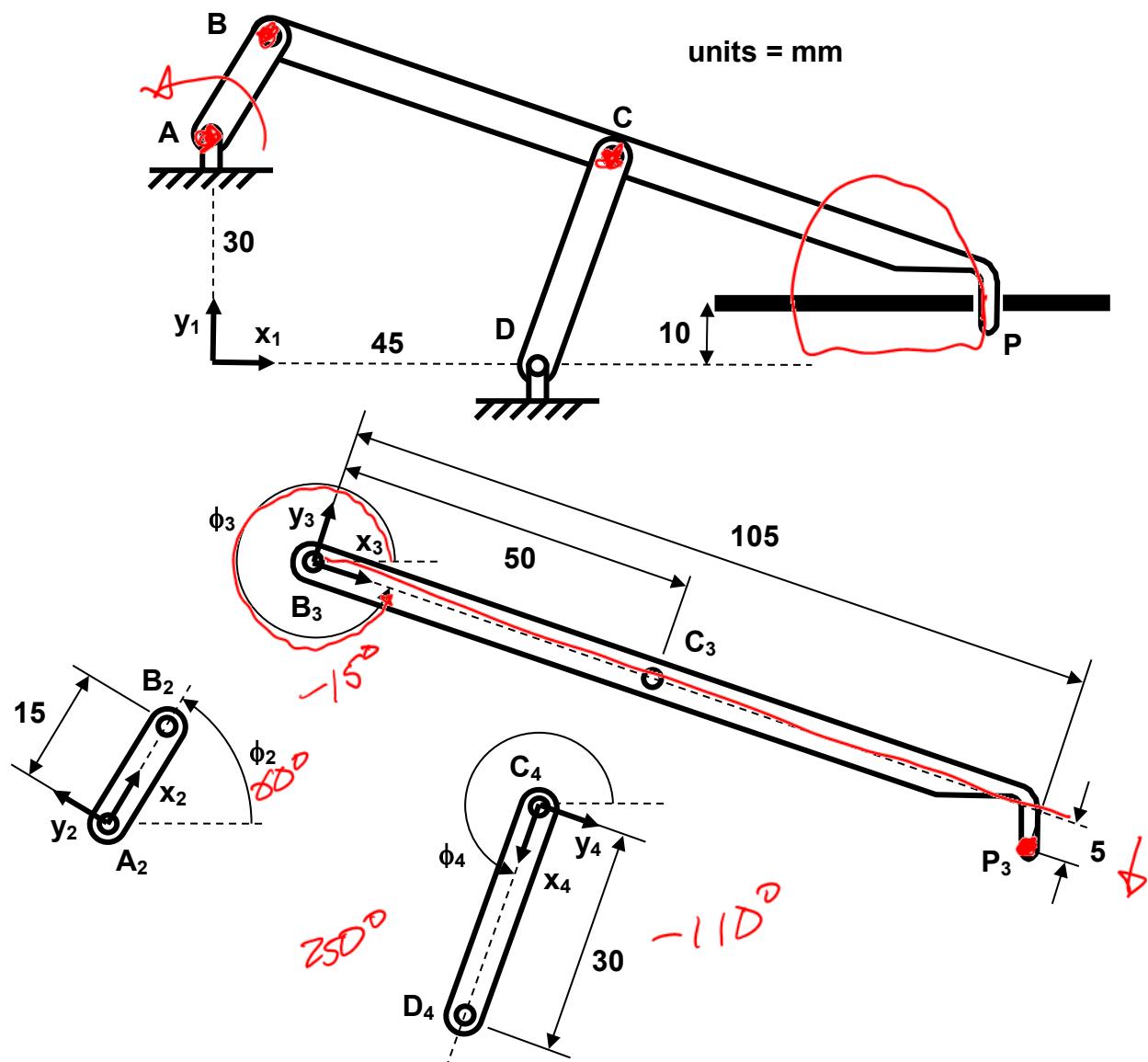


## D-mechanism



CONSTANT LOCAL BODY-FIXED LOCATIONS OF SPECIFIC POINTS

	$\{s_1\}'$	$\{s_2\}'$	$\{s_3\}'$	$\{s_4\}'$
A	$\{ 0 , 30 \}^T$	$\{ 0 , 0 \}^T$		
B		$\{ AB , 0 \}^T$	$\{ 0 , 0 \}^T$	
C			$\{ BC , 0 \}^T$	$\{ 0 , 0 \}^T$
D	$\{ 45 , 0 \}^T$			$\{ CD , 0 \}^T$
P			$\{ 105 , -5 \}^T$	

