

1) Modify your Working Model (WM) slider crank simulation as detailed below and on the following page. Attach a screen shot of your WM mechanism. Be certain to shift the centroid for link 3.

- Use a motor to drive the crank at constant 1000 rpm for  $R = 0.985$  inch and  $L = 4.33$  inch.
- Use a statically balanced crank ( $G_2$  at A).
- Modify your connecting rod and piston to use inertial data from H10.

$m_3$  0.462 lbm    $BG_3$  1.043 inch    $J_{G3}$  1.5 lbm.in<sup>2</sup>    $m_4$  0.781 lbm

2) Plot crank torque as a function of crank angle from your WM simulation and from the two-mass equivalent link approximation on the same MATLAB graph.

$m_{3B}$  0.351 lbm    $m_{3C}$  0.111 lbm

3) Plot shaking force with  $F_{21}^X$  on the x axis and  $(F_{21}^Y + F_{41}^Y)$  on the y axis from your WM simulation and the two-mass equivalent link approximation on the same MATLAB graph.

4) Add a counter balance mass at radius R to the crank equal to  $m_{3B}$  and repeat part 3) above. Use the same scale as part 3).

5) Adjust your counter balance mass to minimize the maximum shaking force and repeat part 3) above. Use the same scale as part 3).

$m_{BAL}$  0.892 lbm    $F_{S\_MAX}$  16.49 lbf   optimum  $m_{BAL} \sim (m_{3C} + m_4)$

### EXTRA CREDIT

Add a second piston and connecting rod to model the two cylinder in-line air compressor demonstrated in class. Plot shaking force from your WM simulation and the two-mass equivalent link approximation on the same MATLAB graph. Use the same scale as part 3). Attach a screenshot of your mechanism.

**WM dynamic analysis for slider crank**

- 1) World Gravity - none
- 2) Select the Motor and then the Split button
- 3) Select the Crank
  - a) Change crank length to 1.97 inches
  - b) Move point A to the center
  - c) Select the Join button
  - d) Add a square point to the left end of the Crank
- 4) Select the Con Rod
  - a) Window Properties - change mass and mass moment
  - b) Window Appearance – show COM
  - c) Window Geometry – change COM x-offset
- 5) Select the Piston - Window Properties - change mass
- 6) Select the Crank – Measure Position Rotation Graph
- 7) Select the Piston – Measure Acceleration X Graph
- 8) Select the Motor
  - a) Measure Torque Transmitted
  - b) Measure Force
- 9) Select the square point for piston slider constraint – CANNOT measure force
- 10) Select wrist pin between Con Rod and Piston – Measure Force
- 11) Run and then Export
- 12) Create a small circular object for counter balance mass
  - a) Place a square point at its center
  - b) Window Properties - change mass
  - c) Select the square point on the over-balance mass
  - d) Hold down the Shift Key and also select the square point on the left end of the Crank
  - e) Select the Join button

Working Model - [h11\_2\_3.wm2d]

