Seppo Juntunen and Ulf Lindqvist *

NOVEL DEVELOPMENTS IN THE AREA OF PRINTING PRESS SIMULATION

Abstract

PRESSIM, the latest version of the VTT/GRA*) offset process simulator has been evaluated both theoretically and in relation to some empirical results. Special attention is paid to the zonal time constants in the inking system. Interesting phenomena in process behaviour predicted by the simulator have been verified in pilot scale printing trials. The ink residence time (the zonal time constant plus dead time) seems to be strongly dependent on the relative ink consumption on the paper. Simulations also show the differences in responses upwards and downwards. When taking the distribution effects into account a more precise comprehension of the press dynamics is attained, which is also demonstrated by simulation results.

One of our next developmets is the PRINTSIM training simulator, the idea of which is to use a press simulator connected with a modern control system to help the printers to get familiar with the newest press operating environments. The aims and the state of this project are discussed.

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*) VTT/GRA = The Graphic Arts Laboratory of the Technical Research Centre of Finland

1. INTRODUCTION

The dynamic character of the offset process causes certain difficulties in the development of control systems. The Graphic Arts Laboratory has made intensive background studies of this process during the last ten years. In the course of these investigations a simulator program was designed for process dynamics. The latest version of this program, PRESSIM, is the main subject of this paper.

2. MODEL EQUATIONS IN PRESSIM

PRESSIM is based on model equations developed in VTT/GRA's experimental an theoretical research /1,2/. These model equations are used to estimate the film splits of ink and water, the emulsification and evaporation of the surface water, the material transfer in two directions, and the print formation.

2.1 Ink transfer in the roller system

2.1.1 An ordinary nip

The film split in the nip between two rollers can be estimated by the equation

$$T_1^{out} = \alpha(T_1^{in} + T_2^{in}) = \alpha T \qquad (1)$$

in which T represents the total amount of ink passing through the nip and α is the so-called film split coefficient. In practice, α , to some extent, depends on the total amounts of ink and water in the nip.

2.1.2 The nip between a form roller and the plate cylinder

A surface with a compact ink layer comes here into contact with a surface that totally or partially rejects ink. We have modelled the behaviour of the ink on the following principles:

- The film split coefficient determines the relative film thickness in all the cases (independent of the relative inked area).

- After the film split the ink layer on the form roller element becomes even.

Mathematically, this principle can be expressed by the equations

$$T_\sigma = T_1^{in} + fT_2^{in} \qquad (2)$$

$$T_2^{out} = \alpha T_\sigma \qquad (3)$$

$$T_1^{out} = T_\sigma - fT_2^{out} \qquad (4)$$

where f represents the relative image area on the element.

2.1.3 The printing nip

The halftone ink transfer is calculated in PRESSIM program by an equation derived by Oittinen /3/:

$$Y(x) = F(x)A(x/F0)(bB(x/F0)(1 - c) + c(x/F0)) \qquad (5)$$

in which $A = 1 - e^{-ax/F0}$ and $B = 1 - e^{-x/bF0}$. a, b and c are the parameters in the Walker-Fetsko equation. F(x) represents the effective halftone dot area. It has been experimentally found that F(x) can be approximated by the equation

$$F(x) = F0^{1 - e^{-s/x}} \qquad (6)$$

in which F0 is the true halftone area on the plate and s represents the physical dot spread.

2.2 Water transfer in the inker

To be able to simulate the water transfer in the system we have had to make certain simplifications. The dependence of the water-ink interaction on the surface chemical aspects and the rheological factors are not included in the model.

The ink-water interaction in the nip is charactrized only by one parameter that describes the emulsification capacity of the ink.

