

UNIT - V

ROBOT DYNAMICS

model of dynamics:-

Robot by the programmable device is which having 4-degree of which is used not only for various torques but also for transferring the parts, tools, with variable programmed motion. In specified manufactured take in robots.

manipulator dynamics:-

The study of motion the various line is nothing but manipulator dynamics. They information various takes torque acting at the joint of the manipulator joints are activated by various devices such as

- 1) hydraulic activation.
- 2) pneumatic activation.
- 3) electrical activation

By giving the information of various lines by the activation there is possibility of simulation of manipulator and also design of manipulator during

made cycle. The dynamic behaviour is affected by the manipulator. The two types of the forces exhaust that of the manipulator.

- ① Internal force
- ② External forces.

Internal forces are obtained by the motion caused by various links and joints.

External forces there are load acting on the manipulator and gravitational force. When the various dynamic behaviour of the manipulator is denoted by the internal forces.

- ① Lagrange
- ② Newton
- ③ Euler

① Lagrange -

It study that various links and motions, energies.

$$L = k - P$$

A scalar function Lagrange which use the mathematical representation of the manipulator.

$$L = k - P$$

Where

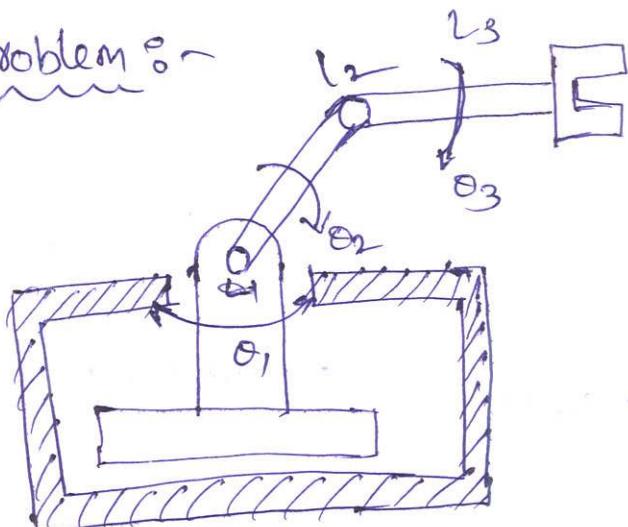
$L = \text{Lagrange}$

$K = \text{Total kinematic energies of the manipulator.}$

$P = \text{Total potential energies of the manipulator.}$

Jacobian

problem :-



$$\alpha_1 = 90^\circ$$

$$\alpha_2 = 0^\circ$$

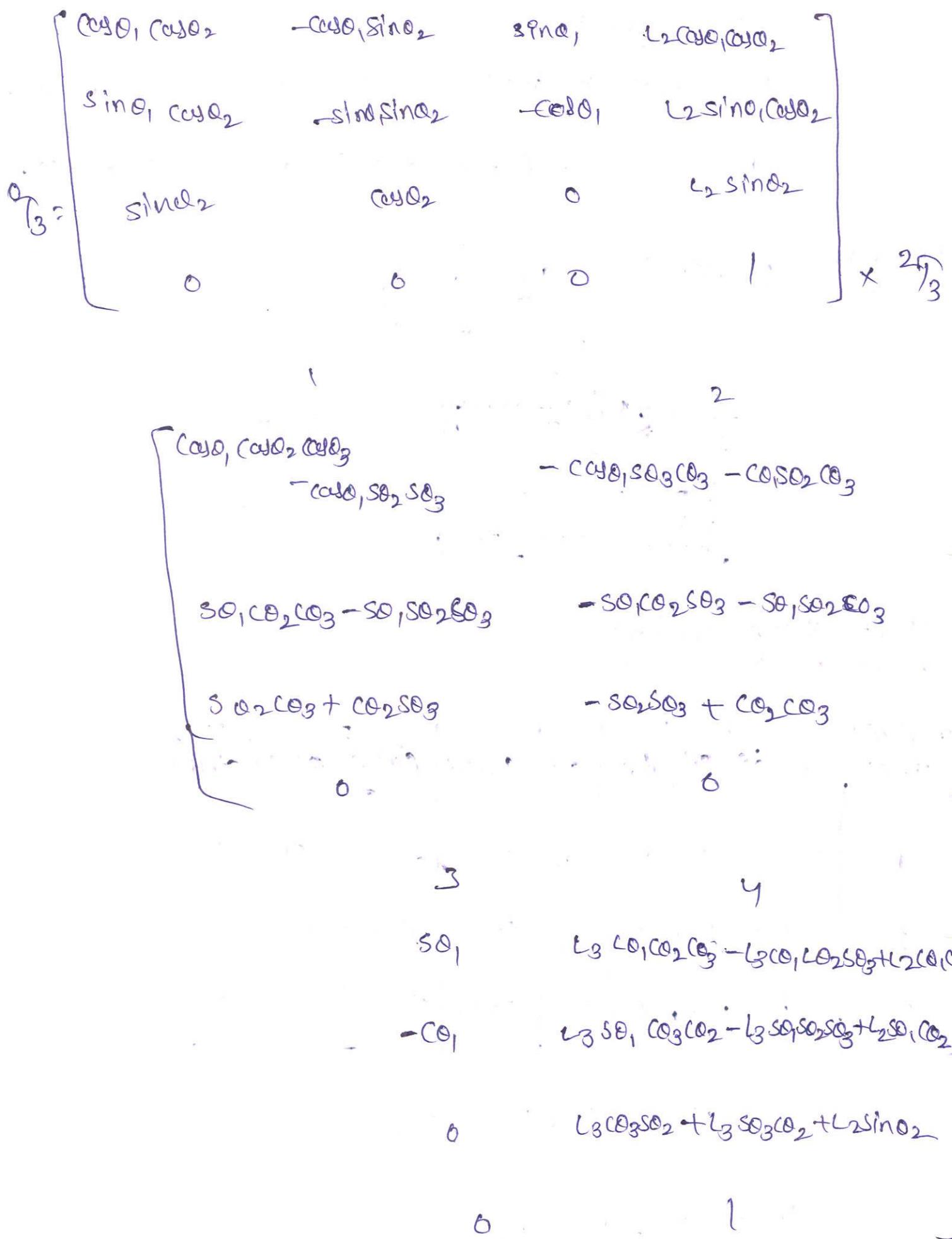
$$\alpha_3 = 0^\circ$$

Joint Link Parameters :-

| Joint Links | a_i | d_i | θ_i | α_i | q_i | $\cos\theta_i$ | $\sin\theta_i$ | $\cos\alpha_i$ | $\sin\alpha_i$ |
|----------------|-------|-------|------------|------------|------------|----------------|----------------|----------------|----------------|
| 1 | 0 | 0 | θ_1 | 90° | θ_1 | $\cos\theta_1$ | $\sin\theta_1$ | 0 | 1 |
| 2 | L_2 | 0 | θ_2 | 0 | θ_2 | $\cos\theta_2$ | $\sin\theta_2$ | 1 | 0 |
| 3 | L_3 | 0 | θ_3 | 0 | θ_3 | $\cos\theta_3$ | $\sin\theta_3$ | 1 | 0 |

$${}^0T_3 = {}^0T_1 \cdot {}^1T_2 \cdot {}^2T_3$$

$${}^0T_3 = {}^0T_1 \cdot {}^1T_2 \cdot {}^2T_3.$$



Compose with end effector Matrix -

$$\left(\begin{array}{cccc} n_x & o_x & a_x & d_x \\ n_y & o_y & a_y & d_y \\ n_z & o_z & a_z & d_z \\ 0 & 0 & 0 & 0 \end{array} \right)$$

$$\Rightarrow n_x = \text{cos}\theta_1 \text{cos}\theta_2 \text{cos}\theta_3 + \text{sin}\theta_2 \text{sin}\theta_3$$

$$n_y = \text{sin}\theta_1 \text{cos}\theta_2 \text{cos}\theta_3 - \text{cos}\theta_1 \text{sin}\theta_2 \text{sin}\theta_3$$

