Total Sliding Mode Position Control of a Linear Variable Reluctance Motor

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Introduction

» Applications of linear motion

- Automation process
- Transportation
- Material handling
- Elevator
- Assembly
- Payload

“Total Sliding Mode Position Control of a Linear Variable Reluctance Motor”
Introduction

- Technologies for linear motion
  - Rotary motors with mechanical transmissions

**Advantages**

Simplicity for implementation, lower cost, more widely use

**Disadvantages**

Mechanical transmission losses, high maintenance, mechanical limitations on acceleration and velocity, limited accuracy

“Total Sliding Mode Position Control of a Linear Variable Reluctance Motor”
Introduction

Technologies for linear motion
- Linear motors (direct drive): permanent magnet, reluctance, induction, DC

Advantages
- Less friction, higher accuracy, no backlash, low maintenance, longer lifetime

Disadvantages
- Higher cost, high maintenance (LPM)
Introduction

 Goals of paper

1. Develop a simple position control with good performance for LVR motor

2. Implement the developed position control, which is based on a simplified sinusoidal flux model for LVR motor

“Total Sliding Mode Position Control of a Linear Variable Reluctance Motor”
Structure and Principle of LVR Motor

- Two E-cores moving along the stator
- Motor windings are installed on each side of the E-cores
- Strong magnetic coupling between phases
- Symmetric structure with zero normal force when balanced

"Total Sliding Mode Position Control of a Linear Variable Reluctance Motor"
Structure and Principle of LVR Motor

Advantages:
Simple structure, compactness, low cost (no permanent magnet)
**Structure and Principle of LVR Motor**

- **Phase voltage equations of the LVR motor in the dq0 domain**

\[
\begin{align*}
    u_d &= R i_d - \alpha L_q i_q \frac{dx}{dt} + L_d \frac{di_d}{dt} \\
    u_q &= R i_q + \alpha L_d i_d \frac{dx}{dt} + L_q \frac{di_q}{dt} \\
    u_0 &= R i_0
\end{align*}
\]

- **Force function of the LVR motor**

\[
f (i_q, i_d) = \alpha \left( L_d - L_q \right) i_q i_d
\]

\[
\alpha = \frac{\pi}{p_t}
\]
Mechanical dynamic equation of the LVR motor

\[ F = M\ddot{x} + B\dot{x} + F_L \]

- \( M \): Moving mass
- \( B \): Viscous friction coefficient
- \( F_L \): External force
Position Control

- Design for high precision position control for manufacturing automation applications

- Use the dq0 theory of classical synchronous reluctance motors
  - Sinusoidal reluctance/inductance approximation
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Position Control

1. S-curve profile command

“Total Sliding Mode Position Control of a Linear Variable Reluctance Motor”
Total Sliding Mode Control

\[ F = M\ddot{x} + B\dot{x} + F_L \]

\[ \ddot{x}(t) = C_{1n}\dot{x}(t) + C_{2n}U(t) + W(t) \]

\[ C_{1n} = -\frac{\bar{B}}{M}, \quad C_{2n} = \frac{1}{M} \]

\[ U = F \]

\[ W(t) = \text{lumped uncertainty} \]
Position Control

2. Total Sliding Mode Control

\[ U = U_{BMC} + U_c \]

- \( U_{BMC} \): Baseline model control
- \( U_c \): Curbing control
Total Sliding Mode Control

Baseline model control

\[ U_{BMC} = -C_{2n}^{-1}C_{1n} \dot{x} + C_{2n}^{-1} [ \ddot{x} + k_p e + k_d \dot{e} ] \]

1\textsuperscript{st} term to compensate nonlinear effects

2\textsuperscript{nd} term to determine system performance
Total Sliding Mode Control

Curbing control

\[ U_c(t) = -\rho(t)C_2^{-1} \text{sgn}(S(t)) \]

To eliminate the perturbation and uncertainty effects

\[ |W(t)| < \rho \]

The selection of \( \rho \) affects the chattering phenomena and system stability performance
Position Control

 Desired phase current command

\[
\begin{bmatrix}
    \dot{i}_1^d \\
    \dot{i}_2^d \\
    \dot{i}_3^d
\end{bmatrix} = \sqrt{F^d} \begin{bmatrix}
    \cos x_1 & - \sin x_1 \\
    \cos x_2 & - \sin x_2 \\
    \cos x_3 & - \sin x_3
\end{bmatrix} \begin{bmatrix}
    1 \\
    \text{sgn}(F^d)
\end{bmatrix}
\]

 Constant parameters

\[
x_j = \frac{\pi}{p_t} x + \left( j - 1 \right) \frac{2\pi}{3}
\]

\[
\gamma = \frac{3\pi}{2p_t} (L_d - L_q)
\]
Current control

\[ u_j = k_i (i_j^d - i_j) \]

- Desired phase voltage

\( k_i \) = Current control parameter
Experimental setup
- dSPACE controller board
- Three phase power inverter
- 14kg payload
- Two desired trajectories for experimental test
  - Short-distance profile: 400 µm
  - Long-distance profile: 10 cm
- Two controllers for experimental test
  - Input-output linearization control [8]
  - Total sliding mode control
Position Control

Experimental setup

“Total Sliding Mode Position Control of a Linear Variable Reluctance Motor”
Experimental Results

Position and position error responses for short-distance profile: 400 µm

*Previous [8] Control*

Max dynamic error ≈ 61.9 µm

Steady state error ≈ 27.5 µm

“Total Sliding Mode Position Control of a Linear Variable Reluctance Motor”
Experimental Results

Position and position error responses for short-distance profile: 400 µm

- Max dynamic error ≈ 31.7 µm
- Steady state error ≈ 10 µm

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Experimental Results

Position and position error responses for long-distance profile: 10 cm

**Max dynamic error**

\[ \approx 331.4 \, \mu m \]

**Steady state error**

\[ \approx 22 \, \mu m \]

Previous [8] Control
Experimental Results

Position and position error responses for long-distance profile: 10 cm

Max dynamic error
≈ 264 µm

Steady state error
≈ 15 µm

“Total Sliding Mode Position Control of a Linear Variable Reluctance Motor”
Conclusions/Future work

➢ **Advantages**
- Simple and computationally efficient for implementation
- System robustness to parameter variations

➢ **Disadvantages**
- Chattering phenomena problem
- Future work to reduce chattering phenomena to achieve higher accuracy for high-precision application
Thank You