A PERSPECTIVE ON KEYLESS INKING

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ABSTRACT

Printing without column control of inking is an inherent feature of flexography; it has become commercially available for letterpress operations; it will soon be available for lithography. In principle, all of these keyless processes simplify the printing operation and make it more productive than conventional letterpress and lithography. At present, the greatest keyless inking benefits are being obtained in newspaper production applications.

Letterpress and flexography have the advantage of being single-fluid processes. The design of the corresponding printing press systems primarily involve mechanical engineering inputs with minimal need for chemical considerations.

Lithography requires two fluids, ink and water. For keyless operation, the press system must be designed to properly bias the interactive chemistry of the two fluids. The research and engineering efforts to do this have shown that keyless lithography meets or exceeds practical expectations and have provided new insights into the very nature of lithography.

BACKGROUND

Keyless inking can now be practiced using any of the four major printing processes. Two of these, gravure and flexography, have been keyless from their inception. Keyless inking for large, high-speed versions of letterpress and lithographic printing systems have only recently been made available.

We have been comparing, considering, and analyzing the

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anticipated relative merits of all four processes in their simplified versions, that is keyless, for many years. We concluded that keyless lithography ought to be just as attractive among the four process alternatives as it is when conventionally practiced. This prompted an intensive R&D program to solve the problems that had relegated lithography the last of the major printing processes to become keyless.

In this paper, we summarize basic hardware and process differences from keyed and not-keyed viewpoints, then present some of the insights that our development of keyless lithography has uncovered about lithography in general.

SIMILARITIES AMONG THE MAJOR PRINTING PROCESSES

As conventionally practiced, all four processes involve unidirectional mass flow of the ink. That is, ink travels from the input source, usually by means of one or more inked rollers, to the image carrier and then to the substrate being printed. There is virtually no return flow of unused ink from the image carrier back to the ink source whether the conventional process is keyless as with gravure and flexography or keyed as with lithography and letterpress.

When considered as keyless processes, Figure 1, hardware for all four can be designed using an engraved metering roller with a doctoring or scraping blade riding on the metering roller to assure that a controlled ink film enters the system. The gravure process represents a departure in that the ink metering roller also serves as the image carrier. In the other three keyless processes, the image carrier receives ink that has been previously metered by the coacting engraved roller and doctor blade.

DIFFERENCES AMONG THE KEYLESS PROCESSES

The first major difference among the four keyless processes arises because of an image carrier difference. In gravure, the metering roller picks up and transfers to the substrate an amount of ink corresponding to the image format requirement. That is, the ink input varies around and across the imaging cylinder. It is inherently a variable-density keyless process. In the other three processes, with typically configured hardware, the amount of ink available to the image carrier from the metering roller is uniform across the press, independent of the image format. In their simplest keyless configuration forms, flexography, letterpress, and lithography are fixed-density keyless processes.

The second major difference among the four keyless processes is due to the nature of the inks being used. The very fluid, liquid inks of gravure and flexography transfer essentially completely from the metering roller in areas corresponding to the image. There are virtually no image or non-image area ink film splits to feed ink back towards the ink source. Thus, although both these processes have a metering roller and scraping blade that are typical of most of today's keyless inkers, flexography and gravure are unidirectional ink flow processes; ink moves only toward the substrate being printed.

The viscous, oil-based, paste inks of lithography and letterpress processes transfer or split essentially 50/50 at all inked image areas of the plate/form roller nips. Half or more of the ink made available to the image carrier is not used and travels back down the inking train towards the ink input source. That return or unused ink film carries a cross-press memory of how much of the input ink was used to form the printed image. This nonuniform ink film must be continuously removed from the inker so that a uniform ink film can be made continuously available to the image carrier. In principle then, two scraping blades are required for paste ink keyless systems as in Figure 2, one located before the metering roller ink replenishment nip to remove the return ink film, and one located just after that nip to help meter the input ink. Fortunately for press designers both functions can be accomplished using only the metering doctor blade as in Figure 3. Nevertheless, an important feature of paste ink keyless inking systems is the existence of bidirectional ink flow; ink flows both toward and from the image carrier.

It is also important to note that the volume of the scraped-off ink in the paste ink keyless systems is always larger than the volume of ink being printed out. This is illustrated in Figure 4. Ratios range from about 4/1 to over 100/1, depending primarily upon percent image and number of rollers in the inking train. One practical consequence of this fact is that the return ink must be cycled back to the ink input system and reused. Its volume is too great to be led away from the press for disposal.

KEYLESS LETTERPRESS IS ALIVE AND WELL

Modifying a keyless letterpress printing couple configuration to incorporate recycling and reuse of the return ink film is a straightforward engineering design task because letterpress, like flexography, is a single fluid printing system. Mechanical feature changes do not moderate the chemical nature of the process. Accordingly, keyless letterpress patents were issued some time ago for instance to Chase (1961) and Granger (1971); more recently to Matalia (1981), Sakamoto (1986), and Bolza-Schunemann (1984). Keyless letterpress operating sites are more prevalent in Europe and Japan than in the United States. Several current press-supplier contenders are Crabtree-Vickers, TKS, and Koenig and Bauer. All of these are based on the Matalia or similar technology.

There is another similarity among three of the major processes that seems to correlate with their front-running positions as keyless processes. Gravure, flexography, and letterpress are all single-fluid printing systems, lithography is a bifluid printing system.

KEYLESS LITHOGRAPHY IS DIFFERENT

If lithography was to become a keyless process, it was apparent to us that we had to replace the uncertainties and sometime mythologies of conventional lithography with better understanding of the ink/water interactions inherent in the lithographic process.

