Application of a Dynamic Measurement Technique for the Investigation of the Causes of Dot Gain in Web Offset Lithography

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ABSTRACT

The purpose of this work is to identify the causes of dot gain in web offset lithography. To do this a system was assembled to dynamically measure, calculate, and record the individual components of dot gain (fill-in and slur) during normal operation of a web offset press. Using this system, experiments (2^4 factorial) were run to test the effect of a total of six factors on fill-in and slur. Analysis of variance of the data show that of the factors tested, solid ink density had the largest effect on fill-in and a smaller, but inverse effect on slur. A large increase in blanket packing had a surprisingly small effect on both fill-in and slur; and water amount, paper tension, press speed, the number of press units on impression and all interactions have no effect on dot gain. Fill-in is shown to be the largest component of dot gain.

INTRODUCTION

Although this work was accomplished in 1979 in conjunction with a previous effort[1], a current review of this unpublished report reveals the information generated remains appropriate for publication at this time. The literature in general reflects a considerable amount of thought and study directed toward an understanding of dot gain from several vantage points. Work by DiPauli[2], published in 1981 Taga, is a survey of some of the possible causes of dot gain on press

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with results similar to our effort. The novelty of our work is the ability to experiment and obtain results in a dynamic mode, on press, in real time. With ever increasing rate of printing production, it has long been our view that response to any change in a real time mode is necessary. In addition to the results of our dot gain investigation, we feel that the demonstration of a working, dynamic measuring apparatus that makes use of optical density as a response variable should be of interest to the printing community. This apparatus can measure a variety of responses critical to the needs of the printer, including solid ink density, slur, fill in and trapping.

OBJECTIVE

The purpose of this study is to identify those factors that affect dot gain in web offset lithography.

DOT GAIN

Dot gain is the increase in the size of the halftone dots during printing compared to their size on the film or plate. For example, a 60 percent relative dot area on the film may print a dot of 80 percent. In this case the dot gain is said to be 20 percent.

THE PROBLEM

Dot gain would not be a problem if it remained constant. The camera operator can compensate for any increase in dot size that occurs later on the press by making the film dot sizes smaller. Such adjustment is not possible because dot gain is not a constant but changes from run-to-run and can also vary between press units on multicolor presses. Unexpected variation between press units can cause color imbalance in color reproduction, which, if severe enough, cannot be compensated for by changes in inking. The result can range from poor to unacceptable quality with the inevitable complaints and problems between the buyer of printing and the printer.

The quality of black-and-white printing can also suffer from the effects of unexpected variations in dot gain. Figure 1 shows two actual plate-press curves (darkness of reproduction versus percent dot area of the halftone film) obtained during routine black-and-white printing on our web press for two different issues of the RIT Reporter, the Institute magazine. Although both press runs were printed at the same solid ink density, the upper curve shows the effect of significantly greater dot gain. If the lower curve represents a good reproduction, then the reproduction afflicted by greater dot gain is too dark everywhere except for the extreme highlight and shadow tones. Furthermore, the tonal separation or contrast is too large in the highlights and midtones and too little in the shadows; that is, detail has been lost in the shadows. This illustrates that large changes in dot gain can distort the tone reproduction curve even though there has been no change in the solid ink density.

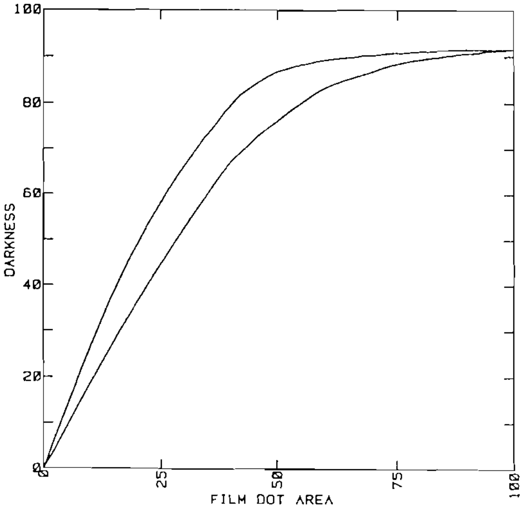


Figure 1. Plate-press curves

Advertisers publishing the same ad in different magazines often find vast and unacceptable differences in the printed results even though all the printers start from the same halftone films. A large part of this variation is due to differences in dot gain.

