THE FACTORS THAT CONTROL RUN-AHEAD ON PRINTING PRESSES

by

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ABSTRACT

Run-ahead is a problem that occurs on printing presses where the paper rolls are braked by metallic bands applied to their periphery. Run-ahead occurs when the web in contact with the band decelerates faster than the roll, or when the web stops completely but the roll continues to rotate. This leads to a bubble, or bunching of paper layers, on the ingoing side of the bands. This breaks the web. A model has been developed to characterize run-ahead that takes into account press operating conditions, as well as paper and roll properties. The model shows that run-ahead depends on the press parameters of wrap angle, deceleration rate, and unwinding tension. It depends on paper parameters such as paper-to-paper coefficient of friction (COF), paper-to-band COF, wound-in tension, and the mass of the roll. We found that the paper-to-band COF increases significantly due to contamination of the band from the paper, and could be a determinant in the run-ahead problem. The probability of run-ahead can be reduced by increasing the wrap angle between the braking band and the paper roll, reducing the rate of deceleration, reducing the web tension on the press, or by increasing the wound-in tension. The key factors are the static paper-to-paper COF and the dynamic COF between the paper and the band material. Increasing the paper-to-paper COF will not be effective if there is also a proportional increase in the paper-to-band COF, so care must be taken when evaluating possible additives or treatments.

NOMENCLATURE

a press deceleration (m/sec^2)
COF coefficient of friction
I moment of inertia of the roll (m^4)
m mass of paper roll (kg)
M moment of the forces applied to the paper roll (N.m)

P_{in} pressure between paper layers (Pa)
P_θ pressure exerted by the band (Pa)
P_p hoop stress exerted by the outside paper layer on the paper roll (Pa)
R radius of curvature and roll radius (m)
T_p wound-in tension (N)
T_f frictional force (N)
T_u unwound web tension (N)
T_1 tension (N)
T_2 braking tension (N)
w width of the band (m)

α tension band contact angle (rad)
θ angle (rad)
μ_b dynamic coefficient of friction between the band and the paper
μ_p static coefficient of friction between paper layers.
ω angular deceleration (rad/sec)

INTRODUCTION

Run-ahead is a problem that occurs with printing presses that brake paper rolls by means of metallic bands applied to their periphery. Run-ahead occurs when the web in contact with the band decelerates faster than the roll or the web stops completely but the roll continues to rotate. In extreme cases, this can lead to a bubble or bunching of paper layers on the ingoing side of the band which will break the web. This problem is associated with large roll diameters, high press speeds, high deceleration rates and low paper to paper coefficient of friction. Paper with a high recycled fiber content is often prone to this problem.

In this study, we define the mechanics of run-ahead and identify important paper properties. The dynamic coefficient of friction (COF) between the copper band and the paper is a significant factor and was measured on a pilot scale at speeds and loading conditions similar to those of commercial printing presses.

DESCRIPTION OF RUN-AHEAD

On many printing presses the paper roll is unwound on a revolving reel stand. The web tension is maintained by a band that acts on the periphery of the paper roll (Figure 1A). One end of the band is fixed and the pressure exerted by the band is controlled by a piston attached to the other end. The web tension depends on the force applied by the piston, the contacting area, the number of bands and the coefficient of friction between the paper and the band.

The bands are also used to brake the paper roll while the press is decelerated. Increased pressure is applied by the bands so that the web deceleration matches the press deceleration to maintain a constant web tension. During an emergency stop the roll must be decelerated rapidly. When the deceleration of the roll is not sufficient the dancer roll will attempt to take up the slack. If the dancer reaches its limit, tension control is lost (Figure 1B) and the web is cut to prevent creases and bags in the web that could damage the press. The accumulation of paper requires the intervention of the operators to clean and thread the web before restarting.

Sometimes the web in contact with the band will decelerate faster than the roll or stop completely as the roll continues to rotate. In these cases the web begins to bubble at the contact point with the band, folds and eventually breaks. (Figure 1C). This phenomenon is called run-ahead.

Run-ahead reduces printing press efficiency because the operators must either re-tighten, repaste or re-thread the web completely. On multi-sheet presses, run-ahead often causes sympathy breaks of adjacent webs.

Run-ahead is usually associated with paper characteristics and not the press because in a single pressroom the problem often occurs with paper from one mill or machine but not others. The coefficient of friction appears to be an important factor in this problem, but observations from press room indicate that other factors are involved.

THE MECHANISM OF RUN-AHEAD

A model was developed to identify the parameters that contribute to the occurrence of run-ahead. The model is based on the assumption that run-ahead occurs because of slippage between the outer two paper layers during the deceleration of the roll. The outer sheet is decelerated by the tension band but the roll rotates faster than the outer web (Figure 1C) which creates an accumulation of paper before the point of contact with the band.