One pervading confounding factor in studying conventional lithography is that the ink must be fed in varying amounts across the press width according to the demand of the image format. This operating situation is further confounded by the pressman's attempts to subjectively optimize the printed result using easily-modulated inking keys or injector pumps. Fortunately, dampening water is generally made available uniformly across the press or plate width. Despite this feature, pressmen also tend to change the overall water input during most of a typical printing run. The result is a confusing cross-press conglomerate of water, of ink, and of ink/water admixtures, all of which are subject to time dependent as well as subjectively imposed changes. This complex situation has, to date, defied systematic resolution, despite admirable attempts to do so by MacPhee (1979), Karttunnen (1979), Schlapfer (1975) and others.

Keyless operation offers a fortuitous set of circumstances for studying lithography at the press. Not only is the dampening water applied uniformly across the press, but the ink is also fed to the plate more-or-less uniformly; both inputs are independent of image format. In these fixed-density keyless inking systems, the pressman cannot interfere with the uniformity of ink input nor with the overall amount of ink input. Our field experience at Memphis Commercial Appeal, New York Times, and Aftenposten in Norway indicates that under this condition, there is no need to adjust dampening water input once it has been set. Consequently, cross-press ink/water content differences are minimized; and sporadic operator-imposed input changes are absent. These circumstances have important advantages in studying the lithographic process.

Another investigative advantage of keyless inking is that the scraped-off return ink/water mix can readily be sampled in sufficient quantity to measure its water content, emulsion stability, structure of the emulsion, its rheology, lint content, content of dampening additives, etc.

LITHOGRAPHY IS LITHOGRAPHY

Comparison of a typical keyless ink-train dampening configuration with a conventional Metro or Metroliner configuration, Figure 5, will verify that from the first inking drum to the substrate being printed these are identical. From a practical standpoint, this is purposeful to enable retrofitting keyless inkers into existing presses. This also infers that keyless lithography and conventional lithography should function identically. The same inks, dampening solutions, and plate technologies are used.

As well known, it is the planographic printing plate that defines the process, not the inker. Consequently, we felt confident that by learning all we could about keyless lithography, we would be learning important principles about lithography in general.

Dampening principles derived from our keyless research were already presented at a recent GATF Dampening Conference (Fadner, 1986A). As appropriate, some of these principles are included in this paper

KEYLESS LITHOGRAPHIC PRESS REQUIREMENTS

Figure 6 is a schematic illustration of a keyless inker design that we have used to study the lithographic process. Important generic features, in addition to the celled metering roller and the doctor blade, are flow of the return ink into an ink pan reservoir, continual recirculation and homogenizing of the ink pan contents, and cross-press redistribution of the ink to the reservoir. The reservoir, circulation and redistribution systems function to continuously erase any cross-press return ink volume differences and water content differences.

Consideration of press configurations brings up the third major difference among the four keyless printing process, namely the metering roller composition. It is not the intention to cover those details in this paper. However, a metering roller for lithography must not only resist the wear imposed by the doctor blade, as with gravure, flexo, and letterpress, it must be manufactured using materials that allow it to meter the ink despite the presence of significant quantities of dampening water. None of the commonly used celled metering rollers are operable under this condition. The roller must be hard, oleophilic and hydrophobic, as discussed in our patent disclosures (Fadner, 1986B).

Keyless lithographic press configurations other than the celled metering roller/doctor blade type have appeared in the patent literature (Warner, 1981; Dahlgren 1983, 1986; TKS 1983, 1984; Barrows, 1985; Jeschke, 1986; Matalia, 1983). Mitsubishi has announced an operating system at a Japanese newspaper that scrapes a smooth inking drum and removes water from the scraped ink before returning the ink to the press.

EXPERIMENTAL OPERATING CONDITIONS

In all of our process investigations, we use the just-above-scum dampening condition. This enables making meaningful comparisons among otherwise considerably different printing conditions. And this condition is quite reproducible from day to day. As we shall see, minimum water input also corresponds to the most practical operating condition in the field. The only criteria used for changing a dampener setting are the appearance of scum and to momentarily verify the just-above-scum condition.

To assure constant conditions, we operate at constant ink reservoir volume both in the lab and in the field. An amount of fresh ink equivalent to that printed out is continuously replenished to the pan reservoir.

Ink samples are obtained by means of a spigot attached to the recirculating line. Water contents of the ink were determined using the xylene Dean-Starke distillation procedure.

Duke water pickup data were determined at room temperature using the Surland (1980) procedure.

A NEW DAMPENING BASIC

Experiments with our first keyless inker revealed an important principle of dampening. Conversion of an Urbanite press to keyless inking resulted in the configuration of Figure 7. The inking rollers became the dampener and a keyless inker was fitted from underneath. We have run hundreds of successful tests on this printing couple and still use it to evaluate metering roller technologies.

One thing about this Urbanite conversion bothered us. It is a water-last dampening system. Everyone knows that water last dampening is to be avoided. Yet we were obtaining excellent printed quality and no ink/water balance control problems.

This printing system also was tested with only three rollers in the dampening train; then with only two; then with a chrome roller in place of the copper drum, Figure 8. Printing quality and ink/water balance control worsened as we used fewer rollers and as we departed from using the copper drum. We concluded that operability of this water-last dampening configuration depended upon design of the dampener rather than upon the dampener sequence relative to the inker at the plate. It seemed that if the the water and ink are mulled together before the water reaches the plate, as in Figure 8, excellent ink/water balance control is possible. We have inferred from this, without proof, that this ink/water mulling principle could also be advantageously used for any direct dampening configurations for conventional lithography.

WHERE DOES THE WATER GO, INDEED!

Another laboratory press was designed and this time it was built as a keyless lithographic press with features similar to that shown in Figure 6. Notice that the unit has direct water-first dampening with the minimal number of rollers. This factor came back to haunt us, as discussed later.

At TAGA 85, MacPhee reported his observations regarding the fate of the dampening water applied to the printing plate during conventional lithographic printing. Our keyless inking research is in complete agreement with his conclusion that the water goes primarily into the ink and that much of it evaporates. Figure 9 is a typical plot of ink reservoir water content versus copy count during one of hundreds of keyless lithography printing runs starting with fresh ink in the reservoir. The initial rate of water input to the five gallon ink reservoir is about 0.19 ml/impression. The dampening water input required to keep the plate clean at just above scum was separately determined to be 0.34 ml/impressions. This shows that over half of the input water is carried by the ink away from the plate and is scraped off into the large reservoir.

