ON-PRESS DENSITOMETRY FOR CLOSED-LOOP CONTROL OF OFFSET INKING

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Abstract: The quality control to avoid waste of printed products is essential in the printing houses when fast printing presses are used. The tone rendering of four-colour images is generally judged through a visual evaluation of print darkness produced by the distinct inks. The measurement of the optical density at specific test spots on a printed sheet is most urgently required for modern web-offset presses which are rather unstable in their inking characteristics when compared with the established technology of large gravure presses. New types of optical sensors, i.e. densitometers, have been designed and implemented for the on-press quality control of fast web-fed presses at the Technical Research Centre of Finland. The operation of the optical transducers at their installation is governed by a microprocessor. The densitometer assembly is capable of measuring the optical density of a small test spot on a paper web moving at speed up to 10 m/s. The opacity of pure paper left unprinted by the offset plate gap is used as a reference level during each press revolution. The chromaticity of overlapping ink layers is determined using a proper selection of gelatine filters. To overcome the slow drift of illumination intensity due to ageing properties of halogen incandescent lamps, the measurement procedure includes the dark level determination which is carried out at preset intervals. The optical measurement devices can be applied to print darkness evaluation both on paper and on aluminium foil. On paper the transducers are used in a diffuse mode, whereas the print density on glossy metal surfaces is to be measured in a specular mode. The specular measurement method employs a polarization filter which cancels the first-surface reflection from a wet print. The density measurements are used as a basis for the closed loop inking control;

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typically eight sensors, each with four colour filters, are used for one web.

Introduction

One of the objectives in modern four-colour printing is to maintain the printed traces, images, of every inker at a preset, constant darkness level.

The print darkness of solid and halftone areas is the primary quality output of a press, in addition to the colour register. These have traditionally been judged by means of visual inspection which has been the basis for correcting adjustments of the actuators in the press.

More reliably than with a bare eye, the inspection is carried out using an electro-optical photometer, i.e. densitometer. A typical desktop densitometer gives the relative print darkness of a surface in logarithmic units for visual compatibility. The print density is referred to white paper, and it is defined in the international standards DIN 5033 and DIN 16536. An on-press densitometer is the instrument for real time evaluation of test spot densities on the running paper web.

Since 1973 six different on-press densitometers have been designed and constructed at the Technical Research Centre of Finland (VTT). The development was started in cooperation between the Graphic Arts Laboratory and the Instrument Laboratory because no commercial multichannel device was available at that time. The manual instruments did not prove useful in studies of the controllability of inking in lithographic printing presses at VTT. A large number of measuring channels is essential in rotational offset presses because of inking variations across the web. The web width and sensor dimensions limit the number.

The desktop densitometers are used to some extent in printing houses. Their practical use and the introduction of standardization has been discussed by many authors: von GALL [1], LAANE [2], BURKHARDT [3], NITSCHE [4], SCHRÖDER [5] and du PONT [6] etc. The commercial availability of these instruments is good; more than forty manufacturers showed their desktop densitometers in DRUPA Exhibition 1982.

Print quality monitoring is rather tedious when based on a manual densitometer. The method is most easily applied to monitoring of sheetfed presses [7], but less so to guarding of web-fed presses. The manual quality control of a reel-to-reel web-fed press is almost impossible [8], because the press must be halted for sample acquisition or the sample must be taken off from the moving web. On-press densitometers have therefore been introduced in recent years. These devices have been often equipped with one sensor only. In an offset press the inking varies strongly across the web width, and therefore a single sensor must continuously traverse across the web to make measurements on separate inking zones. The Macbeth device, KISHNER 1983 [9], scans mechanically. The AEG-Telefunken device, DRUPA 1982, is scheduled to make the electrical measurement scan in 5 seconds. The IGT-densitometer, van DOMSELAAR 1982 [10], is used in sheet-fed presses. An on-press densitometer of traversing type is necessarily so slow that it cannot evaluate the cross-wise density distribution of the succesive sheets on a running web. Therefore a series of various multichannel on-press densitometers has been designed and constructed at the Technical Research Centre of Finland since 1973. The solid sensors of a multichannel device are capable of reading each test spot passing by. Our experiments with feedback control of inking in a web-offset press, reported at TAGA 1984, have shown that density measurements should be made at intervals of 4 to 1 s, corresponding to the press speeds 10 000 rev/h to 40 000 rev/h, if the control interval is set at 20 revolutions. For optimal print noise reduction, the density values should be measured on every impression.

