The Modeling Process step by step

Mechanical Systems

PHYSICAL PARAMETERS

LINEAR MODELS

VEHICLE CRASH TEST TUTORIAL

continued

M = 1500 Kg,  \( k_1 = 1 \times 10^4 \) N/m  \( b_1 = 500 \) N-s/m

m= 100 kg, \( k_2 = 3 \times 10^5 \) N/m  \( b_2 = 8 \times 10^4 \) N-s/m

Model of a vehicle crash test

Physical System
The dummy in the next slide is driving his red VW-Rabbit into a wall! Will his shock absorbing bumper \(k_2, b_2\) and his seat belts \(k_1, b_1\) prevent him from hitting the windshield without breaking his collar bone?

**DATA ON INJURIES (SAE Handbook)**

Seat belts must be tested to 3000 lbs. \((1.334 \times 10^4)\) N
Chest can sustain a force of 1500 lbs distributed over 30 in\(^2\).
Seat belt effective area = 30 in\(^2\).
Shoulder strap-seat belt combination = 60 in\(^2\).

**MAKING A COMPUTER MODEL USING BOND GRAPHS**

**Step 1. Recognize Physical Elements**

\[
\begin{align*}
\text{DUMMY} & \quad \text{SEAT BELT} \\
\text{WALL} & \quad \text{BUMPER} \quad \text{CAR}
\end{align*}
\]

Word bond graph model
Step 2. Recognize Distinct Velocities
Assign each distinct velocity to a 1 “one” junction.

\[ \begin{align*}
1 & \quad V_{\text{dummy}} \\
1 & \quad V_{\text{wall}} \\
1 & \quad V_{\text{V}_{\text{car}} - V_{\text{dummy}}} \\
1 & \quad V_{\text{V}_{\text{car}} - V_{\text{wall}}} \\
1 & \quad V_{\text{V}_{\text{car}}} \\
\end{align*} \]

Step 3. Attach Physical Elements

\[ \begin{align*}
\text{Dummy} & \quad 1 \quad \text{ Dummy} \\
\text{SF} & \quad 1 \quad \text{ Wall} \\
\text{SF} & \quad 1 \quad \text{ Car} \\
\end{align*} \]
Step 4. Represent Relative Velocities with 0’s

[Diagram showing a network of connections with labeled nodes and edges.]

Step 5. Attach elements at Relative Velocities

[Diagram showing a network of connections with labeled nodes and edges, including bond elements such as Inductive (I), Compliance (C), Resistive (R), Source of Effort (SE), Source of Flow (SF), and Bond Junctions (I, C, R) with their respective annotations.]

Bond Elements:
- I - Inductive
- C - Compliance
- R - Resistive
- SE - Source of Effort
- SF - Source of Flow
- Bond Junctions
  - 1 - Common Flow
  - 0 - Common Effort
Step 6. Check Power Flow Directions

Power flow is indicated by the half arrowheads.

\[ V_w = 0 \]

SF (wall) \[ 1 \rightarrow 0 \]

\[ 1 \rightarrow 0 \]

\[ 1 \rightarrow 0 \]

\[ 1 \rightarrow 0 \]

I : M (car)

I : m (dummy)

\[ C : 1/k_2 \]

\[ R : b_2 \]

\[ C : 1/k_1 \]

\[ R : b_1 \]

Step 5. SIMPLIFY AND ADD (CAUSAL MARKS)

Causal marks

\[ V_w = 0 \]

SF \[ 1 \rightarrow 0 \]

\[ 1 \rightarrow 0 \]

\[ 1 \rightarrow 0 \]

\[ 1 \rightarrow 0 \]

I : M

I : m

Final Bond Graph

\[ C : 1/k_2 \]

\[ R : b_2 \]

\[ C : 1/k_1 \]

\[ R : b_1 \]
Completed Bond Graph Model

Wall

\( V_w = 0 \)

Car

\( I : M \)

SF

1

0

5

1

7

0

11

I : m

Dummy

Wall

V_w = 0

SF

1

0

5

1

7

0

11

I : m

Dummy

Car

I : M

Bumper

C : 1/k_2

R : b_2

Seat Belts

C : 1/k_1

R : b_1