A STUDY ON DIESEL ENGINE USED IN LIGHT COMMERCIAL VEHICLES' VARIABLE VALVE ACTUATORS

Nitin Kardekar [1], Prashant Patil [2], Dhanapal Kamble [3] and Kuldip Patil [4]

[1] Associate Professor, Department of Mechanical Engineering, BSCOER, Pune, India.
[2] Principal, Abhinav Education Society's COET, Pune, India.
[3] Assistant Director, Directorate of Technical Education Maharashtra, Mumbai, India.
[4] Associate Professor, Bharti Vidyapeeth's College of Engineering Pune, India.

Abstract

Diesel engines dominate the commercial vehicle market with about 100% market share. The increased thermal efficiency, greater load carrying capacity, increased low-speed torque, and significantly loosened regulations for low-capacity light commercial vehicles are all contributing factors to their domination. Because of their strong torque output, low fuel consumption, and great thermal efficiency, small diesel engines are widely utilized in commercial vehicles & passenger cars. Because of the wide variety of operating & environmental circumstances these engines are subjected to, the emissions they produce are highly variable. The government is doing everything it can to curb this emission by enacting strict emission standards and intending to dismantle obsolete vehicles, but a workable solution has yet to be found. Considering environmental pollution & laws, strategies are needed to improve performance and reduce engine-out emissions. The primary goal of this simulation & experimental work is to identify strategies for performance enhancement & emission reduction for a naturally aspirated engine by examining the impact of valve timing, lift, duration, swirl, injection timings, & EGR. Experimental work has been done to study the impact of these parameters with NTP, injection pressure, and EGR on engine emission and performance, while 1D vehicle simulation is used to get engine operating points & thermodynamic simulation is used to study gas exchange, fuel air mixing, and performance improvement with varying intake valve lift, valve timing, and valve duration with swirl variation.

Keywords: Valve Timing, vehicles, Swirl, Diesel Engine, EGR, Emission

INTRODUCTION

Variable valve actuators (VVA) were not as common in diesel engines for LCVs as they were in gasoline engines. Variable valve actuators are mechanisms that allow for the control of valve timing and lift, optimizing engine performance and efficiency under different operating conditions. They can be either camshaft-based systems with variable cam profiles or camless systems that use electro-hydraulic or electromagnetic actuators to control the valves directly. In recent years, some advancements have been made in diesel engine technology, and certain manufacturers may have introduced variable valve actuation in their light commercial vehicle diesel engines. However, since my information is not up-to-date, I recommend checking with specific diesel engine manufacturers or the latest vehicle specifications for up-to-date information on whether variable valve actuators are being used in LCV diesel engines at present.

Valve actuators are devices or mechanisms used to control the opening and closing of engine valves in internal combustion engines. These actuators play a crucial role in optimizing engine performance and efficiency by precisely regulating the timing and lift of the intake and exhaust valves.

There are two main types of valve actuators:

1. Camshaft-driven Valve Actuators: This is the traditional method used in most internal combustion engines. A camshaft, which is connected to the engine's crankshaft, has lobes that push on tappets or rocker arms. These tappets or rocker arms, in turn, actuate the valves, opening and closing them at specific intervals and durations as determined by the camshaft's design. This system is reliable and cost-effective but lacks flexibility in adjusting valve timing and lift during engine operation.
2. Variable Valve Actuators: These actuators provide the ability to vary the valve timing and lift, allowing the engine to adjust its characteristics based on operating conditions. There are different types of variable valve actuators, including:
   - Cam Phasing: In this approach, the camshaft's position can be altered by rotating it slightly, which changes the valve timing. This can be done hydraulically or electrically and is relatively simple in design.
   - Cam Profile Switching: Some variable valve actuators change the cam profile by using multiple cam lobes with different shapes on the same camshaft. These lobes are switched or engaged depending on the engine's speed and load.
   - Camless Valve Actuation: Camless systems, as the name suggests, eliminate the traditional camshaft and instead use electronic, hydraulic, or electromagnetic actuators to control the valves directly. This offers greater flexibility in valve timing and lift adjustments and can lead to significant improvements in engine efficiency.

Variable valve actuators allow the engine to adjust valve timing and lift based on factors like engine load, speed, and temperature. By optimizing valve timing, the engine can achieve better power output, fuel efficiency, and emissions performance across a wider range of operating conditions.It's worth noting that the use of variable valve actuators has become more prevalent in gasoline engines to meet stricter emission regulations and improve fuel economy. While some diesel engines may also employ variable valve actuators, traditional camshaft-driven systems are still widespread in many diesel applications, especially in light commercial vehicles (LCVs).

Objectives

- To study and analyses the effect of valve timing, lift & duration strategies with intake swirl improvement on engine performance, and exhaust emissions on LCV diesel engine
- To study and Analysis of valve timing,
- To study the Adaptation of valve timing and swirl on engine,
- To optimize the engine performance & reduce engine out emission& Adaptation of EGR strategy.