Because run-ahead is a catastrophic phenomenon, it is difficult to model what is happening during the event. However, the conditions at the point of contact between the band and the paper just before the slippage occurs can be established. We propose that run-ahead occurs when the shear force applied by the band exceeds the maximum frictional force between the two outer-most paper layers as illustrated in Figure 2.

The forces exerted by the band brake on the unwinding roll are illustrated in Figure 3. The tension band contacts the paper roll over an angle α. The braking force is provided by the piston which exerts a tension T_2 on the band. The reaction tension T_1 is:

$$T_1 = T_2\, e^{-\mu_b \alpha} \tag{1}$$

where μ_b is the dynamic coefficient of friction between the band and the paper [1]. The forces for an element $d\theta$ at an angle θ at the surface of the roll, are shown in Figures 3 and 4. The frictional force between the paper and the band over an angle $d\theta$ is the tension difference in the band, dT_θ, which is the derivative of equation 1:

$$dT_\theta = -\mu_b\, T_\theta\, d\theta \tag{2}$$

This is a dynamic coefficient of friction because just before the onset of run-ahead the paper is slipping on the band.

The frictional force, dT_f, over an area dA, between the paper layers opposes dT_θ and keeps the paper layers, together. From the definition of coefficient of friction, the frictional force, dT_f, is:

$$dT_f = \mu_p\, P_{in}\, dA \tag{3}$$

The pressure between the paper layers, P_{in}, is the sum of the pressure exerted by the band P_θ and the hoop stress exerted by the outside paper layer on the paper roll, P_p:

$$P_{in} = P_\theta + P_p \tag{4}$$

The pressure exerted by a curved band is the ratio of the tension divided by the radius of curvature, R, and the width of the band, w, which gives:

$$P_{in} = \frac{T_\theta}{Rw} + \frac{T_p}{Rw} \tag{5}$$

Combining equations 3 and 5 and equating dA to $Rwd\theta$, the frictional force becomes:

$$dT_f = \mu_p (T_p + T_\theta)\, d\theta \tag{6}$$

where μ_p is the static coefficient of friction between paper layers. The static coefficient of friction is used because just before run-ahead there is no displacement between the paper layers.

Run-ahead occurs when the frictional force, dT_θ, between the band and the paper at a position θ, exceeds the frictional force dT_f between paper layers:

$$|dT_\theta| > |dT_f| \tag{7}$$

Substituting the frictional force applied by the band (equation 2) and the frictional force between the outer paper layers (equation 6) into equation 7 gives:

$$\frac{T_p}{T_\theta} < \left(\frac{\mu_b}{\mu_p} - 1\right) \tag{8}$$

Because the band tension decreases with the wrap angle (equation 1), the maximum band tension (T_θ) occurs at an angle of 0°. Therefore, equation 8 predicts that the problem begins where the band first contacts the paper which means that $T_\theta = T_2$. Thus, the criterion for run-ahead becomes:

$$\frac{T_p}{T_2} < \frac{\mu_b - \mu_p}{\mu_p} \tag{9}$$

This criterion indicates that run-ahead depends not only on the paper to paper static coefficient of friction μ_p but also on the dynamic coefficient of friction between the band and the paper μ_b, the wound-in tension, T_p, and the braking tension, T_2. The wound-in tension depends on paper properties and winder operation, but for newsprint 200 N/m would be a typical value. Braking tension in the band to decelerate the roll can vary from 0 to 1500 N/m depending on the deceleration rate and the roll mass.

Both the static paper-paper COF and the dynamic paper-band COF must be evaluated.

If the band to paper COF is less than that for paper to paper ($\mu_b < \mu_p$), the criterion is negative and run-ahead cannot occur.

Roll structure also influences the occurrence of run-ahead. Higher wound-in tension reduces the risk of run-ahead whereas lower wound-in tension caused, for example, by loosely wound rolls or by relaxation over time, would increase the risk of run-ahead.

Run-ahead criterion applied to deceleration of paper rolls

During an emergency stop, the roll deceleration is controlled to maintain a constant sheet tension and match the press deceleration rate. The run-ahead criterion embodied in equation 9 does not account for the geometry or operating conditions of an unwind station on a printing press.

To evaluate different presses and their interaction with a paper roll, a model was developed to account for roll weight, roll diameter, the wrap angle of the tension band and deceleration rate.

