Taping Rollers for Traction and Spreading

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Everyone does it

- Two types
  - Circumferential band under the web edges.
  - Axial strips (lateral taping) of different lengths in a chevron-like pattern extending from each roller edge.
- Two purposes
  - Traction
  - Spreading (approximating a concave roller)

At low speeds it's simple

- Both kinds of patterns will work.
- The circumferential band is the most common.
  - Just make the tape wide enough to extend under the web edges far enough to accommodate web wander and variation in width or centerline.
  - It may take a little trial and error. Keep in mind, though,
    - The tape doesn't have to be thick. One layer may be plenty.
    - A concave spreader tends to destabilize the web centerline. This is not usually significant. But, be aware that it can happen.
    - The tape should have a rough surface – masking tape works well.

Lateral taping

- Similar considerations apply to lateral taping.
  - It's more work.
  - But, you may get the added benefit of improved traction over most of the roller length.
- The results of this paper also indicate that lateral taping may help in overcoming the effects of air entrainment.

Motivation

Air entrainment is a major focus of this paper because of a field observation that indicated lateral taping seemed to improve traction when air entrainment should have defeated it.

Annular grooving

- Air flotation is a very important factor in the behavior of webs on rollers and has been studied extensively (see the paper for references).
- It's generally not important at low speeds. But, as speed increases, a point will be reached where traction begins to decline and the web will eventually "fly" over the roller surface.
- At the heart of all the work is something called "foil bearing" theory.

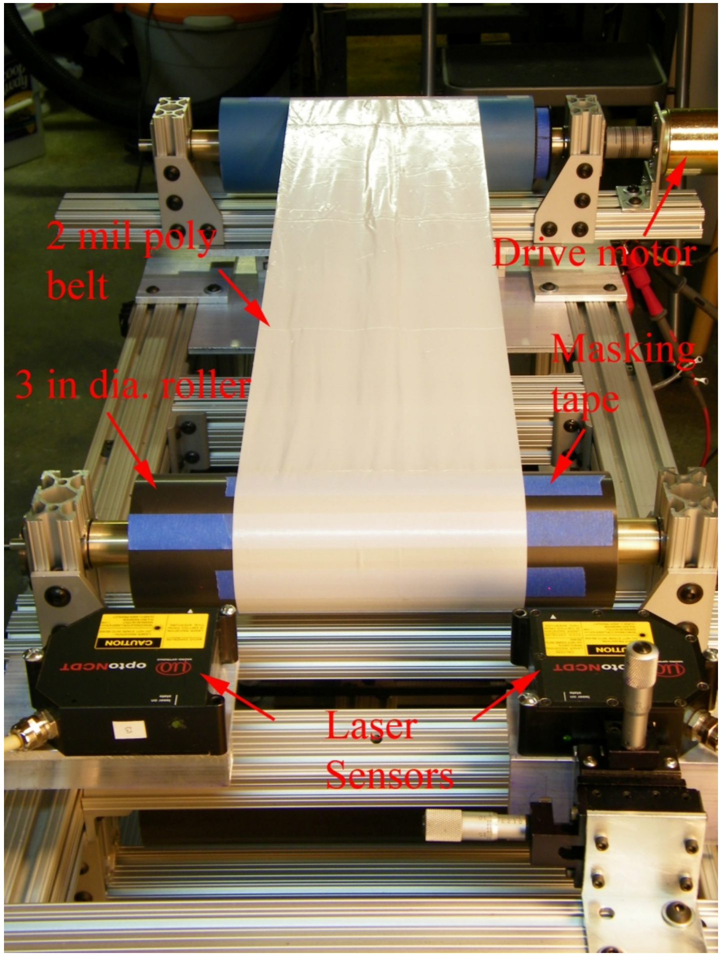
Foil bearing theory

- There will be more discussion of some of the basic results of foil bearing analysis later in the paper.
- It is a remarkably effective simplification of hydrodynamic theory that is used extensively in the analysis of fluid film lubrication.
- It has been successfully extended to rollers with annular grooves. This has been demonstrated to be an effective technique for venting the air film to maintain contact between the web and the roller surface.
  - There is an excellent design methodology for this technique in a 2003 IWEB paper by Rice and Gans (see the paper for reference). The work was done with support and direction from Dr. Cole while at Kodak.

Lateral venting

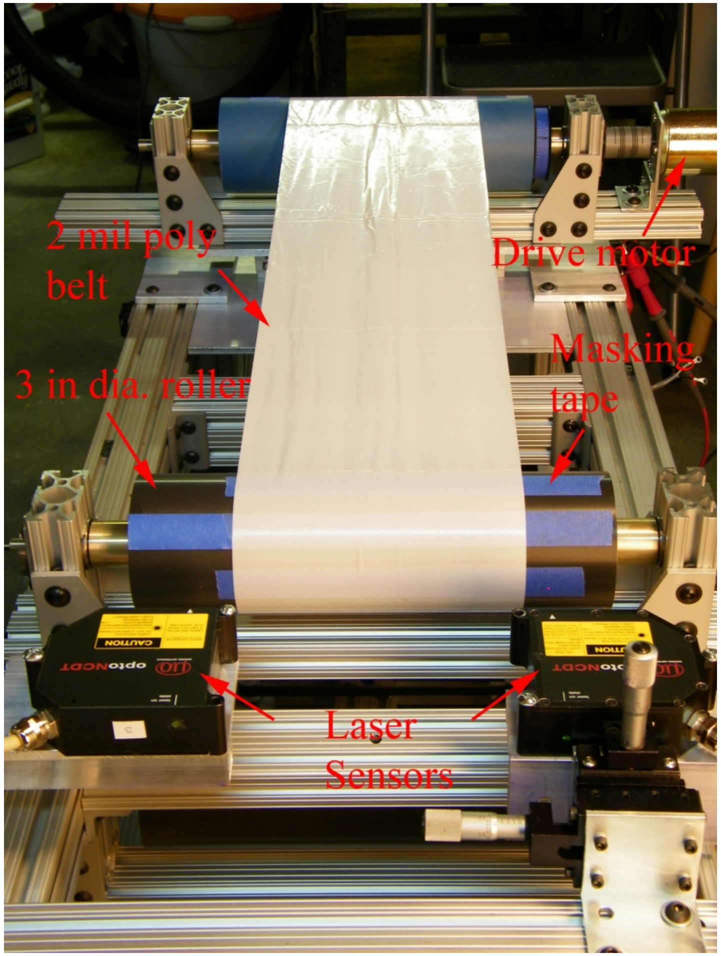
- Can lateral vents be effective – grooves or ridges?
- Unfortunately, some of the simplifying assumptions of foil bearing theory break down when lateral ridges or grooves are present.
- This brings us to the main object of this paper, which is to shed some light on this question with measurements of a film on a roller with lateral ridges made of tape.