In addition to the speed requirements and standard properties specified above, the following design goals were established: the densitometer system should be able to evaluate specific test areas (size 6 mm x 6 mm) at a press speed of v_p = 10 m/s; test areas should be freely locatable on the printed sheet; the measuring sensors should be small and rigid and the system should operate reliably in an industrial environment and be electrically compatible with a control computer. Low cost is also an important factor.

Optical construction

The construction details of the PACKMON IGI on-press densitometer transducer are shown in Fig. 1. The lamp with a radiant power P_λ illuminates the printed test spot. The central beam incidence angle is $\emptyset = 45^\circ$. Corresponding to the standard DIN 5033, the illumination is limited to a cone $2\alpha \leq 2\cdot 10^{\circ}$. On the test spot, the light beams will be scattered diffusely and specularly. The detector acceptance cones (limited $2\beta = 2\gamma \leq 2\cdot 5^{\circ}$) receive reflections $R_D P_\lambda$ and $R_S P_\lambda$, respectively. Before entering the active areas of the detectors, the beams are filtered using filters with spectral distribution functions $\tau_D = \tau_T(\lambda)\tau_F(\lambda)$ and $\tau_S = \tau_T(\lambda)\tau_F(\lambda)\tau_P$, respectively. Here $\tau_F(\lambda)$ is the colour filter transmittance and τ_P means the transmittance of a polarization filter.

The detector output is given as

$$I = \int_0^\infty R(\lambda)P_\lambda \tau(\lambda)S(\lambda)d\lambda, \tag{1}$$

where $S(\lambda)$ is the spectral responsivity of the detector. In expression (1) the subscript D may be added for diffuse reflection and the subscript S for specular reflection.

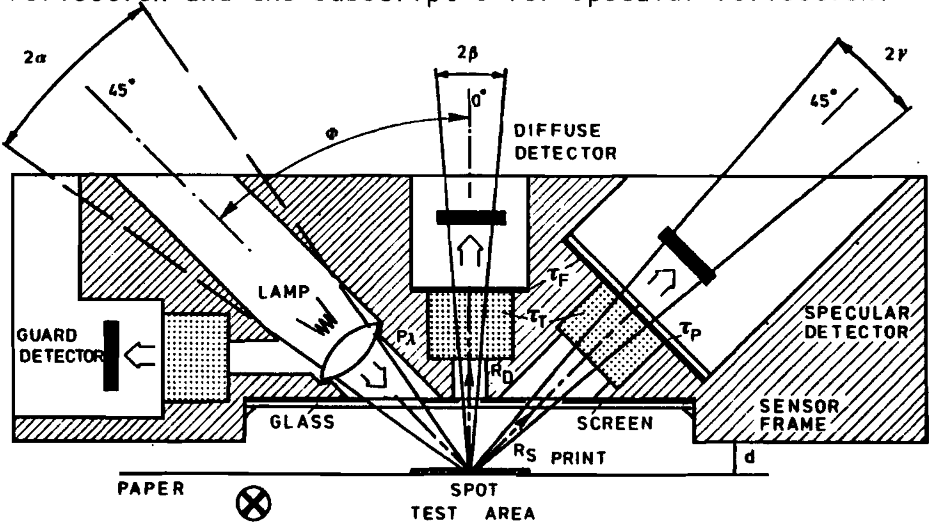

Fig. 1. The optical transducer of PACKMON 1GI on-press densitometer. The paper web movement direction is out of paper.

With the specified geometrical limitations, the diffuse reflection density is

$$D = D_D = \log_{10}\frac{I_o}{I}, \tag{2}$$

where I and I_o are the measurement results from a printed surface and reference area, respectively. When measuring absolute densities, the near white powders MgO and $BaSO_4$ are used as a reference surface. For print density calculation I_o is obtained using unprinted paper as a reference material. When matched spectrally, the diffuse reflection density gives an eye-like, but exact (accommodation-free), expression for print darkness.

