1. Turning Moment Diagrams

A curve showing the variation of the engine output torque or turning moment with the crank rotation is called the turning moment diagram. In a four stroke engine, the four strokes are identified as suction, compression, power and exhaust. Power due to combustion is actually generated only in one of the four strokes and hence the resulting torque on the crank shaft will also fluctuate in a similar manner. In the turning moment diagram there is one power peak for every two revolutions, i.e. 720°, of the crank shaft. The mean height of the torque curve gives the mean torque on the crank shaft.

![Turning moment diagram](image)

**Fig. 1:** Turning moment diagram without flywheel (1-cylinder 4-stroke engine)

For one complete thermodynamic cycle, the turning moment diagram for a single cylinder double acting steam engine is shown in figure-2. The torque is zero, when the crank angle (θ) is zero and maximum when the crank angle is 90° and it is again zero when crank angle is 180°. The area of the turning moment diagram represents the work done per revolution. The line AF is the mean resisting torque curve. In actual practice, the engine is assumed to work against the mean resisting torque, as shown by a horizontal line AF. When the turning
moment is positive, between points B and C (or D and E), the crankshaft accelerates. When the turning moment is negative (between points C and D), the crankshaft retards. The work done per cycle is,

$$ P = T_{\text{mean}} \times \theta $$

where, $T_{\text{mean}}$ = Mean torque,

$\theta$ = Angle turned (in radians) in one revolution.

Fig. 2. Turning moment diagram for a 1- cylinder, double acting steam engine.

Turning moment diagram for a compound steam engine having three cylinders is shown in Fig-3. The resultant turning moment diagram is the sum of the turning moment diagrams for each of the three cylinders. The cranks, in case of three cylinders, are usually placed at 120° to each other.

Fig. 16.3. Turning moment diagram for a multi-cylinder engine.
2. Flywheels

A flywheel is a device used to store energy when the supply of energy is more than the requirement, and releases it during the period when the requirement of energy is more than the supply. In case of steam engines, internal combustion engines, reciprocating compressors and pumps, the energy is developed during one stroke and the engine has to run for the whole cycle on this energy. The excess energy developed during power stroke is absorbed by the flywheel and releases it to the crankshaft during other strokes in which no energy is developed, thus rotating the crankshaft at a uniform speed. Hence a flywheel controls the speed variations caused by the fluctuation of the engine.

Flywheel absorbs mechanical energy by increasing its angular velocity and delivers energy by decreasing its angular velocity. This stored energy is supplied to the engine shaft during other non-power strokes of the engine. In this way a flywheel smoothenes the energy flow to the crank shaft and reduces the variations in engine speed. Few important applications of a flywheel are:

- Punching pressws,
- Steam engines
- Compressors
- Two-stroke and four-stroke cycle engines, etc.
- As energy absorbing device in regenerative braking systems for trains & automobile.

3. Maximum Fluctuation of Energy

The variation of energy above and below the mean torque curve is called fluctuation of energy. The difference between the maximum and the minimum energies during a complete cycle is known as maximum fluctuation of energy.

Turning moment diagram for a multi-cylinder engine is a wavy curve. The horizontal line AG represents the mean torque line. Let \( a_1, a_3, a_5 \) be the areas above the mean torque line and \( a_2, a_4 \) and \( a_6 \) be the areas below the mean torque line. These areas represent some quantity of energy which is either added or subtracted from the energy of the moving parts of the engine. Let the energy of the flywheel be calculated from Fig.,

Energy at A = E,
Energy at B = E + a_1
Energy at C = E + a_1 - a_2
Energy at D = E + a_1 - a_2 + a_3
Energy at E = E + a_1 - a_2 + a_3 - a_4
Energy at \( F = E + a_1 - a_2 + a_4 - a_5 \) 
Energy at \( G = E + a_1 - a_2 + a_3 - a_4 + a_5 - a_6 \) 
= Energy at A (cycle repeats)

Suppose that the greatest of energy is at B and minimum is at E. Therefore,

Maximum energy in flywheel \( = E + a_1 \)
Minimum energy in the flywheel \( = E + a_1 - a_2 + a_3 - a_4 \)
Maximum fluctuation of energy, \( \Delta E = \) Maximum energy – Minimum energy \( = (E + a_1) - (E + a_1 - a_2 + a_3 - a_4) = a_2 - a_3 + a_4 \)

Fig. 4. Turning moment diagram for a multi-cylinder steam engine.

4. Coefficient of Fluctuation of Speed

In most of the applications, particularly engines and machines, the flywheel’s job is to reduce fluctuations in speed by storing and releasing of kinetic energy. A measure of this ability of the flywheel is called the coefficient of speed fluctuation. The difference between the maximum and minimum speeds during a cycle is called the maximum fluctuation of speed. The ratio of the maximum fluctuation of speed to the mean speed is called the coefficient of fluctuation of speed.

Let, \( N_1 \) and \( N_2 \) = Maximum and minimum speeds in r.p.m. during the cycle, then the Coefficient of Fluctuation of Speed will be,

\[
C_s = \frac{N_1 - N_2}{N} = \frac{2(N_1 - N_2)}{N_1 + N_2}
\]

\[
= \frac{\omega_1 - \omega_2}{\omega} = \frac{2(\omega_1 - \omega_2)}{\omega_1 + \omega_2}
\]
5. **Coefficient of Fluctuation of Energy**

The ratio of the maximum fluctuation of energy to the mean energy or work done per cycle, is called the *coefficient of fluctuation of energy*. Let for the flywheel,

\[ m = \text{Mass in kg}, \]
\[ k = \text{Radius of gyration in metres}, \]
\[ I = \text{Moment of Inertia} \]
\[ \omega_1 = \text{maximum speed} \]
\[ \omega_2 = \text{minimum speed} \]

Therefore, energy stored in a flywheel will be,

\[
E = \frac{1}{2} \times I \omega^2 \quad \text{(in N-m)}
\]
\[
= \frac{1}{2} \times m. k^2 \omega^2
\]

A flywheel absorbs energy when its speed increases and gives up energy when its speed decreases. As the speed of flywheel changes from maximum to minimum value,

\[
\text{Maximum } K.E_1 = \frac{1}{2} \times I (\omega_1)^2
\]
\[
\text{Minimum } K.E_2 = \frac{1}{2} \times I (\omega_2)^2
\]

The maximum fluctuation of energy of the flywheel is therefore,

\[
\Delta E = K.E.1 - K.E.2
\]
\[
= \frac{1}{2} I \left[ (\omega_1)^2 - (\omega_2)^2 \right]
\]
\[
= I \left( \frac{\omega_1 + \omega_2}{2} \right) (\omega_1 - \omega_2)
\]
\[
= I \omega \left( \frac{\omega_1 - \omega_2}{\omega} \right)
\]
\[
= 2 I \omega \left( \frac{\omega_1 - \omega_2}{\omega} \right)
\]
\[
= I \omega \left( \omega_1 - \omega_2 \right)
\]
\[
= m. k^2 C_s
\]