GENERAL ANALYSIS OF WEB TENSION CONDITIONS IN AN OFFSET PRESS WITH PRACTICAL TEST METHODS AND RESULTS

Erik Nikkanen*

Keywords: Blanket, Registration, Repeat, Tension, Web

Abstract

A mathematical description of factors that determine print repeat lengths. The analysis is based on non-slip conditions in the impression nip. The analysis explains why tension variations can move up stream through the press even when non-slip conditions exist. Practical test methods to determine parameters that characterize the effect of the blanket will be shown. Methods for plotting the operating envelope and range of the press relative to print repeat length will be demonstrated. Methods for calculating tension between print units will be presented. This work was done to understand the requirements for insetting (printing in register on pre-printed material). Insetting topics will be discussed. Related print register and print length topics will also be referred to.

Introduction

The analysis is a fundamental yet practical look at conditions in the impression nip. The simple relationships that are presented can be used to analyze other press configurations to aid in solving problems or to predict performance.

Testing was done under unusual printing conditions which actually helped in obtaining a more general model.

The press had load cells to measure web tension before the first unit and after the last print unit. These tension levels were also adjustable. The impression rollers

*Fountech Inc. Tel / Fax 416 497 5670
124 Sandyhook Sq., Scarborough, Ont. Canada M1W 3N5

were free wheeling and this meant that the impression rollers were not able to introduce forces that could not be determined. The ink drying system did not heat the web and therefore could not affect repeat length. The web itself was a polyethylene coated board which meant that it was very stable and moisture from the fountain solution would not be able to affect the paper.

The repeat length analysis looks at two specific areas. One is the strain of the web, caused by stresses that act upon it during the printing process. The other is related to the distortion of the blanket surface by forces acting on it that cause changes in the print repeat length. These forces that act on the blanket are from the squeeze of the nip and from unequal web tensions on either side of the nip.

The analysis of these two specific areas are combined into an empirical relationship. Testing on press is done to determine the parameters of this relationship. This relationship for print repeat length is then used to build up other models of interest.

Stress Strain Relationship of the Web

The print repeat Lp is defined as the length from one point in a repeat to the corresponding point in the next repeat. This is measured at a web tension value equal to zero.

The web in the press is at tension T and this causes the length Lp to elastically stretch, with an elongation e, to Lt.

$$Lt = Lp + e$$

$$Lt = Lp\ (1 + e / Lp) \qquad (1)$$

Strain ε by definition is: $\varepsilon = e / Lp$

Then $Lt = Lp\ (1 + \varepsilon)$ (2)

from Hooke's Law $E = \sigma / \varepsilon$
we get $\varepsilon = \sigma / E$
Stress σ by definition is: $\sigma = F / A = T / A$
substituting $\varepsilon = T / EA$

$$Lt = Lp\ (1 + T / EA) \qquad (3)$$

with,

σ stress DAN/mm^2

e	elongation	mm
Lp	print repeat	mm
Lt	stretched print repeat	mm
ε	strain	mm/mm
E	Modulus of Elastisity	DAN / mm^2
A	web cross sectional area	mm^2
F	force	DAN
T	web tension (force)	DAN

DAN decanewton 10 newtons

The curvature of the impression cylinder will also have an effect on the stretch of Lp. This stretch of the printed surface is shown in Fig. 1. The stretch of the surface relative to the neutral axis of the web is described by the impression ratio IR . This ratio can be applied to eq 3 to give eq. 5 which describes Lt.

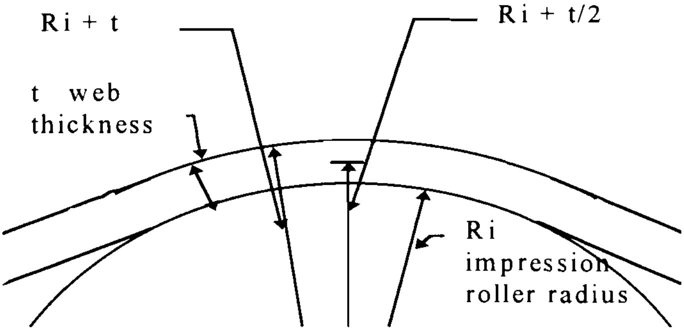

Fig. 1. Web Curvature due to Impression Cylinder

$$IR = (Ri + t) / (Ri + t / 2) \qquad (4)$$

Example Ri = 120 mm, t = 0.28 mm

$$IR = (120 + 0.28) / (120 + 0.14) = 1.00117$$

$$Lt = Lp\,(1 + T / EA)\,IR \qquad (5)$$

Relationship Between Print Repeat and Blanket Cylinder Diameter.

