## SPECIFICATIONS OF ENGINE

<table>
<thead>
<tr>
<th>Make</th>
<th>Honda</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Side valve, 4 stroke, air cooled, horizontal shaft, single cylinder</td>
</tr>
<tr>
<td>Displacement</td>
<td>197 cc</td>
</tr>
<tr>
<td>Bore × Stroke</td>
<td>67 mm × 56 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>4.5:1</td>
</tr>
<tr>
<td>Fuel</td>
<td>Petrol</td>
</tr>
<tr>
<td>Rated brake power</td>
<td>2.28 kW at 3000 rpm</td>
</tr>
<tr>
<td>Max. Torque</td>
<td>0.8 kg·m at 2500 rpm</td>
</tr>
<tr>
<td>Ignition system</td>
<td>Fly wheel magneto</td>
</tr>
<tr>
<td>Ignition timing</td>
<td>20° bTDC (fixed)</td>
</tr>
<tr>
<td>Air cleaner</td>
<td>Oil bath type</td>
</tr>
<tr>
<td>Dry weight</td>
<td>18 kg</td>
</tr>
<tr>
<td>Dimensions</td>
<td>338 mm × 404 mm × 423 mm</td>
</tr>
<tr>
<td>Loading Device</td>
<td>Eddy current Dynamometer</td>
</tr>
<tr>
<td>Starting</td>
<td>Battery</td>
</tr>
<tr>
<td>Connecting rod length</td>
<td>197 mm</td>
</tr>
</tbody>
</table>
### APPENDIX 2

**DYNAMOMETER DETAILS**

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>SAJ Test Plant Pvt. Ltd.</td>
</tr>
<tr>
<td>Type</td>
<td>Eddy current</td>
</tr>
<tr>
<td>Model</td>
<td>AG-20</td>
</tr>
<tr>
<td>Power</td>
<td>Max. 20 kW @ 2500 rpm</td>
</tr>
<tr>
<td>Speed</td>
<td>10,000 rpm</td>
</tr>
<tr>
<td>Effective radius of arm</td>
<td>0.195 m</td>
</tr>
</tbody>
</table>
APPENDIX 3

SPECIFICATIONS OF AVL GAS ANALYSER

Make : AVL
Type : AVL Digas 444
Power supply : 110V-220V ≈ 25 W
Warm up time : ≈ 7 min.
Connector gas in : ≈ 180 l/h, max. overpressure 450 hPa
Response time : T_{95} ≤ 15 s
Operating temperature : 5 … 45 °C
Storage temperature : 0 … 50 °C
Relative humidity : ≤ 95%, non-condensing
Inclination : 0 … 90°
Dimension (w x d x h) : 270 x 320 x 85 mm³
Weight : 4.5 kg net weight without accessories
Interfaces : RS 232 C, Pick up, Oil temperature probe
APPENDIX 4

SPECIFICATION OF COMBUSTION ANALYSER

<table>
<thead>
<tr>
<th>Make</th>
<th>AVL Combustion Analyser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>619 Indimeter Hardware</td>
</tr>
<tr>
<td></td>
<td>Indwin – Software version 2.2</td>
</tr>
</tbody>
</table>

TECHNICAL DATA

General

- Mains connection: 85 – 265 V, 50 – 60 Hz, 60 VA
- 1 fuse 3.15 A slow-blow, Fuse holder on rear panel
- Temperature range: +5 °C to -5 °C, once the system reaches its operating temperature after a initial warm-up period, it can be used at temperatures down to -10 °C
- Maximum relative humidity 80 % for temperatures up to 31 °C, following a linear decrease to 50 % relative humidity at 40 °C, non-condensing
- Dimensions: Approx. 442 mm × 58mm × 370 mm depth incl. cable connectors: 500 mm
- Weight: approx. 8 kg
Analog Part

- 4 (Standard), 6 or 8 differential voltage inputs ± 10 V, input resistance 100 kΩ
- input low-pass filter \( f_g = 100 \text{ kHz} \)
- simultaneous sample & hold input
- ADC 12 bit

Digital Part

- Digital signal processor
- RAM 8 MB
- Measurement resolution: 0.1, 0.2, 0.5, 1 degree CA
- Input CDM, Trigger: TTL - signal (necessary input for LOW signal, approx. 27 mA)
- Entire data transfer rate: Max. 1 MHz
- PC interface: parallel port, Link interface (option)
## Charge Amplifier Data