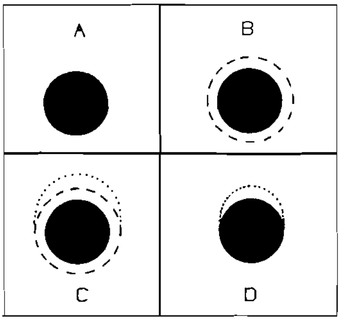
The printer is constantly faced with the increased cost of both paper and energy. The economics of this situation forces them to continue to find ways to minimize the waste of these commodities as well as waste in labor. One important way of conserving labor, energy and material while improving quality and uniformity of the product is to control unexpected changes in dot gain. To achieve such control one must first identify the factors that affect dot gain. The identification of these factors is the objective of our study. This report will describe our progress in measuring dot gain while the press is running and what has been learned from a few preliminary experiments.

COMPONENTS OF DOT GAIN

In this study dot gain is considered to consist of two components: fill-in and slur. Fill-in is the radial enlargement of the dot (Fig. 2B) while slur is defined as directional growth of the dot due to "smearing" in the direction of the moving paper through the press (Fig. 2D). We should note here that slur does not always occur in the direction of printing. In both cases the printed dot is larger than the dot on the film (Fig. 2A). Usually fill-in and slur occur at the same time so that dots will grow as in Fig. 2C. Dot gain has been split into fill-in and slur because it is likely that the corrective measures for each are different.

OVERVIEW

The experiments to identify the causes of slur and fill-in are carried out on an MGD 38-inch, four-unit web offset press at the Technical & Education Center of the Rochester Institute of Technology. A strobing densitometer has been mounted on this press to measure the densities of a test target on the moving web before it enters the folder. As these densities are measured, they are fed into a programmable calculator where



Enlarged dots showing the effects of A) no dot gain, B) fill-in only, C) fill-in and slur, D) slur only.

Figure 2.

they are used to calculate fill-in, slur and average solid ink density. These values are printed by the calculator and plotted on three graphs, respectively, as a function of impression number. The plotter is part of the system and is controlled by the calculator. The median impression number of a given cycle identifies that cycle.

The strategy for finding the causes of fill-in and slur is to run 2^4 factorial screening experiments where each of the suspected factors is run at two levels. The experiment is twice replicated.

FILL-IN AND SLUR TARGET

Figure 3 shows the target which occupies a small part of the printing form. This target must be printed so that its long side is parallel to the direction of the paper moving through the press. This is done so that each of its four patches will pass under the stationery densitometer probe. The size of each patch is 10 by 13 millimeters. The first patch is an outlined unprinted area. Paper density is subtracted from all other densities to zero the densitometer. The remaining three patches are a solid and two 150-line-per-inch line tints. In one of these

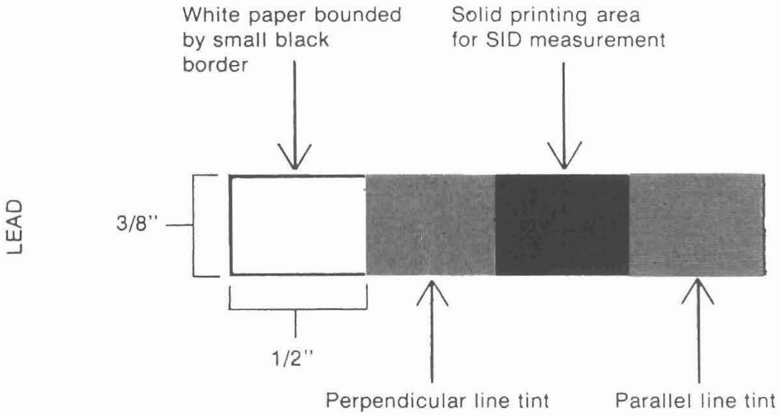


Figure 3. The test target (enlarged)

tints the lines are parallel to the direction of paper travel through the press while the lines of the other tint are perpendicular to paper travel. The width of the lines and the spaces between the lines are equal on the halftone film; i.e., they are 50 percent tints.