One print repeat is printed by one revolution of the blanket cylinder but it is printed on a stretched web. The stretched length of Lp is Lt . Therefore, Lt is related to the blanket circumference.

Since the blanket has a flexible surface, which can be distorted in the nip, a direct calculated value of the circumference from a measured value of its diameter will not be valid. Therefore, we will use the concept of effective circumference Ce and effective diameter De .

Let:

$$Lt = Ce = \pi De \qquad (6)$$

from eq. 5 = eq. 6.

$$Lp (1 + T / EA) IR = \pi De \qquad (7)$$

then

$$Lp = \pi De / [(1 + T / EA) IR \qquad (8)$$

The Effective Diameter De

The effective diameter is related to the flexible surface of the blanket on the blanket cylinder. The blanket cylinder, with the blanket on, will have a diameter that can be determined by a measurement relative to a known machine dimension such as the bearer diameter. See fig. 2.

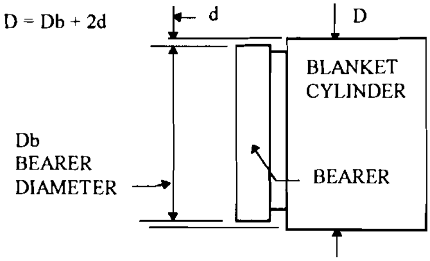

Fig. 2 Blanket Diameter

To find out why the effective diameter is different from the measured diameter lets look at a model of the printing nip in fig. 3.. The web is squeezed between a driven blanket cylinder and a free wheeling impression cylinder. The web has a tension that is equal on either side of the nip, Tout = Tin . Looking at the web first, if we follow a point on the web as it enters the nip we see that it is squeezed by the forces that deform the blanket. The web must take the curvature of the impression cylinder. The pressure of the squeeze will increase until this point reaches the center of the nip and then the pressure will drop as it passes to the other end of the nip.

When the point on the web first enters the nip, the pressure will not be high enough to create enough friction between the web and the blanket to prevent relative movement of the two. This will be a slip region.

As the pressure increases, there will be a point when the frictional forces are high enough to resist any movement of the surface of the blanket relative to the web. This point will be the start of the non slip region.

A this point, the surface of the web and the surface of the blanket are stuck together due to the high frictional force potential. This condition carries through to the start of the slip region on the other side of the nip.

Now we look at the blanket. Well before the nip, the blanket surface has a strain value ε blanket = 0. As a point on the blanket gets closer to the nip, it will see some affect of the blanket squeeze. This may be a bulge just before the nip . This would probably have compressed the surface of the blanket and therefore, the strain will be negative, ε blanket < 0.

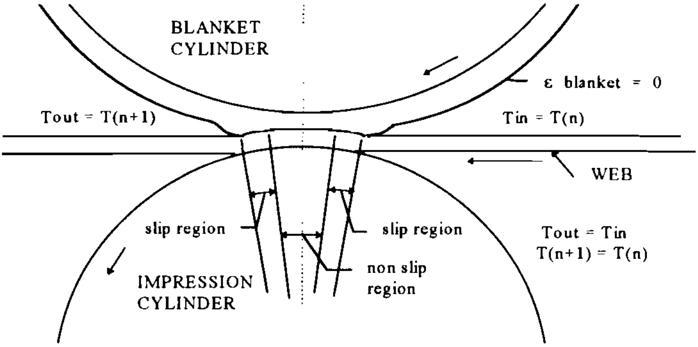

Fig. 3 Model of Printing Nip

As the point on the blanket travels further into the nip, it may experience stretching of the surface, therefore, the strain would be positive, ε blanket > 0.

The important point is to know what the blanket surface strain will be when it reaches the starting point of the non slip region, because at this point the surface strain will become fixed and pass through the nip, locked to the web surface. This has an effect on the effective diameter of the blanket cylinder.

At the start of the non slip region,

if ε blanket > 0, then De > D
or ε blanket = 0, then De = D
or ε blanket < 0, then De < D

A practical representation of the effective diameter is required, because it is not possible to determine directly what the strain of the blanket was when it reaches the start of the non slip region. Therefore, let assume there is a function Ks(s) that will describe the change in the effective diameter.

$$De = D\ Ks(s) \tag{9}$$

where Ks(s) is a function related to nip squeeze

Looking at the plot of Ks vs squeeze s in fig. 15. in APPENDIX B, we can see that Ks(s) is a function of squeeze. One must remember that, that Ks curve is for a particular blanket, on a particular press. Different blanket models, even different batches of the same blanket model could produce different curves.

$$\pi\ D\ Ks(s) = Lp\ (1 + Tin\ /\ EA)\ IR \tag{10}$$

$$Ks(s) = Lp\ (1 + Tin\ /\ EA)\ IR\ /\ \pi\ D \tag{11}$$

The determination of Ks is shown in APPENDIX B.

