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The problems posed by electrostatic charges in printing machines have increasingly gained importance in recent years and have therefore become a significant research subject. More recently, investigations into the build-up of electrostatic charge during the operation of rotogravure printing machines were conducted at the "Institute for Printing Machines and Printing Processes" of the Technical University in Darmstadt.

This paper is intended to serve in clearing up the questions to what extent the designer of printing machines can through suitable measures prevent respectively hold to a minimum the build up of electrostatic charge.

Questions relating to the removal of the charge through the use of dischargers or of increasing the conductivity of a paper by chamical means either during the production process or subsequent surface treatment have not been given consideration. Suffice it to say, that MACOUREK, Prag (1), in 1964 prepared an excellent summary of internationally available electrostatic dischargers, classifying them in groups according to their method of operation. Attempts to reduce the tendency of a paper from building up a change by adding certain substances to the paper stock (2) (3) (4) (5) are somewhat older. Clearly, the difficulty here is that in producing a paper emphasis is laid first and foremost on an optimum printability, but at the same time economic condiderations can never be neglected. Then, there is the fact that plastic films are being used as printing materials in increasing measure. The goal of the subsequent surface treatment with antistatic agents is to reduce friction and hence the contact potential, between the surfaces in contact. Higher alcohols, owing to their hygroscopic nature, affect the conductivity. Surface-active agents also serve to reduce the contact potential.

By way of introduction, let us briefly review the mechanism of electrostatic charge build up and the physical laws which apply. During its run through the printing press the printing medium (paper) comes into contact with widely different materials, such as matals, rubber, printing inks, high polymers and paper. Hereby, the paper experiences everything from lightly touching contact to deformation, heating and eventually friction with paper or other materials is subjected to the most complex combination of stresses. Theoretically, the formation of an electrostatic charge could equally well be a result of the piezo or the pyroelectric effect, as well as of contact, respectively friction with another material. As a result of various experiments (6) the electrostatic charge, resulting from the piezo and pyroelectric effect may be considered negligible.

The following, therefore, is based on the two main sources of electrostatic charge in paper: contact and friction. Generally, the surfaces of previously uncharged materials carry a charge after having been in intimate contact. Hence, it is possible to classify the materials in a potential series (Fig.1). According to the Cöhn Rule (7):

1. The dielectric with the larger dielectric constant (DK) becomes positively charged with respect to the dielectric with the smaler DK.

A larger DK also corresponds to a greater displacement of the charge within the molecules.

2. The charge producted, when two dielectric bodies in contact are separated is proportional to the difference in the (DK) of the two dielectric materials

$$Q = K \cdot (\varepsilon_1 - \varepsilon_2)$$

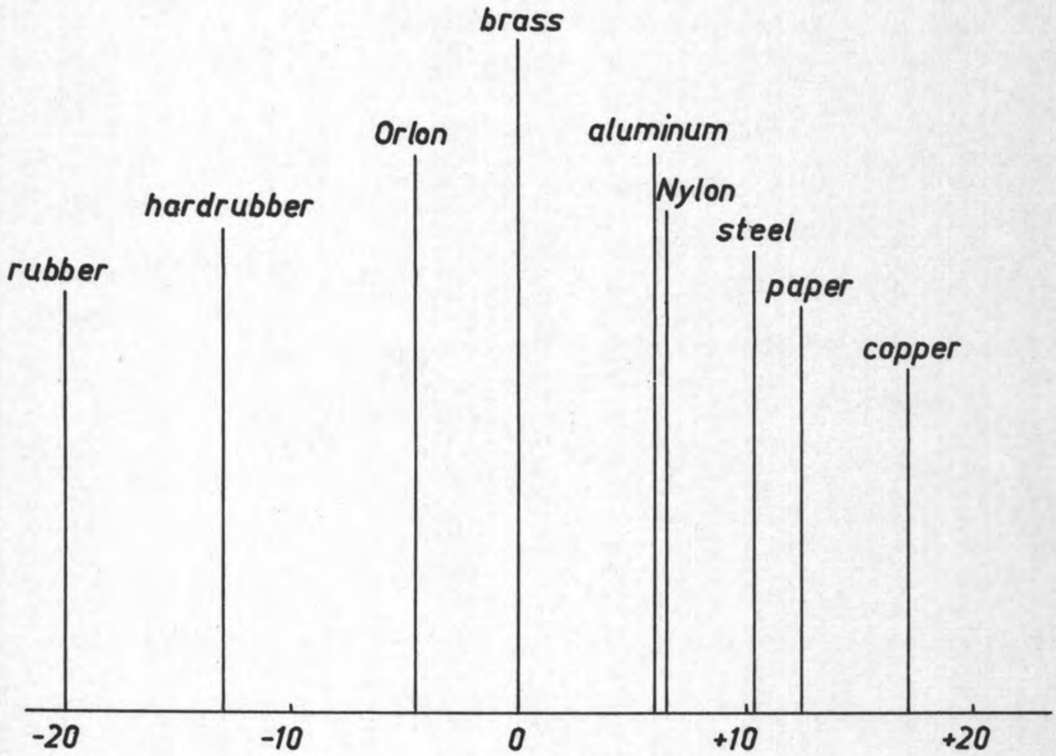


Fig.1 Electrostatic Rtential Series.

Experiments investigating the effect of the ambient air on the built-up of electrostatic charge are presently being carried out in our Institue. It is well-known that at higher humidity, the electrostatic charge developed in printing plants is lower. To what extent this is actually due to lower formation or to a better discharge and to what degree it is affected by the ambient air or by the paper is even now being examined at Darmstadt Institute. At present reference will only be made to the paper (6), (7) and (9).

Two media in contact form electrical double layers at their common surface. This can be explained by the presence of an inwardly directed electric field, which effects a polarisation. Whereas HELMHOLTZ regarded the exchange of charge as due to electrons only and not to ions, BÖNING (10) (11) (12) and GRÜNER (6) advance the theory that, especially by insulators, an exchange of ions is possible. This view has been supported by their experimental results. BÖNING found in the surface of various materials adsorbed fixed "boundary - layer - ions" which are different in charge and mobility. These boundary - layer - ions are surrounded by mobile "complemental - ions", which when removed cause the materials to carry a charge. In addition to the above explanations for two lightly touching materials, GRÜNER defines the so called "area effect", which takes place when two unequally large areas are rubbed together. Generally speaking heat produced by friction increases ion mobility. Thus ions pass from the smaller to the larger surface, and a charge is formed.

In the last analysis, the mechanism of the exchange of charge at the boundary layer is still largely unclear. However, many phenomena can be explained with Böning's theory. Furthermore, the so-called "area-effect", according to GRÜNER, affords unstandable explanation for the formation of electrostatic charge on two materials having the same electrostatic properties, when undergoing friction.

Measuring Instruments and Methods

Electrostatic field density-meters (system SCHWENKHAGEN) were used in making the measurements. These field density-meters employs the induction principle for producing a measuring current from the mechanical motive energy of a separately excited generator. The field to be measured serves as the exciter field. No energy is removed from i:t during the entire measurement as the motor and amplifier supply all the power required by the indicator.

Furthermore, a self-constructed capacitive measuring probe with b uilt-in electrometer amplifiers were used.

Measuring instruments which operate using radioactive elements were not employed in these experiments because of their lower accuracy.