Diffuse density measurements carried out according to DIN 5033 only give a proper measure when the images are printed on (white) paper. The diffuse reflection density does not characterize print darkness on a glossy metal foil, eg. aluminium, because of strong specular reflection. Depending on the ink type, the calculated diffuse reflection density may positive or negative. For glossy printing materials we found the concept of specular reflection density very useful. We define the measure of specular reflection density as

$$D_S = \log_{10} \frac{I_{oS}}{I_S} , \qquad (3)$$

where the subscript S refers to the specular reflection. In the measurement the mirror reflection from the outer surface of ink is rejected by using a polarizing filter with transmission τ_p. According to Brewster's law, only that part of the incident natural light polarized parallely with the surface is reflected by a refracting surface into the angle $\varnothing p$ = arc tan n, where n is the relative index of refraction. The polarizing filter passes the vertically polarized light and does not eliminate glare from uncoated metal surface. This gives the reference value I_{oS}.
We made test measurements with green and red prints on aluminium. The angle of incidence was varied as shown in Fig. 2. The maximum value of specular density D_S was found at the incidence $\varnothing = 60^o$. However, for the mechanical compatibility we chose to use $\varnothing = 45^o$.

Compared with standardized diffuse densities, the specular densities show a clear improvement in sensitivity (Fig. 2). We have also used a polarization filter in on-press densitometers to eliminate the first-surface reflection from the wet print. The neutral HN-type (Polaroid Corporation) polarizer does not affect the spectral response of the system.

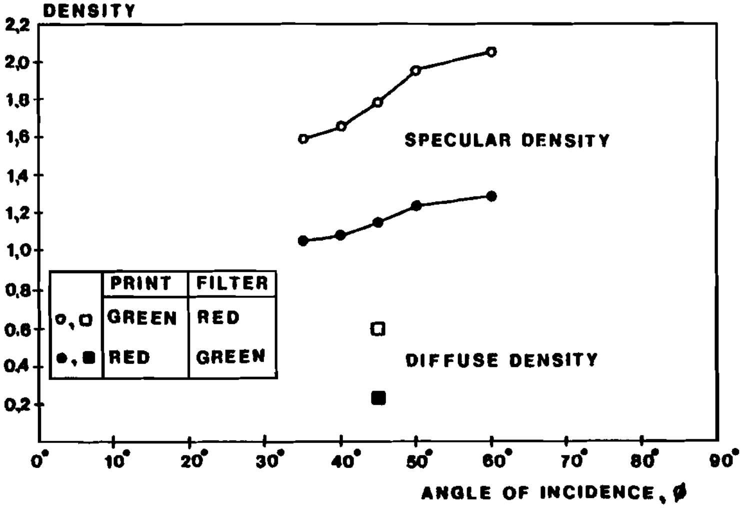

Fig. 2. Specular density vs. diffuse density on Al-foil.

The inking stability for one pigment is most accurately judged when the print is seen through a filter which only passes the wavelength of the minimum transmission of the ink. In this case the highest density values are obtained, because I takes its minimum value.

For this reason, PORTNER and GRAICHEN (1973) proposed [11] narrowband light emitting diodes to be used as the illumination source to provide high accuracy. Using such diodes, the reproducibility of the measurements with respect to time and space is also maximized. KISHNER(1981) investigated [12] the reproducibility of density measurements with common commercial inks and suggested that the system spectral sensitivity be maximized at the following wavelengths: yellow ink (blue filter, 432 nm), magenta (green, 536 nm) and cyan (red, 624 nm). The pass bands were obtained using narrow interference filters.

The DIN 16 536 standard proposes a somewhat different set of pass bands. The specified wavelengths are listed in Fig. 3. Black ink must be monitored with a sensitivity similar to that of the human eye. Final human judgement of completed print should be carried out in day-like D 5000 lighting.

