APPENDIX 3

UNCERTAINTY ANALYSIS

The errors involved in various measurements and in the calculations of different quantities are computed in this section. The maximum possible errors in different measured quantities such as pressure, temperature, exhaust gas emissions estimated from the minimum values of output and from the accuracy of the instruments are calculated by the method proposed by Moffat (1985). Let the estimated quantity be ‘S’, which depends upon various independent variables such as \((x_1, x_2, x_3 \ldots \ldots \ldots x_n)\)

The error associated in the value of “S” is given by,

\[
\frac{\Delta S}{S} = \left[ \left( \frac{\Delta x_1}{x_1} \right)^2 + \left( \frac{\Delta x_2}{x_2} \right)^2 + \cdots + \left( \frac{\Delta x_n}{x_n} \right)^2 \right]^{\frac{1}{2}}
\]  \hspace{1cm} (A3.1)

Where, \(\frac{\Delta x_1}{x_1}, \frac{\Delta x_2}{x_2}, \ldots, \frac{\Delta x_n}{x_n}\) are the errors in the independent variables.

ERRORS ASSOCIATED IN THE MEASURED QUANTITIES

A3.1 PRESSURE MEASUREMENT IN THE COMBUSTION CHAMBER

The combustion chamber pressure was measured by using pressure transducer and charge amplifier. Hence the error in the pressure involved
depends upon the error involved in the transducer and charge amplifier. The error involved in pressure measurement is given as,

\[
\left[ \frac{\hat{c}P}{P} \right]_{\text{Experiment}} = \left[ \left( \frac{\hat{c}V}{V_{\text{Pressure Transducer}}} \right)^2 + \left( \frac{\hat{c}Q}{Q_{\text{Charge Amplifier}}} \right)^2 \right]^{\frac{1}{2}} \quad (A3.2)
\]

\[
= \left[ \left( \frac{0.15}{100} \right)^2 + \left( \frac{0.16}{100} \right)^2 \right] = \left[ (0.0015)^2 + (0.0016)^2 \right]^{\frac{1}{2}} = 0.002192 = 0.22\%
\]

Therefore, the error involved in pressure measurement,

\[
\left[ \frac{\hat{c}P}{P} \right]_{\text{Experiment}} = 0.22\%
\]

**A3.2 ERROR INVOLVED CRANK ANGLE**

Cranks angle encoder was used to measure the crank angle. The error involved in the crank angle is given as,

\[
\left[ \hat{c}(\text{Crank Angle}) \right]_{\text{Crank Angle}} = \left[ \frac{0.02}{1} \right] = 0.02 = 2\% \quad (A3.3)
\]

Therefore, the error involved in the crank angle = 2%.

**A3.3 BRAKE THERMAL EFFICIENCY**

The error associated in brake thermal efficiency is given as,

\[
\left[ \frac{\hat{c}\text{BTE}}{\text{BTE}} \right] = \left[ \left( \frac{\hat{c}\text{rpm}}{\text{rpm}} \right)^2 + \left( \frac{\hat{c}\text{Torque}}{\text{Torque}} \right)^2 + \left( \frac{\hat{c}\text{time}}{\text{time}} \right)^2 \right]^{\frac{1}{2}} \quad (A3.4)
\]
Therefore, the error associated in brake thermal efficiency = 0.31%

**A3.4 EXHAUST GAS TEMPERATURE**

The exhaust gas temperature was measured by an Al/Cr K-type thermocouple. The temperature measured by the thermocouple was displayed by a digital temperature indicator. The maximum possible error in the measurement of temperature is calculated from the minimum values of temperature measured and the accuracy of the instrument i.e. thermocouple with temperature indicator.

The error involved in the measurement of exhaust gas temperature is given as,

\[
\left[ \frac{\partial T}{T} \right]_{\text{Exhaust Gas Temperature}} = \left[ \frac{\partial T_{\text{k-type}}}{T_{\text{k-type}}} \right]^2 + \left[ \frac{\partial T_{\text{Indicator}}}{T_{\text{Indicator}}} \right]^2 \right]^{\frac{1}{2}} \quad (A3.5)
\]

\[
\left[ \frac{\partial T}{T} \right]_{\text{Exhaust Gas Temperature}} = \left[ \left( \frac{0.48 \degree C}{319 \degree C} \right)^2 + \left( \frac{0.468 \degree C}{319 \degree C} \right)^2 \right]^{\frac{1}{2}} = \left[ 0.001505 \right]^2 + \left[ 0.001467 \right]^2
\]

\[ = 0.0021 = 0.2101\%
\]

Therefore,
The error involved in the measurement of exhaust gas temperature = 0.21%.

A3.5 EXHAUST GAS EMISSIONS

The exhaust gas emissions are measured using exhaust gas analysers and smoke meter. The maximum possible error in the measurement of NO, CO, HC emissions and smoke concentration is 5% as per the specifications of the analyzers.