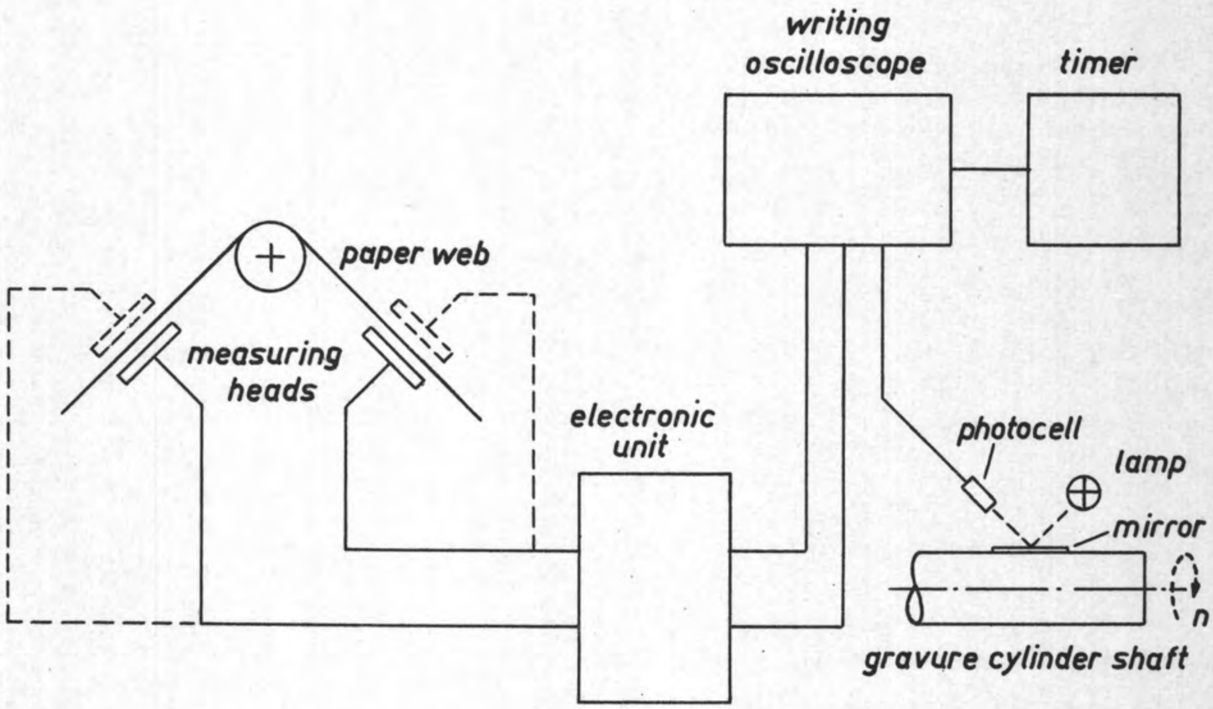


Fig. 2 Schematic Diagram of Measuring Apparatus.

A charge is measured by measuring the force with which it is attracted or repelled by another charge.

$$K = \frac{1}{4\pi \cdot \mathcal{E}_o} \cdot \frac{Q_1 \; Q_2}{r^2} \quad \text{(Newtons)}$$

where K = force (N)

$\mathcal{E}_o$ = the dielectric constant of a vacuum

= $8,859 \cdot 10^{-12} \; \left(\frac{A \;.\; sec}{V \;.\; m} \right)$

Q_1, Q_2 = Charge (Coul)

r = Distance (m)

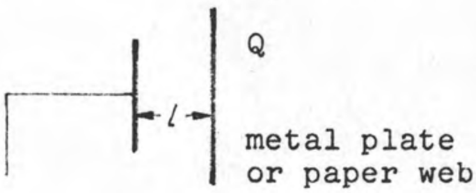
The charge density is defined as the charge/area

$$\sigma = E \cdot \varepsilon \quad (\text{in Coul/m})$$

where E = field density (V/m)

ε = the dieelectric constant of the medium $\left(\frac{A \cdot sec}{V \cdot m} \right)$

In a plate condenser the electric field density is:



$$E = \frac{U}{l} \quad \left(\frac{V}{m}\right)$$

In a homogeneous field the charge is directly proportional to the field density. If the gap, l , is changed at constant charge, E remains constant.

$$Q = C \cdot U$$

where: Q = charge (Coul)

C = capacity (F)

U = potential (V)

By substituting $U = E \cdot l$ and $C = \text{const.}\ 1/l$ in the above, we get

$$Q = \text{const.} \cdot E$$

for a homogeneous field. However, it should be remembered that even on a freely suspended paper web we have to deal with a more or less non-uniform field. In addition, foreign electric fields are usually present near machine parts and other objects. More often than not these cause a distortion of the field. The non-uniformity of the electric field is a function of:

1. The distribution of charge on the paper surface.
2. The presence of stray and foreign fields as well as distortion arising from the geometry of the surroundings.
3. The modus operandi of the measuring apparatus used.

Measurements of the Paper Web of different-sized Rotary Photogravure machines

The curves depicted in Fig.3 were recorded after the fifth printing unit and a few guide rollers before the cross cutter and folding unit. In upper curve, the following were successively recorded: strong fluctuations in the charge build-up prior to printing, smoothing out at the moment of printing of the first printing unit (we shall come back to this later), steep rise of the already negatively charged verso-print (yellow) on the reverse side of the paper, drop-off during recto printing (black) and, finally, the characteristic charge behaviour after the completed 1-color recto and 4-color verso print. During the entire measuring sequence the press ran at a web feeding speed of 0,45 m/sec.

The lower curves showing the field density were recorded using two measuring heads, one on the recto side and the other on the verso side, mounted directly above an almost full-tone area. They show a continous uniform change in the average value of the charge on both sides of the paper web, als well as a change in polarity, but primarily a negative charge. As we shall see this is a typical charging characteristic of both sides of a printed paper web. The electrostatic charges on the upper and lower sides of the paper web are interdependent. The charge measured with measuring head G II on the verso side does not at all appear to be influenced by the guide roller approx. 40 cm removed, owing to the high operating speed (v = 5,4 m/sec). Both measurements were taken at t = 22,4°C and φ = 40 % r.h. in February, 1965.

From the curves which you have just seen, the influence of the ink on the charge build-up is clear. Prof.FLEGLER, in Aachen, in his experiments on the conductivity of gravure printing inks as a function of the ink/solvent concentration found the following correlations.

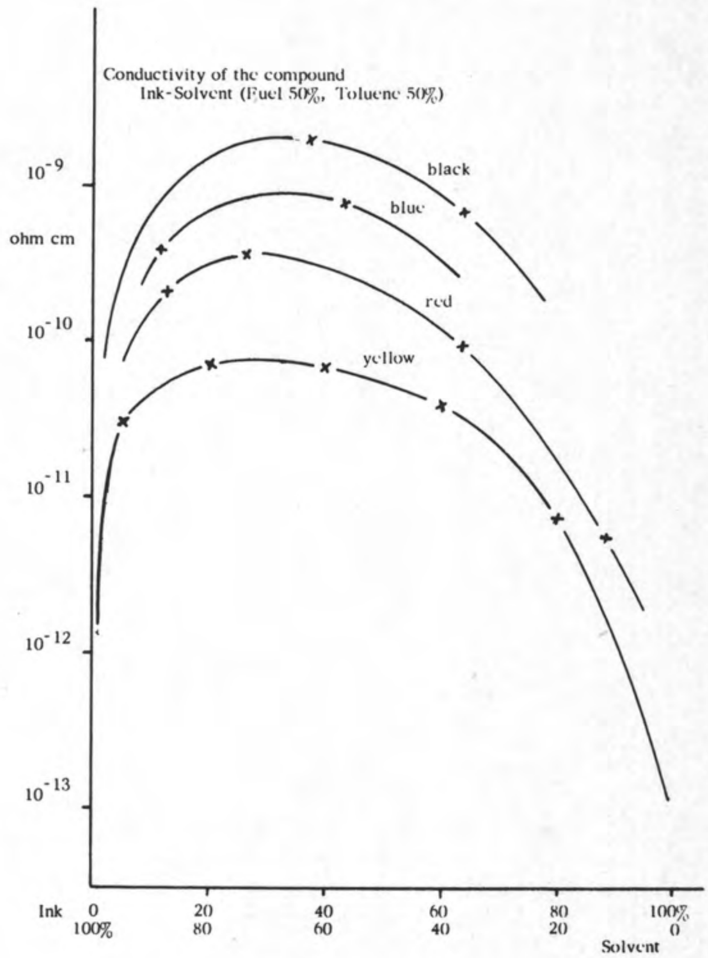


Fig.4 Conductivity of gravure printing inks as a function of their consistency, according to Prof.FLEGLER (13)

Whereas, the fluctuations of charge are small on plain paper, they may, in some cases, be very large on printed paper webs. The size of the charge may vary depending on the tonal value and number of superimposed prints.

The curves depicted in Fig.3 were supported by repeated measurements on a number of presses, thereby confirming the influence of the ink on the charge. Measurements in other zones across the breadth of the cylinder gave different but in principle similar results. The beginning of the first verso printing stage (yellow) is not always noticeable on the recto printing side. This may best be explained by the change in the amount and distribution of the printing ink used. The start of recto printing always causes a drop in the negative electrostatic charge and the remaining 3 verso printing units (red, blue, black) lead to large fluctuations in charge. These fluctuations were repeatedly found to parallel the revolutions per unit time (rph) of the gravure cylinder.

In order to comprehend the role of the individual parameters, the influence of the pasting process in an Autopaster (a two-roll Autopaster System HUCK) on the charge was measured behind several paper guide rollers and printing units. The web speed during the pasting process was always maintained at 5,3 - 5,4 m/sec. The characteristic curves obtained are shown in Fig.5. In all three cases, a noticeable negative charge is formed at the moment of pasting. These typical fluctuations in the charge occuring during pasting decrease with increasing distance from the "Autopaster".

