Getting and Losing Traction

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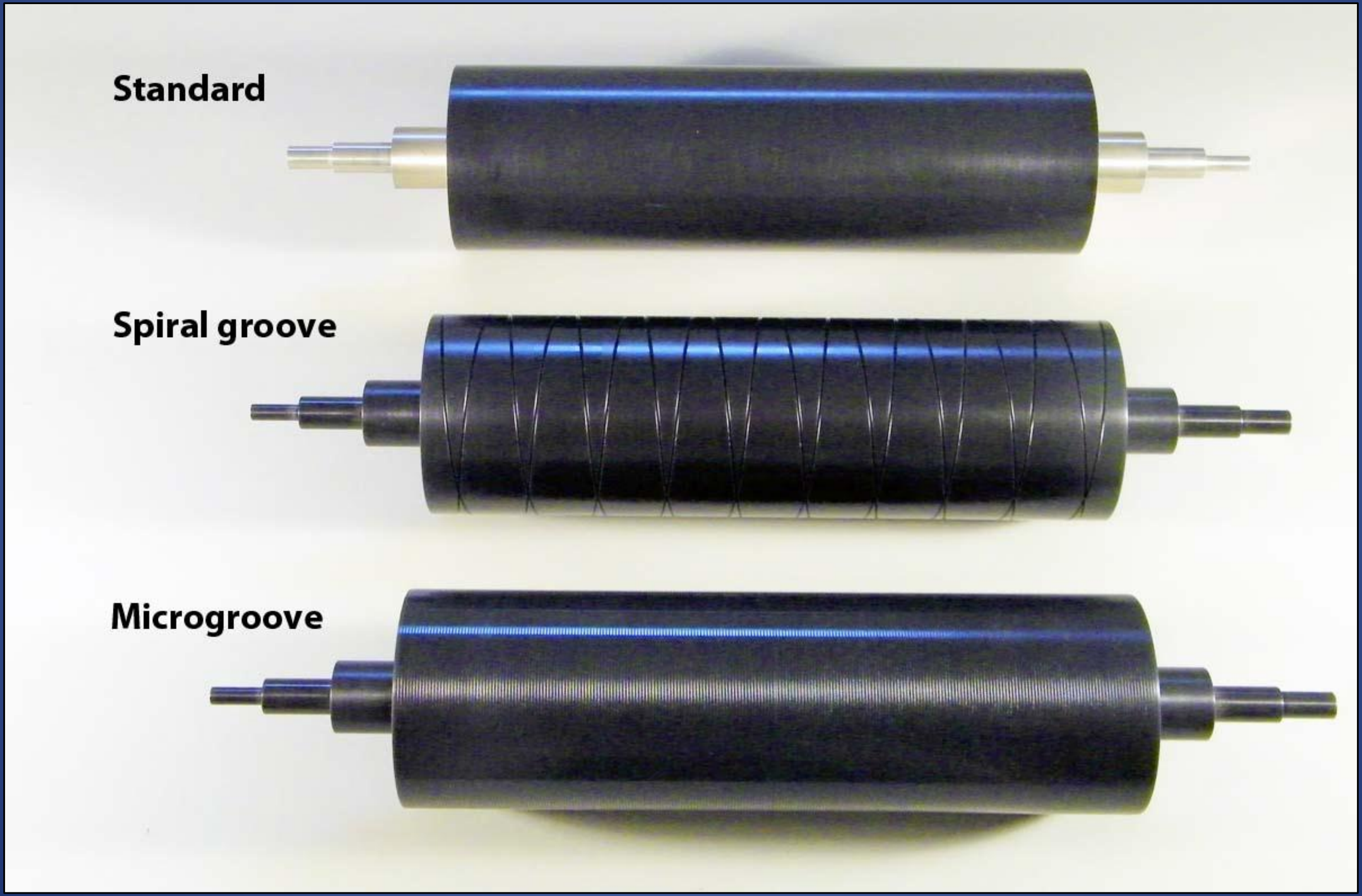
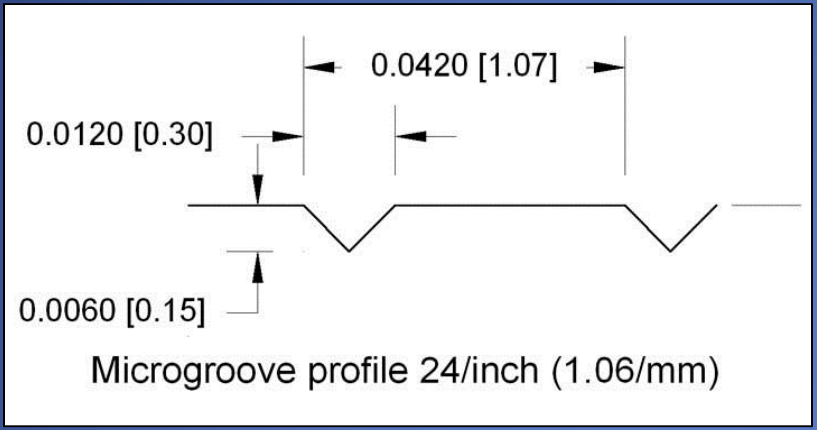
Introduction

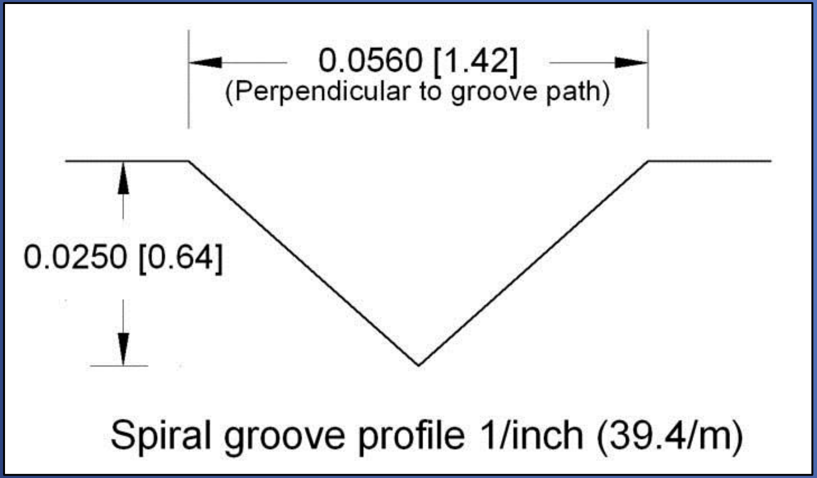
- Assuming good traction … ??? How many times have you read that?
- Because of air lubrication, the web begins to lose traction *as soon as it starts moving*.
- A lot is known about air lubrication. There are even some very good theoretical modeling tools.
  - But the emphasis here will not be on modeling.
  - It will be on getting a sense of how things go when you change something.
- Focus will be on comparisons of tests of three different types of rollers:
  - A standard roller
  - A spiral groove roller
  - A microgroove roller

The rollers



Groove geometries





Microgroove is 2.7 inch (69 mm) wide in the circumferential direction.

Spiral groove is 0.53 inch (13.5 mm) wide in the circumferential direction.

Thanks

- The grooved rollers are commercially available designs which were generously donated by Webex (thank you Pete Eggen).
  - Historical note: The Webex microgroove design was developed in cooperation with 3M many years ago (thank you Tim Walker).
- The web used throughout the tests is Tedlar donated by DuPont (thank you John Wysokowski).

