Modelling & Testing of the Mechatronic Wedge Brake

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Introduction

Trend towards “By-Wire” Technologies: EMB
Large clamping forces required

eStop®: Wedge brake with high self-reinforcement
- Operates around point of neutral stability
- Low operating forces & high dynamics
- Requires mathematical modelling for control law design and validation
Why Self-Reinforcement?

Actuator force in comparison; Alpha = 19.4°; Braking Moment = 2000 Nm

-10 kN
-5 kN
0 kN
5 kN
10 kN
15 kN
20 kN
25 kN
30 kN
35 kN
40 kN

Friction coefficient $\mu$

Outline of Presentation

- Description of Prototype
- Description of Test Environment
- Brief presentation of mathematical model
- Test Results and Comparisons
- Programme status
- Conclusions
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Cross Section Through Prototype

Wedge Construction
Test Environment: Dynamometers

First Dynamometer

125 kW Dynamometer

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Test Environment: Data Recording

- Based on Matlab/Simulink with xPC Target
- Sensor conditioning electronics for Moment Sensor, LVDTs, Force Sensors, and Temperature Sensors
- Target PC Containing
  - PCI-QUAD04 Encoder Card
  - PCI-DAS1602/16: A/D, D/A, Digital IO, and Counters (x2)
  - PCI-DAS1200/JR: A/D and Digital IO
- Host PC
  - Drive experiments
  - Data processing & presentation
Modelling Overview

Work from motor to brake disc

1. Motor x
2. Roller-screw x
3. Brake Heart √
4. Wedge & Brake Calliper √
### Modelling: Wedge & Brake Calliper 1

![Diagram of Wedge & Brake Calliper 1]

- $F_M \rightarrow$
- $F_B \rightarrow$
- $\alpha$
- $K_{CAL}$
- $F_N$
- $F_A$

### Modelling: Wedge & Brake Calliper 2

#### Normal Force:

$$F_N = K_{CAL}x_W \tan \alpha$$

#### Braking Moment:

$$M_B = 2 \mu_B F_N r_B$$

#### Braking Force:

$$F_B = \mu_B F_N = \mu_B K_{CAL}x_W \tan \alpha$$

#### Force on Wedge:

$$F_W = (\mu_B - \tan \alpha)K_{CAL}x_W \tan \alpha + F_M$$
**Design Process**

1. Linear controller design in Matlab/Simulink
2. Non-linear design in Matlab/Simulink
3. Testing in non-linear Simulink model
4. 'Cut & Paste' controller into Host PC Simulink model
5. Code generation using Real Time Workshop
6. Test on dynamometer (xPC Target)
7. Analysis of test results (Matlab)
8. Improvements required?

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**Test Results**

- Some example test results
- Comparison Model to Test
  - Demonstration motor rate controller
  - Moment controller: 200 Nm step and pulse
  - Moment controller: 950 Nm pulse
- Moment Control: 100 Nm fine control
- Moment Control 1500 Nm demand with unstable wedge
Motor Rate Control Example

Gain (V/V) vs. Frequency (Hz)

Phase (deg) vs. Frequency (Hz)

Moment Control: 200 Nm Step

Step 200 Nm: Test Data Comparison

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Programme Status

- Started testing on a larger stand
  - More variation in temperature and friction coefficient
  - Wear of components

- Next prototype
  - Incorporate adjustment mechanism
  - Incorporate parking brake
  - Robust position sensor
  - More packaged electronics

- Vehicle tests to start in Quarter 1 2005
Conclusion

- Rapid prototyping software has been instrumental in the progress made to date:
  - Single software environment for design & testing
  - Faster turn-around for problem solving
  - Reduction in errors: ‘cut & paste’ of controller
  - Simple measures implemented to ensure traceability

- Hardware has demonstrated the high dynamics and low power consumption predicted by theory

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Thank you for your attention