<table>
<thead>
<tr>
<th>INPUT</th>
<th>Type</th>
<th>Unbalanced, high insulation (approx. $10^{14}\Omega$) for connection piezoelectric measurement transducers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input insulation impedance</td>
<td>$\geq 10^{14}\Omega$</td>
<td></td>
</tr>
<tr>
<td>Connector</td>
<td>BNC sockets at front and rear (parallel connection)</td>
<td></td>
</tr>
<tr>
<td>Overload protection</td>
<td>Input protected against excessive electrostatic voltages or charges occurring during operation or handling.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>Type</th>
<th>Unbalanced, output ground electrically isolated from protective ground and input ground via a differential amplifier. Ground loop problems are appreciable reduced due to the use of two electrically isolated $\pm 15$ V sources.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection</td>
<td>13 a to 13 c on the 64-pin connector</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>$0 \leq \pm 10$ V at load $\leq 0.5$ kΩ</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>Max $\pm 18$ mA</td>
<td></td>
</tr>
<tr>
<td>Output impedance</td>
<td>$&lt;0.01$ Ω</td>
<td></td>
</tr>
<tr>
<td>Quiescent potential</td>
<td>Zero or $+1$ V, selectable by slide switch (RESET state) adjustable by $\leq 0.7$ V with potentiometer ZERO</td>
<td></td>
</tr>
<tr>
<td>Temperature drift</td>
<td>RESET, TRANSSENS. (10.00PC/bar): $\leq 1$ mV/°C</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 5

SPECIFICATION OF CHARGE AMPLIFIER

Make : KISLTER instruments AG, Switzerland

Type : 5001

Output voltage : ± 10 V

Output current : ± 50 mA

Output impedance : 100 Ω

Insulation resistance at input : 10^{14} Ω

Frequency range : 0-180 kHz

Linearity : ± 0.05%

Accuracy range : ± 1%
APPENDIX 6

TYPICAL PROPERTIES OF PETROL

Density at (g/cc) : 710-770 kg/cu.m @ 15°C
Boiling range : 45 - 215°C
Colorific value (Net) : 43534 – 44371 kJ/kg
Flash Point (°C) : Below 10°C
Fire Point (°C) : Below 20°C
Auto ignition temperature : 450°C
Reid vapor pressure : 35-60 kPa
Enthalpy of vaporization : 310 kJ/kg
RON : 88
MON : 80
Anti knock index : 84
Sulphur % mass : 0.1 max.
Lead : 0.013 max. g/mlit.
% Aromatics : 15-20
% Saturates : 50-60
% Naphthenes : 15-20
% Olefins : 25-30
% Benzene : 3-5

(Source: Indian oil corporation website)
APPENDIX 7

SPECIFICATION OF PRESSURE TRANSDUCER

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>KISTLER, Switzerland 601 A, water cooled</td>
</tr>
<tr>
<td>Range</td>
<td>0-250 bar</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>≈ -14.80 pC/bar</td>
</tr>
<tr>
<td>Linearity</td>
<td>0.1 ±% FSO</td>
</tr>
<tr>
<td>Acceleration sensitivity</td>
<td>&lt;0.001 bar/g</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>-196 to 200 °C</td>
</tr>
<tr>
<td>Capacitance</td>
<td>5 PF</td>
</tr>
<tr>
<td>Weight</td>
<td>1.7 g</td>
</tr>
<tr>
<td>Connector, Teflon insulator</td>
<td>M4 X 0.35</td>
</tr>
</tbody>
</table>
APPENDIX 8

ERROR AND UNCERTAINTY ANALYSIS

Error is associated with various primary experimental measurements and the calculations of performance parameters. Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. Uncertainty analysis is needed to prove the accuracy of the experiments. The percentage uncertainties of various parameters like load and brake thermal efficiency were calculated using the percentage uncertainties of various instruments given in Table A 8.1. An uncertainty analysis was performed using the equation.

Total percentage uncertainty

\[
\text{Total percentage uncertainty} = \sqrt{\left(\text{uncertainty of TFC}\right)^2 + \left(\text{uncertainty of load}\right)^2 + \left(\text{uncertainty of brake thermal efficiency}\right)^2 + \left(\text{uncertainty of CO}\right)^2 + \left(\text{uncertainty of unburned hydrocarbon}\right)^2 + \left(\text{uncertainty of NOx}\right)^2 + \left(\text{uncertainty of exhaust gas temperature}\right)^2 + \left(\text{uncertainty of pressure pickup}\right)^2}
\]

\[
= \sqrt{(1)^2 + (0.2)^2 + (1)^2 + (0.2)^2 + (0.2)^2 + (0.2)^2 + (0.15)^2 + (1)^2}
\]

\[
= \pm 1.7839 \%
\]
Table A 8.1 List of instruments and their range, accuracy and percentage uncertainties

