Print-through in multicolour printing
Estimated by full-scale and laboratory model printing

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1  Summary

This report presents an evaluation of print-through on different newsprints. The print-through was studied in two different ways: through full-scale test printing in a four-colour sheet-fed offset press and through laboratory test printing with a printability tester of the Prüfbau type. In both these studies, the print-through was evaluated in full-tone prints consisting of one, two or three ink layers printed on top of each other.

The full-scale test printing was carried out in multicolour printing (CMYK) at five different density levels. In order to obtain data for the determination of print-through at the same print density, newsprint from different paper machines and from different suppliers was printed.

In order to study the ability of the paper to absorb the ink components, test printings were carried out on a laboratory scale with three layers of black ink (KKK). For this investigation, three of the ten papers included in the full-scale test printing were chosen. In addition to the best (C) and the worst (G) papers from the full-scale printing, paper A, where the development of print-through was most obvious in the multicolour printing of this series of newsprints, was also chosen.

An increase in the amount of transferred ink always gives a higher print-through, regardless of whether the amount of ink is increased in a single printing or through the printing of several layers of ink on top of each other. The development of print-through in a single printing is of a different character from that in multicolour printing. It appears that the first ink layer provides a barrier against the penetration of oil and pigment from subsequent ink layers.

Extraction of oil vehicle from a finished print always leads to an increase in the print density on the face of the print. This indicates that the ink film collapses slightly as a result of the extraction and consequently that the light absorption increases.

At a print density of 0.95, the increase in unevenness of the print-through as a result of multicolour printing was fairly marginal. The increase in print-through mottle from one to three ink layers was only about 0.2 units. This indicates that, although the print-through mottle increases in multicolour printing, the increase is insignificant from a print quality point of view.

The penetration of oil from the first ink layer greatly reduces the internal light-scattering surfaces in the paper and gives the greatest contribution to the print-through. At a print density of 0.95, the contribution of the oil penetration to the print-through from the first layer is 60-80 %. At the same density, layer two contributes 10-20 % and layer three contributes 5-10 %.

In the laboratory test printing, the same result was obtained as in the full-scale printing with respect to the first ink layer. The print-through in the first ink
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Layer combined with the paper's show-through gives a good indication of the development of the print-through to be expected in multicolour printing. The print-through components contribute to the total print-through to different degrees. The greatest contribution, 65%, comes from the oil separation component. The pigment penetration contributes ca. 25% and the show-through component ca. 10%.
2 Introduction

Print-through is one of the most important properties of finished printed matter. If the material is printed on both sides and the print-through is too strong, it leads to a deterioration in the print quality on the reverse side of the print. If the print-through occurs within an image area, the reverse side appears speckled, dirty or mottled, and the print-through reduces the value of the information which can be printed on the reverse. Among many negative effects which the print-through has on the print quality, three effects are most prominent:

- If the print-through appears within text areas printed on the reverse, the readability of this text will be diminished.
- The print-through in a picture printed on the reverse side reduces the cleanness of the picture, particularly in the light regions of the picture and the print quality will consequently be reduced.
- In a situation where the oil penetration from the print on the top side is too strong, this penetration will influence the ink absorption in the printing on the reverse side, since the ink spreads uncontrollably in a lateral direction. This broadening appears very clearly, particularly if the print on the reverse consists of a drawing or a text with bold letters.

Regardless of which of these three print-through effects appears in the print, they have serious consequences for the print quality. Therefore, it is every printer’s desire to have as little print-through as possible. A printer can influence the print-through to a certain extent during the printing process, e.g. by reducing the applied printing pressure or by choosing a printing ink with another rheology. Other than these two possibilities, however, the printer has little to resort to in the printing process.

Therefore, the paper is the most important factor in the printing process influencing the print-through. The most effective ways of reducing the print-through are of course to apply a coating or to increase the grammage of the paper. For uncoated grades, however, a uniform and optimal structure must be created to ensure that the print-through is as low as possible. Here, an optimal structure is a structure that gives a paper with a high opacity and a low oil penetration. A few studies of print-through have shown that the uniformity or mottle in the print-through leads to more of a disturbance than the print-through level (Eadie 1998). A low print-through which at the same time exhibits a high print-through mottle can be more disturbing with respect to print quality than a high but uniform print-through.

