AMORO Lab 4 Report

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1 Objective

The ADAMS model used for this lab is given and named Biglide.bin. The kinematic architecture of the five-bar mechanism is shown in Fig.1. The geometric parameters of this five-bar mechanism are:

$$d = 0.4m \tag{1}$$
$$l_{A1C} = 0.3606m \tag{2}$$
$$l_{A2C} = 0.3606m \tag{3}$$

The base dynamic parameters are:

$$m_p = 3kg \tag{4}$$
$$m_f = 1kg \tag{5}$$

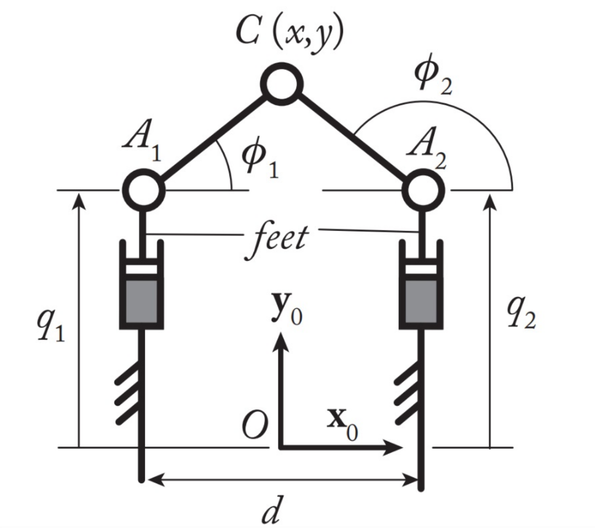

Figure 1: One n-connected region.

2 Direct Kinematic analysis of the Biglide mechanism

In this part we do the kinematic analysis about the mechanism using MATLAB and compare the results with the ADAM solutions.

2.1 Geometric analysis

2.1.1 Analysis models

The direct geometric model(DGM) of this mechanism is :

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \frac{rh}{2a}(q_1 - q_2) \\ \frac{q1+q2}{2} + \frac{rh}{2a}d \end{bmatrix} \tag{6}$$

with

$$a = \|HA_2\| \tag{7}$$

$$h = \sqrt{l^2 - a^2} \tag{8}$$

$$HA_2 = \frac{1}{2}[d, q_2 - q_1]^T \tag{9}$$

The passive angles are given by equation(10).

$$\begin{bmatrix} \tan\phi_1 \\ \tan\phi_2 \end{bmatrix} = \begin{bmatrix} \frac{y-q_1}{x+\frac{d}{2}} \\ \frac{y-q_2}{x-\frac{d}{2}} \end{bmatrix} \tag{10}$$

2.1.2 Simulation results

The errors of DGM are shown in Fig.2. From Fig.2 we can see that there are some small errors between the results of MATLAB and ADAM. Those small errors may be due to the different calculation method of the software. The errors are very small, so we can say that the DGM of this mechanism is acceptable. As the same reason we can see the analysis of passive angles are correct. The errors are shown in Fig.3.

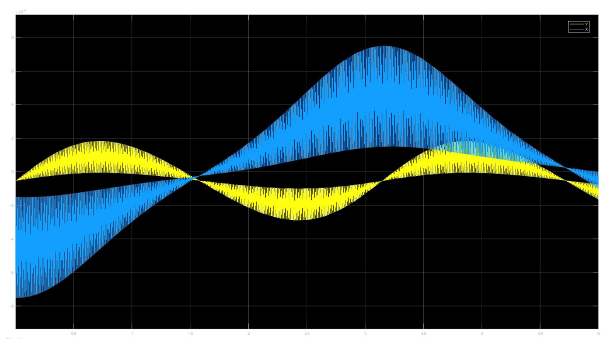

Figure 2: The errors of DGM

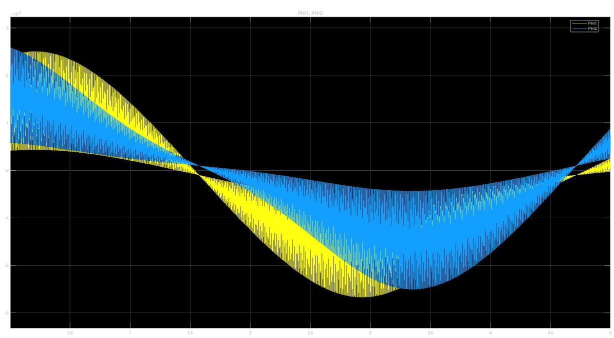

Figure 3: The errors of passive angles

2.2 Velocity analysis of the Biglide mechanism

2.2.1 Kinematic model

For the kinematic models of the Biglide mechanism, there are two model should be considered, which are:

1. The direct kinematic model(DKM)
2. The passive angle velocities model(P_DKM)

The equations of DKM,

$$\begin{bmatrix} x - \frac{d}{2} & y - q_2 \\ x + \frac{d}{2} & y - q_1 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} 0 & y - q_2 \\ y - q_1 & 0 \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix} \tag{11}$$

,which is the function related between the velocities of the actuated joints and the velocity of the end-effector

To control use the function simpler in matlab we seprate the matrix A and B with

$$A = \begin{bmatrix} x - \frac{d}{2} & y - q_2 \\ x + \frac{d}{2} & y - q_1 \end{bmatrix} \tag{12}$$

$$B = \begin{bmatrix} 0 & y - q_2 \\ y - q_1 & 0 \end{bmatrix} \tag{13}$$

The equations of P_DKM,

$$\begin{bmatrix} \dot{\phi}_1 \\ \dot{\phi}_2 \end{bmatrix} = \begin{bmatrix} l & 0 \\ 0 & l \end{bmatrix}^{-1} \left(\begin{bmatrix} (Eu_{31})^T \\ (Eu_{32})^T \end{bmatrix} \dot{P} - \begin{bmatrix} (Eu_{31})^T u_1 & 0 \\ 0 & (Eu_{32})^T u_1 \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix} \right) \tag{14}$$

which link with the velocity of end-effector, the velocity of actuated joints and the velocity of passive joint.

2.2.2 Simulation and results

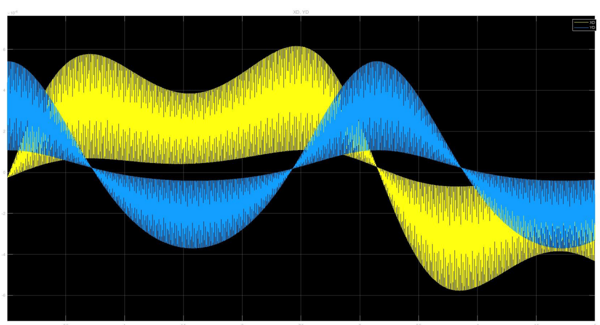

Figure 4: The errors of DKM

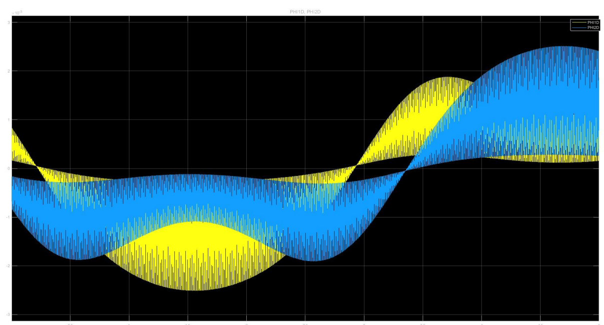

Figure 5: Passive angles velocity

As you can see both of two figure is pretty good, noticed that the dimension is $\times 10^{-4}$, which is means that the error is very small. We could consider the kinematic model is prefect.

But there till have some errors, which caused by the data generated between the adams file and matlab file. The adams file could lead some disturbance and also in calculation of matlab some numerical value would be ignored.