The plan for what follows

- Description of the test machine
  - Schematic
  - Sensors
  - Drive
  - Brake and torque measurement
  - Bearing friction

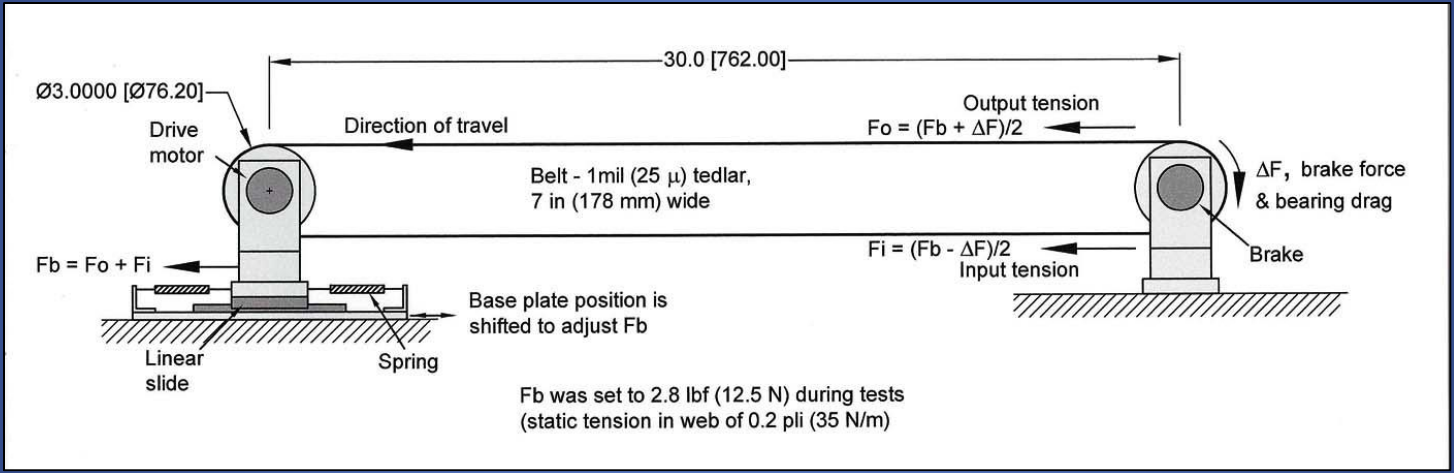
The plan for what follows

- An explanation of what is going on:
  - Effect of friction on traction
    - Capstan behavior
  - Air lubrication
    - How the entrained air behaves
  - Interaction of the air film with web and roller surfaces
  - Venting techniques
    - Annular grooves

The plan for what follows

- Test results
  - Standard roller
  - Microgroove roller
  - Spiral groove roller
- For each type we will see:
  - The speed at which the web begins slipping on the roller
  - How the effective coefficient of friction between the web and roller changes with speed.

The machine



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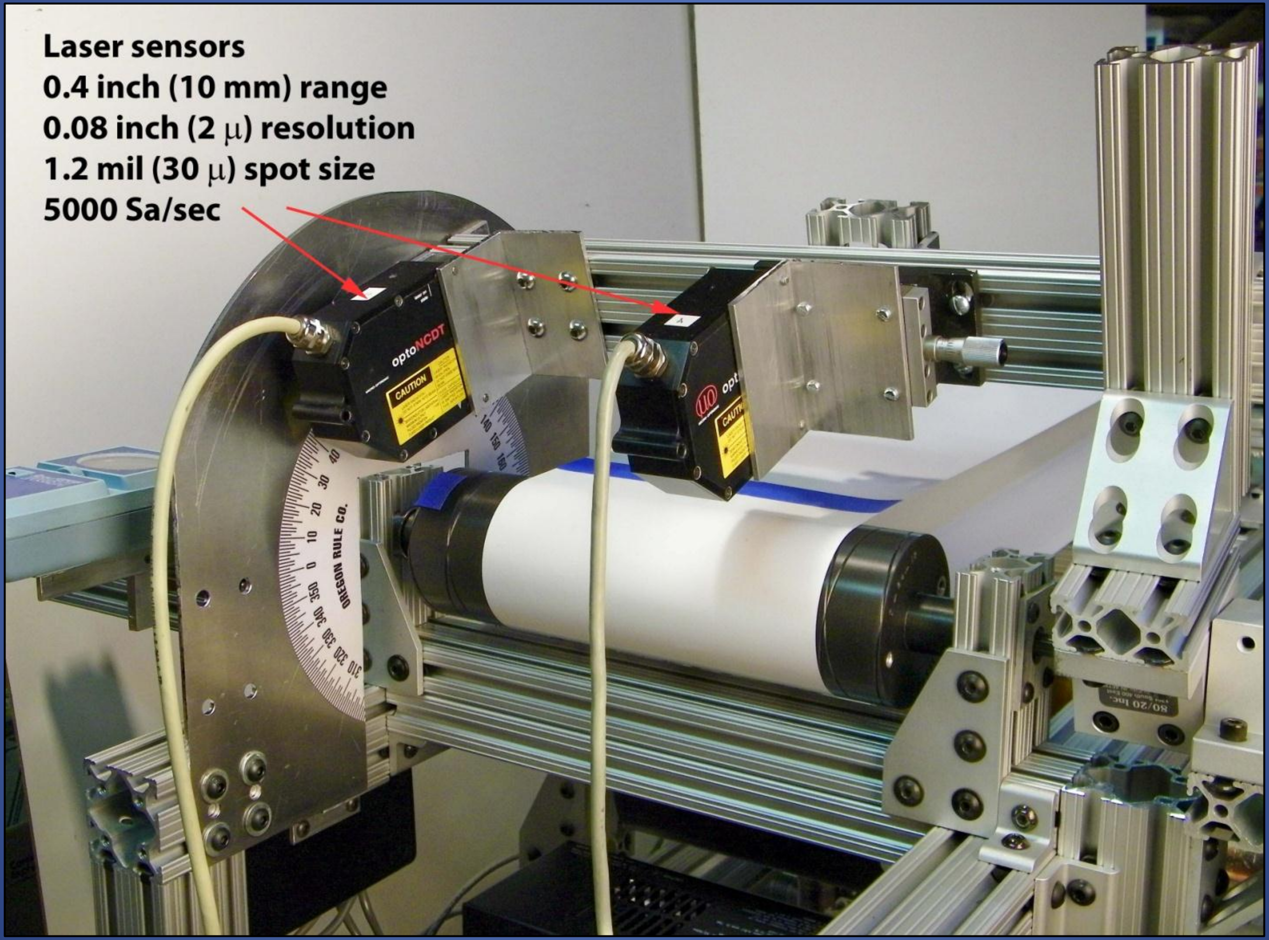
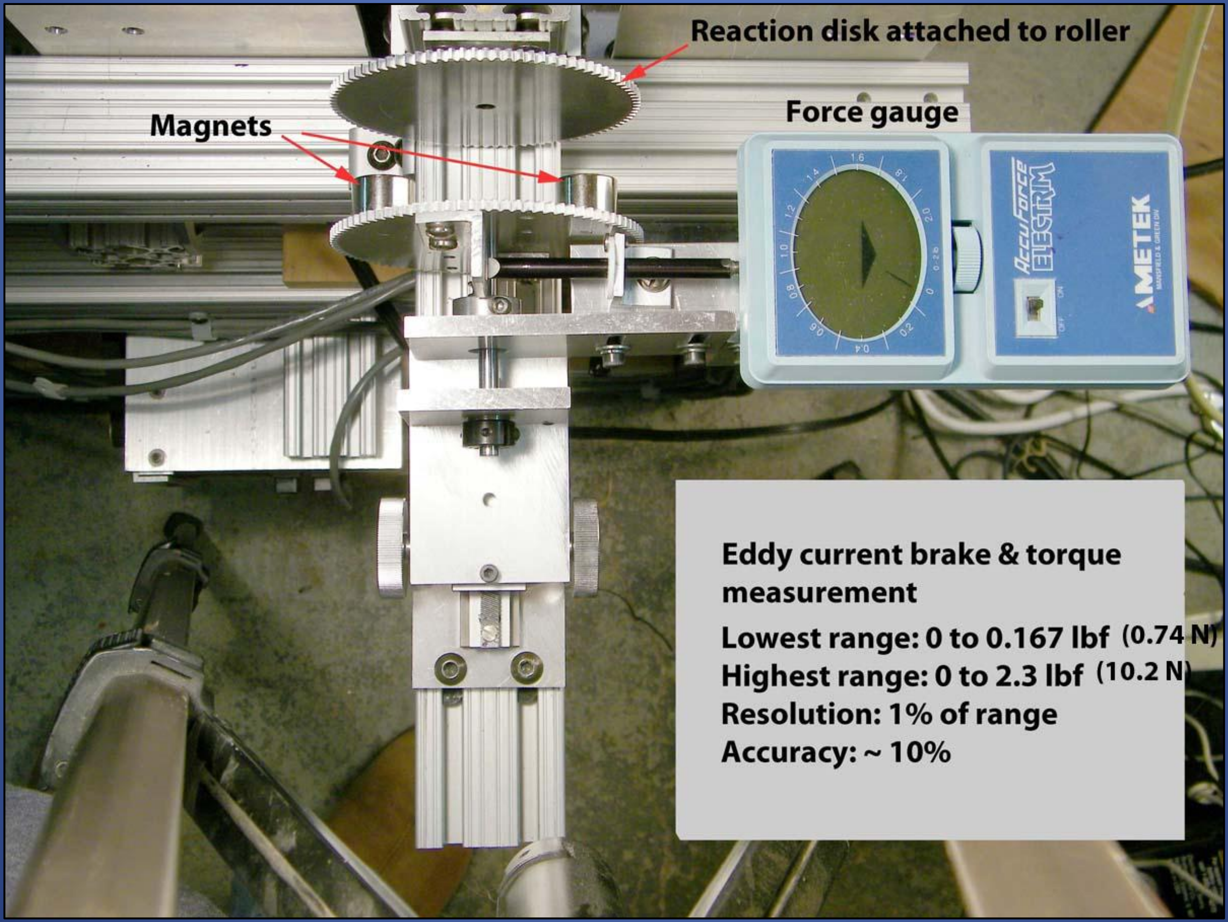
Drive
motor
Direction of travel
Output tension
Fo = (Fb + ΔF)/2
ΔF, brake force
& bearing drag
Belt - 1mil (25 μ) tedlar,
7 in (178 mm) wide
Brake
Fb = Fo + Fi
Fi = (Fb - ΔF)/2
Input tension
Base plate position is
shifted to adjust Fb
Linear
slide
Spring
Fb was set to 2.8 lbf (12.5 N) during tests
(static tension in web of 0.2 pli (35 N/m)

