A STEADY STATE INKING SYSTEM MODEL FOR PREDICTING INK FILM THICKNESS DISTRIBUTION

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Abstract:

A model which calculates the steady state ink film thickness distribution in an inking system as a function of plate coverage has been developed. The method uses inversion of a matrix representing volume continuity of ink within a roller distribution. It is based on an ink split at each nip and incorporates the effect of plate coverage on the transfer. Along with the thickness distribution, the amount of ink contributed to the plate by each form roll and principal ghost magnitudes have been calculated. Model predictions assuming a 50/50 ink split can be used as criteria to categorize different conventional inker styles. In some further simulations, the split ratios at various nips were deviated from 50/50 and the resulting distributions have been included with possible implications sighted.

Based on the assumptions, results show that thickness distribution is highly dependent on coverage as is the amount of ink contribution by each form roll to the plate and ghosting characteristics. In the theoretical limit of zero coverage, all conventional inkers with the same number of form rolls and the same split ratios at the form roll/plate cylinder nip have the same contribution factors. The effect of coverage on the magnitude of the film thickness gradient in the roller train can be seen as a possible factor in lateral ink flow. Varying the split ratio from 50/50 showed that given the same inker configuration, strikingly diverse results can be generated.

Background:

It is generally a common practice to solve a set of simultaneous continuity equations for an ink train to

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determine the amount of ink put down by each ink form roll at uniform (100 percent) coverage. These numbers will subsequently be referred to as ink flow ratios. Very few studies, however, have addressed the effect of printed coverage on these values. Coverage also affects relative ink thickness in the inker as well as nominal principal ghost magnitudes, where a ghost is defined as the repeat of a previously printed image one form roll revolution later and is illustrated in Figure 2a). Considering that an extremely small percentage of printed matter is solid coverage, it seems logical to examine the effect coverage may have on these values.

Regarding split ratio, here defined as the percentage of ink film into the nip which splits onto the specified roll, the 50/50 value is used as the traditional standard for calculations. Several authors, however, Bradford (1954), Mill (1961), Wirz (1964) and others have suggested values other than 50/50, specifically when the two rolls forming the nip have different physical characteristics. The basic premise seems to be that on the average the effect of the split evens out to 50/50. Some representative simulations have shown that the effect of changing the splits on the thickness distribution, and thus, ink flow ratios and ghosting may be larger than expected.

The Model:

To facilitate the analysis, a digital computer program was developed to solve a set of simultaneous equations to obtain ink film thicknesses using simple matrix inversion. The data required is a coefficient matrix of the continuity equations at each nip in the inker. The program is run for various coverages by modifying the equations describing ink transfer at the form/plate nip. Outputs consist of average ink film thickness values versus coverage on each segment between nips in numerical and graphical form, along with ink flow ratios and ghosting magnitudes. A simple set of equations and the variables defined by the method are included in Figure 1, which also illustrates the outputs with some examples.

Model Assumptions:

- The inkers used in the simulations are of the offset type. A thickness of one unit is assumed on the paper with the other thicknesses related to this reference.

- Conservation of volume flow is satisfied by the system of equations. The ink supply is continuous with all the input transferred to the system. Therefore, Volume in = Volume out = Coverage * Print thickness.

- In steady state the values are independent of time and distance between nips. Therefore, volume flow can be replaced by thickness. These thickness values are defined on unique segments as an average thickness between each two nips. On the plate, blanket and paper, the value is defined as the average thickness on the image areas.

- Ink transfer occurs via a specified ink split. At the form/plate nip, this split occurs in the image or coverage areas with no ink transfer in the non-image areas. The output from the plate nip on the form roll is a weighted average of these two conditions. (Figure 1a) thickness T5)

- Coverage is effectively represented by a continuous screen value, therefore the effect of the layout of a form cannot be investigated. There is no coupling laterally between coverages; relationships are strictly for longitudinal ink travel down the roller train.

- At theoretical zero coverage, the inker will reach equilibrium, but it must still allow the form rolls to supply the correct ink thickness to the plate. The term zero+ coverage will be used to suggest the printing of a single dot.

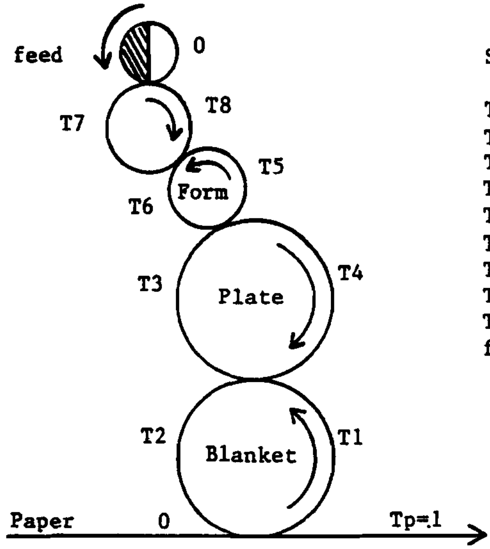
Computer Program Outputs:

The matrix inversion generates the ink film thickness on all the segments in the inker for every 10 percent increment of plate coverage from zero to 100 percent. Figure 1b) represents a typical ink distribution output and the interpretation is illustrated in Figures 1c), d) and e) for zero+, 50 per cent and 100 percent coverage, respectively. From the thickness values, calculations are made of the ink flow ratios and principal ghosting magnitudes, assuming all the form rollers are commensurate.

