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ABOUT MEASUREMENT AND COMPUTATION OF INK TRANSFER IN ROLLER INKING UNITS OF PRINTING PRESSES

Karl R. Scheuter* and Hellmuth Rech*

Abstract: In the development of inking units, the designer even today is dependent on empirical values or on unsatisfactory methods of computation. For this reason, a theoretical model for the numerical computation of ink transfer in roller inking units has been developed.

The inking units to be examined were analyzed by means of a digital simulation with specially developed computer programs. This method permits a variation of the inking unit geometry, of the ink transfer functions, of the printing and non-printing areas of the printing form and of other important parameter by changing the input data.

The final product supplied by the computer is the relief of ink-layer thickness on the imprinted material, allowing an exact quality evaluation of the analyzed inking unit. Parallel to these theoretical examinations, experiments were carried out with a model printing press with variable inking device. A photoelectric multiple measuring device permits inertialess measurement of the ink-layer thickness shapes of the steel distributor roller as well as on the unscreened printing form. The ink-layer thickness relief transferred to the paper may then be determined by difference formation from the ink layer thickness shapes on the form cylinder before and after the nip.

With the help of a special plotting apparatus, the shape of the optical density and also the layer thickness relief may be determined from the imprinted samples. With the aid of some examples the good qualitative consistency of the computed values may be shown. The designer thus is in possession of exact computation methods for the development of inking units.

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Introduction

The purpose of the inking unit in a printing press is to apply the ink as uniformly as possible to the printing areas of the plate. In the ideal case, all printing elements of the plate would have a uniform ink film thickness and then transfer a uniform ink layer to the material to be printed. In reality, however, the inking process is characterized by considerable variations in the ink film thickness. These variations can be caused by the reciprocating movement of the ductor roller. Much more important, however, are variations in the ink film due to substantial nonprinting areas in the printing form, the so called "printing ghosts." Our investigations had the following objectives:

I. Experimental determination of the mechanism of the ink transfer in the inking unit.

II. Development of a mathematical model for the ink transfer in the inking unit.

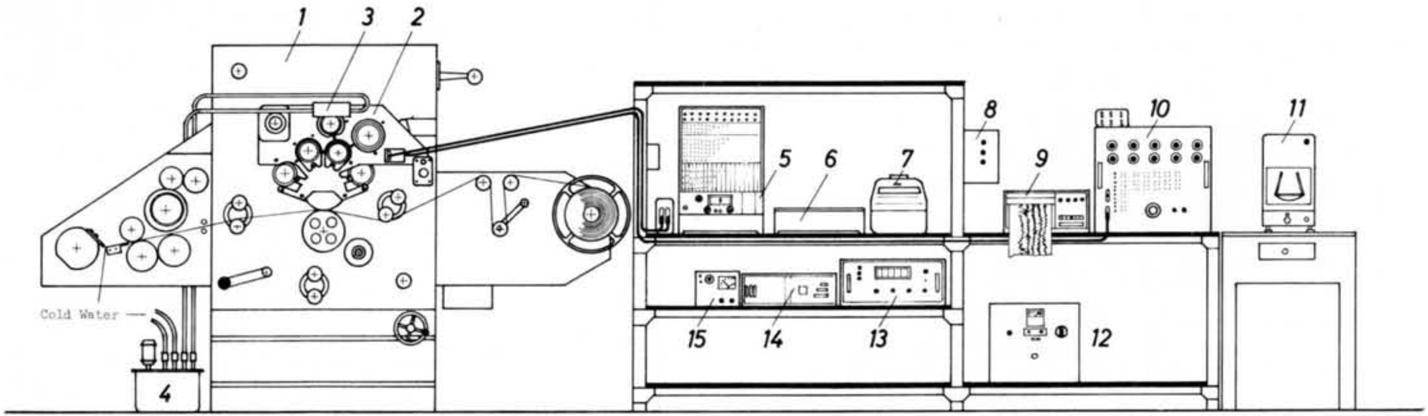
III. Verification of the mathematical model by digital simulation of ink transfer functions obtained by experiments.

IV. Use of the digital simulation method to optimize existing inking systems and to design new inking systems.

Experimental Investigations: Measurement of Ink Film Thicknesses

A special test printing press was designed and then built by the Institute for Printing Machines and Printing Processes of the Technical University Darmstadt, in cooperation with German printing press manufacturers. The outstanding features of this press are easy accessibility to the rollers and high flexibility for arranging different roller configurations.

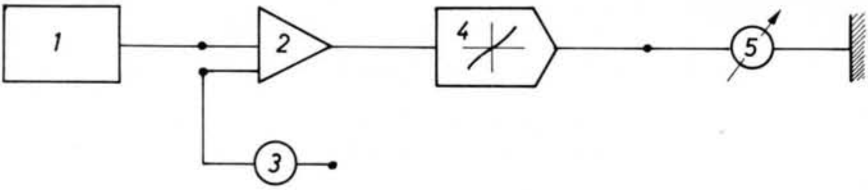
The measuring equipment, consisting of several photo-electronic transducers, is mounted on a removable auxiliary sensor frame. The following measuring method was applied: A light beam is reflected by the surface of an inked steel roller and received by a phototransistor. Part of the reflected light is absorbed by the ink film on the steel roller. The thickness variations of the ink film result in electrical signals which are not proportional to the layer



1. Test Press
2. Auxiliary Sensor Frame
3. Constant Temperature Enclosure
4. Thermostat
5. Analog Computer
6. X-Y Recorder
7. Computer Printout
8. Control Panel
9. U.V. Oscillograph
10. Photocell Power Supply
11. Analytical Balance
12. A.C. Voltage Regulator
13. Digital Voltmeter
14. Automatic Sensor Switch
15. D.C. Voltage Regulator

Figure 1. Schematic of test printing press and measuring equipment.

thickness. For this reason, it was necessary to linearize the signal with the aid of an analog computer.