Assuming that evaporation of water from the various rollers depends only upon available roller surface area and not upon identity of the materials on the rollers, the rest of the input water, about 0.15 ml/imp needs to evaporate at an average rate of only about 0.03 ml/imp from each of the five rollers that are involved. Obviously, for this case of about 25% image content, a very small fraction of the water is transported to the paper.

LONG RUNS PROVIDE ADDITIONAL INFORMATION

Ordinarily, our printing runs involve 20,000 to 80,000 impressions in the lab and 100,000 or more impressions in the field. If we include the rest of the data for the Figure 9 laboratory press run, as in Figure 10, it is apparent that water content in the constant volume ink pan levels off at about 30%. This leveling off behavior is of utmost practical importance because it makes keyless lithography a viable process. It also has scientific importance because it documents, perhaps for the first time, the existence of a true steady-state in the lithographic process. Although we have yet to run all of the definitive experiments, we can predict that the steady-state value for specific ink, dampening solution, and press conditions, is independent of format. This prediction follows from the fact that the required water input is dictated primarily by the minimum requirement per unit area of the printing plate non-image areas rather than by the total non-image area.

Not all of our printing trials start with fresh ink. When a printing run subsequent to the Figure 10 trial is made one day or one week later, the water content results are rather mundane. Nothing happens as shown in Figure 11. The water content remains at 29 to 30%. Again, this observation represents an important practical result, particularly in newspaper printing where a whole reservoir of fresh, dry ink is somewhat of a trivial situation. One only needs to continue with the ink left over from the previous run.

Since this printing is done at a constant dampener setting, it is obvious that 0.34 ml/imp of water is still entering the press system even at steady-state. And, at steady-state, the rate of water disappearance must equal the rate of water input. Consequently, the average evaporative rate from the five rollers becomes about 0.07 ml/imp, still a remarkably low value.

These results infer that the press system will preferentially use the easiest path to accommodate the continual input of dampening water. Obviously, the energy required to emulsify and distribute water is less than that to first emulsify, then distribute, and then evaporate the water. Apparently, most if not all of the excess water at the plate rapidly enters the ink (Fadner, 1985) evaporating as it travels toward and from the ink reservoir. The system reaction that accompanies water buildup in the pan is a gradually increasing rate of water evaporation.

EARLY FIELD EXPERIMENTS

Our first field keyless lithographic experience was with a Metro press at Memphis Commercial Appeal converted to a direct dampening keyless operation at one couple, with a four-roller inked dampener having a spiral brush water input, and converted to ink-train-dampening with similar water input on the second side couple, Figure 12. We could find no clear-cut operational or quality differences between the two couples. In retrospect, this should have been expected because both configurations involved the dampening principle previously discussed; dampening water is mulled into the ink on its way to the plate, with no interfering hydrophilic rollers.

This experience supported our beliefs about inked-roller dampening. The same principle should apply in commercial and sheet-fed dampening. A Dahlgren dampener is an ink-train dampener configured with a minimum number of rollers. To obtain best performance, alcohol or its substitute is generally used to make sure the water is helped into the ink. Considerable industry discussion was evident at the 1986 GATF Dampening Conference, relating to dampening configuration alternatives and the ability to operate without alcohol. It appears that one could add a few rollers to a Dahlgren dampener and make sure they are oleophilic so that they carry ink, then throw the alcohol away.

We gained two other pieces of information from the Memphis experience in addition to demonstration of newspaper operability at production speeds. First, the steady-state is maintained regardless of printing run length; about 1.5 million impressions in five successive 300,000 copy runs. This is currently being substantiated with runs of a million copies per week at the New York Times. Secondly, steady-state water-content value in the reservoir was significantly lower than our laboratory experience, 20% versus 30%. We needed to find an explanation for the latter result.

ALL INKS ARE NOT CREATED EQUAL

About this time in our development program, the ink suppliers found it necessary to switch to specially hydrogenated ink oils in response to hazardous chemical legislation. This turned out to be a mixed blessing. On the negative side, our lab press began operating less predictably just when we needed to qualify inks for the New York Times installation. On the plus side, we were forced to look at many different inks from several suppliers; we learned a few more things about lithography during this time.

Printed optical densities (OD) and reservoir water contents for three typical black inks from three major newsink suppliers are plotted as functions of copy count in Figures 13 and 14 for printing runs starting with fresh dry ink.

Ink I optical density (OD) is constant early in the run, then decreases rapidly after about 10,000 impressions. Together with press-side observations, we have interpreted this behavior to mean that this ink rapidly takes on a limited quantity of water. Free water builds up, which accounts for its subsequent OD loss. This ink cannot handle the additional water being continuously supplied to keep the plate clean and, although it retains its stability as a dispersion and hence its initial OD, it snowflakes badly and fails to lithograph later in the run. The scum condition equals the wash condition within 20,000 impressions due to the large volume of free water that has accumulated in the inker.

Ink III of Figures 13 and 14 remains stable as a pigment dispersion because it continues to lithograph well. However, it rapidly loses OD after about 10,000 impressions by a simple dilution effect. It becomes grey as it takes on and retains more and more of the dampening water. The ink becomes water-logged and eventually will also fail to lithograph. However, no free water is seen on press.

Ink II shows no copy count change in OD. Regardless of the input ink's apparent water content varying from zero to about 30%, its printed OD remains constant. This represents the ideal keyless lithographic ink behavior.

In a general way, we can relate these different ink behaviors to traditional lab measurement techniques such as the Surland water pickup test, although as Chou et al (1987) reports, the specifics are more complicated than considered here. The high Duke test values for Inks II and III, Figure 15, infer strong propensity to pick up water even when the water content of the ink may already be rather high. The leveling-off property of Ink II illustrates that this ink can reach a steady-state corresponding to equal water pickup and water release. Of course, the Duke test shearing conditions are far different from that on press, consequently the absolute value for the Duke steady-state is different. We found very few inks of the treated-oil type that have behavior typified by Ink II of Figures 13, 14, and 15.