If we regard the paper as experiencing a momentary stress impulse, this behaviour can be explained by the "area effect" theory. Any influence exerted by 3 to 4 m long pasted-overlap is indirect see in Fig.11, the influence of the printing pressure).

Any variation in the average value of the charge can be related to the condition of the new paper roll. The electrostatic behaviour of the 3 curves after the pasting process can not be generalized.

The influence of the printing ink was characterized by measuring the time required to discharge a charged paper web when a press operating at V_{cyl} = 18000 rph (V_{web} = 5,3 m/sec) was suddenly stopped. The time required from the moment of stoppage was:
approx. 6 sec for plain papers and
approx. 50 sec for printed papers. The loss of charge was in every case a logarithmic function (e-function) where the time constant

$$T_{printed} > T_{plain}.$$

This plainly illustrates, that a paper wetted with printing ink holds its charge longer. This effect of the ink has been discussed from various view points and can be explained by the theories of BÖNING and GRÜNER mentioned earlier.

Measurements at the Paper Guide Rollers of commercial Rotary Photogravures

In these measurements, designed to further the understanding of the influence of paper guide rollers on the electrostatic charge, two measuring heads were used. From measurements made on the web side which touches the metal of the guide roller it was found that fluctuations in the charge on plain paper webs are essentially completely evened out, whereas in printed paper webs this was only partially the case. The paper is partially discharged.

The charged paper is partially discharged upon coming in contact with the paper guide rollers and is recharged upon separation therefrom. Charge formation before and after the guide rollers are completely independent of one another. At high web speeds the charge can no longer flow completely from the web. There is practically only a smoothing out effect. The parameter, web speed, is a determining factor in all measurements. With increasing web speed, the degree of smoothing out decreases. The charge formed during separation of the paper web from a guide roller is added to the charge already present on the web.

In addition, the charge formed at the guide rollers is, among other things, a function of the paper tension. This was observed on high speed paper webs which were subjected to fluctuations in tension owing to deformations in the paper roll, as well as during start-up (Fig.6). The charge after the guide roller increases rapidly until a press speed of V_{cyl} 3500 rph, after which it remains practically constant to a V_{cyl} = 18000 rph (see Fig. 6). This behaviour can be explained by the "area effect" theory, according to GRÜNER. An increase in the paper tension would serve to increase the contact area between paper and metal. Further experiments, however, are necessary.

Polarity of the Electrostatic Charge on a Paper Web

Plain paper webs were normally positively charged, corresponding to the respective positions of paper and steel in the electrostatic potential series. However, contrary to this finding, negative electrostatic charges were also often registered e.g. when suddenly braking the printing press (Fig.7). This phenomena can be explained by the "area effect" theory, which says that the larger area becomes positively charged. When the paper web is suddenly stopped, the guide roller continues to rotate. Hence, more surface elements of the metal roller come into contact with the paper surface per unit time than vice versa, i.e. the paper has the smaller area undergoing friction and must, hence, become negatively charged.

Both positive and negative charges were measured on printed paper webs. In this case, the ink which is rubbed off by the guide roller plays a role, in that it changes surface conditions among other things.

Measurements made with two measuring heads on the opposite side of the web from the guide roller hardly affected the charge on a plain paper. In contact, a slight smoothing out could be observed on printed papers which generally carry a higher charge. Here, the charge is the source of electric field lines which penetrate the back of the paper and affect the measurement. On a large rotogravure printing press in another printing plant, the influence of the brushes after the first verso printing unit (yellow) was measured (Fig. 8). At a machine speed of V_{cyl} = 8000 rph, the average value of the charge on the verso printing side, without brushes, was -270 KV/m. With the brushes in position, the charge sank to -110 KV/m. From this, we can see that the charge on the recto and verso printing sides of a paper web influence one another.

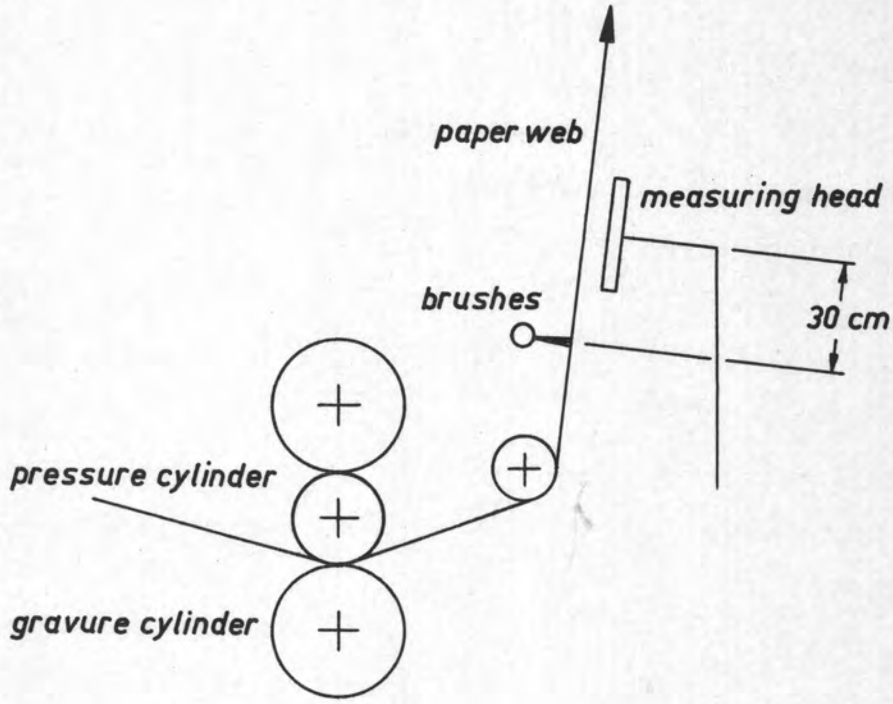


Fig.8 Schematic Diagram of the Measuring Apparatus for Determining the Influence of the Brushes

In summarizing the investigations made on paper guide rollers, mention should be made that in addition to an increase in the average value of the charge with increasing machine speed, there is also an increase in the amplitude of the fluctuations themselves (Fig.9). From the figures we see that the charge increase linearly until about V_{cyl} = 10 000 rph and then at an ever increasing slope. These fluctuations of charge are by no means simple vibrations. They are the resultants of a number of superimposed vibrations of different frequencies, all of which are functions of the revolutions per unit time. To date, the amount and distribution of ink and fluctuations in the tension of a paper web have been established as causes for these fluctuations in charge. There is no doubt, however, that climatic factors arising from drafts, drying cylinder etc. affect the charge.

Measurements at the Printing Units of Different Sized Rotary Photogravure

Before showing a survey of the charges measured at the various printing units of three commercial printing presses, I should like to very briefly point out the general trends.

The values measured after the printing units show different charge characteristics depending on the tonal value and the amount of ink used. This is supported by the fluctuations in charge which vary across the breadth of the web, as already shown.

The charge increases exponentially with increasing web speed (Fig.10).

Investigations to determine the influence of the heating effect of the drying cylinder showed that in a commercial printing press the charge decreased with increasing temperature both before and after the heating zone. Even small charges of approx.200 KV/m drop to 35-40 % of the value measured before the drying cylinder. The charge directly before the drying section fell some 3-5 %. At present nothing definite can be said about the temperature of the drying cylinder, resp.the aluminium guide rollers in the drying unit. Until the necessary laboratory tests are carried out.

Likewise, no definite statement can be made regarding the effect of the couch roll pressure on a commercial printing press. Figures 11 und 12 show that increasing the couch roll pressure can lead to either a positive or negative charge. No definite trend can be seen in the charges measured at printing units 11, 12 and 13. For a complete understanding, it is essential to determine the influence exerted by each of the inks used.

In other experiments carried out at the Darmstadt Institute it was found that the electrostatic charge build-up has a considerable effect on ink transfer during the printing process. These results were gained with the aid of high frequency cinematographic equipments on hand at the Darmstadt Institute.

A suitable apparatus capable of measuring the electrostatic charge arising from the contact between couch roll-ink (recto print) - paper - printing ink - gravure cylinder without weakening the electrostatic field being measured has already been constructed and tested and is at present being improved. At present, runs are being made at the Darmstadt Institute on a small, laboraty-scale photogravure using couch rolls made of a number of different conducting, semi-conducting and non-conducting materials.