2.2.1 Non image elements in the form nips

Here a hydrophilic surface comes into contact with an inked surface with free water and emulsified water. Since the plate has just received some water in the dampening unit. the water transfer into the inker takes place in the contact through the surface water layers or by increasing also the amount of emulsified water. These principles are expressed mathematically as follows:

$$sw_f^{out} = k(sw_p^{in} + sw_f^{in}) = kSW^{out} \tag{7}$$

$$sw_p^{out} = (1-k)SW^{out} \tag{8}$$

$$e_f^{out} = e_f^{in} \qquad \text{or} \tag{9}$$

$$e_f^{out} = \min(p,(sw_p^{in} + sw_f^{in} + e_f^{in} T_f)/T_f) \tag{10}$$

$$sw_f^{out} = k(sw_p^{in} + sw_f^{in} + e_f^{in} T_f - e_f^{out} T_f) = kSW^{out} \tag{11}$$

$$sw_p^{out} = (1-k)SW^{out} \tag{12}$$

in the equations sw is the amount of surface water,
e " " emulsification rate,
k " " split coefficient of the surface water (ca. 0.5), and
p is the emulsification parameter.
Index p represents the plate cylinder and index f the form roller.

The emulsification parameter p describes the relative amount of water that the ink can receive. We have assumed that all the nips have pressure and shear forces strong enough to emulsify the water to the degree limited by p. If the amount of water in the nip is larger than p*the amount of the ink the excess remains in the form of surface water. An experimental work /2/ has confirmed that the water transfer through the non-image areas may be quite intensive.

2.2.2 Image elements in the form nips

This is one of the contacts, in which two ink layers with both emulsified and surface water meet. The following relations are valid if the maximum emulsification rate in the nip is p:

$$W = sw_p^{in} + sw_f^{in} + fe_p^{in} T_p^{in} + e_f^{in} T_f^{in} \tag{13}$$

$$e_f^{out} = e_p^{out} = \min(p, W/(fT_p^{in} + T_f^{in})) \tag{14}$$

$$sw_f = k(W - e_f(fT_p^{in} + T_f^{in})) = kSW^{out} \tag{15}$$

$$sw_p = (1-k)SW^{out} \qquad (16)$$

Here W is the total amount of water. At the outlet of the nip the emulsification rate is supposed to be the same for both rollers.

2.2.3 An ordinary inker nip

In this case equations (13-16) can be used - p and k may be different in each nip. Here, of course, f is 1.

2.2.4 Nip contacts with no ink

Such contacts may be found in the inker in places where the dampening water has come before the ink and in the offset nip. The water film split can be expressed by the equation

$$sw_1^{out} = k(sw_1^{in} + sw_2^{in}) = kSW \qquad (17)$$

which is analogous to the equation (1).

2.2.5 Printing nip

It is very difficult to give a precise description of the way the water behaves in this nip, because the quality of the paper may have unpredictable effects. However, we propose the previous simple film split model (equations 5, 9 and 17) to calculate the material division in the printing nip.

2.2.6 Evaporation of surface water

One of the roller system functions is the undisturbed transfer and evaporation of the dampening water. The evaporation rate depends on several process variables. We have modelled this phenomenon by the equation /4/

$$\Delta W = q_0 \; S(1/v + k)(T/T_0)^b \,/\rho \qquad (18)$$

in which
W is the thickness of the evaporated film, um,
q0 " " evaporation rate, usually ca. 16 mg/m2s,
S " " the length of the evaporation surface, m,
v " " the radial velocity of the rollers, m/s.

k " a constant, ca. 2 s/m,
T and T0 are the absolute and relative temperatures, K,
b is a constant, ca. 16 for normal damping solutions,
ρ is the density of the damping water, kg/m3.

2.3 Material transfer in the machine direction

In the PRESSIM program the roller perimeters are divided into segments of equal length. During the simulation the segments are connected according to the data received on the nip contacts.

During each period all the rollers advance one segment and the following actions take place:

- The ductor roller receives more ink and, in the case of a vibrator roller inker. the state of the vibrator roller is calculated.
- Water is dosed on the plate or to other places in the unit.
- In all the nips the material is distributed in the transverse direction and the splitted.
- The surface water is evaporated and the rest of the water is divided into surface water and emulsified water.
- The substrate receives ink and water.

The run is divided into simulation revolutions, each representing one revolution of the plate cylinder.