The nonsteady-state Duke response for Ink III correlates with the continual water pickup propensity of that ink on press. It simply does not release as much water as it picks up. The very low Duke water pickup of Ink I correlates with appearance of free-water during the press run and the unacceptable scum/wash performance. It fails to pick up all of the excess water being fed to the plate.

We believe that this type II ink readily takes on excess water that is always present at the printing plate regardless of its existing water content (like Ink III but unlike Ink I) but just as readily releases water to the printing plate, to other inked surfaces, and to the plate (unlike Ink III or Ink I). The ink acts as a sink and a reservoir for areas on the plate or on inked rollers that either have excess water or are temporarily deficient in water (Fadner, 1982). The result is an unchanging ink density at the printed sheet.

One very convincing argument that the ink must readily release some or all of the water that it picks up can be seen only under certain conditions on press. While running, we attempt printing an overall solid by turning off the dampener. Inks react in three distinct ways:

Ink I Type - Ink is picked up in both image and non-image areas, but the copy has streaks of differentiated image because of free water being conveyed to the plate by the ink mass. Frequency of streaks increases up to failure of the ink.

Ink II Type - Overall partial image differentiation; inked image areas are surrounded by scummed non-image areas. The ink actually supplies water to the non-image areas of the plate. This occurs only at high water-content steady-states, otherwise an overall black solid is obtained.

Ink III Type - Overall grey solid at all copy counts. There is no indication of water being supplied to non-image areas by the ink.

LITHOGRAPHY IS STILL LITHOGRAPHY

All three inks of Figures 13 and 14 are used routinely on conventional lithographic newspresses. Yet the drastic performance differences seen with our lab keyless inker are not encountered. There are logical explanations, but they are not simple nor single-valued.

Comparable Conditions Effect

All of our keyless press runs, including field tests are run at just-above-scum. Not only does this correspond to minimum operational water input, but it also allows direct comparison of one press run with any other press run independently of the consumables being used. The conditions from run-to-run are comparable provided the press and dampener configurations are the same.

When ink/water problems occur in conventional lithography, the pressman adjusts fluid inputs until he has the best compromise. An ink I compromise is obviously going to be different from an Ink II or Ink III compromise. Consequently, one cannot compare conventional against keyless use of these same inks; one cannot even properly compare conventional lithographic use of the same three inks on the same press.

Predictions about conventional performance with these inks can be made despite these shortcomings:

> Ink I will tend to have free water in the inker; problems with spitting and with sling; its OD will remain acceptable, but wash and snowflaking will appear. Dampener latitude will be narrow for low coverage formats.
>
> Ink II will have the best ink/water operating balance latitude with little effect of format on performance and will have the best press configuration latitude.
>
> Ink III will print gray in low coverage formats. Balancing dampener input for both low and high coverage areas will be difficult. Spitting and slinging should be minimal except for areas corresponding to low coverage forms where built-up ink will be highly water-diluted and soupy.

Dampening System Effect

Recently, we rebuilt our lab keyless inker to correspond with the field configurations that ran successfully at Memphis, New York Times, and elsewhere. The spiral brush input portion of the dampener was moved from the direct, water-first position to the ITD position shown in Figure 5. Reservoir pan water contents at steady-state immediately dropped from the typical 30% range to values less than 20%, similar to that repeatedly measured during field production runs.

This result is of basic significance. It directly supports our contention that optimum dampening, that is minimum water input, must involve mulling of water into ink before the water reaches the plate. The water input rate required to just keep the plate clean dropped from about 0.34 ml/imp for the direct dampener to about 0.24 ml/imp for the ITD system, a 30% decline. We have interpreted this result to mean that many of the industry's direct dampeners are less efficient than ink-train dampeners. This correlates with pressman's observations that certain dampeners seem to require less water. Their reports may be true not because of the dampener input configuration, but rather because of the effectiveness with which water had been carried to the plate by the ink.

This minimum dampening condition is of considerable importance in keyless inking because the less water put into the system, the less water the ink will need to carry at steady-state. This may allow satisfactory use of marginal materials in keyless inking systems, such as Inks I and III previously discussed. It has obvious significance in conventional lithographic dampening.

It's All In The Timing

The ability to define a steady-state condition in keyless lithography is actually an artifact of what could be termed a semi-infinite inking train. We are operating with five gallons; conventional presses operate with about 4 to 10 cc of ink on the inking rollers. This is illustrated in Figure 16 showing water content curves expected for different ink reservoir volumes. In the limit of a very small reservoir, steady-state is reached very rapidly. This applies to conventional press configurations where there is no reservoir other than the inked rollers. However, as Chou et al (1987) point out, conventional lithographic presses have a series of steady-states across the press width because of the variable ink input.

Our keyless inking results demonstrated that an ink may or may not be formulated to react rapidly enough to take care of all the water applied to the plate. In analyzing keyless inking data, it should be recalled that the important ink/water interaction _is_ at the plate and may have no relation to what happens in the inker other than how fast the interactive effects are transported to the inker.

Our data also illustrate that to have optimum lithographic properties, the ink must be formulated to release water just as rapidly as it takes it up. Release of water under shearing conditions can be demonstrated (Chou and Fadner, 1986), Figure 17, but we need yet to correlate this measurable property with press performance.

Efficiency Of Dampening Is The Key To Keyless

Running the same press with a direct dampener and with an ink-train dampener resulted in steady-state ink-pan water contents of about 30% and 20%, respectively. Corresponding relative rates of water input were required to keep the plate just above scumming. The fact is that we needed to apply more water to accomplish direct dampening than to accomplish ink-train-dampening while using exactly the same spiral-brush water-input hardware.