Fig. 13 and 14 show the electrostatic charges measured at the various printing units of three large commercial rotary photogravures. In Fig.13 we see that extreme values of + 1300, + 1200 and + 1450 KV/m were measured after the recto printing unit (black). The second paper web carries a charge of 350 KV/m before entering the recto printing unit (black), picks up a charge of 850 KV/m and leaves the recto printing unit with a charge of + 1200 KV/m, and after the drying unit reaches a charge of + 1450 KV/m. In the first verso printing unit the paper web undergoes an enormous discharge of - 2430 KV/m and leaves the unit with a charge of - 980 KV/m. With - 2430 KV/m an extremely high field density change was reached. All the field densities measured lay much lower than the dielectric breakdown strength of the air. The dielectric breakdown strength (u_d) air is defined as:

$$u_d = f\ (\delta\ .\ a) = f\ (p.a)$$

where: δ = relative air density

a = gap between plates

p = air pressure (atm)

At p = 1 atm; t = 20°C; a = 1 cm, the dielectric breakdown strength of air, u_d, is $\approx$ 32 KV.-

It is interesting to note that REUTER (5) found the highest electrostatic charge (up to + 1750 KV/m) after the verso printing unit of a rotary letterpress. At first glance, the negative charge on the third paper web after the recto printing unit (black) seems surprising. However, paper webs 1 and 3 showed a similar increase in their negative charge between measuring points 15 and 16. In Fig.14 similar trends are evident. The highest measured difference in charge (+ 1140 KV/m) occured in the recto printing unit (black) of press 4. The relatively high drop in charge from positive to negative in the verso printing unit (yellow) of press 3 (approx - 860, resp. - 666 KV/m) and in Press 4 (approx. - 585, resp. - 655 KV/m) may be regarded as typical .

Measurements at the printing units of commercial printing presses clearly indicated that owing to the large number of parameters involved, any statement would needs be of a more or less complex nature. For this reason measurements were simultaneously carried out on a small experimental photogravure printing press as well as on four different types of commercial printing presses.

SUMMARY

Experimental results made on large commercial rotary photogravures were discussed. First, the mechanism of electrostatic charge development and the applicable physical laws were reviewed. Contact and friction between paper web and paper or other materials were regarded as the primary causes for the formation of an electrostatic charge on the paper web.

Questions relating to the removal of the charge through the use of dischargers or of increasing the conductivity of a paper by chemical means either during paper production or subsequent surface treatment have not been considered.

The charge development on the two sides of the paperweb may be different or influence on another. The lost of charge with time is a logarithmic function, where $T_{printed} > T_{plain}$.

The influence of the amount and distribution of ink on the charge is discussed. Printing speed, printing pressure and temperature (room, drying section and press) greatly affect the charge development. The discussion are supplemented by experimental results.

Ink transfer was found to be greatly affected by the electrostatic charge with the aid of the high-frequency cinematographic equipment. Skillful use of this knowledge could lead to improved ink transfer in photogravure printing.

The mechanism of electrostatic charge development in the printing units is very complex owing to the different materials involved.

The experiments of the Darmstadt Institute of Printing Machines and Printing Processes investigating the area of electrostatic charge development in rotary photogravures have not yet been completed and are being continued.

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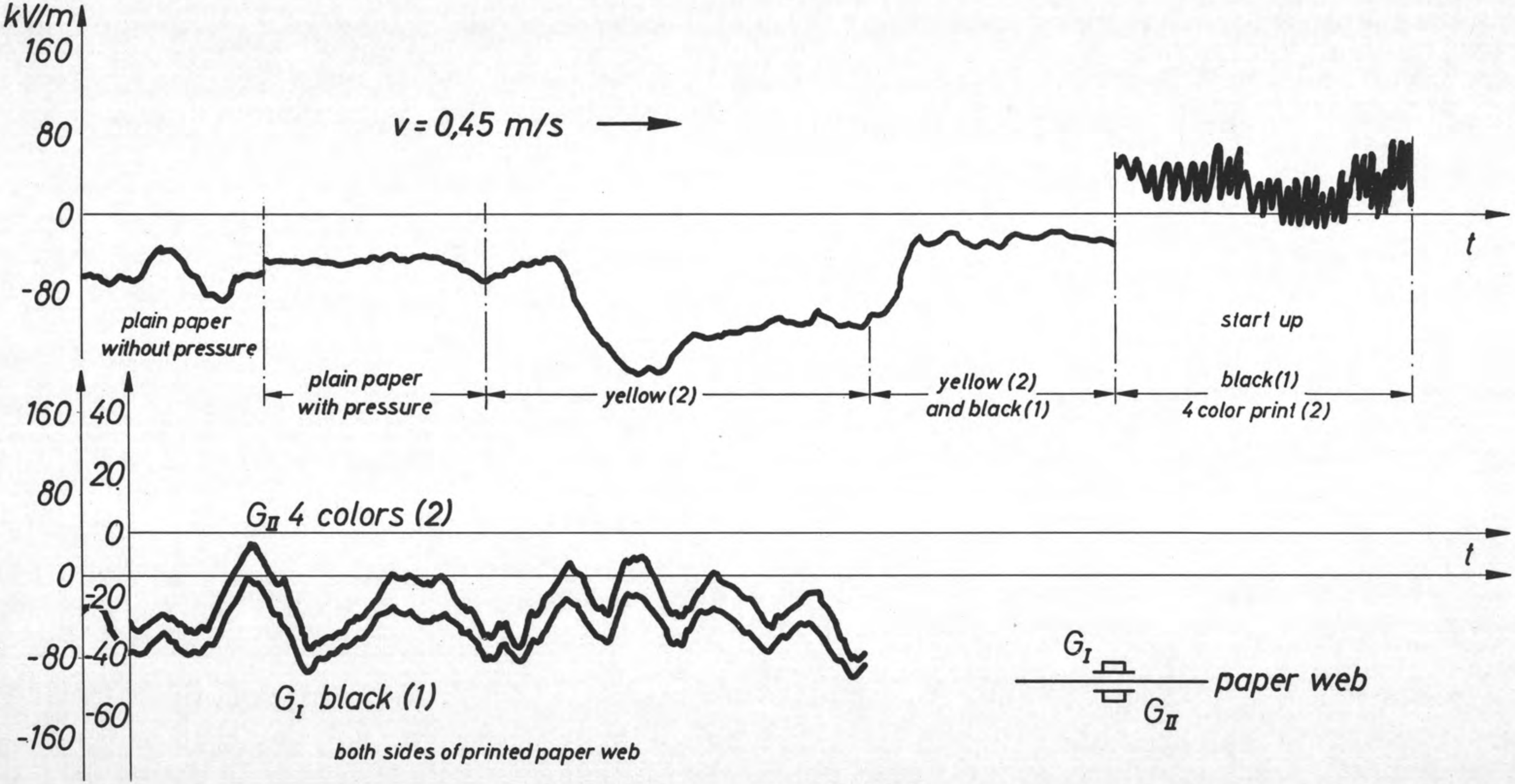


fig. 3 The influence of the amount and distribution of printing ink of the electrostatic charge on the paper web

