ANTENNA (AZIMUTH & ELEVATION) POSITION CONTROL SYSTEM

YASEEN AL-TAIE

213996921

ESSE 3340

SPACE MECHANISM

Brendan Quine

INTRODUCTION

- Using a 4 bar mechanism to control the movements of the antenna.
- A 4-bar Grashof linkage control the elevation angle, while the base of the Grashof linkage control the azimuth angle. As we see in figure (1)(1) and (2)

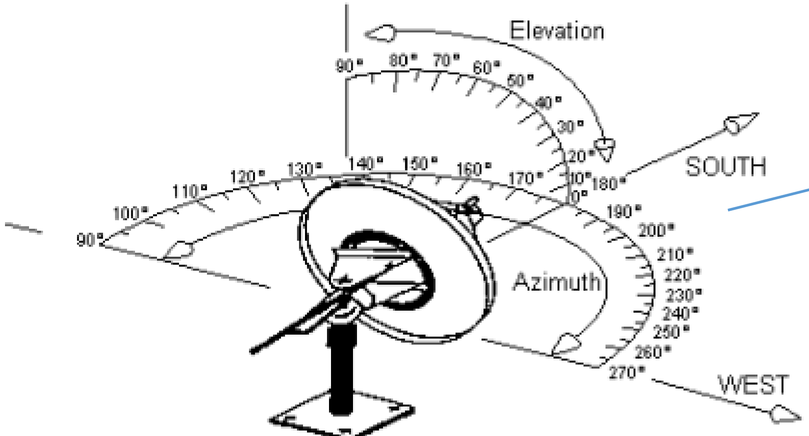

Figure 1

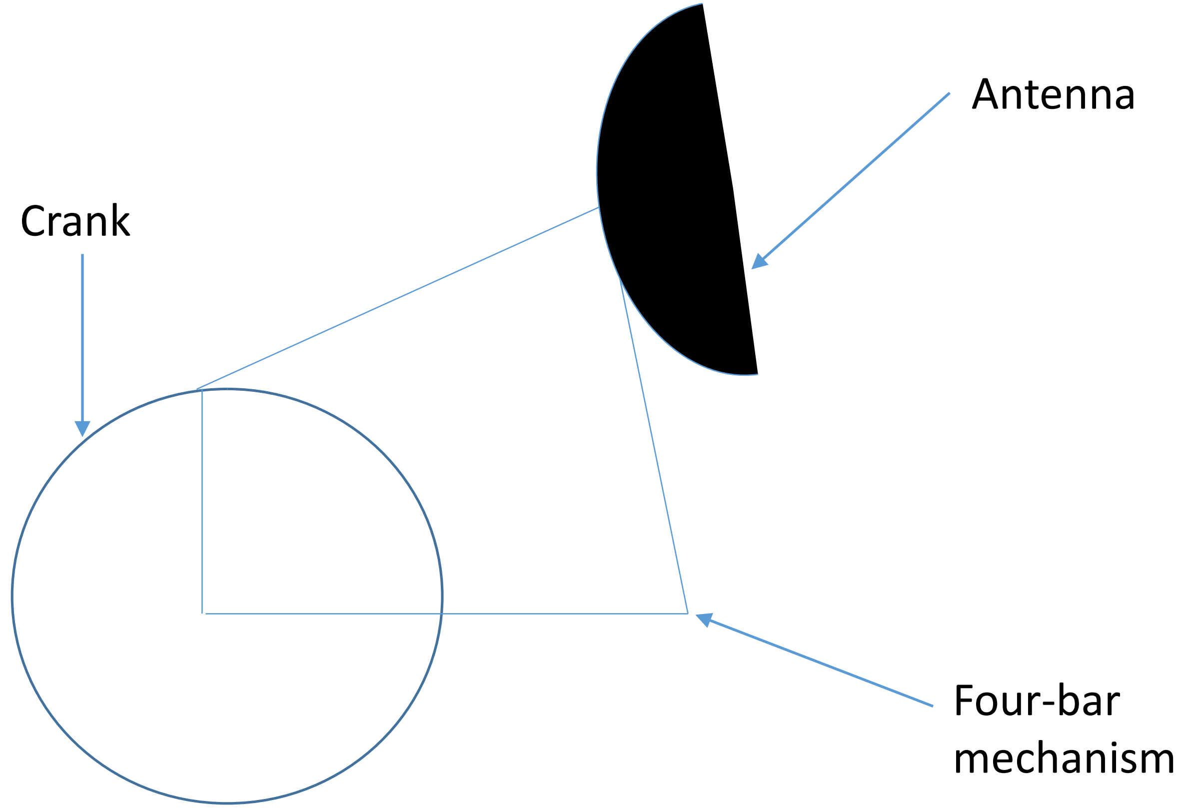

Figure 2

A four-bar Mechanism

- Type of motion : complex motion
- Type of link : Quaternary link, one rigid body, 4 nodes
- Using a 4-bar Grashof crank-rocker-rocker linkage class I, assuming S = 3, L = 7, P = 6, Q = 5, Figure 3.
- Joint classification: Lower pair joint (Spherical), Figure4.
- (Gruebler's equation) M = 3 (L – 1) - 2 J
- L = 4, J = 4 ==> M = 1 DOF.
- Elevation angle has 1 DOF and Azimuth angle has 1 DOF as well.
- If S+L≤ P+Q (Called a Grashof linkage)

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(2). Chapter Two Kinematics Fundamentals