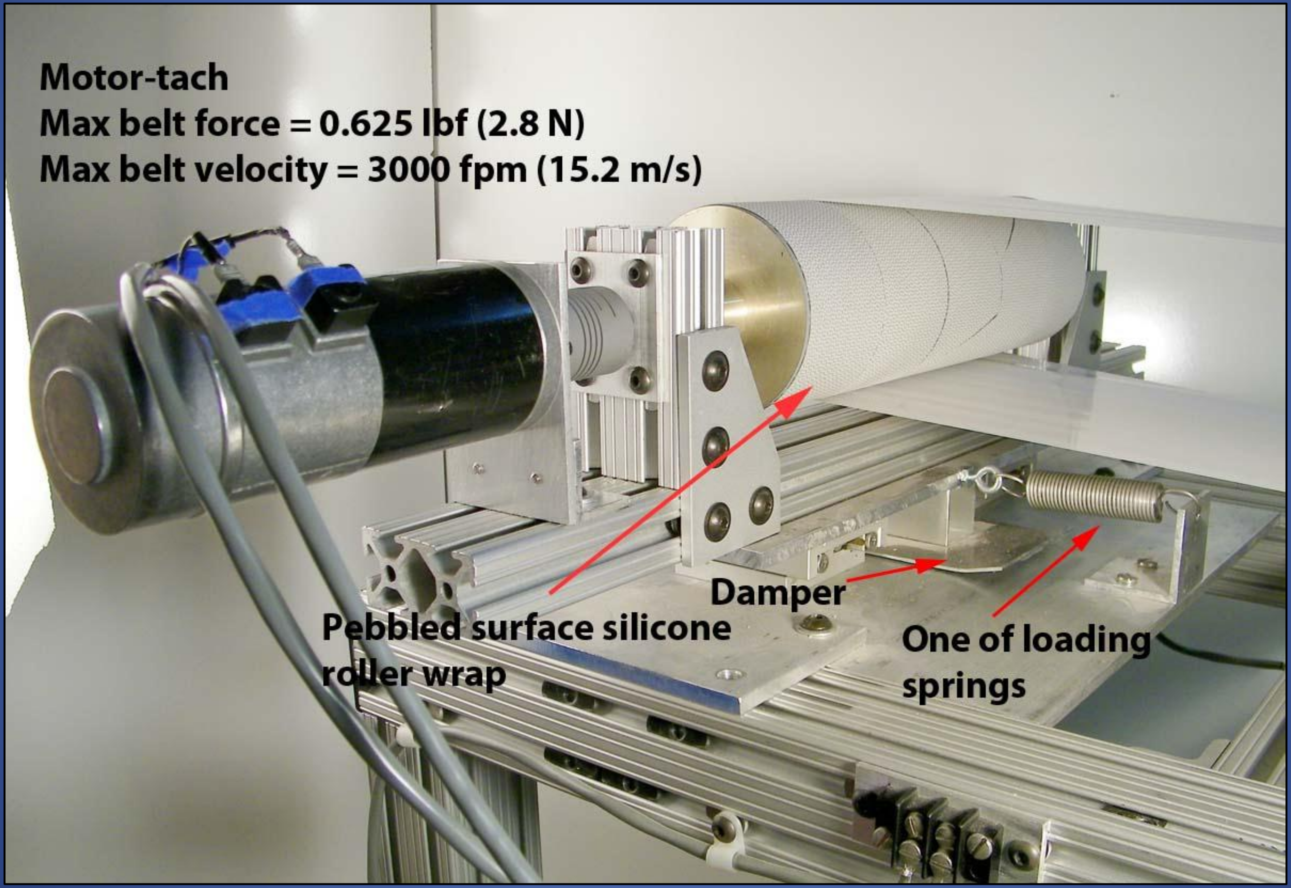
The measurement end



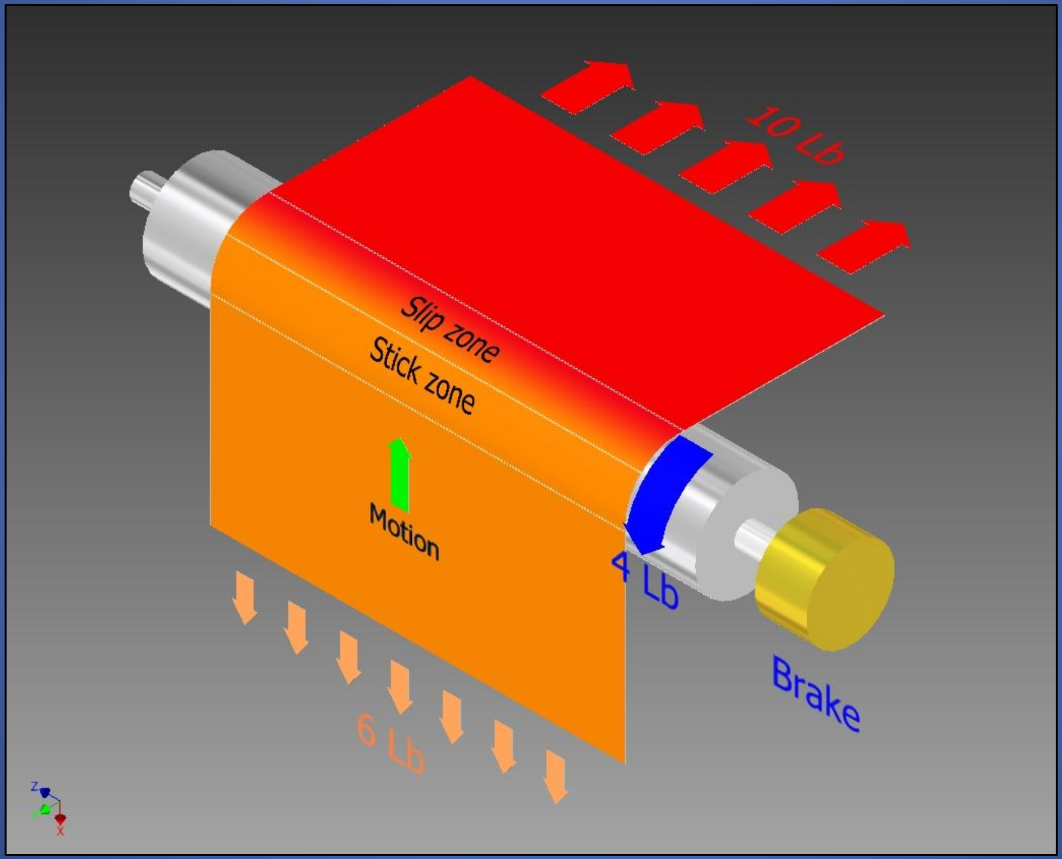
Eddy current brake & torque measurement



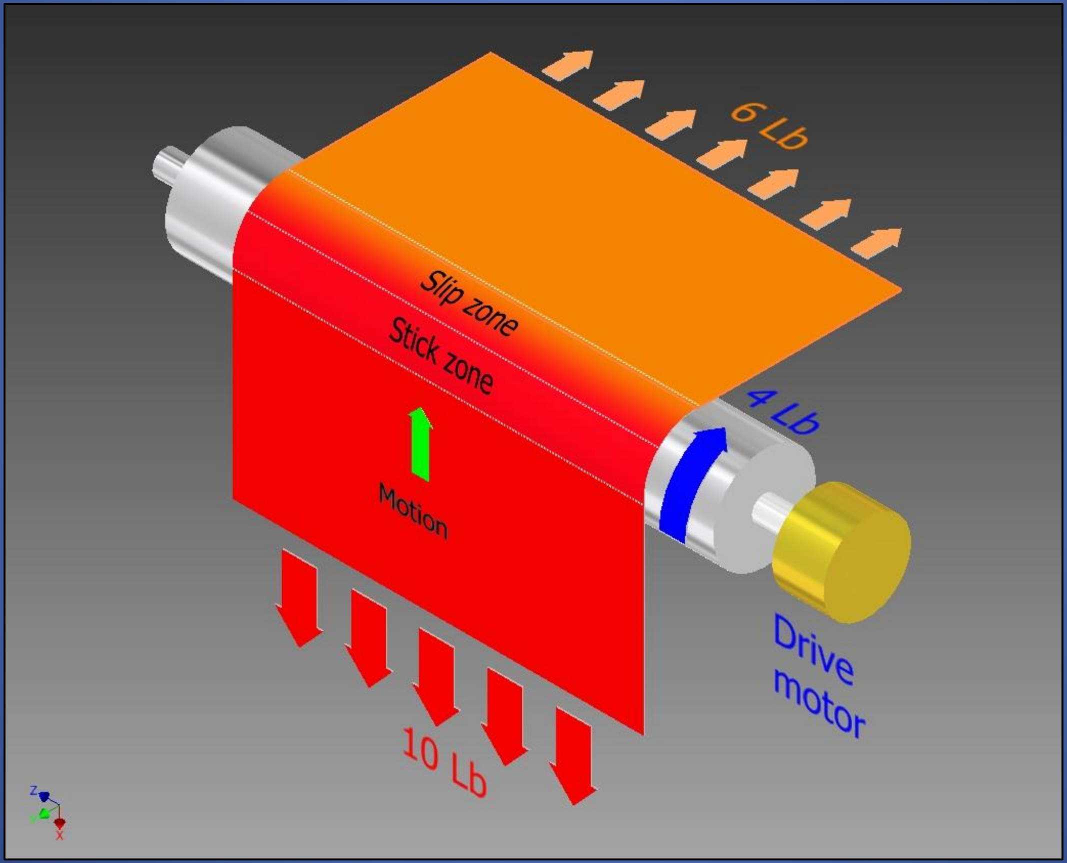
The drive end



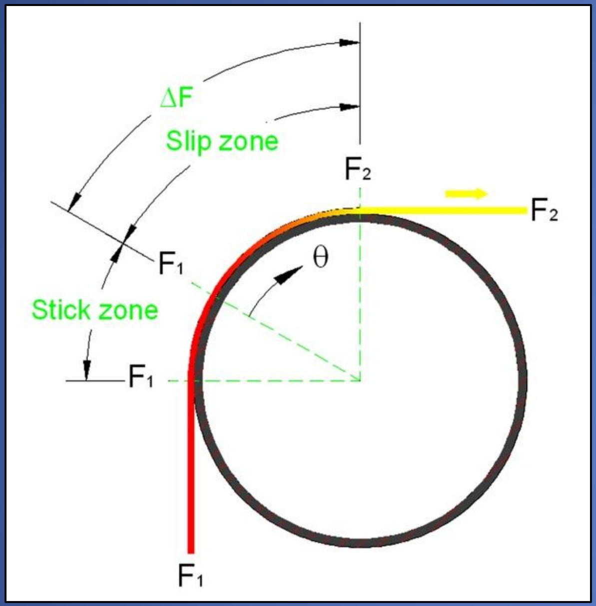
Stick and microslip zones - braking



Stick and microslip zones - driving



Capstan equation



$$\frac{F_2}{F_1} = e^{f\theta}$$

If we know:

F1 , F2 and Θ

f , the coefficient of friction, can be calculated

$$f = \frac{1}{\theta} \ln \frac{F_2}{F_1}$$

Or if we know:

F1, F2 and f

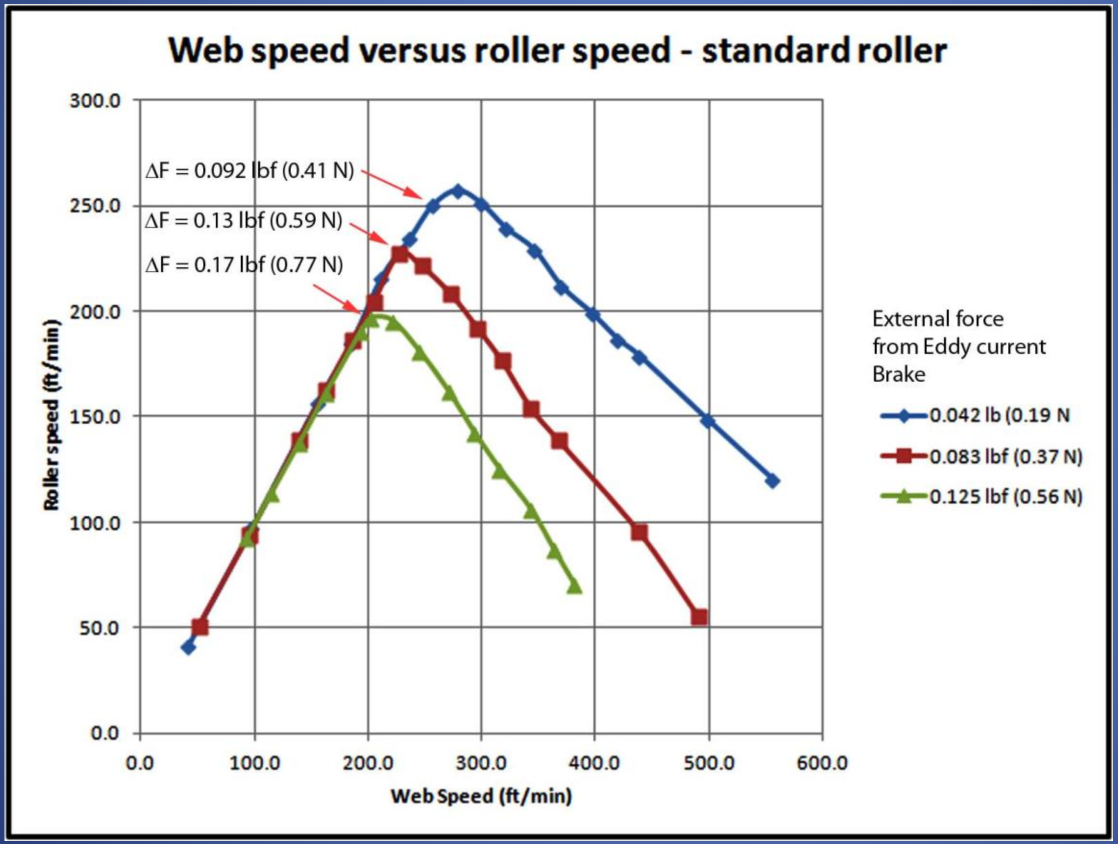
Θ can be calculated

$$\theta = \frac{1}{f} \ln \frac{F_2}{F_1}$$

Tension is transferred between the roller and the web in the <u>microslip</u> zone.

Back to friction vs speed

Web speed vs Roller speed (slip curves) standard roller



These slip curves show web speed vs. roller speed.

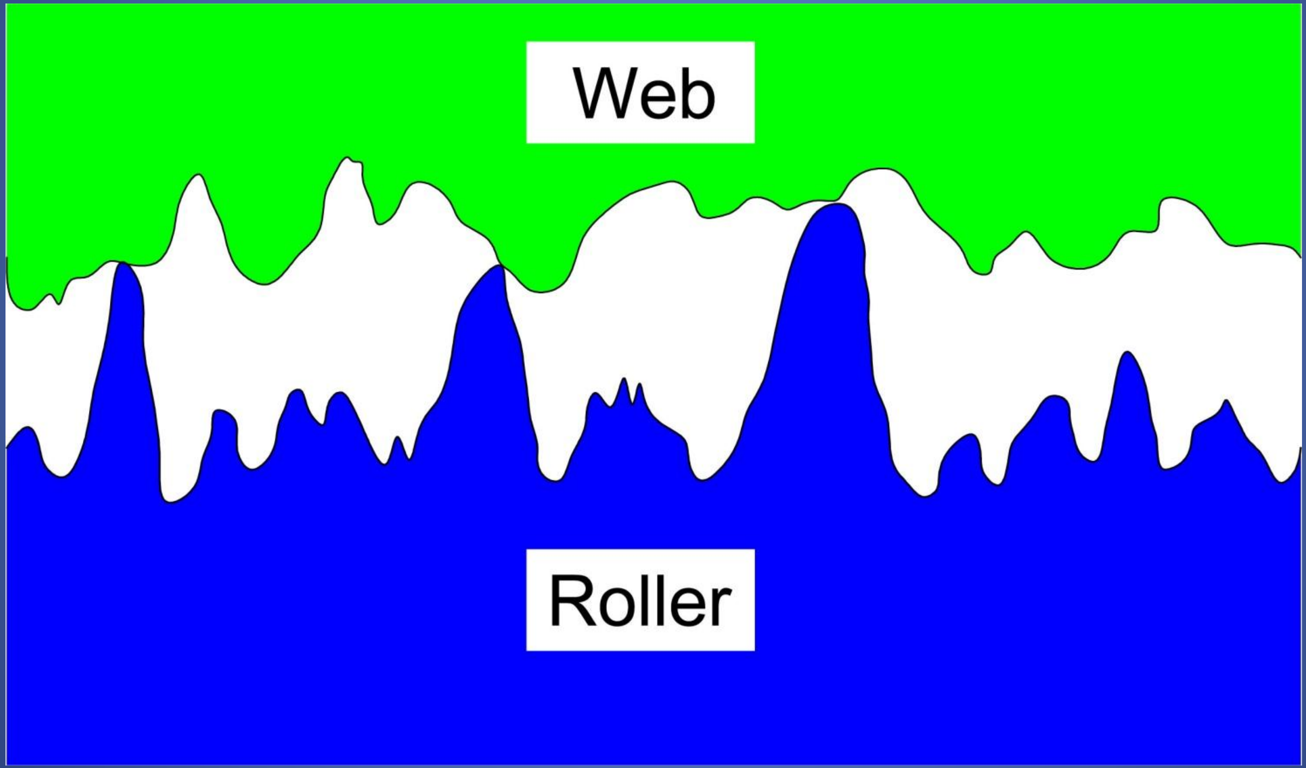
As braking torque increases the breakaway speed decreases.

This is evidence of air lubrication.