$$n_z = \text{sin}\theta_1 \text{sin}\theta_2 \text{cos}\theta_3$$

$$\Rightarrow o_x = -\text{cos}\theta_1 \text{sin}\theta_2 \text{cos}\theta_3 - \text{cos}\theta_1 \text{cos}\theta_2 \text{sin}\theta_3$$

$$o_y = -\text{sin}\theta_1 \text{sin}\theta_2 \text{cos}\theta_3 - \text{sin}\theta_1 \text{cos}\theta_2 \text{sin}\theta_3$$

$$o_z = -\text{sin}\theta_1 \text{cos}\theta_2 \text{cos}\theta_3$$

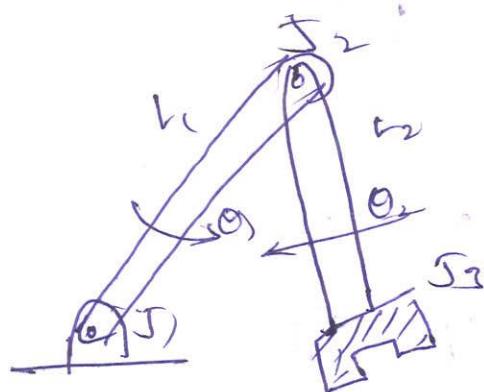
$$\Rightarrow a_x = s\theta_1 \quad a_y = c\theta_1 \quad a_z = 0$$

$$\Rightarrow d_x = l_3 \text{cos}\theta_1 \text{cos}\theta_2 \text{cos}\theta_3 - l_3 \text{cos}\theta_1 \text{sin}\theta_2 \text{cos}\theta_3 + l_2 \text{cos}\theta_1 \text{cos}\theta_2$$

$$d_y = l_3 \text{sin}\theta_1 \text{cos}\theta_2 \text{cos}\theta_3 - l_3 \text{cos}\theta_1 \text{cos}\theta_2 \text{sin}\theta_3 + l_2 \text{sin}\theta_1 \text{cos}\theta_2$$

$$d_z = l_3 \text{cos}\theta_1 \text{sin}\theta_2 + l_3 \text{sin}\theta_1 \text{cos}\theta_2 + l_2 \text{sin}\theta_1$$

②



Joint - link parameters:-

| link(i) | a _i | θ _i | d _i | x _i | q _i | C _{oxi} | S _{oxi} | C _{oxz} | S _{oxz} |
|---------|----------------|----------------|----------------|----------------|----------------|------------------|------------------|------------------|------------------|
| 1 | L ₁ | θ ₁ | 0 | 0 | θ ₁ | C _{ox1} | S _{ox1} | 1 | 0 |
| 2 | L ₂ | θ ₂ | 0 | 0 | θ ₂ | C _{ox2} | S _{ox2} | 1 | 0 |

D-H Ablation:-

$$\begin{pmatrix}
 C_{ox1} & -S_{ox1}C_{oxz1} & R_{ox1}S_{oxz1} & C_{oxz1} \\
 S_{ox1} & C_{ox1}C_{oxz1} & -C_{ox1}S_{oxz1} & A_1S_{ox1} \\
 0 & S_{oxz1} & C_{oxz1} & d_1 \\
 0 & 0 & 0 & 1
 \end{pmatrix}$$

$$OT_2 = OT_1 \cdot T_2$$

$$OT_1 = (87) \cdot 100 = 8700$$

$$OT_2 = \begin{cases} CesO & -SmO_2 \\ SmO_2 & CesO \\ 0 & 0 \\ 0 & 0 \end{cases} \quad \begin{matrix} 0 & 0 \\ 0 & 1 \end{matrix}$$

$L_1(CesO)$
 $L_1(SmO_2)$
 $(L_1 SmO_2 + O)$

$$OT_2 = \begin{cases} CesO & -SmO_2 \\ SmO_2 & CesO \\ 0 & 0 \end{cases} \quad \begin{matrix} 0 & 0 \\ 0 & 1 \\ 0 & 0 \end{matrix}$$

$L_2(CesO)$
 $L_2(SmO_2)$

$$OT_2 = \begin{cases} CesO-SmO_2 & -CO_2-SO_2-CO_2 \\ SO_2-CO_2+SO_2-CO_2 & -SO_2-SO_2+CO_2-CO_2 \end{cases} \quad \begin{matrix} 0 & 0 \\ 0 & 1 \\ 0 & 0 \end{matrix}$$