File Edit World View Object Define Measure Script Window Help

Run StopII Reset

Join Split

Rotation of Crank  
rot --- rad

Acceleration of Pis  
Ax --- in/s<sup>2</sup>

Torque of Motor 14  
Torque --- lb-in

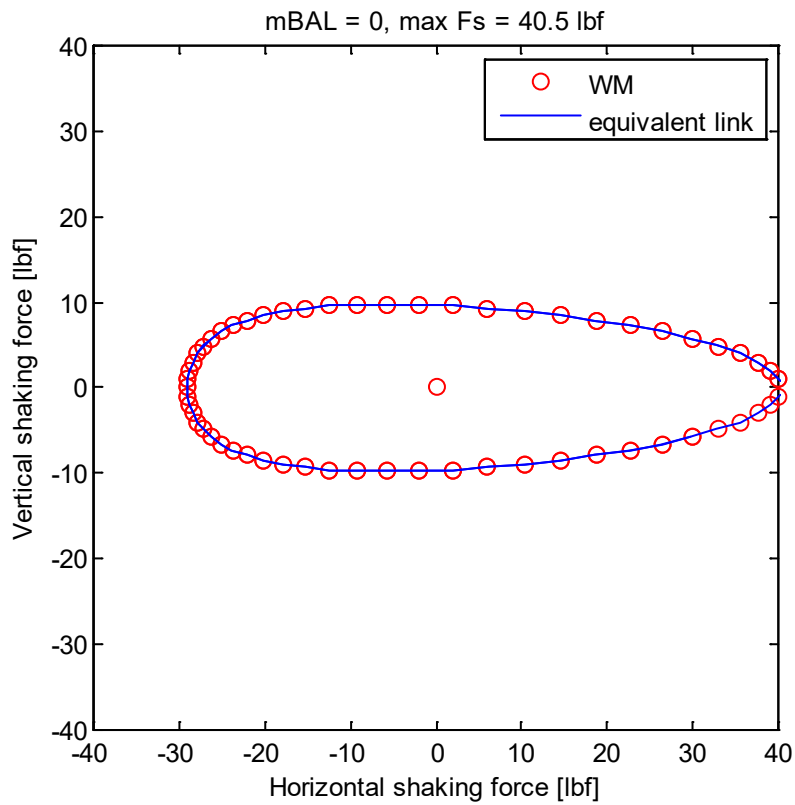
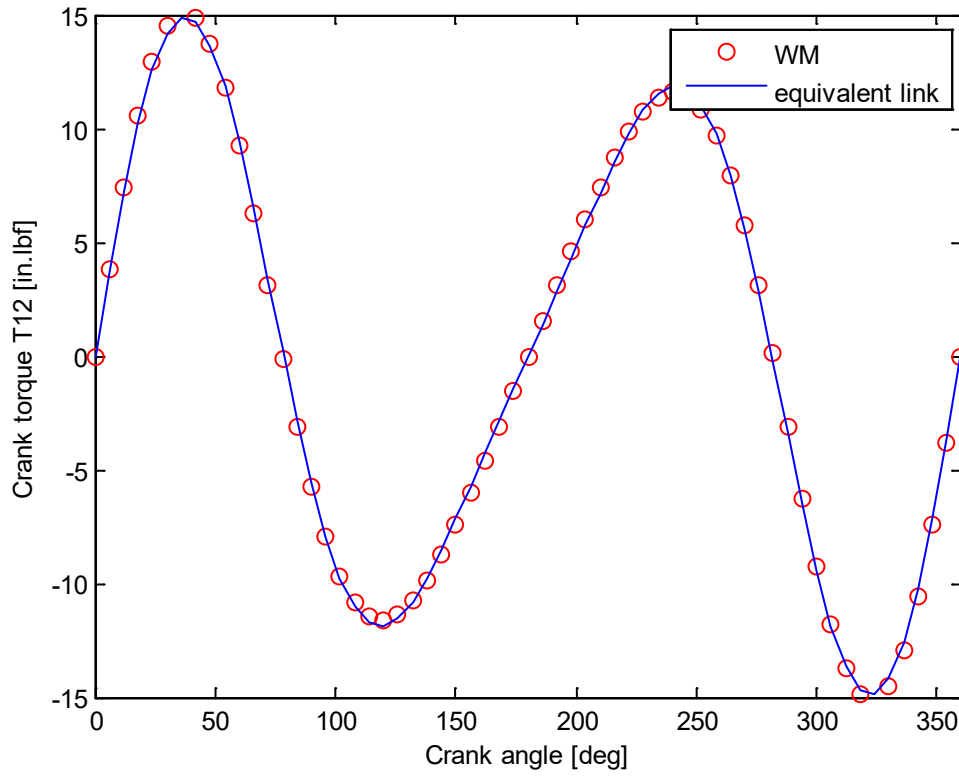
Force of Motor 14  
Fx --- lb  
Fy --- lb  
Fz --- lb

