ADAPTIVE CONTROL METHODS FOR WEB-OFFSET INKING

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Abstract: New adaptive control methods for offset inking have been developed and tried out at the Technical Research Centre of Finland. In early control procedures, the severely nonlinear print density was used as a print quality output. The modified optical intensity, i.e. I = 10exp(D)-1, however gives a better, more stable performance for the control system. The amount of inking is controlled using inking screws; the duct roller speed is set according to the press speed. The ink consumption profile is determined using a new plate scanner and the inking screws are preset corresponding to the image distribution across the web. The ink consumption determines the control gain of each inking zone. The control is based on density measurements at the most important zones. The total number of optical sensors can be reduced due to interpolation rules applied at the "blind" control zones.

The control algorithms are based on the state model of offset inking. The gain factors of the intensity-based state controller are repeatedly updated to conform with the actual press response. The control interval may be chosen from 20 revolutions at the press start to 40 revolutions at production speed. During printing, the pressman is able to change the zonewise target levels at will. The interpolation rules make this possible also for the non-measured "blind" zones.

Introduction

The lack of fast on-press densitometers has retarded the application of modern closed-loop control methods to web-offset printing. Desktop densitometers have been available for a long time and their scanning successors have already been used with new sheet-fed offset presses. In recent years,

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these optical devices have been used to close the control gap between printed sheets and inking actuators. Sofar the process has been partly manual: in a typical control system, the pressman has to fetch the latest sheet from the stack, then bring it onto the evaluation board and finally initiate the measurement sequence. After this, the densitometer sensor moves along a printed test strip, reads the density values at predetermined spots and then transmits the values to a control computer which decides, whether the inking profile must be adjusted or not. Because of the manual operations required, the minimum interval between consecutive measurements is about 250 impressions. This feature implies that the control model is stationary, i.e. the new instructions for inking cannot be given prior to final settling of the earlier adjustments. Therefore, the control algorithms have to be very cautious in order to avoid the overshoot of inking. Thus such a step-by-step controller is necessarily slow. Inspite of these minor inconveniences, the worldwide interest in automated sheet-fed offset presses is strong and more than a dozen of such printing systems have already beeb sold.
The reports of web-offset control systems have been few, however. The large coldset presses are typically equipped with remote control systems incorporating a film or plate scanner for presetting purposes. This composition of control devices may be reasonable even for the fastest newsprinting presses, but the new four-colour heatset presses call for more advanced closed-loop control methods.

The problems involved in the automation of web-offset inking have been studied at the Technical Research Centre of Finland since 1973. The main emphasis has been in the development of solid-state on-press densitometers, capable of evaluating the print density on a web moving at speeds of up to 10 m/s. After implementation of a reliable densitometer system, control methods have been applied in an offset inking process.
The prototype control system was discussed in TAGA 81, the development of digital control algorithms was presented in TAGA 83 and this paper reports the implementation of adaptive closed-loop control methods at a laboratory-scale web-offset press.

Control Hardware

Our control system is schematically shown in Fig. 1. The density regulator has been implemented in our laboratory press, a pilot unit Wepe-0, which was designed and constructed by Wärtsilä Oy, Finland. The press is equipped with a vertical blanket-to-blanket printing unit and the inking is controlled using 32 distinct screws along the inking blade. The maximum web width is 990 mm and the cut-off length is on the order of 620 mm. As is shown in Fig.1, the press is operated using a control board and an interface computer which is connected to the control computer. The latter is a DEC LSI-11/23 micro-mini computer with a 256 kbyte multiuser RAM-memory and a real-time disk-operating system RSX-11M capable of multitask operations. The storage memory is a 30 Mbyte Winchester disk memory with a 1 Mbyte floppy disk back-up driver. The computer system is equipped with a floating point numeric processor to execute instructions fast, instead of using library subroutines. The control computer is connected with a 9600 baud serial line to other system parts, i.e. the remote control board, matrix printer and user terminal. The eight-channel on-press densitometer and the new plate scanner are connected to the computer in a similar manner.

The operation of the remote control board is based on two built-in microcomputers. The first takes care of data transmission between the control computer and the printing press, while the second has the supervision of the console keys and the bargraph plasma display showing the actual inking profile. The data transmitted includes ink screw positions, press speed, duct roller speed, dampening level and relay controls for print sequences, i.e. starting and stopping the press.

