Engineering Physics

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Engineering Physics 1 [Rotational Mechanics]

1. **Angular conversions:** $d = r\Theta$ $v = r\omega$ $a = r\boldsymbol{\alpha}$

2. **Moment of Inertia** (I) kilograms metres squared [kg m²]

3. **Moment of Inertia Equation:** $I = \sum mr^2$

   [where m is the mass of each point (within the body) and r is its distance from the axis of rotation]

4. **Angular Momentum** (L) kilogram metres squared per second [$\text{kg m}^2\ \text{s}^{-1}$ or N m s]

5. **Principle of Conservation of Angular Momentum:** In the absence of external torques the total angular momentum of a system remains constant (i.e. $\Sigma L_{\text{final}} = \Sigma L_{\text{initial}}$).

6. **Flywheel Uses:** Storing rotational kinetic energy; smoothing torque and/or angular velocity (stores energy when input torque > output torque, supplies energy when input toque < output torque).

7. **Flywheel advantages:** Efficient; long lasting; short recharge and discharge time; environmentally friendly. [Disadvantages: large and heavy [with high internal mass]; safety risk [fragmentation]; frictional energy loss; gyroscopic effect can interfere with motion if installed in moving body.]

Engineering Physics 2 [Thermodynamics : Concepts]

1. **First Law of Thermodynamics:** The *net* thermal energy supplied *to* the system (Q) is equal to the sum of the *net* internal energy *gained* by the system (ΔU) and the *net* work done *by* the system (W).

$$Q = \Delta U + W$$

2. **Second Law of Thermodynamics:** It is impossible to convert thermal energy continuously to work without at the same time transferring some thermal energy from a hotter to a colder body. [*ALT: All real processes occur in such a way that there is a net increase in entropy.]*

3. **Work Done Equation:** $W = p\Delta V$

4. **Adiabatic Change:** No flow of *thermal energy* into or out of system. Takes place rapidly, leaving *insufficient time* for flow of thermal energy ($\Delta Q = 0 \therefore +\Delta W = -\Delta U$).

5. **Isothermal Change:** No change in *temperature* of system. Takes place slowly, allowing *sufficient time* for flow of thermal energy ($\Delta U = 0 \therefore +\Delta Q = +\Delta W$).

6. **Isochoric Change:** No change in *volume* of system. No net work is therefore done on or by the system ($\Delta W = 0 \therefore +\Delta Q = +\Delta U$).

7. **Isobaric Change:** No change in *pressure* of system.

Engineering Physics 3 [Thermodynamics : Theoretical Heat Engines]

1. **Heat Engine Definition:** Heat engines extract work from a system when thermal energy flows from a hot space to a cold space along the thermal gradient [i.e. they convert thermal energy into useful work].

2. **Carnot Cycle:** Provides the *maximum* theoretical efficiency of a *reversible* engine. Maximum efficiency depends upon the cold-space to hot-space ratio.

3. **Carnot Indicator Diagram:** Isothermal compression (Q_{out}) → Adiabatic compression → Isothermal expansion (Q_{in}) → Adiabatic expansion.

4. **Otto Cycle:** Idealised petrol engine in which the same air is taken continuously through a cycle. Maximum efficiency depends upon compression and specific heat ratios.

5. **Otto Indicator Diagram:** Adiabatic compression → Isochoric heating → Adiabatic expansion → Isochoric cooling.

6. **Diesel Cycle:** Idealised diesel engine in which the same air is taken continuously through a cycle. Maximum efficiency depends upon compression, specific heat *and* cutoff ratios.

7. **Diesel Indicator Diagram:** Adiabatic compression → Isobaric expansion → Adiabatic expansion → Isochoric cooling.

Engineering Physics 4 [Thermodynamics : Practical Heat Engines]

1. **No Adiabats:** Compression and expansion do not take place fast enough to avoid heat losses from system.

2. **No Isochor(s):** Cooling [and heating] does not take place at constant volume as the pistons are moving continuously.

3. **No Isobar [for diesel]:** Heating does not take place at constant pressure as the rate of combustion of fuel cannot be completely controlled.