In two papers published in the mid-1980s, print-through tolerances have been presented. A print-through level greater than 0.1 is not acceptable from a print quality point of view. With respect to text printed on the back of a heavy (dark) picture, the permissible print-through value is 0.09, while for a bold heading...
behind a light picture the permissible level is only 0.03. A print-through level corresponding to a value of 0.015-0.020 is visible to the naked eye (Ottinen, 1998).

The demand for low print-through has increased during recent decades because the grammage of the newsprint has decreased and the number of pages printed in colour has increased markedly. It is reasonable that the lower the fibre mass that forms the fibre network in the paper, the greater is the risk that the print on the top side will be visible when viewed from the reverse. In this connection, the optical properties of the paper play a decisive role (Brandén 1983).

Another property which influences the evenness in both optical properties and absorption properties is the formation. Flocs have a high density and counteract the print-through whereas the areas between the flocs have a low fibre density and therefore become more sensitive to print-through. The print-through exhibits an unevenness, so-called print-through motting. As has been said earlier, the unevenness in the print-through can be more important from a print quality point of view than the actual mean print-through value.

Papers differ from each other with regard to their ink requirement, i.e. the amount of ink required to attain a given print density. This means that different amounts of ink are applied to different papers, and this in turn gives different conditions for the print-through, since the print-through is influenced by the amount of ink transferred to the paper. Therefore, an evaluation of the print-through of different papers can be made in two different ways: either at the same print density or at the same amount of transferred ink.

In the first case, we study the print-through which arises in practice in printing and, in the second case, we study the paper's ability to take care of the ink pigment and oil. The aim of the present investigation was to evaluate the development of the print-through in both the above-mentioned cases, and to investigate the development of print-through in multicolour printing, i.e. when several layers of ink are transferred to the paper on top of each other.

The aim of the full-scale and laboratory test printings was to demonstrate differences or similarities in these two ways of studying the print-through and, if possible, to show whether multicolour print makes higher demands on the ability of a standard newsprint to resist print-through.

2.1 Background

It is well-known that the print-through of a newspaper print increases with increasing amount of ink on the paper. This can be important for the quality of a multicolour print. The total amount of printing ink and thereby its components transferred to the paper is higher in multicolour printing than in a full-tone print printed with only one ink layer. In printing with several ink layers on the paper, the average print-through is consequently higher since the total amount of ink is higher. It should however be noted that, in the printing of a second,
third or fourth ink layer on top of a previously printed ink layer, the density of the print does not increase in proportion to the total amount of ink on the paper, since the optical density of a full-tone print levels out with an increasing amount of ink on the paper (Dickson et al. 2005; Tollenaar 1971).

An important reason for the increase in print-through when several ink layers are printed on top of each other is that the amount of liquid vehicle present which can separate and be redistributed in the paper increases. Printing inks of different colours from different manufactures can have different pigment contents, and this also influences the relationship between the total pigment content and the total amount of liquid in a multicolour print. The print-through is influenced not only by the amount of ink transferred to the paper, but also by the character of the paper surface. The pore area in the outermost 10 µm thick layer of the paper has an effect on the oil penetration (Dickson et al. 2005).

Thomassen has also shown that the composition of the printing ink plays a decisive role in the separation and penetration of the oil vehicle into the paper (Thomassen 2004). The rate of oil penetration after printing is influenced by the surface chemistry of the paper. Since the print-through is influenced strongly by the composition of the printing ink, ink containing emulsified water should be used in studies carried out at the laboratory. The ink emulsion has a greater effect on print-through than the structure of the paper (Hohtari and Massolt 2003).

Already in 1990, Trollås showed how important the composition of the ink is for the print-through. The density of the oil and its distribution influences principally the light scattering of the paper, whilst the amount and colour of the oil influences principally the light absorption (Trollås 1990).

A simple way of reducing the effect of oil separation and penetration is to add a filler to the paper. A study carried out with GCC showed that this reduced the print-through (Laufman et al. 2004). Another study showed that, if the grammage was reduced below 40 g/m², special fillers must be added to the stock to counteract the decrease in opacity and the increase in oil penetration.

Both the surface structure and the sheet structure influence the print-through in two different ways:

- through the optical properties of the paper, and
- through the absorption properties of the paper.

