Modeling and Identification of Wear in a Robot Joint under Temperature Uncertainties

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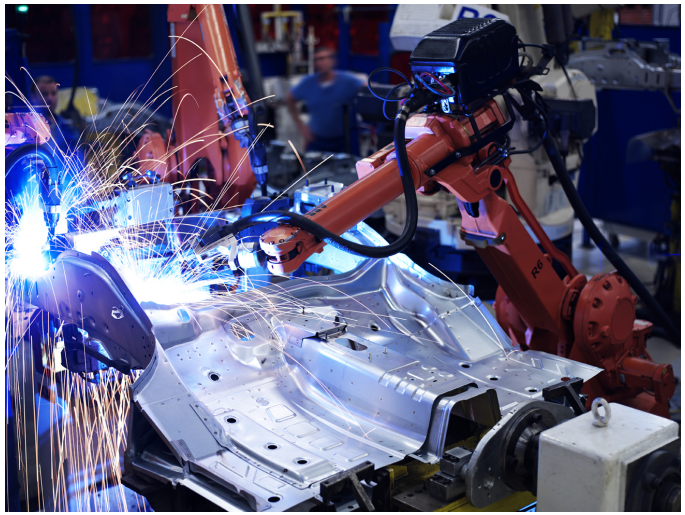
Industrial robots applications may be

- harsh
- dull
- safety critical
- cost critical

Reliability is a key for success!



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- Robots can’t fight time...

Reliability in Robotics

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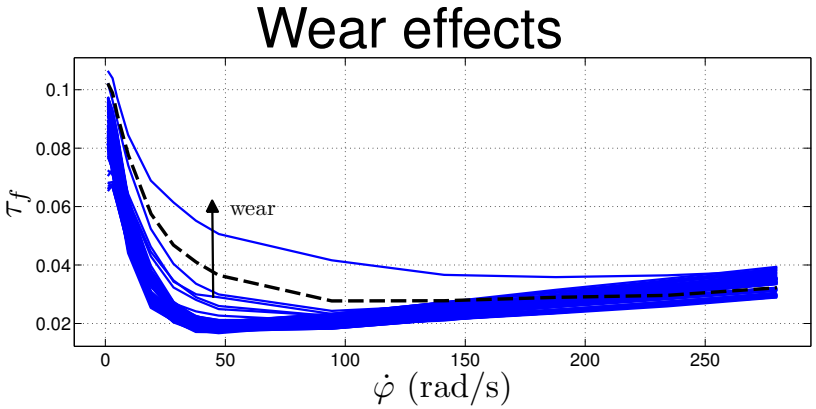
Reliability is a key for success!

- Robots can't fight time...
- But they still need to be reliable

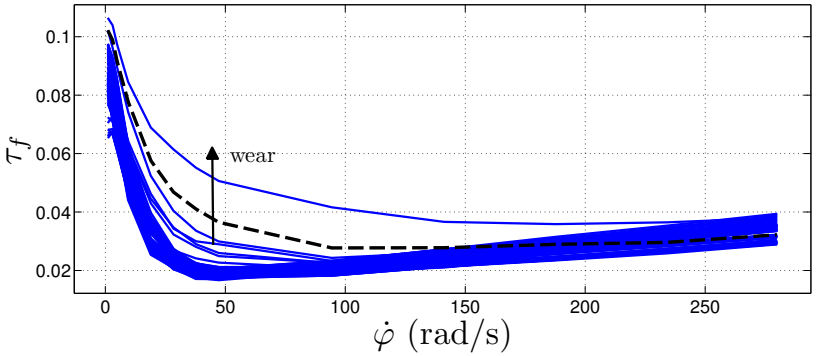
Wear and Friction



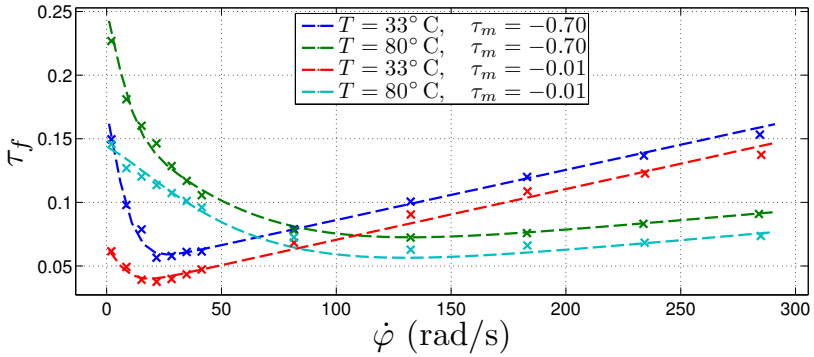
Can we identify wear through friction?