The segmenting principle was first introduced in Rech's dissertation /5/. We have elaborated the idea to calculate also the cross directional transfer. In the machine direction the principle used in the PRESSIM program can be expressed in a simplified form as follows:

$$M_n = M(1,I)_n + M(2,I)_n - (\Delta W1(I) + \Delta W2(I)) \qquad (19)$$

$$M(1,I)_{n+1} = R(I)M_n \qquad (20)$$

$$M(2,I)_{n+1} = (1-R(I))M_n \qquad (21)$$

M is the total material in the nip and W1(I), W2(I) are the amounts of evaporated water between the nip in question and the two preceding nips. The indices (1,-) and (2,-) represent individual rollers and index I represent the nip.

2.6 Distribution of the material in the transverse direction

Each inker has a certain capability to distribute ink. In PRESSIM the varying distribution capabilities of the different nip types have been taken into account. For the distribution we have produced the following hypotheses:

- There is no material transfer between the inking zones during the conveyance from one nip to another.
- The zones of two rollers meet at the inlet of the nip and the material is distributed instantly in the nip before the final film split at the outlet of the nip.

The basic mathematical equations are explained elsewhere /6/ and here we resign ourselves to present the numerical formula used in PRESSIM when calculating material distribution:

$$M(k)_{n+1} = d1(M(k-1)_h + M(k+1)_n) + d2(M(k)_n)$$

in which index **k** represents the zone number.

In our program the cross directional material transfer near the printing surface is neglected, since there is practically no significant distribution in the form nips, in the offset nip and in the printing nip.

3. FUNCTIONS OF THE PRESSIM PROGRAM

For calculations the program divides the total surface area of the roller system into segments in the machine direction and into zones in the transverse direction. The layout data of the image area is fed in the form of a matrix. The elements of the matrix may independently represent any coverage. The ink film split, the division of water into surface water and emulsified water, and also the distribution effects may be parametrized nip by nip.

The ink feed may be continuous or periodical, as the feed level is adjustible zonevise.

The water feed can be arrenged on any roller.

The program has been written in FORTRAN IV an it runs also in FORTRAN V. Installed in the Technical Research Centre's CYBER computer it provides about 70 kbytes. We have installed the program also in our own VAX 750 computer.

4. EXPERIMENTAL VALIDATION OF PRESSIM CALCULATIONS

Evaluations of the dynamics of the offset process made with the PRESSIM program have given a series of new - partly astonishing - results.

First of all it was stated that it is insufficient to estimate the transfer function of the inking unit in the conventional way, without taking into account the influence of mobile ink amounts - i.e. the zonal ink consumption.

Secondly, the simulations have clarified our opinion about the differences in the apparent time constant of the inking unit, dependent on whether ink feed is reduced or increased.

Thirdly, we have been forced to reformulate the comprehension about the influence of the print lay-out on process dynamics.

In the fourth place, our new emulsification model seems to work more realistic - especially in the halftone areas - than the previous one /7/.

Finally we have showed that it is possible to evaluate the influences of the cross flows by introducing oscillating nips in the calculations.

To test the simulator we carried out a test run in the web offset press of our Institute, which is described in Table 1 and Figure 1. The printing conditions are given in Table 2.

4.1 Step response upwards

The lay-out estimate used in the tests can be given in the form of the matrix in Figure 2. The zonal ink consumption was even over the form and of the magnitude 30 per cent. The lay-out was divided into 100 segments in the machine direction and into 12 zones in the cross direction. In the tests of step response the inking profile was increased linearily across the lay-out. As output we measured solid density from five zones. Ink feed was calculated from the density models using parameter values estimated in laboratory scale printing trials. In the same way the ink transfer parameters were estimated.

In Figure 3 the simulated results are given as solid lines while the measured lines are dotted. As can be seen there is rather high correlation between the simulated and experimental data. In the simulations we used the distribution parameters

d_1 = 0.000 or 0.025 and

d_2 = 1.000 or 0.950.

From the results the relationship between the apparent time constant and the zonal ink consumption (or the mobile ink amount) can easily be seen. This result has been further illustrated in Figure 4, where the simulated and experimental time constants have been plotted versus the product of the zonal ink feed and ink consumption. The graph is somewhat similar to that presented by McPhee et al., based on simplified calculations /8/.