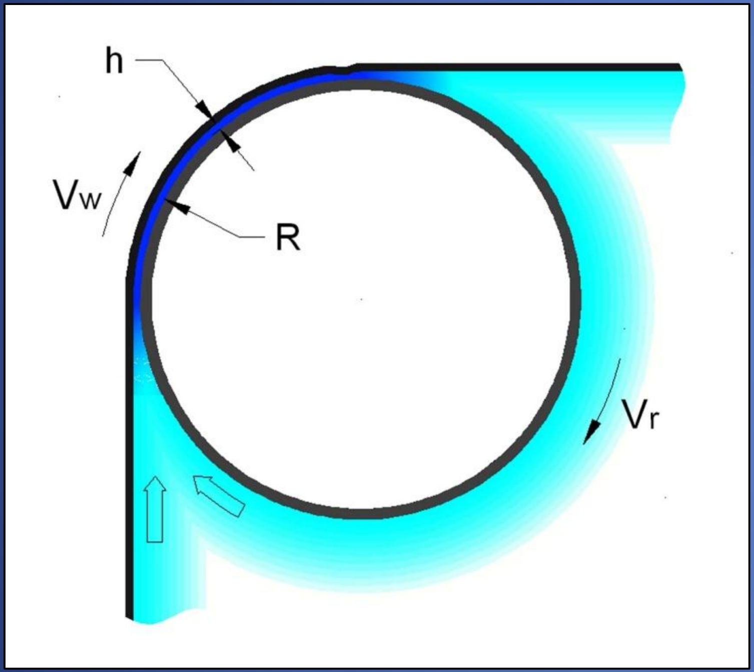
Back to friction vs speed

300 ft/min = 1.5 m/s

Asperities (otherwise known as roughness)



Air entrainment



h ↑ as R ↑, Vw ↑ and/or Vr ↑ .
h ↓ as tension ↑ .

- Air is pumped into gap h by boundary layers that form on the moving surfaces.
- At low speed, the air flows through spaces created by the asperities.
- As web speed increases, air pressure in the asperity space rises. This opposes the pressure due to tension, which, in turn, reduces friction.
- At some speed, the air pressure will become high enough that the web will completely lose contact with the roller.
- Except for a small dip near the exit and narrow zones at the edges, the effective thickness of the entrained air film is nearly constant over the entire angle or wrap.
- Increasing the roughness of the roller surface allows the web to maintain contact at higher speeds.

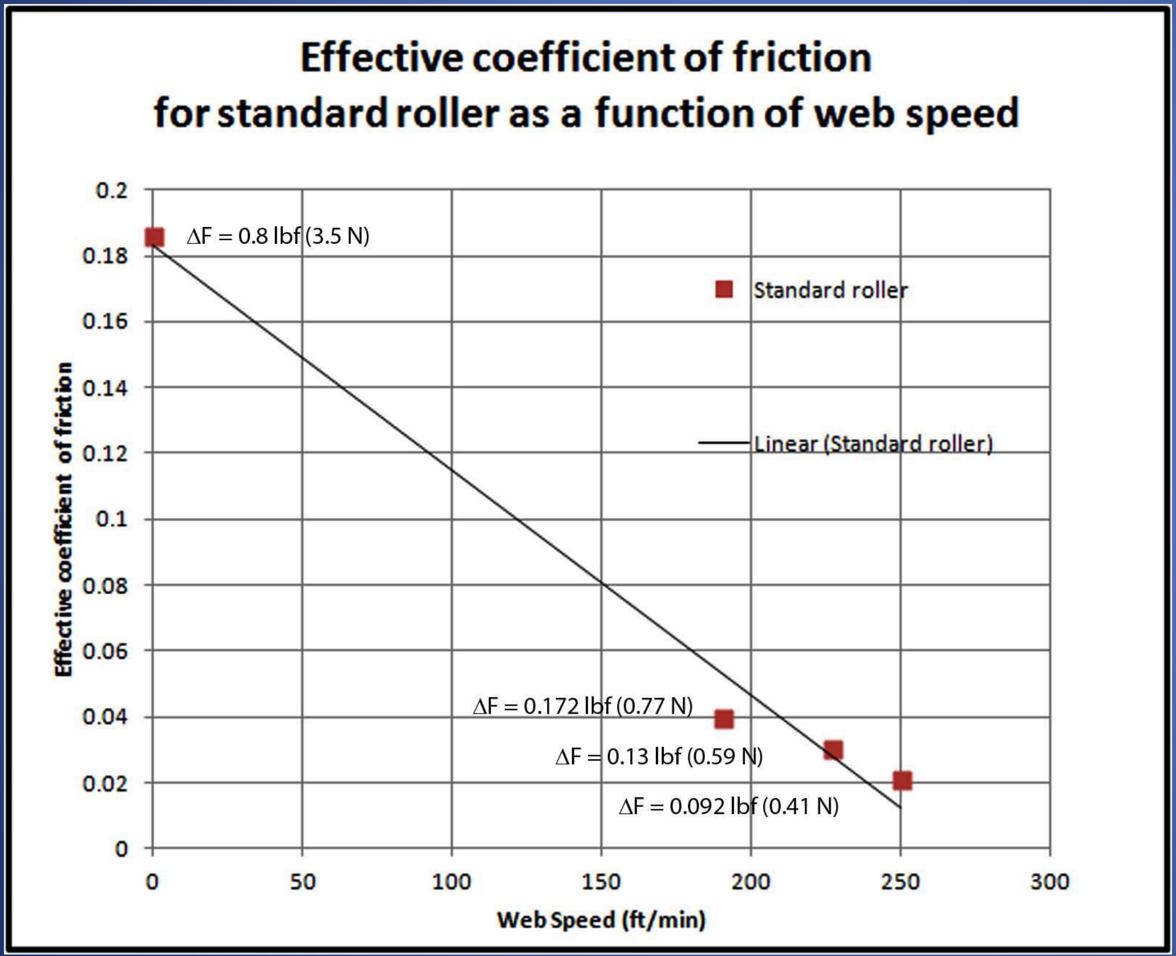
The foil bearing equation

- If a web is nonporous, the effective thickness of the entrained air film, *h*, can be calculated using the foil bearing equation (sometimes known as the Knox-Sweeney equation).
  - *R* = roller radius
  - *V* = the web speed
  - T_w = the nominal web tension (in units of force per unit of web width)
  - μ = the viscosity of air
- Centripetal force must also be taken into account. This is usually done by modifying the tension term.
  - *d* = web thickness
  - ρ = web density