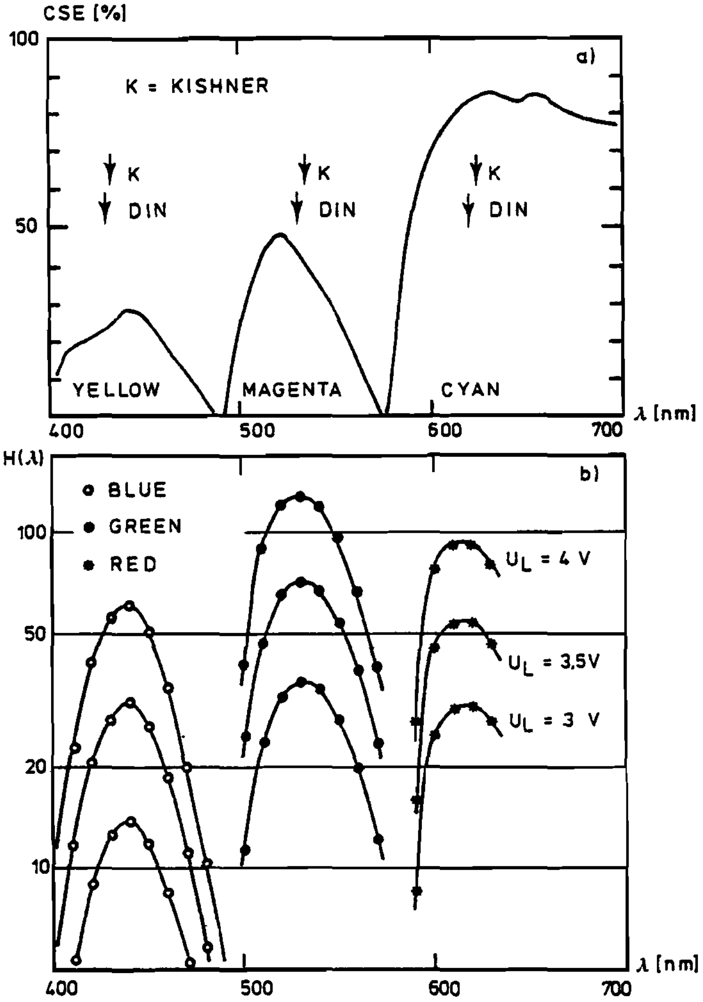

Fig. 3. a) Colour separation efficiency CSE of a commercial EUROPA ink series,
b) Densitometer sensitivity functions with a varying lamp supply voltage.

An incandescent halogen lamp is used as a light source in densitometer sensors and silicon photodiodes are employed as photo detectors.

We have used the following set of Kodak Wratten filters with transmission τ_F for realization of the desired spectral sensitivity:

- black ink, visual observation, CC50G + 2 pcs CC50Y
- yellow ink, blue observation, 47B
- magenta ink, green observation, 58
- cyan ink, red observation, 25

The corresponding sensitivity functions were measured using a Jobin Yvon grating monochromator. The measured curves are given in Fig. 3 b. The lamp was driven with supply voltages of 3 V to 4 V. The varying lamp voltage had no observable effect on the maximizing wavelengths of the curves.

Electrical construction

In a densitometer the photodiode signal current is first converted to voltage inside the transducer enclosure. The grounded conductive case is locally isolated from the press to prevent 50 Hz line interference. The visual, blue, green and red voltages are then sampled, held and fed to the analog/digital converter through a multiplexer circuitry. The assembly of transducer electronics is shown in Fig. 4.

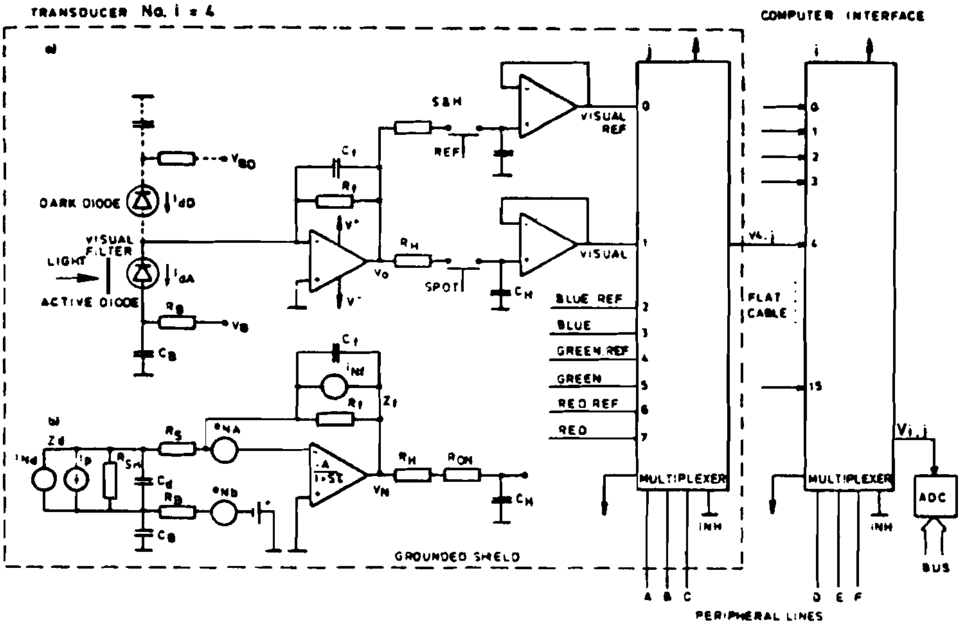

Fig. 4. a) Electrical schematics of the densitometer sensor
b) Principal noise sources of the optical front end