Wear and Friction

Wear effects



... and the bad news!



Bittencourt, et al. "An extended friction model to capture load and temperature effects in robot joints," IROS 2010

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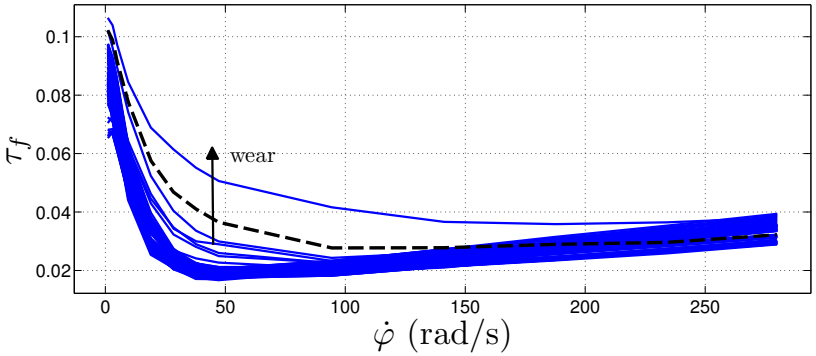

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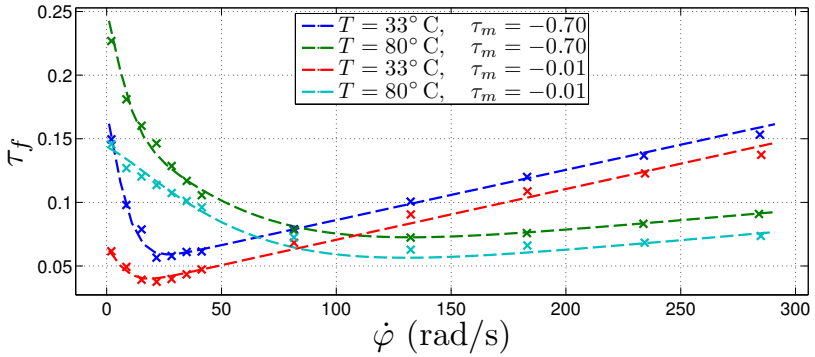

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Can we identify wear through friction?

Basic idea:

$$\hat{\mathbf{w}} = \arg\min_{\mathbf{w}} V\left(\tau_f(\dot{\varphi}) - \hat{\tau}_f(\dot{\varphi}, \tau_m, T, \mathbf{w})\right)$$

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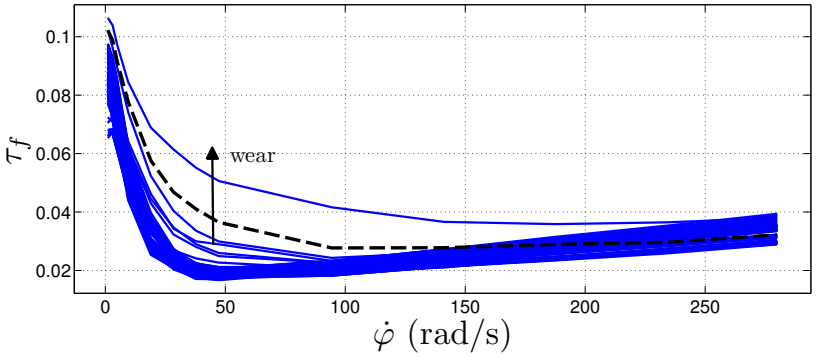

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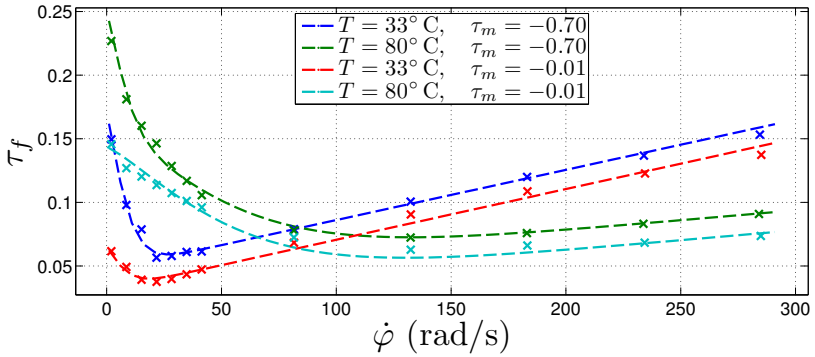

