Interrelationship of the Variables and Parameters Which Affect the Performance of Brush Dampeners

by John MacPhee*

Abstract: Brush dampening systems, of the type in widespread use today on web offset presses, are examined in this paper. The objective is to identify the major variables and parameters of the system and to discover how they interrelate to establish dampening solution feedrate. The modern brush dampening system is described and its analogy to a single roll coater is pointed out. This analogy is employed in presenting the theory whcih explains system performance. Measured feedrate data is also presented, which confirms the validity of the analytical model in the range of interest. Important conclusions relating to system design and performance are given along with a listing of the relatively few major parameters and variables of the system. These findings have significant implications regarding the tracking of press speed by the pan roller motor controller. Background information on the history and evolution of brush dampener designs is also included.

INTRODUCTION

This paper reports on a project which started out as a very modest endeavor but which evolved into a much more comprehensive program aimed at developing a better understanding of the modern brush dampening system. The traditional procedure used in such programs is first to develop an analytical model and then to design and carry out experiments to test the theory. In this instance, the sequence was reversed, because of the extreme limitations of the initial project scope. That is, the original intent was simple and straightforward: run tests to determine the effect of fluid temperature on the feedrate of a brush system. It was only after the experimental data was in hand that it was decided that it would be of value to interpret the data in terms of a relevant analytical model.

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Because of the unorthodox procedure followed in the project a dilema arose in preparing this paper: i.e., in which sequence should the material be organized. The decision was made to present the results as if they had been obtained in the traditional sequence, on the theory that this would make for a more coherent presentation. Accordingly, the first section of substance describes the modern or spiral brush dampening system, recounts its history, and sets forth its merits relative to the other dampening system designs in current use. The next section presents the appropriate analytical model, which was uncovered by a literature search. Following the analysis, a section is devoted to the experimental work. Concluding sections discuss the results, vis-a-viz the model, and set forth what are considered to be the significant findings and conclusions.

BACKGROUND INFORMATION

A recent paper identified the five major dampening systems in use today and presented the results of a survey aimed at determining their relative popularity within the major segments of the printing industry (MacPhee, 1986). The survey results showed that the brush design is in widespread use on both commerical and newspaper type web offset presses.

In the early stages of the evolution of this popular dampener design, two different versions were employed: the spiral brush type and the flicker blade type. Gradually, the flicker blade design gave way to the spiral brush or Harris design. It is this latter design which is the subject of this paper. It is interesting (and perhaps surprising) to note that this design was conceived in about 1954, and patented in 1961 by Harold Dahlgren (Dahlgren, 1961*) who is far better known for the dampener design which bears his name. Although Dahlgren was the inventor of the spiral brush system, it was the Harris Corporation who introduced it and reduced it to practical use on web presses (Anonymous, 1963).

As shown in Figure 1 (Kelley, Crouse, and Supansic, 1974) the spiral brush dampening system consists of two major components: a relatively low speed chrome pan roller and a relatively high speed spiral brush roller. The bristles of the brush are made of a relatively stiff and springy material, like nylon. The two rollers are mounted such that they come in contact with slight interference, to form a nip. The chrome roller is immersed in a pan such that when the pan roller turns it delivers a thin film

* The broad concept of metering with a brush roller was disclosed in an earlier patent (Dahlgren, 1959).

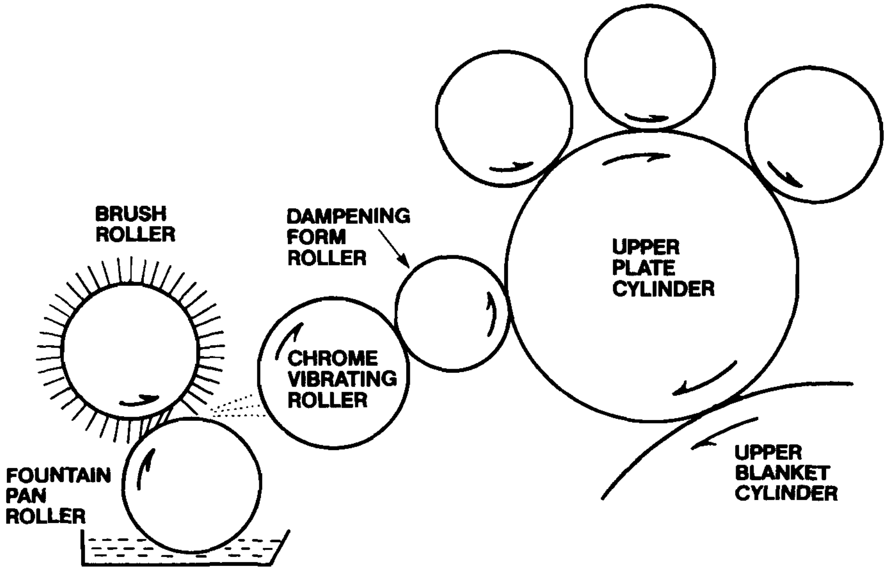

Figure 1 Diagram of Harris Brush Dampener

of fountain solution (water) to the common nip. Because of the interference at the nip, the brush bristles are bent in passing through it. When the bristles leave the nip they quickly spring back to their relaxed position. This wiping and springing action of the bristles against the chrome roller atomizes and propels the water which they have picked up. The former process is so effective that the water particles in the resultant stream are of a size that is invisible to the human eye. In practice, the brush roller is driven at a sufficiently high speed such that all of the water delivered to it is propelled toward the chrome vibrating roller, by the flicking action of the brush bristles. Thus feedrate is determined by the rate at which the pan roller delivers water to the nip formed by its junction with the brush. To permit changes in feedrate, a variable speed motor is used to drive the pan roller, while the brush roller is driven at a constant speed.