4. **Corners rounded** because inlet/exhaust valves are needed and take a finite time to open and close.

5. **Maximum temperature** not realised due to imperfect combustion of fuel and incomplete scavenging of combustion products from cylinder (which also increases friction [and hence friction power] between cylinder and piston due to viscous residue).

6. **Indicated area of main loop smaller** (see all of above) so less work is done per cycle, reducing efficiency.

7. **Pumping Loop:** Pumping loop required (≈ atmospheric pressure) for induction and exhaust because real engines cannot take same fluid continuously through cycle (area of pumping loop subtracted from main loop, further reducing efficiency).

Engineering Physics 5 [Thermodynamics : Four Stroke Engine]

1. **Induction Stroke:** Inlet valve opens; piston moves down cylinder; pressure differential draws in air+fuel mix (for petrol) or just air (for diesel – fuel is injected when air temperature has increased dramatically (≈550°C) during compression).

2. **Compression Stroke:** Inlet value closes; piston moves up cylinder; fuel+air mixture ignites near end of stroke; sudden increase in temperature and pressure.

3. **Expansion Stroke:** High pressure forces piston down cylinder; work is done on piston by expanding gas (hence 'power stroke'); work transferred to output shaft via connecting rod.

4. **Exhaust Stroke:** Exhaust valve opens; pressure differential expels combustion products.

5. **Ignition Process:** Fuel+air mixture is ignited with a spark in a petrol engine but simply through high temperature in a diesel engine.

6. **Ignition Timing:** The fuel+air mixture is ignited just *before* the end of the compression stroke to ensure combustion is ongoing for whole of expansion stroke, maximising pressure (and hence work done) on descending piston.

7. **Additional Key Engine Components:** Camshaft; spark plug; induction coil; electronic control unit (ECU); coolant; sump; bearings; oil; crankshaft; turbocharger+impeller.

Engineering Physics 6 [Thermodynamics : Engine Efficiency]

1. **Input Power:** Calorific power delivered to engine by flow of fuel.

2. **Indicated Power:** The maximum theoretical power developed by expanding gas in cylinders [*ALERT: check number of cylinders and divide engine frequency by two (as each four-stroke cycle requires two output shaft revolutions)*]

3. **Friction Power:** The power lost between cylinder and output shaft due to: friction between piston and cylinder; power used to drive valve gear and pumps (oil/coolant/fuel injection); power used in induction and exhaust strokes.

4. **Brake (Output) Power:** The power delivered to the output (crank)shaft. [Indicated Power – Friction Power or $\tau\omega$]

5. **Thermal Efficiency:** $\varepsilon = \frac{P_{indicated}}{P_{input}}$ [≈ 30-40%]

6. **Mechanical Efficiency:** $\eta = \frac{P_{output}}{P_{indicated}}$ [≈ 80-95%]

7. **Overall Efficiency:** $Overall\ Efficiency = (\varepsilon)(\eta) = \frac{P_{output}}{P_{input}}$ [≈ 30-35%]

Engineering Physics 7 [Thermodynamics : Reversed Heat Engines]

1. **Reversed Heat Engine Definition:** Reversed heat engines do work on a system, causing thermal energy to flow from a cold space to a hot space against the thermal gradient.
2. **Heat pumps and refrigerators** are identical in principle, differing only in their intended use.
3. **Heat Pump Definition:** Heat pumps heat a hot space by doing work on a system, causing thermal energy to flow from a cold space (such as the ground or a lake) to the hot space (such as a house) against the thermal gradient.
4. **Refrigerator Definition:** Refrigerators cool a cold space by doing work on a system, causing thermal energy to flow from a cold space (inside the refrigerator) to a hot space against (outside the refrigerator) the thermal gradient.
5. **Key Design Elements:** Compressor; evaporator; throttle valve; condenser.
6. **Heat pumps** are cheaper to run than conventional electric or gas heaters because more energy is 'pumped' into the hot space than is used to drive the compressor.
7. **Coefficient of Performance:** $COP_{hp} = COP_{ref} + 1$