In experimental printings we have used SC-newsprint WSOP (60 g/m^2) from Metsäliitto, Kirkniemi, Finland. The black ink used was Rotalith 31 000 from Roto Oy, Finland. The dampening water included 15 % isopropanol and 2...3 % Offgen additive.

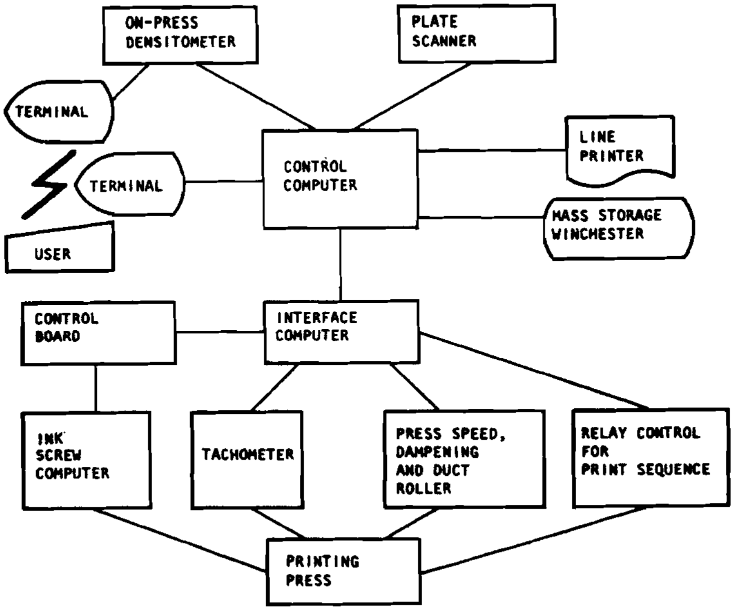

Fig. 1. Web-offset control structure.

Adaptive Control Procedure

Within a proper dampening range, the density output of an offset process is primarily determined by the amount of ink offered at the press zone studied. According to Tollenaar and Ernst (1962), the optical density D of a print, made at a constant pressure and speed, increases monotonously from zero to a saturation value D_∞ if the ink layer thickness t on the paper is incresed. An exponential equation of the following form has been derived for this relationship:

$$D = D_\infty(1 - e^{-mt}), \tag{1}$$

where the factor m determines the steepness of the density curve in the region of very thin ink films. In practice, Eq. 1 may also be applied if the density is plotted against the ink layer thickness x on the forme roller. A typical plot of this relationship is shown in Fig. 2 where the saturation density is chosen to be $D_\infty = 1.4$ and the parameter $m = 0.5\ m^{-6}$. In this case, the target level of solid print density would be around D = 1.1...1.2 in normal printing conditions. The steepness of the density curve varies rapidly around this operating point. The non-linearity of the process calls for certain control intelligency to obtain an equal regulator response both below and above the target level. To avoid an extraordinary complexity of control algorithns, we have tried a linearized darkness model of the printing process, i.e. an intensity model

$$I = 10^D - 1. \qquad (2)$$

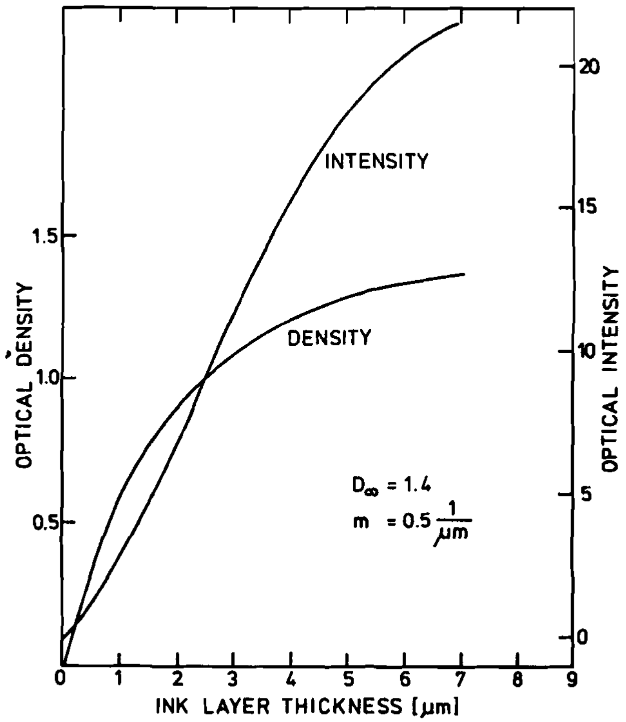

Fig. 2. Comparison of density vs. intensity model.