Effective Diameter When Tension Values Before and After The Nip are not Equal

Fig. 4 shows a model of the nip conditions when Tout < Tin . Since the impression cylinder is free wheeling, the difference in tension ΔT must be taken up by a shear force in the blanket. Fig 4 shows this shear force as an arrow in the blanket which pushes the blanket to the right. This would tend to compress the surface of the blanket and shift the regions to the right. It is expected that the

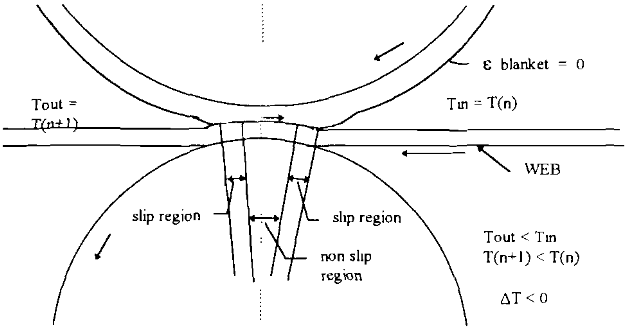

Fig. 4 Model of Printing Nip with ΔT < 0

strain of the blanket at the start of the non slip region would be less than the strain of the blanket shown in fig. 3, where $\Delta T = 0$.

$$\Delta T = [Tout - Tin], \qquad \Delta T = [T(n+1) - T(n)]$$

Fig. 5 shows the effect when Tout > Tin and the regions would shift left. The strain of the blanket at the start of the non slip region could be expected to be greater than the strain of the blanket shown in fig. 3.

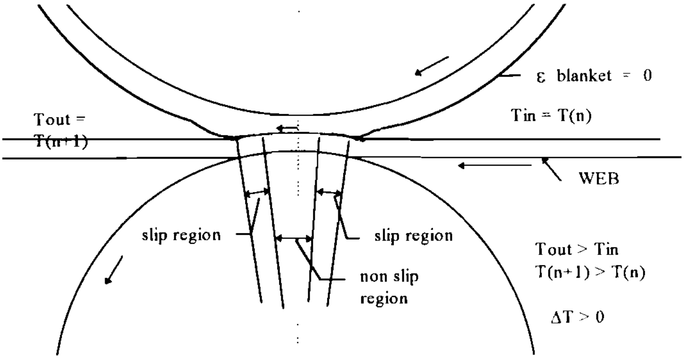

Fig. 5 Model of Printing Nip with $\Delta T > 0$

Let's assume that there is a parameter Kt that is sensitive to ΔT that can be used to describe the change in De.

$$De = D\,[Ks(s) + Kt\,(\Delta T)] \qquad (12)$$

Since there is practically a single value of squeeze s that is used to obtain good print, we can consider the Ks(s) functions as a constant Ks for this analysis.

$$\pi D\,[Ks + Kt\ (\Delta T)] = Lp\,(1 + Tin / EA)\,IR \qquad (13)$$

$$Lp = \pi D[Ks + Kt\,(\Delta T)] / (1 + Tin / EA)\,IR \qquad (13a)$$

$$Kt = [Lp\,(1 + Tin / EA)\,IR - Ks] / (\pi D\,\Delta T) \qquad (14)$$

The determination of Kt is shown in APPENDIX C.

Tension Conditions With All Units Running In The Press

All print units must have the same print repeat length because all units are turning at the same rate. This condition is independent of the blanket diameters, squeeze, tension levels etc. The print repeat length of the press is determined only by the conditions at the first print unit. The rest of the units must follow.

The tension between print units is related to the relative feed rates of each unit and the (EA) value of the web.