2.3 Acceleration analysis of the Biglide mechanism

2.3.1 Analysis models

The DKM is given by equation(11) and the model that provides the passive angle accelerations is :

$$\begin{bmatrix} \ddot{\phi}_1 \\ \ddot{\phi}_2 \end{bmatrix} = \begin{bmatrix} l & 0 \\ 0 & l \end{bmatrix}^{-1} \left(\begin{bmatrix} (Eu_{31})^T \\ (Eu_{32})^T \end{bmatrix} \ddot{P} - \begin{bmatrix} (Eu_{31})^T u_1 & 0 \\ 0 & (Eu_{32})^T u_1 \end{bmatrix} \begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \end{bmatrix} \right) \tag{15}$$

with

$$E = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \tag{16}$$

$$u_{31} = \begin{bmatrix} cos(\phi_1) \\ sin(\phi_1) \end{bmatrix} \tag{17}$$

$$u_{32} = \begin{bmatrix} cos(\phi_2) \\ sin(\phi_2) \end{bmatrix} \tag{18}$$

$$u_1 = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{19}$$

2.3.2 Analysis models

The errors of acceleration are shown in Fig.6. From Fig.6 we can see that the errors between the results of MATLAB and ADAM are very small. So we can say that the model of acceleration is acceptable.

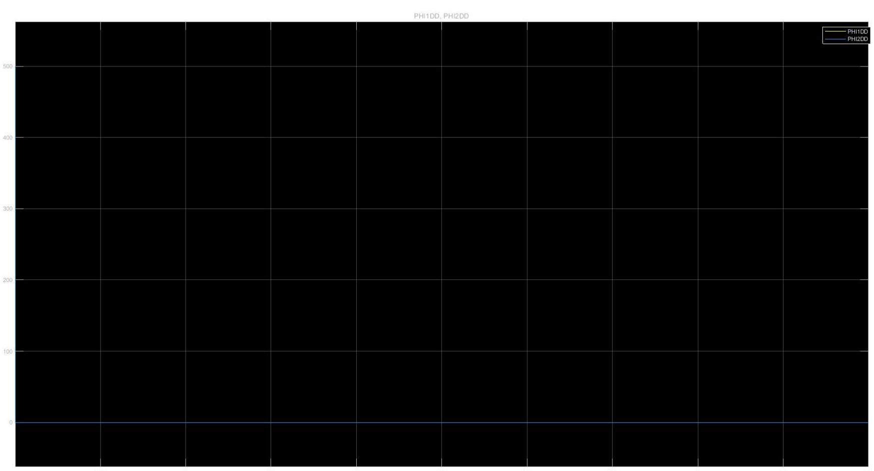

Figure 6: The error of acceleration

3 Dynamic analysis of the five-bar mechanism

3.1 The inverse dynamic model

We calculate the torque τ mainly use the equation:

$$\tau = \tau_a + J^T \omega_r + J_d^T \tau_d \tag{20}$$

with

$$\tau_a = \begin{bmatrix} m_f \ddot{q}_1 \\ m_f \ddot{q}_2 \end{bmatrix} \tag{21}$$

$$J = -A^{-1}B \tag{22}$$

$$w_r = \begin{bmatrix} m_p\ddot{x} \\ m_p\ddot{y} \end{bmatrix} \tag{23}$$

$$J_d = 0 \tag{24}$$

$$tau_d = 0 \tag{25}$$

which τ_a is represented the actuated joint torque, the τ_d represented the passive joint torque