Brush dampeners have many attributes, which account for their widespread acceptance. They also possess some shortcomings, which explains why they are not in universal use. The following is a listing and brief discussion of these relative merits:

1. Print Quality. Most users agree that the print quality achieveable with brush dampeners is equal to the best that can be achieved with other dampener designs.

2. Cost. Broadly speaking brush dampeners are no more or less expensive than other designs.

3. Ease of Operation. The concensus of users is that brush systems are more demanding on operator skill and attention, if equal quality is to be achieved.

4. Cleanliness. One major advantage of the brush system is that there is no feedback of ink into the fountain solution. Thus the pan roller and circulation system stay quite clean and require less maintenance then in other designs. On the other hand, brush rollers do tend to get dirty from ink fly and must be cleaned periodically for proper operation. Many users also believe that presses equipped with brush systems have to be cleaned more frequently because more airbourne debris is generated.

5. Speed of Response. Brush systems have very fast response times if run with bareback rollers. However many brush systems are run with cloth or 3M sleeves on the form roller, to prevent ink buildup, and such sleeves do increase response time (and maintenance).

6. Degree of Lateral Control. Brush systems have both good and bad attributes in this regard. On the positive side, the relatively thick metered film on the pan roller makes it feasible to use water stops to reduce or shutoff the water feed in selected regions across the web. This control capability is advantageous when running narrow webs or extremely light coverage on one side of the web. On the negative side, there is no lateral control comparable to roller skewing, to allow the operator to correct for the tendency to dry up or scum at the edges of the web. This problem, which is not limited to brush type dampeners, is most severe when running a full-width web.

7. Need for Alcohol. In the brush design it is not essential to use alcohol in the fountain solution. However, as in all dampeners, print quality and runability is enhanced if alcohol is used.

8. Tracking of Press Speed. As will be shown in this paper, brush systems possess two unique characteristics in this regard: (i) a link to the press drive must be provided if the dampener is to track press speed and (ii) the required link is nonlinear in form.

ANALYTICAL MODEL

To analyze the brush dampener, one need only consider the pan roller, given the principle that the brush roller accepts and passes on all of the water delivered to it. Thus the system is analogous to a single roll coater, shown in Figure 2.

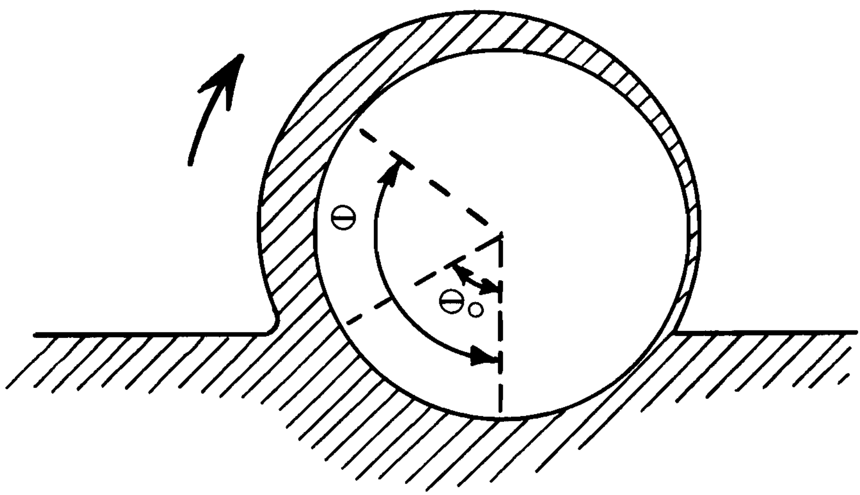

Figure 2 Geometry of Single Roll Coater

In this system the rotating roller carries a thin film upwards from the pan in which it is immersed. Based on first principles, one would expect that the film thickness would vary directly with roller speed and fluid viscosity and inversely with density and angular position Θ, because each elemental volume of fluid is subjected to a generally upward viscous force which is counteracted by generally downward inertia and gravitational forces. One would also expect that immersion angle, Θo, would have an effect. Feedrate, measured as the amount of fluid delivered to the top of the roller ($\Theta = 180^{o}$) obviously is equal to the product of average fluid velocity and fluid thickness at that angle, integrated over the length of the roller. It should also be obvious that the average fluid velocity may be somewhat less than the surface speed of the roller. This broadly stated relationship governing the brush system pan roller performance for a given immersion angle Θo is expressed by Equation (1) as follows:

$$q(\Theta o) = Q\, u^* h^* L \quad (1)$$

where

$q(\Theta o)$ = feedrate at the top of the roller, in unit volume per second, for a given immersion angle, Θo.

Q = a parameter to account for immersion angle and the differences between actual and characteristic velocities and thicknesses.

u^* = characteristic velocity of the fluid film, i.e. roller surface speed.

h^* = characteristic thickness of the fluid film.

L = roller length

A review of the literature disclosed that roll coating is a special form of the more general process of dip coating, wherein a sheet or web of solid material is withdrawn at a constant speed from a quiescent liquid. In this more general process, the web is coated with a thin film of the liquid and the rate at which the liquid is carried away can also be described by Equation (1). Although the theory developed to explain dip coating in the range of low capillary numbers (Landau and Levich, 1942), involved formidable mathematics, the results can be summarized fairly concisely as follows:

(a) The characteristic film thickness in Equation (1) is expressed by Equation (2) as follows:

$$h^* = (\mu u^*/\rho g)^{0.5} \quad (2)$$

where:

μ = dynamic viscosity

ρ = density

g = acceleration due to gravity

(b) The value of Q in equation (1) is a function of the capillary number, Nc, defined by Equation (3):

$$Nc = u^* \mu / \sigma \qquad (3)$$

where:

μ and u^* are defined above

σ = surface tension of fluid

Specifically, for dip coating, Q takes the form

$$Q = 0.93\ Nc^{0.167} \text{ for } Nc \ll 1 \qquad (4)$$

$$Q = 1 \qquad \text{for } Nc \gg 1 \qquad (5)$$

A later paper which analysed dip coating in the rapid flow region (Cerro and Scriven, 1980) confirmed that Equation (2) also applies for high capillary numbers and summarized experimental data that showed that Q is a constant equal to between about 0.55 and 0.65 for capillary numbers greater than unity (which is at variance with Equation (5)).