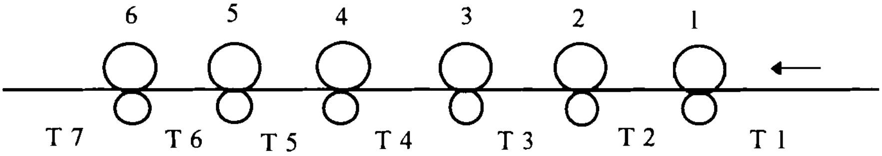

Fig. 6. Model of Six Unit Press

A Qbasic computer program is presented in APPENDIX D and was used to calculate the tension values between print units of a model of a six unit press shown in fig. 6. The program starts with initial conditions but allows for values to be changes to investigate what the tensions will be under different conditions. The program is based on the fact that all print units must have the same print repeat length Lp .

Table 1 shows six cases that demonstrate how the tension levels will be affected under different press conditions. The changes from standard conditions are shown on the second line of each case.

Case 1 & 2 show that stiffer webs will have longer print repeat lengths.

Case 3 & 4 show that when the Tout is different than Tin , the Kt value has an effect on the tension between units. If the Kt value is large enough, the tension at T2 can be affected and that will have an effect on Lp. It also shows that the tension change is not linear through the press, but that it has a sharp change at the end units.

Case 1 & 5 show that small differences in blanket diameter will have an influence on tension between units.

Case 1 & 6 shows that small changes in Ks can cause large tension differences between units.

Table 1

Standard values for the calculations of tensions between units.

EA = 186000 DAN T(1 to 7) = 250 DAN

Ks(1 to 6) = 1.00202 Kt(1 to 6) = 5.1×10^{-6}

D(1 to 6) = 312.1152

CASE	Lp	T7	T6	T5	T4	T3	T2	T1
1	980.05	250	250	250	250	250	250	250
2	978.74	250	250	250	250	250	250	250
	EA = 93000							
3	980.06	350	298	272.7	260.3	254.3	251.4	250
	T(7) = 350							
4	980.69	350	328.9	309.8	292.5	276.9	262.8	250
	Kt(1 to 6) = 5.1×10^{-5}, T(7) = 350							
5	980.07	250	248.1	247.2	246.8	261.9	253.9	250
	D(3) = 312.165							
6	978.73	250	252.6	253.9	254.4	233.7	244.6	250
	Ks(3) = 1.0018							

Press Operating Envelope

The press has a limitation on the print repeat length that it can print. Fig. 7. shows plot of Lp vs Tension. This is the infeed tension to the 1st print unit. This plot assumes that $\Delta T = 0$ at first unit. The operating envelope is limited by the minimum tension Tmin and the maximum tension Tmax that the press can run with. The other limits are based on the minimum blanket diameter Dmin and the maximum blanket diameter Dmax that can be packed up to. The curves for Lp are for specific D, Ks, and EA values. The maximum print repeat length range for the press, for that particular web EA, is shown.

Fig. 8 shows the effect of two different webs (EA)1 and (EA)2 that are run on press with the same blanket diameter. One can see that the repeat length range for the stiffer web is smaller, but its average value of Lp is relatively longer.

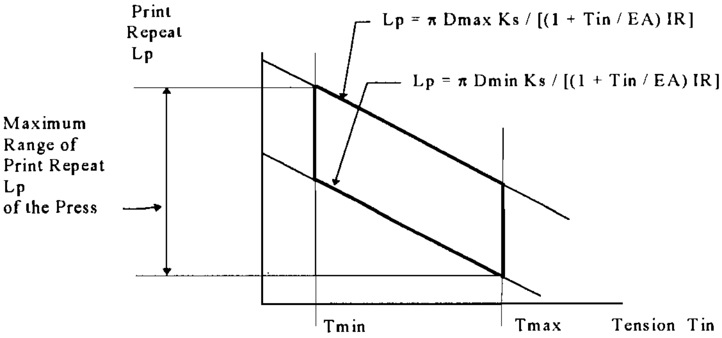

Fig. 7 Press Operating Envelope

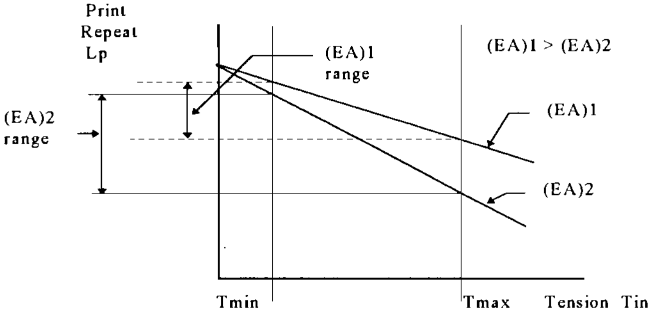

Fig. 8 Print Repeat Ranges for Different EA Values

Insetting

Printing in register to a preprinted web is a demanding process. Fig. 9 shows the basic requirement, which is that the range of the print repeat of the preprinted web must be less than and totally inside the print repeat length range of the press.