Test equipment



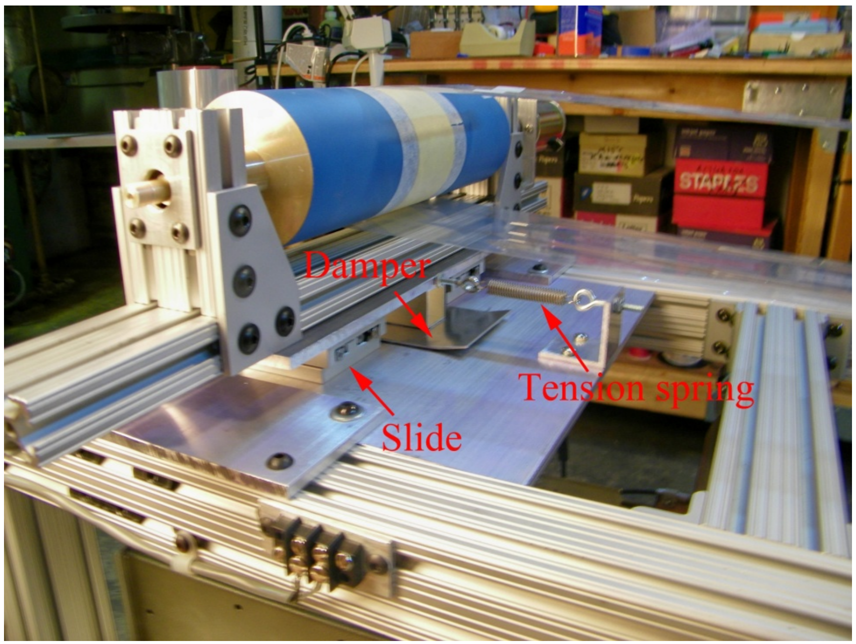
- 50 inch seamless belt cut from a polyethylene compactor bag.
- Width 6 inches
- Thickness 0.002 inch
- Rollers 3 inch diameter.
- Far roller driven with Pittman DC motor.
- Max speed approx. 2,600 ft/min
- Coefficient of friction 0.12

Sensors



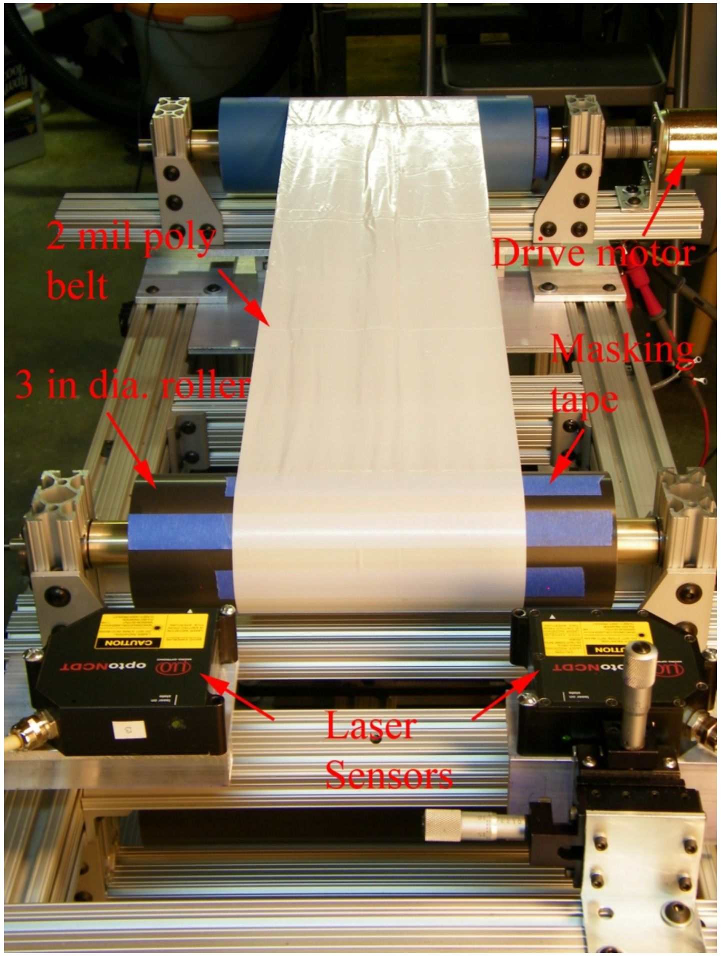
- Two Micro-Epsilon laser triangulation sensors.
- Range = 0.4 inch
- Resolution = 0.08×10^{-3} inch.
- Sample rate = 5,000/s

Tension and damping



- Low friction slides.
- Opposed springs for tension.
- Flat plate and petroleum jelly for damping.
- A slight crown on roller created with masking tape.

Operation



- Left sensor used to trigger measurements once per revolution of the roller.
- Right sensor made film height measurements.
- Easy pushbutton zeroing.
- 0.002 inch eccentricity at the left sensor. 0.0004 inch at the right. It's effects are easy to interpret. So, nothing was done to compensate the data.

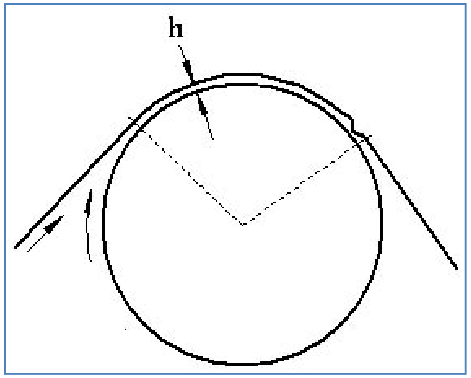
Noise

- It is apparent from the photo that there are creases in the polyethylene. There were also gauge bands from the extrusion process.
- Belt tension didn't help much, because it had to be kept low to increase the foil bearing effect. So, there was a lot of measurement noise.
- This was overcome by scan averaging. One complete set of data would be taken per revolution of the roller and averaged with the next. This was done for a minimum of 50 roller revolutions.
- Each scan was triggered at the same point on the roller circumference. So, the noise would be averaged out, leaving only the effect of the tape pattern and film.