For a given angular deceleration, ω, the torque applied is equal to the sum of the moments M_i:

$$\sum_{i=1}^{n} M_i = I\dot{\omega} \tag{10}$$

where I is the moment of inertia of the roll. For the forces shown in Figure 3 and the definition of moment of inertia, equation 10 becomes:

$$(T_2 - T_1 - T_u)R = \frac{mR^2}{2}\frac{a}{R} \tag{11}$$

where a is the press deceleration, T_u is the unwound web tension and R is the roll radius.

Combining the run-ahead criterion (equation 9) with the tension distribution in the band around the wrap (equation 1) and the moment of inertia of the roll (equation 11) gives the run-ahead criterion for an unwind station in a printing press:

$$\mu_p \geq \frac{\mu_b}{\left[1 + \dfrac{T_p(1-e^{-\mu_b \alpha})}{\dfrac{ma}{2} + T_u}\right]} \tag{12}$$

This equation can be used to evaluate or predict the effect of geometry and paper properties on run-ahead. To avoid run-ahead, the static coefficient of friction of paper must be larger than the dynamic coefficient of friction between the band and the paper divided by a factor which is always greater than or equal to 1.0. The run-ahead criterion is presented in terms of paper to paper coefficient of friction but could be reformulated in terms of any of the paper or press operating parameters.

The parameters related to run-ahead can be separated into two categories: paper and roll properties, and press design. The dynamic coefficient of friction (COF), μ_b, between the band and paper is a very important factor for run-ahead. The evaluation and measurement of μ_b is described in the next section. The static COF of paper is primarily related to surface chemistry [2–8] which can be affected by wood species, pulping process, chemical addition and deinked fibre content (including carry over of deinking chemicals).

The normal force on the outer layer of paper is applied by the hoop stress exerted by the band. The normal force on the next paper layer below the surface is a combination of the force that is applied by the band and the hoop stress applied by the outer paper layer. In effect this layer is exposed to a higher normal force than the paper layer on the surface of the roll. This additional normal force means that the paper to paper coefficient of friction does not have to be greater than the band to paper coefficient of friction to prevent run-ahead. In addition, a larger wrap angle, α, by the band reduces the normal stress. This increases the relative importance of the wound-in tension and makes the roll less susceptible to run-ahead.

Increasing the wound-in tension could be a controlling variable in the run-ahead problem. Wound-in tension is developed during winding but starts to decrease immediately after winding. Rolls that are wound tighter or are used quickly after their manufacture would have a lower tendency to run-ahead. Other factors such as changes in the moisture content of the roll also affect the wound-in tension.

Equation 12 points out that a higher web tension in the printing press increases the braking forces required and, consequently, will increase the risk of run-ahead. The equation also predicts that run-ahead is more likely to occur as the press deceleration rate is increased.

The criterion for run-ahead in an unwinding station has been calculated in Table I in terms of the minimum paper to paper COF to prevent run-ahead. For the base case, the paper to paper COF would have to be greater than 0.42 to prevent run-ahead. The sensitivity of the criterion, defined in equation 12, to paper and operating parameters was estimated by selecting practical changes for each parameter separately. From this analysis, run-ahead is most sensitive to both paper to paper and paper to band COF. Run-ahead is least sensitive to the wrap angle which changes as the roll is unwound. The mass of the roll, the deceleration rate, wound-in tension, and the web tension in the press have a second order, but still important effect on run-ahead. Simultaneously, changing all of the press operating parameters or paper parameters can lower the critical paper to paper COF significantly (Table I). This is illustrated in Figure 5 which shows the change in the criterion as the paper roll is unwound combined with changes to the paper and roll structure, and changes in press operation.

EXPERIMENTAL

The dynamic coefficient of friction between paper and a band was measured using a rig designed to simulate the braking mechanism on a commercial printing press as shown in Figure 6. Paper rolls up to 1.27 m in diameter by 0.6 m wide were mounted on the unwind stand of Paprican's pilot calender. A single band, identical to those used on a commercial printing press, wrapped the paper roll. One end of the band was attached to a solid support and the other was attached to a pneumatic piston to control the tension. The tension in the unwound paper was measured by wrapping a roll which was equipped with load cells in the bearings. The tensions in the band were measured by means of load cells located at the attachment point between the piston and band (T_2) and between the band and support point (T_1). The wrap angle was determined on the run with a template mounted on the side of the unwind. Because the paper roll unwind was undriven, the roll was unwound at a constant speed determined by a balance between web tension and the braking applied by the band.

The dynamic coefficient of friction was determined from equation 1 by measuring T_1, T_2 and the wrap angle, α. Experiments were performed to study the effect of wrap angle, unwind speed, and normal force applied by the band on the coefficient of friction between the band and the paper.