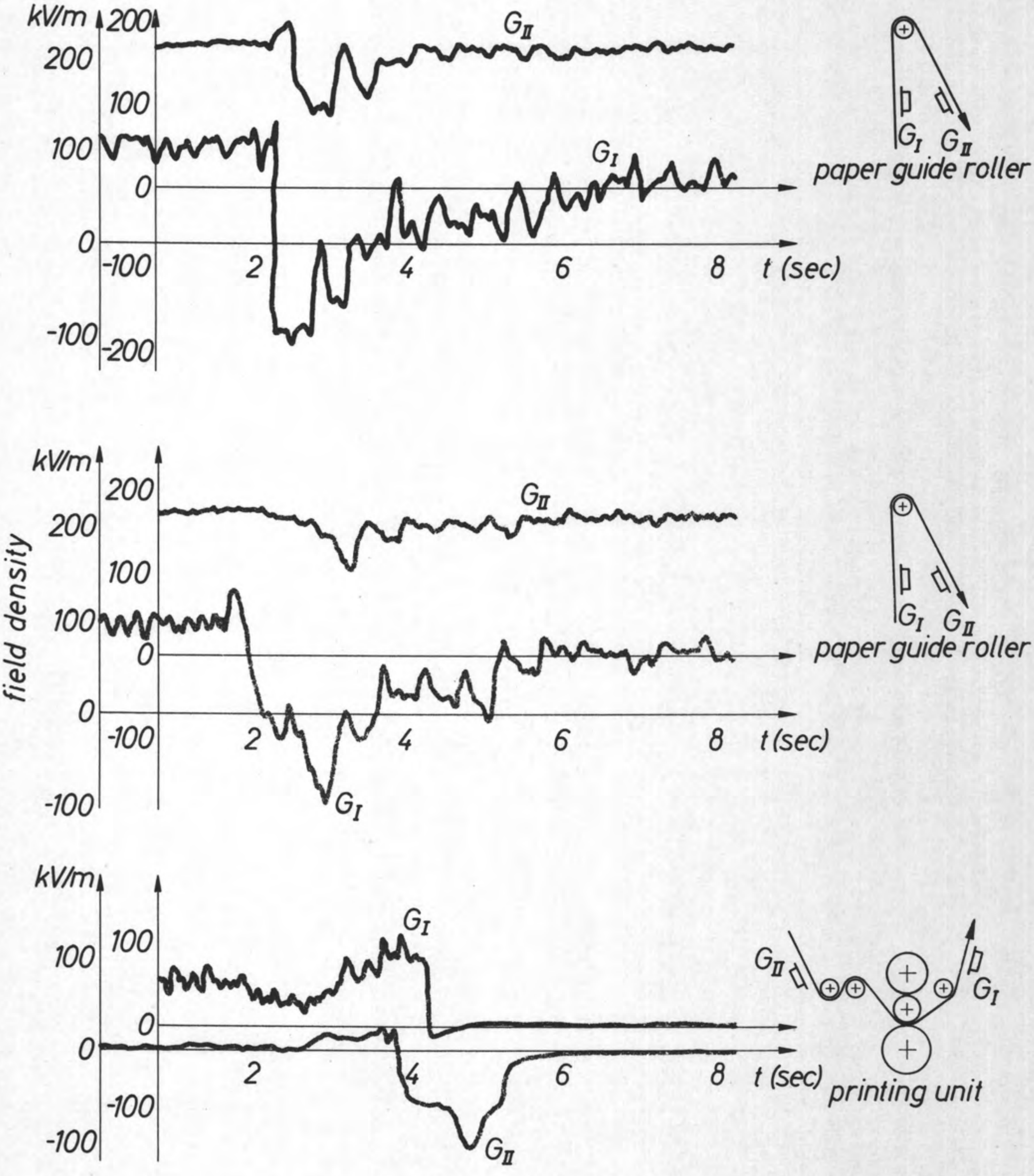


fig. 5 The electrostatic behaviour during the automatic pasting operation at $v_{paper} \approx 5{,}4$ m/sec

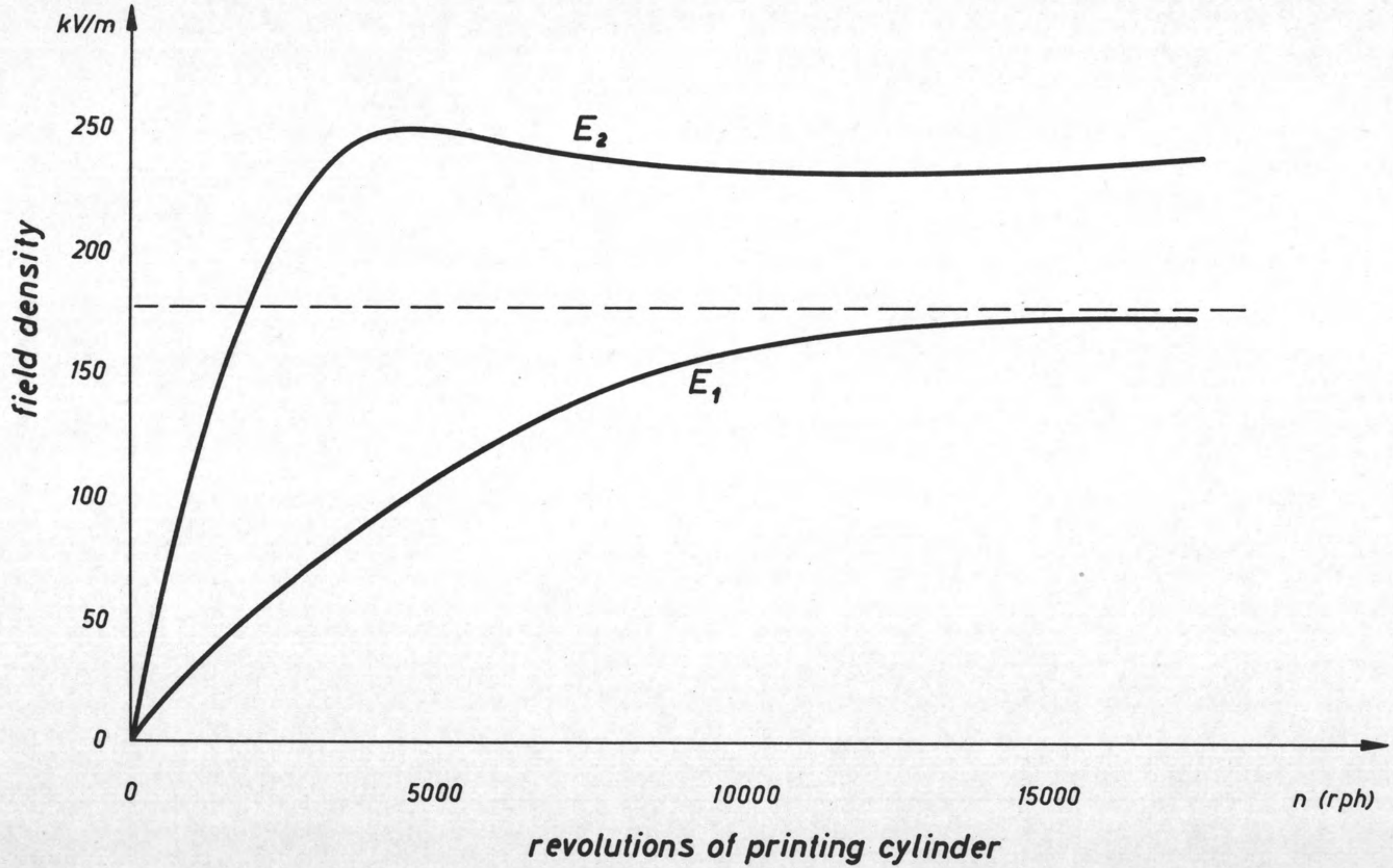


fig. 6 The build-up of electrostatic charge on a plain paper web at the paper guide roller during start up

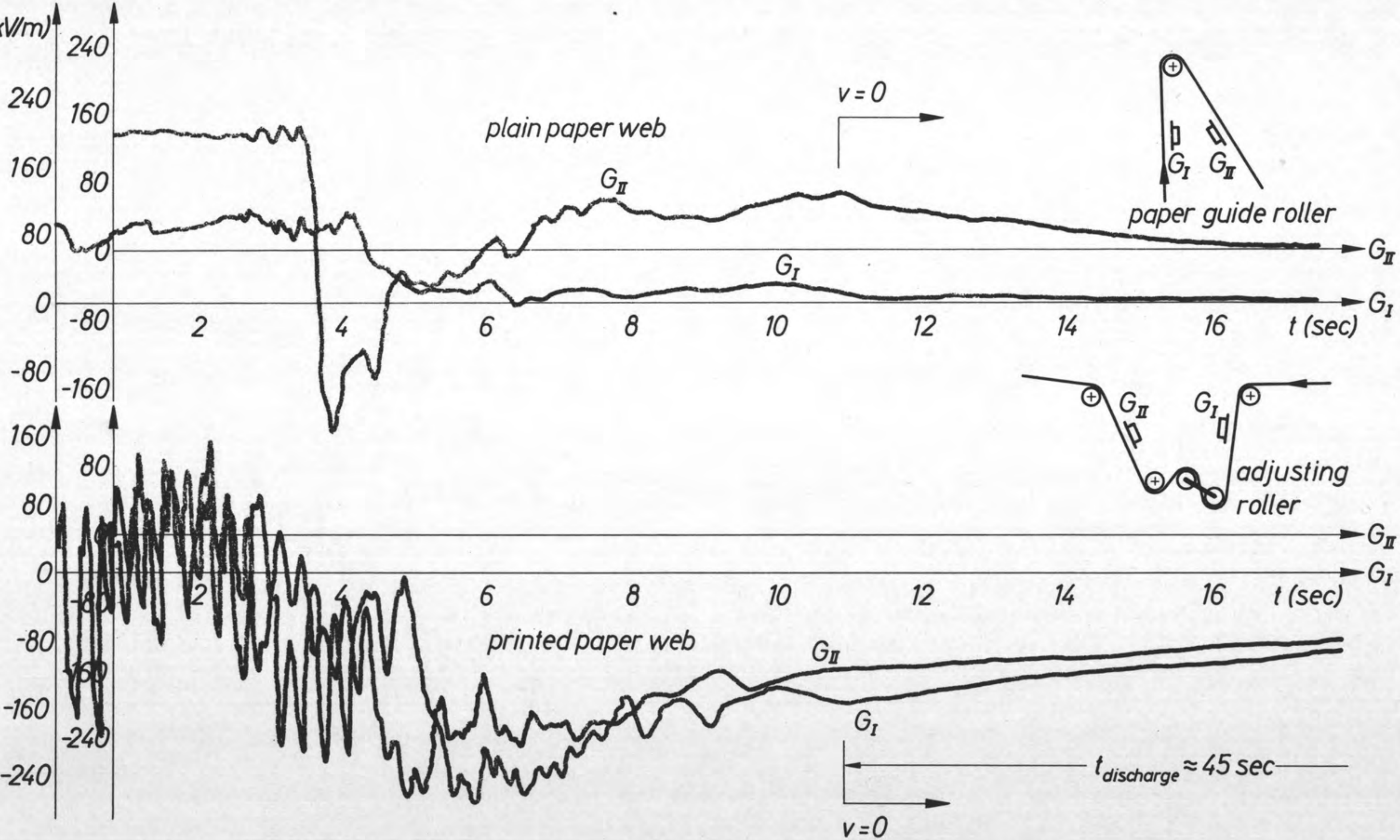


fig. 7 The electrostatic characteristic of a paper web during cut off on a production rotary photogravure