METHODOLOGY

In order to meet these objectives along meeting existing emission norms, research efforts were focused on improvements of engine performance with help of variable valve actuation strategy and swirl modification to enhance performance with lower emission. This work was carried out in different phases.Assessment of vehicle and engine performance on chassis dynamometer and engine dynamometer to get in depth detailed of performance, emissions and combustion parameters of existing engine. The same operation is repeated for exhaust system by keeping best intake system as constant. Special attention is given to the engine torque, BSFC and volumetric efficiency.

RESULTS AND DİSCUSSİON

In order to improve engine performance & experimental analysis, this research focuses on a baseline vehicle & testing to identify the gray area and simulation technique to correct it. Since we already have some data on average vehicles & engine emissions, we can use that to more precisely base our calculations in each individual scenario.

Baseline vehicle testing

The findings of the IDC-based baseline testing performed on the chassis dynamometer are depicted in Fig. 1. Increased HC + NOx emission is the primary cause of a vehicle's inability to comply with emission standards. Results for CO2, CO, NOx, & HC emissions vs time are displayed in Figs. 2–6.

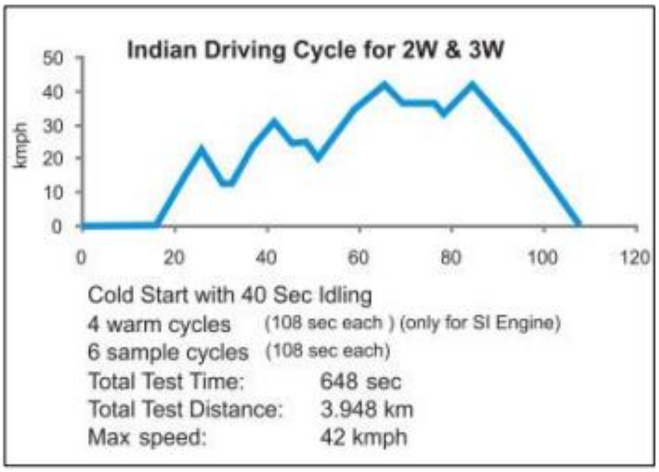