The ghosting calculations are based on those done by Hull (1968) but modified for use with form rolls having

FIGURE 1 - Steady State Model Setup

a) Distribution

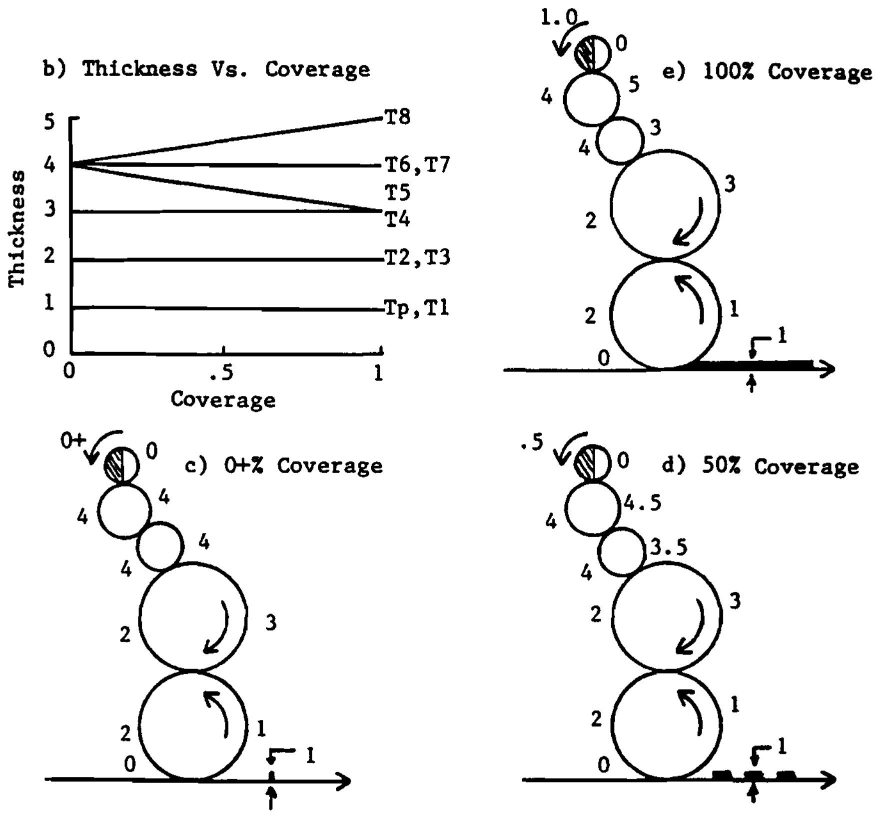


Steady State Continuity Equations

Tp = Sp*(T2+0)
T1 = S1*(T2+0)
T2 = S2*(T1+T4)
T3 = S3*(T1+T4)
T4 = S4*(T3+T6)
T5 = C*S5*(T3+T6)+(1-C)*T6
T6 = S6*(T5+T8)
T7 = S7*(T5+T8)
T8 = T7 + feed
feed = C*Tp

where

C = Fractional Coverage
S = Split Fraction



the same diameters, which requires incorporation of the already existing ghost. The value presented is the sum of the ghost contribution produced by each form roll as a percent of the printed thickness. The individual ghosts are generated from the reduction of the excess ink thickness produced by a non-image area in the plate nip, as it splits in the appropriate ratio at each subsequent nip through which it passes. In this analysis, which is illustrated in Figure 2, all the form rolls are assumed to have the same diameter, this being the worst case. Use of incommensurate rolls reduces the magnitude of the variation since the individual ghosts would occur in different locations and thus not superimpose on each other.

Simulations:

To examine the effect plate coverage, inker configuration and split ratios can have on ink distribution, several test cases were simulated using the computer model. Figures 3a) and 4a) show two typical configurations for a webfed offset press. The first configuration is referred to as a first-down inker, and the other, a second-down inker. The notation refers to the ink form roll which is supplied with the most direct flow of ink. These two inkers will be used to illustrate differences due to configuration and plate coverage. Figures a) through f) of Appendix I are more generic inkers than the first two, and contain either two, three or four ink form rollers, again in this first-down or second-down configuration. The effect of the number of form rolls will be investigated from these.

Several different simulations were run to examine the effect of split ratio on the distribution. The assumptions were based on inferences drawn from literature which suggest that it is possible that physical differences between the two rolls forming the nip may affect splitting parameters. The location of interfaces of this type are typically at a soft rubber roll/hard vibrator (oscillating) roll nip and at the ink form roll/plate cylinder nip. Using only the three form roll inker configuration, the split ratios were varied in both directions as 60/40 or 40/60 at the vibrator/rubber nips, as 60/40 or 40/60 at the inker form/plate nips, and in two combined cases of 60 vibrator/40 rubber with 60 form/40 plate and 60 vibrator/ 40 rubber with 40 form/60 plate. The significance of this 60/40 split is partially for effect, however, several early studies on ink transfer [Bradford (1954), Mill (1961),