1. Photo Transistor
2. Summing Amplifier
3. Coefficient Potentiometer
4. Diode Function Generator
5. Galvanometer of U.V. Oscillograph

Figure 2. Block diagram of signal processing.

By measuring the film thickness at various positions of the inking unit through a number of transducers, we obtained an overall picture of the ink transfer in the roller inking unit. To determine the ink film profile transferred to the printed paper sample, two (2) photoelectronic transducers were mounted on the entering and the leaving side of the printing nip. The difference between the two signals is proportional to the film thickness profile on the printed paper.

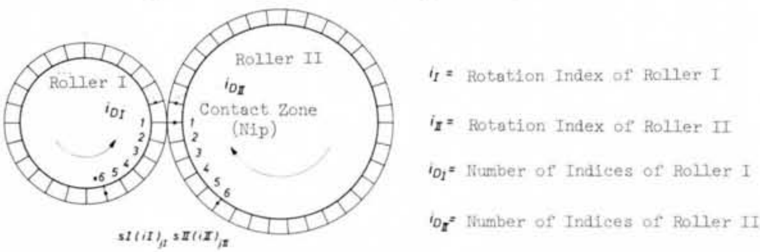
Theoretical Investigations

Previous computing methods allowed only the determination of average values. A point by point, i.e. a local determination of the ink flow as a function of time was thus not possible. These methods can not measure the variation of nonuniform ink feed or those of nonuniform ink transfer caused by an interrupted printing form layout or by the cylinder gap. To obtain the actual instantaneous ink film profile on any roller in the inking unit and on the substrate, a comprehensive theoretical model was developed which requires the use of a computer. The computation is done as follows: Each roller circumference of the inking unit system to be analyzed is subdivided into small segments. For these segments (see Figure 3), a system of equations for the film thickness is set up. The resulting values are used as initial conditions for the next revolution of the roller. As initial condition for the first revolution a constant ink film thickness is assumed for each roller. Subsequently, a number of calculations are carried out until a steady state condition has been reached, which is shown by the fact that the film thickness profile does not change any longer. To simplify the computation according to this theoretical model, the following restrictive assumptions are made:

I. The complete inking unit works without slippage.

II. Possible effects of oscillating roller motions are not taken into consideration.

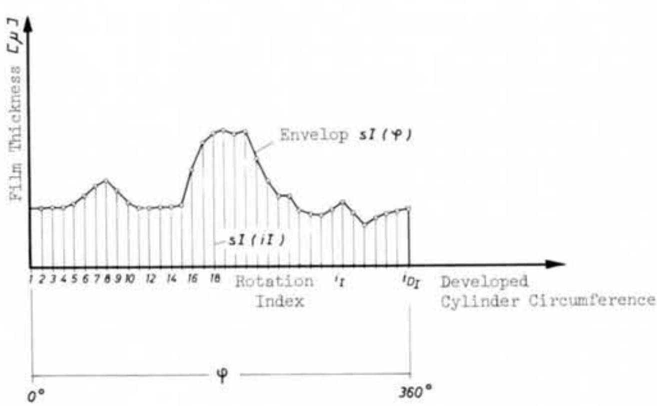
For the explanation of the theoretical model it is necessary, first of all, to examine the basic model of two rollers rolling on each other (Figure 3).



$$s\mathrm{I,II} = s\mathrm{I}(i\mathrm{I})_{j\mathrm{I}} + s\mathrm{II}(i\mathrm{II})_{j\mathrm{II}} \quad (1)$$

$$s\mathrm{I}'(i\mathrm{I})_{j\mathrm{I}} = \alpha \cdot s\mathrm{I,II} \quad (2)$$

$$s\mathrm{II}'(i\mathrm{II})_{j\mathrm{II}} = (1-\alpha)\cdot s\mathrm{I,II} = s\mathrm{I,II} - s\mathrm{I}'(i\mathrm{I})_{j\mathrm{I}} \quad (3)$$



$$s\mathrm{I}(i\mathrm{I})_{j\mathrm{I}+1} = s\mathrm{I}'(i\mathrm{I})_{j\mathrm{I}} \quad (4)$$

$$s\mathrm{II}(i\mathrm{II})_{j\mathrm{II}+1} = s\mathrm{II}'(i\mathrm{II})_{j\mathrm{II}} \quad (5)$$

Figure 3. Schematic of two roller model and formulae.