Whatever system is used to control this process, the outcome will be the same. To match up the press print repeat length with the print repeat length of the preprinted material will mean that the web tension will vary. Preprinted material that has a large variation in print repeat length will run on press with large variations in web tension due to the control system following the repeat length of the web. Tension variations will lead to printing problems such as doubling and registration errors. Therefore, to have a successful insetting process, the prime requirement is to have very consistent repeat length in the preprinted material.

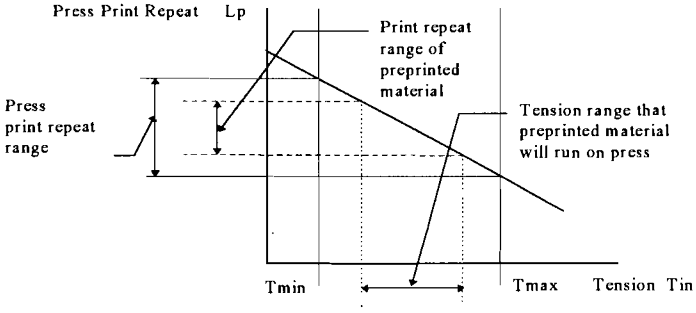

Fig. 9 Print Repeat Range and Tension Range for Insetting

Special Cases

Blanket to Blanket Since both blanket diameters on a blanket to blanket press unit should be packed the same and have the same diameter one can consider it as a single blanket cylinder with a free wheeling impression cylinder for analysis. The impression ratio IR can be dropped since the web is flat in the nip.

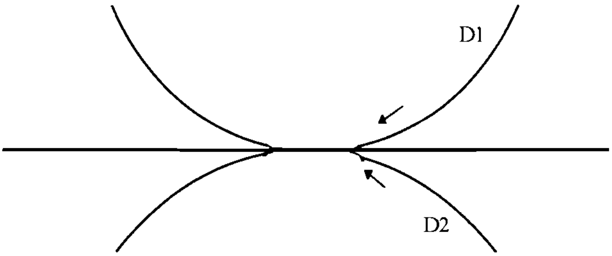

Fig. 10 Blanket to Blanket Nip

let $D = (D1 + D2) / 2$

for De determine Ks, Kt in the usual way

$$Lp = \pi De / (1 + Tin / EA) \tag{15}$$

Since it is not possible to match exactly the effective diameters of the blanket to blanket units, there will always be shear between the units. Too much shear, which is not detectable, may damage web materials. See fig. 11.

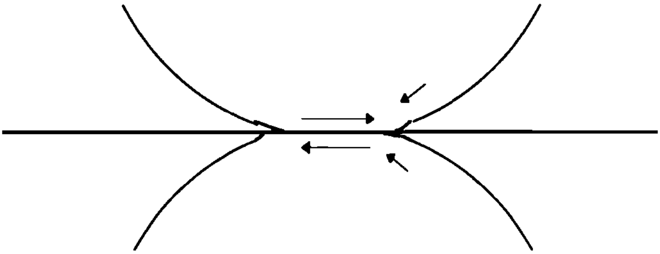

Fig. 11 Blanket to Blanket Nip Inter Unit Shear Forces

Blanket to Driven Impression Cylinder. If the impression roller is not free wheeling, but it is driven by the press, the impression roller will want to drive the web by means of friction. The blanket is also trying to drive the web. It is almost impossible to have the same value for the effective diameter of the blanket and the diameter of the impression cylinder plus the web thickness, so there will always be some shear forces between the blanket and the impression cylinder. This is shown in fig. 12..

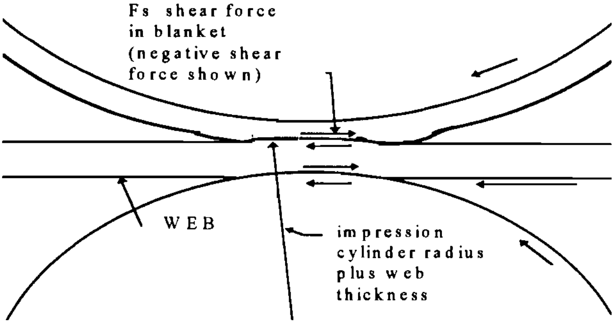

Fig. 12 Blanket to Driven Impression Cylinder Nip

Fig. 13. shows the plot of the forces of friction and web tension vs shear forces in the blanket. As shear forces Fs increases $\Delta T = 0$, until the point when the Fs equals the maximum static frictional force between the web and the impression cylinder. Increasing Fs more results in $\Delta T > 0$, and the web will start to slide on the impression cylinder producing sliding friction. When shear force Fs goes negative a similar situation exists.