It can be shown theoretically that the transfer function of the inking unit can be given by delays (distances between the nips) and gains (film split factors) in a form close to the transfer function of a capasitive process /9/. The inking unit deviates from a capasitive process in the sense that the distribution of the ink elements and their disappearance from the system can be followed theoretically. This particular feature is utilized in PRESSIM. Dividing the roller surfaces into segments in the length direction in fact means, that the required data about the "near history" of the process are deposed in the elements of the printing unit. For a true capasitive process this would not be possible.

4.2 Step response downwards

The fact that the apparent time constant of the inking unit depends on the direction of the step change has been somewhat inconvenient to the experts on process dynamics. In Figure 5 simulated and experimental data are compared for a situation, where the inking unit was run empty. Both the simulated and experimental results lead to the following conclusions: The inking unit tends to retain the accepted ink for a long period. Filling the roller system is a more straightforward process than emptying a filled system. Therefore, the time constant is expected to be shorter in increasing ink feed than in reducing it. The oscillating effects tend to bring the zonal time constants close to a mean value, which effect is most enhanced on the time constant for a change downwards.

Table 3 gives a summary of the results of printing tests and the simulations. In Figure 6 the simulated effects of the distribution parameters are illustrated.

Also regarding water behaviour the simulations have given additional information further clarifying the process image. However, these results are not reported here since the required validity tests are just being made.

5. PRINTSIM - A TRAINING AND RESEARCH SIMULATOR

At the end of 1985 we started a R&D project with the aim to build a simulator feasible for training and research. The unit should imitate typical production situations in the offset process and react on the most important control operations. Moreover, it should indicate the present state of the process for the student.

The hardware and softwares should form a well documented system easy to handle, which is flexible to enlarge and further develop.

Within the frames of the project we also try to fit a modern control system to the TAPA web press of the Institute.

5.1 Limitations

Our basic idea has been to build the hardware from ready available, modular electronics. In the choice ofthe control system and auxiliary computer we wanted to assure the possibility to further independent program development.

We found that the PRINTA System developed by Altim Control Ltd was the most suitable one for our purposes, mainly thanks to its flexibility. The configurations of this system are easy to modify since the work is done on RAM basis.

The system being developed at the moment has the following components (Figure 7):

The operation point; for this we use the operation station of the PRINTA system (OA). The station consists of a control keyboard and a touch screen with multicolour graphics. Process stations; we use two PRINTA stations (PA). One station has the required cards for future connecting of the Institute's web offset press to the system. One system station (JA), which is the central coordinator of the control system. The reporting point consists of a printer connected to the reporting station (RA) and of a colour screen. A PC-computer, that can be connected to the system either via the system station (JA) or via the reporting station (RA). A control keyboard for the ink screws. A keyboard to create special images on the screen. A fast ALCOM data high way connecting the units to eachother. A control desk.

5.2 Principles of realisation

The realisation principles of the simulator are illustrated in Figure 8. The process simulation is performed in the PC-computer (an IBM PC AT). The PC-program communicates with the PRINTA programs via so called parameter tables.

The parameter tables contain the information about the state of the process at each moment, and the values of the parameters can be read or changed either via the PC or the PRINTA programs. The so called circuit simulations are configurated on the process stations of PRINTA.

At the beginning of the simulation period the teacher starts the PC program and initiates information about the lay-out to be simulated. During the simulation the trainee follows the state of the process via PRINTA. After a running period of about 30 minutes a final report containing a list of the run and some characteristic numbers of the result is printed automatically.

Typical configurations for both heatset and newspaper presses are being worked out. It is our task to finish the simulator subproject before the end of 1986.

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Table 1. The roller specifications of the web offset press used in the test runs (see figure 1).