Effect of film translucency

- The white film is not completely opaque. This causes some of the light from the laser sensor to be scattered from the body of the film and from anything immediately behind it.
- When the film is on the roller surface, the sensor reading is approximately 0.0016 inch. But, the true thickness ranges from 0.002 to 0.0025 inch.
- Similar errors occur when there is air under the film.
- The net result is that there is an uncertainty on the order of 0.0015 inch depending on what is under the film.
- In the author’s opinion, this does not change any of the main conclusions of the paper.

Foil bearing basics



- Except for a small dip near the exit, the thickness of the entrained air film is nearly constant over the entire angle or wrap.
- Even rollers with a mirror finish have some roughness. At high enough magnification, peaks (asperities) and valleys will be seen in any surface.
- So even at low speeds, there is a small amount of air flow under the web.
- The web lifts off the peaks of the asperities when the pressure due to the velocity of the air in the gap exceeds the pressure due to web tension.
- Increasing the roughness of the roller surface allows the web to maintain contact at higher speeds.

The foil bearing equation

R = roller radius

V = web velocity

T = web tension

μ = viscosity of air

1.8x10^{-9} kg/(m·s)

2.611x10^{-9} lbf/(in·s)

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

Centripetal force

- Centripetal force is not necessarily just a concern for high speed paper lines and dense materials like steel. At low tensions it can be important for plastic film at speeds that, while high, are not unthinkable.
- It can be incorporated in the foil bearing equation by subtracting a term from the tension.

T_w is the usual tension in pli or N/m
d = web thickness
ρ = density
V_w = web velocity

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

An example

- This example comes from one of the experiments reported in this paper.
- Note that the centripetal term is 23% of T_w

V = 2500 ft/min (500 in/s) R = 1.5 in

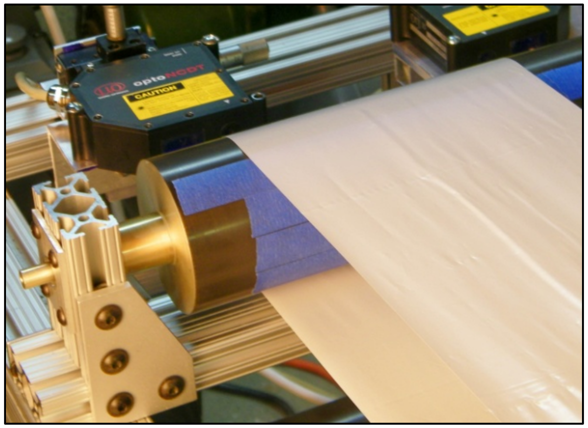
T_w = 0.2 pli d = 0.002 in

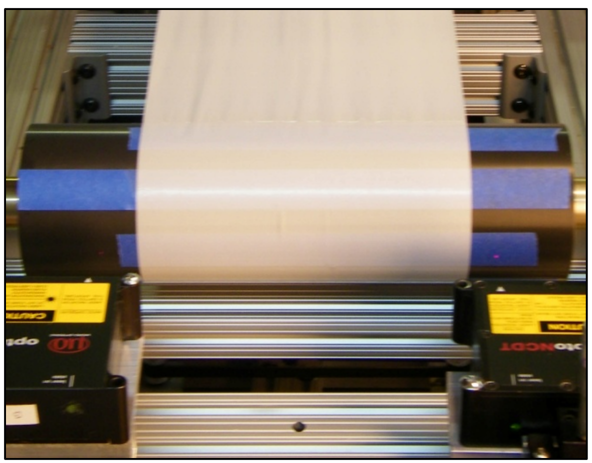
ρ = 9.324 x 10^{-5} lbmass/in^3

$$T = 0.2 - 9.324 \times 10^{-5} \times 0.002 \times 500^2 = 0.2 - 0.047 = 0.153\,pli$$

$$h = 0.643 \times 1.5 \left(\frac{6(2.611 \times 10^{-9}) \times (2 \times 500)}{0.153} \right)^{\frac{2}{3}} = 2.1 \times 10^{-3}$$

