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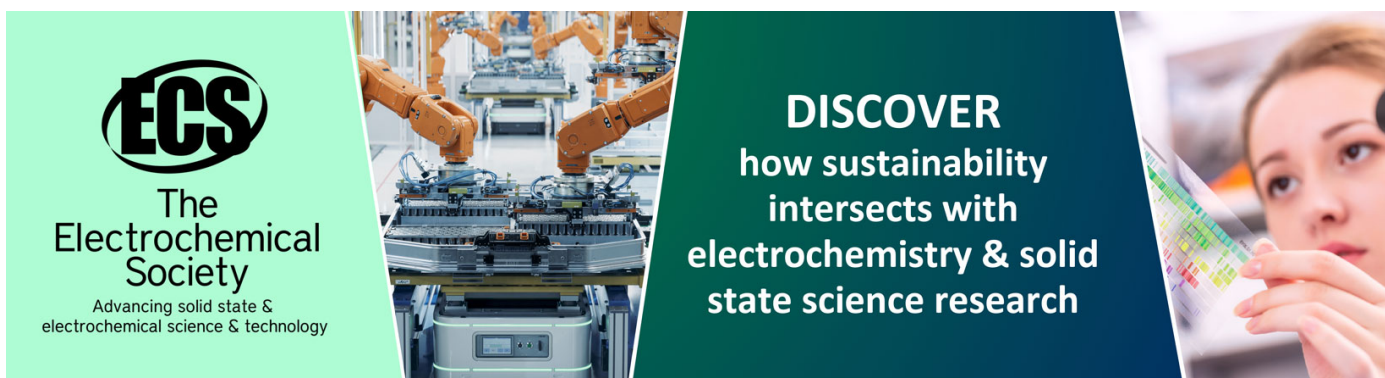
Development of valve stem seals for turbocharged heavy duty compression ignition engine of armoured fighting vehicles

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Development of valve stem seals for turbocharged heavy duty compression ignition engine of armoured fighting vehicles

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Abstract. Valve stem seals (VSS) restrict the amount of oil flowing from the area above the valve guide to the valve port area. Ideally a thin film of oil should exist between the valve guide and valve stem with no transfer of oil into the port area or combustion chamber. Too much oil flowing past the valve guide leads to excessive oil consumption. On other hand too little oil could cause excessive guide wear. In this paper the design of valve stem seals for heavy duty diesel engine working against harsh environment and severe duty cycle are discussed.

Keywords. Valve stem seals, Oil metering

1. Introduction

New requirements like lower oil consumption, lower crankcase pressure and extended life of engine components for heavy duty compression ignition diesel engines of Armoured Fighting Vehicles (AFVs) have led engine designers to review the attributes of positive valve stem seals. Reducing valve guide wear is a challenging task in the heavy duty engine for AFVs operating in severe dusty environment and tough duty cycle. The above factors are affected in part, by the amount of oil flowing through the clearance between the valve guide and valve stem. Bench tests indicate that heavy duty valve stem seals (VSS) could reduce overhead oil consumption by as much as 99% during idling. In addition, they can significantly reduce guide wear and valve stem scuffing under turbocharged conditions [1]. The developed valve stem seal is shown in figure 1.





Figure 1. Developed valve stem seal.

VSS restrict the amount of oil flowing from area above the valve guide to the valve port area. Ideally, a thin film of oil should exist between the valve guide and valve stem with no transfer of this oil into the port area or combustion chamber. Too much oil flowing past the valve guide leads to excessive oil consumption and an increase in particulate emissions. On the other hand, too little oil flow could cause excessive guide wear and/or valve stem scuffing [2].

In order to understand the functionality of VSS, it is required to understand the conditions under which they operate. Typically, when an engine is loaded, the intake and exhaust ports are under pressure, and when it is motoring or idling, very little port pressure exists. Therefore, different engine operating conditions translate into different guide pressure conditions. Thus a difference in pressure between the port area and the area above the guide always exists and there will be a flow of either lube oil or gases [1]. When the port area is at a higher pressure than the area above the valve guide, high pressure gases blow the lubricant out of the valve guide-stem interface. This condition is called the valve guide blow-by and its magnitude is a function of turbo boost [4]. The opposite situation occurs during idle or motoring conditions when the pressure in the port area is lower or equal to the pressure above the valve guide. This results in oil flowing into the port area, resulting in excessive oil consumption and exhaust particulates. To reduce excess oil from flowing down the valve guide at low boost conditions, and to prevent blow-by at high boost conditions, positive VSS should be used.

