BETTER PRESS CONTROL WITH SIMULATION OF INK AND WATER FLOWS

Seppo Juntunen, Gunilla Laakso and Ulf Lindqvist *)

Abstract: The theoretical background of offset unit simulators has been considered. A press unit simulator taking both ink and water split, emulsification and the formation of free water films and evaporation into account is developed. Adequate parameter values have been searched for by means of a test printing series on the laboratory's TAPA press. The ink and water flows in the unit as well as the density profiles have been studied by simulating and by comparing the measured and simulated results. Farther development of the simulator and new projections are discussed.

1. INTRODUCTION

The use of simulation models for progressive testing of industrial processes is widely spread. In studying printing processes, particularly the operation of offset printing presses, simulation models seem to be a profitable aid. The VTT/GRA simulation model for offset printing has been presented in previous reports. The primary reason for the development of the program was to verify the theoretical offset model worked out in the laboratory dealing with the ink and water flows at the same time. Successfully, the simulation program gives a better understanding of the process in an economic way. Different press constructions, their advantages and disadvantages can be studied by means of simulation.

---

*) TECHNICAL RESEARCH CENTRE OF FINLAND
Graphic Arts Laboratory
Tekniikantie 3, 02150 Espoo 15, Finland

The simulation program was constructed on the basis of the Rech model /Rech 1971/, in addition to which the water flows are considered as well. A limitation of both these models is that they do not include the side flows, that is, they are one-dimensional. Other models for the ink flow are the Mill model /Mill 1961/ to optimize the ink feed, the Solna model /Solna 1973/ to improve the inking units, and the Hull model /Hull 1968/ to e.g. calculate the ghosting. McPhee /McPhee 1979/ and Liebing & Riedl /Liebing & Riedl 1978/ have studied and modelled the water flows through the offset units. The influence of the side flows has also been studied by several authors. Schmitt /Schmitt 1979/ has presented an advanced model for the control of the ink balance in the lateral direction. Bernauer & Grubel /Bernauer & Grubel 1975/ have studied both the ink flow and the water flow, but they have not considered the emulsification of water in the ink.

So far the VTT/GRA program has been used to simulate one offset press, the Graphic Arts Laboratory's TAPA press, and test printings have been made to get material for comparison. The printed density profiles that depend on different factors have been studied. The step response of the press has been examined primarily in regard to the ink. One measurement has been taken from the test printings in view of the water response. Studies of the ink and water transport through the unit have been made by simulations only. Factors affecting the transfer of water on the printing substrate, e.g. the parameters, have been analysed.

2. VTT/GRA SIMULATION MODEL

The VTT/GRA simulation model is, as mentioned before, characterized by the simultaneous dealing with the ink and water transport in the press. It gives an opportunity to check how the water transfer is affected by the ink in accordance with the assumptions. The factors considered in every nip are the ink and water film splits and the emulsification of water in the ink. The versatility of the simulation model is obvious also with regard to the types of printing units which can be simulated: both lithographic and letterpress units may be tested.

Postulates (see Appendix):

- ink split in the nips (Eq. 1)
- ink transfer (Eq. 4)
- surface water film split in the nips and on the paper (Eq. 2)
- emulsification in the nips and on the paper (Eq. 2)
- water film split between the nonprinting areas on the plate and the ink form rollers (Eq. 5)
- evaporation of the surface water from the roller surfaces (Eq. 3).

As regards the approximations in the program, rounding-off errors may occur because of the limited accuracy. Every roller is expected to have the same approximate temperature (affecting the evaporation of the surface water), and once emulsified the water cannot return into surface water between two nips. The flows in the lateral direction are ignored.

3. PRELIMINARY RESULTS

Table 1 illustrates the features that theoretically can be estimated by means of a simulator built on the principles mentioned before.

We have consentrated our interest on the features marked by *) in the table. The arrangements of the printing trials and simulations are listed in Table 2. Figure 2 gives an image of the TAPA press used in our experiments.