We believe this dampening efficiency difference is directly related to the mulling of water into ink or lack of it. This infers that one can apply too much water due to mechanical inefficiency even when the printed result infers that the operation is at the lowest allowable level, just above scum. Perhaps mechanical inefficiency conditions should be termed excess water input rather than overdampening. The former is a mechanical press design term, the latter a chemical process term. The effects on ink/water interaction and, therefore on press operation, are not the same.

Water must build up in the ink during the lithographic process. Our keyless printing results point out the importance of efficient dampening. And efficient dampening resides not only in the mechanics of the water input system, it is also a function of how uniformly the water is mulled into the ink before it is presented to the plate.

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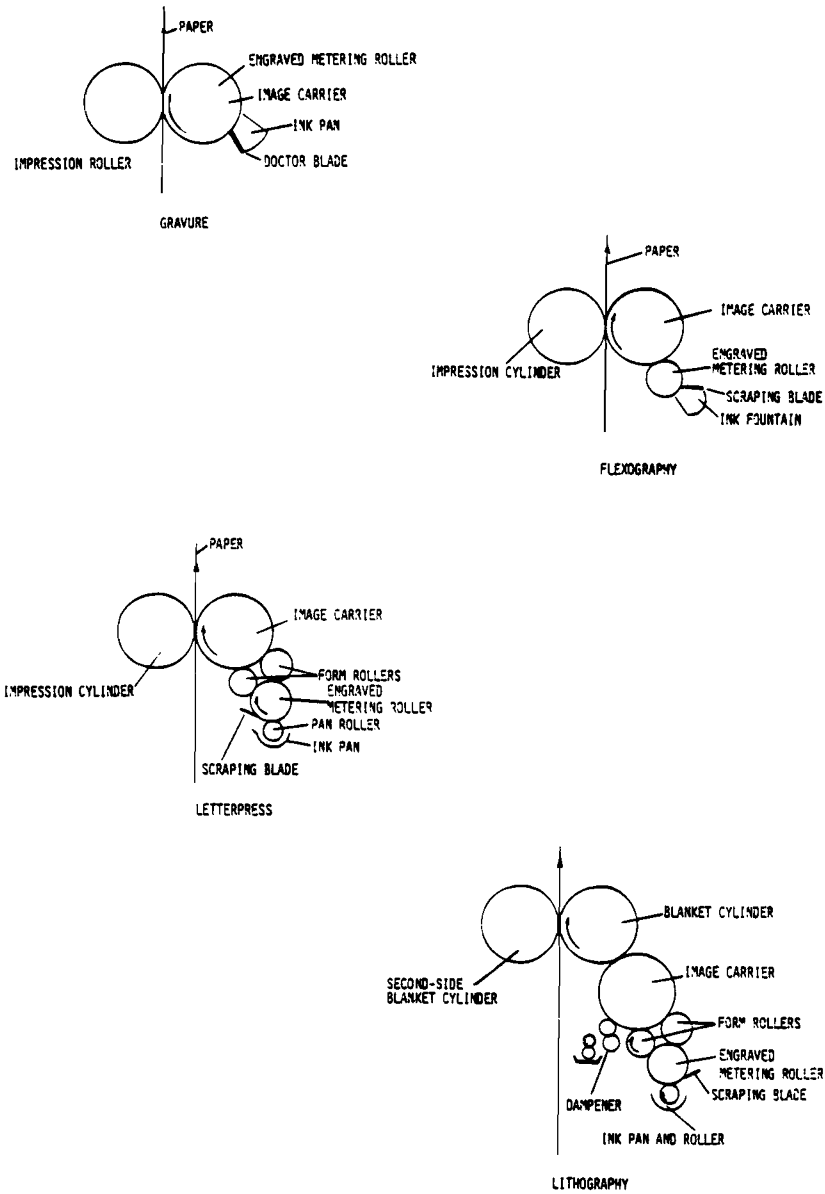
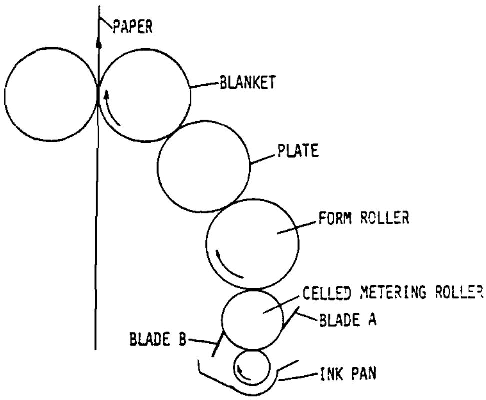
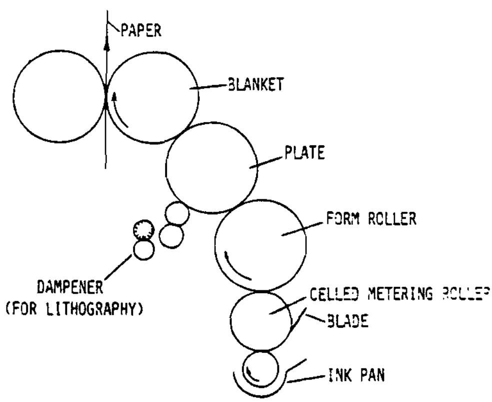