Fig 1: Indian driving cycle for 2-wheelers and 3-wheelers

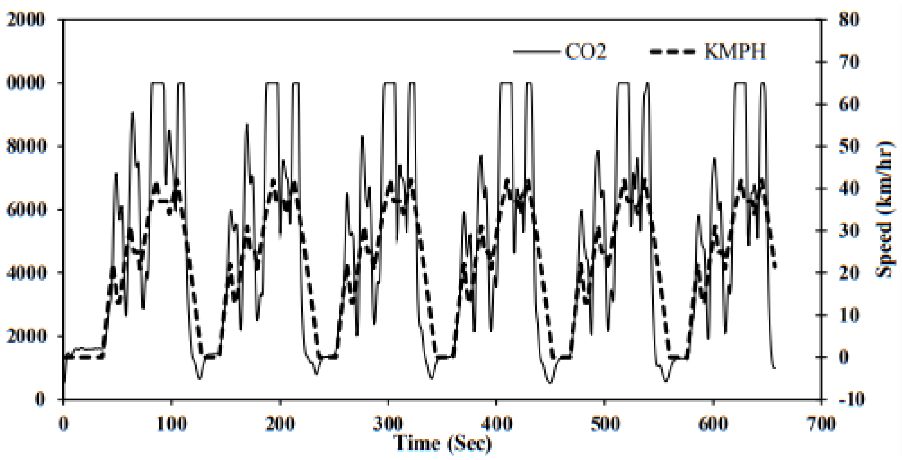

Fig 2: CO2 emission performance for baseline vehicle under IDC

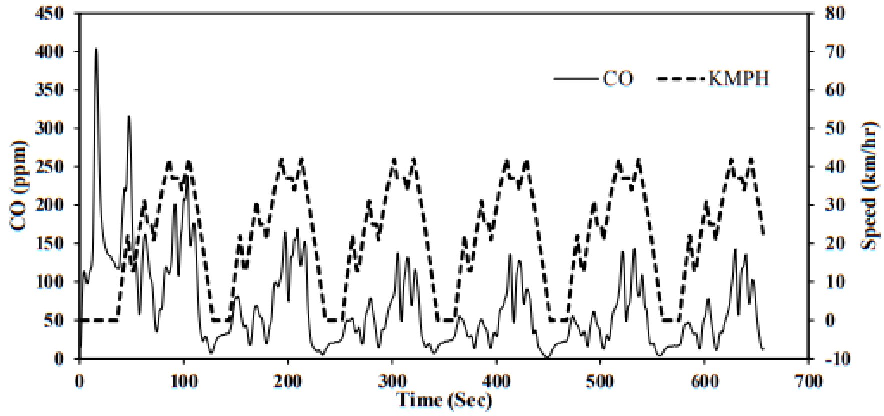

Fig 3: CO emission performance for baseline vehicle under IDC

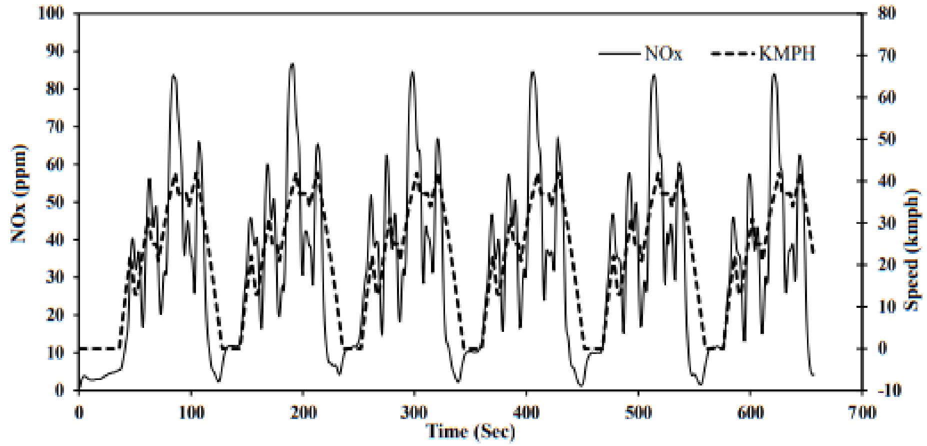

Fig 4: NOx emission performance for baseline vehicle under IDC

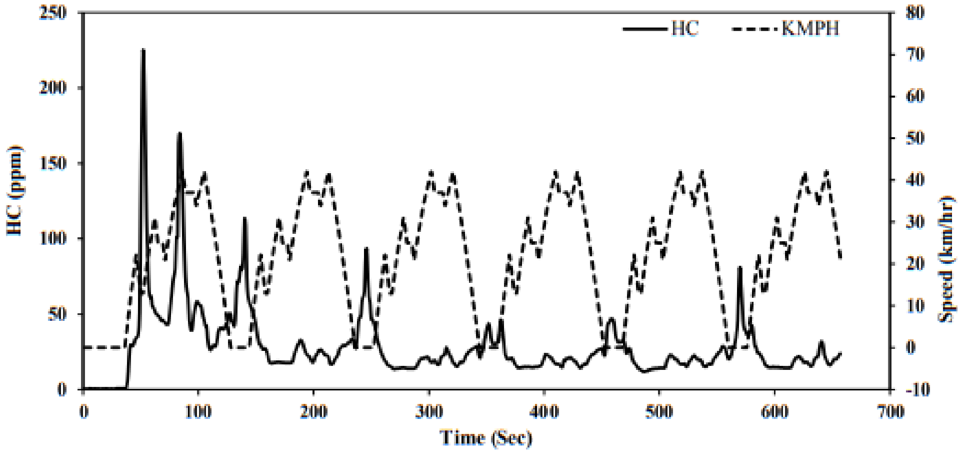

Fig 5: THC emission performance for baseline vehicle under IDC

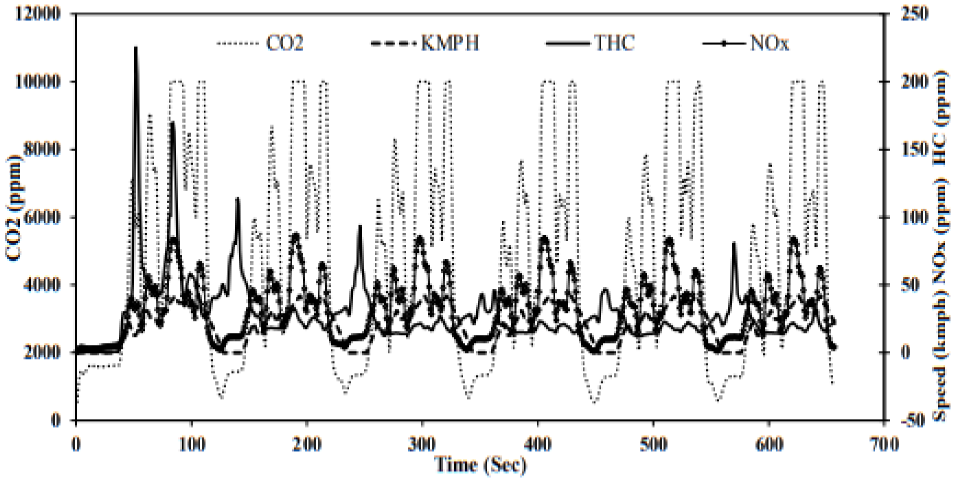

Fig 6: Vehicle baseline emission results at IDC

The data demonstrate that for the first two cycles after soaking & cold starting, the vehicle's NOx emission (ppm) is above the acceptable range. Increases in pressure & temperature cause a greater release of nitrogen oxides because of the greater compression ratio. This raises the average temperature of the operation, which may result in more nitrogen oxides being released. Therefore, engines need to be calibrated for cold start ability for existing emission regulations, and research into possible technological solutions to achieve emissions within limit, taking into account future planned emission norms. You may see the present BS-VI vehicle emission standards as well as the baseline testing limits and results for BS-III vehicles in Table 1. The most significant changes are needed in two parameters that appear to be at odds with one another: NOx& PM emission.

