which ensures smooth and linear flow of air inside the engine cylinder.

Figure-7: Curves over the valve mixer (parallel to the velocity vector)

An intake valve used in an internal combustion engine has a plurality of impellers rigidly attached to its inlet side and oriented to optimize the vaporization and homogeneity of fuel within the combustion chamber. The impellers harness the fuel/air mixture and create overlapping airflow vortexes within the combustion chamber [7].

In the combustion chamber, mixing of fluids can change the freedom of its control features. Figure-8 shows the mixing of fluids inside the cylinder.

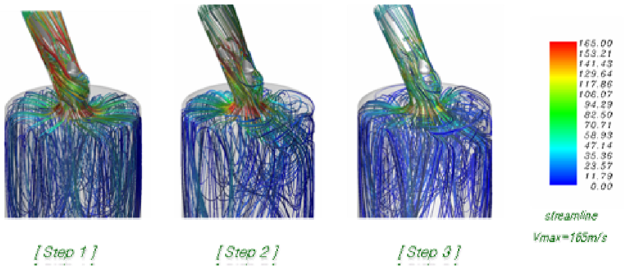


Figure-8: Mixing of fluids inside the cylinder

In existing types, valve influx does not produce swirl. Therefore cylinder head rises from the dead zone. New technology shows that a swirl flow generation at anti-clockwise direction of the cylinder increases the speed and due to suction, the cylinder increases the swirl internally. Figure-9 shows the generation of swirl flow by fins at surface A-A′ and surface B-B′ respectively.

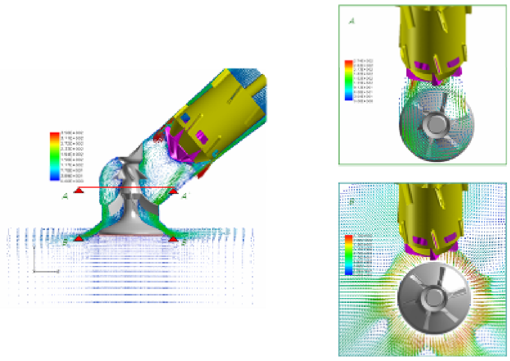


Figure-9: Swirl flow generation by fin

According to figure-10, at the dead zone, swirl flow through the mixer ensures the cylinder head not to rise from the dead zone.

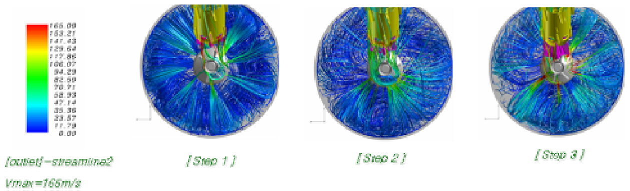
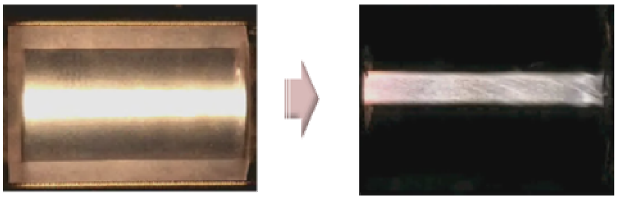


Figure-10: Stream lines at dead zone

V. FLUID FLOW COMPARISONS

Figure-11 refers to the co-axial combustion and swirl combustion in the engine respectively. In the case of combustion, there are some advantages of swirl combustion over co-axial combustion (in respect to co-axial flow and swirl flow) in the engine.



Co-axial combustion in the engine

Swirl combustion in the engine

Figure-11: Co-axial and Swirl combustion

Some advantages of swirl combustion over co-axial combustion are as follows:

- ✓ As the flow increase turbulence generation, uniform combustion takes place inside the combustion chamber.
- ✓ Maximization of the effect of the uniform combustion.
- ✓ Overcoming the difference of turbulent flow.
- ✓ Increase in the speed of flame diffusion/ flame propagation inside the combustion chamber.
- ✓ Reduce the flame to burn.