CALCULATION OF SLUR AND FILL-IN

Details of the calculations are given in the appendix of a previous paper(1). In the present paper we will try to provide an understanding of why and how the calculations are made without going as deeply into the mathematical details.

We can separate fill-in from slur because the optical density of the parallel patch responds only to fill-in while the perpendicular patch is affected by both fill-in and slur. To isolate slur, the response for fill-in (parallel patch) is subtracted from the combined response for fill-in/slur detected by the perpendicular patch.

The measured target optical densities are the raw data from which fill-in and slur are calculated. This is because an increase in slur and fill-in shows up as an increase in the tint densities. This density increase occurs because the lines that make up the tints become wider, thereby increasing the relative area covered by ink. The difference between line width of the print and the starting halftone film provides a numerical measure from which fill-in and slur are derived. The unit of measure will be micrometers.

The conversion of target densities to line-width difference and fill-in and slur is as follows:

1. Relative area of ink coverage for each of the tints is calculated using the tint and solid densities in the Yule-Nielsen equation(3).

2. The difference in relative area between film and print is obtained by subtracting the relative area of the film from that of the print. This is done for both tints.

3. Each difference in relative area is converted to an absolute line-width difference by multiplying it by the reciprocal of the screen ruling (in lines per inch). Multiplying this product by 25,400 gives the line-width difference in micrometers rather than inches.

4. Fill-in is the line-width difference of the parallel tint.

5. Slur is the fill-in value subtracted from the line-width difference of the perpendicular patch.

INSTRUMENTATION

As mentioned in the overview, instruments were mounted on an MGD 38-inch commercial web offset, four-unit perfecting press to measure, calculate and record fill-in, slur and solid ink density.*

The elements in this system are:

1. Hewlett-Packard 9815A programmable calculator, connected by a

2. Hewlett-Packard 98133A BCD cable to a

3. custom-built (Franz Sigg) interface which serves as a liaison between the calculator and elements 4, 5, and 6.

In addition to the calculator, the other three system elements connected to the interface are:

4. a trigger-mark detector;

5. a pulse generator which gives a pulse for every mm of web travel, and a

6. strobing RD-8015 reflection densitometer provided by the Macbeth Corporation.

Also connected to the calculator, and directed by it, is a

7. Hewlett-Packard 9872A four-pen plotter which graphs fill-in, slur and solid density vs. number of impressions.

The Macbeth RD-8015 differs from other densitometers because it can, by program command, be made to read at the right instant the density of a small patch that is moving very rapidly underneath its probe. Another advantage is that this probe operates 3mm above the moving web rather than in contact with it.

Given the distance of a patch from a reference line, the system causes the densitometer to measure that patch as it passes under the probe.

*At this point we will try to give an understanding of how these instruments perform these functions. For greater detail see Reference 1.

FIRST EXPERIMENT

We began by listing suspected causes: solid ink density, water (amount of dampening), press speed, paper tension, blanket packing (pressure), blanket types, ink tack, ink film thickness, paper characteristics and so on. Since there were so many variables to be tested, one large experiment would be unmanageable. Instead it was decided to choose groups of four variables and run a series of screening experiments to select

		Low Ink		High Ink	
		Low Water	High Water	Low Water	High Water
Low Speed	Low Tension				
	High Tension				
High Speed	Low Tension				
	High Tension				

Figure 4. 2^4 Factorial design

those variables having the greatest effect and eliminating those having little or no effect. A twice-replicated 2^4 factorial design was chosen in which every factor is run at two levels. Solid ink density, water, press speed and paper tension were selected for the first experiment. Figure 4 shows the 2^4 factorial design which results in sixteen different treatment combinations.