3.1 Dependence of the Density Profile on the Ink Feed, Layout and Use of Riders

According to the simulation results the absolute density variations increased when the ink feed level was raised (see Fig. 2). On the other hand, if the ink feed is sufficient the print roughness decreases with an increase in the ink feed, as indicated by the simulation calculations (Fig. 3).

TABLE 1. FEATURES ESTIMABLE BY THE SIMULATOR.

-INK ROUGHNESS ON THE ROLLERS
-INK TRANSFER ON THE PAPER
-PRINT DENSITY PROFILE ON THE PAPER *
-PRINT ROUGHNESS ON THE PAPER *
-SURFACE WATER ON THE PAPER *
-EMULSIFIED WATER ON THE PAPER *
-INK AMOUNTS AT THE INLET AND OUTLET OF THE NIPS
-EMULSIFIED AT THE INLET AND OUTLET OF THE NIPS
-SURFACE WATER AT THE INLET AND OUTLET OF THE NIPS
-THE DYNAMIC RESPONSE (WATER AND INK) OF THE PROCESS *
-THE EFFECTS OF VARIOUS INKING AND DAMPENING UNIT CONSTRUCTIONS

TABLE 2. THE RUN SCHEME IN THE SIMULATION AND PILOT PRINTING TRIALS.

TRIAL	INK FEED	WATER FEED	ROLLER CONSTR.	LAYOUT
1	0.437µm	2.000µm	WITHOUT RIDER	1
2	0.540 "	"	"	"
3	0.586 "	"	"	"
4	0.355 "	"	"	"
5	0.710 "	"	"	"
6	0.510 - 0.645µm	"	"	"
7	0.454µm	"	"	2
8	0.462 "	1.290 - 2.530µm	"	1
9	0.710 "	2.000µm	WITH RIDER	"

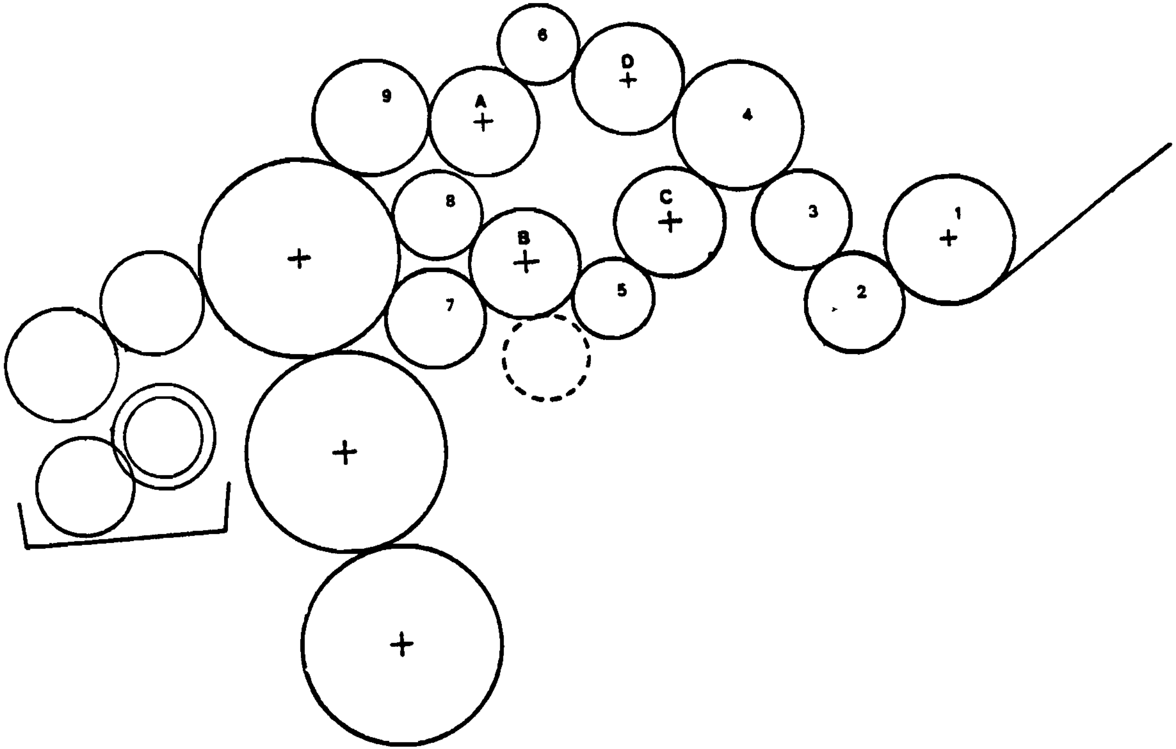


Figure 1. The TAPA offset press.