A more recent paper (Campanella and Cerro, 1984) contains an analysis of roll coaters in the rapid flow region. This analysis showed that the relationships set forth above for dip coating apply equally well to roll coating, with one important caveat: although Q is invariant with Nc, it is a function of the immersion angle Θo. However, this dependency is a weak one in that they found that Q is about 0.54 at an immersion angle of 90^{o} and increases to an assymtotic value of 0.65 as immersion angle approaches zero. Although the paper of Campanella and Cerro is silent on the behavior of roll coaters in the slow flow region, one would guess that the above relationships for dip coating would be close to the mark.

Thus, the analyses reported to date in the literature can be summarized as follows, with regard to the behavior of a brush dampener: by combining Equations (1) and (2) the relationship between feedrate and the system variables and parameters, expressed by Equation (6), is obtained where all of the symbols are as defined above.

$$q = Q\ u^{*1.5} (\mu/\rho g)^{0.5} L \qquad (6)$$

and

$$Q = 0.93\ Nc^{0.167} \text{ for } Nc \ll 1 \qquad (4)$$

$$0.54 < Q < 0.65, \text{ depending on } \Theta o, \text{ for } NcNr^3 \gg 1 \qquad (7)$$

For operation of a given dampener system, the significant variables identified in the above are roller speed (u*) and fluid viscosity (μ). (Although surface tension will vary depending on the fountain solution used, it will be relatively constant for a given installation.) Thus the theory, as embodied by the above three equations, predicts that feedrate will vary with the 1.5 - 1.67* power of roller speed and with the 0.5 - 0.667* power of fluid viscosity, depending on the flow regime.

MEASUREMENTS

Apparatus Used

The dampening system on which measurements were made was installed on a Mark 10 Hantscho printing unit, located in Hantscho's R & D area. The roller arrangement and location of this dampener relative to the plate cylinder is similar to the design shown in Figure 1. The basic approach used was to run the dampener only and measure the amount of time required to collect a prescribed volume of fountain solution. In order to do this, a collection system consisting of a sheet of linen drafting paper and a stainless steel gutter type drain (both of which were slightly wider than the press) was made up. Figure 3 shows how the linen and gutter were arranged, relative to the dampener. The gutter was slanted so that the collected fountain solution would drain into a funnel and thence thru some plastic tubing into either a 96 ounce graduated measuring bowl or a three gallon graduated plastic pail.

In order to be able to vary temperature a refrigerated circulator was installed. To it was added electric immersion heaters and a plastic sight tube for measuring level changes. Two one gallon paint cans (filled with water) were placed inside the tank so as to increase the change in level for a given volume change. For circulating fountain solution to the pan, a low turbulence pump was installed.

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* The lower number results when Equations (6) and (7) are combined (rapid flow) while the higher number results when Equations (6) and (4) are combined (low flow).

Instrumentation consisted of two bimetallic dial type thermometers for temperature, a calibrated DC tachometer and digital voltmeter for surface speed, a hydrometer for IPA concentration, and a stopwatch for timing. A common eyedropper and plastic tubing cap were also used to obtain relative measures of surface tension.

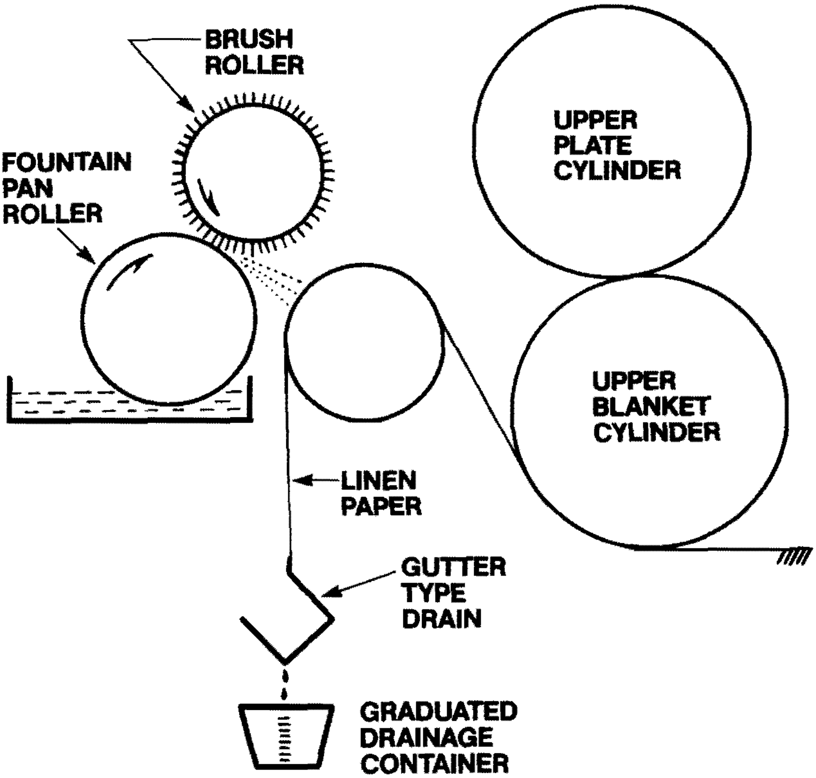

Figure 3 Schematic of Test Setup Used to Measure Feedrate of Brush Dampening System.