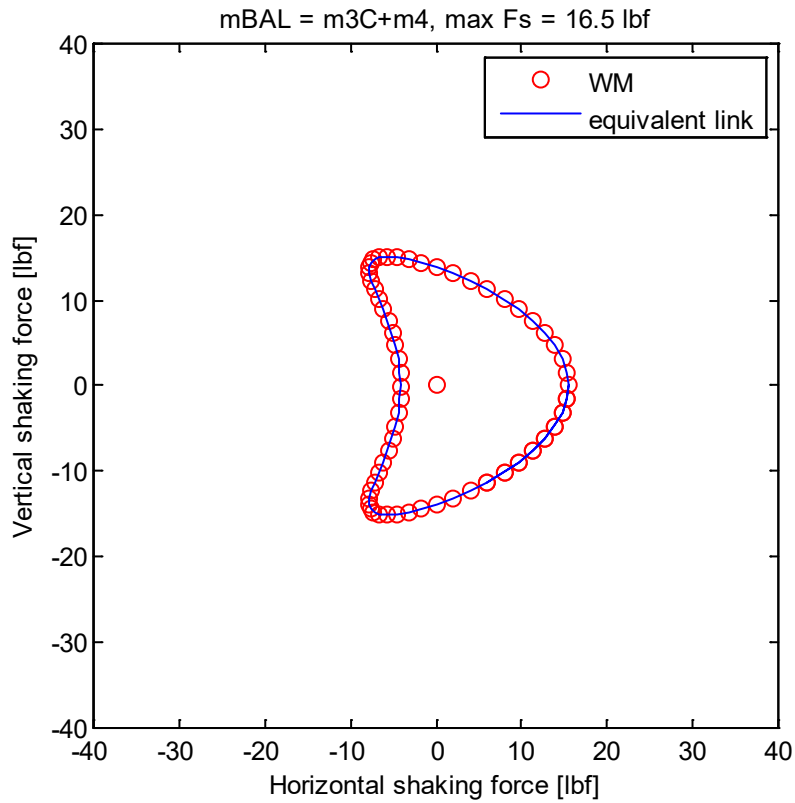
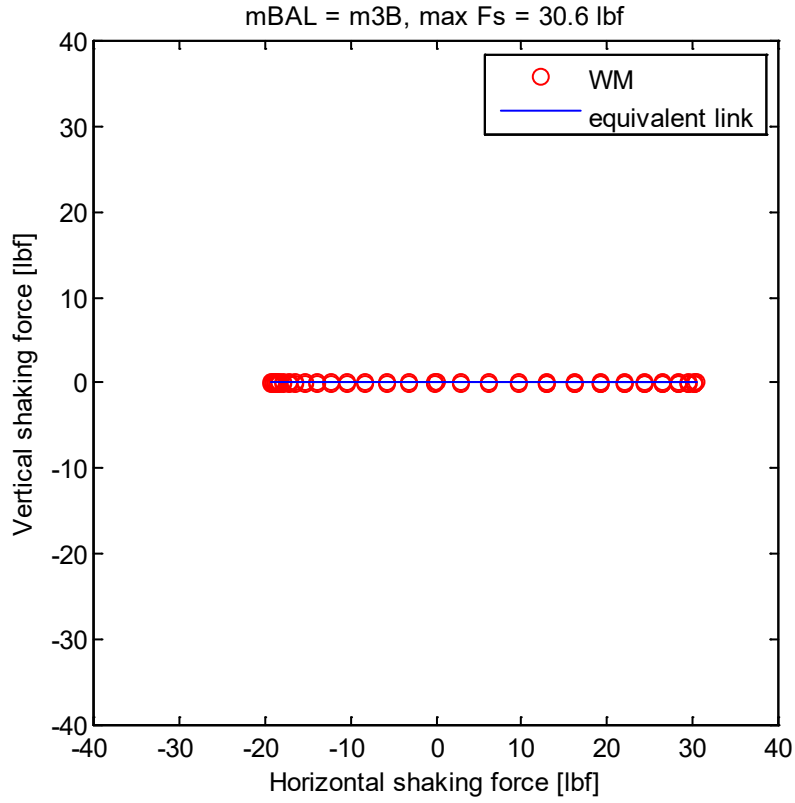
Force of Pin 16  
Fx --- lb  
Fy --- lb  
Fz --- lb

