Camshaft Optimization for BSFC Improvement of 4-Cylinder Turbocharged Diesel Engine

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Abstract: The four cylinder modelling and simulation for four-stroke turbocharged diesel engine requires the use of advanced analysis and development tools to carry out of performance the turbocharged diesel engine model. Steady state 1D simulation of engine systems using 1D GT- Power software has to be used. Both lift profile and events of intake and exhaust valves will be considered for optimization. Predictive combustion model will be used. 5-6 operating points will be considered for engine model calibration. Optimization will be done for rated power only and prediction will be done for rest of the operating points. Among others, critical engine performance parameters that would be reported are power, torque, BSFC, airflow, exhaust flow, lambda, volumetric efficiency, peak cylinder pressure (PCP), pressure & temperature at different locations of the fluid flow circuit.

Keywords: Diesel engine, performance, optimization, simulation, calibration

I. INTRODUCTION

The diesel engines is a type of internal combustion engine, more specifically it is a compression ignition engine, in which the fuel is ignited completely by the high temperature created by compression of the air-fuel mixture[2]. The engine operates using the diesel cycle. Unlike a petrol engine, the incoming air is not throttled, so the engine would over-speed if this was not done[2].

The importance of the diesel engine performance parameters are the geometrical properties, the term of efficiency and other related engine performance parameters. The diesel engines have very high compression ratios to provide good cold starting characteristics at low ambient temperatures. This indicates that they have very little clearance between the piston and valves when the piston is very close to top dead centre (TDC). This shows that the valves can have little or no lift at overlap TDC, which in turn means that any VVA system employed can only advance intake opening (IO) and retard exhaust closing (EC) very marginally otherwise valve to piston contact will occur. If the timings are moved in the other directions, negative overlap would occur which results in undesirable closed cylinder piston motion and pumping work.

GT-POWER is the leading one-dimensional (1D) engine simulation tool used by engine makers and suppliers. It is suitable for analysis of a wide range of issues related to engine performance. The engine performance and acoustics library is designed for steady-state and transient simulations and can be used for analyses of engine and power train control. It is applicable to each types of internal combustion engines and provides the user with many components to model almost any advanced concept. The solution is based on 1D fluid dynamics, representing the flow and heat transfer in the piping and other flow components of an engine system. In addition to the fluid flow and heat transfer capabilities, the code contains many other specialized models - combustion, emissions, friction, cylinder component heat transfer, etc

The of valve timing changes on the performance of diesel engine can be obtained by- a) Keeping exhaust opening timing standard and varying intake closing b) Keeping intake closing standard and varying exhaust opening c) Varying both intake closing and exhaust opening.[3]

This paper target is to reducing brake specific fuel consumption of the engine at rated power by optimizing inlet and exhaust valve timing by using the same coupled 1 D simulation software.

II. NEED OF SIMULATION

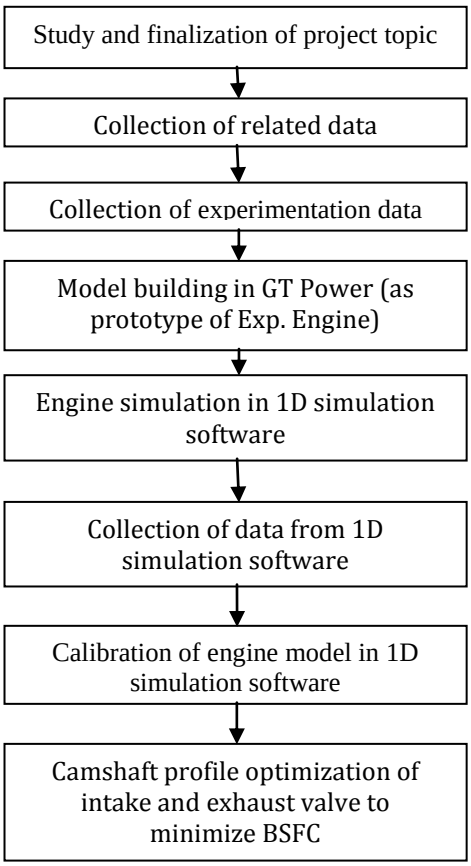
With advancements in mathematical modeling of fluid flow and combustion, internal combustion engine simulation has in part replaced the costly and time-consuming cycle of building and testing engines every time a change to the engine or one of its components is made. Often, only after a component is optimized through simulation is a part actually constructed and tested. Whereas advanced mathematical modeling and simulation have made inroads into the industrial sector, their presence in academic circles is less pervasive except for FEA and CFD software. Factors contributing to this development can be traced to ever-increasing computer skills of user, to the general availability of greater and faster computing in the public domain, to reformatting of complex simulation software to make it more user friendly, and to the perceived need by the technical community to use models and simulation to define and solve problems.