Materials

All but a few of the measurements were made with fountain solution consisting of 3 ounces of Rossos concentrate (AS/M-2, 67A-C-KSP, #500) per gallon of water. For the one run made with alcohol, a concentration of 23% by volume of alcohol was used in the same fountain solution.

Setup

The dampener brush was set in accordance with Hantscho's recommended procedure. This produces a nominal .030 inch interference between the brush and pan roller surface. Unfortunately, the water level in the pan was not measured, except in the last series of runs at different speed settings.

All of the runs were made without disturbing the setting of the valve in the pan feed fitting. Thus the recirculating flow rate to the pan, measured to be 0.425 gpm, was the same for all tests except the last, where it was comparable but not measured.

Procedures

Although two types of measurements (long runs and short runs) were made, the procedure followed was basically the same for both. That is, the primary variable measured was the time required for a prescribed volume of fountain solution to collect in a graduated drainage container. In all cases the timing was only initiated after the dampener has been placed in operation for several minutes so as to insure that the system had reached equillibrium. In the case of the short run tests the volume collected was 64 ounces and the drainage container was a 96 ounce (avoirdupois) transparent graduated plastic bowl. For the long run tests, the volume collected was two gallons and the drainage container was a 3 gallon graduated plastic pail. Although in both cases the times required to collect half the prescribed volume were recorded, this data was only used as a check of the total times measured.

At the conclusion of each measurement, the volume collected was quickly returned to the circulating tank. In the short run tests losses were then measured by noting the amount of makeup needed to return the tank level to the value at the start of the run. In the long run tests, the drop in tank level was measured and converted to ounces using the factor of 3/4" of level change per 64 ounces of volume change.

The temperatures at the pan inlet and outlet were measured periodically during a run and averaged to obtain the single characteristic value recorded in the results. Pan roller surface speed was also measured periodically, but did not require averaging because generally it was constant throughout a run.

Data Obtained

1. Roller Surface Speed. Measurements of roller surface speed in feet per minute were obtained over the full range of the control setting. This data is listed in Table I.

TABLE I MEASURED PAN ROLLER SPEEDS WITH BRUSH RUNNING

RUN NUMBER	CONTROL SETTING	TACHOMETER READING (VOLTS)	SURFACE SPEED (b) (FEET/MINUTE)
(a)	25	0.240	19.63
(a)	50	0.481	39.35
(a)	75	0.750	57.67
(a)	98	0.892	72.97
1	15	0.137	11.21
2	30	0.282	23.07
3	45	0.427	34.93
4	45	0.428	35.01
5	30	0.284	23.23
6	22	0.205	16.77
7	22	0.204	16.69
8	30	0.282	23.07
10	22	0.206	16.85
11	45	0.428	35.01

(a) Measurements made prior to runs with no water in pan
(b) Best Fit Straight Line (control settings <50):
Speed (fpm) = -0.667 + 0.794 x Control Setting
Correlation Coefficient = 0.999

2. Initial Feedrate Measurements. Six short run measurements were made of feedrate vs roller speed, at a constant fluid temperature of 65-66°F. These are listed in Table II. In addition, two short run measurements and seven long run measurements were made at a constant control setting of 22, over a temperature range of 44 to 85°F. These short run measurements are also listed in Table II, while the long run measurements are given in Table III. Three additional short run measurements, at different settings and temperatures, were made and these are also given in Table II.

TABLE II WATER FEEDRATE MEASUREMENTS - SHORT RUNS

RUN NO.	CONTROL SETTING	MEASURED SPEED (feet/minute)	AVERAGE TEMPERATURE (degrees F)	TIME TO COLLECT 64 OZ. (min:sec)	FEEDRATE (gallons/hour)	
					MEASURED VALUE	EXTRAPOLATED VALUE (b)
1	15	11.2	66	22:27	1.28	---
2	30	23.1	66	7:31.3	3.83	---
3	45	34.9	66	4:45	6.06	---
4	45	35.0	66	4:47.8	5.99	---
5	30	23.2	66	7:24.3	3.88	---
6	22	16.8	65	11:33.6	2.49	2.45
7	22	16.7	59	11:17.6	2.55	2.52
8	30	23.1	56	6:52.7	4.18	---
9	30	(a)	44	6:20.2	4.54	---
10	22	16.9	47	9:56.6	2.90	2.83
11	45	35.0	44	4:10.5	6.89	---

(a) Not measured, presumably same as previous run

(b) Extrapolated to pan roller surface speed of 16.5 feet per minute

TABLE III WATER FEEDRATE MEASUREMENTS - LONG RUNS, CONSTANT CONTROL SETTING OF 22

RUN NO.	MEASURED SPEED (feet/minute)	AVERAGE TEMPERATURE (degrees F)	TIME TO COLLECT 2 GALLONS (min:sec)	FEEDRATE (gallons/hour)	LOSSES		
					(ounces)	(gallons per hour)	(percent of total)
12	16.5	63	47:11.8	2.54	13.33	0.132	4.9
13	16.5	47	44:30.2	2.70	10.67	0.112	4.0
14	16.5	44	42:6.8	2.85	9.33	0.104	3.5
15	16.7	85	57:52.5	2.07(c)	24	0.194	8.6
16[a]	(b)	66	36:57.3	3.25	21.3	0.270	7.7
17	16.5	74	52:10.3	2.30	(d)	(d)	(d)
18	(b)	55	44:38.9	2.69	(d)	(d)	(d)

(a) With 23% Isopropyl Alcohol by volume.
(b) Not measured, presumably same as previous run.
(c) Extrapolates to 2.05 gallons per hour at a surface speed at 16.5 feet per minute.
(d) Not measured.