Three different printing conditions are shown, a, b, and c.

Condition a would be quite stable. The shear force Fs would be below the maximum static friction limit and $\Delta T = 0$.

Condition b being close to the transition point may show sudden jumps in register as it randomly goes below and then above the transition point.

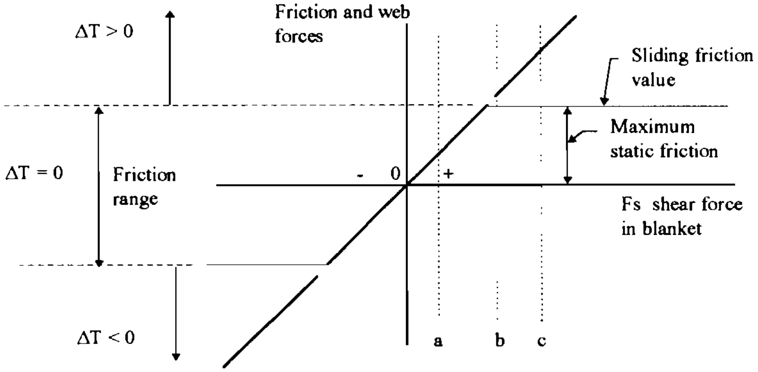

Fig. 13 Plot Friction and Web Forces vs Shear Force in Blanket

Condition c is in a range where there is continuous sliding between the web and the impression cylinder. The amount of sliding is unpredictable and it may not be uniform.

Web Tracking

Even though a press may be aligned perfectly it is possible to have forces exist that will affect the tracking of the web through the press. Fig. 14 shows a plan view of the web in a six unit press with nip lines 1-6. The example shows a situation where unit 3 has a different Ks value due to a different squeeze s on one side of the press. From Table 1, case 1 conditions are shown on one side of the press and case 6 on the other. If one side of a web has more tension than the other side it will stretch more and that can cause the web to steer away from the higher tension side. Fig 14. tries to show in a simplistic way, what might happen to the web under those conditions.

Blanket to blanket presses would be expected to have more problems of this kind because an uneven squeeze in a unit would produce an uneven feed rate, along the nip line, across the width of the web.

A blanket to impression cylinder press would have less of a problem because the impression cylinder is torsionally stiff and would inhibit an uneven feed rate across the web by means of friction between the web and the impression cylinder.

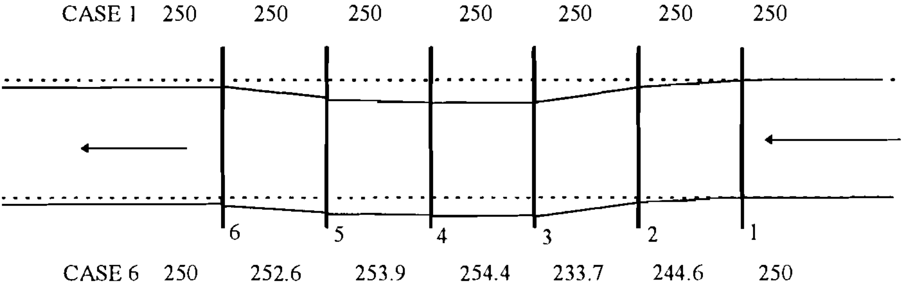

Fig. 14 Web Tracking Through Press

Print Length

A print length is a length, in the machine direction, from one point on a print repeat to another point on the same print repeat. A print length relative to the print repeat length is a ratio that is a constant, for a given set up of the press. It also happens to be the same ratio as the length between the same points, on the surface of the plate cylinder to the circumference of the plate cylinder. This means that any measure or specification of print length must take into account the print repeat length.

Print Register and Fit

Web tension conditions in the press have a great affect on print register and fit. Infeed tensions must be constant. Variations in infeed tensions will cause transient print repeat lengths in the units that will not match exactly, producing print register errors. Large tension differences between units must be avoided because this will cause less stable feed rates in a unit that has a high shear force acting on its blanket. The result will be random register error oscillations.

If tension differences are high enough there may be a discontinuous feed rate on each impression cycle, as the tension builds slowly and then drops quickly as the web is suddenly pulled through the nip, as the blanket gap arrives there. Discontinuous feed rates will affect the print length / print repeat length ratio and that means the print fit will be affected.