Table 1. Specifications of the engine.

Parameter	Details
Engine Type	Up-rated V46-6, Direct Injection, Water cooled, Turbocharged Diesel Engine.
Bore	150 mm
Stroke	180 mm (LH), 186.7 mm (RH)
Compression ratio	14:1
Rated power	1000 hp at 2000 rpm
Maximum torque	3850 Nm at 1400 rpm
No. of intake valves	2

(per cylinder)	
No. of exhaust valves	2
(per cylinder)	
Camshaft arrangement	Overhead arrangement

2. Valve stems seal design

In order to obtain acceptable valve durability, there is a need to vary the amount of oil at the valve guide-stem interface depending on engine operating conditions, valve seals are designed to meter specified quantities of oil to the valve guide area based on operating conditions. The metering design largely depends on the number of grooves over a specified length and the design of the sealing lip.

Even though single lip designs have been believed that they do not meter oil, nor do they control the amount of valve guide blow-by [1], a detailed analysis has proved that they do meter oil and help to reduce valve guide wear and valve stem scuffing. After these findings, single lip design for heavy duty applications was given due consideration. The different types of VSS designs are shown in figure 2 and figure 3.



Figure 2. VSS design type A.



Figure 3. VSS design type B.

The seal type A fulfils the function of metering rate only and is a standard seal. Type B is used for large differences between valve stem and valve guide diameters and also to arrest the wear. All seals incorporate the same dynamic and static sealing properties enabling reliable function over the life of the engine. In order to take the benefit of oil metering and wear, the type B design is considered for this engine [2]. The seals are also exposed to high combustion pressures and temperatures in diesel engines. At high temperatures, there is a high possibility, that the seal might undergo certain deformation that could change the whole flow of oil into the valve guide-stem interface. Hence sufficient care should be taken while design and the selection of the seal material [3].

Valve Stem Seal consists of 3 parts:

- Rubber
- Metal retainer
- Garter Spring

A typical heavy duty valve seal design consists of a rubber (fluoroelastomer material) [1] jacket that is held in place by a metal retainer figure 4. The rubber jacket maintains an interference fit with the valve stem by means of a metal ring. The retainer often has a flange that serves as a wear surface for the valve spring. The garter spring of the VSS serves as an effective retention device during high

boost conditions. A detailed sectional view of the valve stem seal assembled on the valve guide is shown in figure 5.

The skeletal sheet metal forms the basic structure of VSS. This gives necessary stiffness to the seal, thus securing any deformation that it might undergo. Over the sheet metal, rubber is laid on, which is bonded to it, molecularly. Fluroelastomeric rubber is used for this purpose, and it can withstand high temperatures and it is also not going to have an effect on its elasticity [2][3]. The rubber has a lip shaped structure towards the valve stem, which has a tight fit to the stem. This lip controls the amount of lubricating oil that has to enter the interface. As the stem reciprocates, there is certain deformation in the structure of the lip which is reversible, and this allows some lubricating oil to pass through. The garter spring is placed just behind the lip, and is the prime driving force in giving the lip portion of the rubber, the necessary stiffness. The garter spring also gives the necessary radial force and this radial force controls the lubricating oil flow. Valve stem seals are not typical seals, instead they are oil metering device used to control oil and dust flow into the combustion chamber and provide the benefits of improved oil economy, reduced wear, reduced blow-by and carbon build up and increased component life.

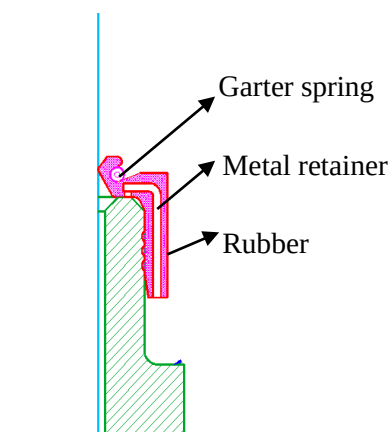


Figure 4. Valve stem seal parts.