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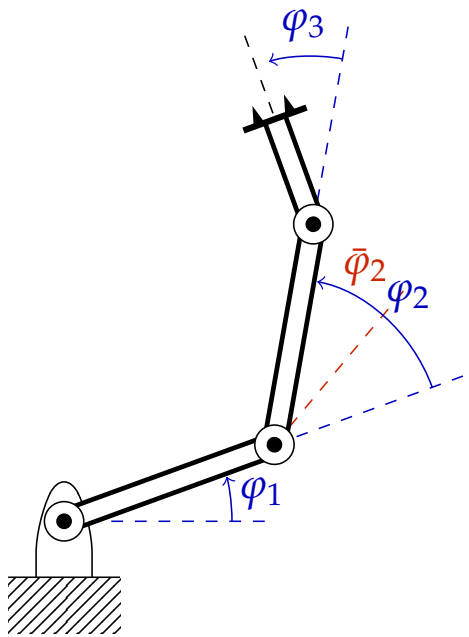
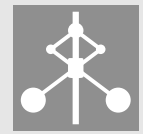
- How to observe friction?
- Can we model the wear effects?
- How to handle T effects?

A Test Cycle

Here is our robot. We want τ_f.

$$M(\varphi)\ddot{\varphi} + C(\varphi, \dot{\varphi}) + \tau_g(\varphi) + \tau_f(\dot{\varphi}) = u$$





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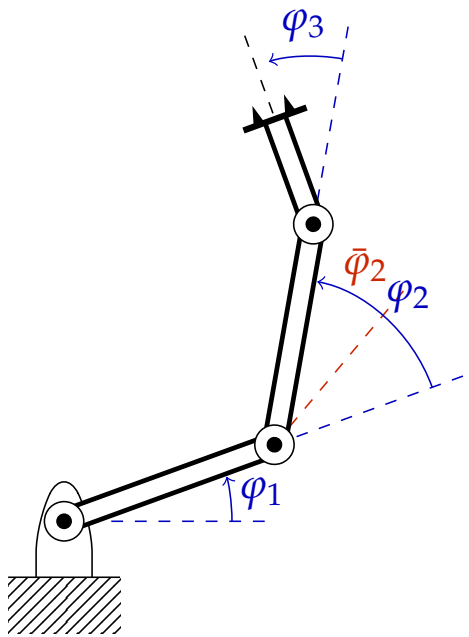

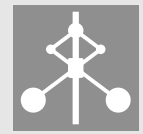

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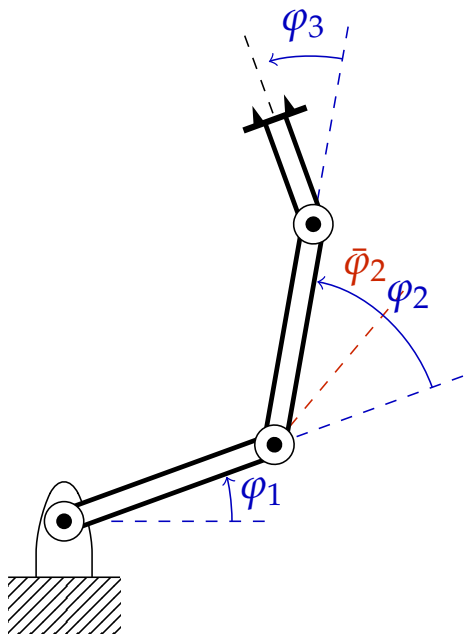

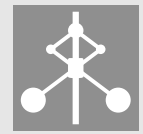

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Move back and forth around $\bar{\varphi}$

$$\tau_f(\bar{\dot{\varphi}}) + \tau_g(\bar{\varphi}) = u^+,$$
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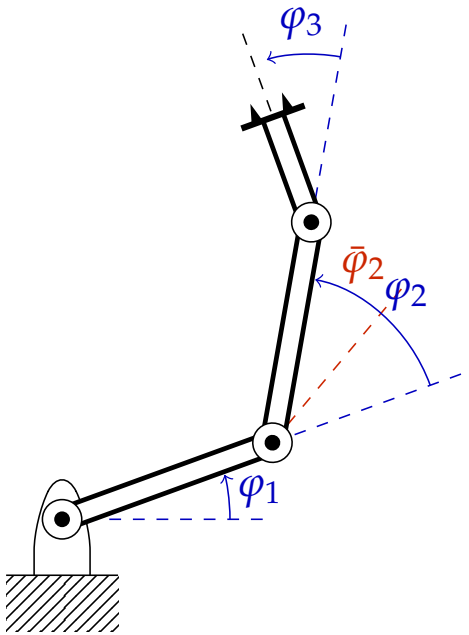