DENSITY PROFILES

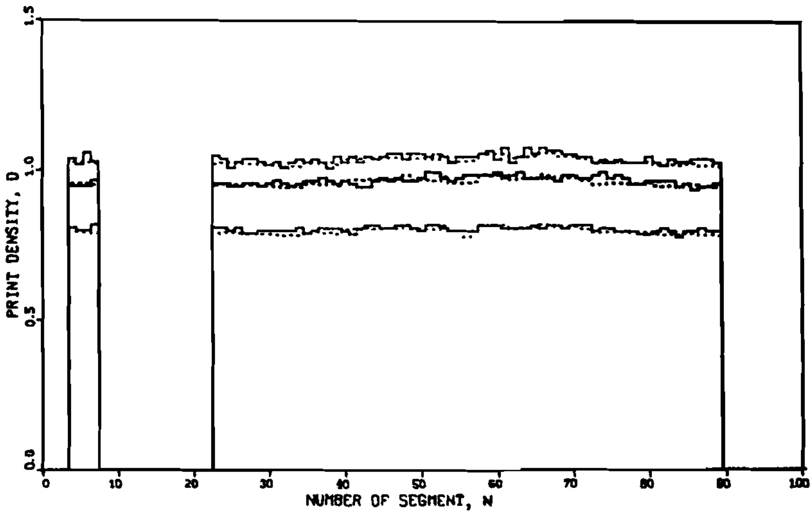


Figure 2. The density profiles produced on three different ink feed levels.

PRINT ROUGHNESS

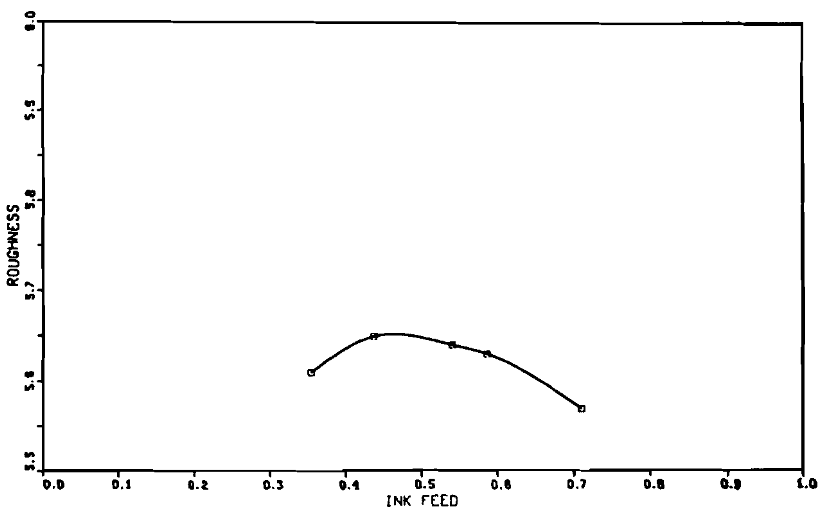


Figure 3. The print roughness as a function of ink feed level according to the simulation calculations.

The print layout has an essential effect on the local density profile produced. Both the relative image area and the form of the layout influence the longitudinal density distribution. Especially problematic is a layout consisting of printing surfaces that correspond to the perimeter of the last form roller. Fig. 4 illustrates how these effects can be predicted by means of simulation calculations.

The use of rider rollers has a dual effect on the process output. The rider roller levels the ink stream and acts as an additional ink capacitor that buffers the instantaneous density variations. The density variations are, of course, smoothed by the roller (Fig. 5).