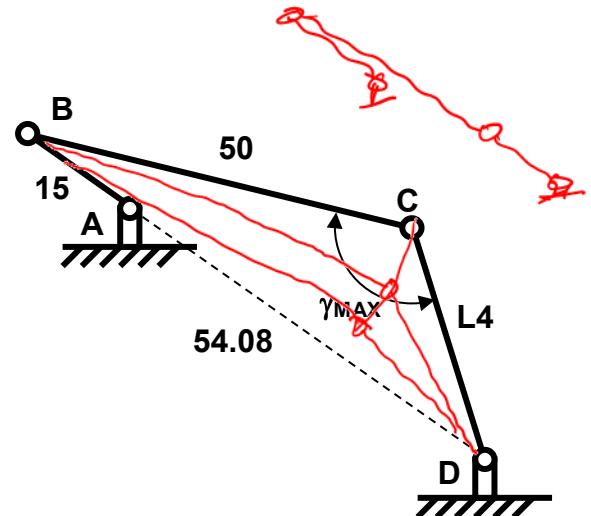
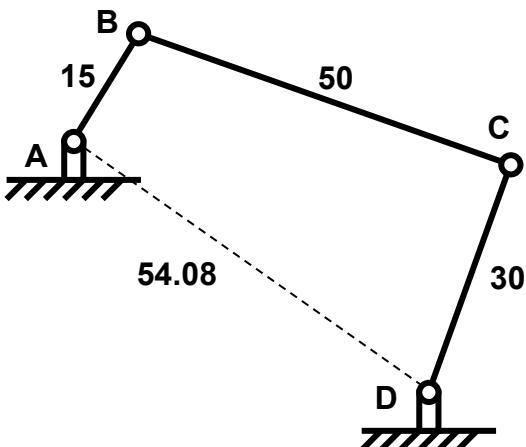
$$\{q\} = \{x_2 \ y_2 \ \phi_2 \ x_3 \ y_3 \ \phi_3 \ x_4 \ y_4 \ \phi_4\}^T$$

## ESTIMATED GLOBAL POSE OF COORDINATE FRAMES

Link	1	2	3	4
Origin $\{r_i\}$	$\{0, 0\}^T$	$\{0, 30\}^T$	$\{7.5, 43\}^T$	$\{55, 28\}^T$
Angle $\phi_i$	0 deg	60 deg	-15 deg	-110 deg

$$\{\Phi\} = \begin{Bmatrix} \{r_2\}^A - \{r_1\}^A \\ \{r_3\}^B - \{r_2\}^B \\ \{r_4\}^C - \{r_3\}^C \\ \{r_4\}^D - \{r_1\}^D \\ \phi_2 - \phi_{2\_START} - \omega_2 t \end{Bmatrix} = \{0\}$$