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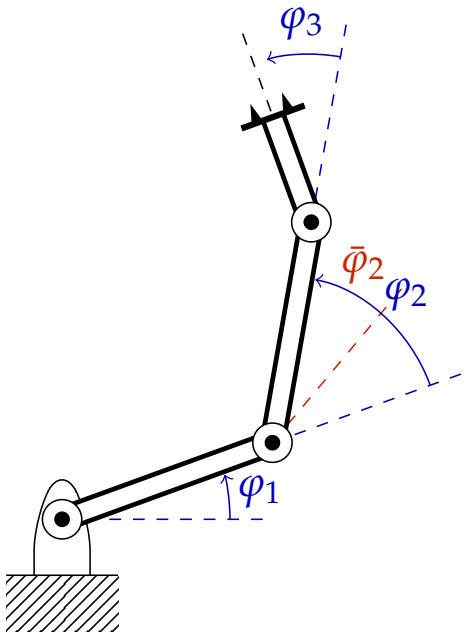

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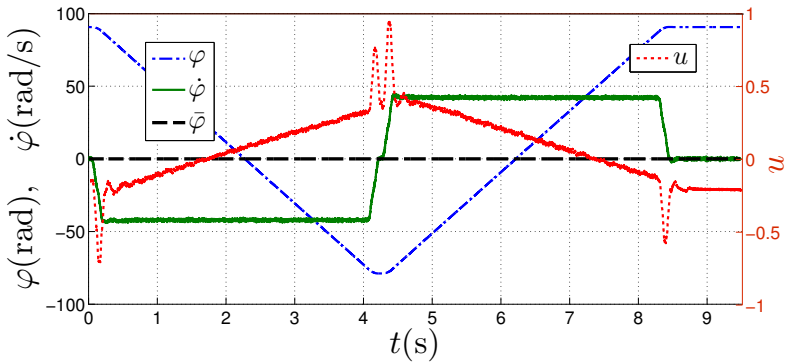

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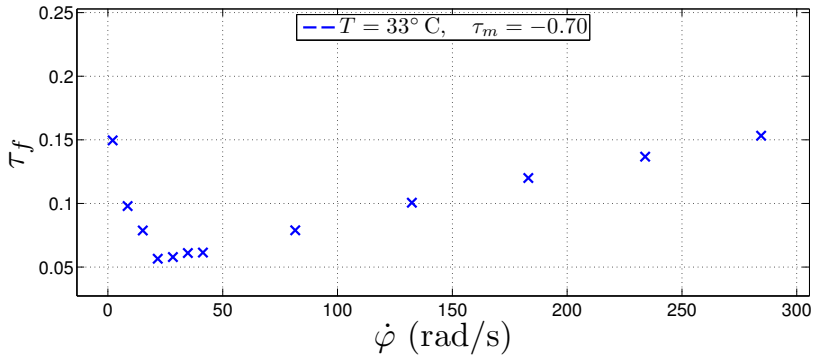
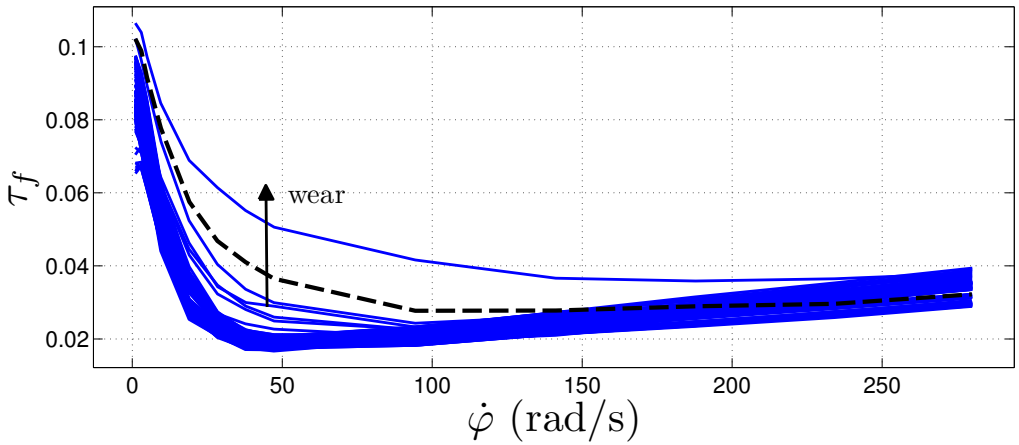