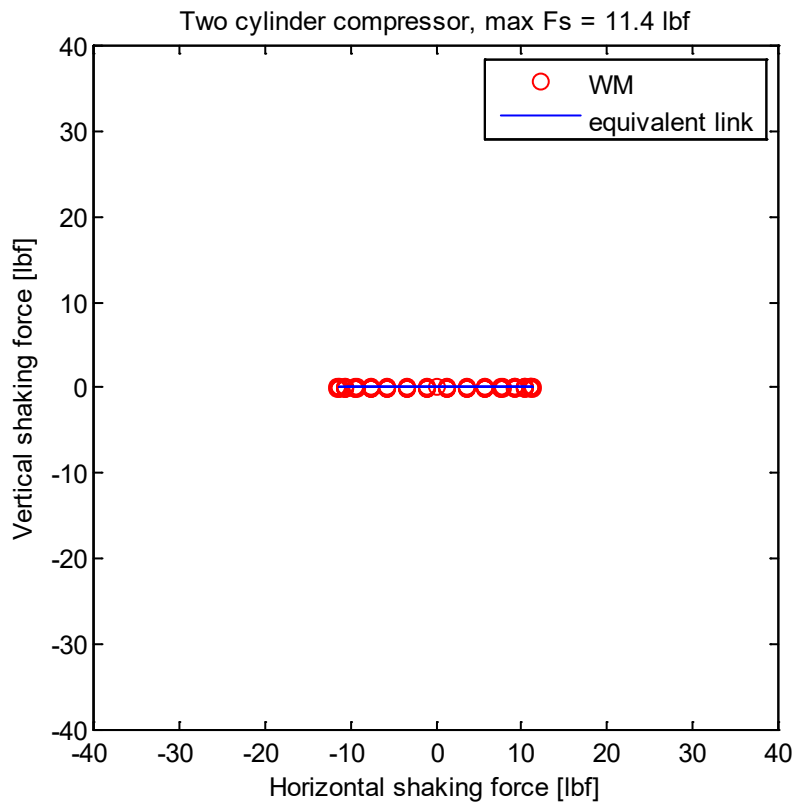
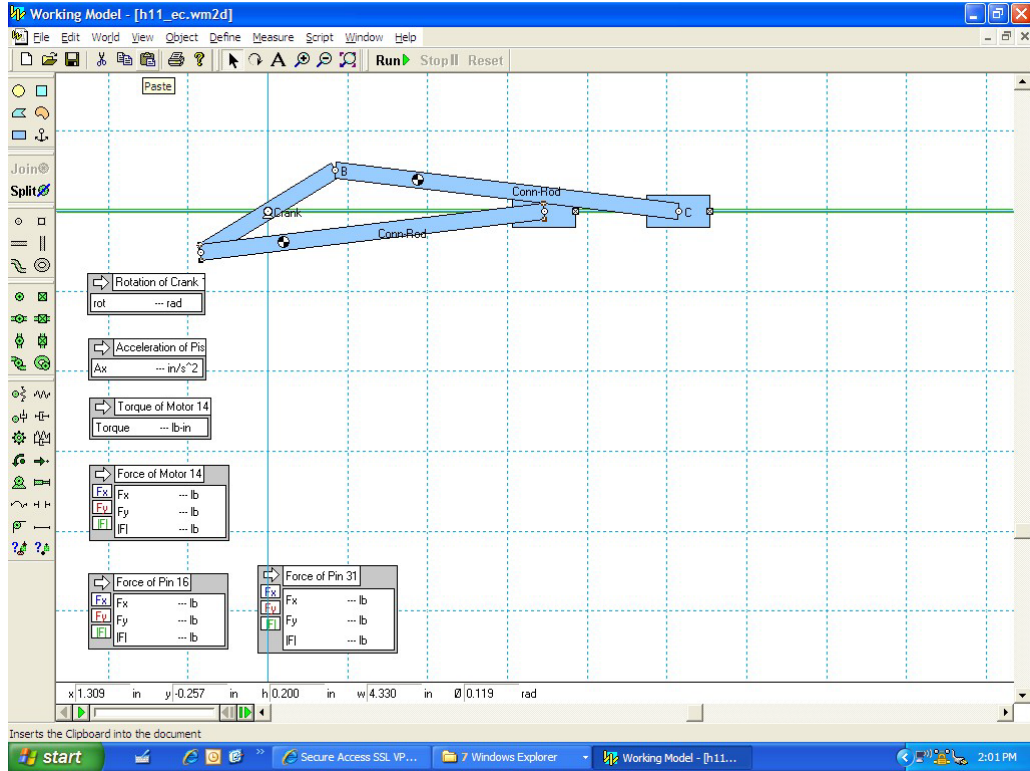
x: -4.535e-0 in y: -1.601e-0 in h: 0.200 in w: 1.970 in theta: 0.510 rad