3. Followup Feedrate Measurements. An analysis of the four initial feedrate measurements versus speed (Runs 1, 4, 5, and 6, Table II) showed poor agreement with theory at the highest feedrate. To investigate this further, a series of followup measurements were made, at two different brush roller settings. This data is presented below in the discussion section.

RESULTS AND DISCUSSION

Effect of Control Setting on Pan Roller Surface Speed.

Measured pan roller surface speed is plotted in Figure 4 as a function of control setting. There are two significant observations which can be made as a result of examining this graph:

(i) Over the control range of practical interest (0-50) surface speed has a precise linear relationship to control setting.

(ii) The pan roller surface speeds used in brush dampeners are much lower than the pan roller speeds used in flooded nip type dampeners. (For example at a press speed of 1000 feet per minute, a brush system pan roller would be running at 14 feet per minute whereas the Dahlgren pan roller speed on a small sheetfed press was measured to be about 110 feet per minute at a press speed of 6000 impressions per hour or 228 feet per minute.)

Effect of Pan Roller Speed on Feedrate

In keeping with the original objective (to determine temperature effect on feedrate) the initial measurements of the effect of speed were very limited. In fact, only four usable points were obtained at speeds of 11.2, 16.8, 23.2, and 35 feet per minute. When plotted, these points fitted a straight line rather nicely. However, second thoughts were raised by the review of the analytical models discussed above — which predict that feedrate should vary as the 1.5 - 1.67 power of speed. Since the lower three points fell in with this, speculation arose that at the highest speed, the brush was not carrying away all of the fluid delivered to it. Before proceeding to recount what was done next, it would be appropriate to review the significance of brush roller settings.

The setting of the brush roller to the pan roller is important in at least two respects. First, the setting must be uniform from

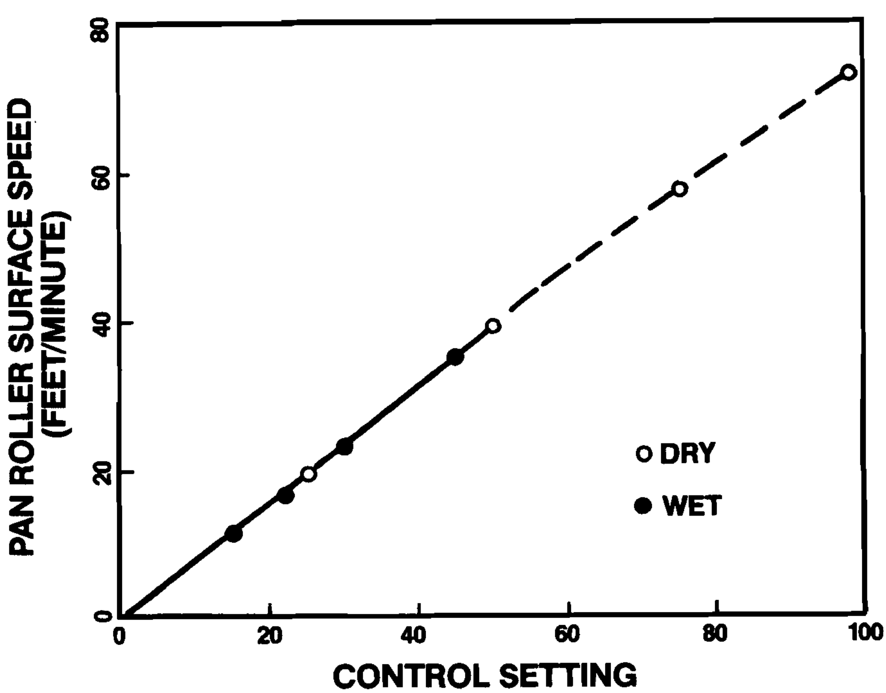

Figure 4 Plot of Measured Surface Speed of Pan Roller in Brush System. Data obtained with brush running. Solid line is best fit straight line with correlation coefficient of 0.999.

one end of the roller to the other, to insure a uniform feedrate across the width of the press (in the event the brush does not flick away all the fluid delivered to it). Second, the setting or stripe must be heavy or wide enough to ensure that the brush flicks away all of the fluid delivered to it. Of course, for any given stripe setting and roller brush speed, there will be some pan roller speed beyond which the pan roller will deliver more fluid than the brush is capable of flicking away. For the brush stripe typically specified — 7/16 inch corresponding to a brush-roller-to-pan-roller interference of 1/32 inch — the limiting ratio of pan roller to brush roller surface speed was estimated to be as low as 1:200 for a typical system geometry. Thus it was deduced that the departure of the highest initial measurement from theory was due to exceeding the critical speed ratio. It was reasoned further that this could be confirmed by making additional measurements at two different brush settings, since a heavier brush setting would in theory increase the critical pan roller speed — i.e. the pan roller speed at which feedrate versus speed departs from theory.

In accordance with the above reasoning more detailed followup measurements were made of feedrate vs speed, at the nominal and at a heavier brush roller setting. In this regard it should be pointed out that the brush roller is normally set by inserting an appropriate gage block between the brush roller core and the pan roller, and adjusting roller position until there is a slight drag on the block. Although this procedure was followed it was considered necessary to also measure the actual stripe, because the normal manufacturing variations in the brush height can cause wide variations in the stripe at a given roller-to-roller setting.* Accordingly, a measure of brush stripe was obtained in the followup tests by inserting a sandwich of carbon paper and vellum between the two rollers while at rest, and then momentarily turning on the brush roller only, while firmly holding the carbon paper and vellum in place. A good impression of stripe could be obtained in this manner — provided that the carbon paper was in contact with the brush, rather than the pan roller. Furthermore, the measured stripes agreed very closely with the values calculated from the known roller diameters and interferences.