The target level is defined correspondingly, i.e.

$$I_{target} = I_{NCI} = 10^{D_{NCI}} - 1, \tag{3}$$

where the abbreviation NCI stands for Normal-Color-Intensity. The subtractor "1" has been introduced to obtain a model starting from zero in the model origo. The comparison between density and intensity curves is shown in Fig.2.

The densitometer output D is transformed to intensity I in our control computer using a fetching procedure to obtain a fast response. In control computations, the scaled value

$$y_i(k) = \frac{I_i(k)}{I_{NCI}} \tag{4}$$

is used as an internal process variable. The traditional density readings are, however, shown in terminal displays for printer's convenience. In Eq. 4, the subscript i stands for the press zone No. i and k is the running index of control intervals. The control commands are actuated at intervals of 40 press revolutions. The control algorithms were discussed in more detail at TAGA 83.
Our adaptive control system is based on the relative ink consumption z_i of each press zone i, which is evaluated using a newly developed intelligent plate scanner. The higher the ink consumption of a particular press zone is, the more the corresponding ink screw must be opened during the presetting phase. Correspondingly, the control gain is chosen according to the ink consumption.
Fig. 3 shows the observed relationship between the optical intensity and relative screw opening for our laboratory press at various ink consumption levels. The parameter varies in range $0 \leq z \leq 1$. The fictive case of z = 1 is estimated in Fig. 3, because it defines the upper limit of the duct roller speed vs. press speed when the practical operation range of inking screws is taken into account.

The stationary inking model is then

$$y_i(k) = \frac{I_i(k)}{I_{NCI}} = P \frac{R_i(k)}{z_i} = u_i(k), \tag{5}$$

where R_i is the actual screw position, i.e. the operating deviation from the zero inking state. The parameter P is used to match the internal control output $u_i(k)$ with the process variable $y_i(k)$ on one-to-one basis. In our press

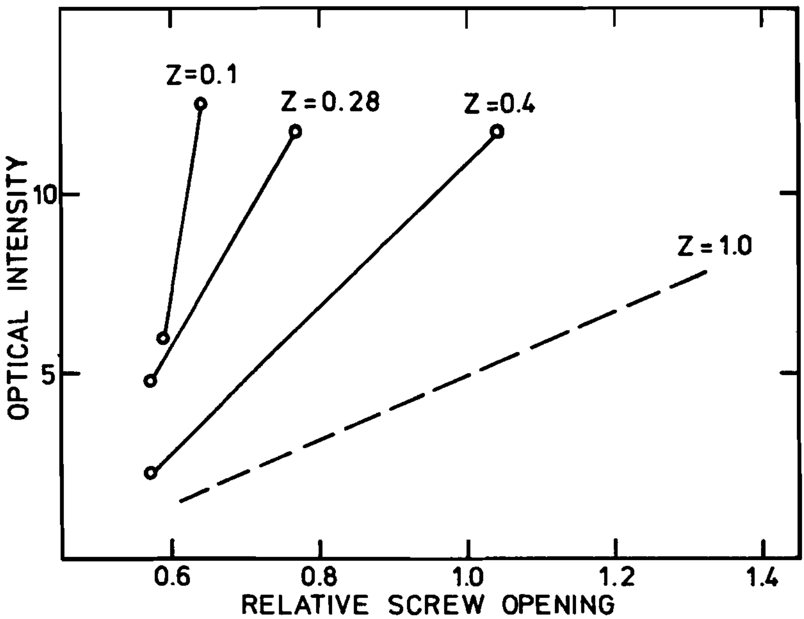

Fig. 3. Stationary intensity model of the laboratory press.

the correction parameter is approximately P = 1.2.

During the presetting phase, the duct roller speed is set according to the press speed v_p, i.e.

$$v_D = Av_P, \quad A = 0.03, \tag{6}$$

where the speeds are given in meters per second. The screw deviation profile is initially computed in the plate scanner according to the rule

$$R_i^o = 0.025 \frac{z_i}{v_D} K_i, \tag{7}$$

where K_i is the initialization parameter for the press used. In many cases, the initial profile is impossible to realize because of the ink blade stiffness. The plate scanner smoothening algorithm then converts the initial profile to the actual presetting profile

$$R_i(k) = R_i(0) : R_1(0), R_2(0), \ldots , R_{32}(0) \; ; k = 0, \quad (8)$$

which gives the starting position of each inking screw of the press.