Table 1: Emission limits & results for various emission regulations

	CO	HC+ NOx	PM
	g/km		
Limits BSIII(g/Km)	0.5	0.5	0.05
Baseline Results(g/Km)	0.159	0.61	0.04
Limits BSIV(g/Km)	0.345	0.38	0.0354
Limits BSVI(g/Km)	0.2	0.2	0.0208

Baseline engine testing

To determine the performance parameters and strategy to fulfill current and future emission regulations, it is necessary to remove the engine from the vehicle due to the increased emission level. The maximum volumetric efficiency of the engine is seen at idling, while it is 72% at the maximum torque valve & 70.7% at the maximum braking power point. When compared to the typical range of 80-90% for normally aspirated engines, this value is shockingly low. We can then determine where the baseline engine can benefit from upgrades based on load & associated speed by analyzing the vehicle's operating points using simulation data.

Vehicle simulation

To better understand the relationship between engine speed & load, a simulation model of the vehicle is built using the available vehicle data and the baseline engine data. The simulation model of the vehicle is displayed in Figure. The vehicle was tested using the same emission cycle used in the development of the Indian national standard

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for three-wheeled vehicles. The correlation model for baseline vehicle emissions is based on data from car and engine simulations. Table 2 displays the results of a comparison between the simulation & testing of a vehicle, showing a positive correlation for fuel efficiency & CO2 emissions and a negative variation of -9.7 percentage points for NOx emissions. The simulation results help us determine which aspects of vehicle operation need further investigation. Simulation results and FTP & PTP data for the baseline engine are used to illustrate 25 different combinations of engine speed vs. load. We describe what we've noticed when shifting into different gears in the forward and reverse zones at different speeds and with different amounts of torque.

Table 2: Evaluation of Baseline Vehicle Test & Simulation Results

Gear Shift	CASE	CO	HC	NOx	FC	CO2
			(g/km)		(km/lit)	(g/km)
7-15-25 & 5-13-23	Vehicle Simulated	-	-	0.473	28.16	94.6
	Vehicle Tested	0.141	0.031	0.524	27.9	94.45
%Variation				-9.7%	0.9%	0.2%