FIGURE 1. ELEMENTS OF KEYLESS PRINTING PRESS SYSTEMS



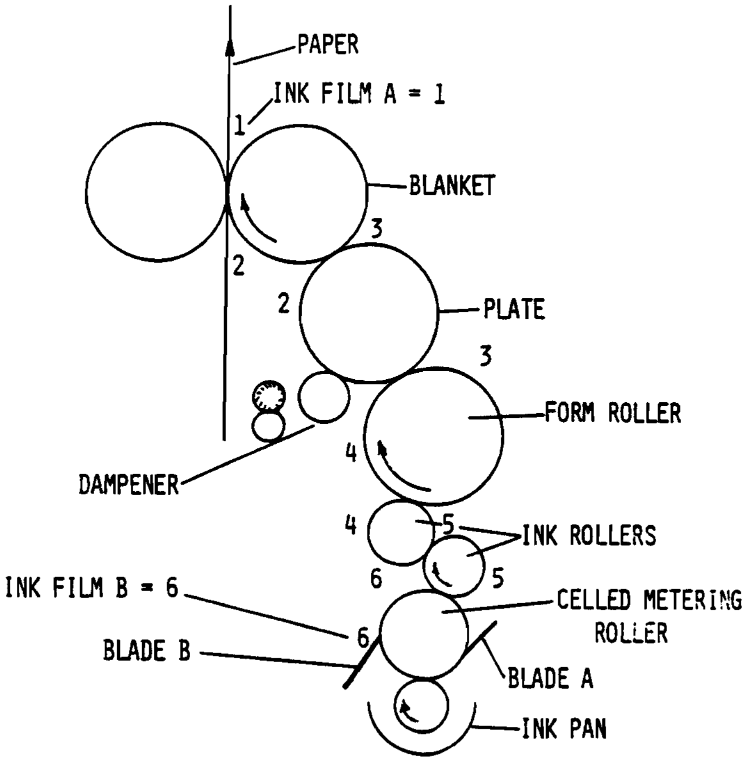
BLADE A REMOVES EXCESS INPUT INK.
BLADE B REMOVES EXCESS UNUSED INK.
SINGLE FORM-ROLLER SHOWN FOR BREVITY.