The output voltage V_o for a particular filter, eg. green, is sampled using the command pulses SPOT and REF. SPOT assumes a high value when the photodiode registers the test area. Correspondingly, REF is high at the unprinted gap of the paper web. The switching resistor R_H, in series with the gate-on resistance, filters out the signal noise above 4 kHz. The value of the holding capacitor C_H was chosen for slow drift, and efficient transient suppression due to digital switching. The capacitor is of polycarbonate type for minimum polarization effects.

The measured voltage signals $V_{i,j}$ are shown in Fig. 4. The subscript i refers to transducer, No 4 being shown in the figure. The subscript j refers to the actual signal: j = 0 is for visual filter reference, etc. In our PORTMON 16GI portable density monitor the signals are fed into a first level multiplexer (eight to one) and the ABC-selected output is fed via a "transducer to transducer to computer interface"- flat cable bus to a DEF-selectable second level multiplexer. The final output $V_{i,j}$ (one of 128; $i = 0...15$, $j = 0...7$) is then digitalized in the analog/digital converter, ADC, of the microcomputer interface.

Density Computations

The densitometer makes one measurement for each press revolution. Densities are measured on three strips, i.e. spots, called "solid", "raster 1" and "raster 2". The measurement results of these strips are displayed on the video terminal as bar graphs. In addition to this, a white paper area is measured for tinting control and a reference measurement is carried out on white paper in the gap between succeeding sheets. The densitometer also makes periodically dark measurements, i.e. switches off the sensor lights for a while and determines the zero levels of the photo amplifiers.

An example of a possible measurement sequence is shown in Table 1.

Table 1. An example of measurement sequence.

dark
reference
tinting
solid
raster 1
raster 2
solid
raster 1
raster 2
solid
raster 1
raster 2
reference
tinting
solid
raster 1
raster 2
"
"
"
dark
reference
"
"
"

As explained previously, the densitometer computes the density values as referred to white paper in the gap. No calibration measurements using magnesium oxide as a reference are done and therefore absolute density values are not obtained. The sensor outputs are proportional to the intensity of reflected light. The density values are computed from the density, reference and dark measurement results according to the following formula:

$$D = \log_{10} \frac{I_o - I_D}{I - I_D}, \qquad (4)$$

where

I = measurement result of a strip
I_o = reference measurement result
I_D = dark measurement result.

The formula (4) is applied to the measurement results on the three density strips and to the tinting measurement results. Before substituting to the formula (4), the raw measurement results are filtered. Each sensor channel and each measurement type has its own filter in the microcomputer program, this means 6 x 8 x 4 = 192 filters altogether. The filterings are computed according to the following formula:

$$NF = OF + (M-OF)\cdot K, \qquad (5)$$

where

NF = new filtered result
OF = old filtered result
M = measurement result
K = filtering coefficient, $0<K<1$.

There are four user selectable filtering coefficients for four different measurement modes: dark, reference, tinting and density. A common filtering coefficient is applied to the three different density measurements, i.e. solid, raster 1 and raster 2.

In addition to the computations previously explained, some validity controls are performed before making the actual computations. If any measurement result is regarded as illegal, the rest of computations are omitted and an error condition flag is set instead. Also the approval limits of the legality controls are user selectable.

Some statistical characteristics based on the density values are also computed. These values include average, variance, minimum and maximum values for each of the four colours.

Computing architecture

The computing part of the densitometer consists of two Motorola 6809 microprocessors. The use of two separate microprocessors is a necessity: firstly the calculation of the density values requires a lot of computing power and secondly the timing of these computations is very tightly coupled with the rotation of the printing press.

