Modeling Mechanical, Electric, and Hydraulic Systems in Simulink®

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Physics-Based Modeling Tools
Physics-Based Modeling Methods Improve Control System Design

- Multidomain systems (mechanical, electrical, hydraulic, chemical, . . .)
- Successful controller development requires thorough and accurate understanding of plant
Important Physical Domains

Mechanical
- 3D Multi-Body Dynamics
- Driveline Mechanics

SimMechanics
SimDriveline
Important Physical Domains

**Electrical**
- Circuits  SimPowerSystems
- Motors and Actuators
- Power Systems
Important Physical Domains

**Hydraulics**
- Circuits
- Motors and Actuators
- Power Systems

![Diagram of hydraulics and electrical components]
Control System
Power Delivery

- Electrical Power Network
- Hydraulic Power Network
- Mechanical Driveline Power Network
Control Systems within Control Systems
Biggest Benefit – Delivered Through Simulink®

- Rich Modeling Environment
  - Physical
  - Behavioral
  - Data-Driven
- Control System Development Tool
  - One environment for controller and plant
  - Code generation that enables HIL testing
  - Easy access to control tools
Why did we build SimHydraulics?

- Hydraulics is widely used in motion actuation systems
- Customer Feedback
  - “Extend benefits of Model-Based Design to hydraulic system design”
  - “Develop better plant models for better controller development”
  - “Co simulation with other products is difficult and impractical”
Pros and Cons for Hydraulics

Pros:
- High power density
- Straight-line actuators are simple, efficient and reliable
- Variable speed is easily obtained
- Simple, efficient, and centralized control
- Overload protection

Cons:
- High cost
- Complex and costly maintenance
- Extremely vulnerable to dirt and contamination
- Possible leaks
- Noise and vibrations
- Fire hazards

Design Trend is Electro-Hydraulics:
Transmit power electrically, but deliver through local hydraulic networks
Hydraulic System Schematic Diagram
Block Diagrams

\[ p_p = p_p(t), \]
\[ q_{O1} = K_1 \sqrt{p_p - p_A}, \quad q_{O2} = K_1 \sqrt{p_A - p_T}, \]
\[ qA = K_A \cdot \frac{dp_A}{dt}, \]
\[ q_P = q_{O1}, \quad q_A = q_{O1} - q_{O2}, \]
\[ p_P - p_T = (p_P - p_A) + (p_A - p_T), \]
Physical System Diagrams

Hydraulic Schematic

SimHydraulics Model
Demonstrations
Building Blocks

Direct-Acting Pressure Relief Valve

This model demonstrates a test circuit to check the pressure flow characteristics of a direct-acting pressure relief valve. The valve model is a subsystem built of an orifice with roundshocks, translational connector, preloaded spring, and a hydraulic pump, which is simulated with an ideal flow rate source. Delivered fluid to a system through an initially-opened variable orifice. As the valve gets closed, pressure gradually builds up and eventually reaches the setting of the pressure relief valve. At this pressure, the valve starts diverting fluid to a tank and maintains preset pressure at the pump outlet. As the valve is opened again, the pressure relief valve is closed and the entire flow passes through the variable orifice.
Actuation

Closed-Loop Electrohydraulic Actuator with Proportional Valve

The actuator consists of a proportional 4-way directional valve driving a double-acting hydraulic cylinder. The cylinder drives a load consisting of a mass, viscous and Coulomb friction, constant force, and a spring. The actuator is powered by a variable-displacement, pressure-compensated pump, driven by a constant velocity motor. Pipelines between the valve, cylinder, pump, and the tank are simulated with the Hydraulic Pipeline block.
Multidomain with SimMechanics
Two Approaches to Modeling Dynamic Systems

First-Principles Modeling

Use an understanding of the system’s physics to derive a mathematical representation

\[ \alpha = \int \frac{-L_2 \sin(\alpha) + nw_2 (-\sin(\alpha - \gamma)) \sin(\gamma) - ne (-\sin(\alpha - \gamma)) \cos(\alpha - \gamma) \alpha^2 - n \cos(\alpha - \gamma) \gamma^2}{1 - ne \sin^2(\alpha - \gamma)} \, d\gamma \]
Two Approaches to Modeling Dynamic Systems

First-Principles Modeling

Use an understanding of the system’s physics to derive a mathematical representation

\[
\alpha = \int \left[ -\frac{\sin(\alpha)}{s^2 + 2} + \frac{1}{s+1} \right] \frac{\sin(\alpha)}{s} \, d\gamma
\]

Data-Driven Modeling

Use system test data to derive a mathematical representation

\[
\int \left( \sin(\alpha) \cos(\alpha - \gamma) \right) \, d\gamma
\]
Each Approach Has Its Merits

First-Principles Modeling

**Advantages:**
- Provides *insight* into the system’s underlying behavior
- Enables performance **prediction** for unbuilt systems

**Disadvantages:**
- Effects like friction and turbulence are difficult to characterize
- May be time consuming to develop

Data-Driven Modeling

**Advantages:**
- Can be a *fast* method for developing an accurate model
- Instills **confidence** because it uses data from an actual system

**Disadvantages:**
- Requires a physical system to acquire test data
- Lacks description of physics of the system
- May need multiple data sets to cover range of system operation
Tools that Span Both Modeling Approaches

Complete Modeling Environment

First-Principles
- Simulink
- SimHydraulics
- SimMechanics
- SimDriveline
- SimPowerSystems

Data-Driven
- Simulink® Parameter Estimation
- System Identification Toolbox
- Neural Network Toolbox
- Fuzzy Logic Toolbox
Inform Model with Test Data

Simulink Parameter Estimation

- Data fitting and optimization techniques
- Sets parameters defined by physics-based modeling tools
Code Generation with Real-Time Workshop®

- Generate ANSI C code
- Hardware-in-the-loop (HIL) simulations
- S-functions
- In-house code
Flexibility of mathematical modeling enables you to simulate almost anything.
SimHydraulics brings you further by reducing your requirements for hydraulic domain knowledge and programming effort.
The MathWorks provides the best combination of tools for multidomain simulations.