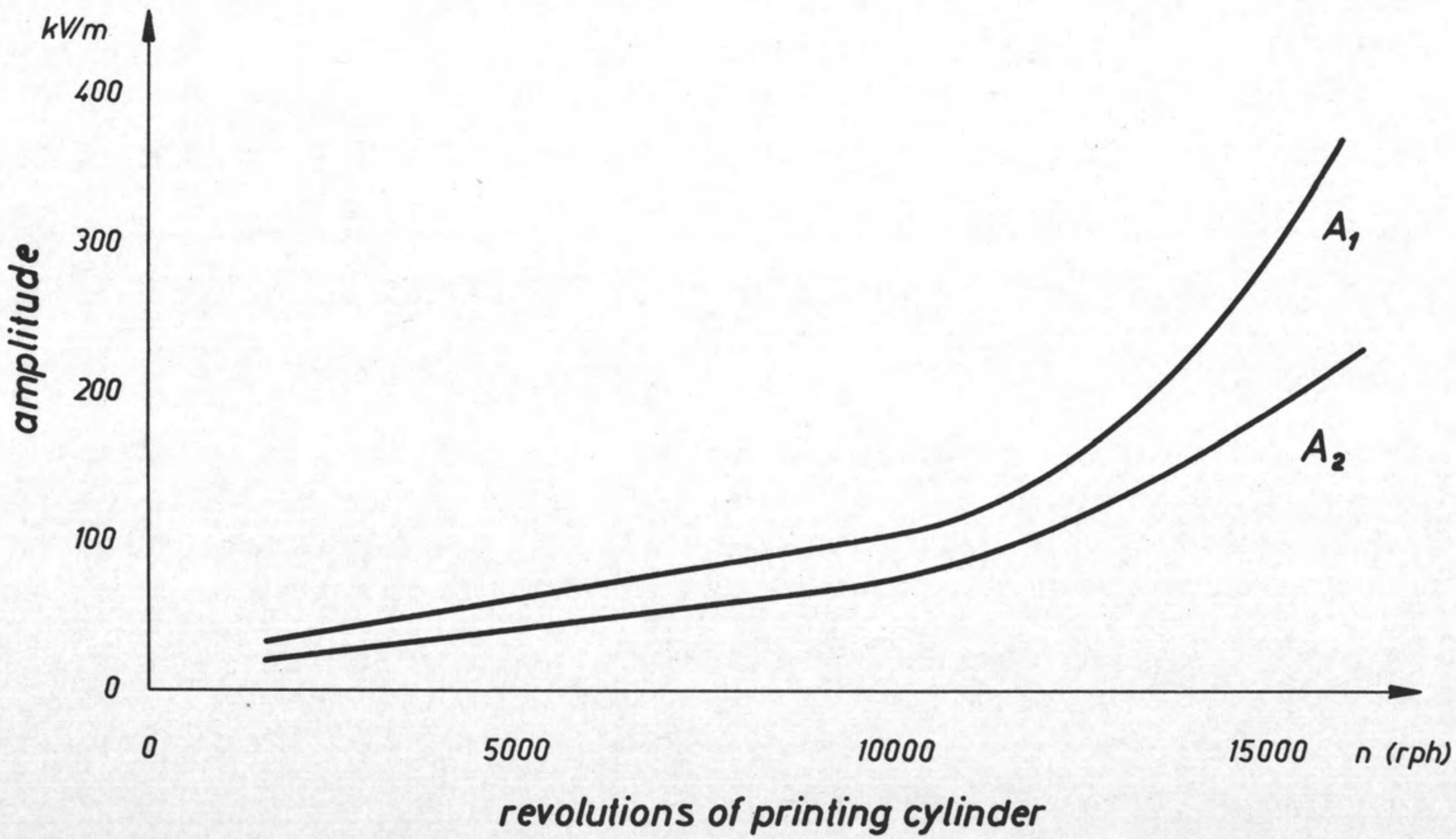


fig.9 Dependence of the amplitude of electrostatic charge fluctuation on the gravure cylinder rph

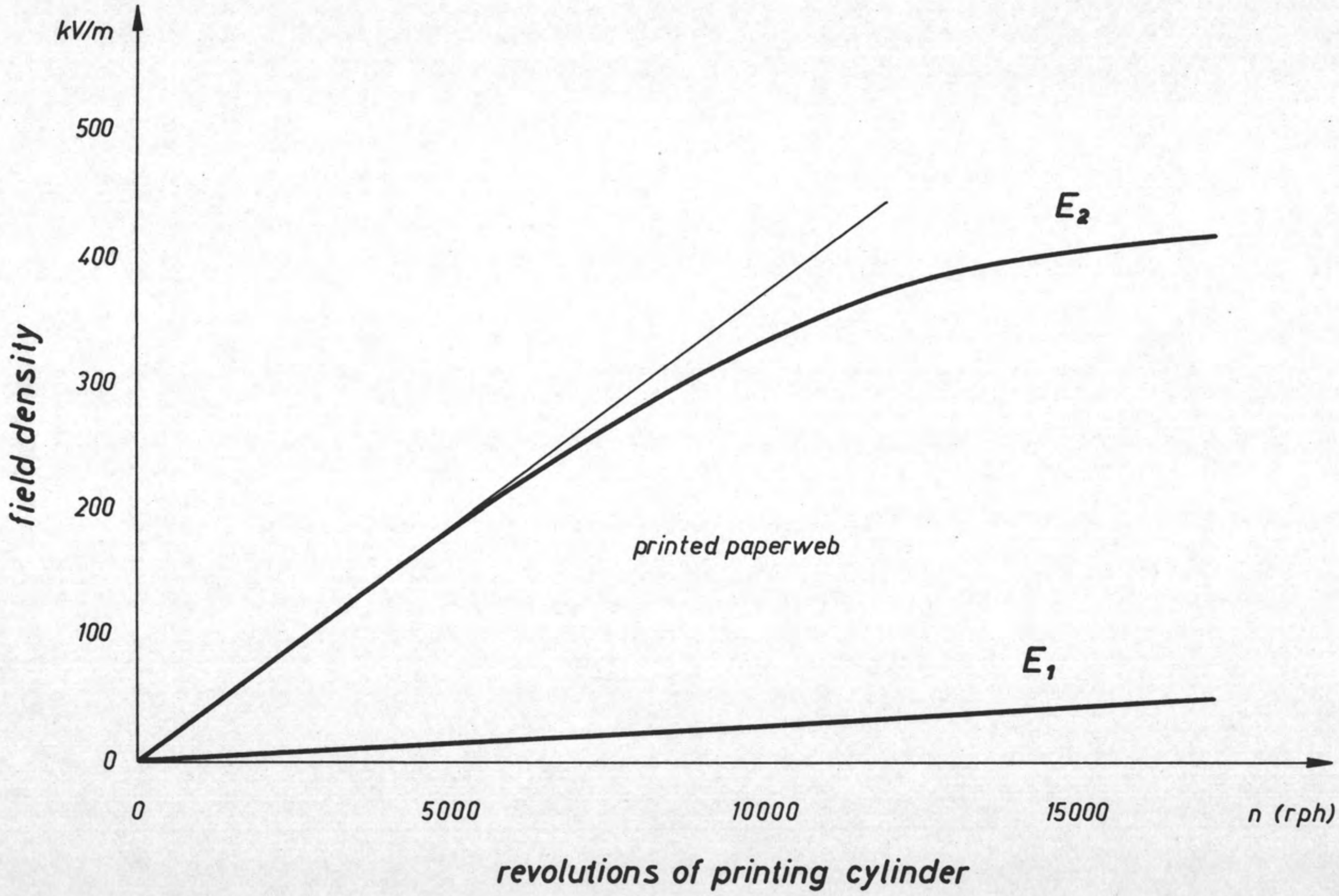


fig. 10 The influence of an operating printing unit on charge development on an already printed paper web