The eight densitometer transducers are located on central press zones Nos. 6,9,12,15,18,21,24 and 27. Consequently, the intermediate press zones remain in the "dark": direct density measurements cannot be used for control on these blind zones. To overcome this problem, we determine auxiliar screw postions for the intermediate zones, i.e.

$$R^*_{i+1} = \frac{2R_i(0) + R_{i+3}(0)}{3} \quad \text{and}$$

$$R^*_{i+2} = \frac{R_i(0) + 2R_{i+3}(0)}{3} \quad (9)$$

together with zonal correction coefficients

$$c_{i+1} = \frac{R_{i+1}(0)}{R^*_{i+1}} \quad \text{and}$$

$$c_{i+2} = \frac{R_{i+2}(0)}{R^*_{i+2}} \; . \quad (10)$$

The computations are started at i = 6 and repeated at increments of 3 up to i = 30. The coefficients c_i are then stored in the computer memory and, in the course of closed-loop control, they are used to obtain a smooth control response at the blind zones. Given the positions of active screws $R_i(k)$ and $R_{i+3}(k)$, the auxiliary screw positions are computed using Eqs. 9. They are then converted to actual screw positions through Eqs. 10, which take the zonal ink consumption into account.
The ink consumption distribution of our test plate is shown in Fig. 4. One final screw setting profile after a succesful closed-loop run is also shown.

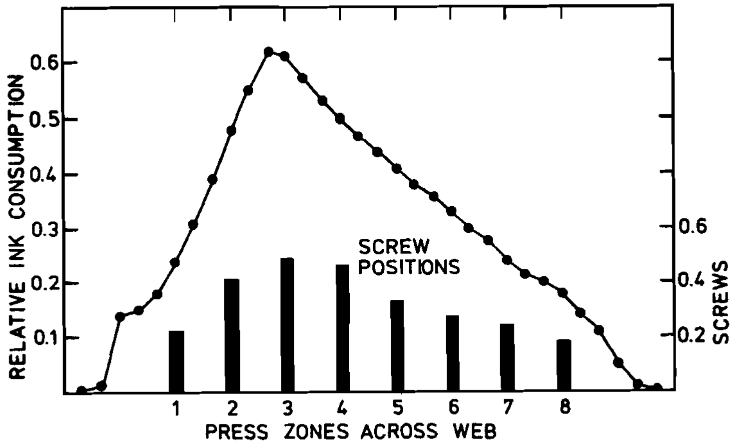

Fig. 4. Ink consumption of the test plate for each press zone.

The closed-loop control of inking is based on digital state algorithms according to Fig. 5. The internal state of the process is estimated using computer software as was shown in our TAGA 83 paper. The actual control variable u(k) is derived from the process estimator

$$
\begin{aligned}
\hat{x}_1 &= -a_3\hat{x}_3 + b_3\hat{x}_4 + h_1^* \cdot \Delta y \\
\hat{x}_2 &= \hat{x}_1 - a_2\hat{x}_3 + b_2\hat{x}_4 + h_2^* \cdot \Delta y \\
\hat{x}_3 &= \hat{x}_2 - a_1\hat{x}_3 + b_1\hat{x}_4 + h_3^* \cdot \Delta y \\
\hat{x}_4 &= \hat{x}_5 + u + h_4^* \cdot \Delta y \\
\hat{x}_5 &= \hat{x}_5 + h_5^* \cdot \Delta y,
\end{aligned}
\tag{11}
$$

where the output error for zone i is

$$\Delta y_i(k) = y_i(k) - \hat{x}_{i3}(k) - w_i(k). \tag{12}$$

The control variable is then

$$u = -\left[k_1^*\hat{x}_1 + k_2^*\hat{x}_2 + k_3^*(y - w) + k_4^*\hat{x}_4 + k_5^*\hat{x}_5\right] \qquad (13)$$