III. CAMSHAFT OPTIMIZATION

Camshaft optimization for BSFC improvement can be done by various methods like - a) optimizing inlet and exhaust timings[3][5][6] b) Optimizing the shape of flat face of follower into a curved face of follower [7][9]. c) Optimizing the geometrical shape and material properties[8][9].

IV. METHODOLOGY

Flow chart:



Study and finalization of project topic:
To improve performance and economy of diesel engine it is necessary to optimize the fuel consumption. And by studying various research papers we come to know that it can be reduced by changing the valve timing.
Collection of related data:
Collection and study of research papers related to camshaft optimization, valve timing changing, and their effects on the engine performance by study of engine simulation software.
Collection of experimentation data:
Collection of the engine test cell data by running a 4 cylinder, 4 stroke turbocharged diesel engine.
Model building in GT Power:
Creating a model same as the actual engine. Each and every part of the engine is used for model making.
Engine simulation in 1D simulation software:
Making of simulation of actual engine in 1D simulation software and run it.
Collection of data from 1D simulation software:
Collection of the model engine data as engine runs in the software it will gives the data of the model engine.
Calibration of engine model in 1D simulation software:
Calibration of the data obtained by model engine and the actual engine to check whether both engines give the same data with some considered approximations.
Camshaft profile optimization of intake and exhaust valve to minimize BSFC:
After the calibration this will be the final step. In this step by changing the camshaft profile in model engine the required performance of engine i.e. the optimum BSFC can be obtained without changing the actual engine design.

4.1. Use of 1D simulation software:

A typical engine model in GT-Power is shown in Fig.1. The code is well suited for integration of all aspects arising in engine and vehicle development. The given flow model contains the solution of the Navier-Stokes equations, namely the conservation of continuity, momentum and energy equations. These equations are solved in one dimension (1D), which means that the all quantities are averages across the flow direction. There are two choices of time integration methods, which generally affect the solution variables and limits on time steps. The time integration methods contain an implicit and explicit integrator. The explicit method includes the primary solution variables which are mass flow, density and internal energy. The implicit method include the primary solution variables like are mass flow, pressure and total enthalpy.

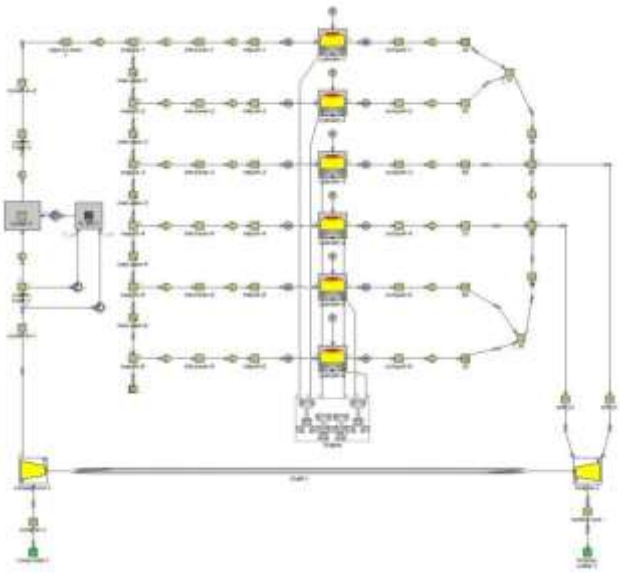


Fig.1: Typical engine model in GT-Power [14]

The total system is discredited into many volumes, where each flow split is represented by a single volume, and each pipe is again divided into one or more volumes. These all volumes are connected by boundaries. The scalar variables like pressure, temperature, density, internal energy, enthalpy, species concentrations, etc. are assumed to be uniform over each volume. The vector variables like mass flux, velocity, mass fraction fluxes, etc. are calculated for each boundary. This type of discretization is referred to as a "staggered grid" (Fig.2)

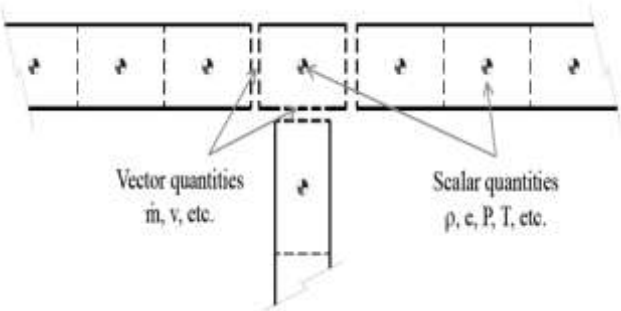


Fig: 2- staggered grid [14]

V. CASE STUDY

A. H. Kakaee and M. Pishgooie[5] set a target to reduce the BSFC of the engine by optimizing inlet and exhaust valve timing by using the same coupled GT-POWER and Simulink software. Thus in this research two targets for the reduction of BSFC will be selected at 5 and 10% respectively.