<table>
<thead>
<tr>
<th>S.No</th>
<th>Instruments</th>
<th>Range</th>
<th>Accuracy</th>
<th>Percentage uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gas analyzer</td>
<td>CO 0-10 %, CO₂ 0-20%, HC 0-10000 ppm, NOX 0-5000 ppm</td>
<td>+0.02% to -0.02%, +0.03% to -0.03%, +20 ppm to -20 ppm, +10 ppm to -10 ppm</td>
<td>+0.2% to -0.2% to -0.2%</td>
</tr>
<tr>
<td>2</td>
<td>Exhaust Gas Temperature indicator</td>
<td>0-900°C</td>
<td>+1°C to -1°C</td>
<td>+0.15 to -0.15%</td>
</tr>
<tr>
<td>3</td>
<td>Speed measuring unit</td>
<td>0-1000 rpm</td>
<td>+10 rpm to -10 rpm</td>
<td>+0.1 to -0.1%</td>
</tr>
<tr>
<td>4</td>
<td>Load indicator</td>
<td>0-100kg</td>
<td>+0.1 kg to -0.1 kg</td>
<td>+0.2 to -0.2%</td>
</tr>
<tr>
<td>5</td>
<td>Burette for fuel measurement</td>
<td>+0.1cc to -0.1cc</td>
<td>+1 to -1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Digital stop watch</td>
<td>+0.6s to -0.6s</td>
<td>+0.2 to -0.2%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Manometer</td>
<td>+1mm to -1mm</td>
<td>+1 to -1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Pressure pickup</td>
<td>+0.1 to -0.1</td>
<td>+0.1 to -0.1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Crank angle encoder</td>
<td>0-110 bar</td>
<td>+1° to -1°</td>
<td>+0.2 to -0.2%</td>
</tr>
</tbody>
</table>

The errors associated with various measurements and in calculations of performance, parameters are computed in this section. The maximum possible errors in various measured parameters namely temperature, pressure, exhaust gas emissions, time and speed estimated from the minimum values of output and accuracy of the instrument are calculated using the method. This
method is based on careful specification of the uncertainties in the various experimental measurements.

If an estimated quantity, $R$, depends on independent variable like $(x_1, x_2, x_3, \ldots, x_n)$ then the error in the value of “$R$” is given by

$$R = f(x_1, x_2, \ldots, x_n)$$  \hspace{1cm} (A8.1)

with ‘$R$’ as the computed result function of the independent measured variables $x_1, x_2, x_3, \ldots, x_n$, as per the relation.

$$x_1, \pm \Delta n_1, x_2 \pm \Delta n_2, \ldots, x_n \pm \Delta x_n$$

as the error limits for the measured variables or parameters and the error limits for the computed result as $R \pm \Delta R$

To get the realistic error limits for the computed result, the principle of root-mean square method was used to get the magnitude of error given by Holman (1998)

$$\Delta R = \left( \left( \frac{\partial R}{\partial x_1} \Delta x_1 \right)^2 + \left( \frac{\partial R}{\partial x_2} \Delta x_2 \right)^2 + \ldots + \left( \frac{\partial R}{\partial x_n} \Delta x_n \right)^2 \right)^{1/2}$$  \hspace{1cm} (A8.2)

Using Equation A8.2 the uncertainty in the computed values such as load, brake thermal efficiency and fuel flow measurements were estimated. The measured values such as speed, fuel time, voltage and current were estimated from their respective uncertainties based on the Gaussian distribution. The uncertainties in the measured parameters, voltage ($\Delta V$) and current ($\Delta I$), estimated by the Gaussian method, are $\pm 3$ V and $\pm 0.14$ A respectively. For fuel time ($\Delta t_f$) and fuel volume ($\Delta t$), the uncertainties are taken as $\pm 0.2$ sec and $\pm 0.1$ sec respectively.
A sample calculation is given below

Example:

Speed \( N = 3000 \text{ rpm} \)

Voltage \( V = 415 \text{ volts} \)

Current \( I = 7 \text{ A} \)

Fuel volume \( fx = 10 \text{ cc} \)

Brake power \( BP = 2.28 \text{ kW} \)

1. Brake power

\[
BP = \frac{VI}{\eta_g \times 1000} \text{ kW}
\]

\[
BP = f(V,I)
\]

\[
\frac{\hat{C}_{BP}}{\hat{C}_V} = \frac{1}{(0.86 \times 1000)} = \frac{7}{(0.86 \times 1000)} = 0.00814
\]

\[
\frac{\hat{C}_{BP}}{\hat{C}_I} = \frac{V}{(0.86 \times 1000)} = \frac{415}{(0.86 \times 1000)} = 0.4825
\]

\[
\Lambda_{BP} = \sqrt{\left(\frac{\hat{C}_{BP}}{\hat{C}_V} \times \Delta V\right)^2 + \left(\frac{\hat{C}_{BP}}{\hat{C}_I} \times \Delta I\right)^2}
\]

\[
(A8.3)
\]

\[
= \sqrt{(0.00814 \times 3)^2 + (0.4825 \times 0.14)^2}
\]

\[
= 0.0005963 + 0.004563
\]
Therefore the uncertainty limits in the calculation of B.P is 2.28 ± 0.00515 kW.