A	INK FOUNTAIN	4" (102mm)	STEEL	–	NO ADJUSTMENTS
B	INK FEED	3" (76mm)	STEEL	A	0.003" (0.08mm) GO 0.004" (0.1mm) NO-GO (FEELER GAUGE)
C	INK TRANSFER	2-3/4" (70mm)	RUBBER	D	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
				THEN B	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
D	VIBRATED DRUM	3-1/4" (83mm)	COPPER	–	NO ADJUSTMENTS
E	INK TRANSFER	2-3/4" (70mm)	RUBBER	D	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
				THEN F	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
F	VIBRATED DRUM	3-1/4" (83mm)	COPPER	–	NO ADJUSTMENTS
G	INK FORM	2-7/8" (73mm)	RUBBER	F	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
				THEN PLATE	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
H	INK FORM	2-5/8" (67mm)	RUBBER	F	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
				THEN PLATE	1/8" to 3/16" (3 to 5 mm) flat using ink stripes
I	DAMPENER FOUNTAIN	3-1/4" (83mm)	STEEL	–	NO ADJUSTMENTS
J	DAMPENER FEED	2-3/4" (70mm)	RUBBER	K	Snug, steady pull on slip sheets
				THEN I	Light, wiping contact with slip sheets
K	VIBRATED DRUM	3-1/4" (83mm)	CHROME	–	NO ADJUSTMENTS
L	DAMPENER FORM	2-3/4" (70mm)	RUBBER	K	Snug, steady pull on slip sheets
				THEN PLATE	Steady pull on slip sheets

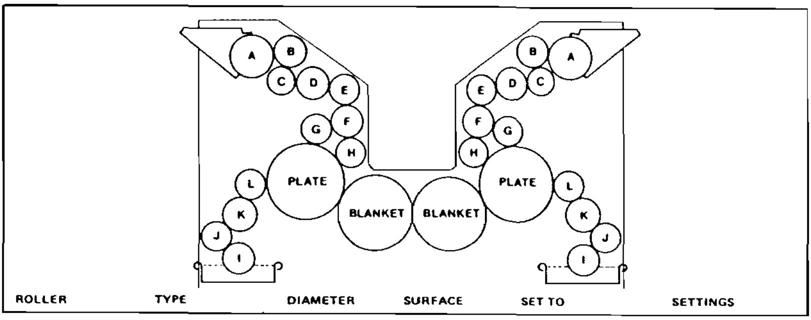

Figure 1. The inker of the web offset press used in the test runs.

Figure 2. The lay-out of the printing surface.

PERIOD/ZONE

Y	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
43	0	0	0	0	0	0	0	0	0	0	0	0
44	39	39	38	36	36	34	32	32	32	33	33	32
45	39	39	38	36	36	34	32	32	32	33	33	32
46	39	39	38	36	36	34	32	32	32	32	33	32
47	39	39	38	36	36	34	32	32	32	33	33	32
48	39	39	38	36	36	34	32	32	32	33	33	32
49	39	39	38	36	36	34	32	32	32	33	33	32
50	39	39	38	36	36	34	32	32	32	33	33	32
51	39	39	38	36	36	34	32	32	32	33	33	32
52	39	39	38	36	36	34	32	32	32	33	33	32
53	39	39	38	36	36	34	32	32	32	33	33	32
54	39	39	38	36	36	34	32	32	32	33	33	32
55	39	39	38	36	36	34	32	32	32	33	33	32
56	39	39	38	36	36	34	32	32	32	33	33	32
57	39	39	38	36	36	34	32	32	32	33	33	32
58	39	39	38	36	36	34	32	32	32	33	33	32
59	39	39	38	36	36	34	32	32	32	33	33	32
60	39	39	38	36	36	34	32	32	32	33	33	32
61	39	39	38	36	36	34	32	32	32	33	33	32
62	39	39	38	36	36	34	32	32	32	33	33	32
63	39	39	38	36	36	34	32	32	32	33	33	32
64	39	39	38	36	36	34	32	32	32	33	33	32
65	39	39	38	36	36	34	32	32	32	33	33	32
66	39	39	38	36	36	34	32	32	32	33	33	32
67	39	39	38	36	36	34	32	32	32	33	33	32
68	39	39	38	36	36	34	32	32	32	33	33	32
69	39	39	38	36	36	34	32	32	32	33	33	32
70	39	39	38	36	36	34	32	32	32	33	33	32
71	39	39	38	36	36	34	32	32	32	33	33	32
72	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0
75	50	54	58	78	78	22	50	36	44	45	50	45
76	49	53	57	76	76	22	50	36	44	45	50	40
77	45	52	55	75	75	22	50	36	44	50	40	35
78	47	51	54	73	73	22	50	36	44	50	30	35
79	46	50	53	72	72	22	50	36	44	20	20	35
80	45	49	52	70	70	22	50	36	44	30	20	35
81	44	48	51	69	69	22	50	36	44	40	30	30
82	43	46	50	67	67	22	50	36	44	40	30	30
83	42	45	48	66	66	22	50	36	44	50	35	30
84	41	44	47	64	64	22	50	36	44	45	35	35
85	40	43	46	62	62	22	50	36	44	40	35	35
86	39	42	45	61	61	22	50	36	44	30	40	40
87	38	41	44	59	59	22	50	36	44	30	40	35
88	37	40	43	58	56	37	100	100	86	40	45	35
89	35	38	40	55	55	37	100	100	88	40	45	35
90	33	36	38	51	51	37	100	100	86	70	50	40
91	31	33	36	48	48	37	100	100	86	70	50	30
92	29	31	33	45	45	37	100	100	85	80	75	30
93	26	28	30	41	41	37	100	100	86	50	100	80
94	40	43	46	62	62	37	100	100	86	40	100	100
95	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
97	100	100	100	100	100	100	100	100	100	100	100	100
98	100	100	100	100	100	100	100	100	100	100	100	100
99	100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100	100	100