The two series of followup measurements are given in Table IV. Analysis of the data taken at the heavier stripe setting (11/16 inch) showed that the corresponding capillary numbers ranged from 0.00052 to 0.00417. This indicated that the model described by Equations (4) and (6) should apply. Thus, by combining these two equations an appropriate single relationship, given by Equation (8), is obtained

$$q = 0.93(u^{*1.67})(\mu^{0.667})(1/\rho g)^{0.5}(1/\sigma)^{0.167}L \qquad (8)$$

* One brush manufacturer stated that the tolerance on brush height is ±1/64 inch or ±.016 inch. The height of twelve brushes was measured and the mean was within .002 inch of the nominal height while the standard deviation was 0.008 inch. Thus the quoted tolerance equals two standard deviations, which represents a confidence interval of 95 percent, i.e. that there is a probability of 0.95 that the variation in brush height will not exceed ±.016 inch.

Table IV Followup Feedrate Measurements at a Constant Temperature of 66 Degrees Fahrenheit and an Immersion Angle, Θo, of 42 Degrees

Brush Roller Set at 7/16 Inch			Brush Roller Set at 11/16 Inch		
Run Number	Speed (feet/min)	Feedrate (gallons/hour)	Run Number	Speed (feet/min)	Feedrate (gallons/hour)
19	4.3	0.14	26	4.4	0.19
20	9.3	0.68	27	9.4	0.95
21	14.7	1.49	28	14.9	2.12
22	20.3	2.39	29	20.5	3.47
23	25.4	3.09	30	25.4	4.63
24	29.9	3.71	31	29.8	5.73
25	35.2	4.30	32	35.0	6.81

This equation is plotted in Figure 5, along with the initial measurements and the two sets of followup measurements.

In reviewing this figure, the following points should be noted:

1. The calculations of Equation (8) were based on handbook values (Hodgman, 1947) for water: of viscosity (1.0333 centipoise), density (62.34 pounds per cubic foot), and surface tension with respect to air (72.8 dynes per centimeter). However, the value of surface tension for water was adjusted for the actual fluid employed, using the "medicine dropper" technique (MacPhee, 1984). This yielded a value of 44 dynes per centimeter for the fountain solution. Measurements with a homemade capillary viscometer showed no significant viscosity differences between tap water and fountain solution. Therefore the above value of viscosity was used.

2. Both the followup set of meaurements at a stripe setting of 11/16 inch and the initial measurements (stripe not measured) show remarkably good agreement with theory at the pan roller speeds of practical interest — i.e. at speeds corresponding to press speeds less than 64,000 impressions/hour or 2,000 feet/minute. These same two sets of measurements also depart from the theoretical curve at higher speeds. This confirms the hypothesis, given above, that there is a limiting pan roller speed above which the brush is incapable of flicking away all of the fluid delivered to it. Further confirmation is provided by the fact that the series of measurements at the heavier stripe setting indicate a higher limiting pan roller speed. (The initial measurements were made with a nominal brush setting which should have

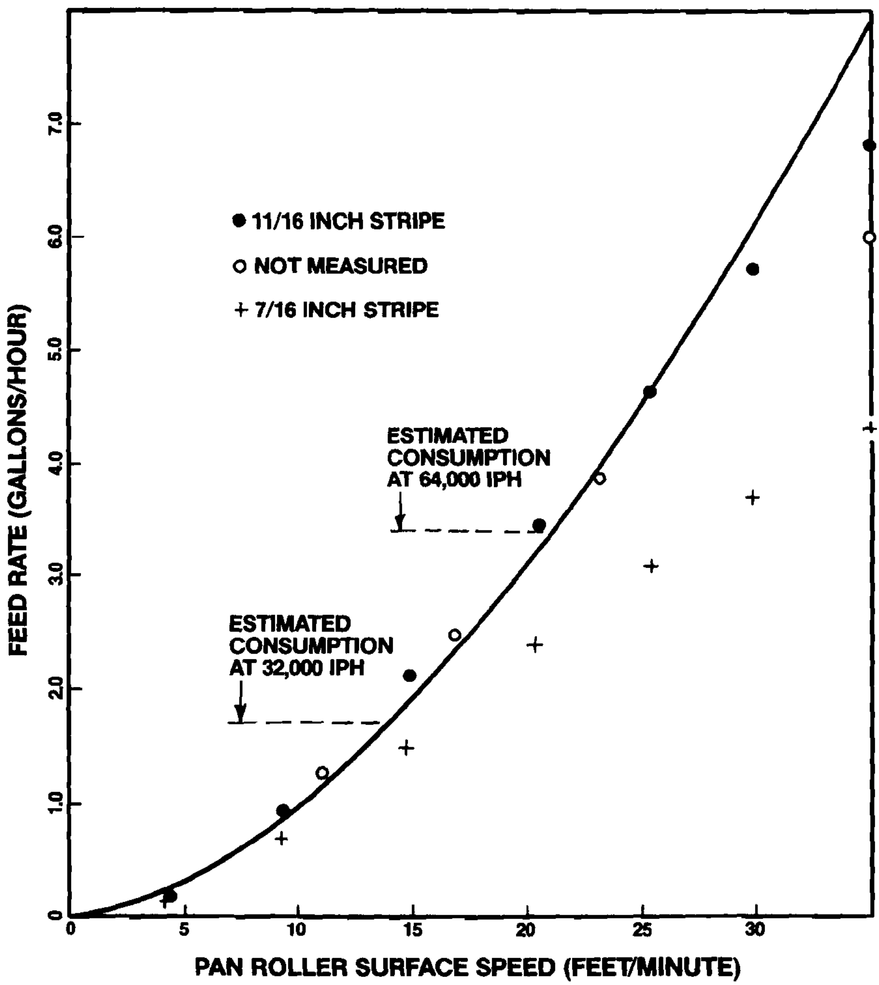

Figure 5 Comparison of Theoretical and Experimentally Determined Values of Feedrate vs Roller Speed. Solid Curve is Plot of Equation (8) for Fountain Solution at 66°F. Measured data is for three different brush roller settings.

produced a stripe of 7/16 inch. Although the stripe was not actually measured, comparison with the other data indicated that probably it was somewhat heavier than 7/16 due to manufacturing variations in the brush.)