In general, the coefficient of friction does not depend on the contact angle. This is confirmed in Figure 7A where the coefficient of friction is constant as a roll was unwound and wrap angle decreased. Unexpectedly, lowering the web speed from 300 to 50 m/min increased the coefficient of friction. Reversing the direction of unwinding, as shown in Figure 7B, did not affect the coefficient of friction.

Lowering the web speed from 900 m/min to 10 m/min caused the coefficient of friction to increase from 0.28 to 0.61, as shown in Figure 8. This phenomenon would exacerbate the problem of run-ahead as the paper roll decelerates after a red-button stop.

To understand why speed has an effect on the COF, the dynamic COF was measured on a TMI horizontal plane friction tester. Two pieces were cut from a band that had been used to brake a paper roll in the test rig. One piece was cleaned with acetone and the other left in its original state. These pieces were laid flat on the bed of the friction tester and a block covered by a sheet from the paper roll was pulled over the band material to measure the dynamic COF. As shown in Figure 8, the dynamic COF using the clean band was 0.23 which was well below that measured in the test rig. In contrast, the contaminated band gave a COF on paper of 0.65 which was equal to the COF measured at the lowest speed and highest normal force on the test rig.

An out-of-round roll will cause periodic variations in the band tension and the normal force applied to the paper roll (Figure 9). This variation in normal force will cause a corresponding variation in the dynamic COF between the band and the paper. For a roll that is prone to run-ahead, this excursion in COF may be enough to exceed the criterion of equation 12 and initiate the problem. Rewinding an out-of-round roll (Figures 9 and 10) restored its symmetrical shape and lowered the tension and normal loading variations.

SUMMARY

A model has been developed to characterize run-ahead on a printing press that accounts for press operating conditions, and paper and roll properties. The potential for run-ahead is inherent to printing presses with band braking systems.

The key factors are the static paper to paper coefficient of friction and the dynamic coefficient of friction between the paper and the band material. Increasing the paper to paper COF will not be effective if there is also a proportional increase in the paper to band COF, so that care must be taken in evaluating possible additives or treatments.

The paper to band friction is determined by material scoured from the paper onto the band which acts like a glue at this interface. The material increases the COF considerably and is influenced by shear forces which causes the band to paper COF to be affected by the operating conditions of the tension system such as speed and loading. Using a band material

which does not accumulate sticky substances could also alleviate this problem.

The occurrence of run-ahead can be reduced by increasing the contact length or wrap angle between the braking band and the paper roll, reducing the rate of deceleration and reducing the web tension in the press.

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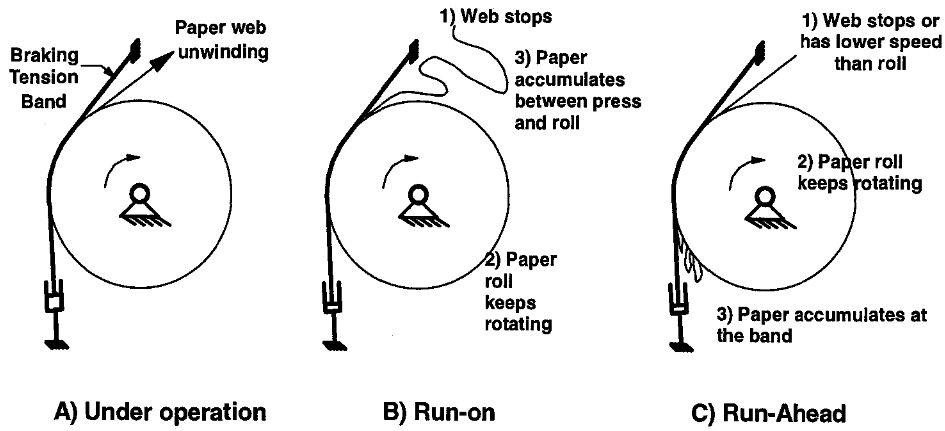


Figure 1. Description of the run-ahead problem.

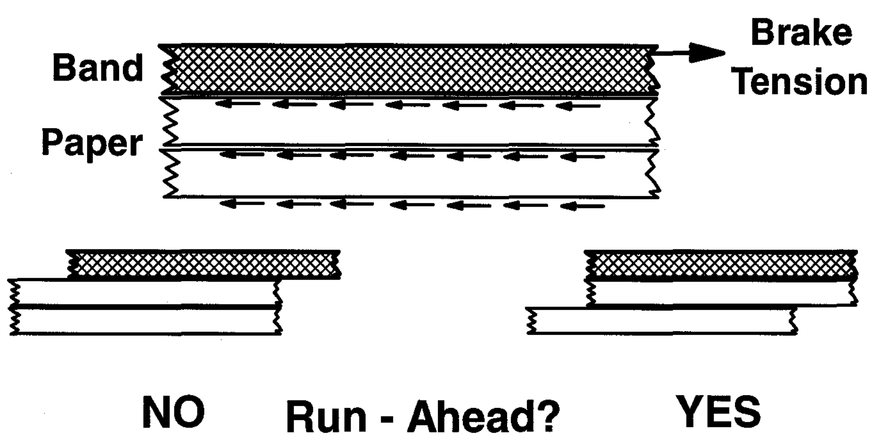


Figure 2. The mechanism for run-ahead.