L_2SO_2, L_2CO_2
 $+ L_1SO_2$

The above matrix compare with end effect matrix

$$\begin{cases} 1 = C^T & \begin{matrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix} \\ 0 = A^T & \begin{matrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix} \\ 1 = E^T & \begin{matrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix} \\ 0 = G^T & \begin{matrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix} \end{cases}$$

$$M_x = \cos\theta_2 - \sin\theta_2$$

$$m_z = -\cos\theta_2 = -\sin\theta_2$$

$$m_n = 0$$

$$dx = \begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$m_y = 0$$

$$\begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

In the above matrix m_{12} subtract m_{12} from m_{12}

$$\begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.707 & 0 & 0.707 \\ 0 & 1 & 0 \\ 0.707 & 0 & 0.707 \end{bmatrix}$$

Interpret this transformation as a rotation of 45 degrees about the z-axis.

$$m_x = -0.707$$

$$m_y = 0.707$$

$$m_n = 0$$

$$dx = -0.707l_2$$

$$m_x = 0.707$$

$$m_y = -0.707$$

$$m_n = 0$$

$$dy = 0.707l_2$$

$$dz = 0$$

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Trajectory planning

Trajectory planning is a major area in robotics as it gives way to autonomy vehicles. Trajectory planning is sometimes referred to as path planning. Trajectory planning is distinct from path planning in that it is parameterized by time.

Path: A path is defined as a sequence of robot configurations in a particular order without regard to the timing of these configurations.

So if a

Trajectory: Trajectory is concerned about when each part of the path must be attained, thus specifying time.

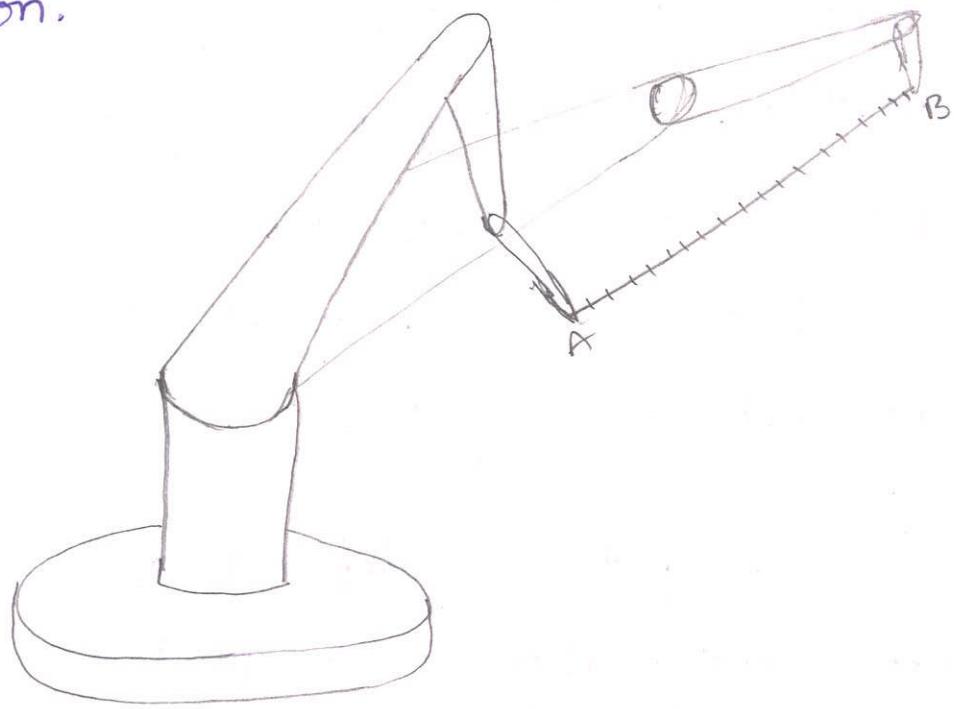
* Path is same while the trajectory is depends on the velocities and accelerations.