3. The other set of followup measurements, also run at the nominal setting (7/16 inch measured stripe) fall well below the theoretical curve, even in the range of practical interest. This was somewhat suprising because it indicated that the limiting pan roller speed is more sensitive to brush setting than had been estimated.

Effect of Temperature on Feedrate

The data obtained at 16.5 feet per minute provided the best measure of fluid temperature effect and this is plotted in Figure 6. The best straight line fit of this data has a correlation coefficient of 0.983 and a slope of -7.3 percent per 10 degrees Fahrenheit at 60 degrees.

Equation (8) is also plotted in Figure 6 and the agreement with the measured data is reasonably good. The calculations were carried out by making corrections to the above data on viscosity, density, and surface tension using handbook tabulations versus temperature (Hodgman, 1947). These calculations showed that the temperature effect on feedrate is due primarily to the temperature effect on viscosity.

Effect of Viscosity on Feedrate

One measurement was made to determine the effect of fluid viscosity on feedrate. This was done by adding 23 percent by volume of isopropyl alcohol to the fountain solution. The resultant feedrate measurement is plotted in Figure 6 and represents a feedrate increase by a factor of 1.34, due to the addition of the alcohol. The was suprisingly low since published data (Hatch, 1961) showed a viscosity increase from 0.891 centipoise for water at 77^{o}F to 2.059 centoise with 20 weight percent (25 volume percent) isopropyl alcohol added. This viscosity ratio of 2.31 would convert to a feedrate increase by a factor of 1.75 according to Equation (8). Also, viscosity data at a temperature of 68^{o}F (Irany, 1943) shows a viscosity ratio of 2.62 which would project that feedrate would increase by a factor of 1.90. Because of this large discrepancy, measurements were made of the viscosity ratio of the two fluids actually run using a homemade capillary viscometer, described elsewhere (MacPhee, 1984). Relative viscosity was

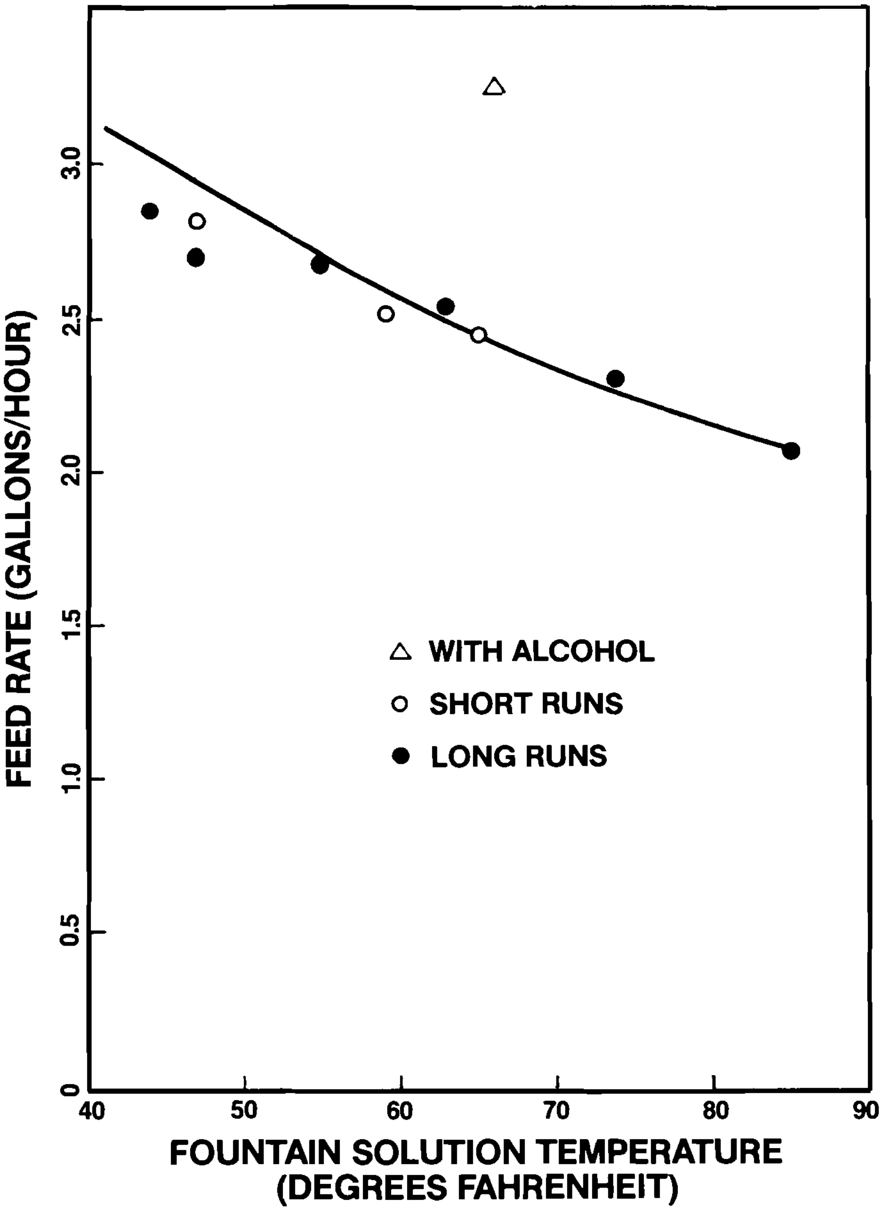

Figure 6 Effect of Fountain Solution Temperature on Feedrate at Pan Roller Surface Speed of 16.5 Feet per Minute. Solid curve is plot of Equation (8). Measured data is for fountain solution with and without isopropyl alcohol.

obtained by measuring the time required to drain 100 cubic centimeters of the test fluid from the sample cup while maintaining a constant liquid level in the cup. These measurements, which were reproducible to within two percent, yielded a viscosity ratio of 1.37 and this in turn would predict a feedrate increase by a factor of 1.23. When density and surface tension effects are included, the overall factor becomes 1.30, which is resonably close to the measured increase of 1.34. The large discrepancy between the measured viscosity ratio of 1.37 and the values (2.31 and 2.62) reported in the literature has not been explained to date.