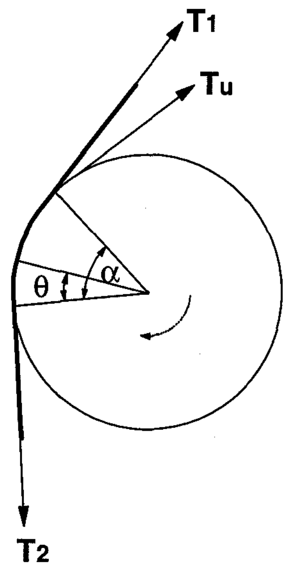


Figure 3. Forces applied to a paper roll in an unwind that has tension bands.

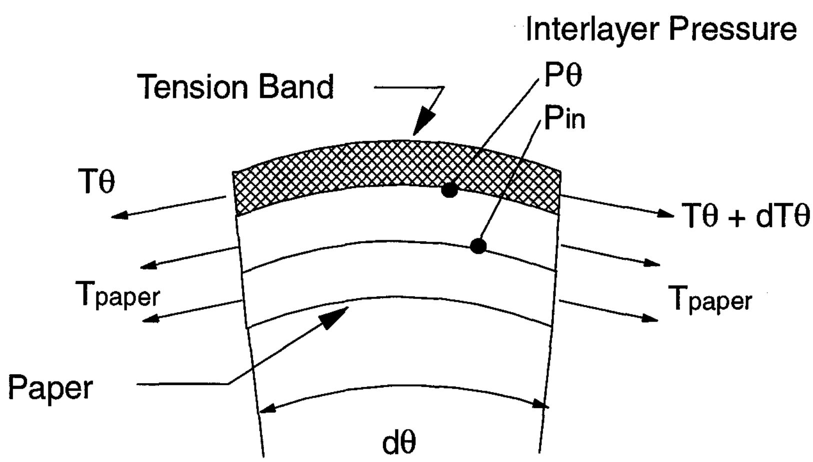


Figure 4. Analysis of the forces acting on two paper layers located underneath the band over an angle $d\theta$.

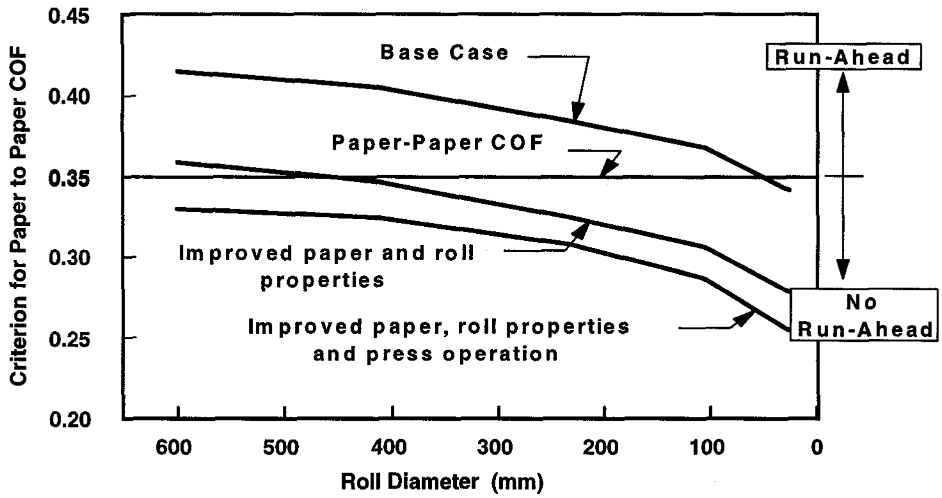


Figure 5. The risk of run-ahead is reduced as the roll diameter becomes smaller during unwinding for the base case described in Table 1. The risk of run-ahead can be reduced by improving the paper and the roll properties by decreasing the band to paper COF and increasing the wound-in tension. The risk can be further reduced by lowering the deceleration rate and unwinding tension and by increasing the wrap angle.