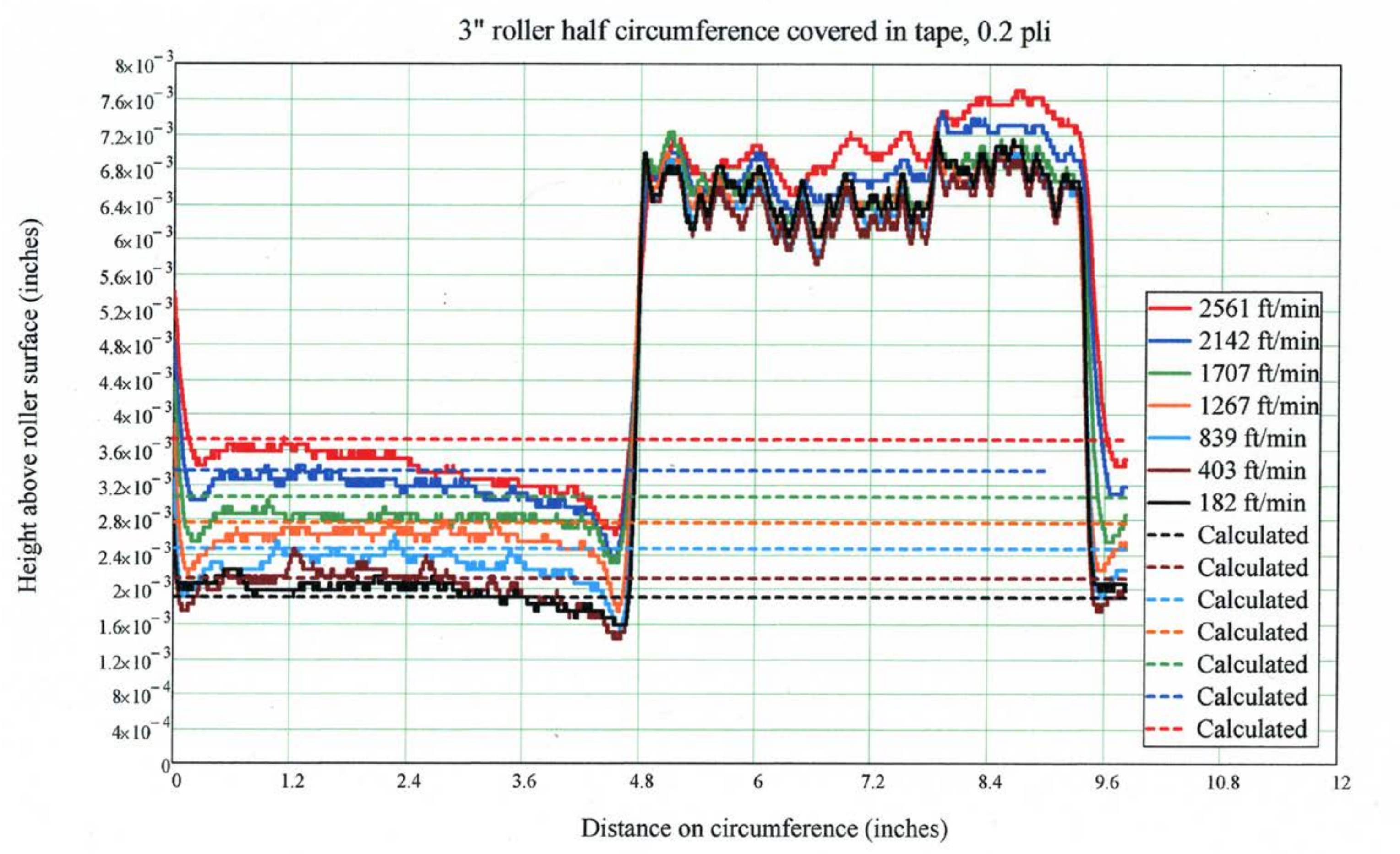
Two types of tests





- Half the circumference was covered with masking tape (Scotch Blue #2090)
- Eight equally-spaced strips of the tape were applied parallel to the roller axis.

Half-circumference test data



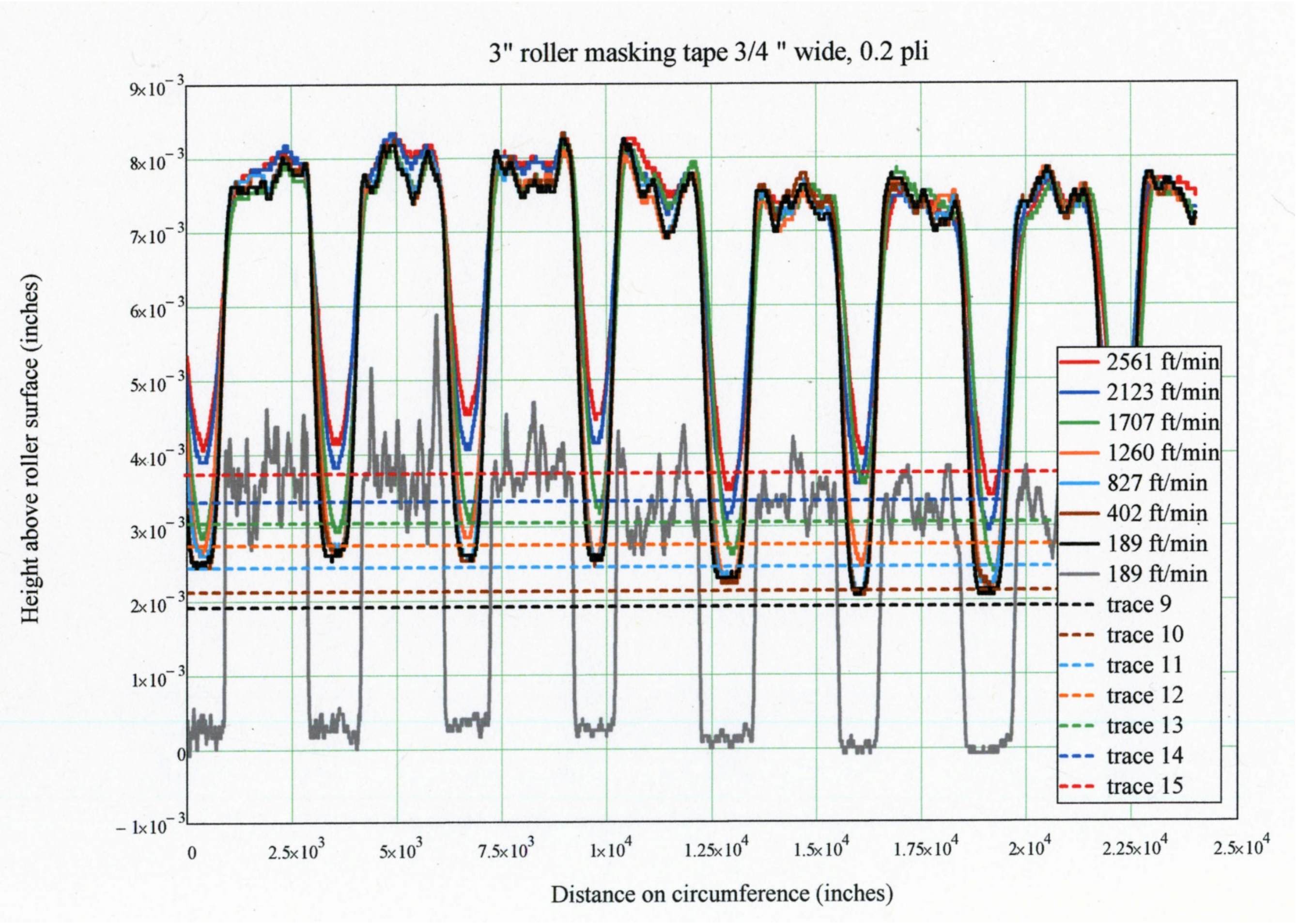
Interpretation of results

- The foil bearing equation does a good job predicting the peak film height over much of the uncovered part of the circumference.
- At speeds below 1,700 ft/min the film does not rise from the tape surface. This is undoubtedly due to the roughness of the tape (tall asperities). Above 1,700 ft/min the film is beginning to rise off the asperities in the last 2/3 of the taped section.