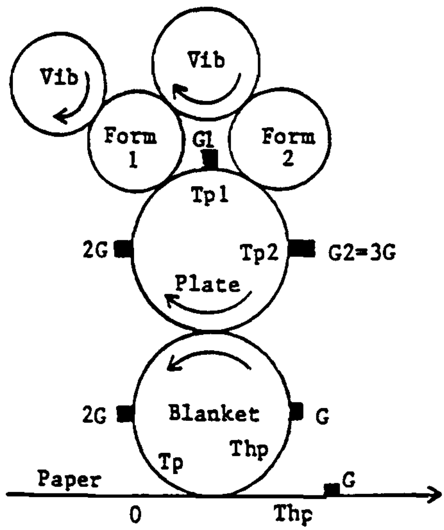
FIGURE 2: GHOSTING DERIVATION

a) Ghosting Definition

non-image passes under form

ghost formed on plate one form roll turn later

b) Calculation of Principal Ghosts



T - Nominal Thickness

G - Additional Thickness from Ghost

N - Number of Vib/Form Nips

Sv - Vib/Form Split Factor

Sp - Form/Plate Split Factor

Commensurate Form Rolls:

$$G1 = Sp*((Tp1-Tp)*Sv^{N1}+2G)$$

$$G2 = Sp*((Tp2-Tp1)*Sv^{N2}+G1)$$

$$\% \text{ Ghost} = \frac{G}{Thp} * 100$$

Typical Calculation:

2 Form Roll Inker
1st-Down 50/50 Splits
Zero+ Coverage

Thp = 1	Sv = 1/2
Tp = 2	Sp = 1/2
Tp1 = 2-2/3	N1 = 2
Tp2 = 3	N2 = 1

$$G1 = G + \frac{1}{12}$$

$$G2 = \frac{G}{2} + \frac{1}{8} = 3G$$

therefore:

$$G = \frac{1}{20}$$

% Ghost = 5.0%

Wirz (1964)] report a deviation of this magnitude may not be unreasonable. Variations in split ratio at the plate/ blanket nip or the blanket/paper nip only affect net flow through the inker, and thus, are not included.

Discussion:

Figures 3 and 4 show the two configurations and graphical results of the simulations. Parts b) and c) of these figures are plots of ink film thicknesses on the individual segments between nips versus plate coverage, while parts d) are plots of the ink flow ratios versus coverage. Some other pertinent data is contained in the first two columns of Table I. These simulations were run with 50/50 split ratios at all nips and assuming a film thickness of one unit on the paper.

With examination of the overall ink film distributions, one can see in both cases that as coverage increases, the ink thickness increases linearly in the tail of the inker near the ink feed, i.e., the thicknesses referred to by letters a though d (or e) of Figures 3a) and 4a). Specifically, for each additional nip the film thickness increases by the quantity of print thickness multiplied by coverage.

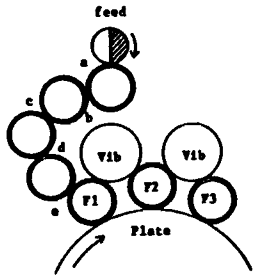
Once the flow path begins to branch off in the oscillating roll/form roll area, we see the effect of the differences between the two configurations. The thickness profiles on the vibrator and form rolls are expanded in parts c of Figures 3 & 4. Note particularly the overall distribution and shape of these curves. For the first-down inker, these thicknesses are not greatly affected by coverage, and the maximum and minimum thicknesses occur at intermediate coverages. The thicknesses for the 2nd-down inker in this region vary essentially linearly with coverage with the maximum spread at solid coverage. In both styles, we see that not all the thicknesses in the roll train increase as coverage, and thus the net ink flow through the train, increases.

The range of ink thicknesses due to coverage near the ink feed may give an indication as to how tolerant the inker is to changes in the ink supply. Inferences could also be drawn relating the thickness gradients to ink capacity and time response of the system. Since the coverage for a printed form varies across the press, this would suggest that the distributions will also have an effect on lateral variation in an inker. For a first-

Figure 3:

3 Form Roll Inker
1st Down (Long)

a) Inker Roll
Configuration



b) Ink Thickness Distribution

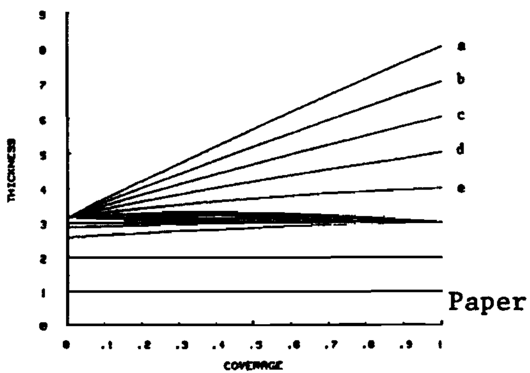
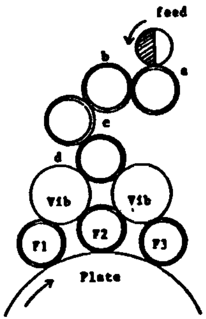


Figure 4:

3 Form Roll Inker
2nd Down (Long)

a) Inker Roll
Configuration



b) Ink Thickness Distribution

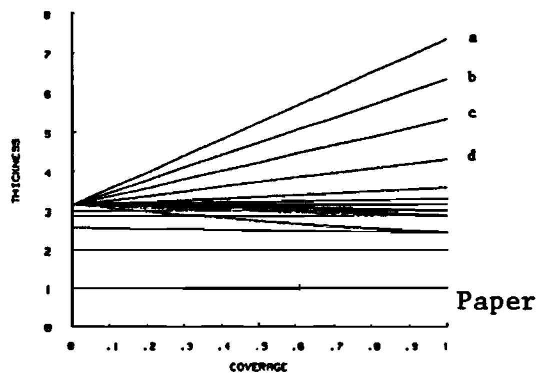
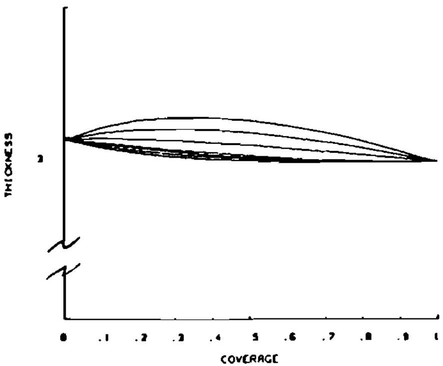