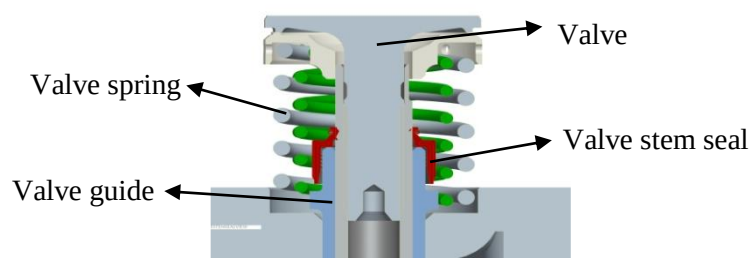


Figure 5. Sectional view of valve assembly with VSS.

3. Valve stem seal design considerations

The region of the VSS above the lip, experiences an oil pressure of magnitude 0.3 MPa. The lip is exposed to both suction and compression pressures by the piston, and they form a major component in determining the amount of deformation that has been suffered by the seal. The suction pressure is 0.2 MPa, which acts in the negative and the compression pressure is 3.2 MPa, which acts in the positive. A radial force is exerted by the garter spring on the back of the groove for the spring, which gives the lip stiffness.

Table 2. Radial load calculation

Parameter	Symbol	Unit	Value
Pi	π	-	3.14
R value	Rr	m	0.00038
Distance from flex to lip contact	L	m	0.002
Spring tension	F	N	1.13
Force due to spring	Fs	N	5.753
Cross sectional area of lip	A	m ²	0.00599
Total force	Ft	N	98.394
Radial load	RL	N/m	1739.29
		N	31.31

Average temperature of the valve guide is 200°C, for the purpose of running the case an average temperature has been given. Average temperature of the valve stem is 440°C. The lip region and the regions in contact with the spring are free to get deformed as the valve stem reciprocates against them. Their deformations will lead to the annular orifice, which leads to the desired oil leakage. The radial load acting on the valve stem seal is given in the below Table 2. The critical dimensions of the valve stem seal is shown in figure 6.

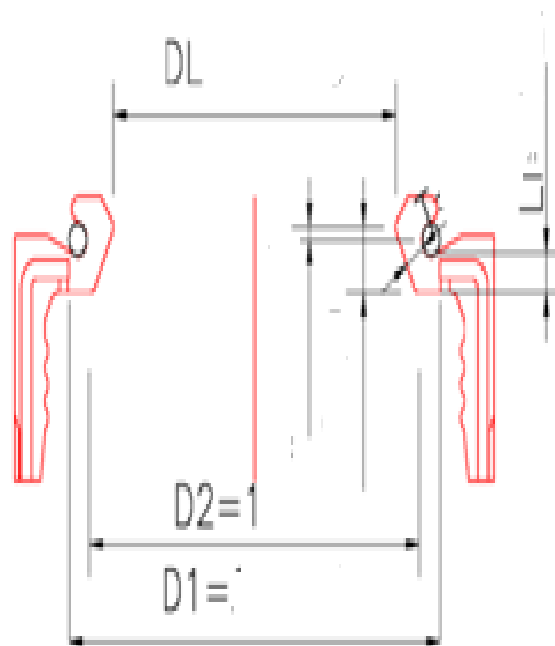


Figure 6. Designed VSS

4. Oil metering

Oil metering of the valve guide-stem interface is the prime function of a valve stem seal. Although the requirements for each engine differ according to the design parameters and operating conditions, the oil metering rate is generally within the range of 0.1 -1.0 mg per valve per hour. These data have been generated through extensive comparative testing on cylinder heads. From the results that have been obtained from Ansys, it is found that the radial deformation of the lip lies within the range of 0.00237 mm to 0.002982 mm. The flow rate of the lubrication oil is governed by the annular orifice area that allows the oil to be metered in. The maximum value of deformation is taken in order to find out the maximum flow rate of the lubrication oil. So the deformation taken in for calculation is 0.002982 mm. Using the lip radius and the radial deformation we can find out the annular area that allows the lubrication oil to pass through it for the lubrication purpose. For calculating the flow rate, the oil has to flow through the orifice area. The formula for flow rate is given in equation (1).

$$\text{Flow rate} = \text{Oil speed} * \text{Area of the orifice} \quad (1)$$

$$= 4.59 * 10^{-8} \text{m}^3/\text{s}$$

Study on various parameters has shown that the correct oil metering rate for the VSS can be provided. This is true for intake and exhaust valves. This can be tuned to the exact requirements of a specific engine by changing the geometry of the sealing lip. For doing this, the major factors are the radius of the sealing lip and lip angle to the oil side. However, the radial force of the seal which is important for assuring lip contact to the valve stem under operating conditions is not a major factor in determining the oil metering rate [3]. The passage of the oil through the valve stem seal is shown in figure 7.