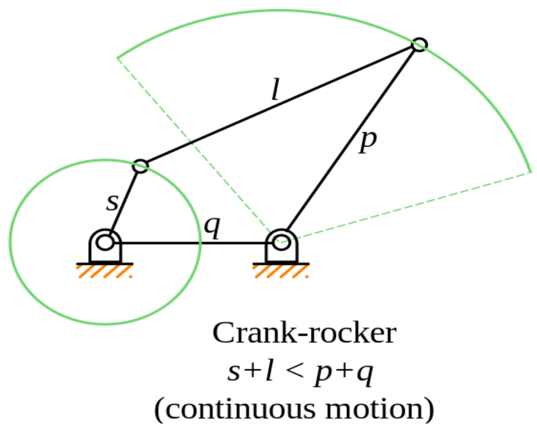


Figure 3

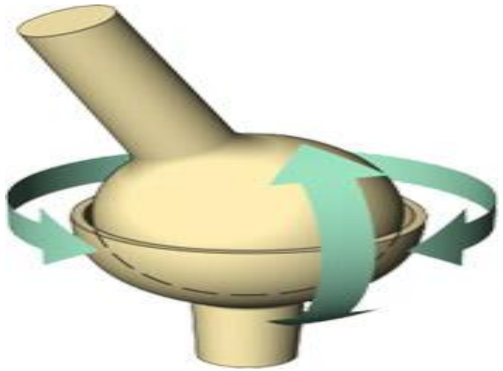


Figure 4

Position Analysis of Linkages

- The main objective of Position analysis is to find the output variable by knowing each one of the input variable and the links length.
- Vector loop equation➔ $\overrightarrow{AO_2} + \overrightarrow{BA} + \overrightarrow{O_4A} - \overrightarrow{O_4O_2} = 0$
- Link a = 3, Link b = 6, Link c = 7 and Link d = 5, assuming θ_2= 40°
- Coordinates of nodes➔ Figure 5

$x_a = \text{a} \cos\theta_2,\ y_a = \text{a} \sin\theta_2, x_b = \text{a} \cos\theta_2 + b\cos\theta_3$

$y_b = \text{a} \sin\theta_2 + b\sin\theta_3,$

$x_{O4} = \text{a} \cos\theta_2 + b\cos\theta_3 - c\ cos\ \theta_4 = d$

$y_{O4} = \text{a} \sin\theta_2 + b\sin\theta_3 - c\ sin\ \theta_4 = 0$

- $C^2 \equiv (d - a\cos\theta_2 - bcos\theta_3)^2 + (a\sin\theta_2 + bsin\theta_3)^2$

$b^2 = (d - a\cos\theta_2 - ccos\theta_4)^2 + (a\sin\theta_2 - csin\theta_4)^2$

- Then➔

$c^2 = d^2 + a^2 + b^2 - 2a\,d\cos\theta_2 + 2ab\,(\cos\theta_2 cos\theta_3 + \sin\theta_2 sin\theta_3) - 2bd\cos\theta_3$

$b^2 = d^2 + a^2 + c^2 - 2a\,d\cos\theta_2 - 2ac\,(\cos\theta_2 cos\theta_4 + \sin\theta_2 sin\theta_4) + 2cd\cos\theta_4$

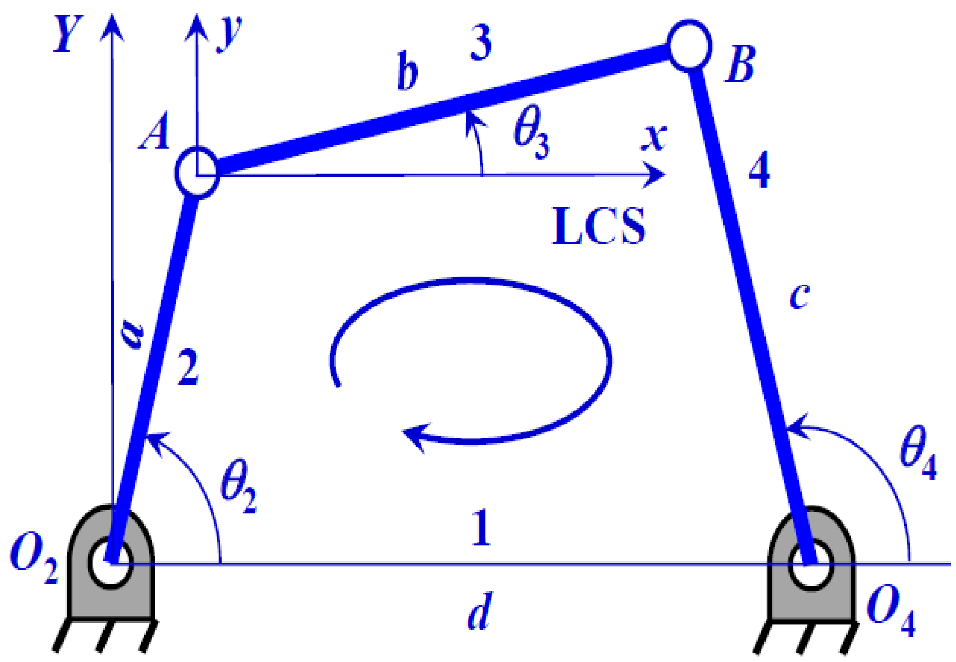


Figure 5

Position Analysis of Linkages

- Solve for θ_4 ➔

$$b^2 = d^2 + a^2 + c^2 - 2a\,d\ \cos\theta_2 - 2ac\,(\cos\theta_2 cos\theta_4 + \sin\theta_2 sin\theta_4) + 2cd\cos\theta_4$$

$$k_3 - k_2\cos\theta_2 + K\cos\theta_4 - cos\theta_2\cos\theta_4 - \sin\theta_2\, sin\,\theta_4 = 0$$

$$k_1 = \frac{d}{a},\ k_2 = \frac{d}{c},\ k_3 = \frac{a^2 - b^2 + c^2 + d^2}{2ac},\ A = k_3 - k_1 + (1 - k_2)\,cos\theta_2,\ B = -2sin\theta_2,$$

$$C = k_3 + k_1 - (1 + k_2)\,cos\theta_2.$$

- Sub values for a, b, c and d ➔ A = - 0.32879, B = - 1.28557, C = 1.47244

- $[\theta_4]_{1,2} = 2\arctan[\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}]$ ➔ $[\theta_4]_1 = -156.63°,\ [\theta_4]_2 = 85.60°$

