Modeling the Thrust Regulator of a Liquid Rocket Engine

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Thrust Developed by Liquid Rocket Engine

Thrust, \[ F = \dot{m} \times v_2 + A_2 (P_2 - P_3) \]

For a Given Nozzle Mass Flow rate \( \alpha \) Chamber Pressure and \( A_t \)

\[ F = C_f \times P_c \times A_t \]

Thrust can be maintained constant by regulating chamber pressure, \( P_c \)
Problem Statement

✓ Modeling the Thrust Regulation System of a Bipropellant Liquid Rocket Engine.
✓ Capturing the Behavior During Shut Down Transient
Thrust Regulation System

- Chamber Pressure Feedback.
- Reference Pressure.
- Three Regulators
  - Fuel
  - Oxidiser
  - Water

Thrust Regulation System control the mass flow rate to GG to keep the turbine power at the level necessary to achieve the required thrust chamber pressure.
Modeling Approach

Grey Box Modeling

- Governing Equations from First Principles
- Parameter Estimation Using Measured Data
- Integrated Nonlinear Model
The regulators work on the principle of pressure balance over the faces of the regulator piston.

Any difference in the balancing pressures, makes the piston to move.
Modeling of Regulator

Dynamics Of Regulator Piston

- $M$ - Mass of the piston
- $B$ - Damping constant
- $X$ - Piston Position
- $P_{in}$ – Inlet Pressure.
- $P_{ref}$ – Reference Pressure
- $P_{out}$ - Regulated Pressure

Conservation of Momentum

$$M \ddot{x} + B \dot{x} = A (P_1 - P_2)$$

Substituting

$$q_1 = \rho_1 A \frac{dx}{dt}$$

$$P_1 = P_{ref} - \left[ R_1 \times q_1 + L_1 \times \frac{dq_1}{dt} \right]$$

$$P_2 = P_{out} + \left[ R_2 \times q_2 + L_2 \times \frac{dq_2}{dt} \right]$$

Flow Through Variable Area Orifice

$$\Delta P = K \times Q^2$$

$$K = f(x)$$

$$K_{reg} = \frac{a}{x + b} + c.$$
Model Formulation

Equations 1, 2 and 3 completely represent one typical fluid circuit line of the thrust regulation system.

\[ P_{\text{in}} = K_{\text{reg}} \times Q^2 + K_{\text{or}} \times Q^2 + P_{\text{gg}} \]

\[ Q = \sqrt{\frac{P_{\text{in}} - P_{\text{gg}}}{K_{\text{reg}} + K_{\text{or}}}}. \]

\[ M_{\text{eq}} \ddot{x} + B_{\text{eq}} \dot{x} = A(P_{\text{ref}} - P_{\text{out}}) \]

\[ P_{\text{in}} - P_{\text{out}} = \left[ \frac{a}{x + b} + c \right] \times Q^2 \]
Parameter Estimation

1. Create File Describing model structure
2. Provide Model Orders
3. Initial States
4. Use 'idnlgrey' to create Non Linear grey Model
5. Iddata from measured data
6. Use 'pem' to estimate parameters
Data acquired in one of the tests is used for validating the model. Shut down transient regime after the shutdown command is issued is considered for model validation.
Model validation indicates that the predicted regulator outlet pressure during transient is fairly accurate.

The model has been developed by using System Identification Toolbox available in MATLAB.

The regulator outlet pressure decides the propellant flow rate to GG and thereby controls the thrust chamber pressure.
Thank you .....