EC4.404: Mechatronics System Design

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General Information

Mechatronics: Study of the integration of mechanical hardware, electrical/electronic hardware with computer hardware and software. Named by Tetsuro Mori from Japan when working with Yaskawa Electric Coorporation.
Applications: Robotics, Aerospace industry, automotive industry, process industry etc.

Course Objective: To introduce the design and development of a mechatronic system.
Instructors: Harikumar Kandath and Nagamanikandan Govindan.

Course Contents

UNIT 1 ◊ Sensors - structure of measurement systems, static characteristics, dynamic characteristics. ◊ Sensors in robotics - position, speed, acceleration, orientation, range. ◊ Actuators - general characteristics, motors, control valves.

UNIT 2 ◊ Computer based feedback control: Sampled data control, sampling and hold, PID control implementation, stability, bilinear transformation.

Instructor: Harikumar Kandath

Course Contents

UNIT 3 ◊ : Introduction to mechanical elements and transformations, basic concepts of kinematics and dynamics.

UNIT 4 ◊ Design and analysis of mechanisms.

UNIT 5 ◊ Programming and hardware experiments.

Instructor: Nagamanikandan Govindan

Sensors in Ground Robot

- Wheel Encoder
- Magnetometer
- Inertial Measurement Unit (IMU): contains Accelerometer and Gyroscope.
- Global Positioning System (GPS)
- Range measuring sensor (LIDAR, ultrasonic, camera)

Sensors in UAV

- Inertial Measurement Unit (IMU) contains Accelerometer and Gyroscope.
- Altimeter
- Airspeed sensor
- Magnetometer
- Global Positioning System (GPS)
- Range measuring sensor (LIDAR, ultrasonic, RADAR, camera)

Sensors in Robotic Manipulator

- IMU
- Encoder
- Force-Torque sensor
- Camera

Range Measurement

Applications

- Obstacle Avoidance
- SLAM (Simultaneous Localization and Mapping)
- UAV Landing
- Accurate mapping of a region with elevation
- Distance to the target vehicle
- Atmospheric Physics
- Underwater survey

Major Classification

- Active (LIDAR, RADAR, ultrasonic)
- Passive (Camera)

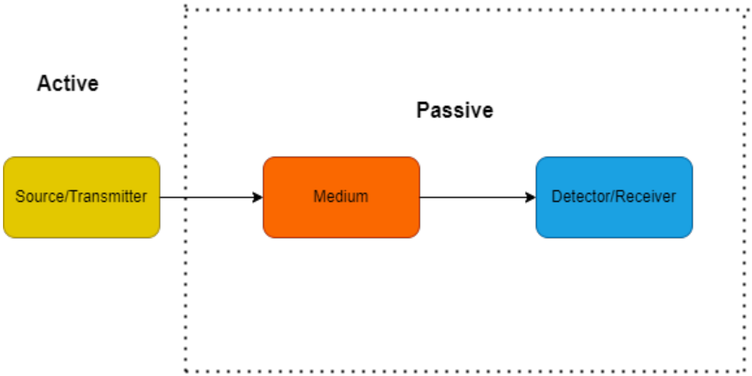

Figure: Structure of a range measuring system

Ultrasonic Range Measurement (SONAR)

- Utilizes sound waves with frequencies higher than human audible limit (typically above 18 KHz).
- Main component is piezoelectric material that undergoes deformation when a voltage is applied (transmitter) and also can convert a deformation into an electrical signal (receiver).
- Applying a sinusoidal voltage with a specified frequency vibrates the piezoelectric material with the same frequency, resulting in the generation of ultrasonic waves through the medium.

$$Range = 0.5 \times (V_s \times t) \tag{1}$$

V_s= speed of sound (m/s), t = time elapsed between sending and receiving (s).

Frequency Response

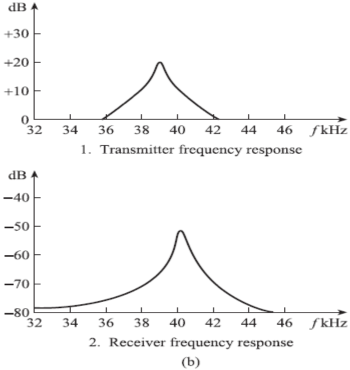

Figure: Transmitter and Receiver Frequency Response

Force-Torque Sensor

Force sensors are designed to detect forces applied between their base and sensing plate. Force-Torque Sensors, also known as FT Sensors, detect both forces and torques. They are usually placed on a robot's arm, just before the end-effector.