3.2 Simulation and Results

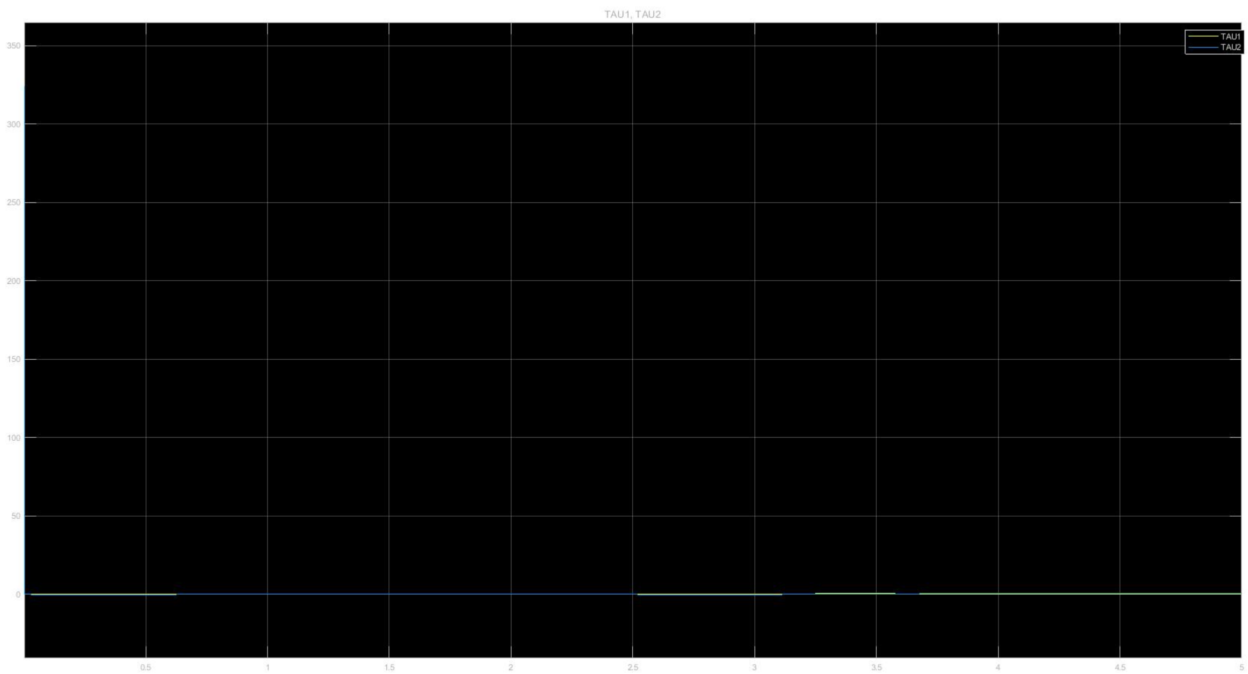

Figure 7: The error of τ

Not very clearly in the figure, but the fact is that the torque are nearly to 0, which is means that the dynamic model is seems very good.

4 Control co-simulation

In this part, we design two control laws ,kinematic and dynamic(torque) control laws, to control the mechanism follows the desired trajectory.

4.1 Kinematic control law

4.1.1 Control law

The kinematic control law is given by equation(26)

$$\dot{q} = -B^{-1} * A * (\dot{X}_t - \lambda * e) \tag{26}$$

where X_t is the desired trajectory and e is the error between the desired trajectory and the real one.

$$X_t = \begin{bmatrix} x(t) \\ y(t) \end{bmatrix} \tag{27}$$

with

$$x(t) = x_A + s(t) * (x_B - x_A) \tag{28}$$

$$y(t) = y_A + s(t) * (y_B - y_A) \tag{29}$$

$$s(t) = 10 * (t/t_f)^3 - 15 * (t/t_f)^4 + 6 * (t/t_f)^5 \tag{30}$$

4.1.2 Simulation results

The desired and real trajectory are shown in Fig.8 and the error is shown in Fig.9. We can see the error converges to zero which means our control law is good.