Table 2. The printing conditions in the test runs

Speed	1.25 m/s
Web	Commercial, sized, woodfree, uncoated printing paper
Ink	Rotalith 31 000

Printing on one side, the width of the pressure line was 7 mm.

Water feed was steady during the runs.

Table 3. Summary of the simulated and experimental responses

PRINTING TRIALS

Upwards				Downwards		
A0x	Time const	r2	Ro (lag)	Time const	r2	Ro (lag)
0.031	117.970	0.661	0.011	82.840	0.818	0.000
0.077	57.070	0.774	0.000	86.910	0.927	0.090
0.135	40.670	0.787	0.000	85.810	0.926	0.000
0.171	31.380	0.928	0.000	81.220	0.897	0.000
0.201	28.540	0.984	0.002	78.520	0.949	0.000

SIMULATIONS

Upwards	No distribution			Downwards		
A0x	Time const	r2	Ro (lag)	Time const	r2	Ro (lag)
0.032	95.260	0.869	0.310	91.450	0.984	0.270
0.082	58.360	0.960	0.214	80.530	0.986	0.180
0.158	43.450	0.987	0.132	73.310	0.982	0.160
0.197	38.920	0.985	0.108	92.700	0.952	0.100
0.223	33.970	0.987	0.066	102.490	0.971	0.240

Upwards	Distrib.	0.95/0.025		Downwards		
A0x	Time const	r2	Ro (lag)	Time const	r2	Ro (lag)
0.032	101.310	0.867	0.598	101.250	0.980	0.580
0.082	67.120	0.962	0.347	81.770	0.989	0.330
0.158	48.440	0.987	0.154	83.260	0.991	0.320
0.197	41.660	0.983	0.082	84.910	0.992	0.290
0.223	38.290	0.987	0.000	92.270	0.972	0.220

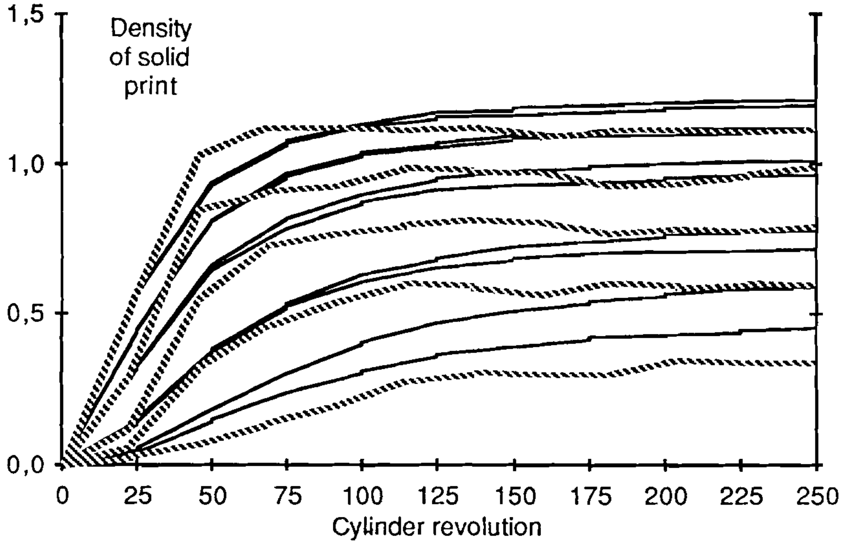

Figure 3. The step responses upwards.