Oxidizer mass flow rate = 0.0359 Kg/s

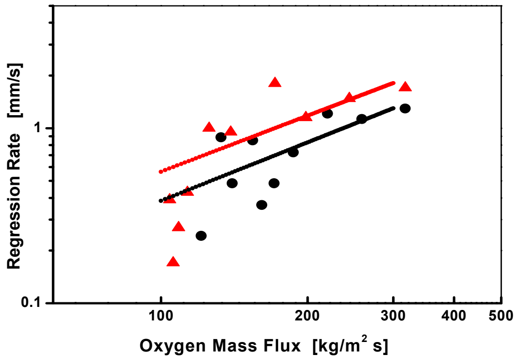


Figure-12: Regression rate of two combustions

Figure-12 refers to the regression rate of co-axial and swirl combustion with respect to oxygen mass flux when oxidizer mass flow rate is 0.0359 Kg/s for both the combustions. Triangles are the points for swirl combustion and circles are for co-axial combustion. Comparison result shows, the regression rate of swirl combustion is about 40% higher than the co-axial combustion.

VI. TEST ENGINE SPECIFICATIONS

For the experimental analysis, ***Mercedes Benz Ssangyong*** motor engine used. For measuring different parameters; a dynamo (model: ASM/lug down 5.5 ton) used. Table-I refers the specifications of the test engine.

Table-I: Test engine specifications

Items	Specifications
Bore x Stroke	89 mm x 92.4 mm
Displacement volume	2784 cc
Compression ratio	22:1
Number of cylinder	5 (five)
Cooling type	Water cooling type
Valve system	Single overhead cam
Air flow	Natural

VII. RESULT AND DISCUSSION

The performance analysis of the engine was carried out at 3 (three) different modes i.e. mode-1 (4020 RPM), mode-2 (3600 RPM) and mode-3 (3200 RPM). Mode-1 followed between 41 to 51 seconds, mode-2 between 61 to 71 seconds and mode-3 between 81 to 91 seconds respectively.

A. *Shoot Concentration (%)*

In case of conventional procedure, at the starting stage the shoot concentration is about 10% and at mode-1, it increases up to 50% whereas in the VCDC system the shoot concentration at starting stage lies below 10% and at all modes it remain in an average of 10%. Therefore, compared to the existing engine system, VCDC system reduces shoot concentration more than two times and improves the combustion rate about 60% or above (figure-13).

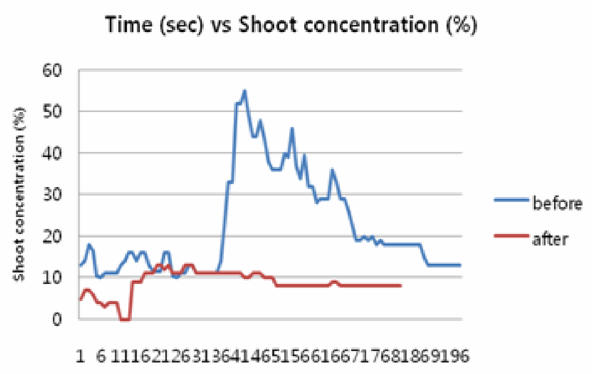


Figure-13: Shoot concentration (%) analysis

B. *Speed (Km/h)*

In case of speed, before reaching at mode-1, the speed increases up to 97% (figure-14). VCDC system reaches to mode-1 within a short time as the existing engine system takes more time to reach the mode-1. Also, conventional system has variation of speeds than the VCDC system.

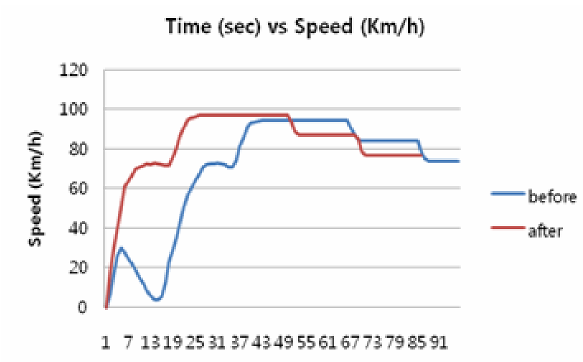


Figure-14: Speed (Km/h) analysis

C. *Engine Rotation (rpm)*

Application of VCDC system increases the engine rotation at 4000 rpm (figure-15) that ensures certain level of stabilization (before reaching to mode-1) but in conventional system there are several rotation variations which results efficiency losses.