Figure 3: 3 Form Roll Inker
1st Down (Long)

c) Form and Vibrator Thicknesses



d) Ink Flow Ratio Vs. Coverage

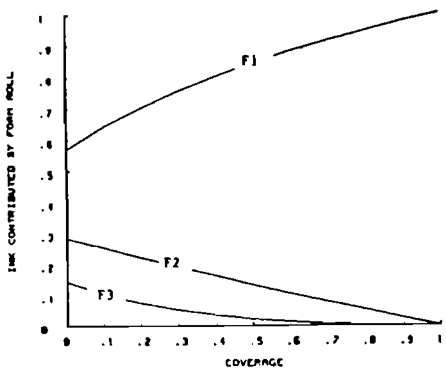
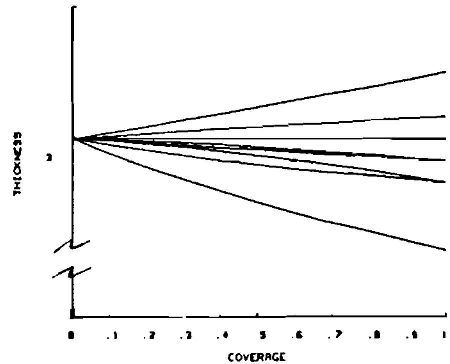
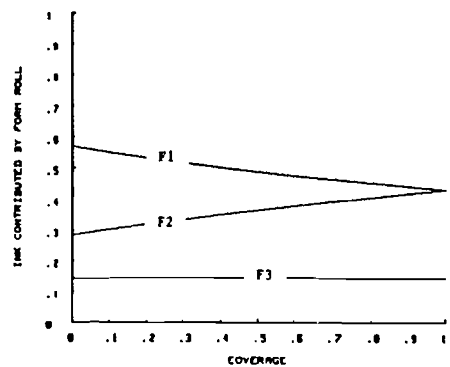


Figure 4: 3 Form Roll Inker
2nd Down (Long)

c) Form and Vibrator Thicknesses



d) Ink Flow Ratio Vs. Coverage



down inker, the difference in thickness between adjacent rolls decreases from supply to plate for all coverages. The second-down inker follows a similar trend, however is much more dependent on coverage. Comparisons between the two inker styles regarding sensitivity to lateral variations caused by lateral print layout could possibly be extrapolated from this.

Parts d show the effect plate coverage has on the ink flow ratios. At 100 percent coverage, the first-down inker, as the reference would suggest, has 100 percent of the ink contribution from the first form roll. The second-down inker (as configured here) has ink forms one and two contributing the same percentage of ink, with the third adding the remainder. As the coverage decreases, the contributions change quite significantly and at zero+ coverage, the two inkers have reverted to the same ink flow ratios. This is an expected result since at the limit of zero coverage, the inker becomes a closed system. It must still, however, maintain the correct thickness needed on a single dot.

The fact that the film thicknesses change with coverage also affects principle ghost magnitude values. Referring to Table I, the first-down inker shows about a two to one change over the coverage range with the larger values at lower coverage. The coverage effect on coverage for the second-down inker is not as prominent, however, the magnitudes are larger than the first-down case. The change in ghosting with coverage appears to be related to the coverage effect on ink flow ratios. Also, it is possible to configure the inker such that the ghosting magnitude is the same at zero+ coverage for the first-down and second-down versions.

The remaining information contained in Table I applies to the configurations and distributions of Appendix I with varying numbers of ink form rolls. From these, we can generalize regarding distribution patterns and ink flow ratios. All the first-down inkers have the same pattern in the form roll region where the thickness is not strongly affected by coverage as described earlier. The second-down inkers show an essentially linear variation in this region with coverage. For ink flow ratios, we see that for each set of inkers with the same number of form rollers, the same flow ratios are reached at zero+ coverage.

TABLE I: SUMMARY FOR COMPARISON OF INKER STYLE AND NUMBER OF FORM ROLLS
ALL WITH 50/50 SPLIT RATIOS

CONFIGURATION		3 FORMS 1ST DOWN LONG TAIL	3 FORMS 2ND DOWN LONG TAIL	2 FORMS 1ST DOWN	2 FORMS 2ND DOWN	3 FORMS 1ST DOWN	3 FORMS 2ND DOWN	4 FORMS 1ST DOWN	4 FORMS 2ND DOWN
INK FLOW RATIOS	@ 100% Cov.	100-0-0	43-43-14	100-0	50-50	100-0-0	43-43-14	100-0-0-0	43-43-14-0
	@ 0% Cov.	57-29-14	57-29-14	67-33	67-33	57-29-14	57-29-14	53-27-13-7	53-27-13-7
* THICKNESS NEAREST INK FEED	@ 100% COV.	8.0	7.29	5.0	5.0	5.0	4.29	5.0	4.29
	@ 0% COV.	3.14	3.14	3.33	3.33	3.14	3.14	3.07	3.07
PRINCIPAL GHOSTING MAGNITUDES	@ 100% COV.	1.14	3.24	2.50	7.50	1.14	3.24	0.54	1.24
	@ 0% COV.	2.60	3.25	5.00	6.66	2.60	3.25	1.48	1.78
COMMENTS			MAX GHOST 3.27 @ 50% COVERAGE				MAX GHOST 3.27 @ 50% COVERAGE		

* WITH ONE UNIT OF THICKNESS ON THE PAPER

For each successive addition of a form roll, examination of the ghosting values shows that the ghosting magnitude reduces by the split ratio at this new plate nip, which for these cases was one-half. This is a much known fact in the industry as more form rolls generally suggest higher quality such that common newspaper web presses use two forms, commercial web presses use three and sheetfeds use four ink forms. For ghosting, the first-down inkers have smaller ghosting values compared to the second-down inker but are more affected by coverage with the smallest ghost at solid coverage. For the second-down inkers, ghosting compared to coverage follows no particular trends.

