Position Control and Friction Identification of a DC Hybrid Stepper Motor

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MAE 171B - Spring 2006

Jacobs School of Engineering

Objectives / Project Goals:

- To Model the Dynamics of a DC Hybrid Stepper Motor
- To Model the Internal Friction of a DC Hybrid Stepper Motor
- To Apply a Feedback Control Algorithm to the Motor System
  - To Promote System Stability
  - Allow for Accurate Position Tracking
- To Apply a Friction Compensator to Estimate and Minimize Frictional Effects

Experimental Setup

Equipment Used:

- Windows PC
- Mathworks Matlab Software with Simulink Toolbox
- Real-time Workshop Software
- Quanser Multi-Q3 DAC system
- Dynaserv DM Series 1030B Hybrid DC/Stepper Motor

Design

• Initial motor equation:

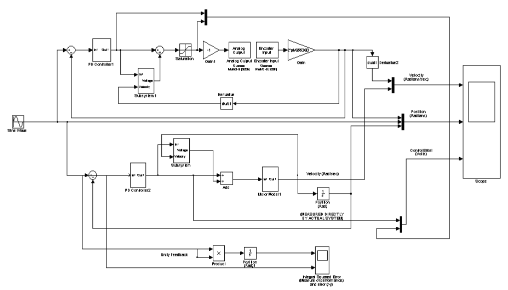
• Developed a basic motor model using the Simulink Toolbox
  - Compared the step response of the model vs. true
  - Tuned model parameters (Inertia, inductance, motor constant, etc.)

• Developed and implemented a friction model that accounted for:
  - Back emf - Viscous/Coulomb
  - Stiction - Stribeck Effect

• Developed a PD Controller and applied in actual system
  - Adjusted parameters using loop shaping and root locus techniques

• Developed and implemented friction compensation
  - Tested parameters for stability verification
  - Tested overall performance of closed loop feedback system

Simulink Model of closed loop feedback response



References:

-H. Olsson, K.J. Åström, C. Canudas de Wit, M. Gäfvert, P. Lischinsky, *"Friction Models and Friction Compensation"*

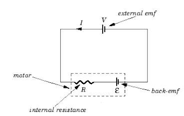
- R. M. Hirschorn and G. Miller, *"Control of Nonlinear Systems with Friction"*
Pierre Dupont, Vincent Hayward, Brian Armstrong, and Friedhelm Altpeter, *"Single State Elastoplastic Friction Models"*

- Ron H. A. Hensen, Marinus (René) J. G. van de Molengraft, and Maarten Steinbuch, *Member, IEEE, "Frequency Domain Identification of Dynamic Friction Model Parameters"*

Theory

Back EMF Phenomena

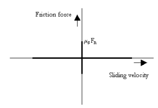
We modeled the Dynaserv DM Series Model 1030b, seen in below, as a dc motor consisting of a multi-turn coil which is free to rotate in a constant magnetic field. As a external dc voltage source is connected across the motor, the voltage source drives a steady current "I" around the external circuit. As the current flows around the coil, the magnetic field exerts a torque causing the motor to rotate. As the motor attains a steady-state rotation frequency, the rotating coil generates a back-emf, *"ε"*, whose magnitude is directly proportional to the frequency of rotation.



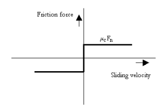
The motor is modeled as a resistor, *"R"*, which represents the internal resistance of the motor, in series with the back-emf, *"ε"*. The back-emf acts in the opposite direction to the external emf *"V"*.

Static Friction Phenomena

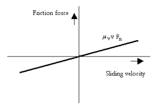
The following static friction phenomena have a direct dependency on velocity.



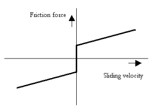
Static Friction Model: Friction force opposes the direction of motion when the sliding velocity is zero.



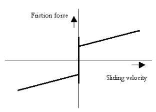
Coulomb Friction Model: Friction force is proportional to load, opposes the direction of motion and is independent of contact area.



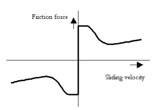
Viscous Friction Model: Friction force caused by the viscosity of lubricants.



Coulomb-Viscous Friction Model



Static-Coulomb-Viscous Friction Model

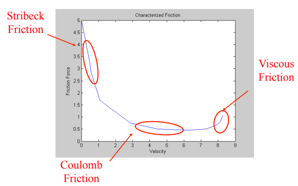


Static-Coulomb-Viscous-Stribeck Effect Friction Model
Stribeck Effect describes how the friction force is decreasing continuously with increasing velocity.

Analysis

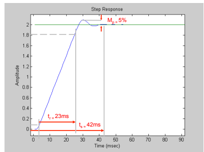
Characterized Friction of Our Model

Experimentally derived the characterization of friction of our model measuring voltage vs gain. Our friction model shows a characteristics of Stribeck, Coulomb and Viscous friction.



System Response to Step Signal

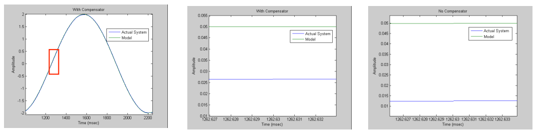
With implementation of compensator and controller, our system achieves a 5% overshoot, 23ms rise time, and a 4.2ms settling time



Results

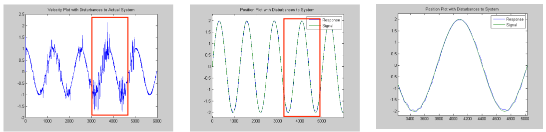
Friction Compensator

The below graphs depict the steady state error of our system with and with out the friction compensator. Our fit is not perfect, yet we see that the order of magnitude of the difference is significant



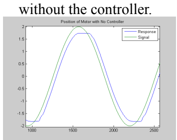
Disturbance Rejection

A disturbance is applied to actual motor. We can see from our plot of voltage and position that our system remains stable and quickly recovers.



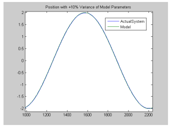
No Controller Implemented

The graph below depicts our system with our PD controller not yet implemented, as shown, there exists a small phase shift without the controller.



Test for Stability

We varied the parameters of our motor model by +/- 10% to determine the robustness of our system design.



Conclusions

- Created an Approximated DC Hybrid Stepper Motor Model
- Modeled Non-Linear Frictional Effects Present in System
- Position Control Performance acceptable
  - Step Response Performance:
  - 5% overshoot, 25 ms rise time, 40 ms settling time

• Stiction, Coulomb and Viscous Friction Effects minimized through implementation of friction compensator
• Stability and Robustness of Feedback Control System acceptable

Recommendations

• Apply a more complex motor model to account for stepper motor dynamics
• Attach Flexible Beam to system and re-evaluate system stability and robustness
• Apply Advanced Dynamic Friction Component to Friction Model and Compensator
• Create and apply an Adaptive Controller to system to compensate for system degradation and external variables