Time and space constraints

Wear debris accumulate in the joints



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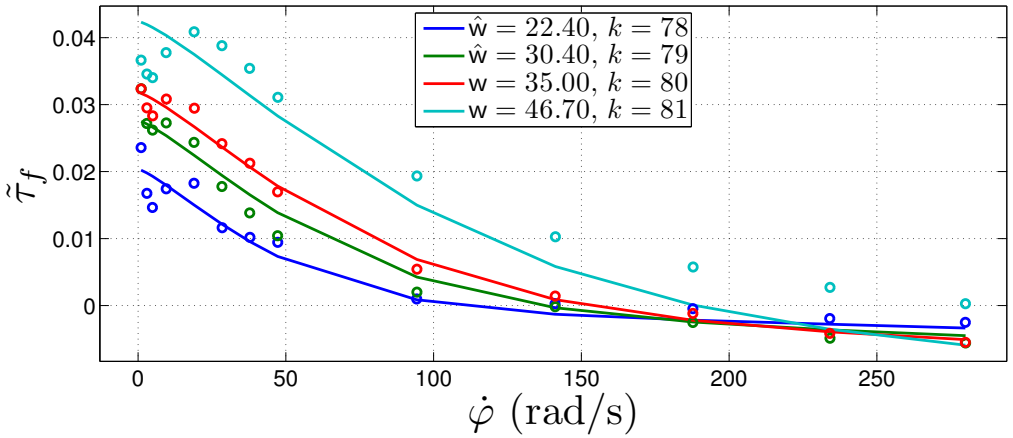

Look at the changes only

$$\tilde{\tau}_f(\dot{\varphi}, \mathsf{w}) = F_{s,\mathsf{w}}\mathsf{w}e^{-\left|\frac{\dot{\varphi}}{\dot{\varphi}_{s,\mathsf{w}}\mathsf{w}}\right|^{\alpha}} + F_{v,\mathsf{w}}\mathsf{w}\dot{\varphi}$$

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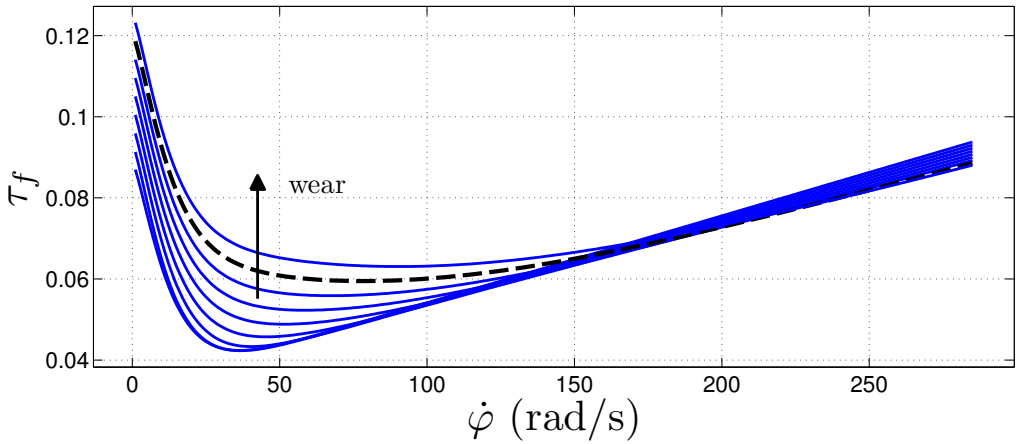


Assuming effects are independent

$$\tau_f(\dot{\varphi}, \tau_m, T, \mathsf{w}) = \tau_f(\dot{\varphi}, \tau_m, T) + \tilde{\tau}_f(\dot{\varphi}, \mathsf{w})$$

Wear Identification

A setup used for analysis

- Only 1 friction observation allowed
- A known friction model (13)
- Temperature treated as random with known bounds