The three form roll configurations were also used in simulations to analyze the effect of having split ratios other than 50/50. Summaries of pertinent data are contained in Tables IIa) and IIb), and the ink distribution graphs comprise Appendix II. The 50/50 split case is repeated for reference.

We see that the first-down inker always has a 100-0-0 ink flow ratio at 100 percent coverage, regardless of the split. The ink flow ratio for the second-down inker, however, depend somewhat upon all the split ratio combinations in the inker. At zero+ coverage, though, the ink flow ratios appear to be only a function of the split ratio at the form roll/plate cylinder nip. This further specifies the statement made earlier. At zero+ coverage, all inkers with the same number of ink form rolls and the same form/plate split factors tend toward the same ink flow ratio. Also note that the contribution from each form roll tends to equilibrate as less ink is transferred to the plate due to the split ratio.

There are several cases where the thickness on certain groups of rolls vary significantly from the surrounding rolls. For the 60 vibrator/40 rubber case, the thickness on the vibrator roll is sometimes greater than the thickness at the ink feed where one would expect the maximum thickness. On the other hand, for the 40 form/60 plate case, the thicknesses on the plate are greater than in the inker train.

Ghosting magnitudes vary substantially with split ratio, especially for the form/plate split. Note the large magnitudes for the 60 form/40 plate case and the negative values for the 40 form/60 plate case. Negative

TABLE IIa: 3 FORM ROLL INKERS - 1ST DOWN
SUMMARY FOR INKER COMPARISONS WITH SPLIT RATIOS

CONFIGURATION (SPLITS & LOCATION)		50/50 SPLITS	60 VIB / 40 RUBBER	40 VIB / 60 RUBBER	60 FORM / 40 PLATE	40 FORM / 60 PLATE	60 VIB / 40 RUBBER / 60 FORM / 40 PLATE	60 VIB / 40 RUBBER / 40 FORM / 60 PLATE
INK FLOW RATIOS	@ 100% Cov.	100-0-0	100-0-0	100-0-0	100-0-0	100-0-0	100-0-0	100-0-0
	@ 0% Cov.	57-29-14	57-29-14	57-29-14	64-26-10	51-31-18	64-26-10	51-31-18
* THICKNESS NEAREST INK FEED	@ 100% COV.	5.0	5.0	5.0	6.50	4.0	6.50	4.0
	@ 0% COV.	3.14	3.14	3.14	4.60	2.18	4.60	2.18
PRINCIPAL GHOSTING MAGNITUDES	@ 100% COV.	1.14	0.91	1.36	8.69	-5.23	6.75	-3.96
	@ 0% COV.	2.60	1.97	3.27	9.63	-3.26	7.44	-2.53
COMMENTS			MAX FILM @ 0% COV ON VIBES 4.71			MAX FILM ON OUTPUT OF PLATE @ 0% COV 3.00	MAX FILM ON VIBES 6.75 @ 100% 6.90 @ 0%	MAX FILM @ 0% COV ON VIBES 3.28

* WITH ONE UNIT OF THICKNESS ON THE PAPER

TABLE IIb: 3 FORM ROLL INKERS - 2ND DOWN
SUMMARY FOR INKER COMPARISONS WITH SPLIT RATIOS

CONFIGURATION (SPLITS & LOCATION)		50/50 SPLITS	60 VIB / 40 RUBBER	40 VIB / 60 RUBBER	60 FORM / 40 PLATE	40 FORM / 60 PLATE	60 VIB / 40 RUBBER / 60 FORM / 40 PLATE	60 VIB / 40 RUBBER / 40 FORM / 60 PLATE
INK FLOW RATIOS	@ 100% Cov.	43-43-14	48-40-12	37-46-17	49-39-12	38-45-17	55-36-9	43-43-14
	@ 0% Cov.	57-29-14	57-29-14	57-29-14	64-26-10	51-31-18	64-26-10	51-31-18
* THICKNESS NEAREST INK FEED	@ 100% COV.	4.29	4.20	4.44	5.73	3.34	5.65	3.24
	@ 0% COV.	3.14	3.14	3.14	4.60	2.18	4.60	2.18
PRINCIPAL GHOSTING MAGNITUDES	@ 100% COV.	3.24	2.32	4.42	10.57	-3.20	8.05	-2.69
	@ 0% COV.	3.25	2.49	4.05	10.50	-3.11	8.14	-2.41
COMMENTS		MAX GHOST 3.27 @ 50% COVERAGE	MAX FILM ON VIBE 5.12 @ 100% 4.71 @ 0%			MAX FILM @ 0% ON OUTPUT OF PLATE 3.00	MAX FILM ON VIBES 7.32 @ 100% 6.90 @ 0%	MAX FILM ON VIBES 3.79 @ 100% 3.28 @ 0%

* WITH ONE UNIT OF THICKNESS ON THE PAPER

ghosting here means the repeat of the image would print lighter than its surroundings, instead of darker. The same trends still hold as for 50/50 splits with the second-down inker having larger ghosts yet being less affected by coverage as compared to the first-down inker style.