Joint space scheme:

Consider a six-axis robot at a point A in space, which is directed to move to another point B. Using the inverse kinematic equations of the robot the total joint displacements that the robot needs to make to get the new location.

The joint values they calculated can be used by the controller to drive the robot joints to their new values and consequently, move

the robot arm to its new position. The description of the motion to be made by the robot by its joint values is called - joint space description.



Third order Polynomial Trajectory Planning:-

The initial location and orientation of the robot is known, and using the inverse kinematic equations. we find the final joint angles for the desired position and orientation. Now consider one of the joints which at the beginning of the motion segment at time t_i is at θ_i . We desire to have the joint move to a new value of θ_f and t_f . One way to do this is to use a polynomial to plan the trajectory, such that the initial and final boundary conditions match what we already know. namely that θ_i and θ_f are known, and that the velocities at the beginning and the end of the motion segment are zero. These four pieces of information allow us to solve for four unknowns in the form of

$$\theta(t) = c_0 + c_1 t + c_2 t^2 + c_3 t^3 \rightarrow 1$$

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where the initial and final conditions are.

$$\theta(t_i) = \theta_i, \quad \dot{\theta}(t_f) = \dot{\theta}_f, \quad \ddot{\theta}(t_i) = 0, \quad \ddot{\theta}(t_f) = 0.$$

taking the first derivative of the eq ①

$$\dot{\theta}(t) = c_1 + 2c_2 t + 3c_3 t^2.$$

Substituting the final and initial condition into equation ①.

$$\theta(t_i) = c_0 = \theta_i$$

$$\theta(t_f) = c_0 + c_1 t_f + c_2 t_f^2 + c_3 t_f^3.$$

$$\dot{\theta}(t_i) = c_1 = 0.$$

$$\dot{\theta}(t_f) = c_1 + 2c_2 t_f + 3c_3 t_f^2 = 0.$$

By solving the four equations simultaneously we get the necessary values for the constants.

→ Similarly fifth-order polynomial trajectory planning. equation is

$$\theta(t) = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + c_4 t^4 + c_5 t^5$$

$$\dot{\theta}(t) = c_1 + 2c_2 t + 3c_3 t^2 + 4c_4 t^3 + 5c_5 t^4$$

$$\ddot{\theta}(t) = 2c_2 + 6c_3 t + 12c_4 t^2 + 20c_5 t^3.$$

⇒ Higher order trajectories:-

$$\theta(t) = c_0 + c_1 t + c_2 t^2 + \dots + c_{n-1} t^{n-1} + c_n t^n.$$

Robot actuators and feed back component

Hydraulic actuators:-

- Hydraulic Systems and actuators offer a high power-to-weight ratio, large forces at low speeds (both linear and rotary actuators) compatibility with microprocessor and electronic controls, and tolerance of extreme hazardous environments.
- However, due to leakage problems, which is almost inevitable in hydraulic systems, and due to their power unit weight and cost, they are not used any more. Nowadays most robots are electric. However there are still many robots in industry, that have hydraulic actuators.

$$T = \int_{r_1}^{r_2} P \cdot r \cdot dA = \int_{r_1}^{r_2} P \cdot r \cdot t \cdot dr = pt \int_{r_1}^{r_2} r \cdot dr = \frac{1}{2} pt(r_2^2 - r_1^2)$$

A hydraulic system generally consists of the following parts:-

Pneumatic devices:-

Pneumatic devices are principally very similar to hydraulic systems.

A source of pressurized air is used to power and drive linear or rotary cylinders, controlled by manual or electrically controlled solenoid valves. Since the source of pressurized air is separate from the moving actuators, these systems have lower inertial loads.

however, since pneumatic devices operate at a much lower air pressure, usually up to 100-120 PSI, their power-to-weight ratio is much lower than hydraulic systems.