Position Analysis of Linkages

- Solve for θ_3 ➔

$$c^2 = d^2 + a^2 + b^2 - 2a\,d\cos\theta_2 + 2ab\,(\cos\theta_2 cos\theta_3 + \sin\theta_2 sin\theta_3) - 2bd\cos\theta_3$$

$$k_5 + k_4\cos\theta_2 + K\cos\theta_3 - cos\theta_2\cos\theta_3 - \sin\theta_2\,sin\,\theta_3 = 0$$

$$k_4 = \frac{d}{b},\ k_5 = \frac{(c^2 - a^2 - b^2 - d^2)}{2ab}\ ,D = k_5 - k_1 + (k_4 + 1)\,cos\theta_2,,\ \ B = -2sin\theta_2,$$

$$E = k_5 + k_1 + (k_4 - 1)\,cos\theta_2.$$

- Sub values for a, b, c and d ➔ D = , B = - 1.28557, E = 1.47244

- $[\theta_3]_{1,2} = 2\arctan[\frac{-B \pm \sqrt{B^2 - 4DE}}{2D}]$ ➔ $[\theta_3]_1 = -125.52°,\ [\theta_3]_2 = 45.76°$

Position Analysis of Linkages

- Using MATLAB to illustrate the linkage path motion of each one of the crank (A) and rocker (B) and the linkage angular motion (output).

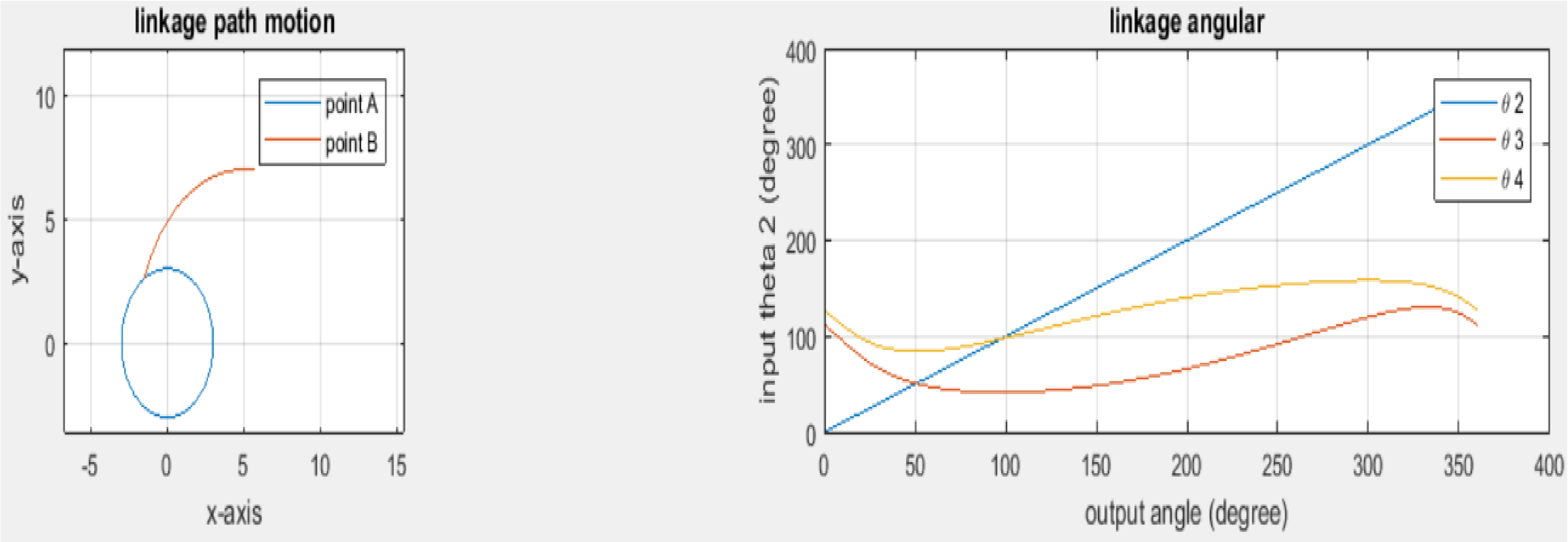


Figure 6

Velocity analysis

➔ Velocity analysis involves determining, how fast certain points on the links of a mechanisms are travelling.

➔ Write the vector loop equation ➔ $\overrightarrow{\omega_4} \times \overrightarrow{BO_4} - \overrightarrow{\omega_3} \times \overrightarrow{BA} = \overrightarrow{\omega_2} \times \overrightarrow{AO_2}$

➔ Calculate derivative with respect to time, t ➔

$$\begin{bmatrix} -\mathrm{b}\sin\theta_3 & c\sin\theta_4 \\ -b\cos\theta_3 & c\ sin\ \theta_4 \end{bmatrix} \begin{Bmatrix} \omega_3 \\ \omega_4 \end{Bmatrix} = \omega_2 \mathrm{a} \begin{Bmatrix} \sin\theta_2 \\ \cos\theta_2 \end{Bmatrix}$$

$$\begin{Bmatrix} \omega_3 \\ \omega_4 \end{Bmatrix} = \omega_2 \mathrm{a} \begin{bmatrix} -\mathrm{b}\sin\theta_3 & c\sin\theta_4 \\ -b\cos\theta_3 & c\ cos\ \theta_4 \end{bmatrix}^{-1} \begin{Bmatrix} \sin\theta_2 \\ \cos\theta_2 \end{Bmatrix}$$

➔ Using the known variables for the four-bar linkage (a =3, b =6, c =7, θ_2=40°, $\theta_3 = 45.76°, \theta_4 = 85.60°$) ➔ assuming ω_2 = -0.4 rad/sec

$\begin{Bmatrix} \omega_3 \\ \omega_4 \end{Bmatrix} = \begin{Bmatrix} 0.226 \\ 0.051 \end{Bmatrix}$ ➔ $\overrightarrow{V_B} = \overrightarrow{\omega_4} x \overrightarrow{BO_2} = 0.357\ \frac{m}{s}$, $\overrightarrow{V_A} = \overrightarrow{\omega_2} x \overrightarrow{AO_2} = 1.2\frac{m}{s}$,

$$\overrightarrow{V_c} = \overrightarrow{V_A} + \overrightarrow{V_{CA}} = \overrightarrow{\omega_2} x \overrightarrow{AO_2} + \overrightarrow{\omega_3} x \overrightarrow{CA} = 0.1108\ \frac{m}{s}$$