When a web in the press is stretched, the result is also a reduction in its width. Units on the same press that have higher web tensions feeding into them will print wider than units that have lower tension . This can cause fit problems across the web.

Squeeze settings must be even so the print unit has an even feed rate across the web. Uneven feed rates across the web can cause web tracking problems and side register errors. Skewed registration, where the image on one side of the web leads the other, can also result.

Conclusions

Even though the general analysis required mathematical calculations and press testing to develop, it demonstrates very practical concepts. The analysis confirms what printers have always regarded as good trade practices, that carefully setting blanket heights, using blankets of the same make and batch, and careful setting of impression squeeze, helps insure good printing and registration performance.

Printing operations that are sensitive to print repeat length, can see that there are only a few parameters that affect print repeat length. Adjusting infeed tension is a simple way to trim the print repeat length of a press. Knowing the operating limits of a press can help avoid problems in trying to run a condition that is outside its limits.

A better understanding of the web tension conditions should help designers of related control systems and press manufacturers. Computer simulations of web tension conditions can apply blanket characteristics to give a more accurate prediction of press and control performance.

Blanket manufacturers can design blankets to optimize blanket characteristics. A flatter Ks curve would mean a blanket less sensitive to errors in setting squeeze. That means better tracking and register performance.

It is hoped that the analysis will be a practical tool that will eventually help printers, print with less problems.

APPENDIX A

Test Method for Determining EA with Test Results

The EA value can be determined as a single value by the following procedure.

-First look at the following relationships:

$$\sigma / \varepsilon = E$$
$$\sigma = F / A = T / A$$
$$EA = T / \varepsilon$$
$$\varepsilon = e / L$$

$$(EA) = T\,L / e \qquad (16)$$

-Take a sample length L.
-Stretch it with a tension T.
-Measure the elongation e.
-Keep the value of e / L to less than 0.0025 so that the sample stays in the elastic range.
-Calculate (EA) as one value.
-The results below are related to a full web that was stretched and measured. If possible, it is recommended to test full webs.
-If a small sample is tested then the (EA) sample value must be adjusted to the full web width value.

(EA) = [(EA) sample] x (full web width) / (sample width)

Test Results

$$e = 37.5 \text{ mm}$$

$$L = 19900 \text{ mm}$$

$$T = 350 \text{ DAN}$$ (DAN decanewton)

$$EA = T\,L / e = 350\,(19900) / 37.5$$

$$EA = 186000 \text{ DAN}$$

APPENDIX B

Test Method for Determining Ks with Test Results

Test Method

-Set up the press for the test
-Print with only one print unit. All other units have impressions off.
-Set infeed tension (just before print unit) to tension Tin.

-Measure blanket over bearer dimension d and calculate the blanket cylinder diameter D. Fig. 2.

-Set the squeeze s .

-Run the press at about 60 meters / min. and start printing at that one print unit only.

-Set the pull through tension Tout (just after the print unit) to equal the infeed tension. Tout = Tin

-Wait for the press to settle. Flag the material that samples can be taken from.

-Stop the press.

-Collect at least 4 samples and measure the repeat length on a flat table (T = 0) to an accuracy of +/- 0.1 mm.

-Calculate Ks using the following equation: Eq. (11)

$$Ks(s) = [Lp\,(1 + T/EA)\,IR\,] / \pi D \tag{11}$$

		units	
print repeat length	Lp	mm	
web tension	T	DAN	(DAN decanewtons)
	EA	DAN	
blanket diameter	D	mm	
	Ks	dimensionless	
impression ratio	IR	dimensionless	

-Average the values of Ks(s) calculated for each sample. That average value of Ks(s) will be used as the value of Ks(s).

-Repeat the test for other values of s .

-Plot Ks(s) vs the values for squeeze s .

Test Results

Blanket Diameter D = 312.1152 mm
IR = 1.00117
Squeeze = 0.15 mm to 0.30 mm range
Blanket - Grace Polycell
Web - EA = 186000 DAN
Tin = Tout = 250 DAN