$$h = 0.643R\left(\frac{6\mu\left(V_w + V_r\right)}{T}\right)^{\frac{2}{3}}$$

$$T = T_w - d\rho V_w^2$$

Putting it all together
The friction curve

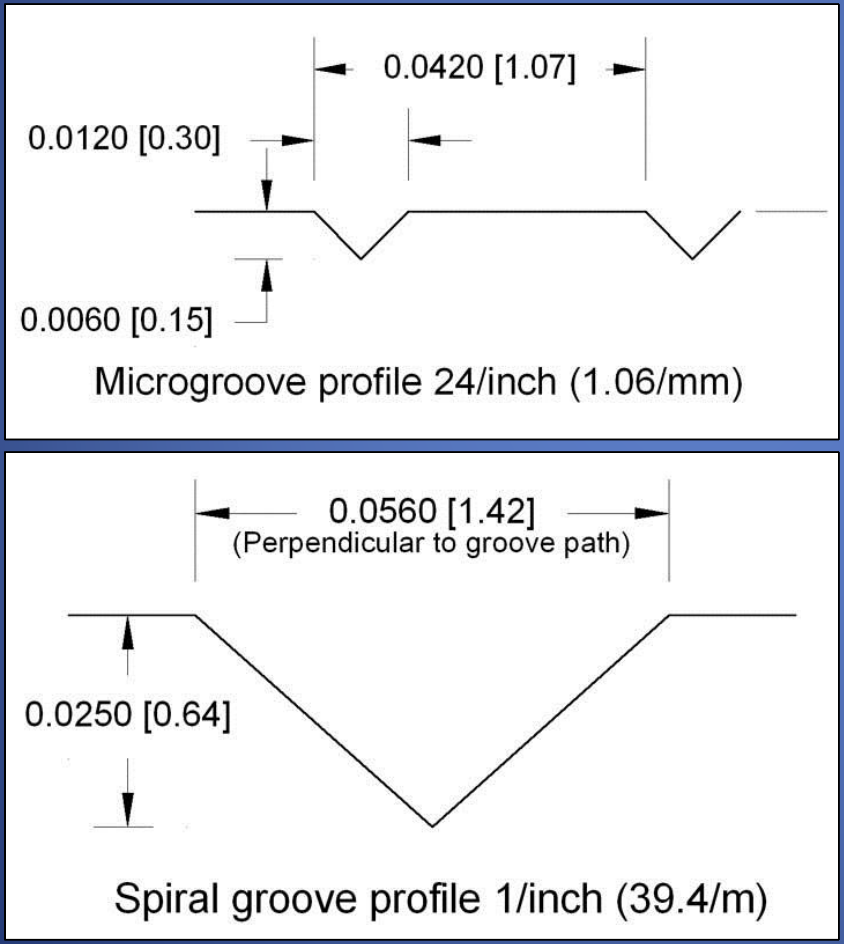


When the web slips, the angle Θ in the capstan equation is equal to the wrap angle. So, if we know the entering and exiting tensions it is possible to use slip curves to calculate the effective coefficient of friction.

So, what do you lose when it slips?

- The normal entry rule no longer works. This has two important consequences.
  - First, (the bad news) the web's location on the roller is no longer determined by its angle of entry. So, it's lateral position will be unstable, changing with tension and other things.
  - Second, (the good news) it will be harder for wrinkles to form because the normal entry effect is an important factor in turning troughs into wrinkles.
- The web may be scratched.