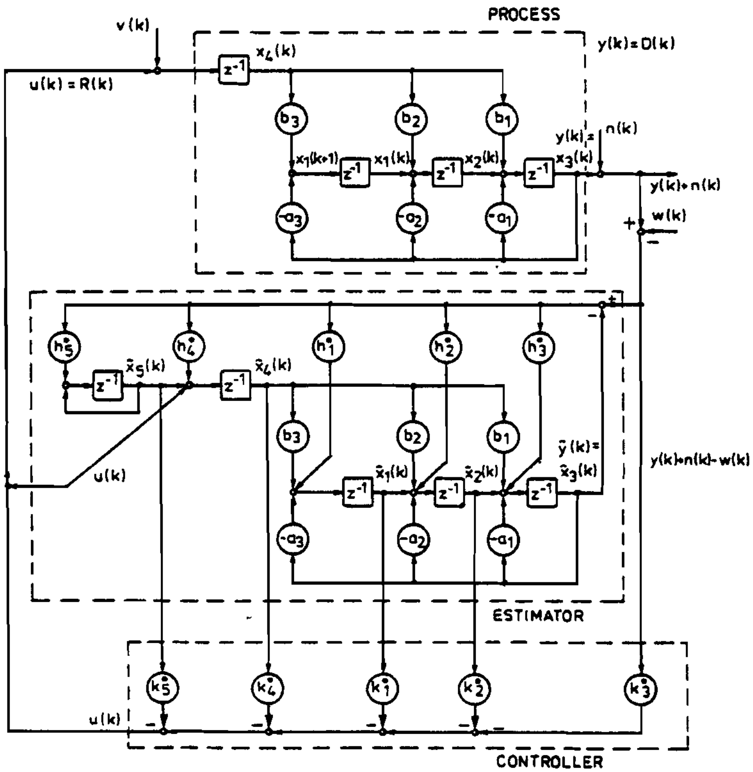

Fig.5. Digital control algorithm.

The process parameters a_1, a_2, a_3, b_1, b_2 and b_3 have been determined using modern identification methods and the estimator parameters h^* as well as control parameters k^* have been optimized using computer simulations for falsified process parameters.

In the closed-loop control mode, the computation according to Eqs. 11, 12 and 13 is carried out at intervals of 40 press revolutions for each measured zone i. The control output $u_i(k)$ gives the actual screw position

$$R_i(k) = K_C z_i u_i(k), \quad (14)$$

where K_C is an experimentally found control coefficient.

Control Software

The control computer software of the present work has been developed employing the multitask features of our operating system. Because of the large volume of software the programs partly use overlay segments. The most significant parts of tasks requiring fast execution are permanently stored in RAM-memories, while some subroutines of lower priority use an overlay segment. Such an overlay segment is a common part of RAM, where the requested subroutine is loaded upon call. The device dependent program parts were written using system directives which offer an asynchronous attach to devices and particular memories. The programs use system event flags for synchronisation and to declare the state of each task.

The software consists of six tasks: master task, priority task, sequence task, control task and update task as is shown in Fig. 6. The user is connected to the system by the

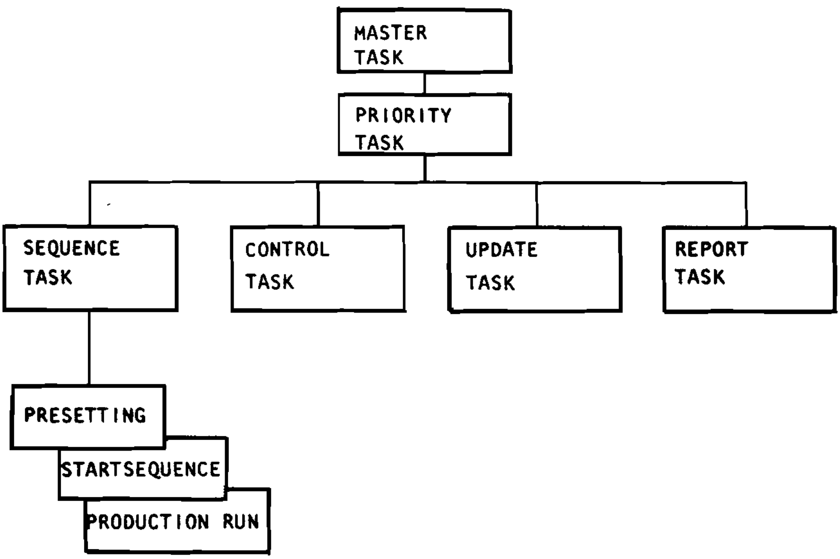

Fig. 6. Software tasks.

master task. This task controls and calls for other tasks, and it sets or clears the corresponding activity flag. To control the run of a task, the master task sends a control message block of 13 integers to the task.
The priority task is a simple procedure to read task activity flags and change the running priorities according to flag states. Only two tasks are allowed to run with high priority at the same time. The tasks with low priority are checkpointed to the Winchester memory, if no free space is available in RAM. The priority task is independently rescheduled with a high priority to ensure fast execution of programs.