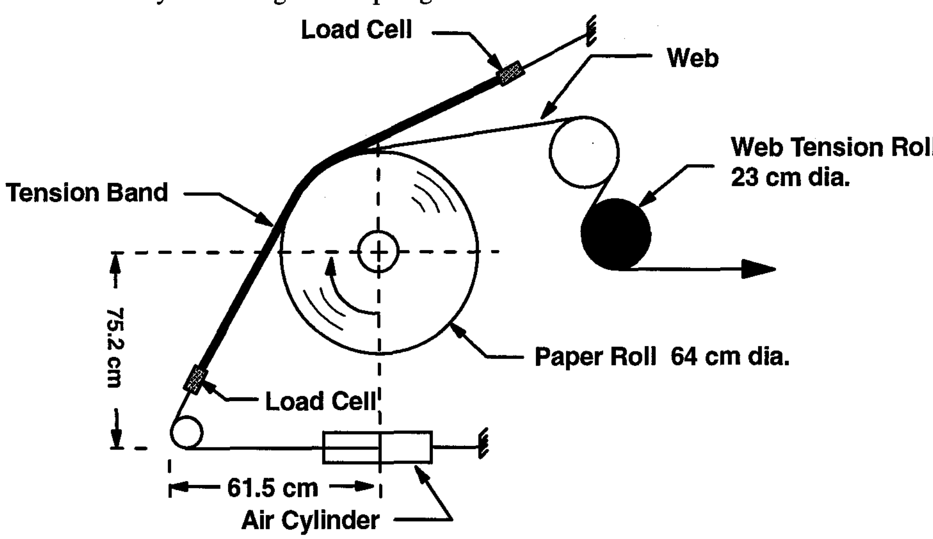
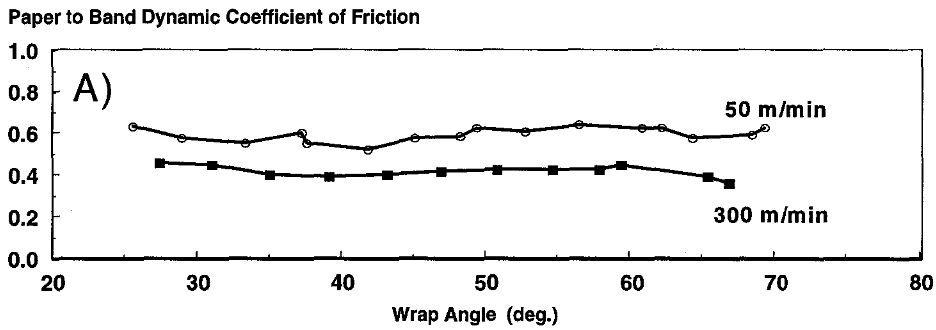


Figure 6. Description of experimental set-up on the Paprican pilot calender to measure the dynamic coefficient of friction between the band and the paper.



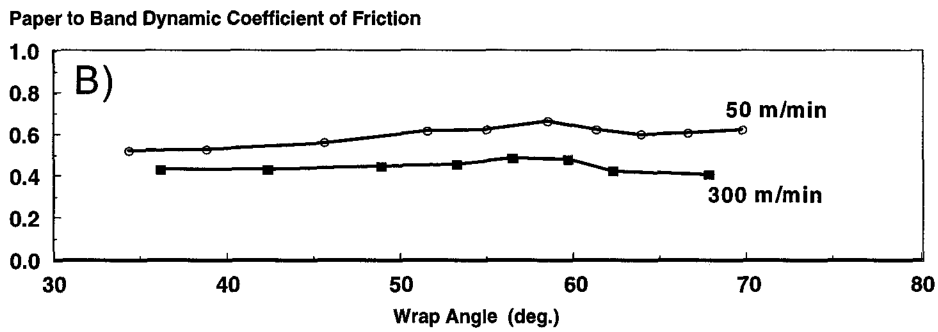


Figure 7. The dynamic coefficient of friction was measured for clockwise(A) and counter-clockwise unwinding directions (B).