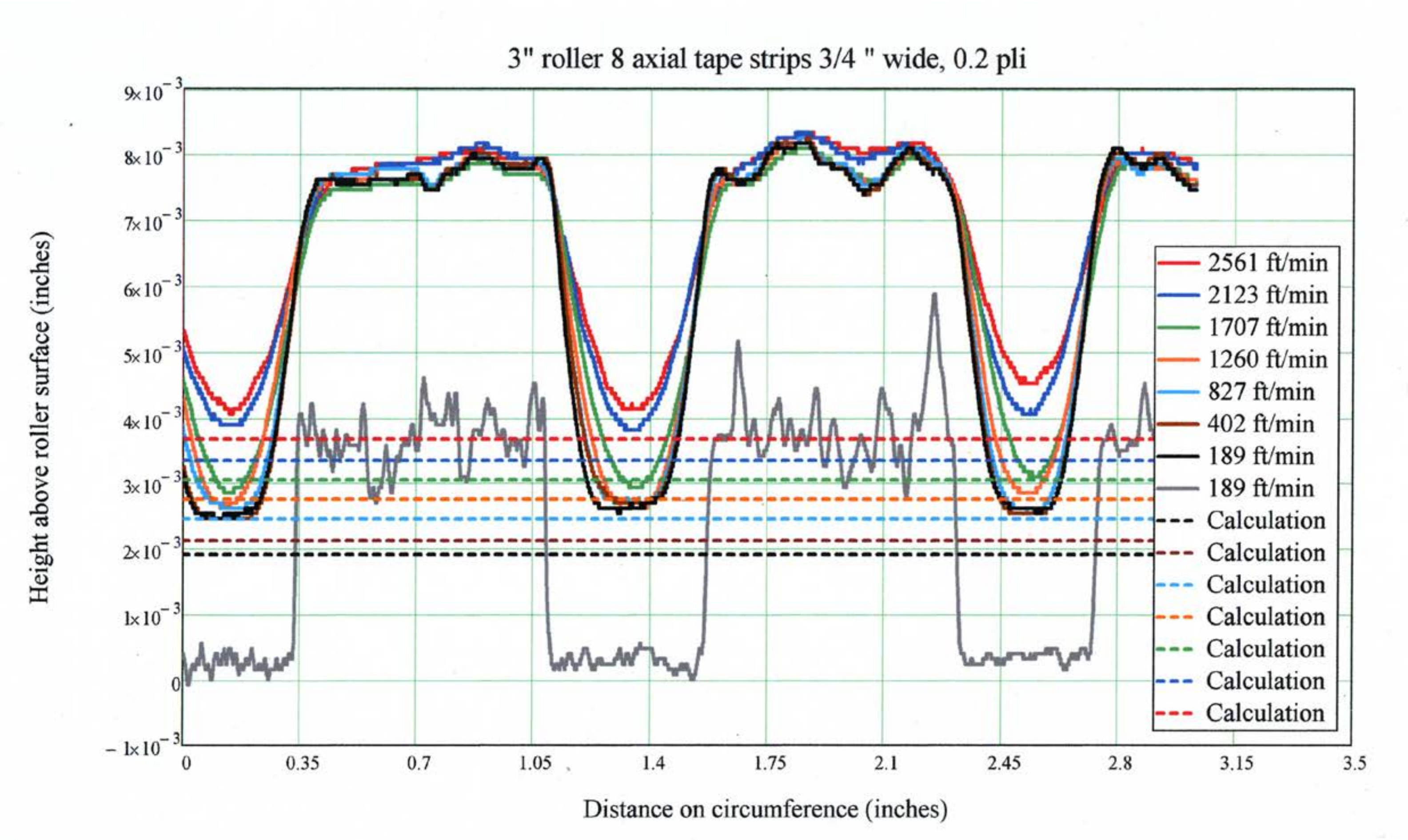
Interpretation of results (Cont.)

- At the leading edge of the taped portion all the curves intersect. This could be due to two things
  - The film may be pulled down at the edge by a low pressure zone caused by the sudden change in height. Muftu and Hintegger discuss sub-ambient pressures for certain tape recording head geometries where the film is forced to diverge rapidly.
  - There may also be an increase in the pressure caused by web tension. It is proportional to tension/radius and there is a very sharp bend at the edge of the tape.