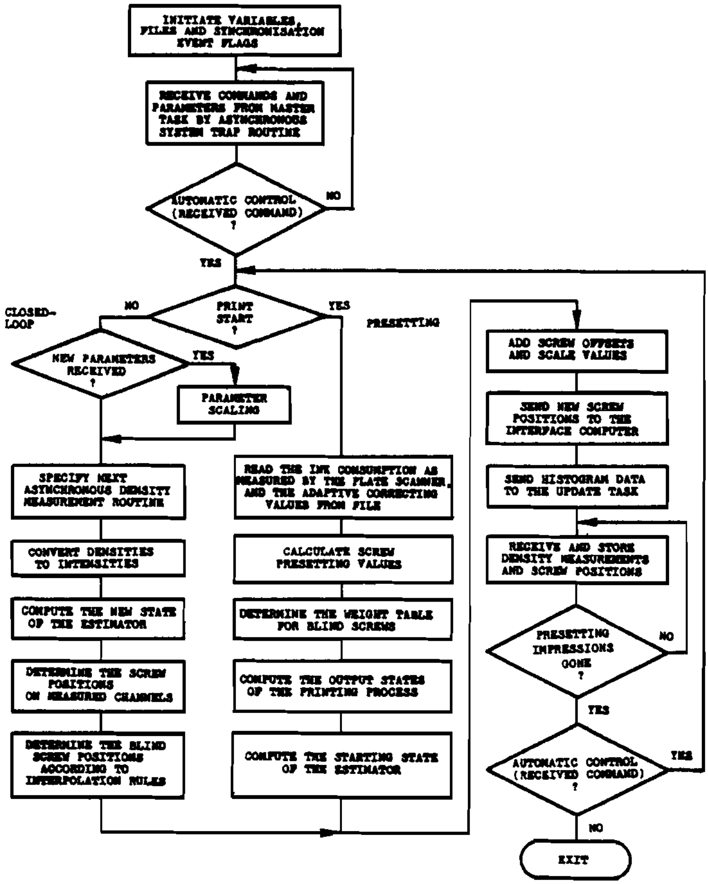

Fig. 7. Control task.

The sequence task sees the printing process as divided into five program states which are Stop, Wait, Run, Production and Speed Change. In each state, only certain state transitions are allowed. Insists the user illegal commands, the system does not respond. The master task initiates the sequence task by requesting it through the system directive. Starting and stopping the printing press is a logical sequence of relay controls.
Prior to the closed-loop control phase, the smoothened ink screw profile from the plate scanner is transmitted to the press via the interface computer. When available, the adaptive inking data from earlier runs is used to better match the amount of ink offered with the amount of ink actually consumed. The start sequence also sets the press speed, dampening level, and duct rollers. The process runs in a non-regulated state for some 400 press revolutions before the closed-loop control is turned on.
In a running state the sequence task priority is high. In the production state, the sequence task becomes blocked and the control task gets a higher priority. The press speed changes, however, give a temporary increase to the sequence task priority.

The control task is illustrated in a block diagram, Fig. 7. First, the program specifies a Receive Data asynchronous system trap routine, i.e. an interrupt program, which starts when another task transmits a data message block. After that, the program waits for the message block to enter and it becomes blocked, i.e. it does not consume processing time. The message block includes target densities, other user parameters and operational commands. According to the commands, the next steps are defined.
The update task is used to show the density histogram on the terminal screen. The display is refreshed at one minute intervals. The report task receives information from other tasks. The information supplied by the user is processed by the master task, data from sequence events comes from the sequence task and the production information enters from the control task.