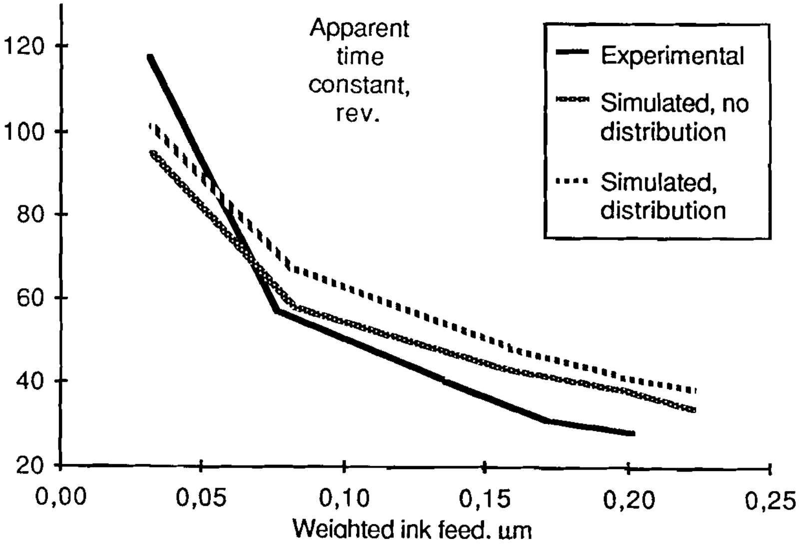

Figure 4. The apparent time constant as a function of the product of the zonal ink need and feed.

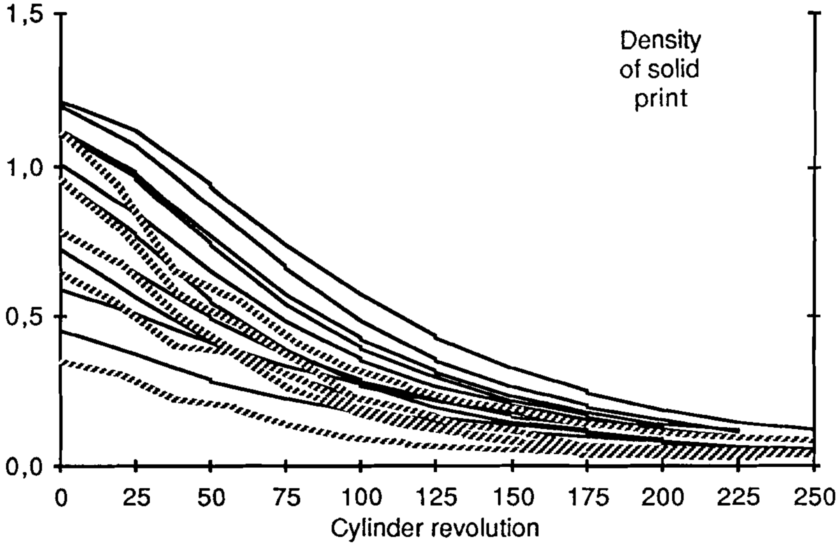

Figure 5. Step responses downwards.