5.1. A 5% target reduction in BFSC:

The results are presented in Figure 3 for the sensitivity analysis with a 5% reduction target in BSFC
In Figure 3 comparison of targeted BSFC, BSFC of optimized model with VVT (VVT BSFC) and BSFC of base model (Output BSFC) has shown. BSFC is reduced in most engine speeds but in few engine speeds it is observed that there is increment in BSFC using coupled cam phasing system. The average reduction is about 4.5%.

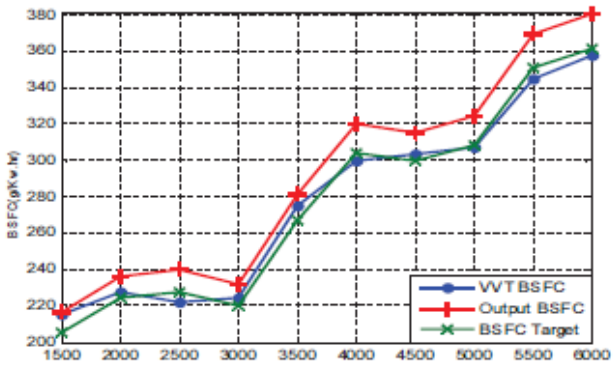


Fig. 3 BSFC vs engine speed

In table 1 the achieved fuel consumption reduction values in every engine speed using coupled cam phasing are summarized.

Table 1: Percent of reduction in BSFC in different engine speed.

Engine Speed	BSFC Reduction(%)
1500	0.45%
2000	3.58%
2500	7.39%
3000	3.12%
3500	2.31%
4000	6.24%
4500	3.71%
5000	5.36%
5500	6.69%
6000	6.06%
Average Reduction	4.49%

5.1. A 10% target reduction in BSFC:

In figure 4 for a 10% target results for BSFC are presented. This time it is found that the average reduction about 8.49%

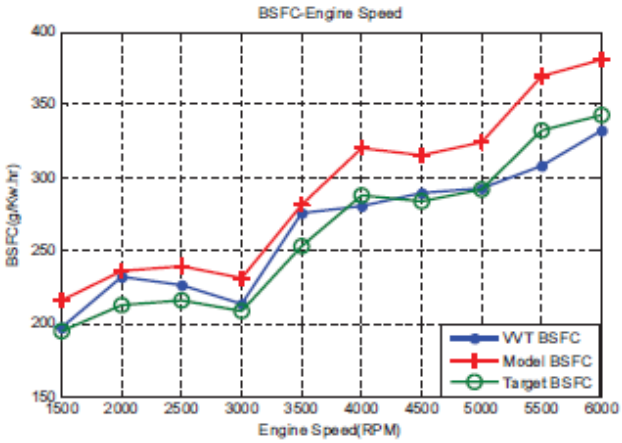


Fig: 4 BSFC vs Engine speed Diagram

Fuel consumption reductions are summarized in Table 2. The average value is 8.5% that is almost twice that of the 5% target.

Table 2: Percent of reduction in BSFC in different engine speed.

Engine Speed	BSFC Reduction(%)
1500	8.64%
2000	1.76%
2500	5.65%
3000	7.94%
3500	1.83%
4000	12.18%
4500	8.15%
5000	9.69%
5500	16.54%
6000	12.56%
Average Reduction	8.49%

A. H. Kakaee and M. Pishgooie concluded that for a 5% target an average of 4.5% reduction was obtained. For a 10% reduction in BSFC the results are 8.49% reduction for BSFC. Also the inlet valve timing advance leads to improvement in engine performance approximately for all engine speeds, but exhaust valve timing advance enhancement will be considerable in mid to rather high engine speeds, as again in agreement with theoretical and experimental data.