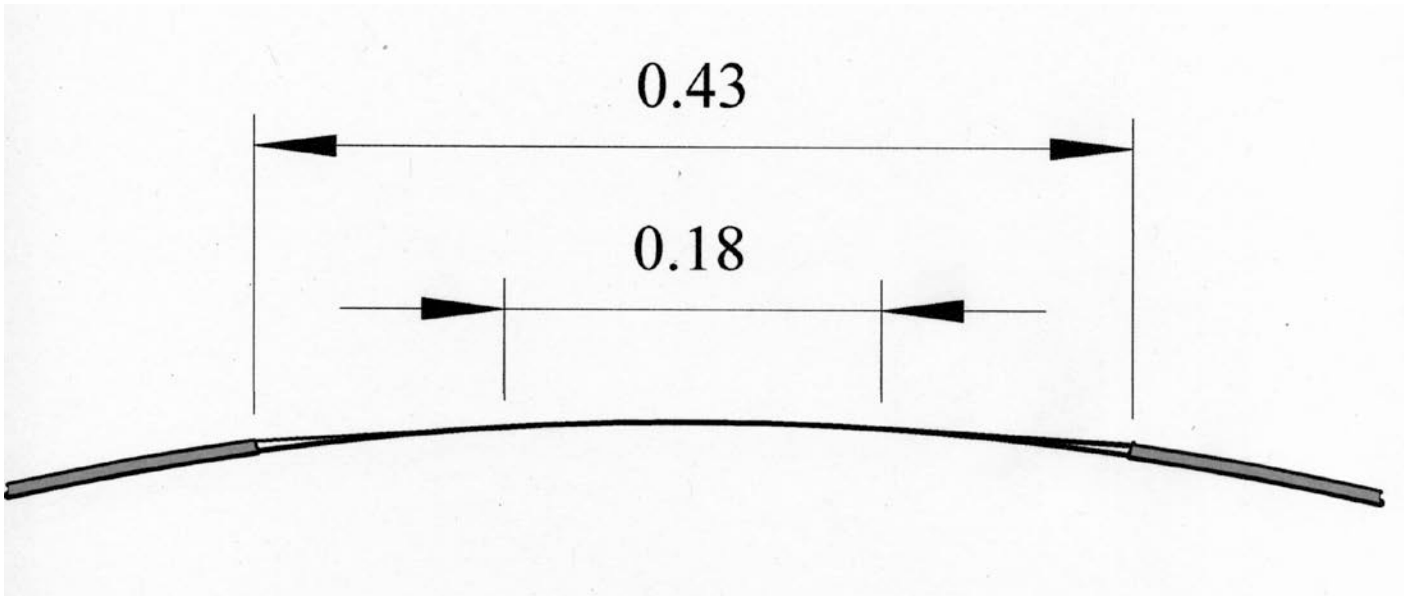
Eight-strip test at 0.2 pli



Enlarged view of eight-strip test at 0.2 pli



Scale drawing of the eight-strip geometry



Interpretation of results

- The film is pulled down into the gaps between the tape. But it does not appear to be reaching the roller surface at low speeds even though the geometry of the scale drawing of indicates this should happen.
- Also, at higher speeds the foil bearing equation does not predict height.
- The eight-tape test shows the same intersection of curves as with the half-circumference taping. In this case, it is seen on both the leading and trailing edges of the tape. So, there may be a narrow zone of traction on both edges of the tape.

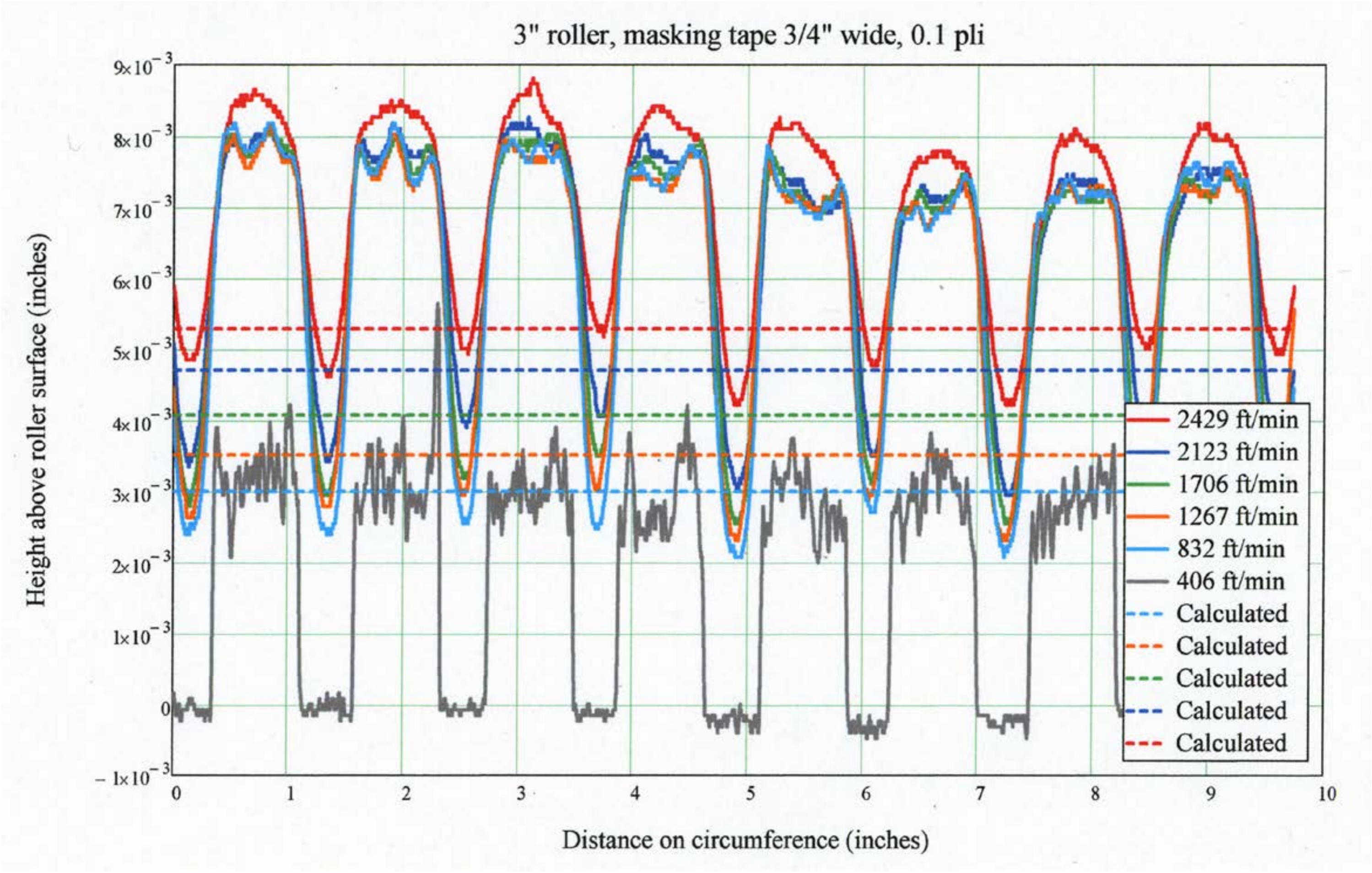
Interpretation of results (Cont.)

- Looking closely at the data for the full circumference, the curve intersections at the edges widen a bit as the strips get further in time from the trigger pulse.
- The drive motor speed was unregulated and the variability in time probably increased as the delay after triggering became larger.
- This may mean that the intersection on the trailing edge of the tape shown in the half-circumference test was better than the data indicates.