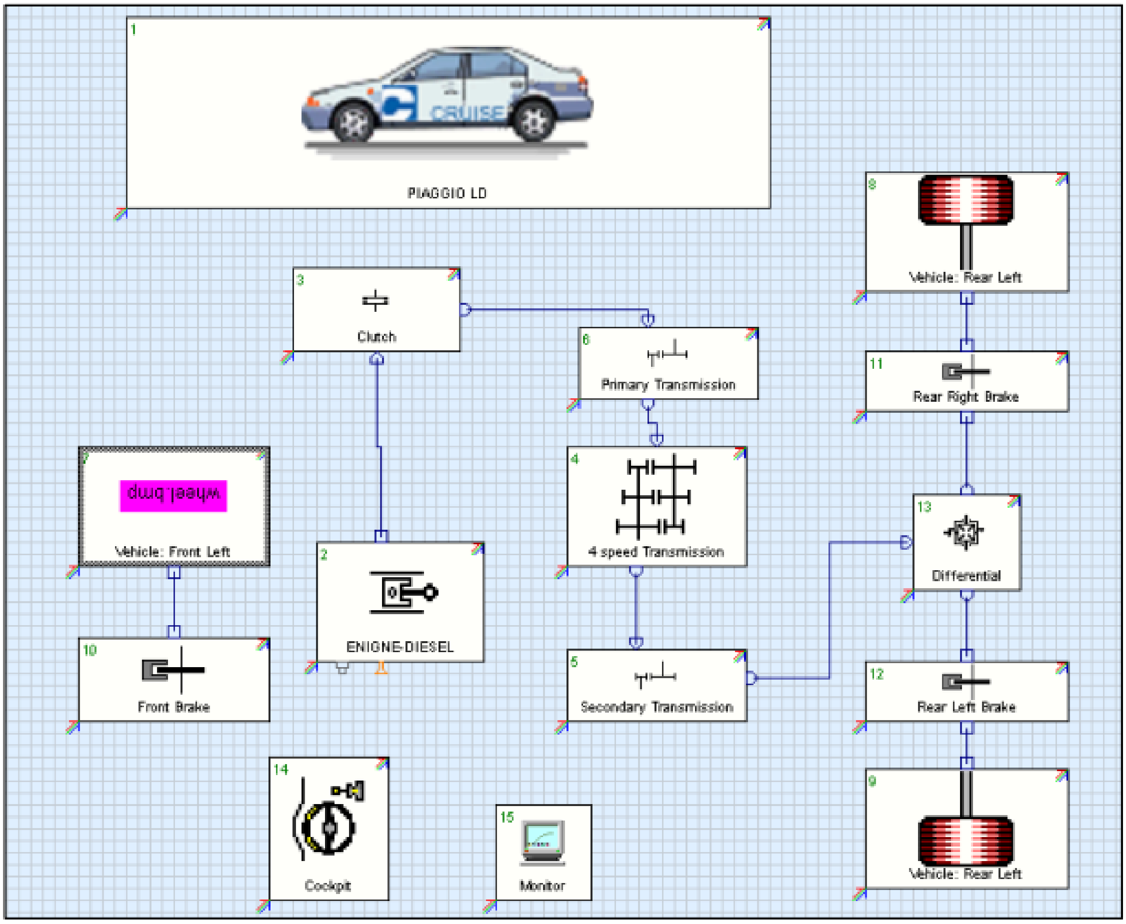

Fig 7: Vehicle simulation model of the baseline vehicle

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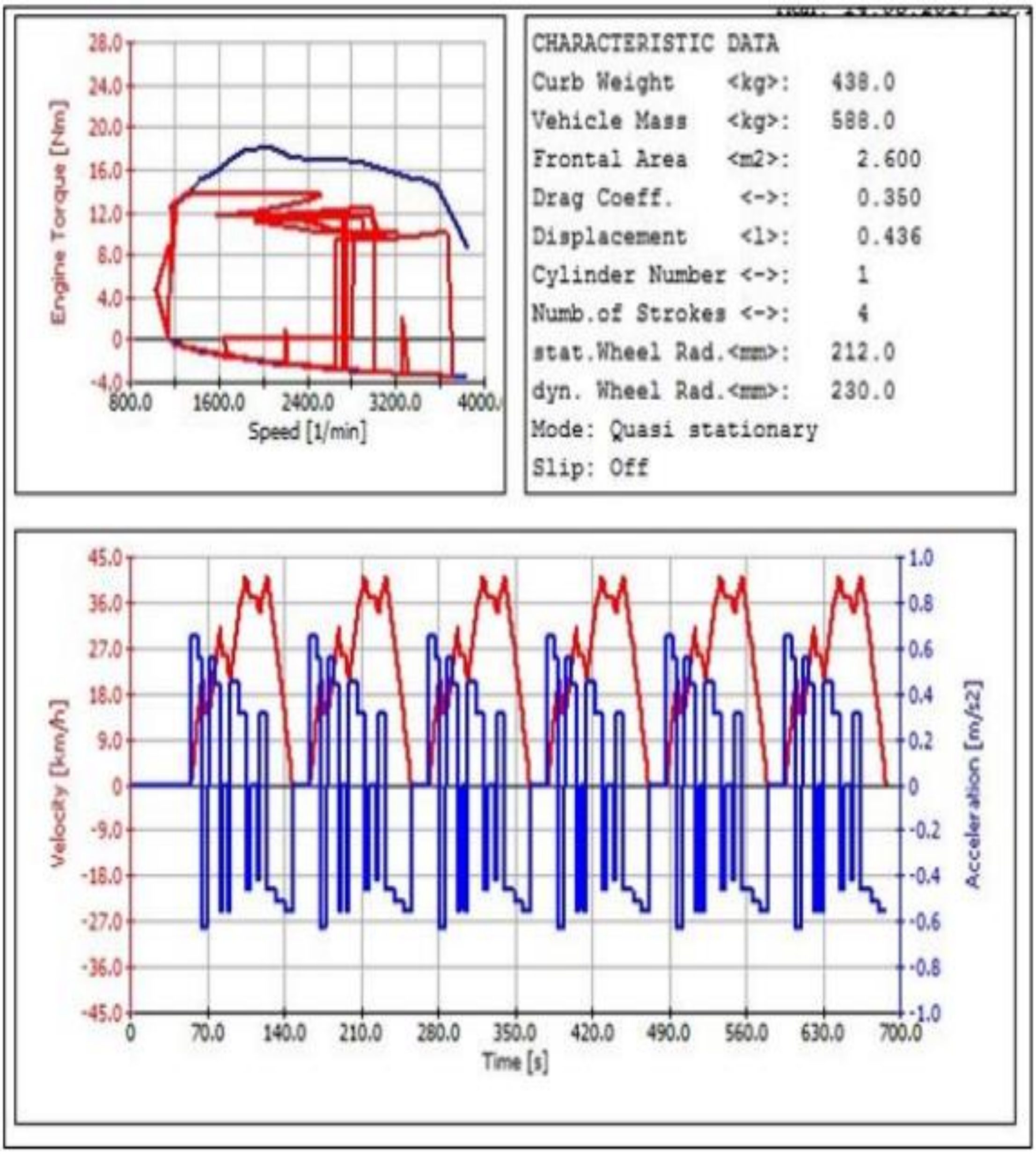

Fig 8: Vehicle operating zone, time, velocity, acceleration & torque zones

The remaining 78% of the time the vehicle is in motion is split between the acceleration zone & deceleration zone. The idle speed condition accounts for 23% of the time the vehicle is in motion. Seventy-eight percent of the total cycle duration is spent in the acceleration zone, whereas 35 percent is spent in the deceleration zone. The torque zone in which an engine operates is depicted by the time vs. velocity & acceleration curve in Fig. 8. From this, the optimal load & speed combination can be determined. Since the engine speed is typically higher than 2000 rpm at acceleration locations, this speed can be used as a cutoff. The engine's torque at this stage, along with other performance metrics, is used to identify potential for enhancement.