For the two composite cases, where the splits were varied both at the vibrator/rubber and form/plate nips, it can be seen that the values in the tables generally fall between those of the two individual cases, where the splits were only varied at one type of interface. For both composite cases, the results were closer to those of the individual case having the same form/plate ratio suggesting this nip to have the stronger affect. Superimposing the effects of several separate cases is not advisable. Comparing to the 50/50 case, having previously assumed that if the splits averaged to 50/50 so would the overall effects on the inker, this does not appear to have occurred. The only similar values are the ink flow ratios for the first-down case, which were found to be independent of split. The ink flow ratio for second-down inker with splits of 60 vibrator/40 rubber, 40 form/60 plate was also the same as the 50/50 value, but may be an isolated case. The point to be made here is that changes in split ratio occurring in an inker could significantly affect the character of an inker and what it prints.

Conclusion:

The major points to be summarized are that inherent differences exist between the various inker styles and the way they react to changes in plate coverage. Affected by coverage are overall ink distributions, ink flow ratios, ghosting parameters or variations in the machine direction, and most likely, variations in the lateral direction. Regarding split ratios, it can be inferred that given a group of "identical" inkers, if for whatever reason the split ratios from inker to inker vary, the difference in the printed output could be significant.

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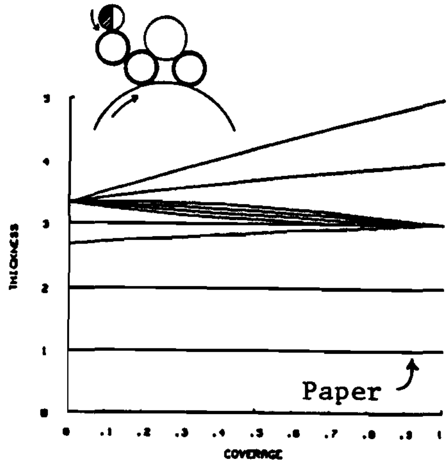
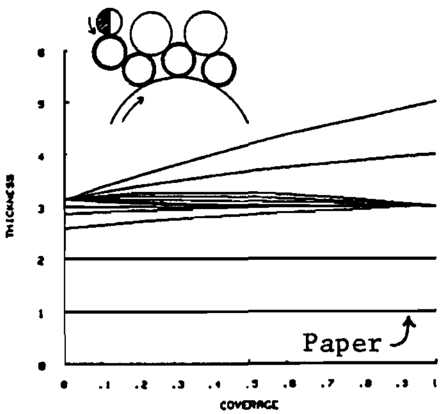
Appendix I:

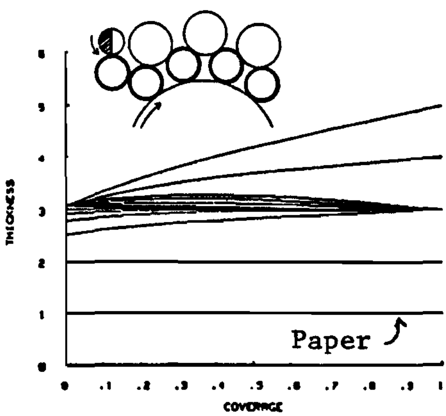
a) 2 Form Roll Inker
1st Down
Ink Thickness
Distribution



b) 3 Form Roll Inker
1st Down
Ink Thickness
Distribution

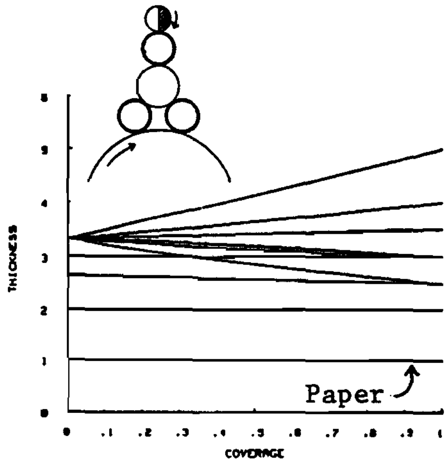


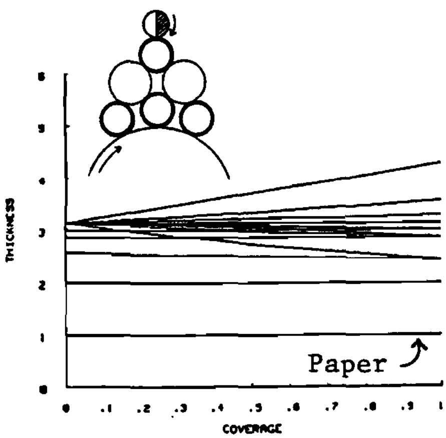
c) 4 Form Roll Inker
1st Down
Ink Thickness
Distribution



Appendix I:

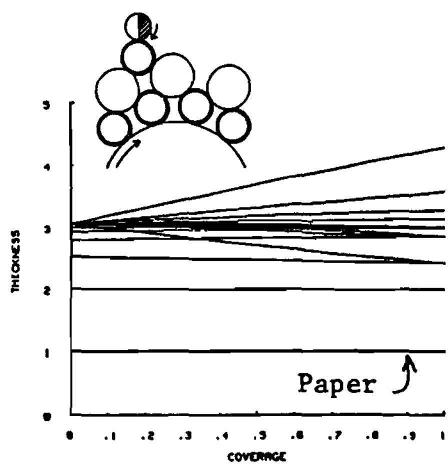
d) 2 Form Roll Inker
2nd Down
Ink Thickness
Distribution