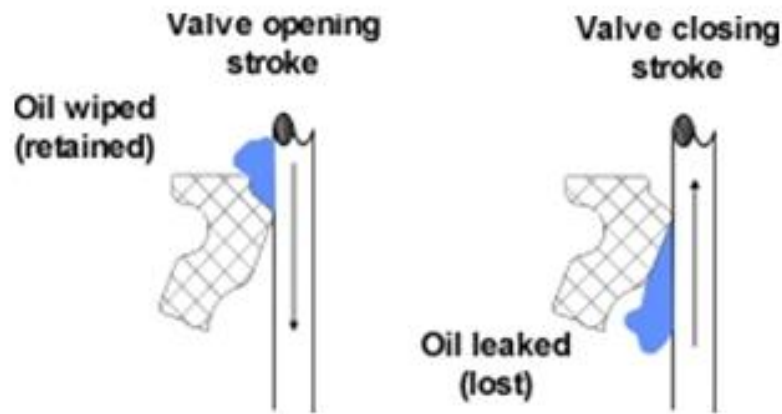


Figure 7. Oil passage through the VSS.

VSS are generally designed to meter oil at precise metering rates. The single lip design is considered as the standard design. In the operating environments the single lip design will provide excellent performance over the entire seal life. The use of lower friction, reduced wear materials is strongly recommended for longer seal life when using lower metering rate grade seals due to more concentrated pressure distributions on the seal lip. From a design point of view, lip angles, lip radius, and lip offset from spring pocket are the geometrical factors, that combined with radial lip load define oil-metering rate. These are the geometrical factors that define the pressure distribution (pressure gradients) of the seal lip to the valve stem. Additionally, lip flexibility and material heat resistance have an impact on the metering rate due to the effects of lip geometry changes during operation from stem oscillation and heat. Finally, the viscosity of the oil also determines the actual metering rate of the seal in the engine. As viscosity increases the film thickness on the valve stem also increases, thus allowing more oil to flow past the seal lip on a given stroke. The oil viscosities at two different temperatures are given in Table 3.

Table 3. Oil properties

Oil type	Viscosity (centistokes)
Mobile 5W50	108 at 40°C
	17.5 at 100°C

5. Valve stem seal materials

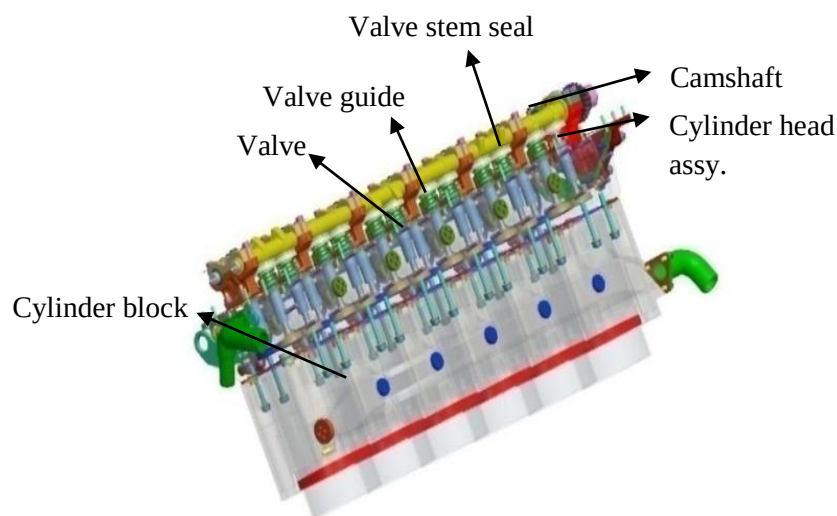
The materials enlisted below, provide excellent chemical and temperature resistance as well as mechanical properties to ensure minimal wear and high reliability.

Table 4. Materials for VSS parts.