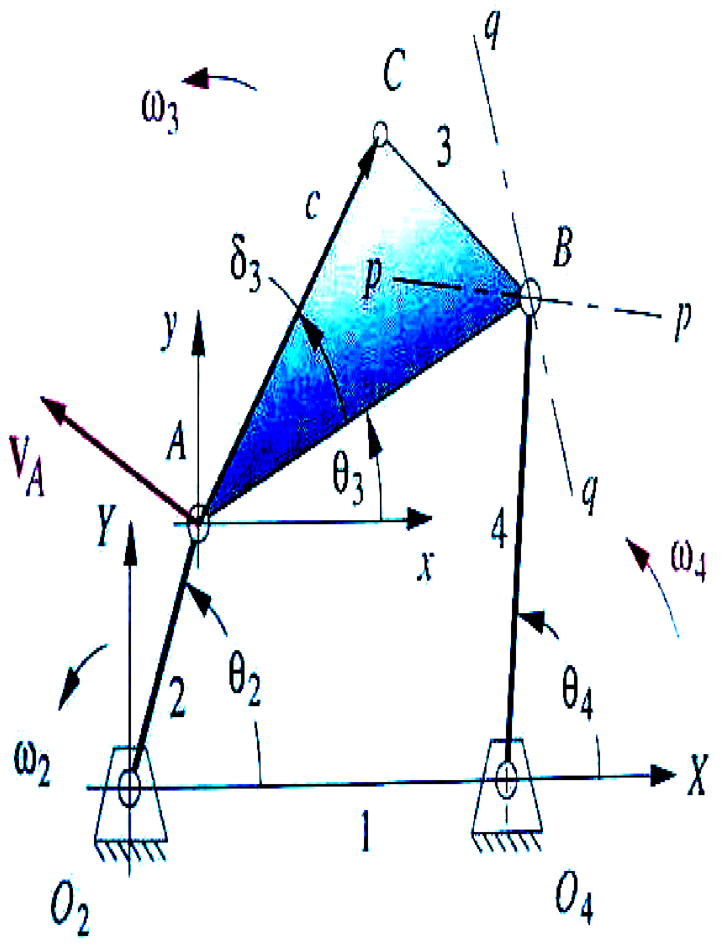


Figure 7

Velocity analysis

- Using MATLAB to illustrate the linkage angular velocity and the linear velocity.

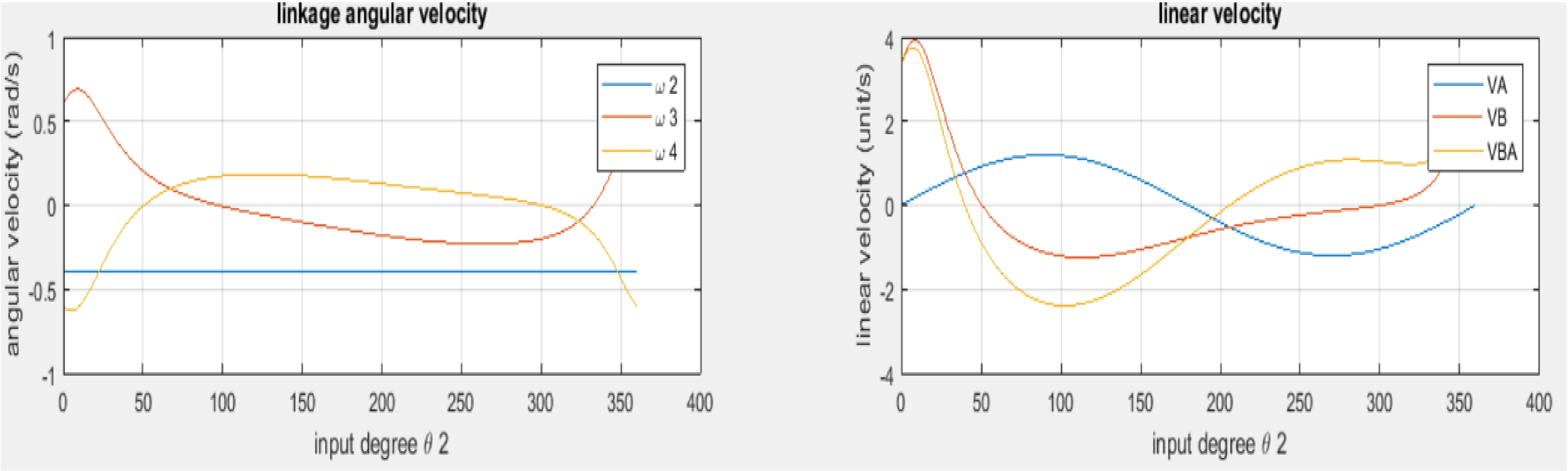


Figure 8

Acceleration analysis

- Acceleration analysis involves determining the amount that certain points on links of mechanism are either, speeding up or slowing down, Figure 9.
- Acceleration by derivative w.r.t time➔

$$x = a\alpha_2 \sin\theta_2 + a\omega_2^2 \cos\theta_2 + b\alpha_3 \sin\theta_3 + b\omega_3^2 \cos\theta_3 - \quad c\alpha_4 \sin\theta_4 - c\omega_4^2 \cos\theta_4 = 0$$

$$y = a\alpha_2 \cos\theta_2 - a\omega_2^2 \sin\theta_2 + b\alpha_3 \cos\theta_3 - b\omega_3^2 \sin\theta_3 - \quad c\alpha_4 \cos\theta_4 \mp c\omega_4^2 \sin\theta_4 = 0$$