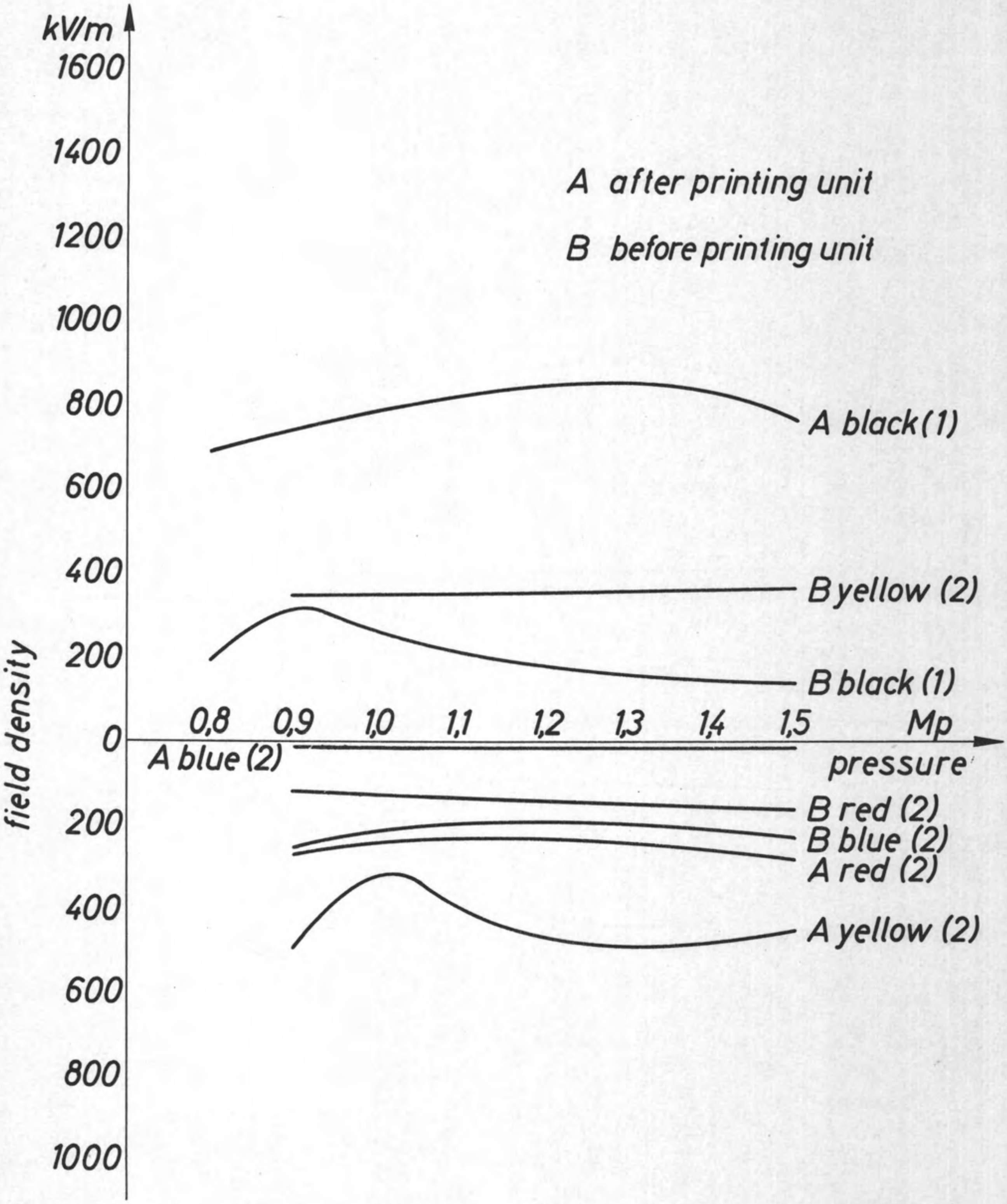


fig.11 Dependence of the electrostatic charge development on the printing pressure before and after the printing units

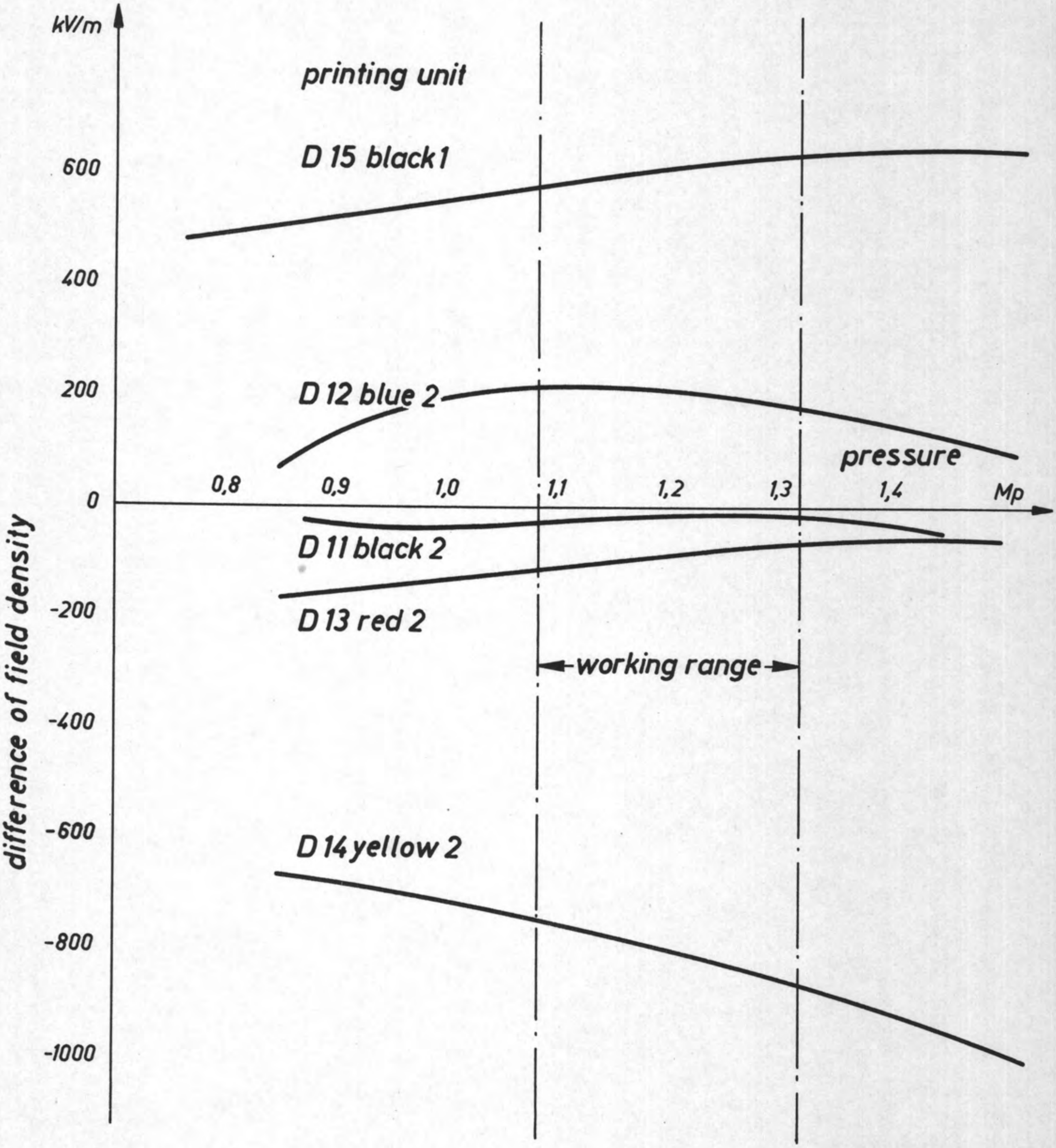
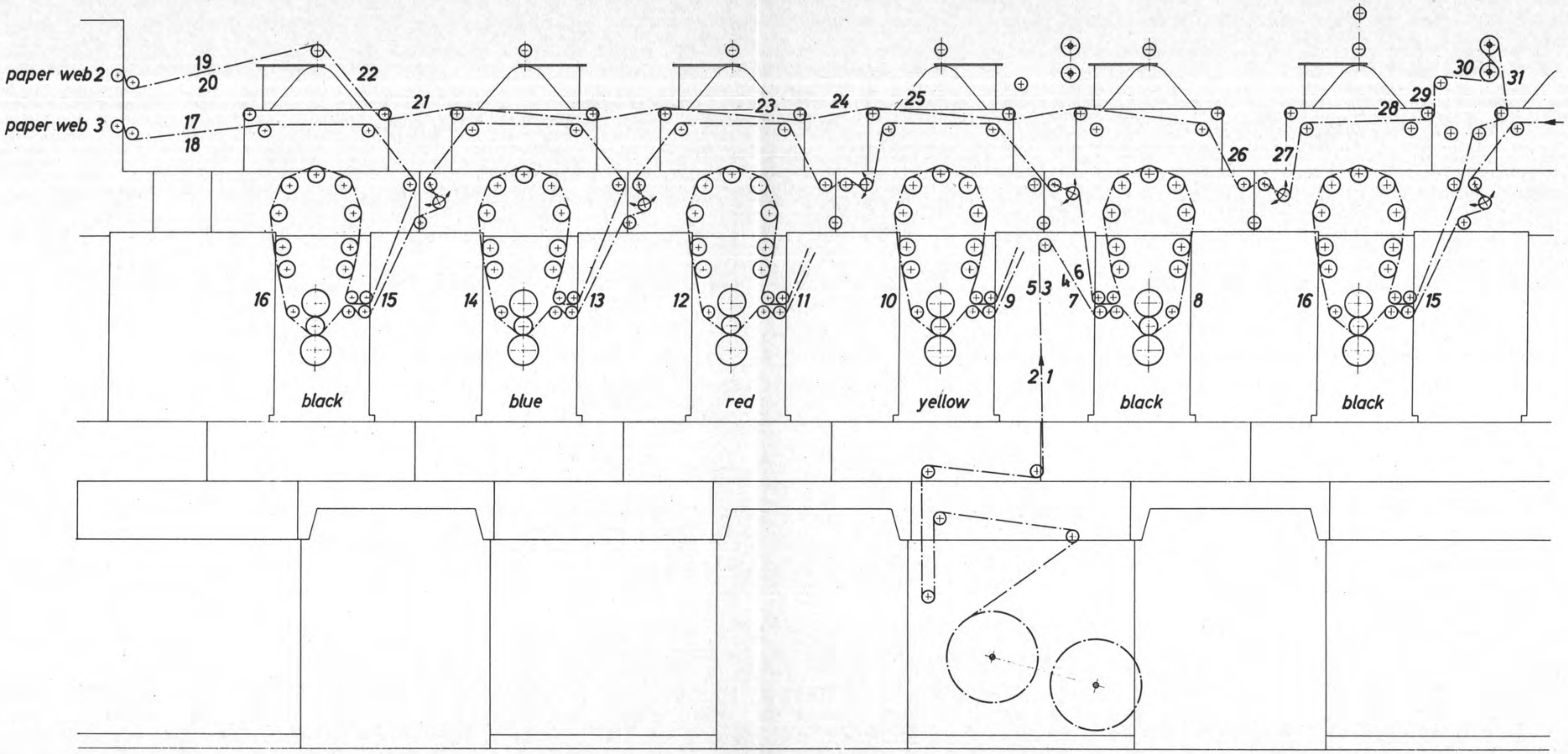