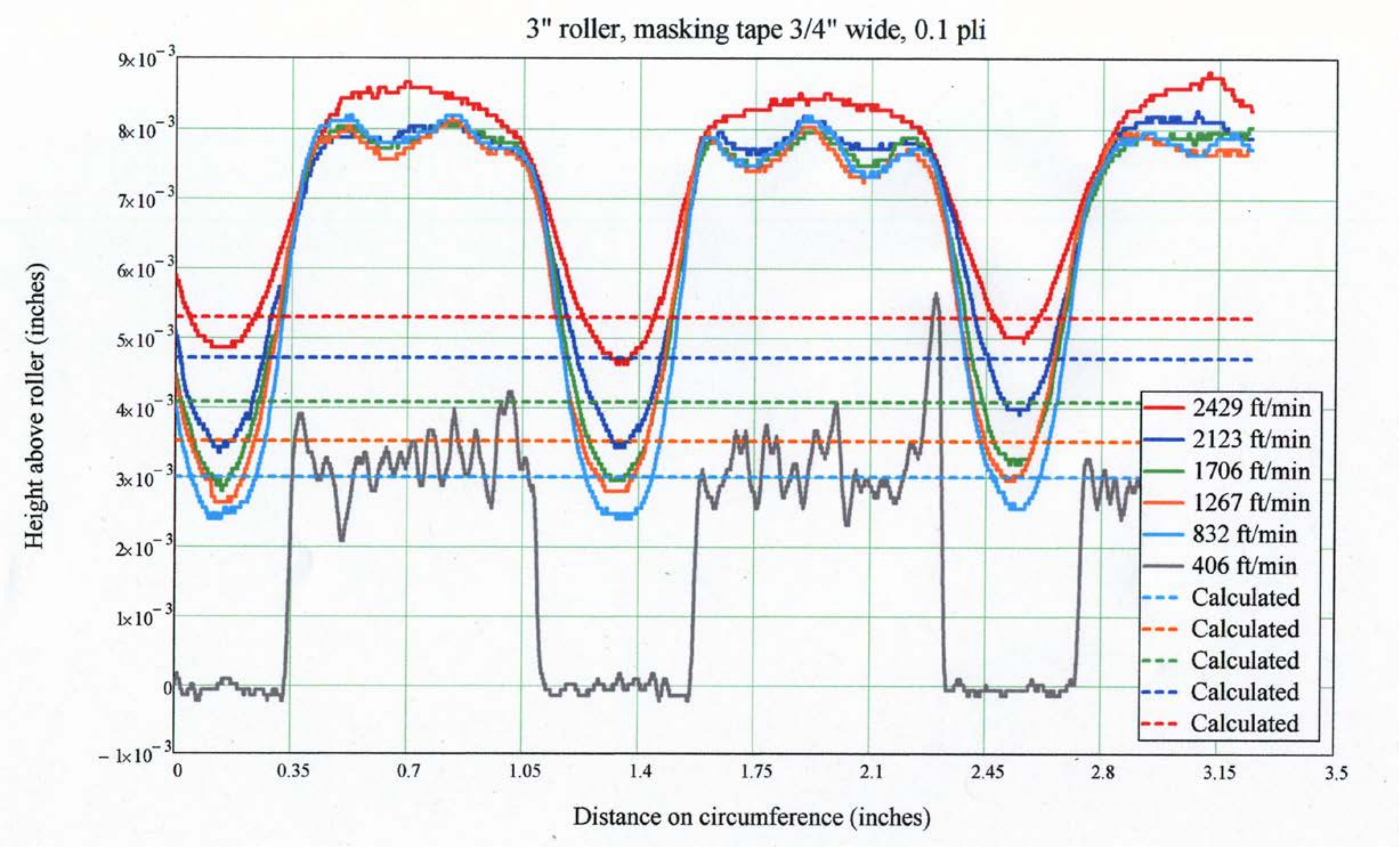
Interpretation of results (Cont.)

- Above 1700 ft/min the film is showing signs of lifting off the top surfaces. However, it continues to maintain contact at the edges.

Eight-strip test at 0.1 pli



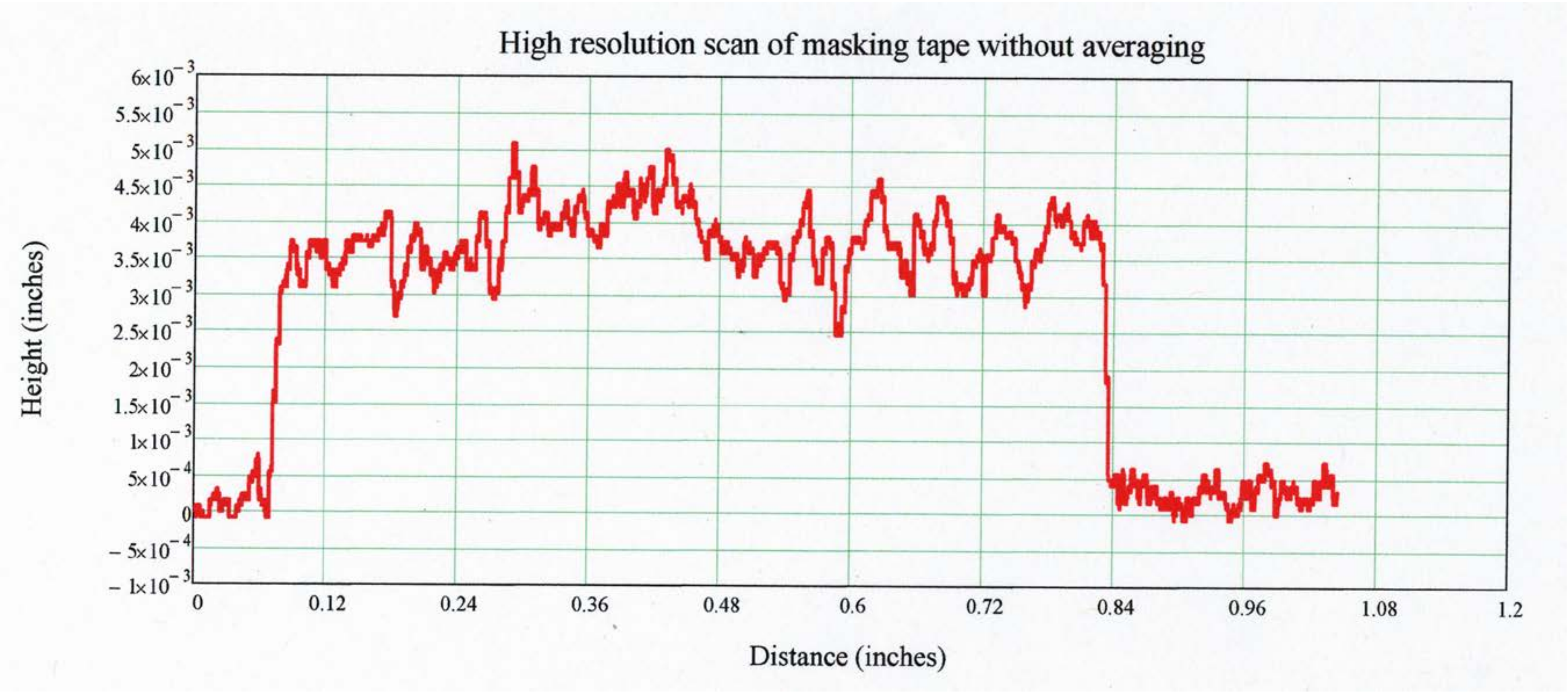
Enlarged view of eight-strip test at 0.1 pli