Parts	Material
Rubber	Fluroelastomer
Garter spring	Spring steel wire as per IS4454:2001
Sheet metal	IS 513-2008

6. Valve stem seal installation

This design incorporates a metal ring bonded directly to the rubber elements. The valve stem seal can be installed by using a suitable tool. However in order to ensure the correct function in the engine, the installation procedure is very important. This begins with the designs of the VSS and valve guide which must be turned to each other for best results. The seal must be positioned at the correct height on the guide and remain there for the life of the engine. It is always advisable to design a tool for assembly. A cylinder assembly with the valve stem seal used in it is shown in figure 8.

**Figure 8.** Assembled cylinder head with VSS

7. Bench testing

There were several bench test apparatus for testing positive valve stem seals. Bench testing is essential due to difficulties in separately determining the amount of oil consumed by the valve assembly. The bench testing layout is shown in figure 9.

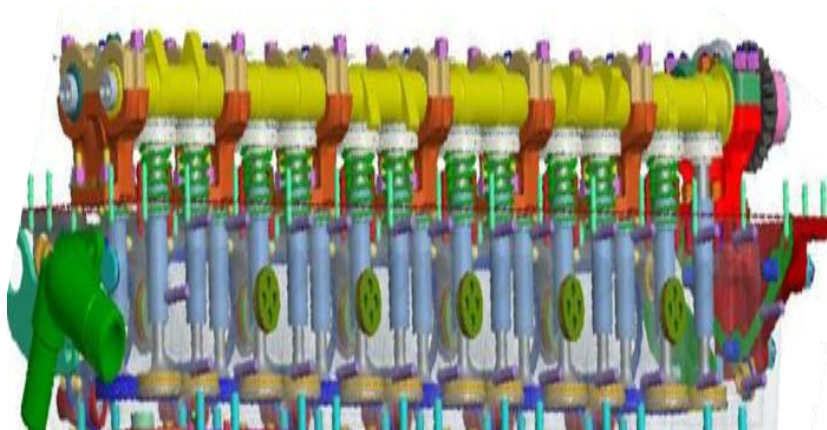
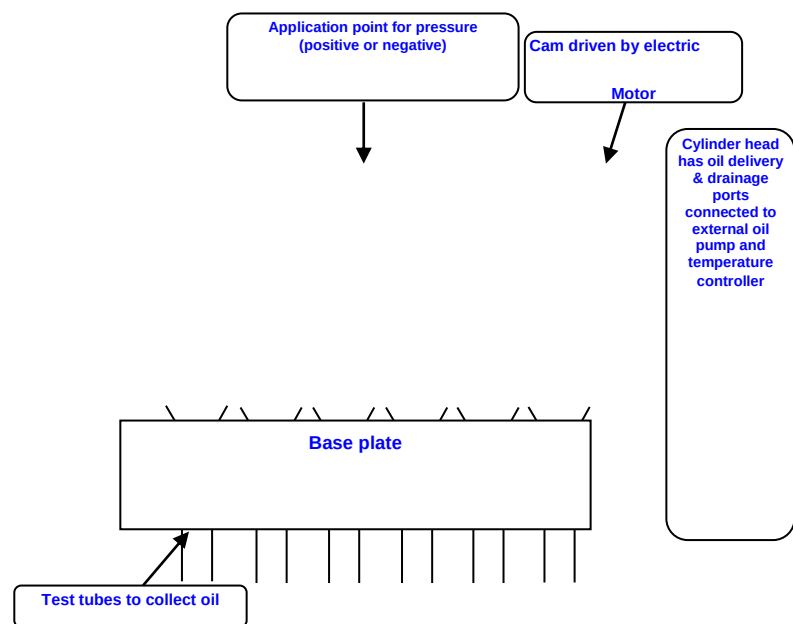


Figure 9. Bench testing layout

8. Test procedure

The engine head with two cylinders is selected. In one cylinder the guide was modified and is fitted with the designed VSS. The other cylinder head is used without VSS. The engine head is assembled in the test bench and the provision for drive, oil circulation, oil heating and collection of oil from the valves are provided. The following parameters were controlled a) Oil temperature b) Cam shaft speed c) Duration for testing. The oil flow is continuously set so that all the valves are lubricated. The test was done for a total duration of 100 hours (hrs) consisting of 4 cycles, with oil temperature at $110^{\circ}\pm 5^{\circ}\text{C}$ for two cycle and also at $140^{\circ}\pm 5^{\circ}\text{C}$ for two cycles. Oil metered from each valve is

measured at regular intervals of 5 hrs oil metering from the engine intake valves (V1,V2) and exhaust valves(V3,V4) was done and the oil metering data for the valves with and without the seal were compared. The experimental set up is shown in figure 10. The cylinder head assembly considered for the testing is shown in figure 11.