Printing Results

The test printings with a full-scale closed-loop control system started early in 1981, and some 50 000 impressions were printed to study the system robustness against typical process disturbances. Input-output data of succesful runs were then used to identify the inking process at various dampening levels. On the basis of the inking model

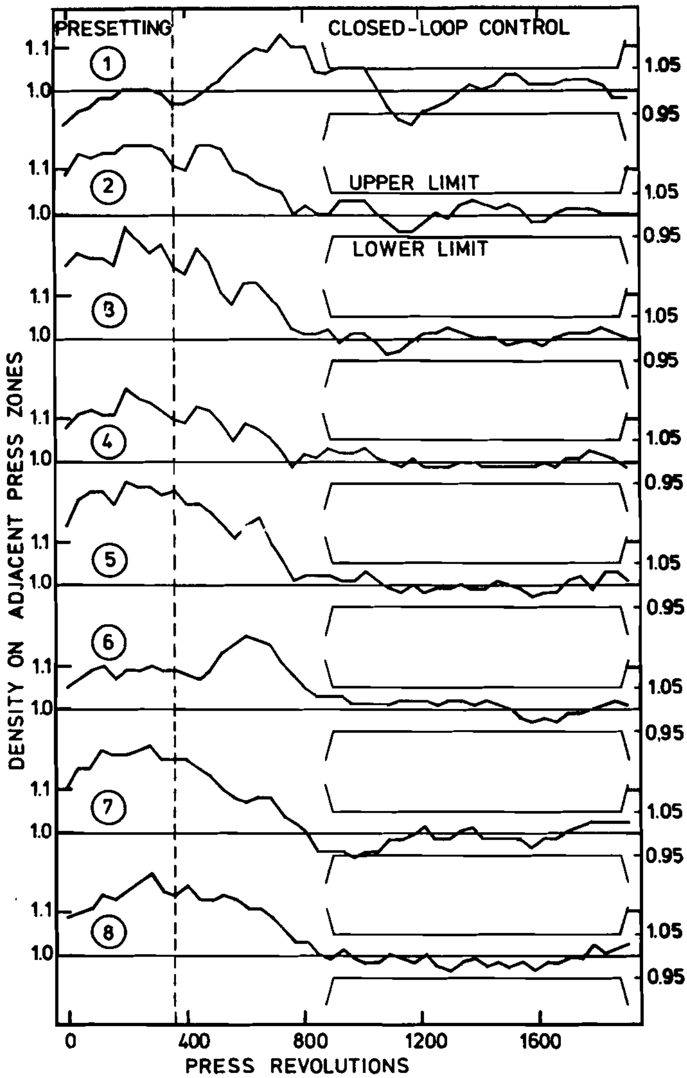

Fig. 8. Closed-loop run with coarse presetting.

obtained, the present control structure was implemented early in 1983. About one hundred separate test runs have been carried out since that. In the first phase some 40 000 impressions were printed in order to generate a proper Start/Stop sequence. About 50 000 press revolutions

were run to optimize the regulator algorithm, and some 100 000 press revolutions have been run in order to test the final control appliance.
A typical run starting with a coarse presetting phase is shown in Fig. 8. The inking screws were set according to plate scanner readings, Eqs. 6, 7 and 8. Soon after the printing nip was pressurized, the print densities settled at D = 0.92...1.14, while the target density level was D = 1.00. The closed-loop control of print density was then turned on at 360 press revolutions. During the next 400 impressions, the density values were brought into range 0.95<D< 1.05. With the exception of press zone No.1, the density values were kept inside this tolerance during the last 1000 revolutions. Although not shown in Fig. 8, the intermediate press zones also behaved well.

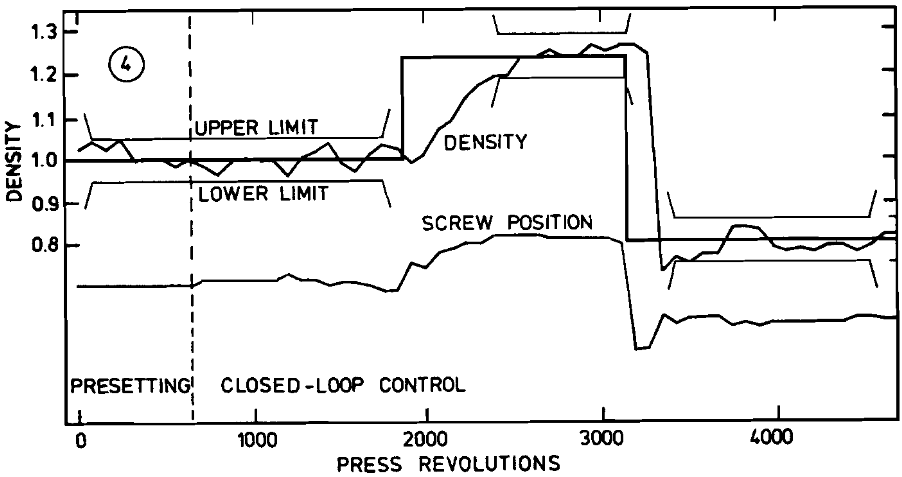

Fig. 9. Closed-loop control after adaptive presetting.