Interpretation of results

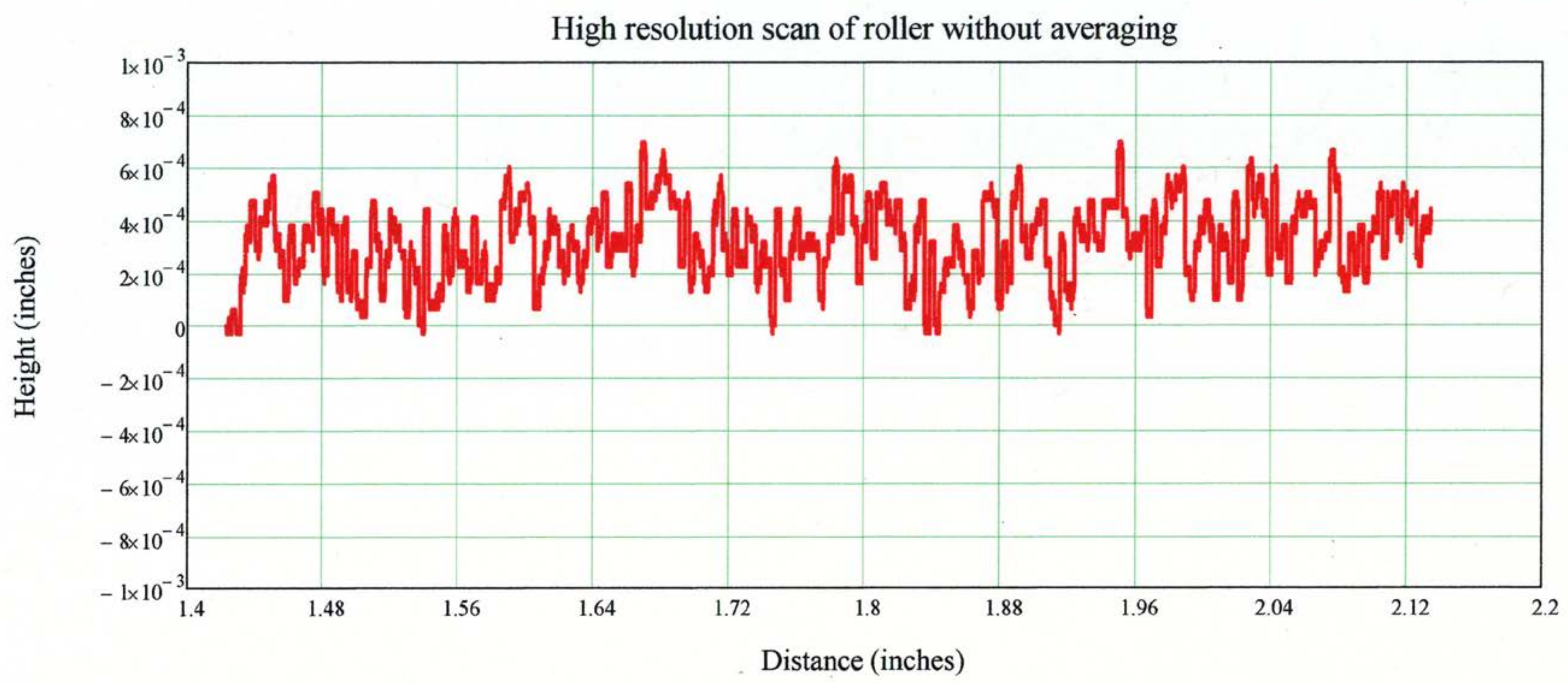
- For speeds below 1,700 ft/min the peak film heights are the same as those at the higher tension.
- The lowest speed valleys are also close to the same. But, at for mid-range and higher speeds the valleys are not as deep.
- The most important difference is in the height of the film over the tape at 2,429 ft/min. It is clearly floating above the tape surface. However, even at this speed the film is catching the tape edge.

Roughness of the tape



RMS roughness = $0.440\text{x}10^{-3}$ inch, Max = $5.1\text{x}10^{-3}$ inch, Min = $2.5\text{x}10^{-3}$ inch

Roughness of the roller



RMS roughness = 0.146×10^{-3} inch, Max = 0.7×10^{-3}, Min = -0.03×10^{-3} inch

Circumferential bands

- It would have been interesting to make some measurements of web behavior at both the edge of the web and the inner edge of the tape.
- But, as work progressed it became clear that expensive apparatus would be required to horizontally scan and trigger the measuring sensor.

Circumferential bands (Cont.)

- Many important aspects of circumferential bands can be predicted from work on annular venting.
- One important conclusion that can be gleaned from the horizontal strip measurements is that masking tape is particularly effective because it has such a rough surface.

Conclusions

- One obvious conclusion is that masking tape has a very rough surface that enables it to vent entrained air very effectively.
- Narrow zones at lateral tape edges can maintain contact with the web at speeds where the foil bearing equation predicts a complete loss of contact.
- When simulating a concave roller with tape, horizontal chevron patterns may be able to maintain traction at speeds higher than the foil bearing equation would predict (even when the effect of the roughness of the tape is included) because of contact at the tape edges.

Conclusions (Cont.)

- These results may not apply to webs that can't bend to conform well to the tape profile.
- Smooth tape (vinyl for example) should not be used.
- More work is needed
  - Tests should be made that include a provision for measuring the torque at which slipping begins.
  - A better sensor is needed or alternatively webs that are more opaque.

QUESTIONS?

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