Modeling the Thrust Regulator of a Liquid Rocket Engine

Mathew Saxon A.
Vishnu Suresh Nair
Sajeev.P
Bejoy John
Liquid Propulsion System Centre.
ISRO.
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, \( P_c \)

- \( \dot{m} \): Mass flow rate
- \( V_2 \): Exit velocity
- \( A_2 \): Exit Area
- \( P_2 \): Exit pressure
- \( P_3 \): Ambient pressure.
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
Working Principle of Regulator

- 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

\[ q_1 = \rho_1 \times A \times \frac{dx}{dt} \]

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

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

\[ \Delta P = K \times Q^2 \]

\[ K = f(x) \]

\[ K_{reg} = \frac{a}{x + b} + c. \]

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

-----(2)

\[ M_{eq} \ddot{x} + B_{eq} \dot{x} = A(P_{ref} - P_{out}) \] ----- (1)
Model Formulation

Typical Fluid Circuit Line Of The Thrust Regulation System

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

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

\[ Q = \sqrt{\frac{P_{in} - P_{gg}}{K_{reg} + K_{or}}} \]  \hspace{1cm} (3)

\[ M_{eq} \ddot{x} + B_{eq} \dot{x} = A(P_{ref} - P_{out}) \]  \hspace{1cm} (1)

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

Create File Describing model structure

Provide Model Orders

Initial States

Use 'idnlgrey' to create Non Linear grey Model

Iddata from measured data

Use 'pem' to estimate parameters
Model Validation

Data acquired in one of the tests is used for validating the model. Shutdown 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 .....