Table 2

s	Ks average
0.15	1.00184
0.20	1.00202
0.25	1.00180
0.30	1.00119

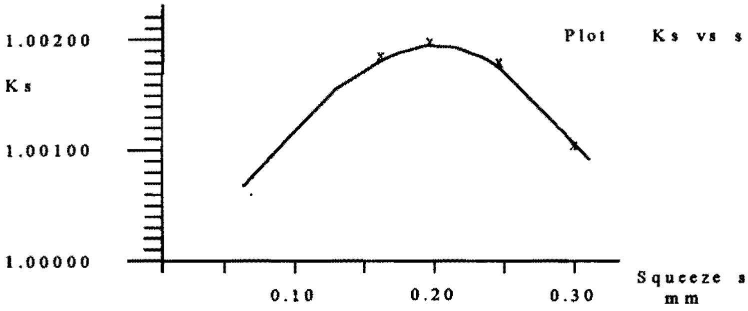

Fig. 15 Plot Ks(s) vs Squeeze s

APPENDIX C

Test Method for Determining Kt with Test Results

The test to determine Kt is similar to the test to determine Ks in that it uses only one print unit. All other units have impressions off.

The Ks value for this test will be the value that was determined using the value of s used for normal printing. There maybe a different set of values for different Ks values but it was not practical to investigate them. Therefore Ks will be assumed to be a constant.

Test Method

-Set up the press for the test.
    -Use one printing unit only.
    -Determine blanket diameter D .
    -Set squeeze s .
-Run the press at about 60 meters / min. and print with one unit.
-Set tension before print unit to Tin.
-Set tension after print unit to Tout where Tout = Tin + 40 DAN
-Wait for press to settle and flag test material for GROUP 1.
-Set tension after print unit to Tout where Tout = Tin - 40 DAN
-Wait for press to settle and flag test material for GROUP 2.
-Measure and average several print repeat length values Lp for each group.
-Calculate Kt for each group.

$$Kt = [Lp\ (1 + T(n) / EA)\ IR - Ks] / \pi D\ [T(n+1) - T(n)] \qquad (14)$$

Test Results

Blanket - Grace Polycell Ks = 1.00202
IR = 1.00117
D = 312.1152 mm
s = 0.20 mm
Web - EA = 186000 DAN

Table 3

ΔT	T(n)	T(n+1)	Lp (average)	Kt
-40	250	210	979.8	0.0000065
+40	250	290	980.2	0.0000037

The value of Kt is more variable than Ks and there seems to be a bias when ΔT is positive or negative. Other tests had shown different or no bias in Kt and it is assumed that there is more random variation in this value. Therefore an average of Kt is used in the belief that the relative magnitude is more important.

Therefore: $Kt = 0.0000051 = 5.1 \times 10^{-6}$

APPENDIX D

This program was written using Qbasic. The purpose of the program is to determine tension values T(2 to 6) of a six unit offset press. The program is based on the fact that the print repeat length Lp of all units must be equal. After initial values and special values are set, calculations of Lp(1 to 6) is done. All Lp values must be equal within a specified tolerance TOL The program uses an iterative approach and modifies the tension values T(2 to 6) with a convenient modifier [LP(JJ) - LP(1)] and recalculates Lp values until the TOL condition is met. The tension values T(2 to 6) have then been determined.

Setting constant values

```
CLS
60 TOL = 0.001
65 PI = 3.141593
70 IR = 1.00117
```

Initializing standard values

```
200 FOR I = 1 TO 6
300 KS(I) = 1.00202
320 T(I) = 250
340 KT(I) = 5.1 * 10 ^ -6
360 D(I) = 312.1152
```

```
400 NEXT
```

Setting special values for investigation

```
402 KS(3) = 1.00202
403 EA = 186000
404 T(7) = 250
405 D(3) = 312.1152
```

Resetting KKT counter, calculating LP(1 to 6)

```
410 KKT = 0
420 FOR K = 1 TO 6
430 LP(K) = PI * D(K) * (KS(K) + KT(K) * (T(K + 1) - T(K))) / ((1 + T(K) / EA * IR)
450 NEXT
```

Conditional check for TOL

```
460 FOR JJ = 2 TO 6
470 IF ABS(LP(JJ) - LP(1)) < TOL THEN KKT = KKT + 1
480 NEXT
```

If KKT counter is 5 then print (line 500)

```
490 IF KKT = 5 THEN 500
```

If KKT counter is not 5 then modify tension values T(2 to 6)

```
491 FOR JJ = 2 TO 6
492 T(JJ) = T(JJ) + (LP(JJ) - LP(1))
494 NEXT
```

Go to line 410 and recalculate Lp values.

```
496 GOTO 410

500 FOR J = 1 TO 6
600 PRINT J, T(J), LP(J)
700 NEXT
710 PRINT “  7     “, T(7)
711 PRINT “  EA=“; EA, “D(3)=“; “KT =“; KT(1), “KS(3)=“; KS(3)
800 END
```