- $$\begin{Bmatrix}\alpha_3\\ \alpha_4\end{Bmatrix} = \begin{Bmatrix}-a\alpha_2 \sin\theta_2 - a\omega_2^2 \cos\theta_2 - b\omega_3^2 \cos\theta_3 + c\omega_4^2 \cos\theta_4\\ -a\alpha_2 \cos\theta_2 + a\omega_2^2 \sin\theta_2 + b\omega_3^2 \sin\theta_3 - c\omega_4^2 \sin\theta_4\end{Bmatrix}\begin{bmatrix}b\sin\theta_3 & -c\sin\theta_4\\ b\cos\theta_3 & -c\cos\theta_4\end{bmatrix}^{-1}$$
- Assuming ➔ $\alpha_2 = \frac{rad}{s^2}$, Using the same previous values (ω , θ and abc)
- $$\begin{Bmatrix}\alpha_3\\ \alpha_4\end{Bmatrix} = \begin{Bmatrix}0.1438\\ 0.1717\end{Bmatrix}$$
- Establish acceleration vector equations

$$\vec{A}_A = \underbrace{\vec{\alpha}_2 \times \vec{AO}_2}_{\vec{A}^t_A} + \underbrace{\vec{\omega}_2 \times (\vec{\omega}_2 \times \vec{AO}_2)}_{\vec{A}^n_A}$$

$$\vec{A}_B = \underbrace{\vec{\alpha}_4 \times \vec{BO}_4}_{\vec{A}^t_B} + \underbrace{\vec{\omega}_4 \times (\vec{\omega}_4 \times \vec{BO}_4)}_{\vec{A}^n_B}$$

$$\vec{A_B} = \vec{A_A} + \vec{A_{B}}_A \;➔\; \vec{A_A} + \vec{\alpha_3} \times \vec{BA} + \vec{\omega}_3 \times (\vec{\omega}_3 \times \vec{BA})$$

➔ $\vec{A_A} = 0.48\,\frac{\mathrm{m}}{\mathrm{s}^2}$ ➔ $\vec{A_B} = 1.22\,\frac{\mathrm{m}}{\mathrm{s}^2}$