Fig. 9 gives an illustration of adaptive presetting procedures. The passage of a completed run after coarse presetting shown in Fig. 8 was routinely examined using a histogram task by the computer. The procedure searches for a stable state where the densities of each measured zone have settled close to the target level for at least 150 impressions. Based on corresponding process data, the adaptive ink consumption factors are then derived from the actual screw positions vs. the values proposed by the plate scanner. The run of Fig. 9 was performed about one week after the run of Fig. 8. Only press zone No. 4 is shown, but the bahaviour of other zones was essentially similar, i.e. the density level was inside the tolerance range from

the very start. During the run, the target density was changed twice, first D = 1.25, then D = 0.80. The test printings showed clearly that the most stable response of density was generally obtained at higher density values, say D = 1.25. This also conforms better with the NCI-level of the paper used. The relaxed screw position passage during closed-loop control is also shown.
The process stability has been studied against disturbances, such as sudden changes of dampening, duct roller shaking, ink clodding etc. The effect of ink expiration at zone No. 4 is shown in Fig. 10. The ink feed was intentionally

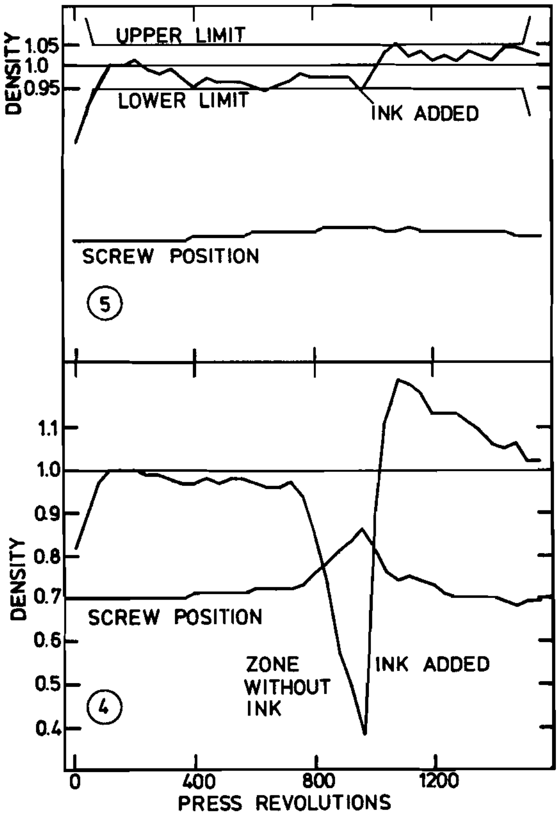

Fig. 10. Effect of ink expiration on zone No. 4.

stopped at 700 press revolutions from the start, but the ink screw movement was not disturbed. The screw was then gradually opened more due to error integration, but the density state was not restored until ink was added. It resulted in an overshoot of density, which was slightly observed also at the adjacent zone No. 5. No tendency to process oscillations was found.

Conclusions

In offset printing process, there are many fast and slow disturbances that can be observed in the output variable, optical density. The rapid variations are primarily due to paper quality fluctuation and to ever-changing combination of roller positions in the inker. Their control cannot be based on density measurements. Slow drifting is also typical to the web-offset printing process. Temperature variations have an effect on ink transfer characteristics and the ink-water balance has rather long time constants. During printing, the blankets become hard, the plates wear and linting occurs.
The response time of our closed-loop control system is less than four hundred press revolutions. We may therefore conclude that slower disturbances of inking may be cured using closed-loop control algorithms employing on-press density measurements. The compensation for incorrect dampening is hardly possible.
It is reasonable to assume that an adaptive inking control system can provide a web-offset printing system which reaches an acceptable print quality state after some four hundred impressions from the start of running. Furthermore, we may assume that the density profile remains inside a five percent tolerance range as the run is continued. Such a control system is capable of increasing the print quality as well as of decreasing the bulk of wasted paper.

Acknowledgments

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