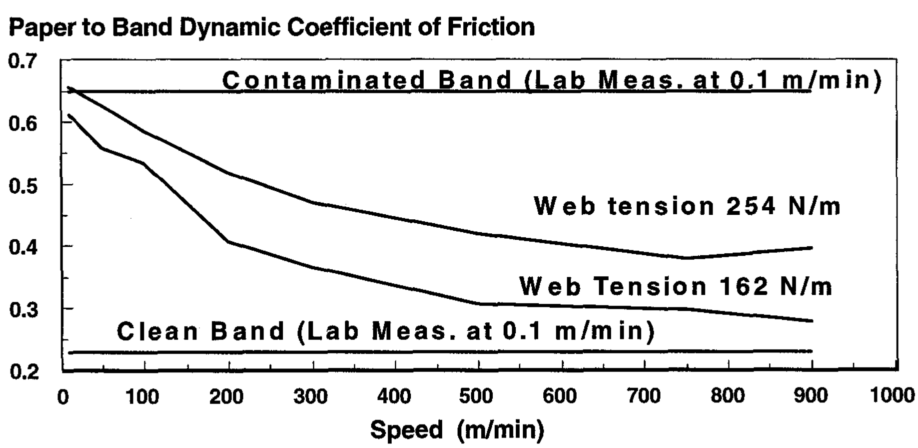
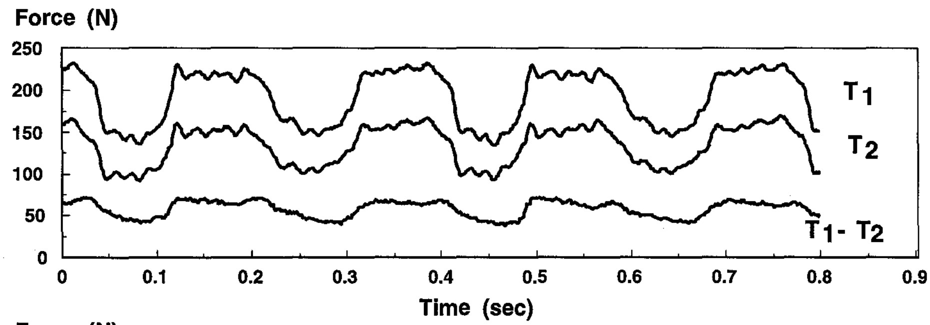


Figure 8. The dynamic paper to band coefficient of friction increases with decreasing web speed and increasing web tension in the sheet run. A clean band gives significantly lower COF than one that has been contaminated by rubbing the roll surface.



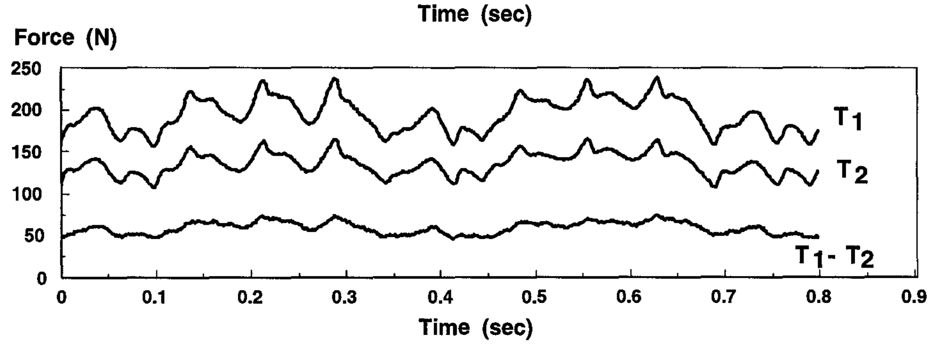


Figure 9. A) An out-of-round roll causes the band tension and paper tension to vary. B) The tension variations for an out-of-round roll can be reduced by rewinding.

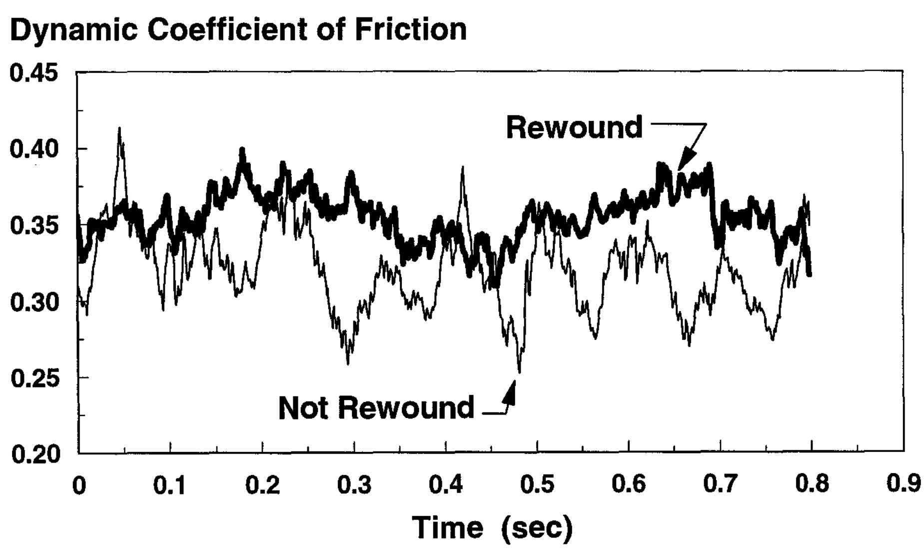


Figure 10. The variation in coefficient of friction for an out-of-round roll can be reduced by rewinding.