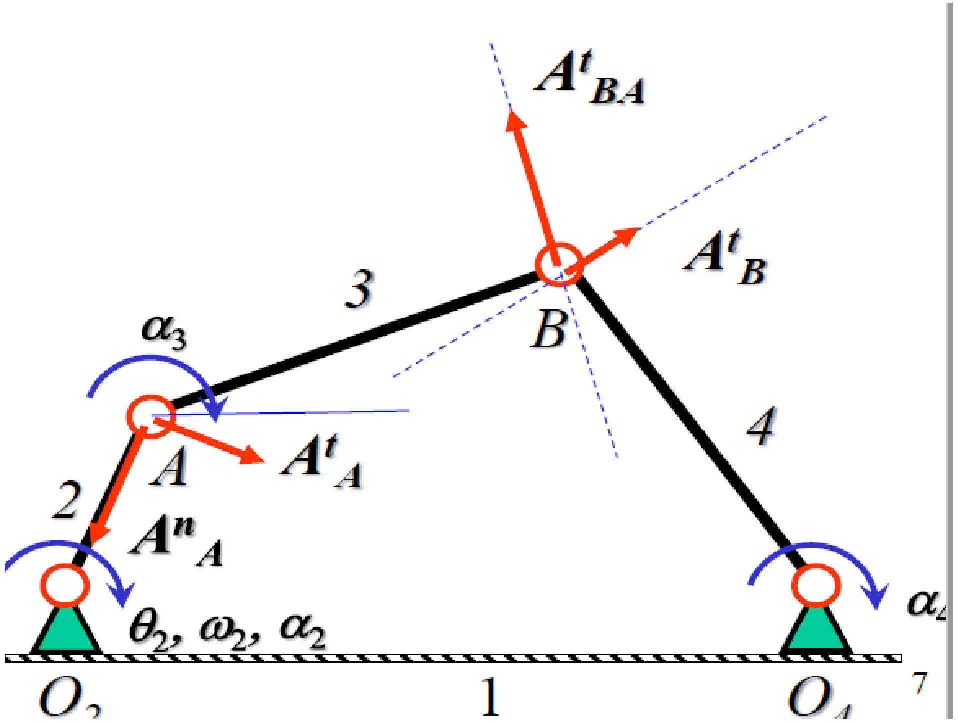


Figure 9

Acceleration analysis

- Using MATLAB to illustrates the angular acceleration and acceleration vector

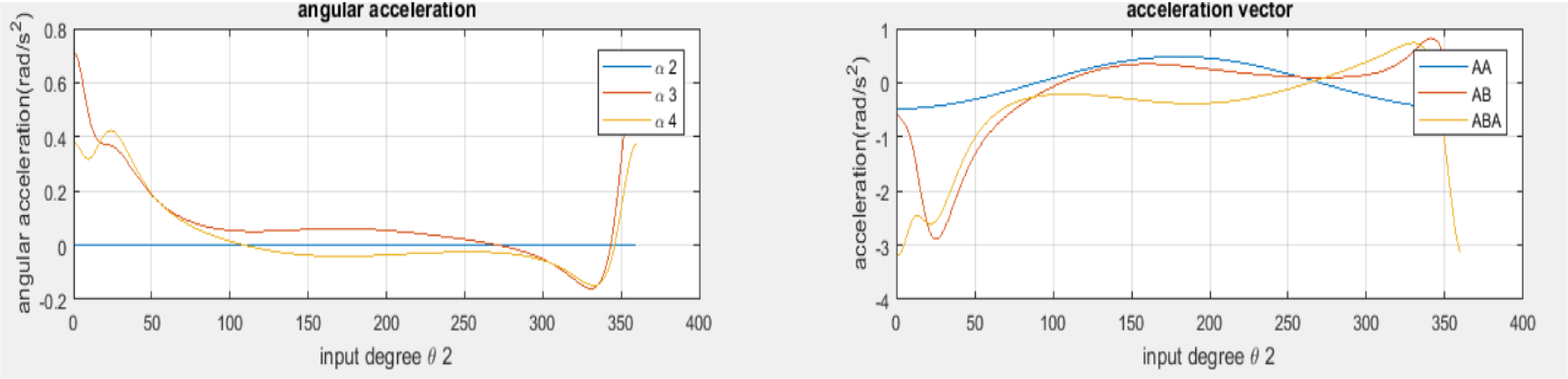
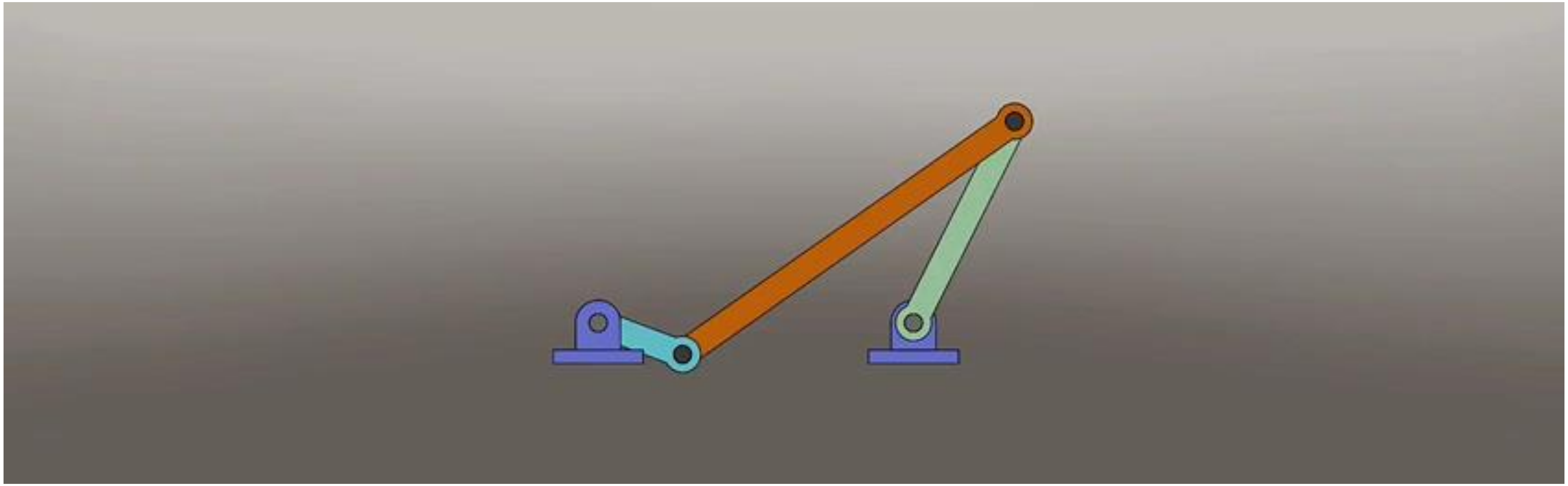


Figure 10

Mechanical movements For Elevation



Type of Gear

- Super Gear➔ This is a cylindrical shaped gear in which the teeth are parallel to the axis. It has the largest applications and, also, it is the easiest to manufacture.
- Based on this mechanism, we can control the azimuth by using this super gear.

Specifications for standard gear teeth

Item	Full depth & pitches coarser than 20		Full depth & pitches finer than 20	14½° full depth
Pressure angle	20°	25°	20°	14½°
Addendum (in.)	1.0/P	1.0/P	1.0/P	1/P
Dedendum (in.)	1.250/P	1.250/P	1.2/P + 0.002	1.157/P

Figure 11

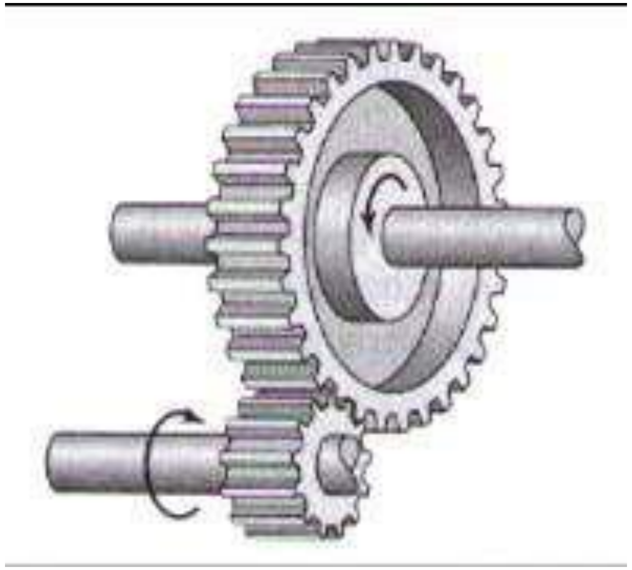
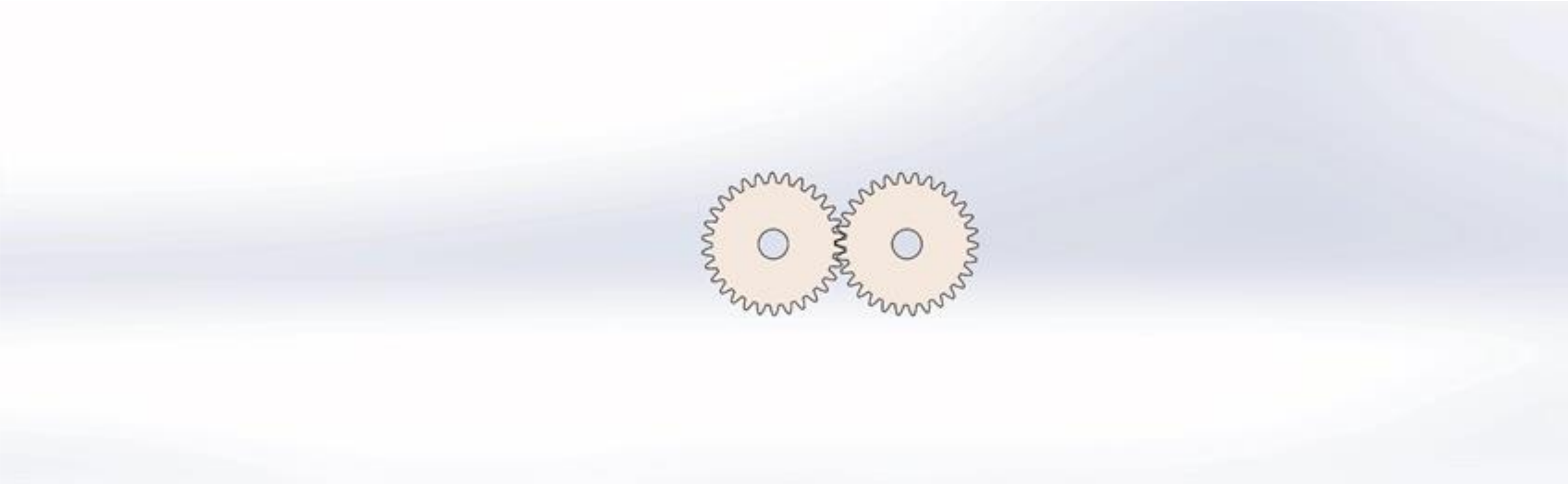