One of the microprocessors is connected to the sensor interface and is equipped with timing electronics. This microprocessor is called Measurement Processor. The second microprocessor, called Calculation Processor, is equipped with serial connections to a display terminal and a control computer or a tape recorder. There is a fast bidirectional parallel connection between the two microprocessors.

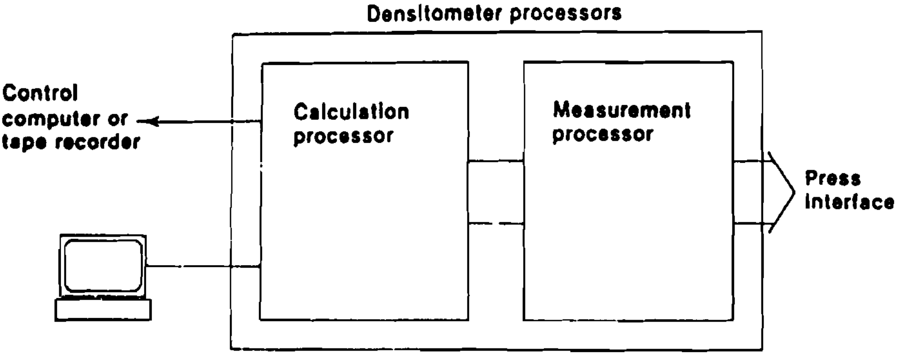

Fig. 5. The computing architecture of the densitometer.

Both the parallel connection between the microprocessors and the serial connection between the densitometer and the computer have similar protocols. The measurement results are transmitted to the computer via a serial connection. The control computer can also completely control the operation of the densitometer by means of transmitting messages to the densitometer.

Both microprocessors have similar scheduler-programs which control the execution of different tasks. Using its scheduler program, each task gives turn to the next task when having nothing to do, or when waiting for an input or output operation . The scheduler of the calculation processor runs asynchronously, whereas the scheduler of the measurement processor is synchronized with the printing press, i.e. each task is performed once during each press revolution.

The division of the computing tasks between the two microprocessors is based on the timing requirements of these tasks. All the tasks which handle measurement results of individual press revolutions are performed in the measurement processor: they include filterings, legality controls and density computations. Also the raw material for statistical computations; i.e. minimum values, maximum values, sums and square sums, are computed in the measurement processor. These results are transmitted periodically to the calculation processor. The transmission interval is user selectable. The calculation processor performs the final statistical computations, updates the display and transmits the measurement results to the control computer.

Measurement timing

The locations of the measuring spots are changeable in the direction of web movement. The user can determine the locations of the three density measurement strips separately for each colour and also the common locations of the reference and tinting measurements for each colour. The determination of the measuring spots is based on a synchronization mark which is printed in addition to the actual measurement strips. The distances between the measurement points and the synchronization mark are measured in millimeters using thumbwheels on the front panel.

The location of the synchronization mark is checked using a synchronization sensor. The determination of the locations of the measurement points is based on a tachometer which measures the web movement. The tachometer gives 10 pulses per one millimeter. In addition to these, there is an inductive sensor inside a printing unit giving one pulse for each press revolution.

Because the synchronization mark obviously is not the only printing image on that zone, an observation window is reserved for the synchronization mark. A synchronization mark found by the sensor is accepted only within the window. The user gives the starting point and the ending point of the window as millimeters from the moment when the inductive sensor gives a pulse. The timing procedure is shown in Fig. 6.

The timing logic is implemented with hardware using three pieces of Motorola 6840 programmable timer/counter circuits, Fig. 7. Therefore the determination of measurement locations is accurate. Each timer contains three separate counters. Two counters are used for generating the synchronization window. The synchronization mark initializes the counters which in turn determine the locations of the actual measurement spots. These counters actuate a sample and hold operation in the sensor interface part when the measurement strips are straight below the sensors. The sampled measurement results are A/D-converted