Figure 10. Experimental set up.



Figure 11. Cylinder head assembly considered for testing.

9. Results

The figure 12 and figure 13 show the test results of the oil collected for 5hrs, for intake valves V1 and V2 for both with and without VSS cases. The results observed for the with VSS case are found to be in the range of 1.02 to 1.16 cc/5hrs. While the metering rate observed for the without valve stem seal case are found to be higher, in the range of 2.2 to 2.3 cc/5hrs.

The figure 14 and figure 15 show the test results of the oil collected for 5hrs for exhaust valves V3 and V4 for both with and without valve stem seal cases. The results observed for the with VSS case are found to be in the range of 1.35 to 1.45 cc/5 Hrs. While the metering rate for the without VSS are

again found to be higher in the range of 3.1 to 3.25cc/5hrs. Thus for all the cases the permissible metering rate is 0.50 to 1.90 cc/5hrs. Hence the oil metered for the designed VSS is within the permissible limit and will lead to reduced oil consumption.

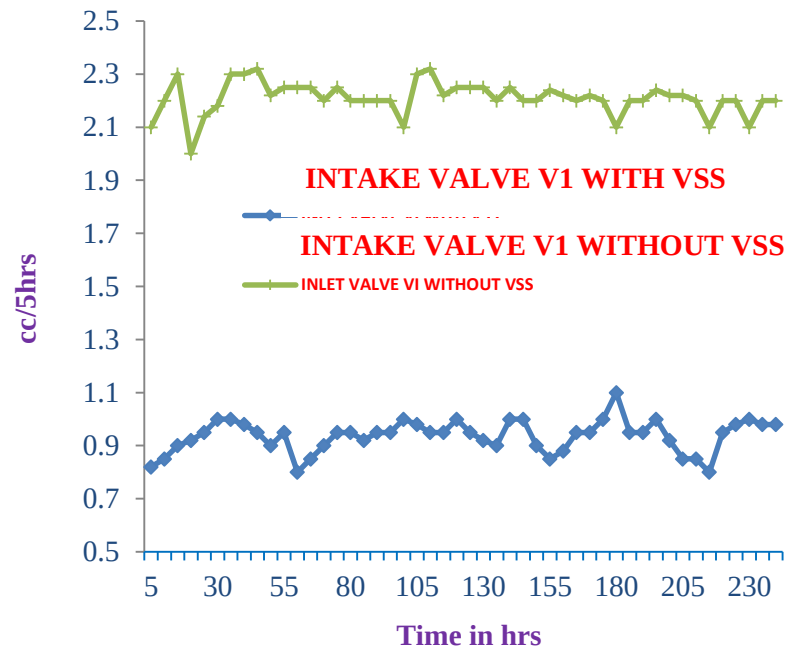


Figure 12. Experimental results for intake valve V1.