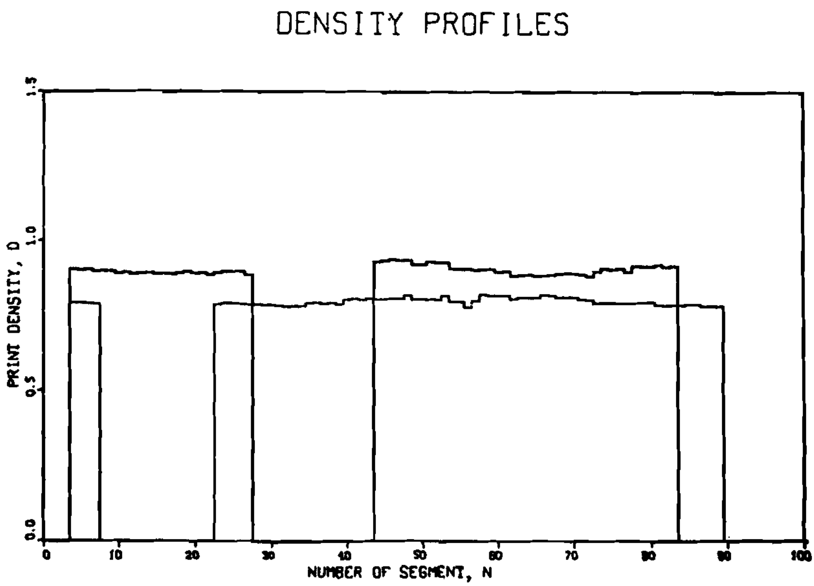


Figure 4. The density profiles produced using two different print layouts.

DENSITY PROFILES

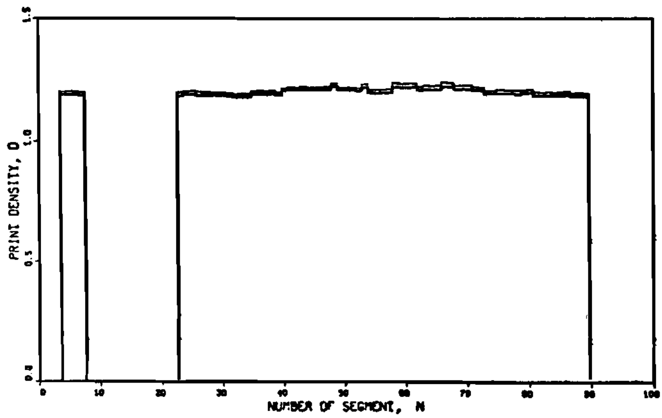


Figure 5. The effect of a rider roller on the density profile produced.

3.2 Step Responses of the System

The transfer function

$$G(s) = \frac{e^{-\theta s}}{(\tau_1 s+1)(\tau_2 s+1)}$$

was used to identify the process. The parameters θ, τ_1 and τ_2 were calculated on the basis of the simulation and pilot printing tests. The responses were determined by using the print density as the output signal (not the actually transferred ink amounts).

The capacities and dead times calculated on the basis of the printing trials were consistenly greater than those determined by the simulations (see Figs. 6 and 7). Table 3 gives a summary of the results. The differences between the results may be due to the following points:

- In practice, the distributing flows (distributors) affect the zonal ink transfer

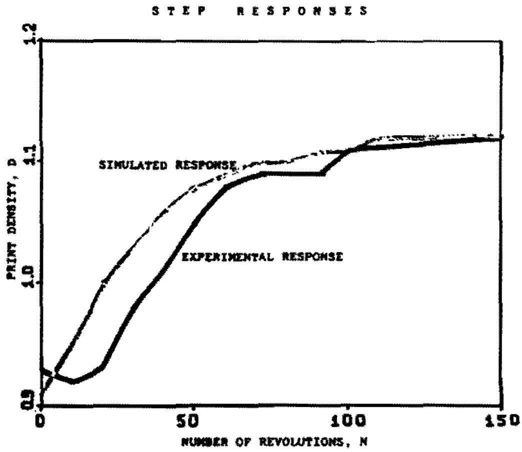


Figure 6. The simulated and experimental step responses of the inker.

