**D-mechanism**

**10**

**45**

**30**

**x1**

**y1**

**A**

**B**

**D**

**C**

**P**

**units = mm**

**50**

**x3**

**y3**

**105**

**5**

**3**

**P3**

**C3**

**B3**

**15**

**x2**

**y2**

**2**

**A2**

**B2**

**30**

**x4**

**y4**

**4**

**D4**

**C4**

CONSTANT LOCAL BODY-FIXED LOCATIONS OF SPECIFIC POINTS

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | {s1}’ | {s2}’ | {s3}’ | {s4}’ |
| A | { , }T 0 30 0 0 AB 0 0 0 BC 0 0 0 45 0 CD 0 105 -5w | { , }T |  |  |
| B |  | { , }T | { , }T |  |
| C |  |  | { , }T | { , }T |
| D | { , }T |  |  | { , }T |
| P |  |  | { , }T |  |

{q} = { x2 y2 2 x3 y3  3  x4 y4 4 }T

ESTIMATED GLOBAL POSE OF COORDINATE FRAMES

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Link | 1 | 2 0 30 7.5 43 55 28 -15 -11055 | 3 | 4 |
| Origin {ri} | { 0, 0 }T | { , }T | { , }T | { , }T |
| Angle i | 0 deg | 60 deg |  deg |  deg |





**15**

**A**

**B**

**D**

**C**

**50**

**30**

**54.08**

**15**

**A**

**B**

**D**

**C**

**50**

**L4**

**54.08**

**MAX**







% dm\_main.m - D-mechanism four-bar - ref: Haug, Fig P5.1, page 196

% main

% HJSIII - 22.02.13

% initialize

dm\_ini

% starting position

phi2\_start = 0 \* d2r; % start at zero

% time loop

tpr = 2 \* pi / w2; % one revolution at constant speed

t\_start = 0; % start

t\_end = tpr; % end

nt = 180; % number of time steps

dt = (t\_end - t\_start) / nt;

keep\_q = [];

keep = [];

for t = t\_start : dt : t\_end;

% kinematics

 dm\_kin

% save kinematics

 detJAC = det(JAC);

 x3P = r3P(1);

 y3P = r3P(2);

 x3Pd = r3Pd(1);

 y3Pd = r3Pd(2);

 keep\_q = [ keep\_q ; q' qd' qdd' ];

 keep = [ keep ; detJAC x3P y3P x3Pd y3Pd ];

% bottom - for t

end

% data for plotting

ang2 = keep\_q(:,3) /d2r;

phi4d = keep\_q(:,18);

phi4dd = keep\_q(:,27);

detJAC = keep(:,1);

x3P = keep(:,2);

y3P = keep(:,3);

x3Pd = keep(:,4);

y3Pd = keep(:,5);

% four figures per page

figure( 1 )

% locus of coupler point

subplot( 2,2,1 )

 plot( x3P,y3P,plot\_str )

 hold on

 axis( [70 140 -25 45] )

 axis square

 xlabel( 'xP [mm]' )

 ylabel( 'yP [mm]' )

% follower velocity

subplot( 2,2,2 )

 plot( ang2, phi4d, plot\_str )

 hold on

 axis( [ 0 360 -100 100 ] )

 xlabel( 'Phi2 [deg]' )

 ylabel( 'Omega4 [rad/s]' )

 legend( [ 'L4=', num2str(len4) ] )

% follower acceleration

subplot( 2,2,3 )

 plot( ang2, phi4dd, plot\_str )

 hold on

 axis( [ 0 360 -40000 20000 ] )

 xlabel( 'Phi2 [deg]' )

 ylabel( 'Alpha4 [rad/s^2]' )

% Jacobian

subplot( 2,2,4 )

 plot( ang2, detJAC, plot\_str )

 hold on

 axis( [ 0 360 -1500 0 ] )

 xlabel( 'Phi2 [deg]' )

 ylabel( 'det(JAC) [mm^2]' )

% coupler point velocity - quiver plot

npos = length( x3P );

iskip = (1:12:npos);

figure( 2 )

 quiver( x3P(iskip),y3P(iskip), x3Pd(iskip),y3Pd(iskip) )

 axis( [70 140 -25 45] )

 axis square

 hold on

 plot( x3P(iskip),y3P(iskip),'bo' )

 xlabel( 'xP [mm]' )

 ylabel( 'yP [mm]' )

 title( [ 'D mechanism - L4 = ' num2str(len4) ] )

% bottom - dm\_main

% dm\_ini.m - D-mechanism four-bar - ref: Haug, Fig P5.1, page 196

% initialize constants and assembly guesses

% HJSIII - 22.02.13

% general constants

d2r = pi / 180;

R = [ 0 -1; 1 0 ];

% mechanism constants

len2 = 15;

len3 = 50;

len4 = 30;

% possible lengths for parameter study of link

len4 = 19.1; plot\_str = 'r';

len4 = 20; plot\_str = 'b';

len4 = 25; plot\_str = 'g';

len4 = 30; plot\_str = 'k';