Numerical measures are available for only two of the four variables: solid ink density and press speed. The low and high levels of solid density were 0.8 and 1.15. The use of uncoated offset (50 pound) paper limited the high level to 1.15. Press speed was 400 ft. per min. for the low and 700 for the high. Levels of paper tension of low/19 and high/42 were set with a Martin infeed. These are not tension units but rather dial settings associated with this infeed unit. Both extremes of water setting were arrived at during the experiment while the press was running. The low setting was obtained by first decreasing the water until "ink catch-up" occurred; in other words, until the ink began to spread beyond the image area and then water amount was increased just enough to clear this condition. The process of setting the high water level starts by increasing the water until "flooding" is seen, that is, until the image area begins to repel ink which shows up as a localized but drastic drop in printed density. Once flooding occurs, the amount of water is cut back until flooding disappears.

The order of running the sixteen treatment combinations was arranged so that only the level of one factor was changed between treatment combinations. For example, if for one treatment combination all four factors were run at the low level, then, in the next treatment combination, only one of the factors will be raised to the high level. This was done to cut down on the amount of time and paper needed for the press to reach equilibrium.

For each treatment combination, the press was run until the plots of solid density, fill-in and slur indicated that equilibrium had been reached. After this, a minimum of 1000 impressions were run during which time sample sheets were collected for later measurement. Each of the sixteen treatment combinations is represented by pre- and post-equilibrium sections on the graph produced on the plotter. Only the data from the post-equilibrium section is considered representative of the treatment combination. The decision as to whether the press has reached equilibrium is made quicker and easier because the plotter continually shows the performance record as the press is running.

Additional experimental details:

1. The same test form is printed on both sides of the web using only the fourth printing unit.

2. On-press density measurements are made on the top of the web only.

3. The samples collected during the run are measured with a conventional densitometer to provide data for the bottom of the web.

Fill-in, slur and average solid density are calculated from these measurements.

4. Black ink was used (K&M CH 72 128288EH).
5. RBP dampening solution (2.5 oz/gal of water, pH 4.0) was used in a brush dampener system.
6. Reeves 714, 4-ply compressible blankets were used.
7. Dates run: First run - 8 Aug. 1978
   Second run - 24-25 Oct. 1978

RESULTS--FIRST EXPERIMENT

The data for the top and bottom of the web were each evaluated using an analysis of variance (ANOVA). For all practical purposes, the results were the same for both sides of the web. See Table I. This is a point of interest since the data for the top of the web was generated dynamically and the bottom was the result of static measurement.

Table I
Results of First Experiment
FILL-IN

	Top		Bottom	
	Avg Eff	Stat Sig	Avg Eff	Stat Sig
Ink	35	***	32	***
Water	3	NS	0	NS
Tension	1	NS	0	NS
Speed	- 6	NS	- 5	NS

SLUR

	Top		Bottom	
	Avg Eff	Stat Sig	Avg Eff	Stat Sig
Ink	-10	***	- 3	**
Water	- 2	NS	0	NS
Tension	0	NS	0	NS
Speed	2	NS	2	NS
I x W	- 2	**	0	NS

** alpha level of 0.05
*** alpha level of 0.01
NS not significant

The numbers under average effect represent the average fill-in and slur in micrometers when the factor is changed from the low to the high level. For example, eight of the treatment combinations were run at a solid density of 0.8 and the other eight at 1.15. In going from 0.8 to 1.15, the fill-in went up on the average of 35 micrometers. To judge the practical significance of these numbers, one must know how much of a change in the slur or fill-in value represents a visible change in the printed reproduction. So far this has not been experimentally determined. However, experience provides an arbitrary guide: changes of less than five micrometers will be said to have no visual significance.

The column marked "statistical significance" is used in conjunction with the average effects column in making a judgement about a given factor. This column gives the probability of whether the observed effect is due to the factor or to random chance. Depending upon the sensitivity of the experiment, it is possible for a factor to be statistically significant and yet have no practical significance whatsoever. An example of this situation is found in Table I where the ink-water interaction for slur is statistically significant but has no practical significance because a change of two micrometers has little or no visible effect on the reproduction.

The results of the ANOVA not only confirmed our suspicions but surprised us as well. It confirmed that solid ink density had a large and direct effect on fill-in; that is, fill-in increased with solid density. To our surprise we found that solid density had an inverse effect on slur; when solid density went up, slur went down. The effect was smaller but definitely there. However, the most surprising result was that none of the other three factors nor any of the interactions had any practical effect! Water, tension and speed had no effect on fill-in and slur.