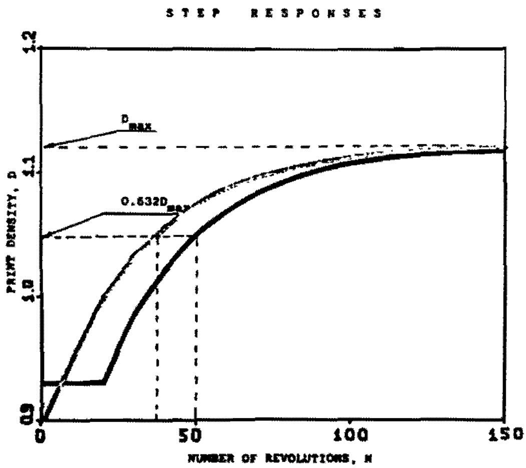


Figure 7. The step responses of the inker calculated by the identified transfer function.

TABLE 3. THE TRANSFER FUNCTION PARAMETERS AS IDENTIFIED BY SIMULATIONS AND PILOT TRIALS

PARAMETER	VALUE ESTIMATED BY SIMULATIONS/PILOT TRIALS
Θ	0 / 20
T_1	30.3 / 30.4
T_2	0 / 0

- The time dependence of the ink's rheological behaviour influences the response of the ink feed
- The method of calculating the water amounts on the rollers idealizes the adapting rate of the unit.

The dead time in the inking unit, i.e. the time during which an ink dose from the ductor reaches the paper, was about 20 printing revolutions according to the pilot trials and 0 revolutions according to the simulation runs. This difference is mainly explained by the rheological behaviour of the ink. The ink split and the settling on the roll surfaces are affected by its yield strength and its viscosity level. These aspects are not taken into account in the VTT/GRA simulator. In the calculations, too, the changes in the thickness of the ink layer are assumed to happen instantly, while in practice reaching a new balanced ink layer on the ductor roll takes some time.

In the simulation runs, following a step change in the ink feed level a new balance was reached after circa 220 revolutions, whereas in the pilot tests the corresponding period was about 230 revolutions (see Fig. 7).

The simulation calculations did not show any noticeable differences between the step responses upwards and downwards. In practice, the inking unit has a certain ink and water retaining capacity, which surely affects the responses. The literature /Lehtonen 1978/ also brings references to the difference between the two responses. Increasing the ink feed has shown a smaller time constant than decreasing.

In the test printing to study the water feed response an 'overshoot' was registered, reaching a peak after circa 15 revolutions. The reason for this phenomenon was most likely the short distance between the water input and output points. Part of the applied water reached the output point very quickly, while the rest circulated through the inking unit and reached the output little by little. The final balanced level could not be reached until after some hundred revolutions. In the simulations the final level was attained more quickly. The simplifications made in the modelling of the water feed and emulsification mechanisms make the simulated response more direct. The degree of emulsification is in fact dependent on the actual amounts of ink and water. The surface chemical aspects, too, are very complicated in the sense of mathematical modelling.

Summarizing the experience attained in this work we may say that both the simulation and experimental runs showed the dynamic character of the offset process. A change in the water feed level for example may require an unexpectedly long time to get balanced.

3.3 Ink Flows

Rech's /Rech 1971/ simulations have shown that it is advisable to lead the main ink flow by way of the first form rollers to let the last form rollers act as smoothing units.

An increased number of rollers does not necessarily improve the quality. The geometry of the roller structure on the other hand has a great influence on the quality.

Fig. 8 illustrates the ink and water flows in an offset press.

According to a simulation run a rider roll placed in the lower part of the inking unit decreases the printing roughness and the rate of the ink flow changes.

To find out the effect of the ink split coefficient on the ink flows some additional simulations were carried out. When the split coefficient was estimated at 0.6, the total ink flow, that is, the total ink transfer was found to be affected. The simulation calculations indicated that the relations between the ink streams were not changed, only the ink feed level was changed.