% local body-fixed locations

s1pA = [ 0 30 ]';

s1pD = [ 45 0 ]';

s2pA = [ 0 0 ]';

s2pB = [ len2 0 ]';

s3pB = [ 0 0 ]';

s3pC = [ len3 0 ]';

s3pP = [ 105 -5.00 ]';

s4pC = [ 0 0 ]';

s4pD = [ len4 0 ]';

% global locations

r1A = [ 0 30 ]';

r1D = [ 45 0 ]';

% initial guesses - angles measured by protractor

phi2 = 60\*d2r;

phi3 = -15\*d2r;

phi4 = -110\*d2r;

q(1,1) = 0;

q(2,1) = 30;

q(3,1) = phi2;

q(4,1) = 7.5;

q(5,1) = 43;

q(6,1) = phi3;

q(7,1) = 55;

q(8,1) = 28;

q(9,1) = phi4;

% driver for crank - phi2 = phi2\_start + w2\*t

phi2\_start = 60 \* d2r;

w2 = +1000 \* 2 \* pi / 60; % 1000 rpm CCW, convert to rad/sec

% start time

t = 0;

% bottom - dm\_ini

% dm\_phi.m - D-mechanism four-bar - ref: Haug, Fig P5.1, page 196

% evaluate constraints and Jacobian for crank driving constraint

% HJSIII - 22.02.13

% global location of local frames and rotation matrices

% Eq 2.4.4, page 33 - Eq 2.6.5, page 42

r2 = q(1:2);

r3 = q(4:5);

r4 = q(7:8);

phi2 = q(3);

phi3 = q(6);

phi4 = q(9);

A2 = [ cos(phi2) -sin(phi2); sin(phi2) cos(phi2) ];

A3 = [ cos(phi3) -sin(phi3); sin(phi3) cos(phi3) ];

A4 = [ cos(phi4) -sin(phi4); sin(phi4) cos(phi4) ];

B2 = R \* A2;

B3 = R \* A3;

B4 = R \* A4;

% global locations - Eq 2.4.8, page 33

r2A = r2 + A2\*s2pA;

r2B = r2 + A2\*s2pB;

r3B = r3 + A3\*s3pB;

r3C = r3 + A3\*s3pC;

r4C = r4 + A4\*s4pC;

r4D = r4 + A4\*s4pD;

r3P = r3 + A3\*s3pP;

% revolute constraints - A,B,C,D - Eq 3.3.10, page 65

PHI(1:2,1) = r2A - r1A;

PHI(3:4,1) = r3B - r2B;

PHI(5:6,1) = r4C - r3C;

PHI(7:8,1) = r4D - r1D;

% crank driving constraint

PHI(9,1) = phi2 - phi2\_start - w2\*t;

% Jacobian by rows - Eq 3.3.12, page 66 for revolutes

JAC = zeros(9,9);

JAC(1:2,1:3) = [ eye(2) B2\*s2pA ];

JAC(3:4,1:3) = [ -eye(2) -B2\*s2pB ];

JAC(3:4,4:6) = [ eye(2) B3\*s3pB ];

JAC(5:6,4:6) = [ -eye(2) -B3\*s3pC ];

JAC(5:6,7:9) = [ eye(2) B4\*s4pC ];

JAC(7:8,7:9) = [ eye(2) B4\*s4pD ];

% driving constraint in Jacobian - Eq 3.1.9, page 52

JAC(9,3) = 1;

% current results

current\_crank = phi2 / d2r;

% bottom - dm\_phi

% dm\_kin.m - D-mechanism four-bar - ref: Haug, Fig P5.1, page 196

% positon, velocity, and acceleration at desired\_crank

% HJSIII - 20.03.04

% Newton-Raphson position solution - Eq 3.6.7 and 3.6.8, page 100

assy\_tol = 0.00001;

dm\_phi

while max(abs(PHI)) > assy\_tol,

 q = q - inv(JAC) \* PHI;

 dm\_phi

end

% velocity - Eq 3.1.9, page 52 - also page 66 for revolutes

velrhs(9,1) = w2;

qd = inv(JAC) \* velrhs;

% global velocities - Eq 2.6.4, page 41

r2d = qd(1:2);

r3d = qd(4:5);

r4d = qd(7:8);

phi2d = qd(3);

phi3d = qd(6);

phi4d = qd(9);

r3Pd = r3d + phi3d \* B3 \* s3pP;

% acceleration - Eq 3.1.10, page 53 - also page 66 for revolutes

accrhs(1:2,1) = A2\*s2pA\*phi2d\*phi2d;

accrhs(3:4,1) = A3\*s3pB\*phi3d\*phi3d - A2\*s2pB\*phi2d\*phi2d;

accrhs(5:6,1) = A4\*s4pC\*phi4d\*phi4d - A3\*s3pC\*phi3d\*phi3d;

accrhs(7:8,1) = A4\*s4pD\*phi4d\*phi4d;

accrhs(9,1) = 0;

qdd = inv(JAC) \* accrhs;

% global accelerations

r2dd = qdd(1:2);

r3dd = qdd(4:5);

r4dd = qdd(7:8);

phi2dd = qdd(3);

phi3dd = qdd(6);

phi4dd = qdd(9);

r3Pdd = r3dd + phi3dd\*B3\*s3pP - phi3d\*phi3d\*A3\*s3pP;

% bottom - dm\_kin