The circumferences of the two rollers are subdivided into small segments. The selected segment length is the same for both rollers when rolling. The number of the segments on each roller must be integral. For this purpose, the final integer (number of segments) must be obtained by rounding off to the nearest whole number. Before entering the contact zone in the nip, roller I has a film thickness of $S_I(i_I)$ and roller II a film thickness of $S_{II}(i_{II})$. The sum of the two film thicknesses is:

$$S_{I,II} = S_I(i_I)_I + S_{II}(i_{II})j_{II} - - - -$$

If we assume that the two rollers contact each other in discrete small segments (contact zone) the ink film thickness after splitting can be defined as:

$$S_I'(i_I)j_I \text{ and } S_{II}'(i_{II})j_{II}$$

Each film thickness is identified by two indices: index i indicates the specific position on the roller circumference. Index j indicates the number of roller revolutions. Whereas index i varies from 1 to i_{D1}', index j remains constant in any one revolution and increases by 1 for each revolution. The factor α in the following system of equations is the ink splitting coefficient. For the simple case of the two-roller system, to which no ink is fed and from which no ink is removed, the following system of equations can be derived.

$$S_I'(i_I)j_I = \alpha.\ S_{I,II}$$

$$S_{II}'(i_{II})j_{II} = (1 - \alpha)S_{I,II} = S_{I,II} - S_I'(i_I)j_I$$

Thus, the film thickness profile of rollers I and II leaving the zone of contact can be determined in a discrete form. With the aid of these discrete film thickness values, an approximation of the profile can then be drawn as an envelope. The smaller the segments the higher the accuracy with which the envelope describes the actual ink film profile.

The values calculated for any one revolution are used as initial conditions for the subsequent revolution as follows:

$$S_I(i_I)j_{I+1} = S_I'(i_I)j_I$$

$$S_{II}(i_{II})j_{II+1} = S_{II}'(i_{II})j_{II}$$

The computation or programming of larger inking systems involves, of course, a considerable effort in programming (Figure 4).

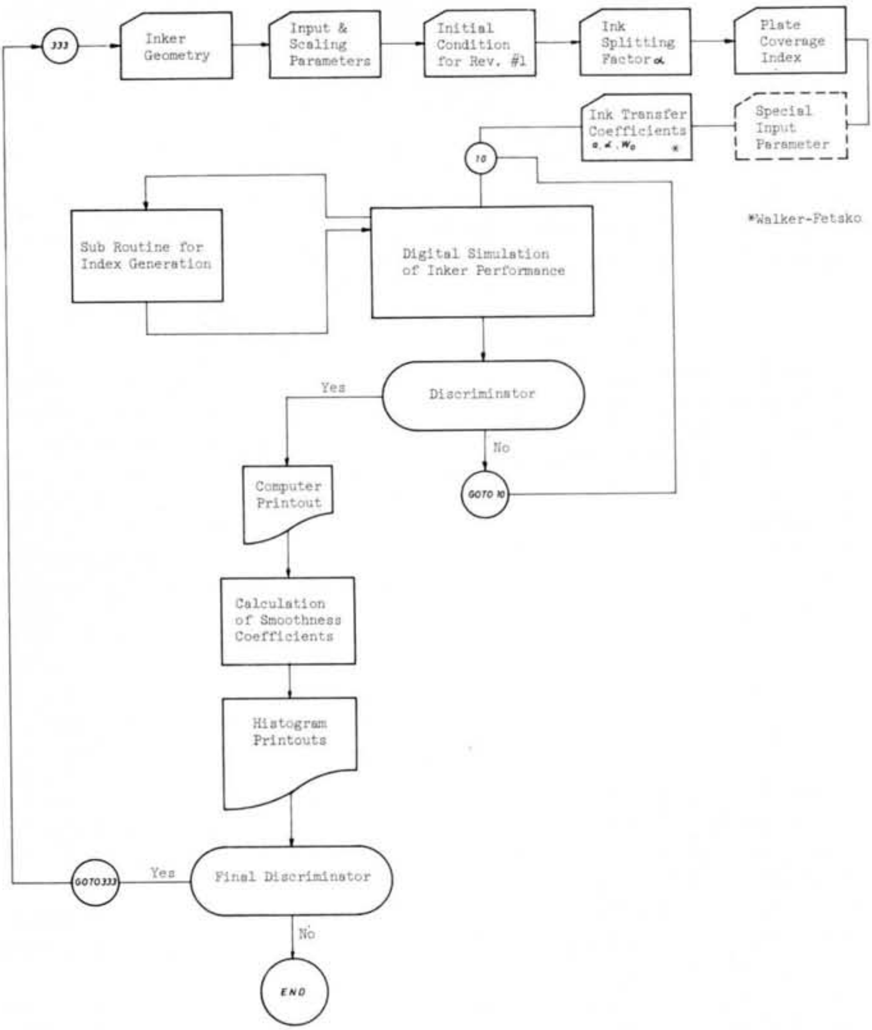
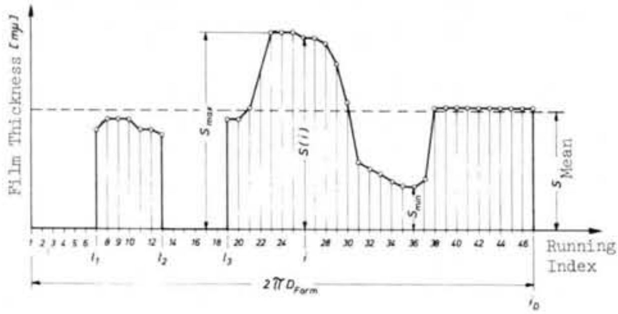


Figure 4. Block diagram (Typical programming -- State of computer).

