CHAPTER 5

ANALYSIS PROCEDURE

The following paragraphs describe the procedure adopted for the analysis of the experimental data obtained during this investigation.

The engine processes, terms and the important parameters necessary for the performance analysis and their implications are described below.

A schematic representing engine kinematics is given in fig. 5.1 where slider crank mechanism converts reciprocating motion of piston to the rotary motion of the shaft. The distance 's' shown in the figure is given by the equation

\[ S = a \cos \theta + (l^2 - a^2 \sin^2 \theta)^{\frac{1}{2}} \]

where \( a \) is crank radius, \( l \) is connecting rod length, \( s \) is instantaneous piston position and \( \theta \) is instantaneous crank angle.

![Fig. 5.1 Slider crank mechanism of an IC engine](image)
The thermodynamic cycle of a four-stroke diesel engine consists of four important processes.

i. Intake (IVO-IVC)

ii. Compression (IVC-SFI-TDC)

iii. Combustion and expansion (SFI-SIGN-ECOMB—EVO)

iv. Exhaust (EVO-EVC)

These events of the engine are represented on a pressure-volume diagram in Fig. 5.2.

As compression starts, both the curves begin close together but the fired engine pressure starts separating out gradually from the motoring curve on account of combustion energy release. This drift from motored diagram enables estimate of the ignition delay which is the period elapsed between the start of injection to the onset of combustion.
The following useful performance characteristics are estimated from the measured values.

Brake thermal efficiency: (BTH)  \[ BTH = \frac{\text{output power}}{\text{FC} \times \text{CV}} \]

Brake specific fuel consumption: (BSFC)  \[ \text{BSFC} = \frac{\text{FC}}{\text{BP}} \]

Fuel consumption: (FC)
\[ \text{FC} = \left[ \frac{\text{known quantity of fuel consumed}}{\text{time taken for the known quantity of the fuel to be consumed}} \right] \times \text{density of the fuel} \]

Brake power: (BP)  \[ \text{BP} = \frac{\text{W} \times \text{N}}{\text{C}} \]

where \( W \) is the load on the dynamometer, \( N \) is the speed of the engine, \( C \) is the dynamometer constant.

The following two aspects are needed through analysis in order to explain the experimental results of these investigations.

i. Combustion analysis

ii. Mixing / Turbulence analysis

5.1 COMBUSTION ANALYSIS

The instantaneous experimental data are acquired over several cycles. For averaging, pressure data of approximately 100 thermodynamic cycles are chosen. The first rise in the voltage signal due to IDC indicator is taken as a IDC position. At a fixed clock frequency of the data acquisition card of 100 kHz, approximately 370-380 pressure-voltage readings are acquired by the PC for each rotation of the crankshaft. By interpolation, the pressure-voltage readings are arranged at a spacing of 1 CA degree. The interpolation is more accurate, if done through spline fitting. Since the engine is four-stroke type, 720 such interpolated data correspond to one complete thermodynamic cycle (intake, compression, combustion and exhaust) of the engine. The interpolated data are corrected for the transducer drift by subtracting from them, a linearly increasing voltage (-2mV/s). Subsequently these data is multiplied by the constant "B" to obtain it into relative
pressure values at each instant. These pressure data are required to be referenced using a particular known pressure, hence pressure at inlet BDC is taken equal to the inlet manifold pressure.

5.2 MIXING / TURBULENCE ANALYSIS

One of the aspects of investigations carried out in the present work relates to the in-cylinder turbulence inducement and assessing its consequent effects on engine performance and combustion characteristics through the measured pressure-time diagram. Hence along with combustion analysis procedure described above, a method to evaluate the changes in the turbulence level affecting fuel-air mixing/combustion becomes necessary. For the purpose of these interpretations about turbulence parameter needed in this work, a detailed three dimensional fluid dynamic analysis became imperative. From the IC engine applications stand point the licensed CFD package-STAR-"CI) available in the institute is found appropriate and made use of.

The numerical method for STAR-CD (User Guide. 2001) includes the following steps:

i. Approximation of the unknown flow variables by means of simple functions

ii. Discretisation by substitution of the approximations into the governing flow equations and subsequent mathematical manipulations

iii. Solution of the algebraic equations.

Prior to the use of STAR-CD solver, the geometry of the object has to be created and meshed. The closed cycle three-dimensional engine simulation involving compression and expansion strokes is attempted on two different geometries viz. base engine combustion chamber and that with modifications for internal jets. The total combustion space is divided into two regions that is piston bowl and outer annular space. The bowl region is meshed in GAMBIT while the outer annular space is meshed in PROST AR and then merged together. Since there are no valves all open surfaces are
taken as wall boundary condition with no slip. Initial pressure and temperature inside the
cylinder is assumed as 1 bar and 293 K. The initial velocity is taken as zero. When the
meshed object is imported in the STAR-CD, the mesh can be made to translate, rotate or
distort in any prescribed way, by specifying time- varying positions for some or all of the
cell vertices due to its general dynamic meshing capabilities. Some practical applications
of moving meshes require a large variation in the solution domain size. STAR-CD
overcomes these potential problems by enabling cells to be removed or added during the
transient calculation. Thus, the average cell size can remain roughly constant. The general
approach in cell removal is that mesh motion causes two or more opposing pairs of cell
faces to become coincident at a specified time step, thereby causing all other faces to
collapse to lines or points and thus making the cell disappear. The mass, momentum and
energy associated with collapsed layer will be added to neighboring layer in
volumetrically conservative manner.

The opposite process is used for cell addition, i.e. a previously removed cell
(taken out either during or prior to the fluids calculation) is made to reappear. The initial
conditions for added layer are extrapolated from neighboring layer. This capability of cell
removal and addition was used extensively in this project. The general methodology for
cell activations and deactivations is that of specifying 'events'. Each event is associated
with a unique time step. When the simulation time matches with the event time, that
particular event is executed. The actual mesh movement is specified in terms of the latest
vertex positions in another file called 'cgrid'. In the present work since all cases requires
mesh movement i.e. addition or removal of cell layers, structured hexahedral cells has
been used.