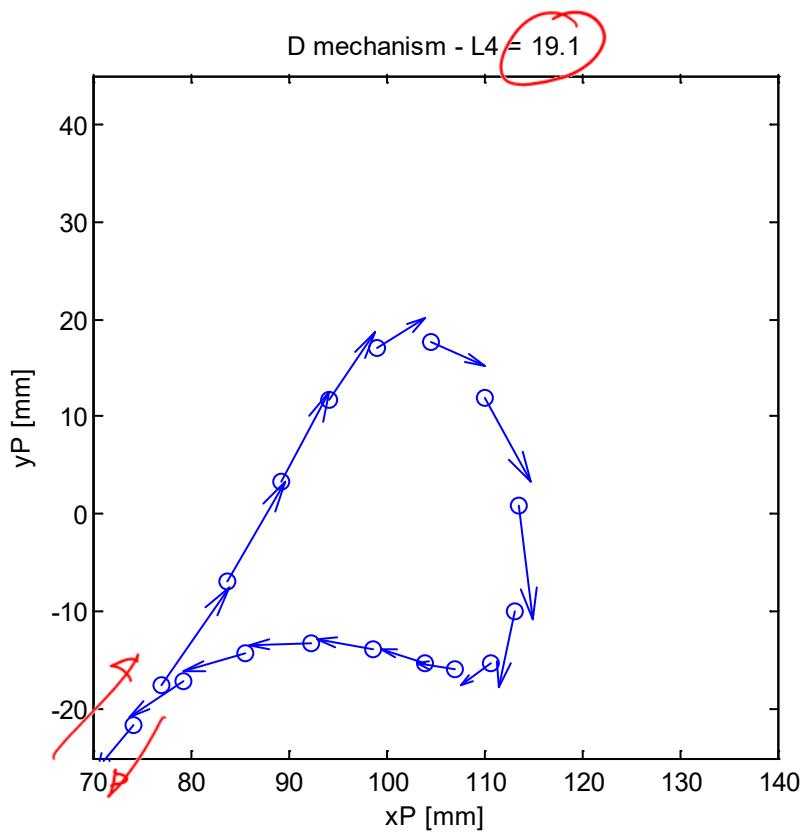
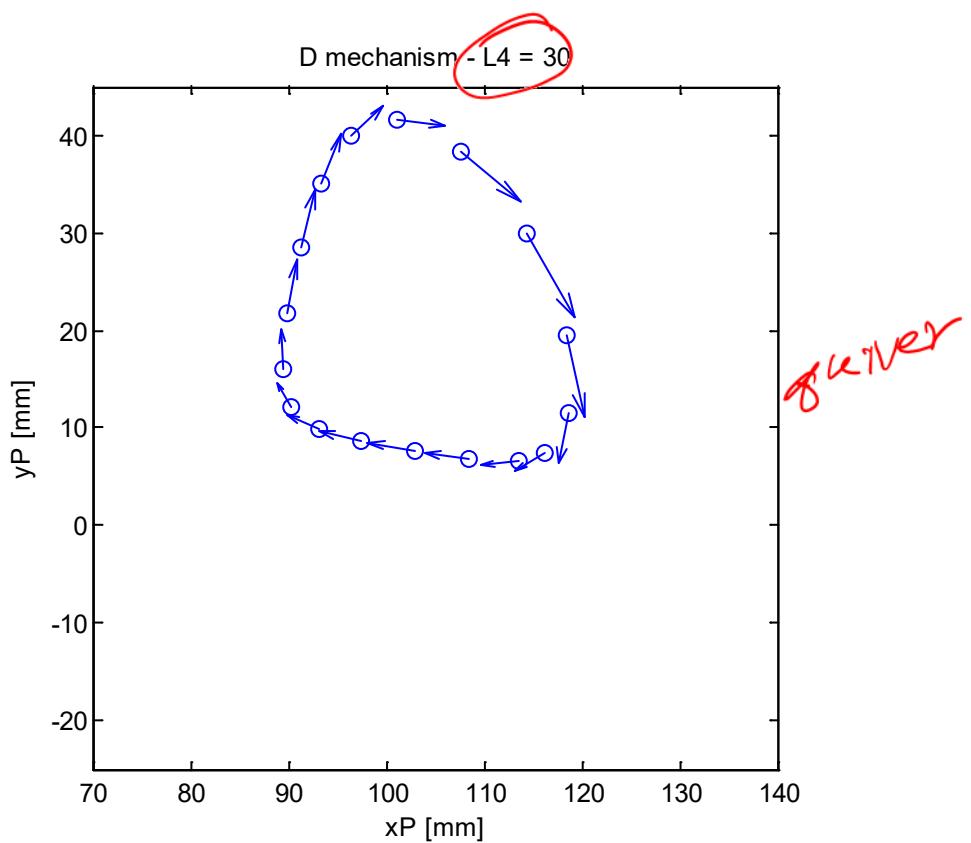
$$[\Phi_q] = \begin{bmatrix} +[I_2] & +[B_2]\{s_2\}^A & [0_{2x2}] & [0_{2x1}] & [0_{2x2}] & [0_{2x1}] \\ -[I_2] & -[B_2]\{s_2\}^B & +[I_2] & +[B_3]\{s_3\}^B & [0_{2x2}] & [0_{2x1}] \\ [0_{2x2}] & [0_{2x1}] & -[I_2] & -[B_3]\{s_3\}^C & +[I_2] & +[B_4]\{s_4\}^C \\ [0_{2x2}] & [0_{2x1}] & [0_{2x2}] & [0_{2x1}] & +[I_2] & +[B_4]\{s_4\}^D \\ [0_{1x2}] & 1 & [0_{1x2}] & 0 & [0_{1x2}] & 0 \end{bmatrix}$$