Variable / Parameter change	α	m	μ_b @300 m/min	a	T_p	T_u	Criterion $u_p \geq$
	deg.	kg		m/sec²	N/m	N/m	
Base Case	60	600	0.45	2.5	200	200	0.42
Increase angle	**90**	600	0.45	2.5	200	200	0.41
Half roll	60	**300**	0.45	2.5	200	200	0.40
Reduce band to paper COF	60	600	**0.40**	2.5	200	200	0.37
Reduce Deceleration Rate	60	600	0.45	**2.0**	200	200	0.41
Increase wound-in tension	60	600	0.45	2.5	**300**	200	0.40
Decrease unwind tension	60	600	0.45	2.5	200	**100**	0.41
Press parameters	**90**	600	0.45	**2.0**	200	**100**	0.39
Paper parameters	60	600	**0.40**	2.5	**300**	200	0.36
All parameters	**90**	600	**0.40**	**2.0**	**300**	**100**	0.33

Table 1 The effect of press operating parameters, and paper and roll properties on the criteria for run-ahead expressed as the minimum paper to paper COF to prevent its occurence. Parameters that differ from the base case are underlined and in bold.

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The Factors that Control Run-Ahead on Printing Presses

6/8/99 Session 2 1:15 - 1:40 p.m.

Question – Wolfermann, Technical University of Munich
I am a little bit surprised that printing presses use brakes such as you have shown. Why can they not use brakes or motors on the core or the shaft?

Answer – J. Hamel, Paprican
That's what all papermakers are asking. Maybe some people in here have some history on why these braking mechanisms are used but the problem is that papermakers have no empowerment to request modifications of the printer's press. We can't tell them to change anything because as papermakers, it's always a question of cost. The second thing is that problem often occurs from one paper source and not the other? So printers are not interested to make any modification and invest any money to solve the problem for one papermaker.

Question – Rolf Bosse, Munich
I didn't ever see such breaking mechanisms on a press. Is it on newsprint presses, on offset, heat, and letterpress? I would like to say on modern presses do have central braking or a driven belt but not a static belt so the friction is important but not in the same sense.

Answer – J. Hamel, Paprican
This is on newsprint. That's mainly the case where we have been exposed on newsprint presses and I don't have much experience with other types of presses. The thing is there is a considerable number of tons that are printed everyday on different kinds of presses so I don't know. If the number of presses is not large not great, the impact on the newsprint industry when you have such a problem is very important.

Question – Keith Good, Oklahoma State University
So in reference to Dave McDonald's keynote speech talk this morning, and knowing what you know, is there anyone out there making paper that's adding some resin acid to the surface to increase the coefficients of friction or decrease your run ahead problems?

Answer – J. Hamel, Paprican
Well, this information is mainly for the band and so what we are doing is decided to monitor with some newsprint companies this coefficient of friction and see how we could control it. One thing I did not mention is that the contamination happens very quickly. In fact you can easily reproduce the contamination by holding a piece of tension band with a piece of foam and rubbing it against the roll for only 30 seconds or 1 minute and then you bring this band into the lab and you can have a good estimate of the contaminated band coefficient of friction.

Question – Keith Good, Oklahoma State University
It was not particularly surprising to me to see your coefficient of friction drop between to 300 and 900 meters per minute because I think even though the web is porous, the band isn't and you may be witnessing air entrainment.

Answer – J. Hamel, Paprican
That's a good point. The heat generation is also a factor.

Comment - Pete Werner, Rockwell Corporation
This type of unwind is very prevalent on newsprint unwind stands because it is simple and very inexpensive rather than having a brake or regenerative control. There is one tension control system, its linear force so you don't have to calculate diameter so it's simple, straight forward and on newsprint presses that's extremely critical. It's very common on newsprint printing presses.

Answer - – J. Hamel, Paprican
These belt braking systems are potentially the source of another problem which is lint generation. The bands create some lint as a result of abrasion between the paper and the belt and this lint is transferred to the web and to the print unit and on the blanket. You see a lot of dust, or linting exactly at the position of the band. What we believe now is that the increase of coefficient of friction might be a contributing factor to the linting created by the band.

Comment - D McDonald, Paprican
To answer Keith Good's question about resin acid, one of our other developments is related to additives in the de-inking process. I talked earlier about fatty acids as a lubricant in flotation de-inking; fatty acids soaps are used as ink collectors. A very small carryover of these soaps causes havoc in papermaking. One of the inventions is a resin acid soap for the flotation process. Several of our members are using it to increase the friction of their products.