The shape of the curves found by computation and measurement can be compared more easily by numerical analysis. To permit a comparison between calculated and measured values derived, the characteristic numbers in Figure 5 have been defined.



$$x(i)\left\{\begin{matrix} l_1 & \leq & i & \leq & l_2 \\ \vdots & & \vdots & & \vdots \\ l_m & \leq & i & \leq & l_n \\ l_{n+1} & \leq & i & \leq & i_o \end{matrix}\right\} \qquad 6$$

$$n = (l_2 - l_1) + \ldots + (l_n - l_m) + (i_D - l_{n+1}) \qquad 7$$

Arithmetic Mean x_{mittel}

$$x_{mittel} = \frac{1}{l_2 - l_1}\sum_{i=l_1}^{i=l_2} x(i) \ldots + \frac{1}{l_n - l_m}\sum_{i=l_m}^{i=l_n} x(i) + \frac{1}{i_D - l_{n+1}}\sum_{i=l_{n+1}}^{i=i_D} x(i) \qquad 8$$

Quadratic Mean $x_{qu\,mi}$

$$x_{qu\,mi} = \sqrt{\frac{\sum_{i=1}^{i=i_D}\left[x(i)\right]^2}{n}} \qquad 9$$

Roughness Factor

$$\eta = \frac{x_{max} - x_{min}}{x_{mittel}} \cdot 100 [\%] \qquad 10$$

Form Factor

$$f = \frac{x_{qu\,mi}}{x_{mittel}} \qquad 11$$

Mean Deviation

$$d = \frac{1}{n}\left[\sum_{i=l_1}^{i=l_2}\left[x(i) - x_{mittel}\right]^2 + \ldots + \sum_{i=l_m}^{i=l_n}\left[x(i) - x_{mittel}\right]^2 + \ldots + \sum_{i=l_{n+1}}^{i=i_D}\left[x(i) - x_{mittel}\right]^2\right] \qquad 12$$

Quadratic or Standard Deviation

$$q = \frac{1}{n-1}\left[\sum_{i=l_1}^{i=l_2}\left[x(i) - x_{mittel}\right]^2 + \ldots + \sum_{i=l_m}^{i=l_n}\left[x(i) - x_{mittel}\right]^2 + \ldots + \sum_{i=l_{n+1}}^{i=i_D}\left[x(i) - x_{mittel}\right]^2\right] \qquad 13$$

Sum of the Squares

$$q_s = \left[\sum_{i=l_1}^{i=l_2}\left[x(i) - x_{mittel}\right]^2 + \ldots + \sum_{i=l_m}^{i=l_n}\left[x(i) - x_{mittel}\right]^2 + \ldots + \sum_{i=l_{n+1}}^{i=i_D}\left[x(i) - x_{mittel}\right]^2\right] \qquad 14$$

Figure 5. Evaluation figures and their formulae.

With the aid of these numbers, shapes of ink film profile found by computation or obtained by experiment can be compared and numerical values can then be deduced representing quality criteria of inking units.

Comparison of Theoretical Values with Those Found by Experiment

Of considerable interest were the results of the investigations of the rather complicated roller configurations which correspond to those used in practice and which are shown in Figure 6.

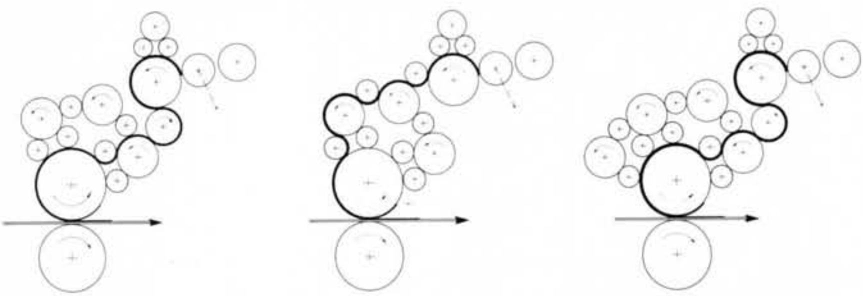


Figure 6. Primary ink flow diagram for three specific roller configurations.

The comparative experimental and theoretical invesigation was based on variously and repeatedly interrupted printing form layouts (Figure 7).

The optical density of the printed samples was considered to be a first order approximation of the ink film thickness. For a rough estimate of the validity of the theoretical results it is sufficient to compare the computed ink film profile with the measured optical density profile. The results of the roller combination 2,4,5,10 are shown in Figure 8.

The shape of the computed film thickness curve and the experimentally obtained optical density curve shown in this diagram are substantially identical. The maxima are in the same positions. The comparison of the profile curves also shows a good conformity with the printed sheet. Similar results were found for the other roller configurations (Figure 9 and 10).