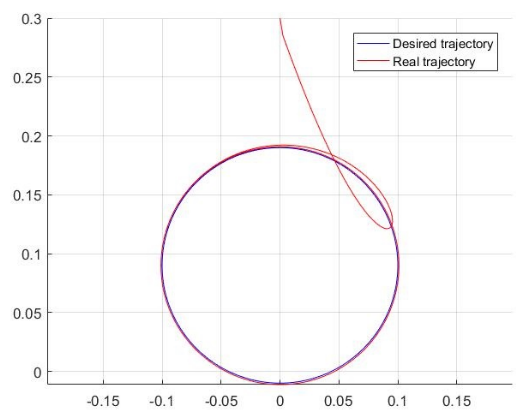

Figure 8: Desired and real trajectory with t=0.005

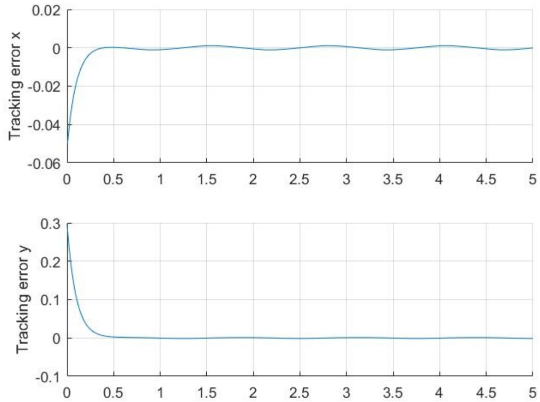

Figure 9: Trajectory error with t=0.005

When we change the time interval we can get the following results. From Fig.10 we can see that when we decrease time interval the error will be smaller than before. And when we increase time interval the error will be bigger. But the error will converges to zero finally. In fact, the changing of time interval affects the number of sampling points. When time interval is small, we get more points which will make the error smaller.

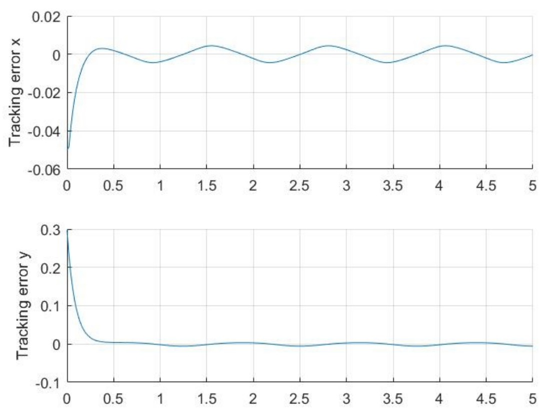

Figure 10: Trajectory error with t=0.02

4.2 Computed Torque Control law

4.2.1 Control law

The torque control law can be linearised as:

$$\tau = M * v + c \tag{31}$$

with

$$v = \ddot{q}_t + K_d * (\dot{q}_t - \dot{q}_a) + K_p * (q_t + q_a) \tag{32}$$

Where M is the inertia matrix, definite positive and c the vector of Coriolisis and Centrifugal effects. Since we have calculated the inverse dynamic model(IDM) of this mechanism, we can easily get M matrix by calculating the partial derivation of M about $\ddot{q}$:

$$M = \partial\tau/\partial\ddot{q} \tag{33}$$

And matrix c can be calculated by

$$c = \tau - M * \ddot{q} \tag{34}$$

4.2.2 Simulation results

The desired and real trajectory are shown in Fig.11 and the error is shown in Fig.12. We can see the error converges to zero which means our control law is good.

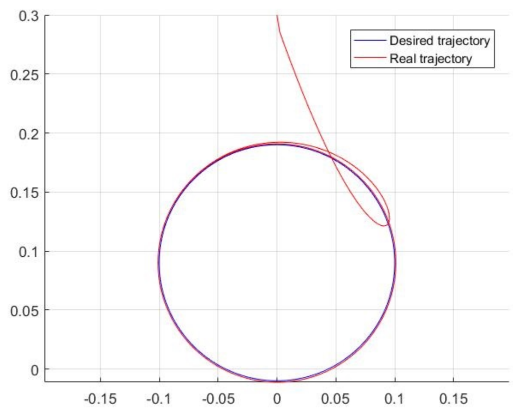

Figure 11: Desired and real trajectory of CTC

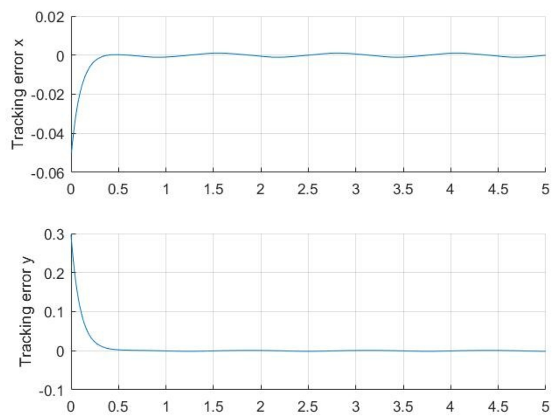

Figure 12: Trajectory error with of CTC