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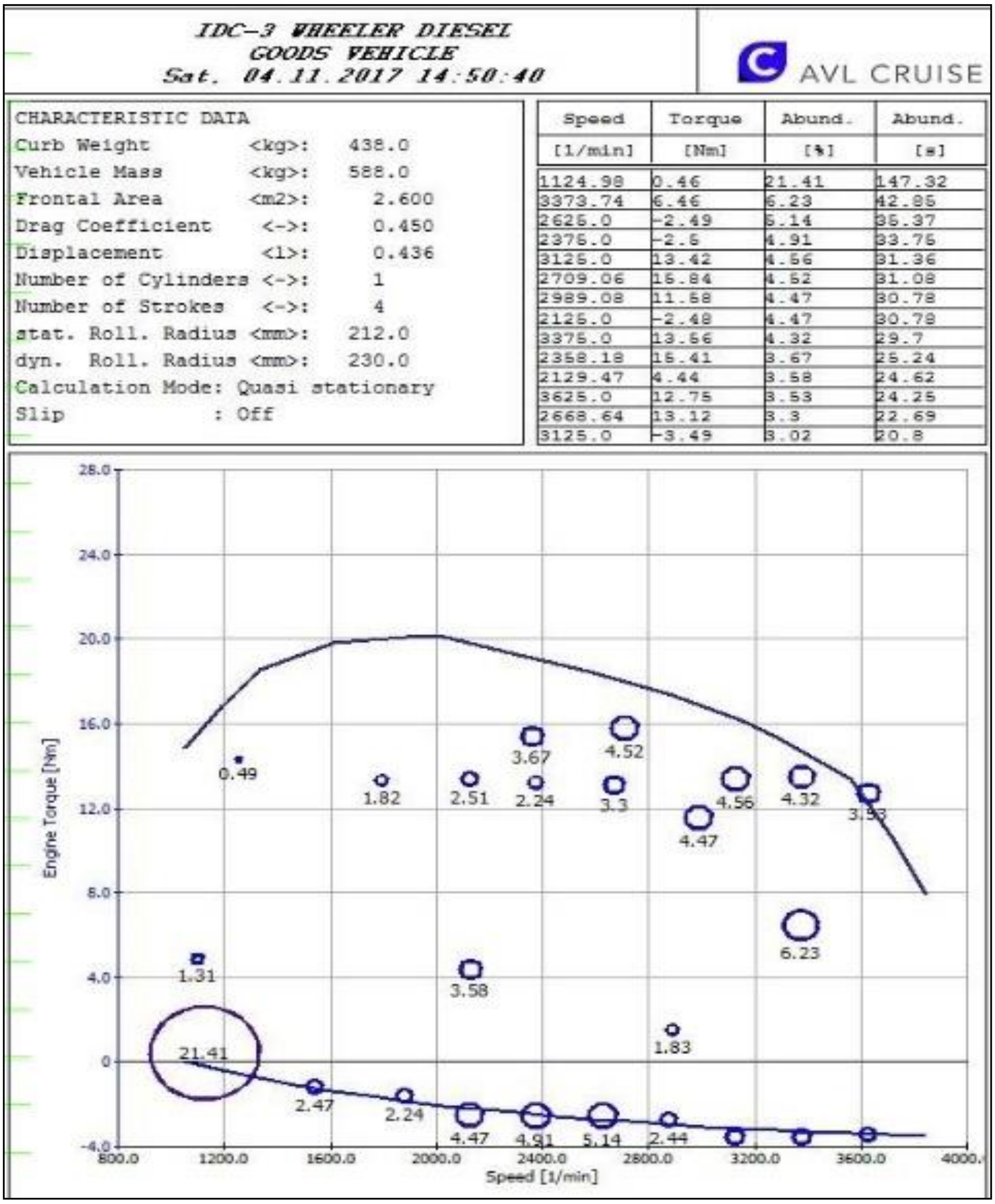

Fig 9: Vehicle operating zones &torque w.r.t speed

Swirl modelling

Computational fluid dynamics handles difficult mathematical problems with discrete boundary conditions using numerical methods and algorithms to approximate solutions. Calculations depend on computer speed and setup since millions of equations are calculated simultaneously. Industry uses it because fundamental research yields solutions at cheaper cost and time. High-end workstation setup & servers minimize solution time, but complex equations & numerical algorithms limit solution accuracy. Each assembly subcomponent is defined separately. Paddle wheel is 1.75D from liner top face in simulation & testing. In physical test, inlet end is directly exposed to atmosphere. In simulation, one hemisphere is generated at inlet to attain identical velocities. Baseline 3D CFD simulation model exhibits very strong swirl & flow

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correlation with testing data for 7 valve lifts. Table 3 shows deviation. Computational fluid dynamics handles difficult mathematical problems with discrete boundary conditions using numerical methods and algorithms to approximate solutions. Calculations depend on computer speed and setup since millions of equations are calculated simultaneously. Industry uses it because fundamental research yields solutions at cheaper cost and time. High-end workstation setup & servers minimize solution time, but complex equations & numerical algorithms limit solution accuracy. Each assembly subcomponent is defined separately. Paddle wheel is 1.75D from liner top face in simulation & testing. In physical test, inlet end is directly exposed to atmosphere. In simulation, one hemisphere is generated at inlet to attain identical velocities. Baseline 3D CFD simulation model exhibits very strong swirl & flow correlation with testing data for 7 valve lifts. Table 3 shows deviation**.**