3.4 Water Flows

The ink transfer is important for the water flows; the water content is greater in areas with a small ink requirement than in areas with a large ink requirement. These differences become more obvious when the water feed is increased.

The simulation model gives a clear picture of the water transfer in the inking unit. Fig. 9 shows the water distribution in the TAPA-unit on two different damping levels. The percentages are the total water amounts given by simulations.

When the emulsification parameter was increased from 0.3 to 0.5 the water amounts in the inking unit rose a little. Also the relative water amounts in the image on nonimage areas corresponded better with the practical results. When the amount of water fed on to the plate was 1.4 μm, the corresponding amounts on the paper were 0.33 (image area) and 0.32 μm (nonimage area), using the emulsification parameter 0.3. The increasing of the emulsification parameter to 0.5 resulted in the water amounts of 0.32 and 0.24 μm.

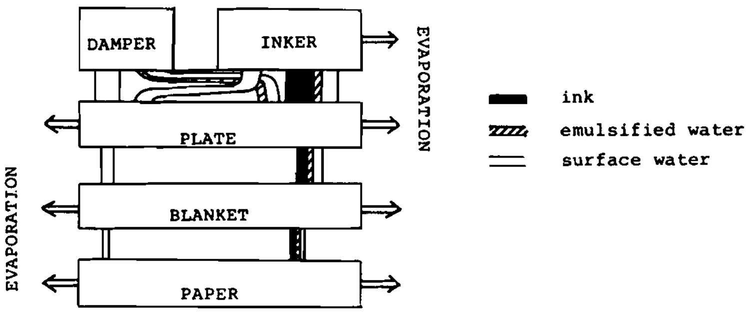


Figure 8. The ink and water flows in an offset press unit.

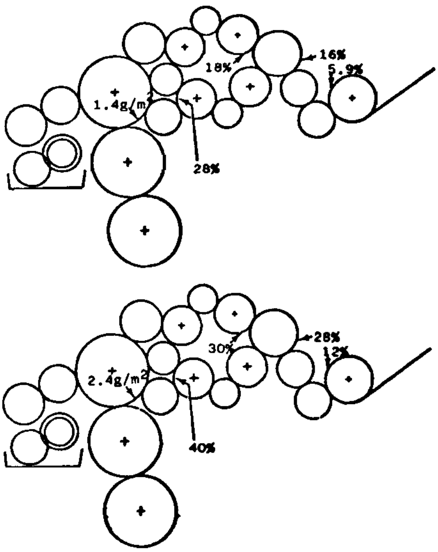


Figure 9. The water distribution in the inker on two different damping levels according to the simulation calculations.

The parameter that describes the division of water between the nonimage area on the plate and the form rollers, influences the water amounts in the inking unit and on the paper. If the image areas of the plate receive more water in the emulsified form, the overall water transfer decreases.

According to the simulation calculations the emulsification parameter in the nips can vary in the range of 0.3-0.5. The water split coefficient of the nips with ink on both rollers is about 0.5.

3.5 Validity Evaluations

The simulation of the ink feed in continuous inking units revealed to be a real problem. A proper way of dealing with this problem would be to consider an even ink film on the ductor roller after the ink blade and a correct ink split between the ductor roller and the following roller, which rotates at the same speed as the rest of the inking unit, whereas the ductor roller has a remarkably slower speed. Despite the fact that a series of measurements was taken on the ductor roller both before and after the nip to ascertain the ink film thickness, no valid ink split factor or even ink split function depending on the film thickness could be found in relation to the test printings, i.e. the printed results.

For good reason the ink feed can then be simulated by giving a constant supplement of ink to every segment on the roller next to the ductor roller in the nip, supposing that the other nips' ink split factors are known, generally 0.5. This constant addition of ink then equals in a steady state the ink transfer on the paper per segment.

By comparing the step response of the ink, achieved by means of the test printings, with the step response simulated by the two methods referred to above we found that the response simulated with a constant ink supplement on to the roller next to the ductor roller comes much closer to the printed response. This applies to the final value and the slope of the curve and can be considered to be another indication of the validity of the simulation method.