Ready

start Secure Access ... 7 Windows Ex... Working Model ... Microsoft Photo... 1:35 PM







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% h11.m - ME 481 H11 shaking force
% HJSIII, 13.03.19

clear

% constants
d2r = pi / 180;

% geometry [inches]
R = 0.985;
L = 4.33;

% crank speed 1000 rpm
w = 1000 * 2 * pi / 60; % [rad/sec]

% masses [lbm]
m3B = 0.351;
m3C = 0.111;
m4 = 0.781;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% parts 2 and 3
% load WM data
data_WM = load( 'h11_2_3_cut.txt' );
[ nr, nc ] = size( data_WM );
skip = ( 1 : 10 : nr )';
data_WM = data_WM( skip, : );

% extract WM values
th      = data_WM(:,2);
th_deg  = th / d2r;
T12_WM = data_WM(:,6);
F12x_WM = data_WM(:,8);
F12y_WM = data_WM(:,9);
F34y_WM = data_WM(:,13);

Fx_WM = -F12x_WM;
Fy_WM = -F12y_WM + F34y_WM;

% piston acceleration [inch/s/s]
sdd = -R*w*w*( cos(th) +R*cos(2*th)/L );

% balancing mass
mBAL = 0;

% equivalent link equations
% torque [lbm.in.in/s/s] * [lbf.*s*s / 31.174 lbm.ft] * [ft / 12 in]
T12 = -0.5*(m3C+m4)*R*R*w*w*( R*sin(th)/2/L - sin(2*th) - 3*R*sin(3*th)/2/L ) / 386; % [in.lbf]

% shaking force [lbm.in/s/s] * [lbf*s*s / 32.174 lbm.ft] * [ft / 12 in]
Fx = ( (m3B-mBAL)*R*w*w*cos(th) - (m3C+m4)*sdd ) / 386; % [lbf]
Fy = ( (m3B-mBAL)*R*w*w*sin(th) ) / 386;
Fs = sqrt( Fx.*Fx + Fy.*Fy );
Fs_max = max( Fs );

% plot torque
figure( 2 )
clf
plot( th_deg,T12_WM,'ro', th_deg,T12,'b' )
xlabel( 'Crank angle [deg]' )
ylabel( 'Crank torque T12 [in.lbf]' )
axis( [ 0 360 -15 15 ] )
legend( 'WM', 'equivalent link' )

% plot shaking force curve
figure( 3 )
clf
plot( Fx_WM,Fy_WM,'ro', Fx,Fy,'b' )
axis square
axis( [ -40 40 -40 40 ] )
xlabel( 'Horizontal shaking force [lbf]' )

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ylabel( 'Vertical shaking force [lbf]' )
title( [ 'mBAL = 0, max Fs = ' num2str(Fs_max,3) ' lbf' ] )
legend( 'WM', 'equivalent link' )

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% part 4
% load WM data
data_WM = load( 'h11_4_cut.txt' );
[ nr, nc ] = size( data_WM );
skip = ( 1 : 10 : nr )';
data_WM = data_WM( skip, : );

% extract WM values
th      = data_WM(:,2);
th_deg  = th / d2r;
F12x_WM = data_WM(:,8);
F12y_WM = data_WM(:,9);
F34y_WM = data_WM(:,13);

Fx_WM = -F12x_WM;
Fy_WM = -F12y_WM + F34y_WM;

% piston acceleration [inch/s/s]
sdd = -R*w*w*(cos(th) +R*cos(2*th)/L);

% balancing mass
mBAL = m3B;