Figure 12

Figure (11), (n.d.). Retrieved from https://uni.edu/~rao/MD-12%20Spur%20Gear%20Design.pdf
Figure (12), From Chapter 6

Gear Movement



ANTENNA DESGIN

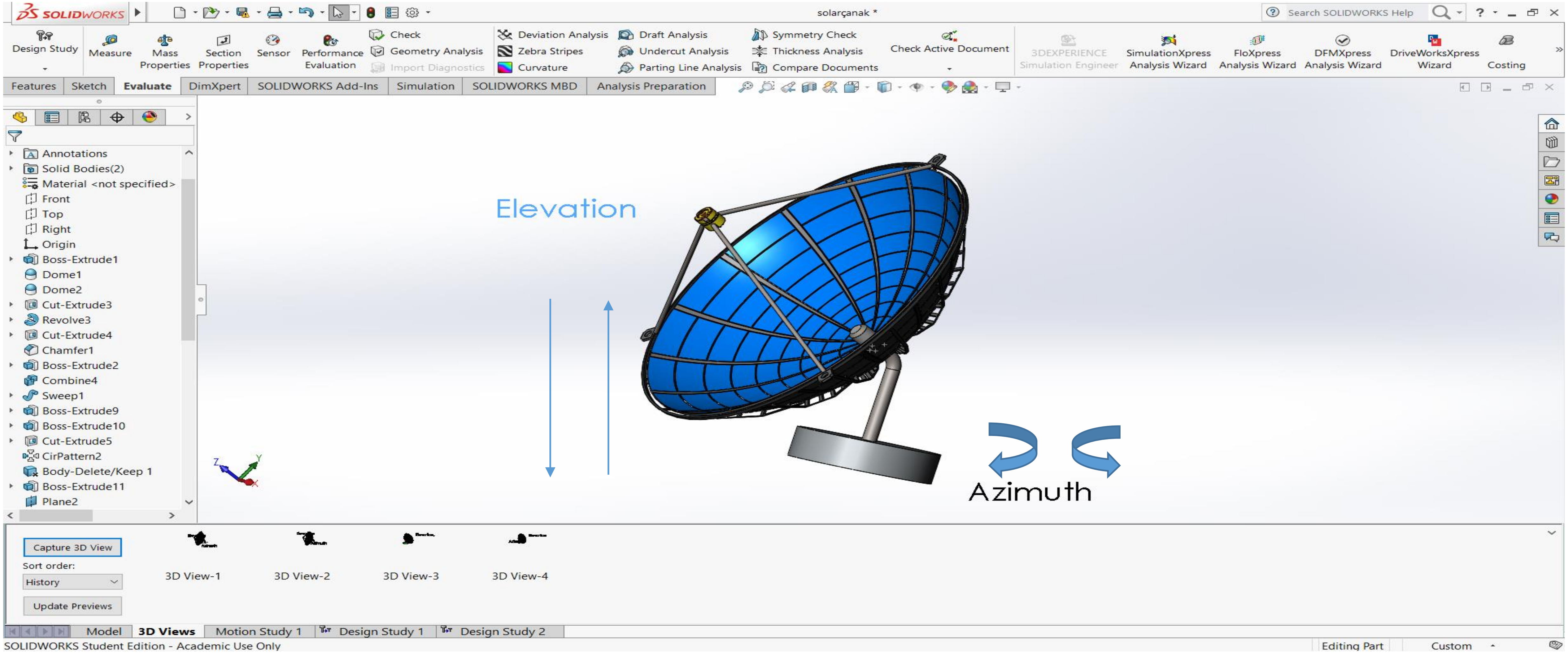


Figure 13

MOTOR-Servomotor

- A servomotor is a rotary actuator that allows for precise control of angular of linear position, velocity and acceleration(9).
- Advantages➔ low cost , high reliability, high torque at low speeds
- Disadvantages➔ When stopped, the motor's rotor continues to move back and forth, so that it is not suitable if we are looking for an accurate data.

