Torque and RPM in Robotics

1. What is Torque?

Torque is the rotational equivalent of force. While force makes an object move in a straight line, torque causes it to rotate or twist around an axis. For example, when you tighten a screw using a screwdriver, you apply force at the handle, which creates torque that turns the screw.

Formula:

Torque (τ) = Force (F) × Distance (r)
Where:
τ = torque (N·m)
F = applied force (N)
r = distance from axis (m)

The farther away you apply force from the pivot, the greater the torque. In robotics, torque is crucial because motors rotate parts like wheels, arms, and joints.

Torque in Robotics

In robotics, torque determines how much twisting force a motor or joint can produce. It influences how much weight the robot can lift or move.

1. Motor Torque: Motors have torque ratings that show how much twisting force they produce.
   - High torque: lifts heavy loads.
   - Low torque: moves fast but can't lift heavy things.

2. Torque-Speed Trade-off: Torque and speed (RPM) are inversely related. Higher torque reduces speed, and higher speed reduces torque.

3. Torque in Joints: Each joint must generate enough torque to lift itself, other parts beyond it, and the payload.

4. Torque Sensors: Advanced robots use torque sensors for safety, collision detection, and precise motion control.

5. Types of Torque:
- Static Torque: to hold a position.
- Dynamic Torque: to move or accelerate.
- Stall Torque: maximum torque before the motor stalls.

Example of Torque Calculation

A robotic arm lifts a 2 kg object at 0.5 m distance.
Weight Force = 2 × 9.8 = 19.6 N

Torque = 19.6 × 0.5 = 9.8 N·m
Hence, the motor must produce at least 9.8 N·m of torque.

2. What is RPM?

RPM stands for Revolutions Per Minute. It indicates how fast something rotates. High RPM means fast rotation (less torque), and low RPM means slow rotation (more torque).

Torque vs RPM Relationship

They have an inverse relationship because the motor's power is limited.
Power (P) = Torque (τ) × Angular Speed (ω)
where $\omega = 2\pi \times \text{RPM} / 60$.

If torque increases, RPM decreases to keep power constant, and vice versa.

Example: Calculating Power from Torque and RPM

Given: Torque = 1 N·m, RPM = 3000
$\omega = 2\pi \times 3000 / 60 = 314.16$ rad/s
Power = 1 × 314.16 = 314.16 W (≈ 0.42 HP)

Role of Gears in Robotics

Gearboxes adjust torque and RPM:
- 1:1 → No change.
- 1:5 reduction → Torque ×5, RPM ÷5.
- 5:1 increase → Torque ÷5, RPM ×5.

Example: Motor = 1 N·m at 3000 RPM, 1:5 gearbox → 5 N·m at 600 RPM. Result: slower but stronger motion.

Motor Specifications in Robotics

Key motor parameters:
- Rated Torque: Continuous torque (e.g., 2 N·m)
- Stall Torque: Max torque before stalling (e.g., 5 N·m)
- No-load RPM: Speed when no load is attached (e.g., 5000 RPM)

Summary Table

Concept | Meaning | Unit
Torque (τ) | Twisting force | N·m
RPM | Rotational speed | rev/min
Power (P) | Work per second | Watts
Formula | $P = \tau \times 2\pi \times \text{RPM} / 60$ | —
Trade-off | More torque = less speed, and vice versa | —

Example in a Robot Arm

If your robot arm needs 10 N·m torque at 100 RPM and your motor provides 1 N·m at 1000 RPM:

Use a 10:1 gearbox → Output = 10 N·m torque, 100 RPM speed. This makes the arm stronger and suitable for lifting loads.