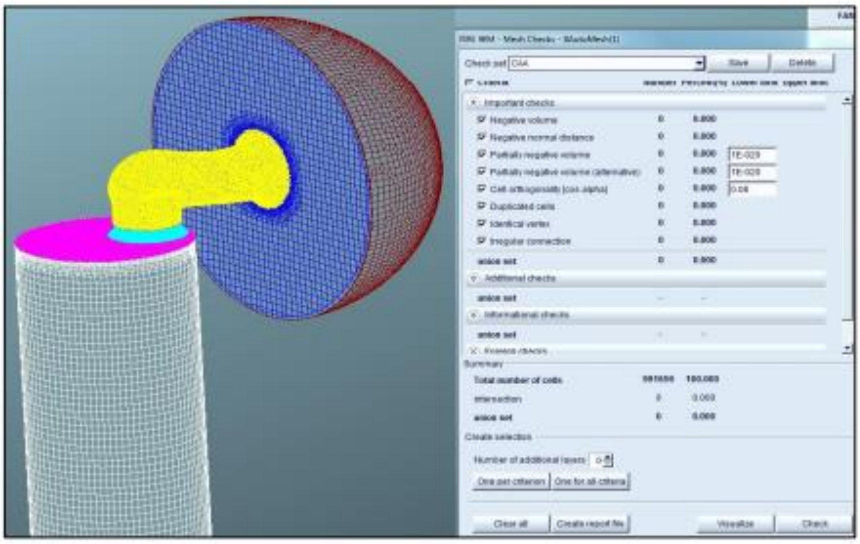

Fig 10: Inlet port volume meshed details

Table 3: Evaluation of Baseline intake port simulation vs. test bench

Valve Lift	**Swirl**			**Flow coefficient**		
	Exp.	**CFD**	**%dev**	**Exp.**	**CFD**	**%dev**
8	1.914	1.859	2.959	0.424	0.453	-6.840
7	1.873	1.793	4.462	0.410	0.442	-7.805
6	2.052	1.898	8.120	0.395	0.410	-3.797
5	1.835	1.689	8.644	0.393	0.389	1.018
4	1.660	1.593	4.180	0.318	0.328	-3.145
3	0.991	1.031	-3.898	0.240	0.257	-7.083
2	0.328	0.294	11.565	0.219	0.230	-5.023

Lower lift values allow 11% swirl value deviation. Lower lifts have less valve-to-seat clearance space, so airflow is more challenging. Since 3D geometry has a greater surface polish than casting, all CFD iterations have lower swirl values and higher flow values. As per conservation of energy, this surface polish lowers flow path pressure, increasing velocity.

EGR Effect

According to emission baseline data, this vehicle emits more pollutants during cold soak & low starting temperature circumstances. While changes to injection timings, swirl, IVO, & FIP can significantly reduce emissions and enhance performance, these changes are not sufficient to remedy the higher emissions that occur when the engine is first warmed up. Further modification is required to optimize the engine's combustion & minimize emissions in order to satisfy future emission regulations & lessen stress on after-treatment equipment. There is always a compromise between smoke &NOx emission, although EGR is one of the known techniques for reducing NOx emissions. The most effective combination of EGR with injection strategy, IVO, & swirl strategy can simultaneously reduce both parameters. Two primary approaches are utilized to incorporate EGR into the motor. The first technique involves starting EGR supply at 80% throttle, rather than 100%; this has the disadvantage of not meeting the necessary EGR quantity requirements at low engine speeds due to the smaller pressure differential. The second method uses EGR at full throttle, which reduces the amount of oxygen available to the engine & results in a loss of stopping power & penalty in BSFC. At rated speed, the engine's performance is unaffected by the lack of available fresh air and so does not require EGR. Since a small, single-cylinder, naturally aspirated engine would spend 75% of its time running at full throttle, the second tactic is used (Kaleemuddin& Rao, 2012). Various EGR rates are tested in a comprehensive investigation. Because fresh air is diluted by some of the exhaust gases, volumetric efficiency begins to drop when EGR is introduced. When hot exhaust gases are introduced to cooler entering air, the volumetric efficiency of the engine decreases. Engine performance is compromised when fresh air is combined with exhaust gases; this is why EGR rate selection is done with the goal of minimizing performance loss while maximizing emission benefits. As Figure demonstrates, there is a clear upward trend in BSFC with increasing EGR rates. The engine's performance is impacted by the EGR rates, and additional fuel and air are needed to restore it to its previous state or improve upon it. The range of EGR rates from 3-to-10 millimeter holes under various loads has been investigated. Tuning the engine's injection timing, injection pressure, swirl, & IVO can all lead to better combustion quality, which in turn leads to better BSFC. Comparing the EGR rates for 5 & 7 mm hole sizes, it is clear that the BSFC is lower for the larger hole sizes (6 & 10 mm).