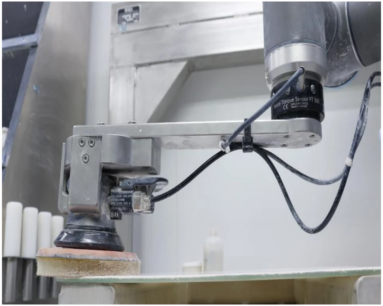

Figure: Force-Torque sensor installed in a robotic manipulator

Force-Torque Sensor

- Piezoelectric
- Strain Gauge
- Capacitive

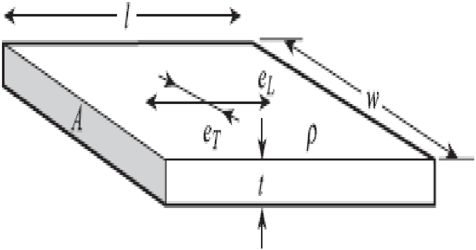

Figure: Strain Gauge

Strain Gauge : Basics

strain $= \delta_d / d$ (change in dimension/ original dimension).

$$E = \frac{stress}{strain} \tag{2}$$

E is the Young's modulus of the material.

$$e_T = -\nu e_L \tag{3}$$

e_T is the transverse strain and e_L is the longitudinal strain and ν is the Poisson ratio (0.25 to 0.40).

$$R = \frac{\rho l}{A} \tag{4}$$

R is the resistance in ohms, l is the length of the material, A is the cross sectional area and ρ is the resistivity in ohm-m.

Relation between applied force and change in resistance

NB: Applied force is called "stress" here.

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho} \tag{5}$$

$$\frac{\Delta R}{R} = (1 + 2\nu) e_L + \frac{\Delta \rho}{\rho} \tag{6}$$

$$\frac{\Delta R}{R} = G e_L \tag{7}$$

$$G = (1 + 2\nu) + \frac{1}{e_L} \frac{\Delta \rho}{\rho} \tag{8}$$

G is the gauge factor (2.0 to 2.2).

Actuators

Role of Actuator: To enable/disable or to control motion.

- Motor: DC motor, Servo motor, Stepper motor, BLDC motor.
- Control valve: ON-OFF (solenoid), linear, quick opening, equal percentage.

Key parameters:

- Amplitude range
- Bandwidth
- Slew rate
- Power output
- Efficiency

Direct Current (DC) Motor

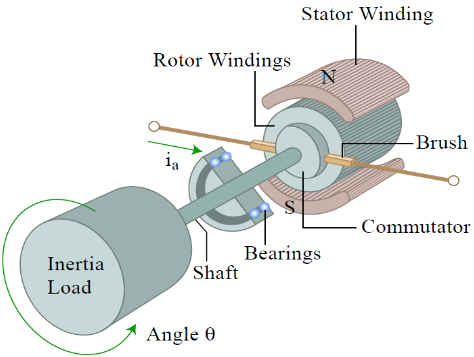

Figure: Parts of a DC motor

DC Motor - Basic Equations

Motor torque τ_m (Nm), current i_m (A), K_t is the torque constant (Nm/A), η_m is the motor efficiency (0-1), $\omega_m = \frac{d\theta_m}{dt}$ is the motor angular velocity (rad/s).

$$\tau_m = K_t i_m \tag{9}$$

Power input (w)

$$P_{in} = V_m i_m \tag{10}$$

Power output (w)

$$P_{out} = \tau_m \omega_m \tag{11}$$

Considering losses,

$$P_{out} = \eta_m P_{in} \tag{12}$$

$$\tau_m \omega_m = \eta_m V_m i_m \tag{13}$$

$$\omega_m = \frac{\eta_m}{K_t} V_m \tag{14}$$

Dynamics

Electrical circuit

$$L\frac{di_m}{dt} + Ri_m + E_b = V_m \tag{15}$$

Mechanical circuit

$$J\frac{d^2\theta_m}{dt^2} + B\frac{d\theta_m}{dt} + k\theta_m = \tau_m \tag{16}$$

$$E_b i_m = \tau_m \omega_m \tag{17}$$

DC Servomotor

DC Servomotor: A DC motor with angular position feedback and control mechanism to maintain the desired angular position under varying load torque.