% equivalent link equations
% shaking force [lbm.in/s/s] * [lbf*s*s / 32.174 lbm.ft] * [ft / 12 in]
Fx = ( (m3B-mBAL)*R*w*w*cos(th) - (m3C+m4)*sdd ) / 386; % [lbf]
Fy = ( (m3B-mBAL)*R*w*w*sin(th) ) / 386;
Fs = sqrt( Fx.*Fx + Fy.*Fy );
Fs_max = max( Fs );

% plot shaking force curve
figure( 4 )
clf
plot( Fx_WM,Fy_WM,'ro', Fx,Fy,'b' )
axis square
axis( [ -40 40 -40 40 ] )
xlabel( 'Horizontal shaking force [lbf]' )
ylabel( 'Vertical shaking force [lbf]' )
title( [ 'mBAL = m3B, max Fs = ' num2str(Fs_max,3) ' lbf' ] )
legend( 'WM', 'equivalent link' )

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% part 5
% load WM data
data_WM = load( 'h11_5_cut.txt' );
[ nr, nc ] = size( data_WM );
skip = ( 1 : 10 : nr )';
data_WM = data_WM( skip, : );

% extract WM values
th      = data_WM(:,2);
th_deg  = th / d2r;
F12x_WM = data_WM(:,8);
F12y_WM = data_WM(:,9);
F34y_WM = data_WM(:,13);

Fx_WM = -F12x_WM;
Fy_WM = -F12y_WM + F34y_WM;

% piston acceleration [inch/s/s]
sdd = -R*w*w*(cos(th) +R*cos(2*th)/L);

% balancing mass
mBAL = m3C + m4;

% equivalent link equations

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% shaking force [lbm.in/s/s] * [lbf*s*s / 32.174 lbm.ft] * [ft / 12 in]
Fx = ( (m3B-mBAL)*R*w*w*cos(th) - (m3C+m4)*sdd ) / 386; % [lbf]
Fy = ( (m3B-mBAL)*R*w*w*sin(th) ) / 386;
Fs = sqrt( Fx.*Fx + Fy.*Fy );
Fs_max = max( Fs );

% plot shaking force curve
figure( 5 )
clf
plot( Fx_WM,Fy_WM,'ro', Fx,Fy,'b' )
axis square
axis( [ -40 40 -40 40 ] )
xlabel( 'Horizontal shaking force [lbf]' )
ylabel( 'Vertical shaking force [lbf]' )
title( [ 'mBAL = m3C+m4, max Fs = ' num2str(Fs_max,3) ' lbf' ] )
legend( 'WM', 'equivalent link' )

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% extra credit
% load WM data
data_WM = load( 'h11_ec_cut.txt' );
[ nr, nc ] = size( data_WM );
skip = ( 1 : 10 : nr )';
data_WM = data_WM( skip, : );

% extract WM values
th = data_WM(:,2);
th_deg = th / d2r;
F12x_WM = data_WM(:,8);
F12y_WM = data_WM(:,9);
F34y_WM_piston1 = data_WM(:,13);
F43y_WM_piston2 = data_WM(:,17);

Fx_WM = -F12x_WM;
Fy_WM = -F12y_WM + F34y_WM_piston1 - F43y_WM_piston2;

% piston acceleration [inch/s/s]
sdd = -R*w*w*(cos(th) +R*cos(2*th)/L);

% balancing mass
mBAL = 0;

% equivalent link equations
% shaking force [lbm.in/s/s] * [lbf*s*s / 32.174 lbm.ft] * [ft / 12 in]
Fx = ( R*w*w * 2*R*(m3C+m4)*cos(2*th)/L ) / 386; % [lbf]
Fy = zeros( size(Fx) );
Fs = sqrt( Fx.*Fx + Fy.*Fy );
Fs_max = max( Fs );

% plot shaking force curve
figure( 6 )
clf
plot( Fx_WM,Fy_WM,'ro', Fx,Fy,'b' )
axis square
axis( [ -40 40 -40 40 ] )
xlabel( 'Horizontal shaking force [lbf]' )
ylabel( 'Vertical shaking force [lbf]' )
title( [ 'Two cylinder compressor, max Fs = ' num2str(Fs_max,3) ' lbf' ] )
legend( 'WM', 'equivalent link' )

% bottom of h11

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