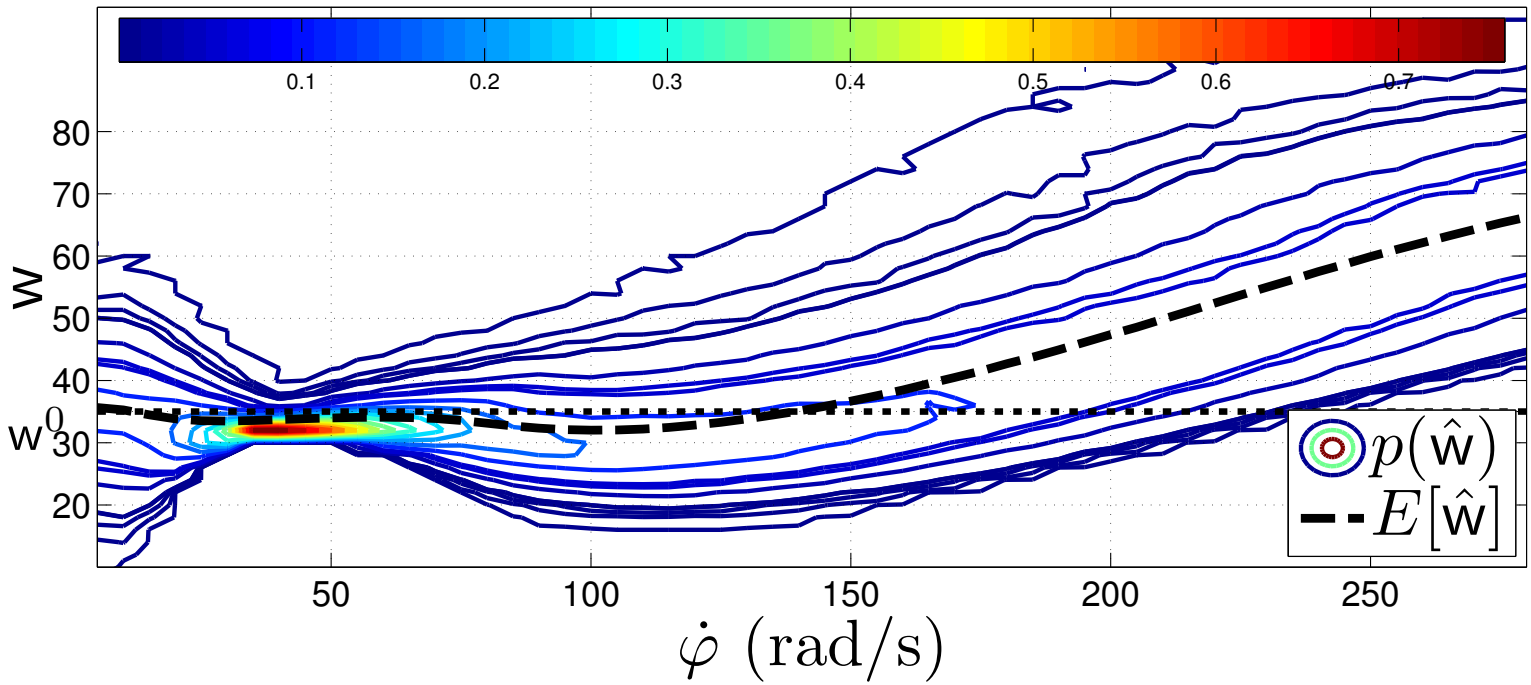
$$\hat{\mathsf{w}}_i(\dot{\varphi}) = \arg\min_{\mathsf{w}} V\left(\tau_f(\dot{\varphi}) - \hat{\tau}_f(\dot{\varphi}, \tau_m, T_i, \mathsf{w})\right), \quad T_i \sim \mathcal{U}(\underline{T}, \overline{T})$$

$$\hat{\mathsf{w}}(\dot{\varphi}) = E\left[\hat{\mathsf{w}}_i(\dot{\varphi})\right], \quad i = 1, \ldots, N$$

Choice of $\dot{\varphi}$ is a design criteria. What region is best?

Wear Identification

Estimated distribution for a critical wear level



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- Large variance at low/high $\dot{\varphi}$
- Selective $\dot{\varphi}$ region where $\hat{w}$ estimates are useful

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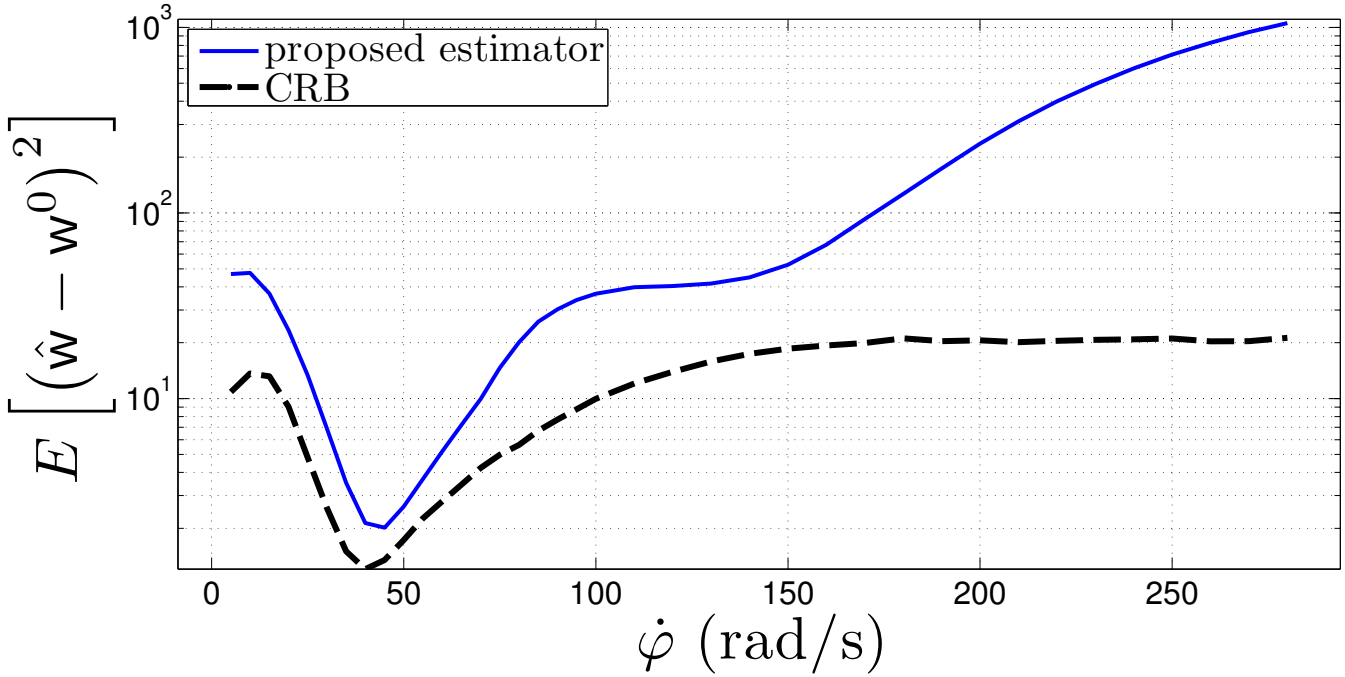