FIGURE 2. KEYLESS INKING WITH PASTE INKS



SINGLE FORM-ROLLER SHOWN FOR BREVITY

FIGURE 3. OPERATIONAL COMPONENTS FOR PASTE-INK KEYLESS PRESSES



INPUT AND RETURN INK FILMS IN LONG-INKER KEYLESS LITHOGRAPHY

INPUT/RETURN RATIO (B/A) = 6

AT 100% IMAGE, B/A VOLUMES = 6

AT 20% IMAGE, B/A VOLUMES = 30

AT 5% IMAGE, B/A VOLUMES = 120

FIGURE 4

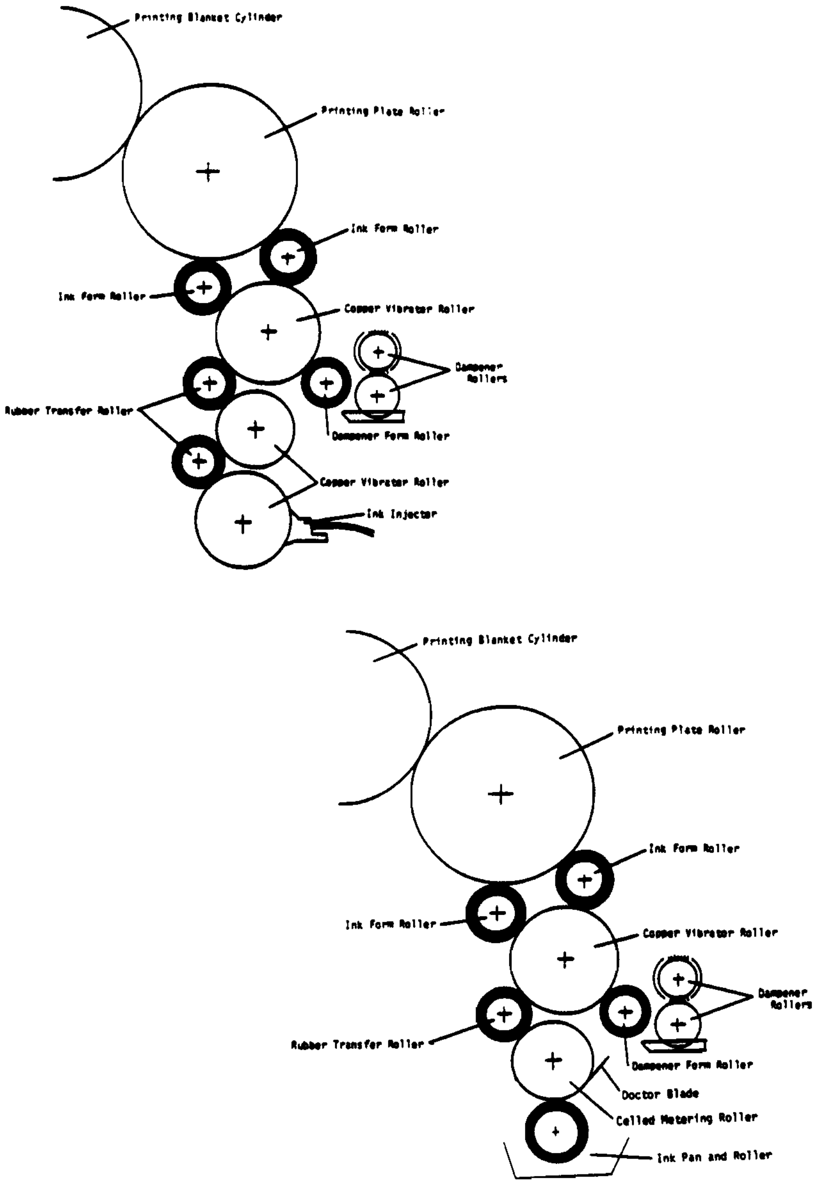


FIGURE 5. TYPICAL CONVENTIONAL NEWSPAPER PRESS INKER CONFIGURATION COMPARED WITH KEYLESS RETROFIT

SHORT-INKING-TRAIN VARIATION OF GOSS KEYLESS INKER

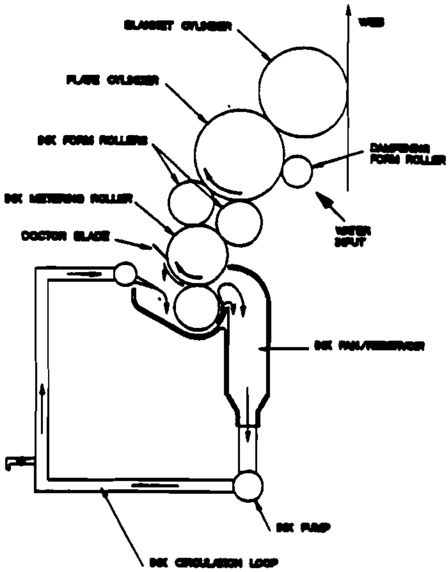


FIGURE 6

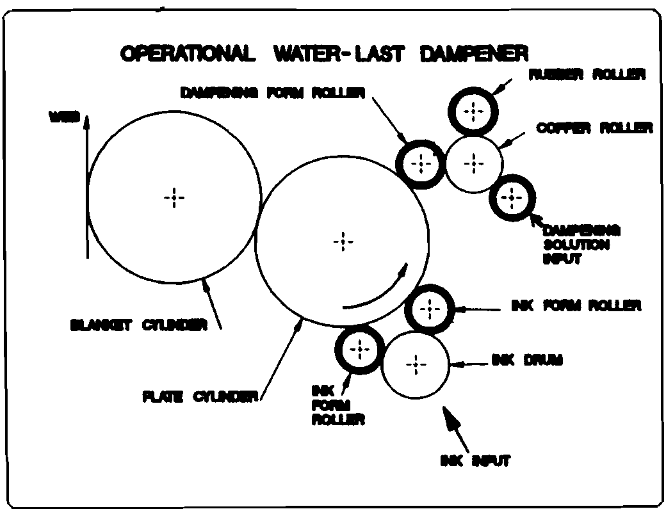


FIGURE 7

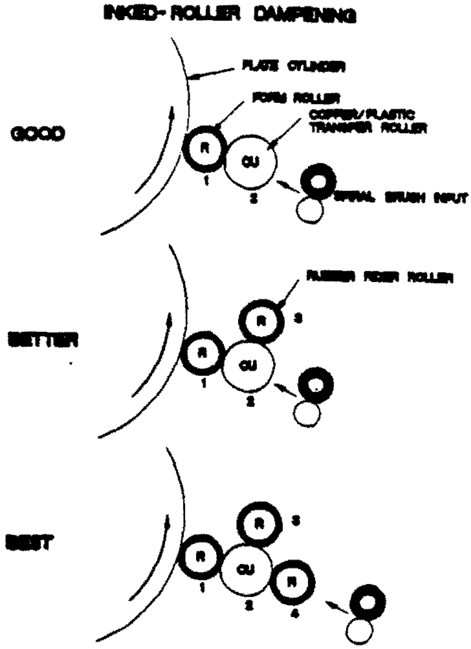


FIGURE 8

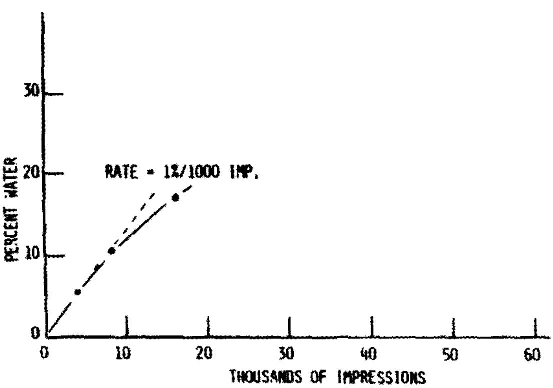


FIGURE 9. INK PAN WATER CONTENT DURING KEYLESS LITHOGRAPHIC PRINTING

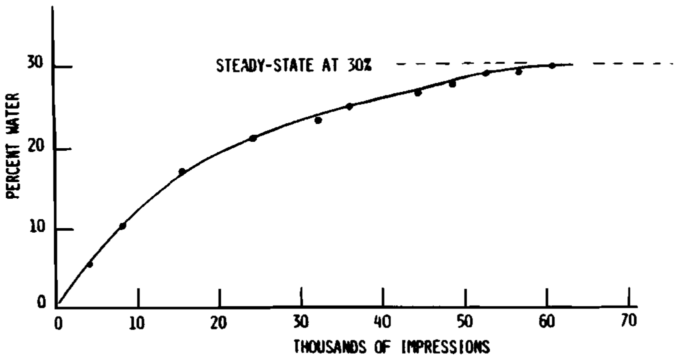


FIGURE 10. INK PAN WATER CONTENT FOR EXTENDED KEYLESS LITHOGRAPHIC PRINTING

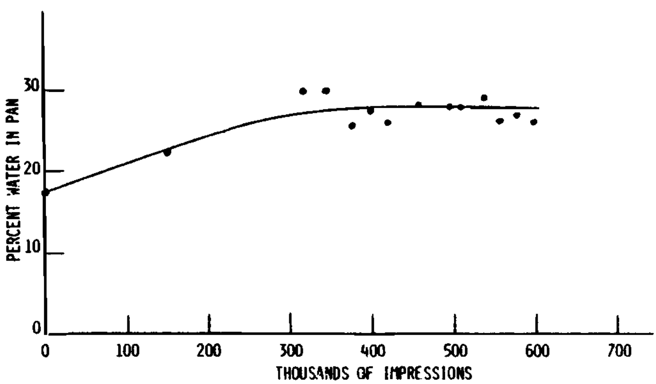
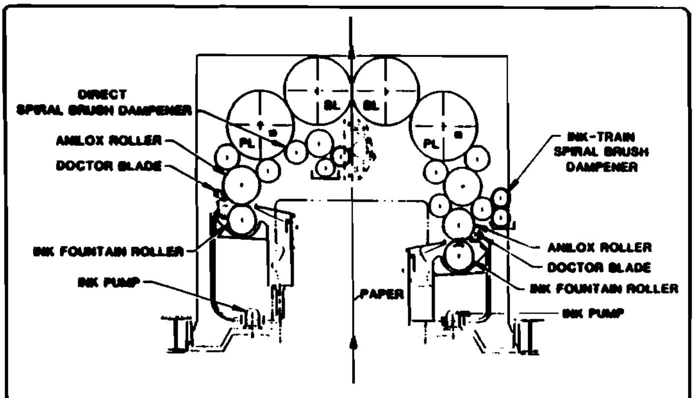