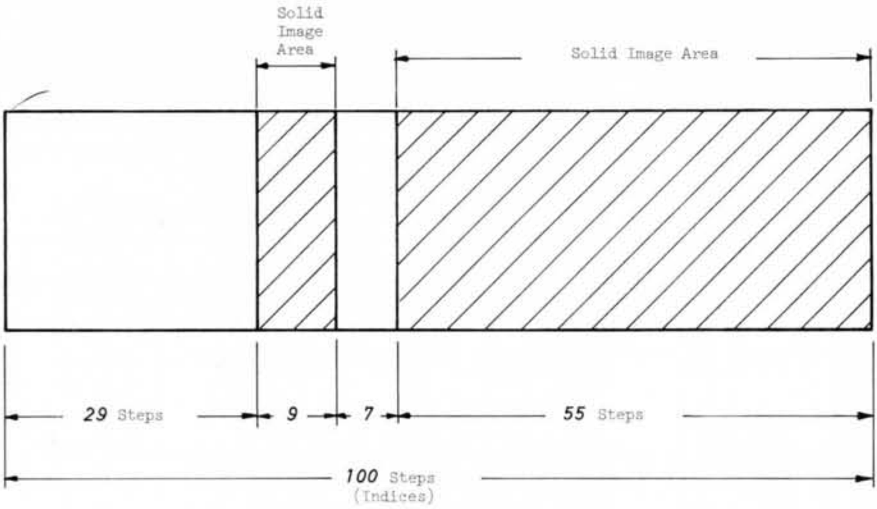


Figure 7. Schematic layout of printing form.

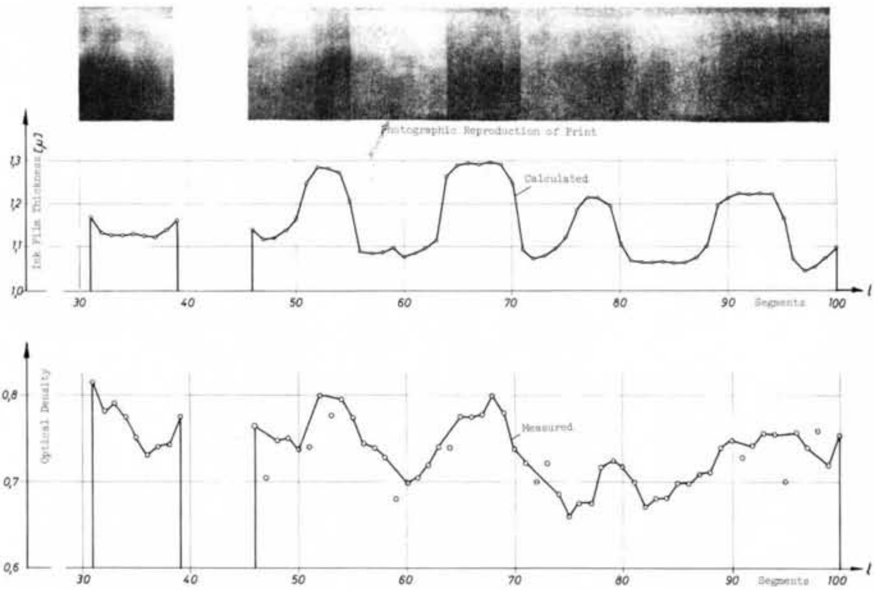


Figure 8. Comparison of measured and calculated data for configuration 2.4.5.10.

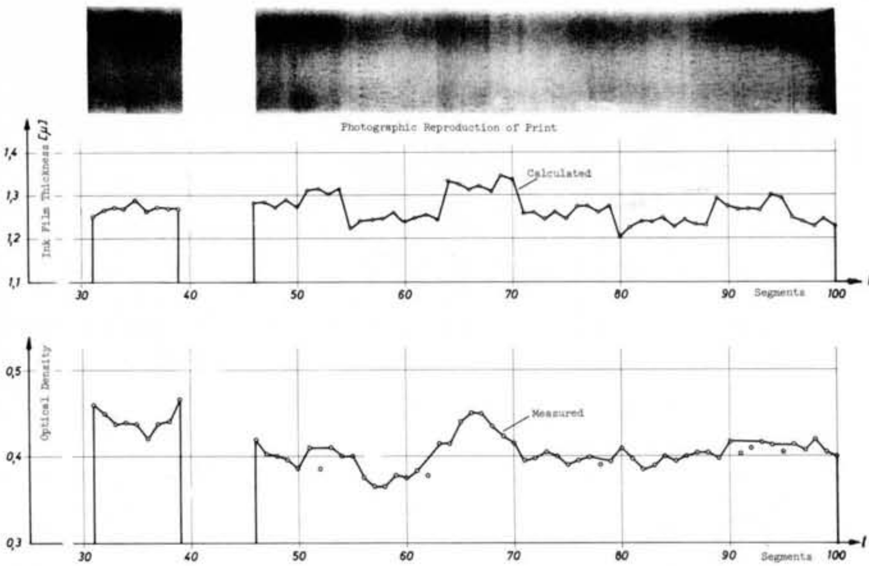


Figure 9. Comparison of measured and calculated data for configuration 1.4.5.10.