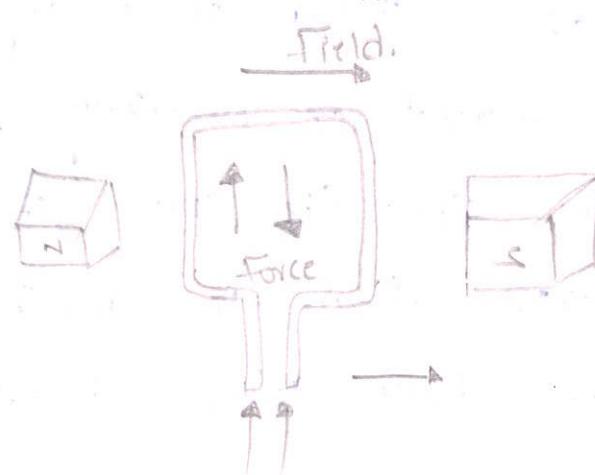
The major problems with pneumatic devices is that air is compressible and thus it compresses and deforms under load. As a result, pneumatic cylinders are usually only used for insultn purposes.

Electric Motors:-

When a wire carrying a current is placed within a magnetic field, it experiences a force normal to the plane formed by the magnetic field and the current as $\vec{F} = \vec{I} \times \vec{B}$. If the wire is attached to a center of rotation, the resulting torque will cause it to rotate about the center of rotation.

- DC motors
- reversible DC motors
- brushes DC motors
- Stepper motors.

Except for stepper motors, all other types of motors can be used as a servomotor.



Feedback Components:

Sensor characteristics :-

To choose an appropriate sensor for a particular need, one has to consider a number of different characteristics.

→ cost

→ Size

→ weight

→ Type of output

→ Interfacing

→ Resolution

→ Sensitivity

→ Linearity

→ Range

→ Response time

→ Frequency response

→ Reliability

→ Accuracy

→ Repeatability

Position Sensors :-

Position sensors are used to measure displacements. Both rotary and linear, as well as movements.

Potentiometers :-

A potentiometer converts position information into a variable voltage through a resistor. As the Sweeper on the resistor moves due to a change in position, the proportion of the resistance before or after the point of contact with the sweeper compared with the total resistance

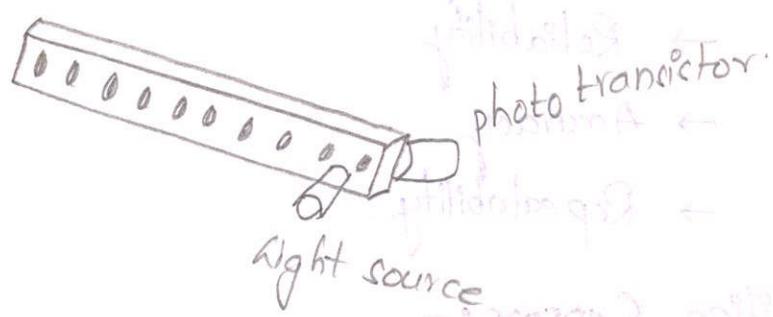
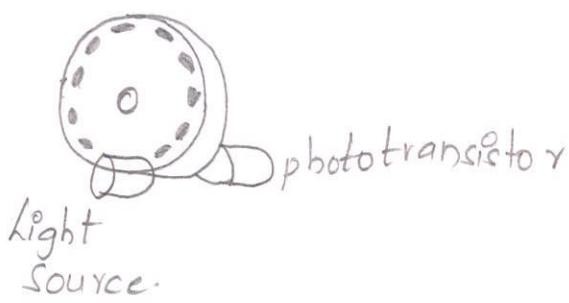
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Varies. Since in this capacity the potentiometer acts as a voltage divider, the output will be proportional to the resistance as

$$V_{out} = V_{cc} \frac{R_1}{R},$$

Encoders :-

An encoder is a simple device that can output a digital signal for each small portion of a movement. To do this, the encoder wheel or strip is divided into small sections as shown in figure.



The encoder disc is mounted on a rotating shaft. The distance between the holes is measured from center to center.

This is also referred to as the "pitch" of the encoder. If the pitch is equal, all the pulses are equally spaced. It is important that the pitch is equal so that when the phototransistor is being triggered, it is triggered consistently.

Robot Application in manufacturing.