SECOND EXPERIMENT

The next 2^4 experiment (singly replicated) retained solid ink density and paper tension as factors while adding blanket packing and the number of press units on impression during printing. This fourth factor was chosen because it was felt that the effect of paper tension on fill-in and slur might depend upon whether the paper was held by the previous three nips or not.

Press speed for this run was 550 ft. per min. Levels of solid density (0.8 and 1.15) and paper tension were the same as in the first experiment. For both blankets the two levels of blanket packing were 0.004 and 0.010 inch above bearers. The lower of the two is considered normal packing and was used in the first experiment. As for the fourth factor, one printing unit on impression was the low level and all four units on impression is considered the high level. All other conditions were the same as in the first experiment.

After all treatment combinations were run, a blanket packing gauge was used to check the packing. The height above bearers for the top blanket stayed at 0.010 but the bottom measured 0.005, a drop of 0.005 inch. The bottom blanket was repacked to bring it back up to 0.010 inch and the last four treatment combinations were repeated. The blankets were rechecked and this time the only change was a drop of 0.002 in the bottom blanket. The new data from the last four treatment combinations replaced the old and the analysis of variance was redone. For all practical purposes, the results were the same.

RESULTS--SECOND EXPERIMENT

Table II shows the results of the analysis of variance carried out on the data.

Table II
Results of Second Experiment

FILL-IN

	Top		Bottom	
	Avg Eff	Stat Sig	Avg Eff	Stat Sig
Packing	7	***	- 1	NS
Ink	34	***	28	***
Tension	1	NS	- 1	NS
Units	1	NS	- 2	NS

SLUR

	Top		Bottom	
	Avg Eff	Stat Sig	Avg Eff	Stat Sig
Packing	6	***	3	**
Ink	- 7	***	- 3	**
Tension	0	NS	1	NS
Units	0	NS	- 2	*
P x I	- 4	***	0	NS

* alpha level of 0.10

Again, solid ink density had the greatest effect on fill-in and a smaller, inverse effect on slur. Packing had a small effect on fill-in for the top of the web but not the bottom. Except for packing, all other results apply equally to both sides of the web. We were surprised that such a large change in packing had a remarkably small effect on slur. All other factors and all other interactions had no practical effect on fill-in and slur.

CONCLUSIONS

For the conditions of these preliminary experiments, it is concluded that:

--Solid ink density has the greatest effect on fill-in and a small, inverse effect on slur.

--Packing has a small effect on both fill-in and slur on the top of the web but not the bottom.

--Water, paper tension, press speed and number of units on impression and all interactions have no effect on fill-in and slur.

--Fill-in is the largest component of dot gain.

Until these experiments are verified on other presses, these conclusions should not be considered to apply to all presses.

DISCUSSION

There is little doubt that dot gain has a large effect on the level of quality and uniformity of printing. Equally certain is that its control can mean large savings in energy, paper and labor, all of which translates into saving money. Because understanding the causes of dot gain is so important, a great deal of thought and effort has gone into building the system for measuring dot gain and into the preliminary experiments presented here. Not only is it important to know what causes dot gain, it is equally important to reveal the factors having little or no effect. The absence of concrete information is often the cause of wasted time and money in the control of factors that do not affect the printed result.

ACKNOWLEDGMENTS

We thank Richard McAllen for his support and dedicate this work to his memory.

REFERENCES

1. "Instrumentation for the Measurement of Slur and Fill-in on a Lithographic Web Press," M. Pearson, I. Pobboravsky, C. Daniels, 1979 Proc. Tech. Assoc. of Graphic Arts.

2. "The Effect of Printing Conditions on Dot Gain; An Offset Newspaper Study," A. DePaoli, 1981 Proc. Tech. Assoc. of Graphic Arts.

3. "The Penetration of Light into Paper and its Effect on Halftone Reproduction," J.A.C. Yule and W.J. Nielsen, 1951 Proc. Tech. Assoc. of the Graphic Arts, pp. 65-76.