VI. SPECIFICATIONS

The diesel engine (4-cylinder 4-stroke turbocharged diesel engine) on which the test is taken has the following specifications:

1) Bore = 85 mm
2) Stroke = 90 mm
3) 4 cylinder
4) 2.04 L Engine
5) Compression Ratio = 16.7
6) Rated power = 108 kW @ 4000rpm
7) Peak torque = 272 Nm @ 2000rpm

And the test cell data obtained is-

Speed	Torque	Power	BMEP	Lambda	BSFC
RPM	Nm	kW	bar	-	g/kW.h
4500	212.2	100.0	13.05	1.243	258.6
4000	257.8	108.0	15.86	1.209	235.9
3000	270.6	85.0	16.64	1.189	216.2
2000	272.2	57.0	16.74	1.161	210.4
1500	210.1	33.0	12.92	1.013	228.0
1000	152.8	16.0	9.40	1.188	243.5

6.1. From the current test data the graphs obtained are as below :

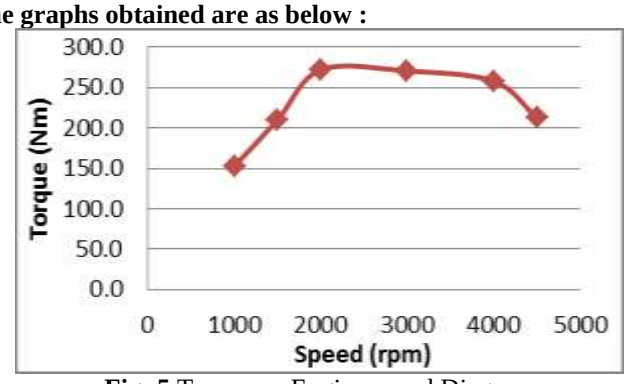


Fig: 5 Torque vs Engine speed Diagram

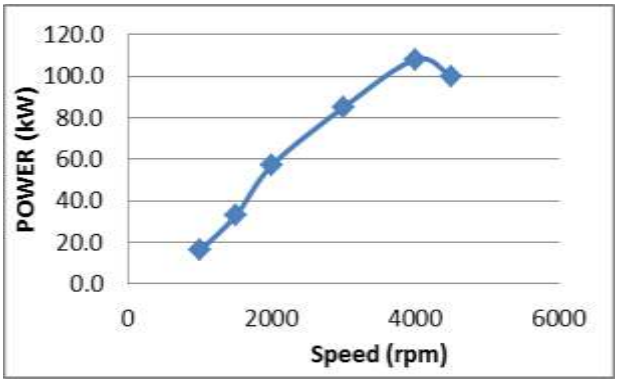


Fig: 6 Power vs Engine speed Diagram

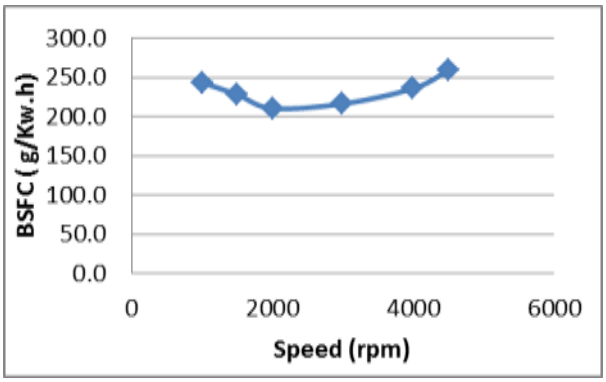


Fig: 7 BSFC vs Engine speed Diagram

As A. H. Kakaee and M. Pishgooie had optimized the BSFC also this data can be optimized using 1D simulation software to reduce BSFC.

SUMMARY:

1) By varying the intake and exhaust valve closing and opening timing the BSFC can be improved. While optimizing BSFC other engine parameters should be considered such as torque, power etc. Because change in the valve timings can improve the BSFC but it may affects the other performance parameters. Hence it is expected to optimize BSFC by 4-8% but least affect on other performance parameters.
2) During camshaft optimization, the objective would be to minimize BSFC without violating the design limits of mechanical parameters such as peak cylinder pressure, turbine inlet temperature, compressor outlet temperature, turbocharger speed, and clearance between piston and valves.
3) It is expected to achieve lower BSFC through a combination of reduced pumping loss, higher volumetric efficiency, good turbocharger performance. The optimization will be done for rated power only and prediction will be done for rest of the operating points by using this optimized camshaft profile.
4) 1 D simulation software can create an almost limitless range of engine models. These models can simulate real engines with the high degree of confidence and accuracy. At both design and off-design modes it has the ability to simulate and quantify engine performance. The 1D simulation model results must be compare with the experiment or engine performance theoretically for validation.

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