General Considerations in robot material handling.

a) Part positioning and orientation :-

In most parts-handling applications the parts must be presented to the robot in a known position and orientation. Robots used in these applications do not generally possess highly sophisticated sensors (e.g. machine vision) that would enable them to seek out a part and identify its orientation before picking it up.

b) Gripper design :-

Special end effectors must be designed for the robot to grasp and hold the workpart during the handling operation. Design considerations for these grippers were discussed in chap. 5

c) Minimum distances moved :-

The material handling application should be planned so as to minimize the distances that the parts must be moved. This can be accomplished by proper design of the workcell layout (e.g. keeping the equipment in the cell close together) by proper gripper system (e.g. using a double gripper in a machine loading/unloading operation) and by careful study of the robot motion cycle.

d) Robot work volume :-

The cell layout must be designed with proper consideration given to the robot's capability to reach the required extreme locations in the cell and still allow room to maneuver the gripper.

e) Robot weight capacity :-

There is an obvious limitation on the material handling operation that the load capacity of the robot must not be exceeded. A robot with sufficient weight-carrying capacity must be specified for the application.

Accuracy and repeatability :-

Some applications require the materials to be handled with very high precision. Other applications are less demanding in this respect. The robot must be specified accordingly.

Robot Configuration, degrees of freedom and control :-

Many parts transfer operations are simple enough that they can be accomplished by a robot with two or four points of motion.

Machine-loading applications often require more degrees of freedom.

Robot control requirements are unsophisticated for most material-handling operations, palletizing operations, and picking parts from a moving conveyor are examples where the control requirements are more demanding.

Machine utilization problems :-

It is important for the application to effectively utilize all pieces of equipment in the cell. In a machine loading / unloading operation it is common for the robot to be working and the machine to be idle a high proportion of the time. To increase the utilization of the robot, consideration should be given to the possibility for the robot to service more than a single machine.

13.2 Material transfer applications.

- a) pick-and-place operations
- b) palletizing and related operations

13.3. Machine loading and unloading.

- a) Machine load / unload :- the robot loads a raw work part into the process and unloads a finished part. A machining operation is an example of this case.

- b) Machine loading :- the robot must load the raw work part or materials into the machine but the part is ejected from the machine by some other means. In a press working operation

The robot may be programmed to load sheet metal blanks into the press, but the finished parts are allowed to drop out of the press by gravity.

Machine unloading :- The machine produces finished parts from raw materials that are loaded directly into the machine without robot assistance. The robot unloads the part from the machine. Examples in this category include die casting and plastic modeling applications.

Robots have been successfully applied to accomplish the loading and or unloading function in the following production operations.

1. Die casting.
2. Plastic molding.
3. Forging and related operations
4. Machining operations
5. Stamping press operations.

Assembly and robotic Assembly Automation.

The term assembly is defined here to mean the fitting together of two or more discrete parts to form a new subassembly. The process usually consists of the sequential addition of components to a base part or existing subassembly to create a more complex subassembly or a complete product.

In our coverage of the application of robotics to assembly, the subject is divided into three areas as suggested by the preceding discussion:

1. Parts presentation methods
2. Assembly tasks.
3. Assembly cell designs.

Parts presentation methods:-

In order for a robot to perform an assembly task, the part that is to be assembled must be presented to the robot.

1. Parts located within a specific area (parts not positioned or oriented)
2. Parts located at a known position (parts not oriented)
3. Parts located in a known position and orientation.

Assembly operations.

Parts Mating :-

- a) Peg-in-hole
- b) Hole-on-peg
- c) Multiple peg-in-hole
- d) Stacking

Designing for robotic Assembly :-

Certain assembly tasks are more difficult for a robot to perform than others. If possible, this difficulty factor should be considered in the design of the product. As an example, for a robot to accomplish the screw-fastening operation without the use of an automatic screwdriver is difficult.

Inspection automation :-

Inspection is a quality control operation that involves the checking of parts assemblies, or products for conformance to certain criteria generally specified by the design engineering department.

Integrating inspection into the manufacturing process:

As it has been discussed earlier in this chapter, inspection is a vital component of the automated assembly process. This is true not only in assembly but also in other automated manufacturing methods as well. As the human operator is removed from the workstation, the function of checking the work must be taken over by other means. One of the features of a robotic workcell is that the inspection can usually be added for a nominal capital cost.