In principle the water feed can be calculated per segment of the plate cylinder when the total consumption of water from the water trough is known. In compliance with the ink feed the water feed can be simulated by providing a constant amount of water on to the plate and allowing the image areas to take up a certain part of it. This method signifies an oversimplification, but it should be usable since this part of the offset process has been explored very little.

Some of the simulation results have been verified by means of the test printings, others being either sensible or in congruence with other measured results. This is how the tolerance limits of the essential parameters used in the simulation model have been estimated. Simulations then permit a satisfactory study of the effect of the layout on the density profile. The simulation program also gives valuable information on the ink and water flows, i.e. the amounts of ink and surface and emulsified water in the different parts of the press. It seems that the water amounts are too high in the upper part of the inker, which indicates, that the evaporation of the surface water should be more effective.

4. DISCUSSION AND CONCLUSIONS

Because of its complicated character the offset process is a well reasoned object of simulation studies. Simulation offers a fast and inexpensive method for obtaining information of the dynamic behaviour of the process and for making comparisons between the various constructions. Simulation is also a valuable instrument in developing control strategies.

4.1 Evaluation of the Accomplished Work

The simulation program now introduced is based on the principle of segmenting the rolls of the inking unit. The water and ink films on the segments of equal length are calculated as they advance from one nip to another by using the numerical values of the previous nip as input information. This provides a convenient description of the process for studying both the static and the dynamic behaviour.

The following mechanisms are taken into account in the program:

- Ink film split in the nips
- Water film split in the nips
- Emulsification of water in the ink
- Formation of surface water films
- Surface water evaporation
- Ink transfer to the paper
- Water transfer to the paper
- Formation of print density.

To verify the simulator, pilot test runs were performed in the laboratory's TAPA-press. According to the results the simulator is well-suited for evaluating the ink and water flows in an offset press.

Density variations in the longitudinal direction (ghosting) can be successfully predicted by means of simulation runs.

When identifying time constants and dead times for the ink and water feeds smaller values were registered in the simulation runs than in the pilot test runs. The practical reasons for this were easy to find.

The simulation results indicate that the so-called emulsification parameter has a practical value close to 0.5.

In its present form the program is an effective way of accessing the time domain performance of the inking and dampening units, the water and ink transfer to the paper and the density profiles. We plan to use the offset (and letterpress) unit simulator to

- evaluate the feasibility of the inking unit construction,
- evaluate the feasibility of the dampening unit construction,
- test different strategies of the press run, the press start and the press stop,
- optimize the location of the testing devices

in order to control the press,
- characterize the behaviour of different materials by means of certain measured parameters,
- get information about a particular press construction with a particular material combination.

4.2 Needs for Further Development

The most important deficiences of the model are its one-dimensionality, the layout being restricted to solid prints, the complicated printout and the exclusion of some important special mechanisms.

"Trapping", i.e. the hindered transference of ink in multicolour wet-on-wet printing is the most significant of these mechanisms. Press manufacturers do not regard one-dimensionality as a great lack, because the side flows and distributing effects are well known and controlled phenomena. The halftone prints, on the other hand, may seriously affect the reliability of simulation calculations. Also, the effects of the damping level on the ink tack and the print density may be remarkable.

4.3 New Projections

Today the simulator is being developed further to incorporate

- more printing units (1...4 units) and
- to include halftone prints in the layout.

We intend to investigate and model the effects of the damp feed on the print density.

The program printout will be developed from its present compactness into a more illustrative form.

ACKNOWLEDGEMENTS

The authors are greatly indepted to Solna Offset AB, and especially their technical manager Rune Lundbladh, for their support and cooperation, and also for their permission to publish the results. We also want to thank Ms Airi Gaib, M.A., for linguistic corrections.

REFERENCES

Rech, H.
1971 "Beiträge zur experimentellen und rechnischen Untersuchung des Farbtransportes in Walzenfarbwerken von Druckmaschinen," Technical University, Darmstadt, Institutsbericht 1/1971.

Mill, C. C.
1961 "An experimental test of a theory of ink distribution," Advances in printing Science and Technology, vol. 1.
Ed. W. H. Banks, Pergamon Press, Oxford.