FIGURE 11. STEADY-STATE IN KEYLESS LITHOGRAPHY



EXPERIMENTAL KEYLESS OFFSET UNIT
METRO OFFSET CONVERSION

FIGURE 12

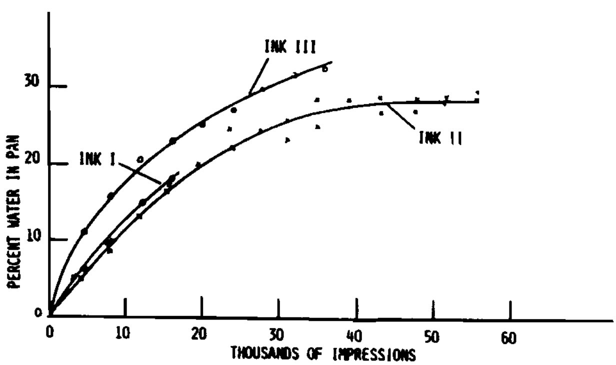


FIGURE 13. WATER PICK-UP DURING KEYLESS LITHOGRAPHY BY THREE INKS

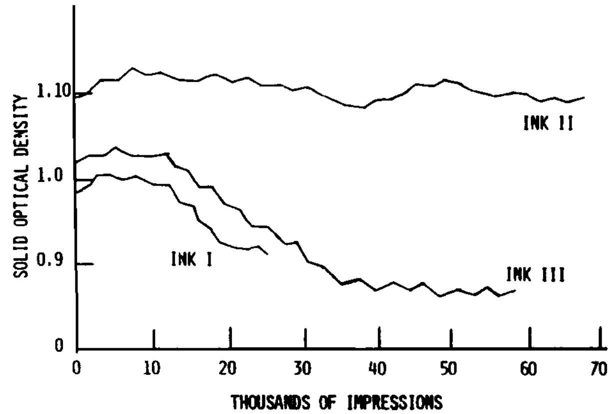


FIGURE 14. OPTICAL DENSITY OF THREE INKS PRINTED BY KEYLESS LITHOGRAPHY

KEYLESS INKING RESULTS VERSUS DUKE TEST

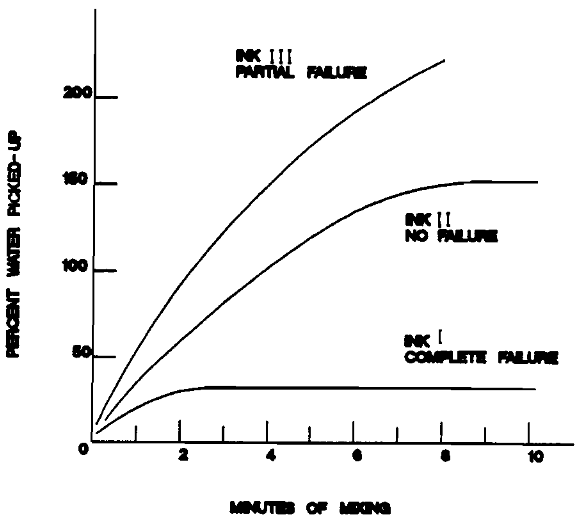


FIGURE 15

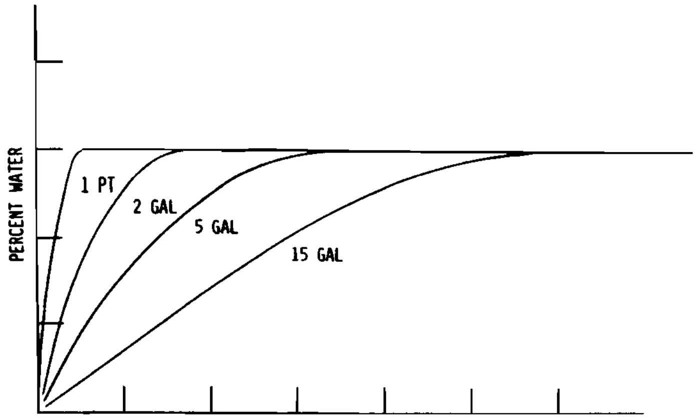


FIGURE 16. STEADY-STATE AS A FUNCTION OF INKER VOLUME

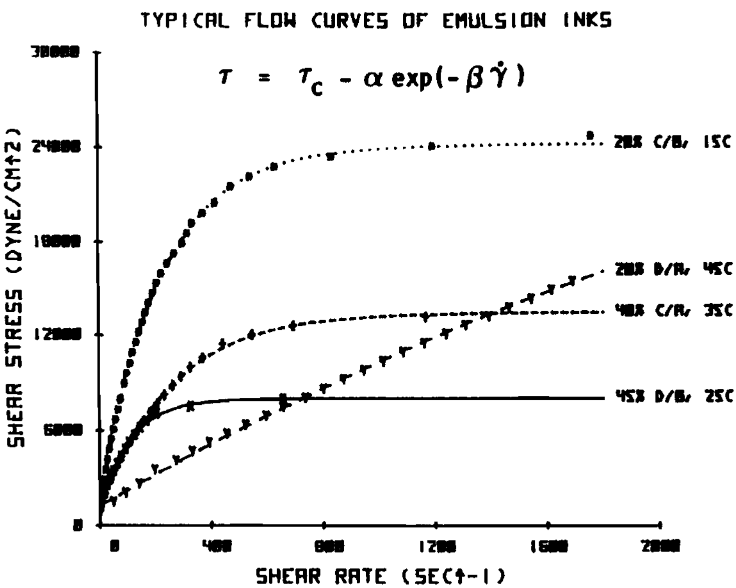


FIGURE 17