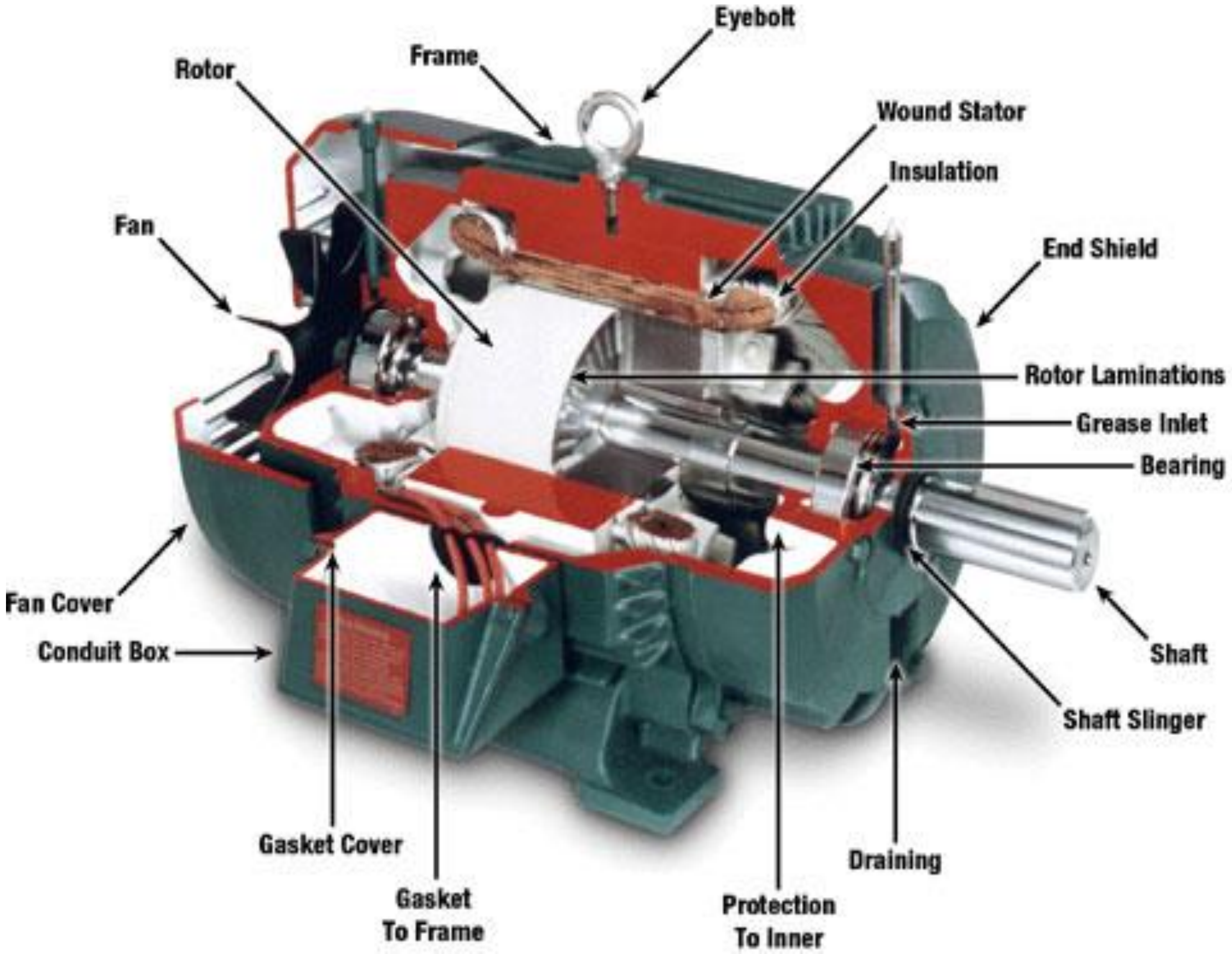


Figure 14

Figure 14, (n.d.). Retrieved from https://www.elprocus.com/difference-dc-motor-servo-motor-stepper-motor/

Thank you
for listening

Appendix

- Code of figures 6,8 and 10

```
%% // plot path A and B
subplot(3,2,1);
plot(Ax,Ay, Bx,By)   % path for A and B
title('linkage path motion')
legend('point A','point B')
ylabel('y-axis')
xlabel('x-axis')
axis([xmin*1.5 xmax*1.5 ymin ymax])
daspect([1 1 1]) % fix plot ratio 1:1
set(legend,'color','none');
grid on
%% // plot theta q for open circuit
subplot(3,2,2);
plot(q2d,q2d, q2d,q31d, q2d,q41d)  % linkage angular
title('linkage angular')
legend('\theta 2','\theta 3','\theta 4')
ylabel('input theta 2 (degree)')
xlabel('output angle (degree)')
grid on
%% // plot omega w for open circuit
subplot(3,2,3);
plot(q2d,w2,q2d,w3,q2d,w4);   % plot angular velocity
legend('\omega 2','\omega 3','\omega 4')
title('linkage angular velocity')
ylabel('angular velocity (rad/s)')
xlabel('input degree \theta 2')
grid on
```

```
%% // plot linear velocity
subplot(3,2,4);
plot(q2d,(VA),q2d,(VB),q2d,(VBA)) % plot linear velocity
legend('VA','VB','VBA')
title('linear velocity')
ylabel('linear velocity (unit/s)')
xlabel('input degree \theta 2')
grid on
%% // plot angular acceleration
subplot(3,2,5);
plot(q2d,a2,q2d,a3,q2d,a4); % plot angular acceleration
legend('\alpha 2','\alpha 3','\alpha 4')
title('angular acceleration')
ylabel('angular acceleration(rad/s^2)')
xlabel('input degree \theta 2')
grid on
%% // plot linear acceleration
subplot(3,2,6);
plot(q2d,AA,q2d,AB,q2d,ABA); %  plot linear acceleration
legend('AA','AB','ABA')
title('acceleration vector')
ylabel('acceleration(rad/s^2)')
xlabel('input degree \theta 2')
grid on
```

References

- 1) https://www.linkedin.com/pulse/azimuth-elevation-angle-antenna-satellite-tracking-jawad-ali
- 2) (2). Chapter Two Kinematics Fundamentals
- 3) Figure 5,7 and 9. From Chapter (2,3,4) Space mechanism.
- 4) MATLAB SOURCE➔ Fourbar_linkage_analysis.m. (n.d.). Retrieved November 27, 2017, from https://www.dropbox.com/s/bp9nc6xupt7yv68/fourbar_linkage_analysis.m?dl=0
- 5) Solidworks source, Figure 13➔ https://grabcad.com/library/solar-dish-gunes-canagi-1
- 6) Figure 11, Figure (11), (n.d.). Retrieved from https://uni.edu/~rao/MD-12%20Spur%20Gear%20Design.pdf
- 7) Figure 12, From chapter 6
- 8) Figure 14, (n.d.). Retrieved from https://www.elprocus.com/difference-dc-motor-servo-motor-stepper-motor/
- 9) Servomotor. (2017, October 02). Retrieved November 27, 2017, from https://en.wikipedia.org/wiki/Servomotor