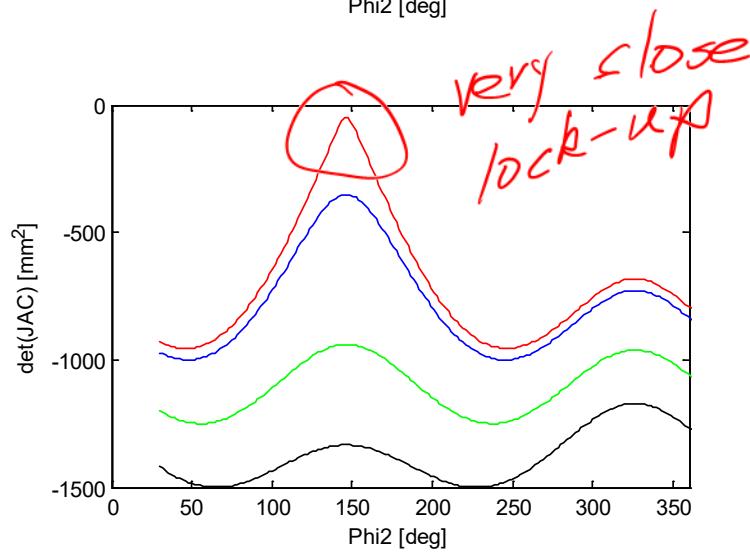
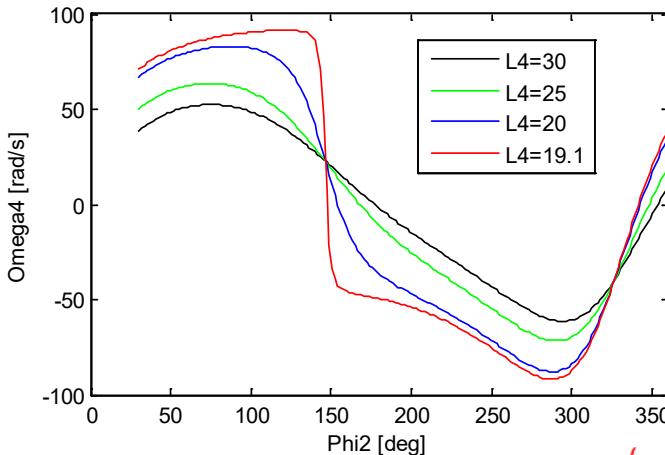
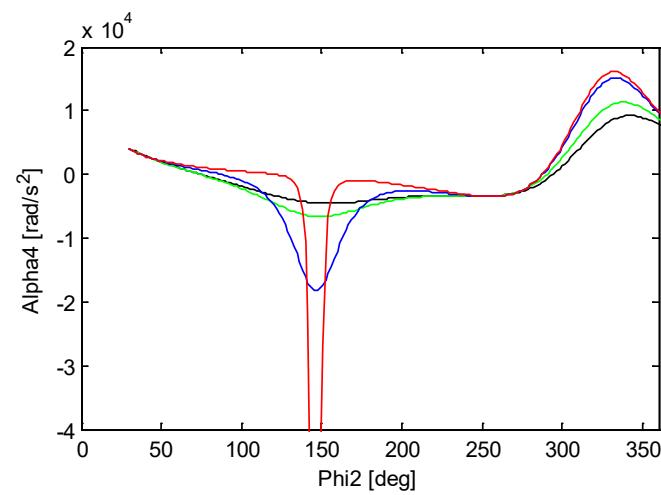
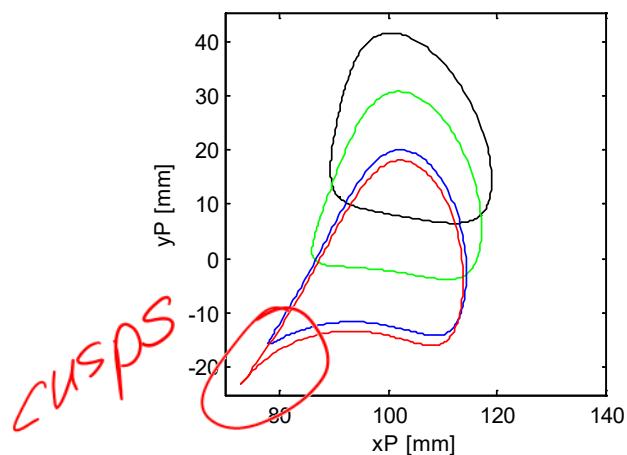