Characteristic Film Thickness

Although no measurements were made of the fluid film thickness on the pan roller, the good agreement between theory and the other measurements suggested that a calculation would give fairly realistic values. Such calculations were made and are given in Table V, along with other calculated values of interest.

Effect of Fountain Solution Chemistry

Another suprising result was obtained when a few feedrate measurements were made using a different commercial fountain solution concentrate -- also mixed in the proportion of 3 ounces per gallon. On the first occassion when this was done, at a speed of 35 feet/minute, and a brush stripe of 7/16 inch, the measured feedrate was 1.4 gallons/hour or one third the value obtained under the same conditions with the (standard) concentrate used in most of the runs. A second measurement was made at the end of the program at a stripe setting of 11/16 inch. Here the measured value was 72 percent of the value obtained with the standard concentrate. These large discrepancies remain unexplained because relative measurements of viscosity and surface tension of the two fountain solutions did not indicate any major difference in fluid properties. Possible explanations are that the first run was made with a brand new system and the surfaces of the brush bristles and/or pan roller may have been contaminated with grease. In the last run the presence of tiny bubbles on the pan roller surface was observed whenever the brush roller was turned on.

TABLE V SOME CALCULATED VALUES OF INTEREST

Surface Speed, u* (feet/minute)	4.4	9.4	14.9	20.5	25.4	29.8	35
Characteristic Thickness, h* (inches ÷ 1000) (a)	1.92	2.80	3.53	4.14	4.61	4.99	5.41
Product of u*h*L (gallons/hour)	0.95	2.95	5.90	9.51	13.1	16.7	21.2
Capillary Number Nc (x 1000) (b)	0.52	1.12	1.77	2.44	3.03	3.55	4.17
Q (Equation 4)	0.263	0.299	0.323	0.341	0.353	0.363	0.372
Flowrate - Equation (6) (gallons/hour)	0.249	0.88	1.90	3.24	4.63	6.05	7.90
Q (inferred from measurements) (c)	0.2	0.322	0.359	0.365	0.351	0.344	0.321

(a) At 4.4 feet per minute, h* = 0.00192 inches
(b) At 4.4 feet per minute, Nc = 0.00052
(c) Inferred Q equals measured flowrate divided by u*h*L

CONCLUSIONS

1. The brush dampening concept can be looked upon as a Jekyll and Hyde; in principle it is a very simple system which behaves in a rational manner, whereas in practice it is complex and not altogether predictable.

2. In theory the brush dampener is configured so that the brush roller is capable of flicking away all of the fountain solution delivered to it by the fountain roller. This requires that the brush roller turn at a very high speed relative to the pan roller, and that the brush roller be set to the pan roller with a sufficiently heavy stripe. Under these conditions feedrate is determined by the pan roller, which is analogous to a single roll coater. Theory predicts that feedrate will vary directly with the 1.67 power of pan roller speed and the 0.667 power of fluid viscosity, and inversely with the 0.167 power of fluid surface tension with respect to air. The measurements of feedrate reported on in this paper are in good agreement with this theory, which dates back to the year 1942.

3. In practice, the brush dampener is less well-behaved because of two factors: significant variations in the diameter of the brush roller (due to tolerance in brush manufacturing), and contamination of the brush by ink. The manufacturing variations (± 1/64 inch in brush height) are one half the normal nominal interference between the brush roller and the pan roller. Because of this the actual interference can vary significantly, leading to marked variations in the relationship between feedrate and pan roller speed (from one system to the next). Contamination of the brush by ink reduces the springyness of the brush, which has an effect equivalent to a reduction in roller interference. In practice, these vagaries in behavior are not looked upon as a major problem and, as a result, the brush system of dampening is extremely popular because of its many other merits.

4. Because the pan roller in a brush dampener is driven by a separate variable speed motor, feedrate does not automatically track press speed. Thus some link must be provided if tracking is to occur. For an ideal system, the results of this paper have shown that the link should cause pan roller speed to vary as the 1/1.67 power of press speed — so that feedrate will vary linearly with press speed. However, the vagaries encountered in actual use (discussed in the preceding paragraph) would appear to render consistent tracking an impossibility in practice.

5. The feedrate of a brush system is subject to a significant negative temperature effect. Measurements reported on here show this effect to be a decrease in feedrate of 7.3 percent for every ten degree Fahrenheit rise in fountain solution temperature. This change is large enough to warrant the use of mechanical refrigeration equipment to maintain a constant temperature.

6. The measurements reported on here had two surprising results. First, the increase in fountain solution viscosity, due to the addition of isopropyl alcohol, was less than expected, based on earlier published data. Second, the use of an alternate fountain solution concentrate resulted in a significant reduction in feedrate. To date, satisfactory explanations for these two phenomena have not been found.

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* The analysis referenced here also appears in the last chapter of the book by V.G. Levich entitled Physicochemical Hydrodynamics, published by Prentice Hall (Englewood Cliffs, New Jersey), in 1962.