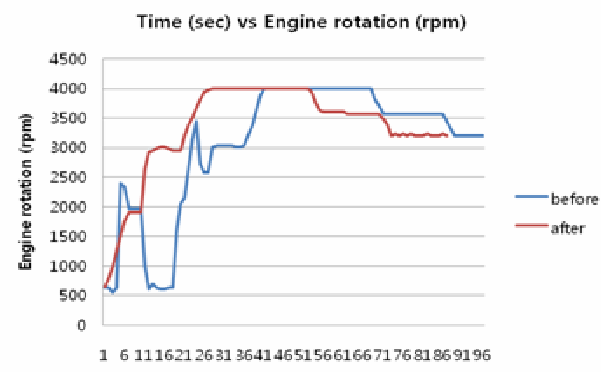


Figure-15: Engine rotation (rpm) analysis

D. *Temperature (℃)*

In VCDC system, rises of temperature (starts from 40℃) with respect to time and increase in combustion efficiency results change of exhaust temperature (figure-16).

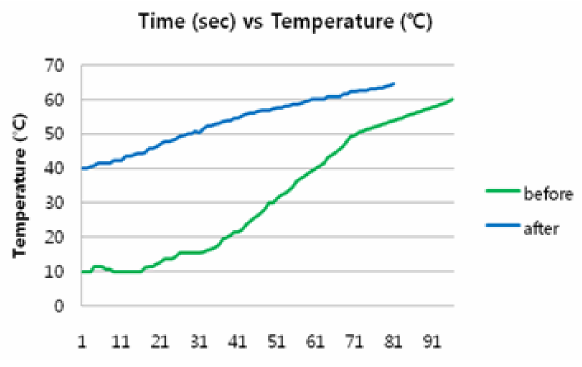


Figure-16: Temperature (℃) analysis

E. *Output power (ps)*

The amount of power generated by the engine is related to its speed. Increase in angular speed results more output power. In VCDC system, as the conversion of kinetic energy increases, output power also increases (figure-17).

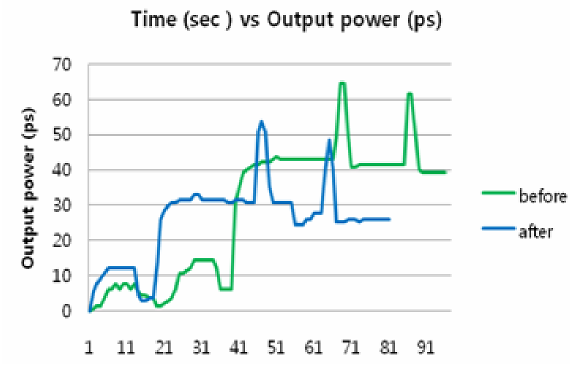


Figure-17: Output power (ps) analysis

F. *Torque (Kgf m)*

As like output power, it is a proportional system. A diesel engine produces useful torque only over a limited range of angular speeds. Increase of torque is the result of increase in output power. The peak of that torque curve occurs somewhat below the overall power peak. The torque peak cannot appear at higher rpm than the power peak. In VCDC system, torque in mode-1 reaches about 38 Kgf m (figure-18).

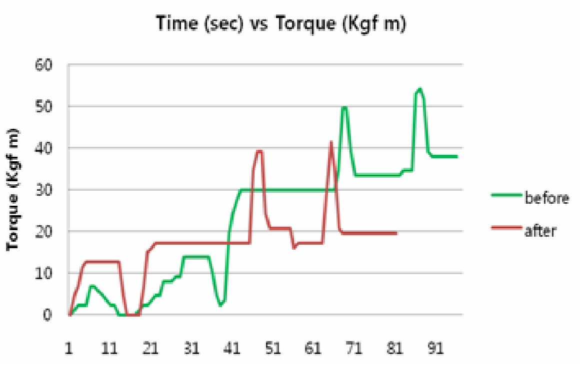


Figure-18: Torque (Kgf m) analysis

VIII. CONCLUSION

The technology highlights the reduction and improved system of automobile VCDC that related to its technical and commercial applications. In terms of price, it has cost effective advantages compared to conventional one. Using of the system to the existing engines, it is possible to achieve enhancement of output by more than 40% by overcoming the difference of turbulent flows, making the flame diffusion faster and speedy through uniform combustion of the fuel in the internal combustion engine. The system follows low pressure practicalization and has various advantages such as proper control of airflow, improvement in durability, excellent ignition in cold seasons, silence with equal combustion, smaller atomizing particle, excellent mixing ability, excellent interaction minimize the initial exhausts, zero smoke, lowest NO_x etc.

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