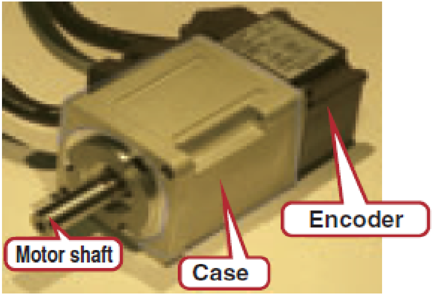

Figure: Servomotor: DC motor with encoder feedback

Brush-Less Direct Current (BLDC) Motor

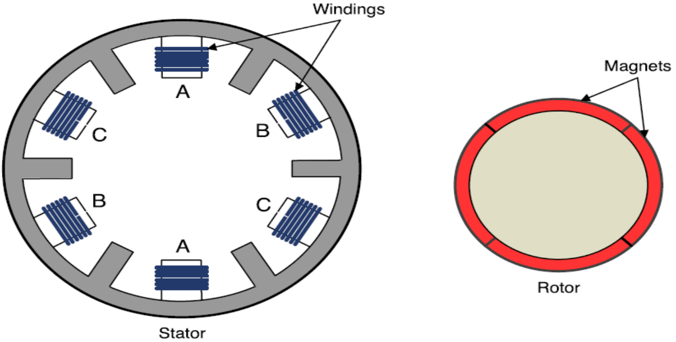

Figure: Brush-Less DC motor with 3 phases

Input to (BLDC) Motor

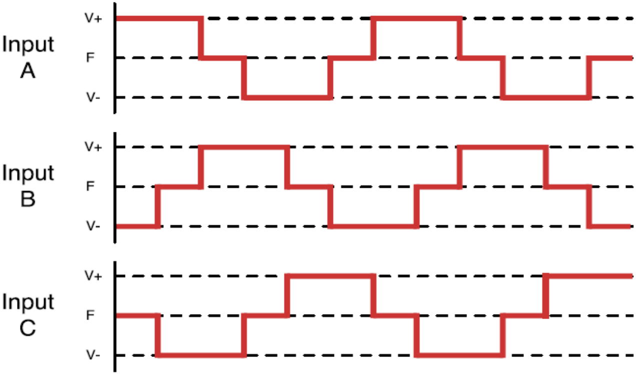

Figure: Input sequence to Brush-Less DC motor

Stepper Motor

Rotates for a specified angular displacement and then stop.

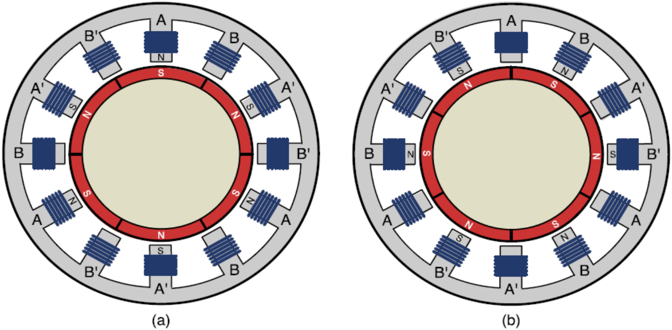

Figure: Stepper motor: Winding arrangement for 30^o rotation.

Control Valves

Control valves regulate the flow of a fluid (liquid or gas).

- ON-OFF (Solenoid) valve.
- Quick opening valve.
- Linear valve.
- Equal percentage valve.

Basic operation

Pneumatic signal based control.
Change in flow rate related to change in pressure across the valve opening.

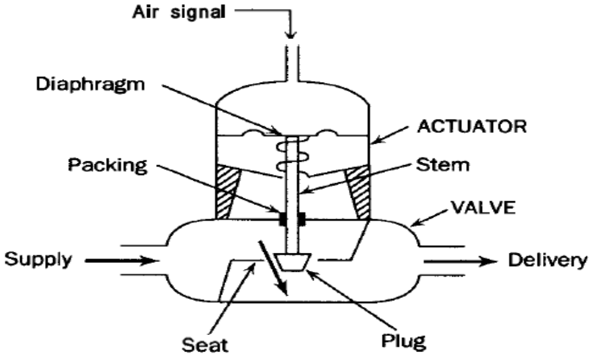

Figure: Working of a control valve

Types of Valve

I: Linear, II: Equal percentage, III: Quick opening.

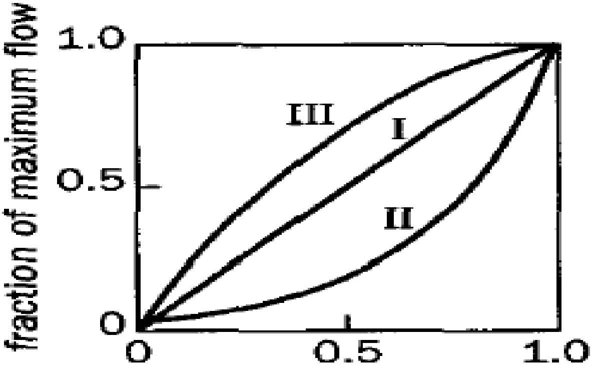

Figure: Input-Output relation for 3 types of control valves

THANK YOU