fig. 12 The influence of printing pressure and printing ink on the charge development

(measured on a large commercial rotary photogravure)

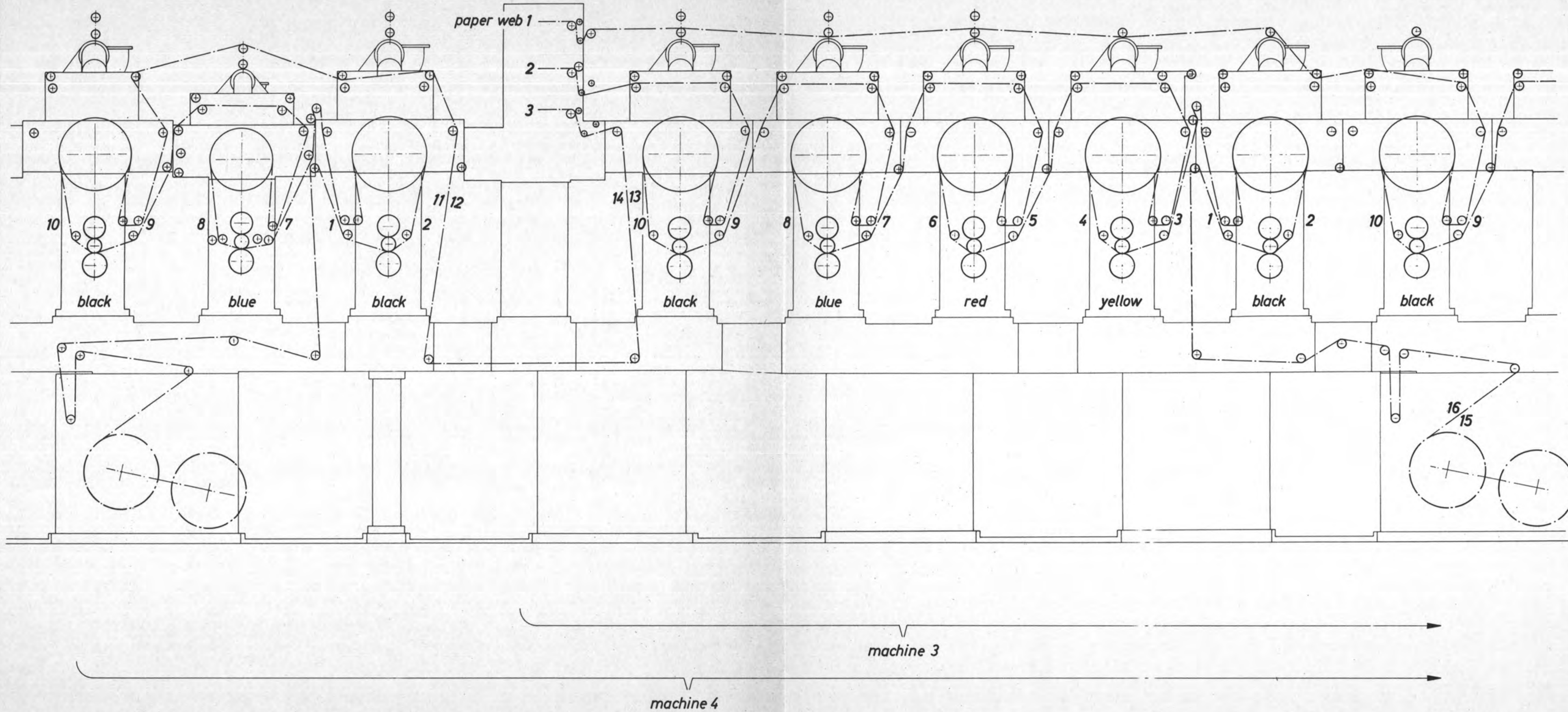


field density kV/m

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
web	1	120	133	220	260	120	128	490	1300	100	-525	-385	-590	-332	-760
	2	-	-	-	-	-	-	350	1200	1450	-980	-300	-332	-360	-280
	3	-	-	-	-	-	-	28	-210	-	-	-	-	-100	-245
measuring point		1	2	3	4	5	6	7	8	9	10	11	12	13	14

		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
web	1	-410	-420	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	-300	210	-	-	-238	-240	-698	-200	-175	-375	-383	-760	-665	-134	-110	-239	-295
	3	-205	-240	120	65	-	-	-	-	-	-	-	-	-	-	-	-	-
measuring point		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

fig. 13 Partial view of machine 5 listing the values measured at the various printing units Scale 1:25



machine 3 — field density kV/m

web 1	230	990	455	-405	-262	-175	-405	-300	-446	-340
web 2	315	970	226	-440	-315	220	-490	150	-245	-190
web 3	70	-226	-	-	-	-	-155	-310	-155	-253
measuring point	1	2	3	4	5	6	7	8	9	10

machine 4

web 1	-69	1070	270	-315	-245	-263	-230	-245	236	-300	-	-	-	-	-	-
web 2	320	1050	340	-315	-376	-230	-385	-235	-315	85	-	-	-	-	-107	-15
web 3	-68	-152	-	-	-	-	-165	-270	-315	-62	-275	-235	-240	-230	-	-
measuring point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

fig. 14 Partial view of machines 3 and 4 listing the values measured at the various printing units Scale 1:25