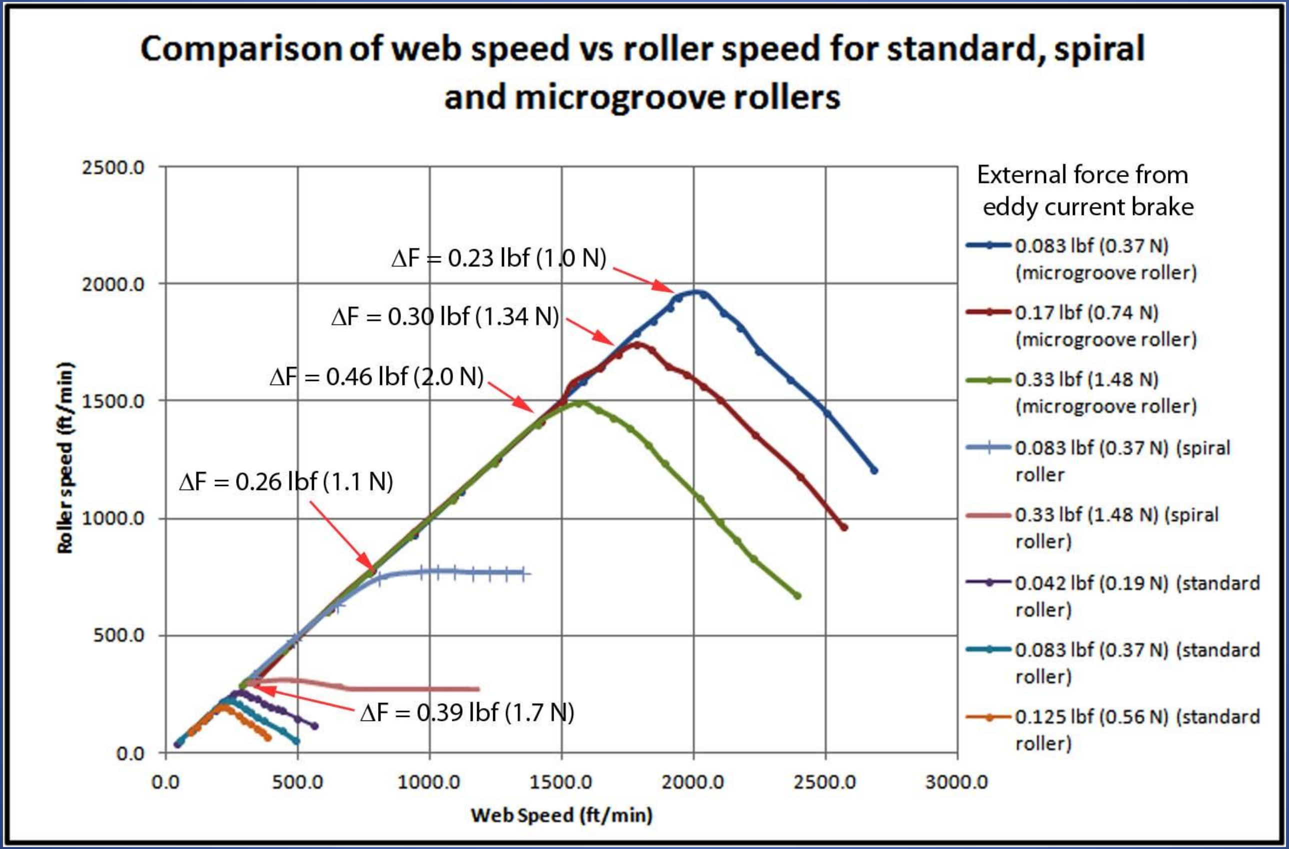
What to do about slipping



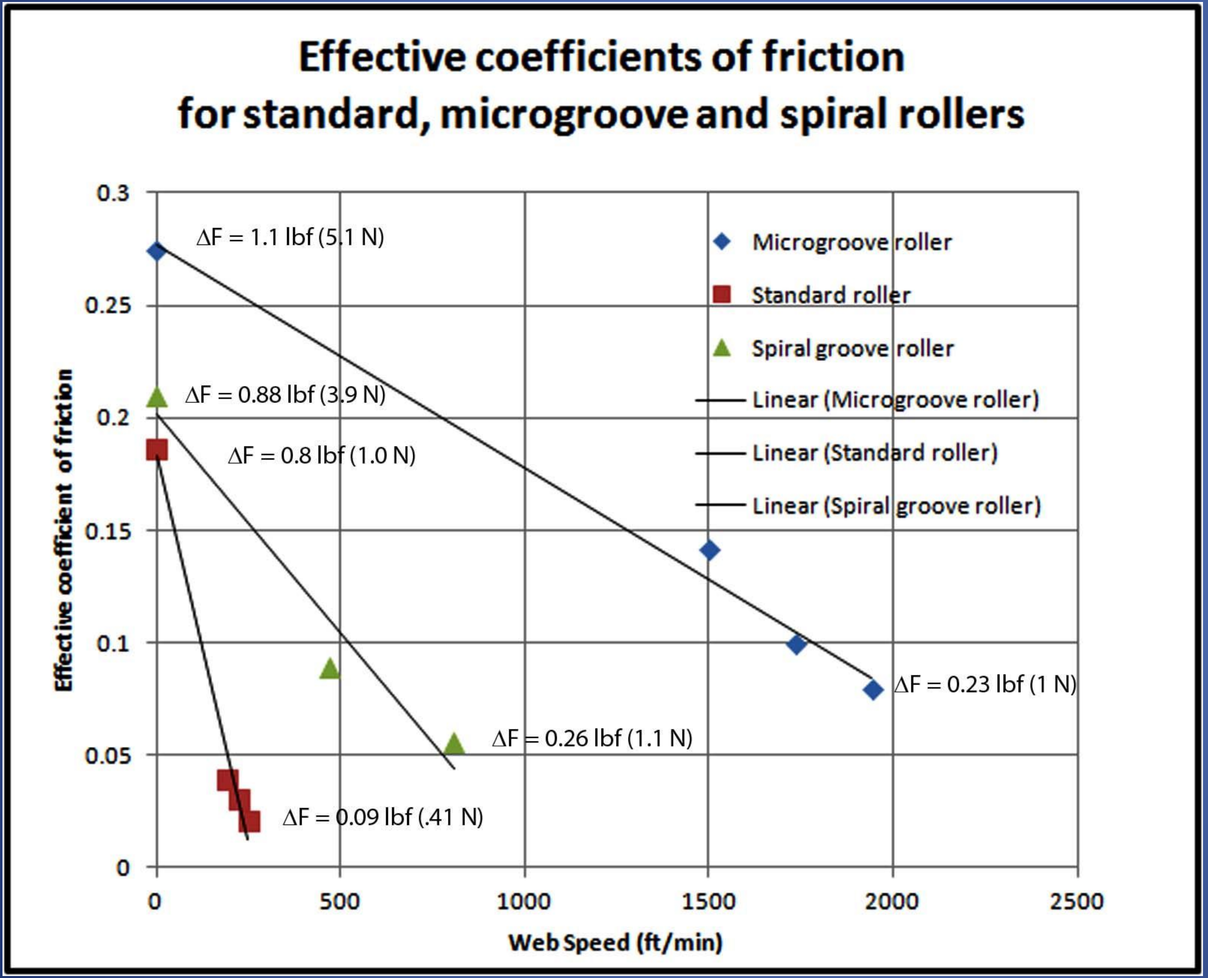
- Make the roller surface rougher (bigger asperities).
- Create artificial asperities (grooves).

Back

Comparison of the three rollers



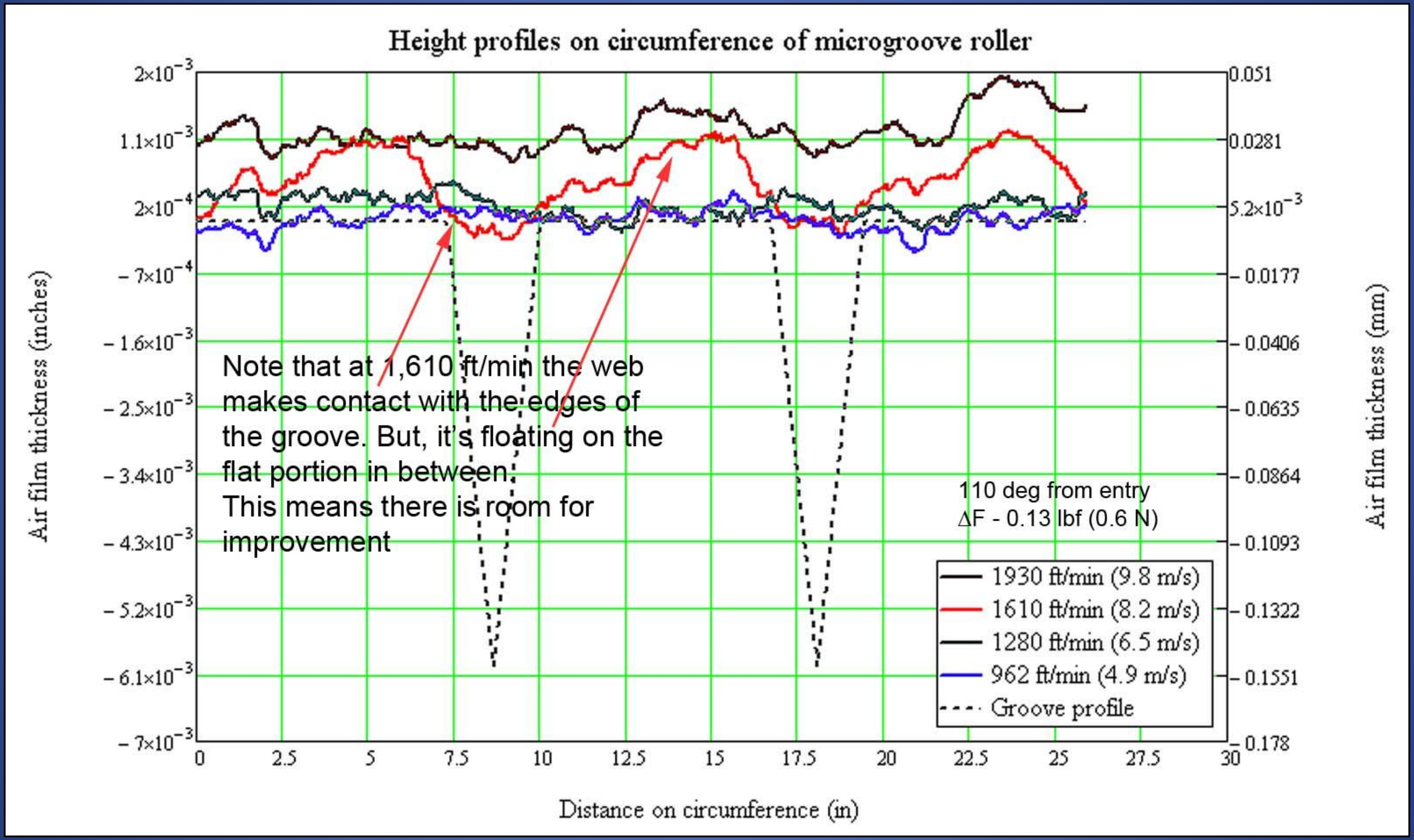
Comparison of friction curves for the three rollers



The microgroove roller clearly provides a big improvement in traction.

And, surprisingly, even the spiral groove is an improvement over a typical ungrooved roller.

Air gap profile on microgroove roller



Groove geometries

Summary

- The purpose of the foregoing data is only to illustrate “how things go”. Results will be different depending on just about everything.
  - Roller diameter
  - Tension
  - Bearing drag
  - Web material and roller surface finish
  - Grooving pattern

If you want to learn more

- Dobbs, J. N., Kedl, D. M. "Measurement and Modeling of Bearing Drag in Idler Rollers", Proceedings of the Fourth International Conference on Web Handling, June, 1997, pp 559-571
- Jones, D. P., "Traction in Web Handling: A Review", Proceedings of the Sixth International Conference on Web Handling, June 2001, pp 187-210
- Roisum, D. R., "The Mechanics of Rollers", Tappi Press, 1996, pp 58, 110
- Ducotey, K. S., "Good, J. K., Predicting Traction in Web Handling", Transactions of ASME, July 1999, Vol 121, pp 618-624
- Rice, B. S., Gans, "A Two-Dimensional Model to Predict Web-to-Roller Traction at Small Wrap Angles", Proceedings of the Seventh International Conference on Web Handling, June 2003, pp 223-273
- Rice, B. S., "Reduction in Web to Roller Traction as a Result of Air Lubrication", PhD Dissertation, University of Rochester, 2003

Thank you

Questions?