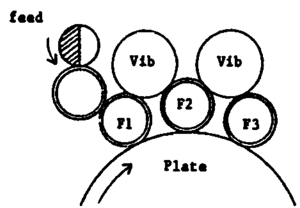
e) 3 Form Roll Inker
2nd Down
Ink Thickness
Distribution

f) 4 Form Roll Inker
2nd Down
Ink Thickness
Distribution

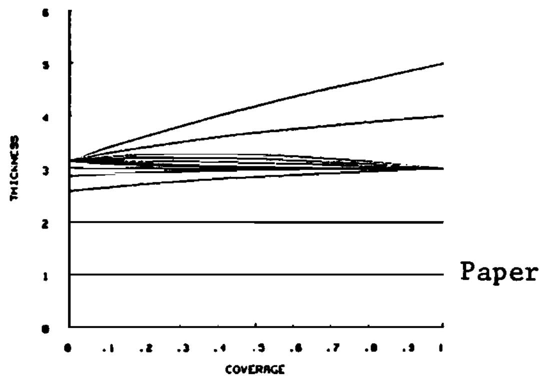


Appendix II:

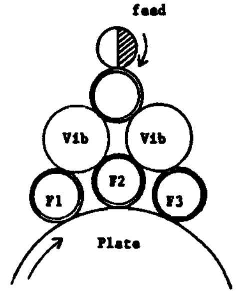
3 Form Roll Inker
1st Down



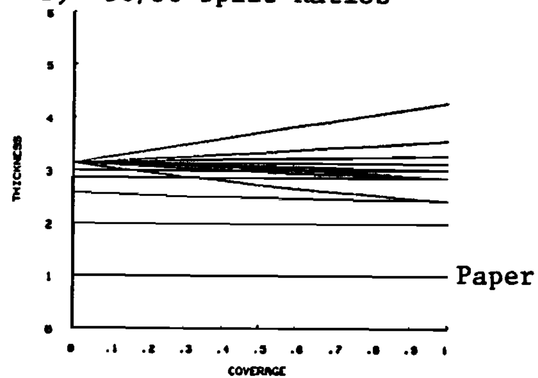
a) 50/50 Split Ratios



3 Form Roll Inker
2nd Down



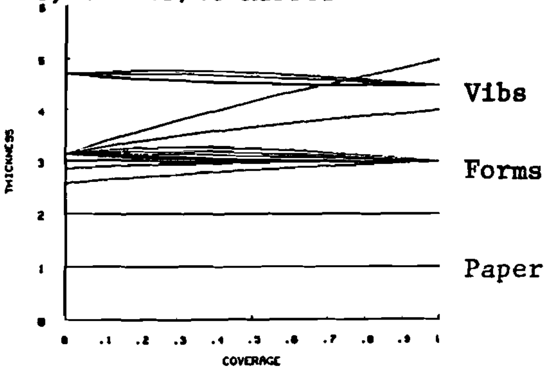
b) 50/50 Split Ratios



Appendix II: 3 Form Roll Inker

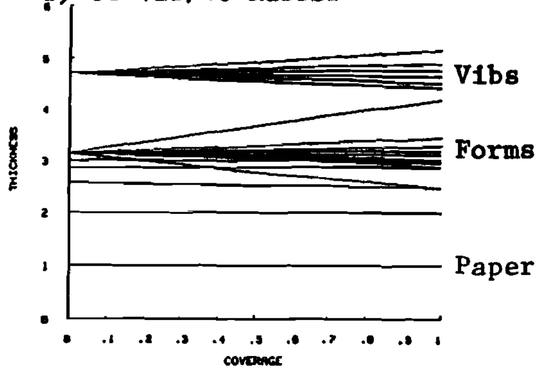
1st Down

c) 60 Vib/40 Rubber



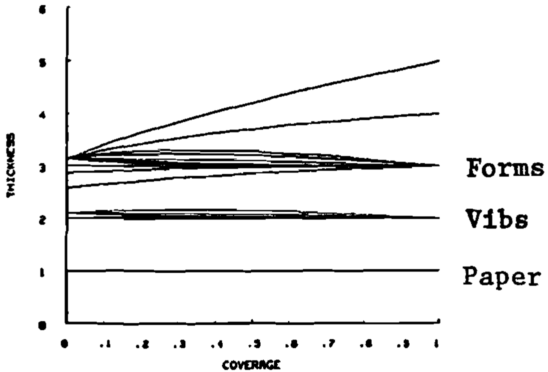
2nd Down

d) 60 Vib/40 Rubber



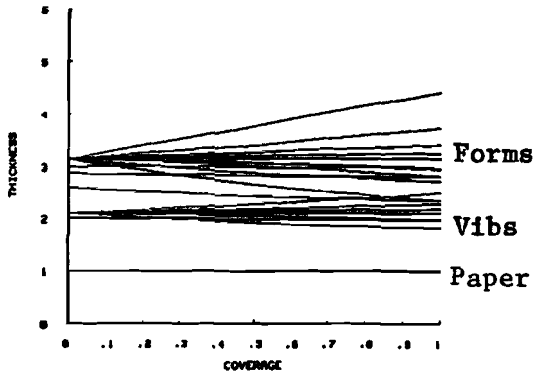
1st Down

e) 40 Vib/60 Rubber