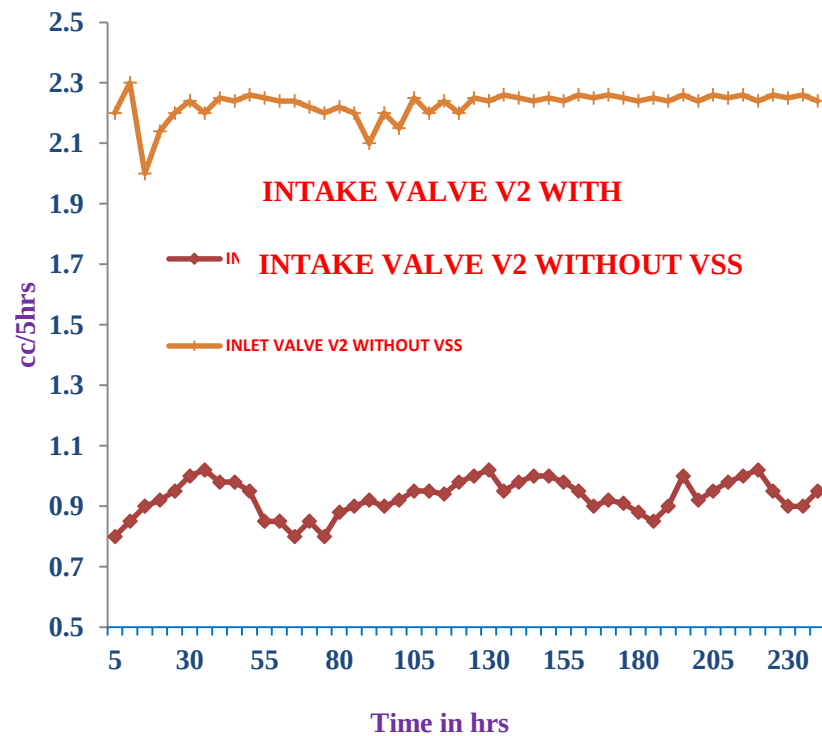


Figure 13. Experimental results for intake valve V2.

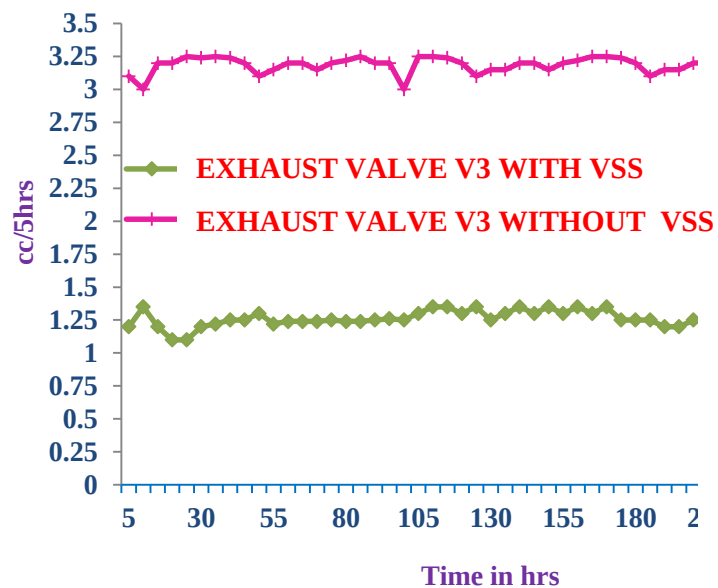


Figure 14. Experimental results for exhaust valve V3.

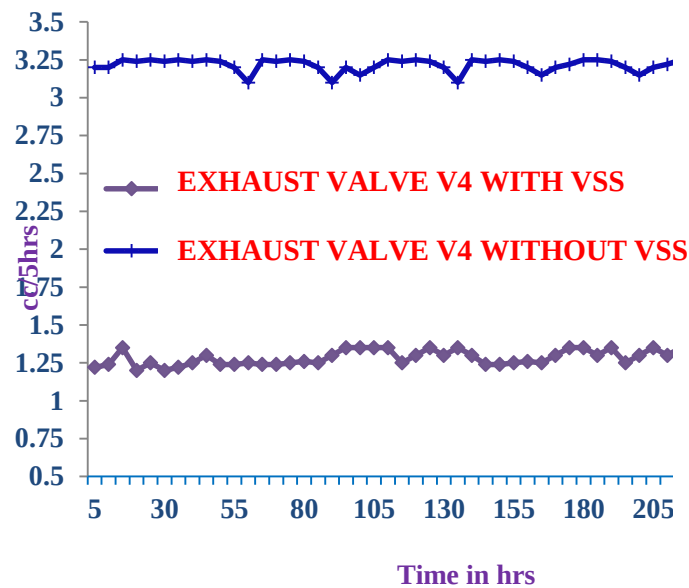


Figure 15. Experimental results for exhaust valve V4.

10. Summary

Positive VSS have become a vital component in improving oil economy, and reducing guide wear in compression ignition engines for AFVs in harsh environment and with severe duty cycle. The presence of VSS lowers particulate emission by reducing the amount of lube oil in the intake and exhaust ports. This in turn decreases the amount of particulates in the exhaust gases which result from partially burnt lube oil. Oil economy is improved in the same way by controlling the amount of oil flowing into the port area. VSS also reduces guide wear and valve scuffing by providing the proper amount of lubrication at the valve guide-stem interface and by minimizing valve guide blow-by during high load conditions.

11. References

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