$$SD + LA > 15 + 54.08$$

$$69.08$$

$$LA > 19.08$$





```

% dm_main.m - D-mechanism four-bar - ref: Haug, Fig P5.1, page 196
% main
% HJSIII - 20.03.04

% general constants
d2r = pi / 180;
R = [ 0 -1; 1 0 ];

% 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=30', 'L4=25', 'L4=20', 'L4=19.1' )

% 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), 'o' )
xlabel('xP [mm]')
ylabel('yP [mm]')
title('D mechanism - L4 = 30')
% title('D mechanism - L4 = 19.1')

% bottom - dm_main
```

```

% dm_ini.m - D-mechanism four-bar - ref: Haug, Fig P5.1, page 196
%   initialize constants and assembly guesses
% HJSIII - 20.03.04

% mechanism constants
len2 = 15;
len3 = 50;
len4 = 30;

% possible lengths for parameter study of link 4
len4 = 19.1;    plot_str = 'r';
len4 = 20;       plot_str = 'b';
len4 = 25;       plot_str = 'g';
len4 = 30;       plot_str = 'k';

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 ]';

% 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) = q(1) + len2*cos(phi2);
q(5,1) = q(2) + len2*sin(phi2);
q(6,1) = phi3;

q(7,1) = r1D(1) - len4*cos(phi4);
q(8,1) = r1D(2) - len4*sin(phi4);
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

% 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 - 20.03.02
```

*if current from Eq 3.1.9*

*r1 = [ 0 0 ]';*

*r2 = q(1:2);*       $\{r_1^3\}$

*r3 = q(4:5);*       $\{r_1^3\}$

*r4 = q(7:8);*       $\{\dot{\theta}\}$

*phi1 = 0;*

*phi2 = q(3);*

*phi3 = q(6);*

*phi4 = q(9);*

*A1 = [ cos(phi1) -sin(phi1); sin(phi1) cos(phi1) ];*

*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*

*r1A = r1 + A1\*s1pA;*

*r1D = r1 + A1\*s1pD;*

*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 - 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 ];*       $\oplus$

*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*

*check*

$\{ \dot{\theta} \}$

$d1 \{r_1^3\}$

*revolutes*

```

% dm_kin.m - D-mechanism four-bar - ref: Haug, Fig P5.1, page 196
% position, 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 dm_phi
while max(abs(PHI)) > assy_tol,
    q = q - inv(JAC) * PHI;
    dm_phi dm_phi
end

% velocity - Eq 3.1.9, page 52 - also page 66 for revolutes
velrhs(9,1) = w2;
qd = inv(JAC) * velrhs; vel same

% 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

```