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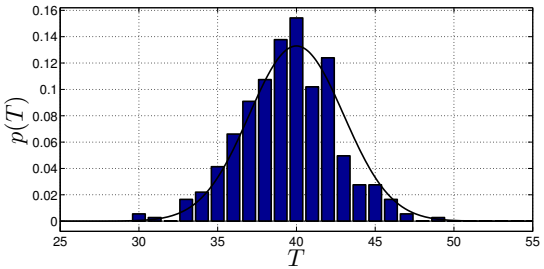
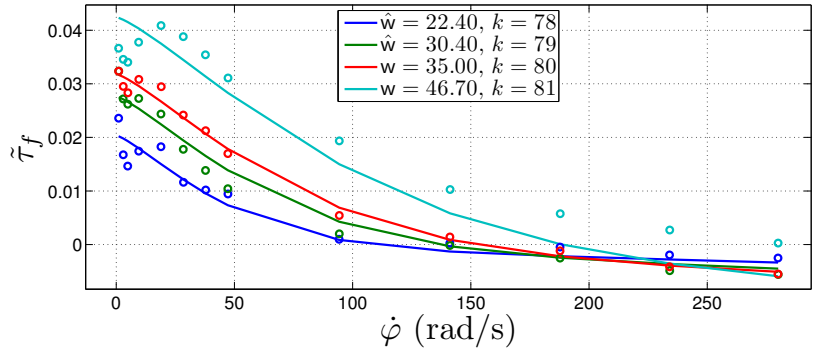
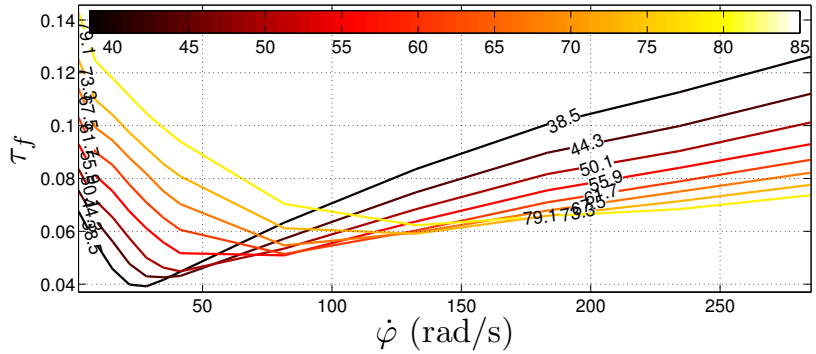
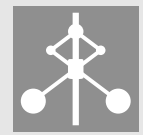
Real failure data combined with fault free data (temperature)