2. **Total fuel consumption (TFC)**

\[
TFC = \frac{(10 \times 3600 \times 0.83)}{(t \times 1000)}
\]

\[
TFC = \frac{(10 \times 3600 \times 0.83)}{(20 \times 1000)} = 1.494 \text{ kg/h}
\]

\[
TFC = f(t)
\]

\[
\frac{\partial TFC}{\partial t} = -\frac{(10 \times 3600 \times 0.83)}{t^2 \times 1000}
\]

\[
\frac{\partial TFC}{\partial t} = -\frac{(10 \times 3600 \times 0.83)}{20^2 \times 1000} = -0.0747 \text{ kg/h}
\]

\[
\Delta TFC = \sqrt{\left(\frac{\partial TFC}{\partial t} \cdot x(\Delta t_t)\right)^2}
\]

\[
\Delta TFC = \sqrt{(-0.0747 \times 0.2)^2}
\]

\[
\Delta TFC = 0.0149 \text{ kg/h}
\]

The uncertainty in the TFC 0.0149 kg/h and the limits of uncertainty are 1.494 ± (0.0149) kg/h.

3. **Brake thermal efficiency (η)**

\[
\eta = \frac{(BP \times 3600 \times 100)}{(TFC \times CV)}
\]
\[ \eta = f(BP, TFC) \]
\[ \eta = \frac{(2.28 \times 3600 \times 100)}{(0.84 \times 44000)} = 22.2 \% \]
\[ \frac{\Delta \eta}{\Delta BP} = \frac{(3600 \times 100)}{TFC \times 44000} \]
\[ = \frac{3600 \times 100}{(0.84 \times 44000)} = 9.74 \]
\[ \frac{\Delta \eta}{\Delta TFC} = \frac{(BP \times 3600 \times 100)}{(TFC)^2 \times 44000} \]
\[ = \frac{(2.28 \times 3600 \times 100)}{(0.84)^2 \times 44000} \]
\[ = 26.43 \% \]
\[ \Delta \eta = \sqrt{\left(\frac{\Delta \eta}{\Delta BP} \times \Delta BP\right)^2 + \left(\frac{\Delta \eta}{\Delta TFC} \times \Delta TFC\right)^2} \]
\[ (A8.5) \]
\[ \Delta \eta = \sqrt{(9.74 \times 0.0615)^2 + (26.43 \times 0.0114)^2} \]
\[ = 0.678 \% \]

The uncertainty in the brake thermal efficiency from Equation A8.5 is ±0.678 % and the limits of uncertainty are 22.20 ± 0.678 %.

4. Exhaust Gas Temperature Measurement

Al/Cr K-type thermocouple is used to measure the exhaust gas temperature. Digital temperature indicator displays the temperature measured by thermocouple. The maximum possible error in the case of temperature measurement is calculated from the minimum values of the temperature measured and accuracy of the instrument (thermocouple with temperature indicator) the errors in the temperature measurement are:
\[(\tilde{c}T/T)_{\text{EGT}} = ( (\tilde{c}T_{\text{k-Type}}/ T_{\text{k-Type}})^2 + (\tilde{c}T_{\text{indf}}/ T_{\text{indf}})^2)^{1/2}\]

\[(\tilde{c}T/T)_{\text{EGT}} = ( (0.48/160)^2 + (0.468/ 160)^2)^{1/2}\]

\[(\tilde{c}T/T)_{\text{EGT}} = 0.0041 = 0.41\%\]

5. Combustion chamber pressure measurement

The combustion chamber pressure was measured by using pressure transducer and charge amplifier.

\[(\tilde{c}P/P)_{\text{Exp}} = ( (\tilde{c}q_{\text{charge}}/ q_{\text{charge}})^2 + (\tilde{c}V_{\text{PT}}/ V_{\text{PT}})^2)^{1/2}\]

\[(\tilde{c}P/P)_{\text{Exp}} = ( (0.16/ 100)^2 + (0.15/ 100)^2)^{1/2} = 0.002193 = 0.22\%\]