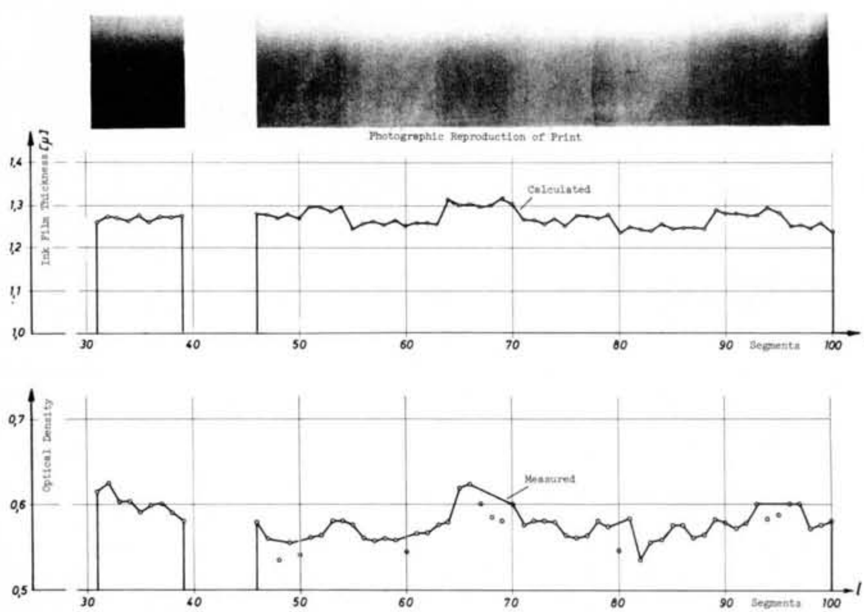


Figure 10. Comparison of measured and calculated data for configuration 2.5.6.12.

By comparing the shape of the curves of Figures 8, 9 and 10, the validity of the theoretical calculations can be demonstrated. To allow qualitative judgement of the three different roller configurations the characteristic numbers described above have to be determined and compared with each other.

A convenient estimate of the smoothness of a computed ink film thickness curve can best be made by having it plotted by a high speed print out of a computer in the form of a histogram or by an x-y-recorder as an envelope. In Figure 11, the computed ink film thickness profiles of the three roller configurations are plotted by a high speed print out.

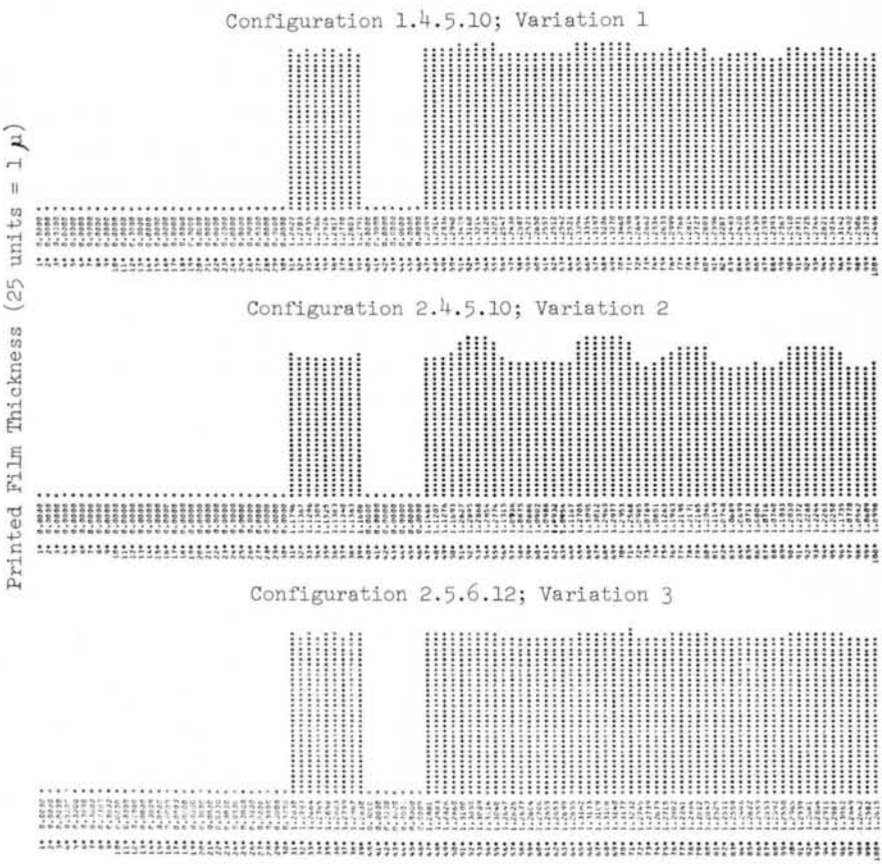


Figure 11. Histogram from high-speed printout for the 3 different roller configurations.

A comparison of the three roller configurations shows that those in the center (2, 4, 5, 10) have the most unfavorable values, whereas that of 2, 5, 6, 12 has the best values, i.e., the smoothest ink film thickness curve. The characteristic numbers for the configurations 2, 4, 5, 10 and 1, 4, 5, 10 vary considerably although they have the same number of form rollers (Table 1).