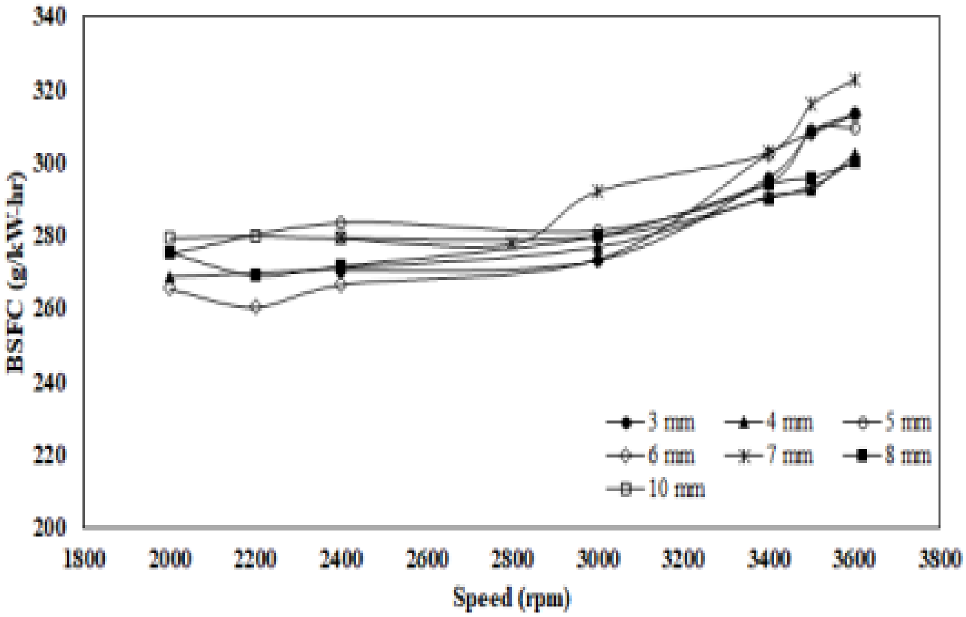

Fig 11: Analysis of the Full-Load Effect of Changing EGR Rates on BSFC

Figure displays the influence on engine torque and NOx emission from varying EGR supply rates. By delaying the combustion process through its effect on the fuel air interaction caused by the reduced supply of fresh air caused by increasing EGR rates, combustion temperatures can be lowered. NOx forms most effectively at higher temperatures and pressures. EGR pauses the combustion process, lowering the temperature and pressure in the cylinder, which in turn reduces NOx generation & emissions. Emissions using EGR are affected in various ways by the various engine parameters and operating circumstances. Reduced NOx emissions of 60-180 ppm across a range of engine operating conditions have been attributed to a combination of lower swirl, delayed SIT, and higher hpp. Higher EGR rates have a greater impact on these metrics at intermediate and high speeds, but they also have a 6% negative impact on the engine's peak torque. Kaleemuddin and Rao's (2012) findings mirror these tendencies.

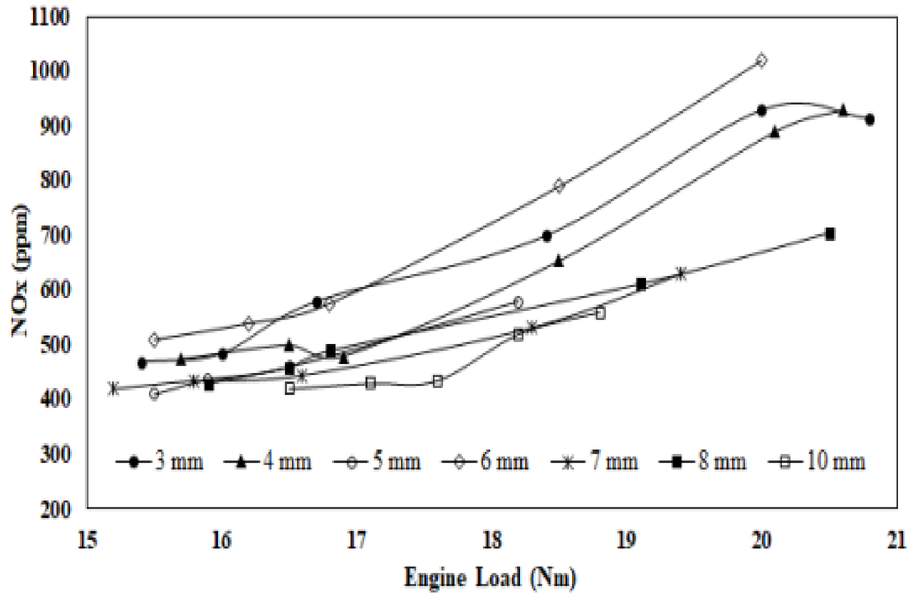

Fig 12: Analysis the NOx Emission Effect of Changing Load for Several EGR Rates

CONCLUSION

Engine operating points & chassis dynamometer measurements are compared to determine the vehicle's speed range & potential for improvement. The efficiency of the engine is compared to a known benchmark in order to identify the system's weaknesses & potential development targets. This has a domino effect on the efficiency & pollution levels of the engine. For shorter times, more lift increases both the beginning air velocity & filling rate, but the overall quantity remains same. By increasing the flow & decreasing the velocity, cylinder head swirl can be reduced. The method of increasing the flow coefficient aids in allowing a greater quantity of air into the combustion chamber by decreasing the resistance of the air flow channel. Different VVA strategies were predicted to increase engine Torque by 8%, volumetric efficiency by 21%, and BSFC by 3% in a 1D simulation.

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