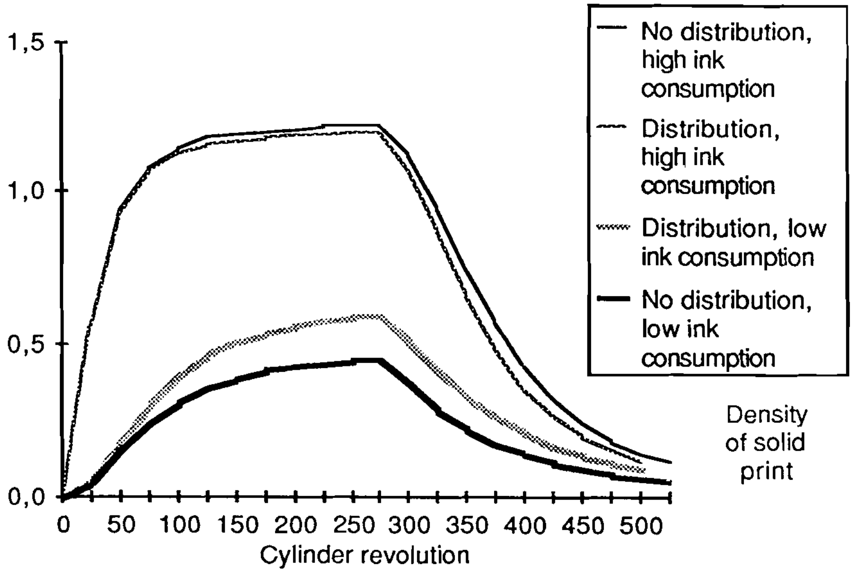

Figure 6. The effects of the distribution parameters on the zonal step responses of the inker.

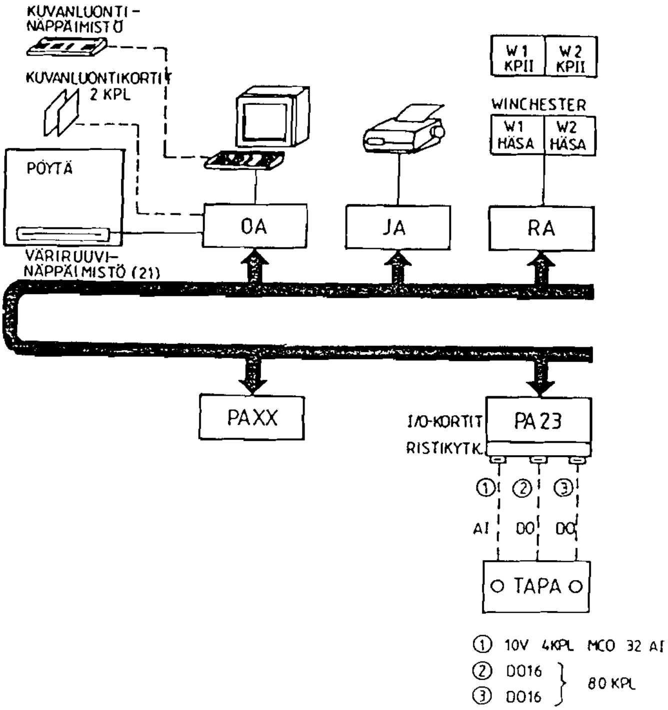

Figure 7. The components of the PRINTSIM-system.

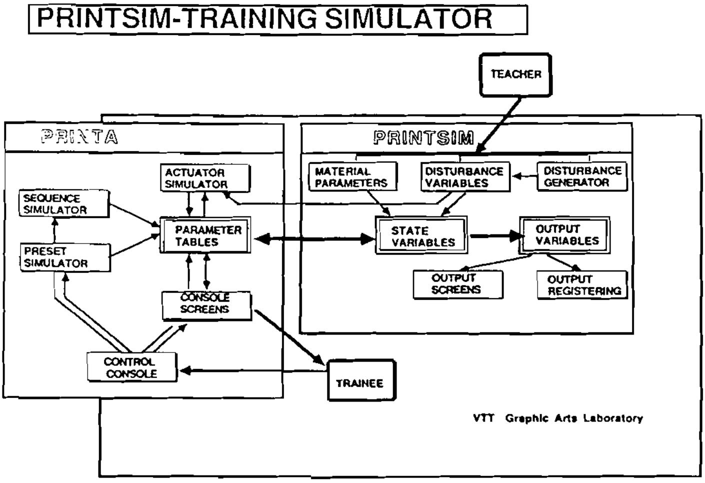

Figure 8. The functional principles of PRINTSIM.