BOND GRAPH MODELING AND SIMULATION IN MECHATRONICS SYSTEMS. AN INTEGRATED SOFTWARE TOOL: CAMP-G, MATLAB-SIMULINK

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Piezoelectric Sensor

Housing

Piezoelectric Cristal

Oscillator

Operational Amplifier

\[ U_2 \]

\[ U_a \]
Operational Amplifier Bond Graph Model
Equivalent relations

\[ i_q = -i_2 \]
\[ i_q = -\frac{U_a}{R} - \frac{dU_a}{dt} C \]
\[ RC \frac{dU_a}{dt} + U_a = -R \frac{dq}{dt} \]

\[ f_6 = i_q \]
\[ f_{12} = i_c \]
\[ f_{13} = i_r \]
\[ f_7 = -f_6 \]
\[ i_q = -i_2 \]
\[ f_{11} = f_7 = -f_6 = -i_q \]
\[ f_{12} = f_{11} - f_{13} \]
\[ ic = iq - ir \]
\[ f_{12} = \frac{dU_a}{dt} C \]
\[ \frac{dU_a}{dt} C = i_q - \frac{U_a}{R} \]
\[ RC \frac{dU_a}{dt} + U_a = -R \frac{dq}{dt} \]
Piezoelectric Transformation

\[ q = K_q y \]

\[ \frac{dq}{dt} = K_q \frac{dy}{dt} \]
Sensor Mechanical Side Model

\[ m \ddot{y}_r + b \dot{y}_r + ky_r = -m\ddot{u} \]

Simplified Bond Graph
CAMP-G Sensor Model

Mechanical Oscillator

Piezoelectric Transformation

Operational Amplifier

Previous session loaded (from "session") and placed
move segment (... I_4 ...) (marked), done
delete single BOND 7, done
bond from 1_8_11 to 0_6 (bond 7)
Camp-G State Space Model

Inputs vector

\[ u = [ \text{SE1} \ SE10 ] \]

State variables vector

\[ p_q = [Q3;Q12;P4]; \]

A MATRIX

\[
\begin{bmatrix}
0 & 0 & 1 \\
0 & 0 & 0 \\
& & I_4 \\
& & T_{5x6} \\
0 & 1 & T_{5x6} \\
0 & C_{12} & R_{13} \\
1 & T_{5x6} & R_{2} \\
\end{bmatrix}
\]
State Space (cont)

B MATRIX

\[
\begin{bmatrix}
0 & 0 \\
0 & 0 \\
1 & -T5x6
\end{bmatrix}
\]

C MATRIX

\[
\begin{bmatrix}
1 \\
0 & --- & 0 \\
0 & C12
\end{bmatrix}
\]

D MATRIX

\[
\begin{bmatrix}
0 & 0 \\
0 & 0
\end{bmatrix}
\]

System Order = 3

Rank of A MATRIX = 3
Characteristic Polynomial

\[ s^2 + \frac{3 (C_3 C_{12} R_{13} R_2 + C_3 I_4) s}{C_3 I_4 C_{12} R_{13}} + \frac{(C_3 T_{5\times6} R_{13} + C_{12} R_{13} + C_3 R_2) s}{C_3 I_4 C_{12} R_{13}} + \frac{1}{C_3 I_4 C_{12} R_{13}} + \frac{1}{C_3 I_4 C_{12} R_{13}} \]
Computer Generated Transfer Function SIMULINK block

... Transfer Functions Matrix H ...

\[
H = \begin{bmatrix}
3 & 2 \\
- s T5x6 C2 R13 / (s C2 C12 R13 I4 + (C2 C12 R13 R3 + C2 I4) s^2 + (C2 T5x6 R13 + C12 R13 + C2 R3) s + 1) \\
2 & 2 \\
+ (C2 T5x6 R13 + C12 R13 + C2 R3) s + 1) \\
2 \\
+ (C2 T5x6 R13 + C12 R13 + C2 R3) s + 1)
\end{bmatrix}
\]
Frequency and Time Response

Sensor Frequency Response

Magnitude

Phase

Step Response

Impulse Response
Electromechanical Actuator
% [num,den]=ss2tf(A,B,C,D,1)
% bode(num,den)
% figure (1)
% subplot (111),bode(num(1,:),den)
% subplot (111),title('First transfer function ')

4 2
G4x5/(s I12 C9 G4x5 I7 I3

2 2 2 3
+ (R11 C9 G4x5 I7 I3 + I12 C9 G4x5 R6 I3 + I12 C9 G4x5 I7 R2) s + (2 2 2

G4x5 I7 I3 + R11 C9 G4x5 R6 I3 + R11 C9 G4x5 I7 R2 + I12 G4x5 I3

2 2 2 2
+ I12 C9 + I12 C9 G4x5 R6 R2) s + (G4x5 I7 R2 + G4x5 R6 I3

2 2
+ R11 C9 G4x5 R6 R2 + R11 G4x5 I3 + R11 C9 + I12 R2 G4x5 ) s

2 2
+ R2 G4x5 R6 + 1 + R11 R2 G4x5 )
Computer generated state space equations and corresponding A and B matrices.

\[ d\bar{P}_{12} = \frac{Q_9}{C_9} - \frac{P_{12}}{I_{12}}R_{11} \]

\[
A(1,:) = \begin{bmatrix} -\frac{1}{I_{12}R_{11}} & 0 & \frac{1}{C_9} & 0 \end{bmatrix}; \\
B(1,:) = [0];
\]

\[ d\bar{P}_7 = \frac{P_3}{I_3G_{4\times5}} - \frac{P_7}{I_7R_6} - \frac{Q_9}{C_9} \]

\[
A(2,:) = \begin{bmatrix} 0 & -\frac{1}{I_7R_6} & \frac{1}{C_9} & \frac{1}{I_3G_{4\times5}} \end{bmatrix}; \\
B(2,:) = [0];
\]

\[ dQ_9 = \frac{P_7}{I_7} - \frac{P_{12}}{I_{12}} \]

\[
A(3,:) = \begin{bmatrix} -\frac{1}{I_{12}} & \frac{1}{I_7} & 0 & 0 \end{bmatrix}; \\
B(3,:) = [0];
\]

\[ d\bar{P}_3 = S_{E1} - \frac{P_3}{I_3R_2} - \frac{P_7}{I_7G_{4\times5}} \]

\[
A(4,:) = \begin{bmatrix} 0 & -\frac{1}{I_7G_{4\times5}} & 0 & -\frac{1}{I_3R_2} \end{bmatrix}; \\
B(4,:) = [1];
\]
Computer Generated C and D matrices

\[ f_{12} = \frac{P_{12}}{I_{12}} \]

\[
C(1,:) = \left[ \frac{1}{I_{12}}, 0, 0, 0 \right];
\]
\[
D(1,:) = [0];
\]
Control System - Simulink

Amplifier and control

Plant

-1

Bond Graph

Actuator Model

GainPID Controller
(with Approximate Derivative)

PID

Scope
Controller output and input signals
CONCLUSIONS

What can be done with CAMPG/MATLAB?

- CAMP-G generated symbolic Transfer Functions useful feature for design of control systems.
- A new tool in system sensitivity analysis using bond graphs.
- Transforming a bond graph model in the form of transfer functions in the S domain, allows building close loop feedback systems in the S domain.
- If the physical model is changed, the derivation of the equations and MATLAB M files in source code form can be generated quickly using CAMP-G.
- It can save a tremendous amount of time as opposed to having to derive new equations by hand and having to modify a whole block diagram.
- The generation of MATLAB M files is oriented to produce a generalized model structure that makes it possible to simulate non-linear systems using MATLAB.