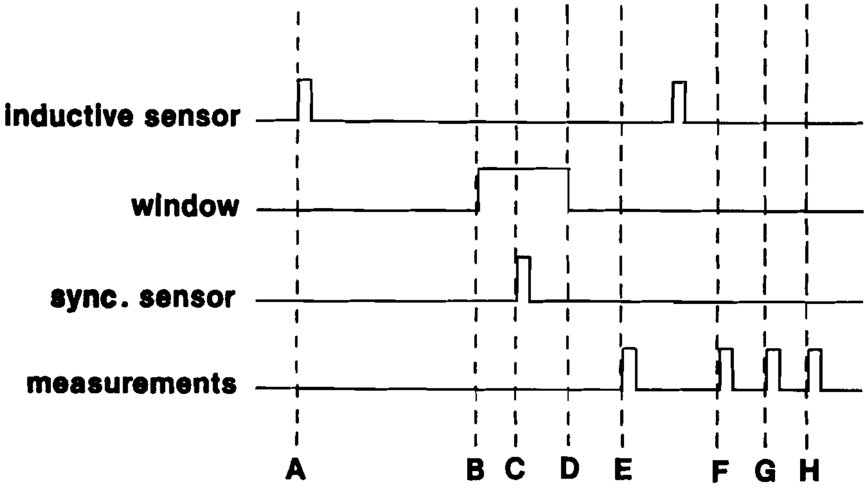

Fig. 6. The timing of measurements.

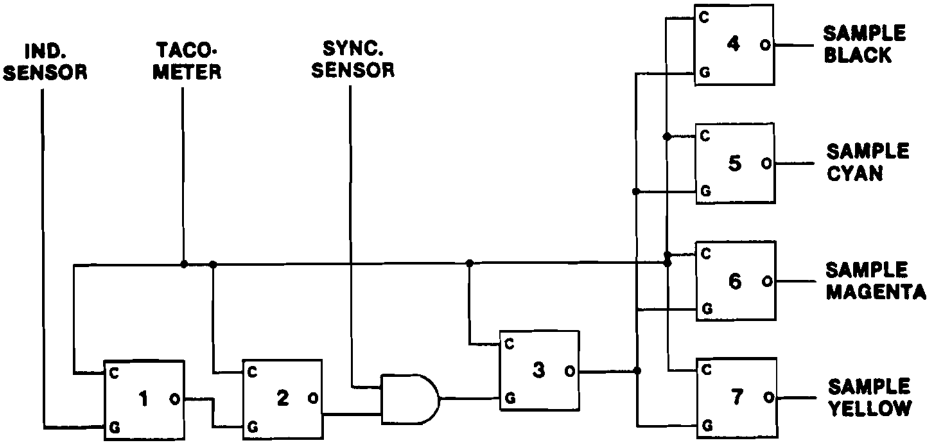

Fig. 7. The timing logic of the densitometer.

during the same press revolution and the density computations are performed during the following press revolution.

Closed-loop control use

The density values are displayed as bar graphs. The densitometer has 12 different displays for the three density measurement strips and the four colours. Each of the 12 displays have two display modes: an absolute display mode and a differential display mode. In the absolute display mode the bars show the actual density values. In the differential display mode the deviations from user selectable optimum density levels are shown instead. The densitometer has separate optimum density values for each ink, sensor and measurement strip. The user has two alternative methods for selecting the optimum density levels. Firstly, he can transfer the last computed results to optimum values by pressing an OK buttom. Secondly, he can change each optimum density value by means of the terminal.

The results of statistical computations are displayed as decimal numbers on the terminal. The terminal display has a special area reserved for error codes: they are for instance a high tinting level or an illegal measurement result.

The densitometer operation is controlled by means of various parameter values which determine the filtering coefficients, the measurement sequence and the frequency of the display updatings. The user can change these parameter values by means of the display terminal.

Four different message types are transmitted between the densitometer and the control computer: control messages, data messages, express messages and status messages. Using control messages, the control computer can change all parameters values which control the densitometer operation.

The data message and the express message are two different message types by means of which the measurement results are transmitted from the densitometer to the control computer. The former is mainly used for statistical measurement results and the latter for actual density profiles. The contents and the duty cycles of these messages are also changeable by means of control messages.

The error codes displayed on the terminal are transmitted to the control computer by means of status messages. The data traffic has two operating modes called passive and active. In the passive operating mode the densitometer transmits only when requested. This operating mode is used with the control computer. In the active operating mode, which is mainly used with a tape recorder, messages are transmitted without request.

Conclusions

The use of fast on-press densitometers is a condition of reasonable application of closed-loop control algorithms for web-offset presses. The high measuring speed required has been accomplished by means of multichannel optical sensor construction and using a computing system of two microprocessors and fast timers for measurement synchronization.

Acknowledgments

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