Anon.
1974 "Simplified inking," British Printer, May, pp. 114-115.

Hull, S.
1968 "The theoretical analysis and practical evaluation of roller ink distribution system," TAGA Proceedings, pp. 288-315.

MacPhee, J.
1979 "An engineer's analysis of the lithographic printing process," TAGA Proceedings, pp. 237-277.

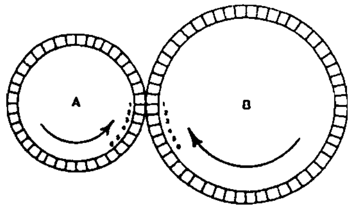
Liebing, H. and Riedl, R.
1978 "Zur vorbestimmten Feuchtung im Offsetdruck," Papier und Druck, vol. 27, no. 7, pp. 101-105.

Schmitt, H. J.
1979 "Steuerung der Farbdosierung bei Offsetdruckwerken durch rechnergestutzte Modellvorhersagen," Karlsruhe Kernforschungszentrum, 94 pp.

Bernauer, J. and Grubel, H.
1975 "Verfahrenstechnik des Offsetdrucks und dessen Simulation als Grundlage für Konstruktion und Praxis," Der Polygraph, vol. 28, no. 4, pp. 216-218, 220; vol. 28, no. 7, pp. 448, 450, 452.

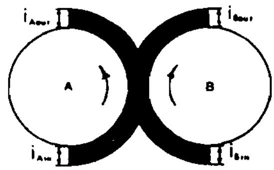
Lehtonen, T.
1978 "Studies on the controllability of inking in lithographic printing presses," Technical Research Centre of Finland, Graphic Arts Laboratory, Report 16.

APPENDIX A



SIMULATION MODEL FOR A ROLLER INKING UNIT

INK SPLIT

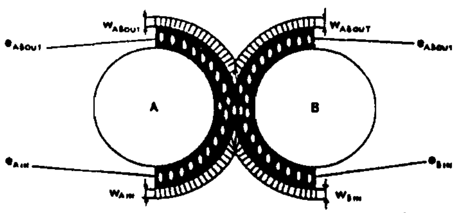


$$i_{Ain} + i_{Bin} = i_{Aout} + i_{Bout}$$

$$i_{Aout} = a_{Aout}\left(i_{Ain} + i_{Bin}\right) \quad (1)$$

INK SPLIT MODEL

WATER SPLIT



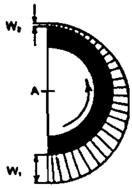
$$w_{Ain} + w_{Bin} + e_{Ain} i_{Ain} + e_{Bin} i_{Bin} = 2 w_{ABout} + e_{ABout}\left|i_{Aout} + i_{Bout}\right|$$

$$p\left(w_{Ain} + w_{Bin} + e_{Ain} i_{Ain} + e_{Bin} i_{Bin}\right) = e_{ABout}\left(i_{Aout} + i_{Bout}\right) \quad (2)$$

WATER SPLIT MODEL

(APPENDIX A, continued)

TOTAL EVAPORATION OF SURFACE WATER



$$\Delta w = \frac{q_0 S}{\rho}\left[\frac{1}{v} + k\right]\left[\frac{T}{T_0}\right]^b \qquad (3)$$

EVAPORATION OF SURFACE WATER

For the ink transfer on the paper the Walker-Fetsko equation is used

$$\begin{cases} y = C_A\left[b\,C_B + f\,(x - b\,C_B)\right] \\ C_A = 1 - e^{-kx}, \quad C_B = 1 - e^{-x/b} \end{cases} \qquad (4)$$

The water film split between the nonprinting areas on the plate and the ink form rollers is assumed to happen in accordance with equation 5 (A = plate, B = form roller)

$$\begin{cases} W_{B_{out}} = c\,(W_{A_{in}} + W_{B_{in}}) \\ W_{A_{out}} = (1-c)\,(W_{A_{in}} + W_{B_{in}}) \\ e_{B_{out}} = e_{B_{in}} \end{cases} \qquad (5)$$