	Configuration 1.4.5.10	Configuration 2.4.5.10	Configuration 2.5.6.12
Maximum Value	0,13412E 01	0,13095E 01	0,13232E 01
Minimum Value	0,12094E 01	0,10542E 01	0,12496E 01
Roughness Factor	0,10409E 02	0,21992E 02	0,57461E 01
Arithmetic Mean	0,12663E 01	0,11611E 01	0,12816E 01
Quadratic Mean	0,12667E 01	0,11637E 01	0,12817E 01
Form Factor E2/E1	0,10003E 01	0,10022E 01	0,10001E 01
Mean Deviation	0,24648E-01	0,68616E-01	0,16046E-01
Variance of Film Thickness	0,92855E-03	0,59534E-02	0,36661E-03
Standard Deviation	0,30472E-01	0,77158E-01	0,19147E-01

Table 1

Possibilities for Optimization

The mathematical model for simulating the ink transfer in inking units was developed, not only for analyzing existing systems, but also to give the designer of inking units a tool for the development of new systems. This can best be explained by an example.

The inking unit of a small sheetfed offset press (in Figure 12) was examined.

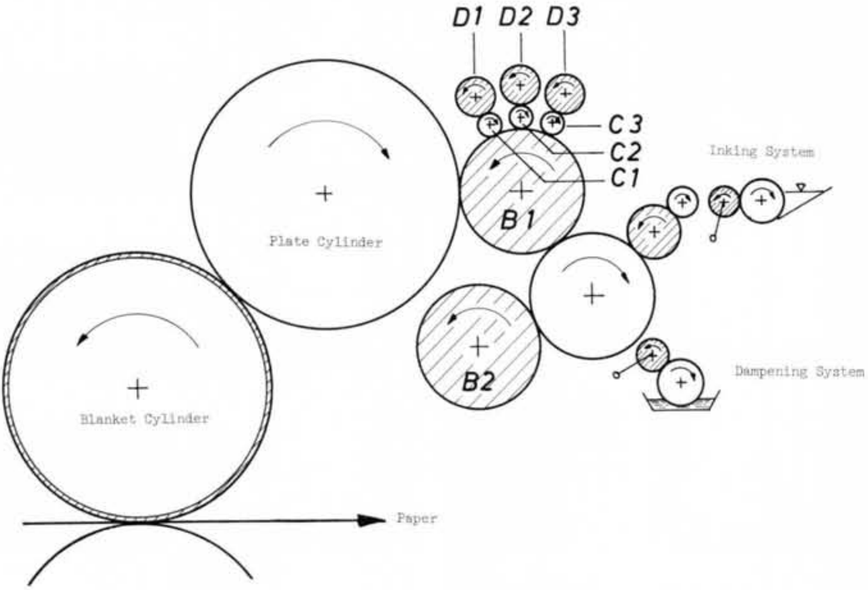


Figure 12. Roller combination B.1.2.2.4.

This press originally did not have rider roller groups. For this inking system (Figure 12), a computer program was developed which allows simulation of the unit. By putting in certain control figures K Fall 1 and K Fall 2, the unit can be modified as follows:

K Fall 1 = 1	all rider roller groups are in contact
K Fall 1 = 2	rider roller groups D3 and C3 have been removed
K Fall 1 = 3	rider roller groups D2, C2 and D3, C3 have been removed
K Fall 1 = 4	all rider roller groups have been removed

In Figure 13, the results of the simulations are shown as histograms given by the high speed print out.

The best comparison can be made by plotting the roughness factor versus the number of the rider roller groups, so that one can easily judge which arrangement offers the most favorable conditions (Figure 14).

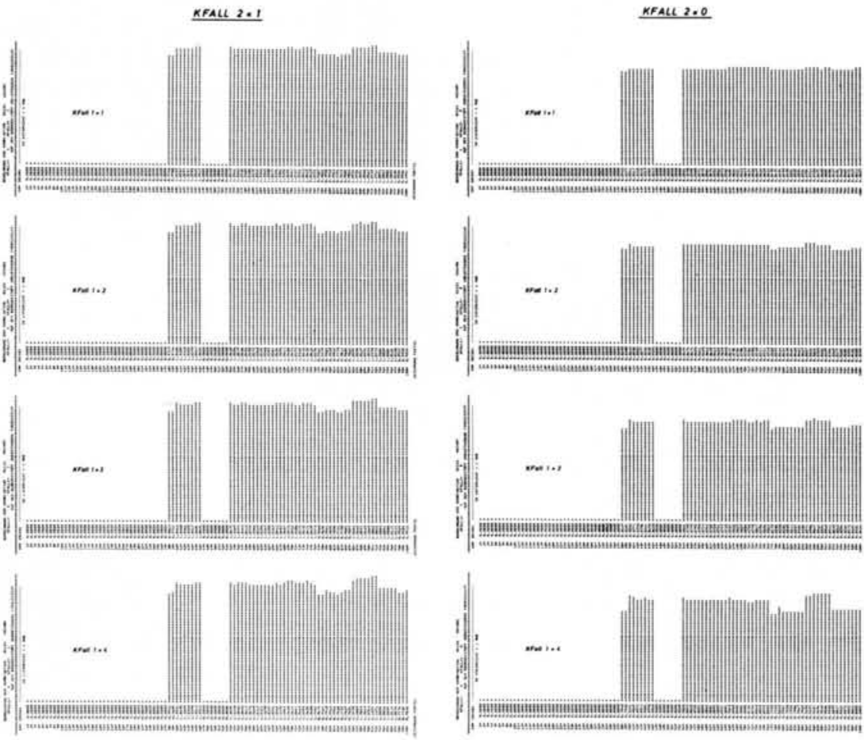


Figure 13. Histogram of roller configuration B.1.2.2.4.