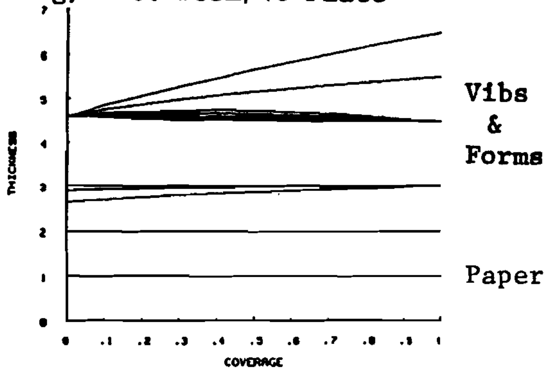
2nd Down

f) 40 Vib/60 Rubber

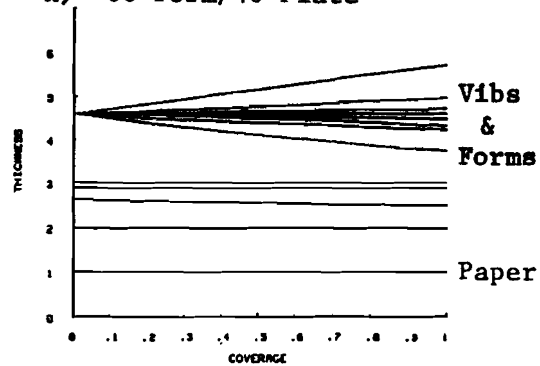


Appendix II: 3 Form Roll Inker

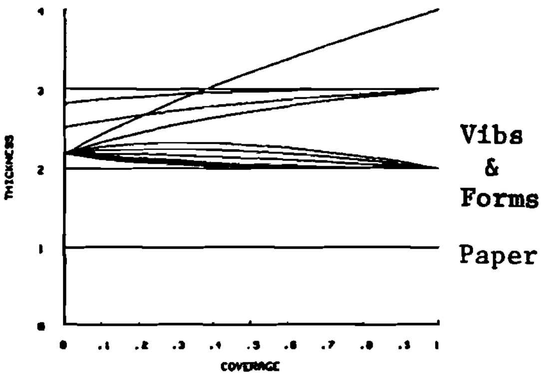
g) 1st Down
60 Form/40 Plate



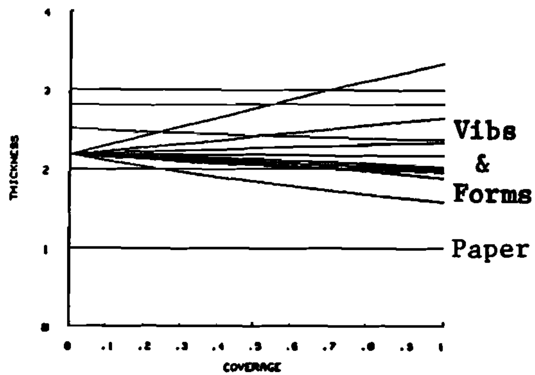
h) 2nd Down
60 Form/40 Plate



i) 1st Down
40 Form/60 Plate



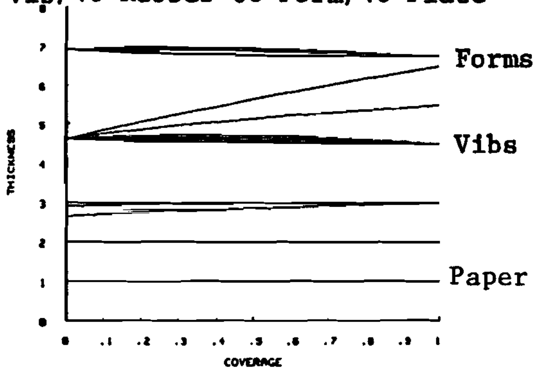
j) 2nd Down
40 Form/60 Plate



Appendix II: 3 Form Roll Inker

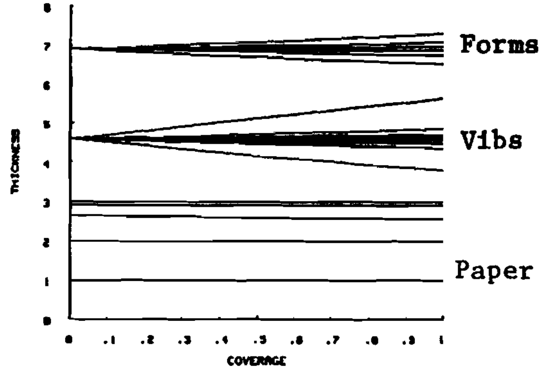
1st Down

k) 60 Vib/40 Rubber-60 Form/40 Plate



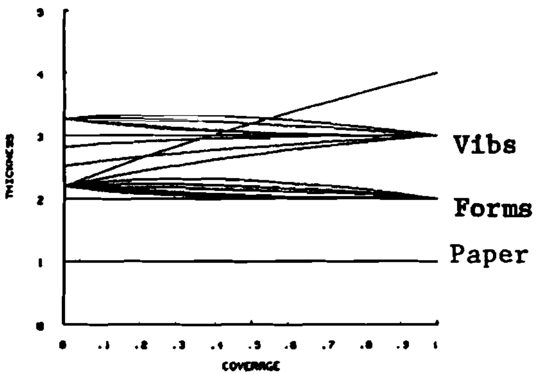
2nd Down

l) 60 Vib/40 Rubber-60 Form/40 Plate



1st Down

m) 60 Vib/40 Rubber-40 Form/60 Plate



2nd Down

n) 60 Vib/40 Rubber-40 Form/60 Plate