6. Percentage of uncertainty for the measurement of speed, mass flow rate, NO\textsubscript{x}, hydrocarbon and smoke is given below:

i) Speed : 1.1
ii) Mass flow rate of air : 1.3
iii) Mass flow rate of diesel : 1.0
iv) NO\textsubscript{x} : 1.1
v) Hydrocarbon : 0.01
vi) CO : 0.8
vii) CO\textsubscript{2} : 1.2
APPENDIX 9

HEAT RELEASE ANALYSIS

The details about combustion stages and events can be determined by analyzing the heat release rates determined from cylinder pressure measurements. Analysis of heat release can help to study the combustion behavior of the engine. The analysis for the heat release rate is based on the application of first law of thermodynamics for an open system. It is assumed that the cylinder contents are homogeneous mixture of air and combustion products and are at uniform temperature and pressure during the combustion process. The first law for such a system is written as

\[ \delta Q_{hr} = \delta U + \delta W + \delta Q_{ht} \]  \hspace{1cm} (A9.1)

where,

\[ \delta Q_{hr} \quad \text{Instantaneous heat release modeled as heat transfer to the working fluid} \]

\[ \delta U \quad \text{Change in internal energy of the working fluid} \]

\[ \delta W \quad \text{Work done by the working fluid} \]

\[ \delta Q_{ht} \quad \text{Heat transmitted away from the working fluid (to the combustion chamber walls)} \]

Change in internal energy is written as,

\[ \delta U = (C_v/R) (pdV + Vdp) \]  \hspace{1cm} (A9.2)
Work done by the working fluid $dW = pdV$

Heat transfer rate to the wall is written as

$$\frac{dQ_{ht}}{dt} = h A (T_g - T_w) \quad (A9.3)$$

where $R =$ Gas constant

$T, P, V$ are Temperature, Pressure and Volume respectively.

$C_v =$ Specific heat at constant volume

$h =$ Heat transfer coefficient

$T_w =$ Temperature of the wall: 400 K

$$h = 3.26B^{-0.2} p^{0.8} T^{-0.55} w^{0.8}$$

where

$B$ (bore) = 0.067 m

$P$ (cylinder pressure) = 13.274 bar

$T$ (gas temperature) = 1100 K

$w$ is average gas velocity in m/s which is calculated from the equation

$$w = \left[ C_1 S_p + C_2 \frac{V_L}{p_c V_c} (p - p_m) \right] \quad (A9.4)$$
where

$S_p$ is the mean piston speed in m/s, $V_d$ is the displaced volume in m$^3$

$T_c, p_c, V_c$ are temperature, pressure and volume respectively during combustion

$p$ is the cylinder pressure during combustion

$p_{mi}$ is the pressure in motorized condition

$C_1$ is 2.28 and $C_2$ is $3.24 \times 10^{-3}$ during combustion

From the equation, the first law of thermodynamics can be written as follows with suitable assumptions:

$$\frac{d}{dt}(h + V) = \frac{\gamma}{\gamma - 1} P \frac{dV}{d\theta} + V \frac{1}{\gamma - 1} \frac{dp}{d\theta} + hA_s(T_g - T_w) \frac{dT}{d\theta} \quad (A9.5)$$

Where $\theta$ is the crank angle in degrees

$\gamma$ is the ratio of specific heats of the fuel and air

$A_s$ is the area in m$^2$ through which heat transfer from gas to combustion chamber walls takes place.

The pressure value is obtained from the cylinder pressure data at corresponding crank angle. Equation (9.1) makes it possible to calculate the heat release rate. The calculated heat release rate is as follows with the given values

Clearance volume = $3.69 \times 10^{-5}$ m$^3$, Swept volume = 0.00019743 m$^3$

$\gamma = 1.3$, Crank radius = 0.055 m
Stroke = 0.056 m, Compression ratio = 4.5

At 350°CA the pressure is 8.3480 bar and at 351°CA the pressure is 8.6070 bar. The heat release rate is

\[ \frac{dQ}{dt} = \frac{\gamma}{\gamma - 1} \frac{dV}{d\theta} + V \frac{1}{\gamma - 1} \frac{dp}{d\theta} + hA_s(T_g - T_w) \frac{dt}{d\theta} \]

\[ dQ_{int} = \frac{1.3}{1.3 - 1} \frac{1327400}{1} \frac{0.00000480}{1} + 0.000297128 \frac{1}{1.3 - 1} \frac{20780}{1} \text{ Joules/°CA} \]

\[ dQ_{int} = (27.60 + 20.58106 + 6.018) \]

\[ dQ_{int} = 54.19 \text{ Joules/°CA} \]