In case of K Fall 2 = 1 the form roller B2 is in contact with the plate cylinder. The mounting of rider rollers brings about only a very slight improvement. If, however, the form roller B2 is taken out of contact with the plate cylinder (K Fall 2 = 0), the roughness factor can be decreased considerably. Even adding one rider roller B1 with disengaged form roller B2 gives better results than the original inking unit. These investigations were made for two printing forms. In both cases the same tendency can be observed which is confirmed by the printing tests. This last example shows clearly the possibility of computation as an instrument for optimum design

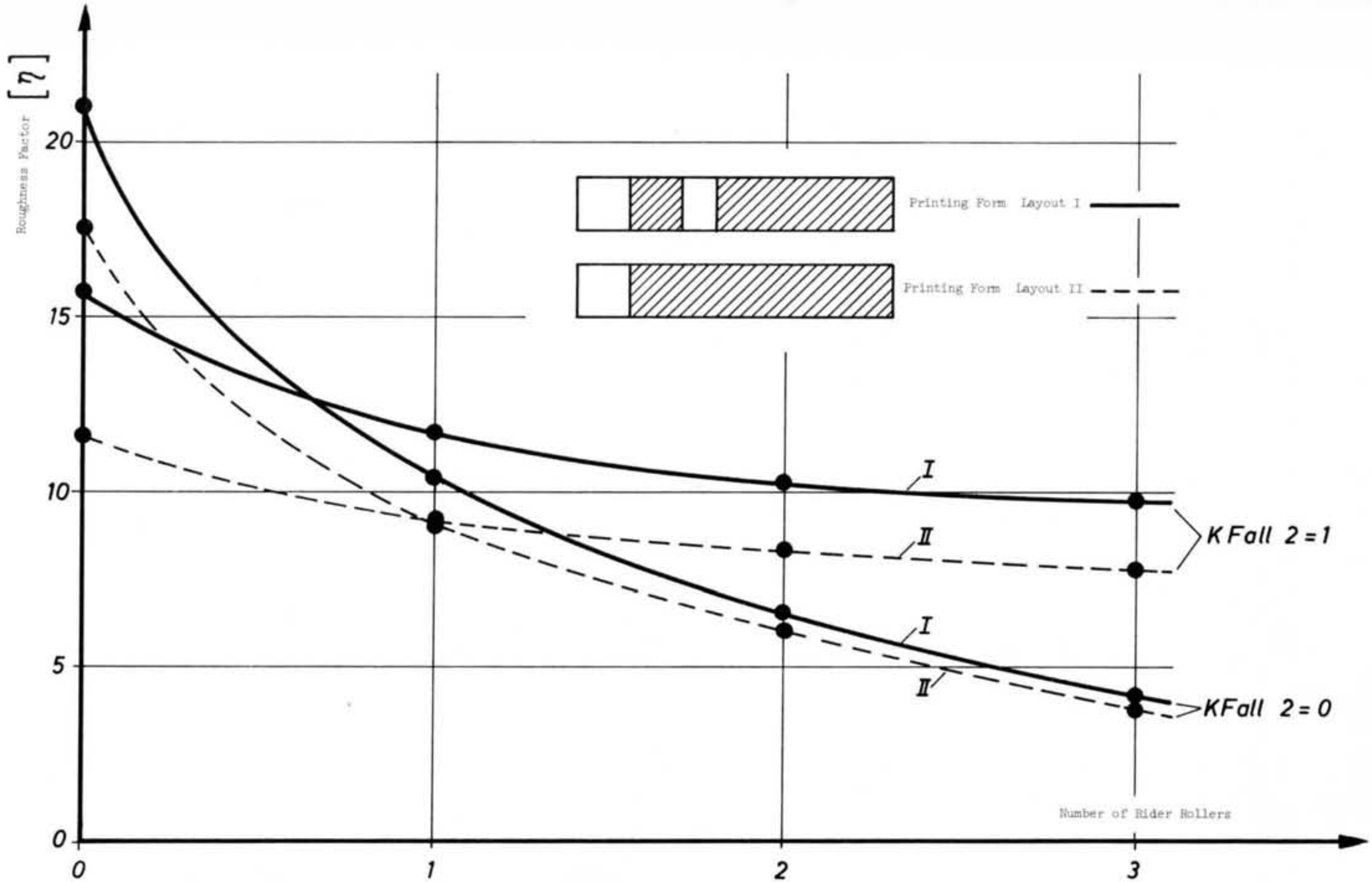


Figure 14. Roughness factor as a function of the number of rider roller groups with roller configuration B.1.2.2.4 using two different printing forms.

Summary

A mathematical model was developed for the theoretical investigation of roller inking units. Using this model, digital simulations were made of the ink transfer in the inking units. Comparisons of these simulations with practical printing tests showed good correlation. Methods were shown for utilizing the digital simulation method to optimize existing ink systems and to design new systems.

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