$$\tau_f^*(k) = \tilde{\tau}_f(k) + \tau_f^0(T)$$

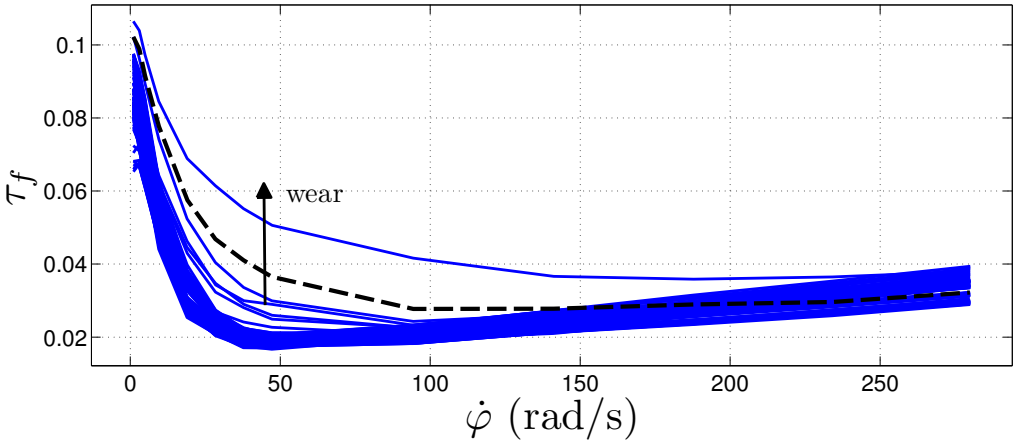


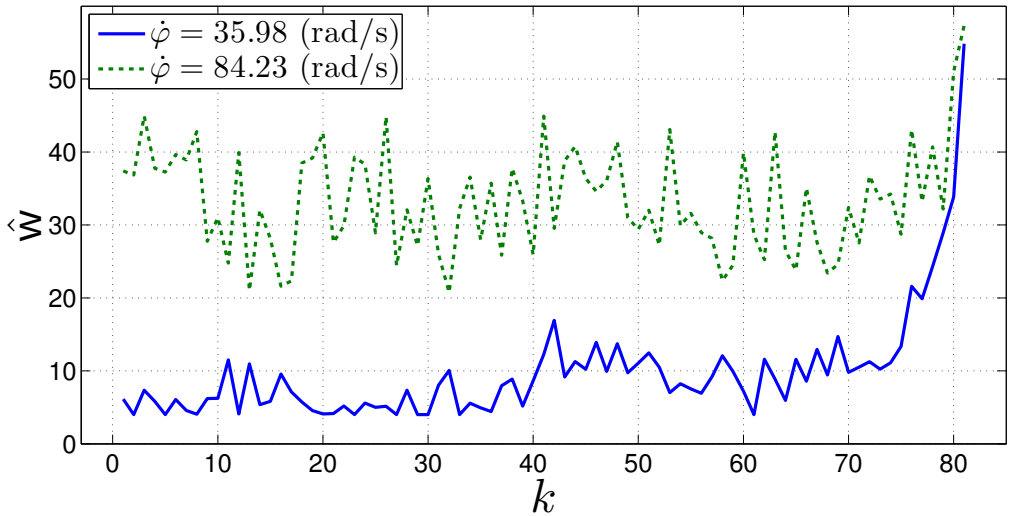






Results


0.1
0.08
0.06
0.04
0.02
τ_f
wear
0
50
100
150
200
250
$\dot{\varphi}$ (rad/s)


$\dot{\varphi} = 35.98$ (rad/s)
$\dot{\varphi} = 84.23$ (rad/s)
50
40
30
20
10
0
$\hat{w}$
0
10
20
30
40
50
60
70
80
k

Conclusions

- Robust wear estimation is possible!
- Revealed basic characteristics
- Friction model useful for analysis/design
- Practical restrictions (known model, test cycle)

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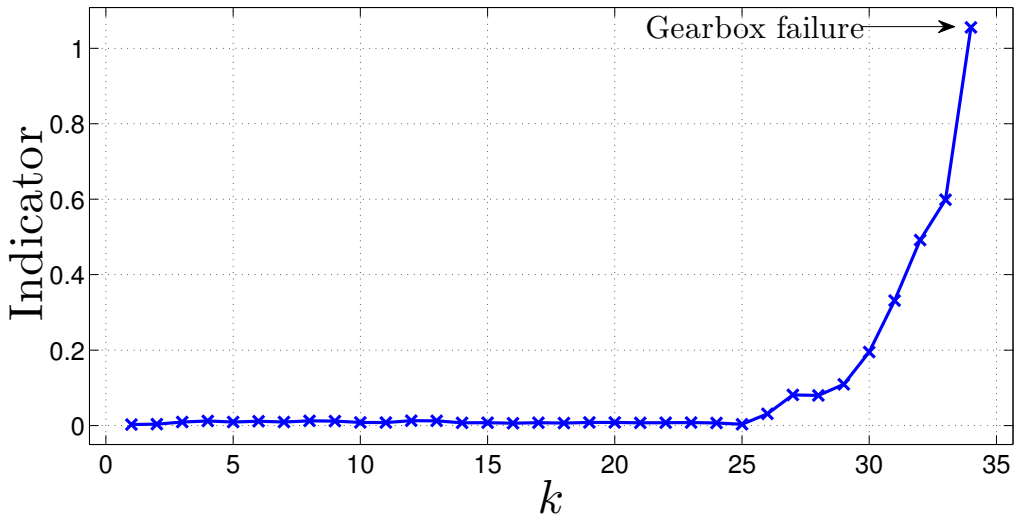

No test cycle/model required.

Thank you!