Through a well-chosen composition of the quality and quantity of fibres and fines, the properties of the substrate can be tailored to meet the customers' wishes. Corson has studied the effects of the fines/fibres ratio on print quality, print-through and optical properties. The results of his study showed that primary fines had a greater effect on the print-through and strike-through than secondary fines. The latter have a greater influence on the freeness than on the printability of the paper (Corson. et al. 2004).
2.2 Components of print-through

During the printing of a newspaper, an ink, which conventionally consists of a suspension of pigments in a binder with other additives, is pressed into the structure of the paper. After the transfer has been completed, i.e. when the paper web has left the printing nip, the capillary system of the paper takes over. The vehicle, i.e. the oil, separates from the printing ink and continues further into the structure. At first, a small part of the pigment also accompanies the oil into the structure. However, the continuation of the penetration is principally a penetration of binder.

Print-through can be defined as the print density observed from the reverse side of the print, and it is calculated as:

\[ PT = \log \frac{R_{\infty}}{R_q} \]  \[1\]

where \( PT \) = print-through

\( R_{\infty} \) = reflectance of an unprinted surface placed on top of an opaque pad of the same paper

\( R_q \) = reflectance of the reverse of a printed surface placed on top of an opaque pad of the same paper

The print-through is the result of three different physical factors (Bristow 1988; Larsson 1972), viz.: the translucence of the paper, the absorption of the vehicle and the penetration of the pigment. In the literature, these components are designated as:

- Print-through component due to show-through \( PT_{ST} \)
- Print-through component due to vehicle oil separation \( PT_{VS} \)
- Print-through component due to pigment penetration \( PT_{PP} \)

The first-mentioned of these components (\( PT_{ST} \)) relates to the optical transparency properties of the paper, whilst the second (\( PT_{VS} \)) and third (\( PT_{PP} \)) relate to the penetration of printing ink. The total print-through (\( PT \)) is then the sum of these three components:

\[ PT = PT_{ST} + PT_{VS} + PT_{PP} = \log \frac{R_{\infty}}{R_s} + \log \frac{R_{qs}}{R_q} + \log \frac{R_s}{R_{qs}} \]  \[2\]
2.2.1 Symbols

In the following tables and diagrams, the reflectance factor is designated $R$ with an appropriate index. This reflectance is always measured on the reverse of the printed sheet, i.e. on that side of the paper which is not printed. The different indexes to $R$ indicate whether the measurement has been carried out on an unprinted or on a printed surface and before or after extraction of the oil with petroleum ether. The figure added to the index in tables (appendices) shows the number of printed ink layers. In the same table, “G” indicates print-through and “D” print density.

\[
\begin{align*}
R_{qx} &= \text{print side downwards after extraction, on top of an opaque pad of the paper} \\
R_x &= \text{unprinted paper on top of a printed paper, on top of an opaque pad of paper} \\
R_{ox} &= \text{unprinted paper after extraction, on top of an opaque pad of paper} \\
R_o &= \text{unprinted paper on top of a black cavity} \\
R_c &= \text{unprinted paper on top of an opaque pad of paper} \\
R_q &= \text{print side downwards, on top of an opaque pad of paper.}
\end{align*}
\]

Figure 1 shows a schematic representation of the procedure used for the measurement of the different reflectance factors. The same procedure was used in reflectance measurements after the oil had been extracted from the substrate.

![Figure 1. Schematic representation of the procedure for the measurement of different reflectance factors.](image)

2.2.2 Translucence, show-through

Since the paper cannot be completely opaque, the printed image is more or less visible through it. The fact that the paper is to some extent transparent, or more correctly translucent, is of course connected with the optical transparency properties of the paper, which in turn are influenced by the structure of the paper and its evenness. The effect of transparency can be assessed by making a measurement on a sheet of paper placed over the printed paper as background. The show-through component is, of course dependent on the ink density on the
background paper, and it increases with increasing amount of ink, particularly when the paper surface is not fully covered with ink. After complete coverage of the surface with printing ink has been reached, the show-through component PTST remains constant at a value which is determined solely by the opacity of the paper, i.e.:

\[
PT_{ST} = \log \frac{R_\infty}{R_0}
\]

Since the opacity of the paper principally determines the show-through component of the print-through, it will not be very sensitive to whether the printing involves one or several inks. The show-through component is practically constant after a complete coverage of the front of the sheet.

2.2.3 Oil absorption

The mineral oil which is used as a binder and carrier in the printing ink has approximately the same refractive index as the paper fibres, which means that when the oil penetrates between and into the fibres, the structure is made more transparent. The greater the amount of oil which separates from a printing ink and fills the voids in the fibre structure, the greater is the effect on the print-through. The oil which is absorbed into the structure reduces the opacity of the paper and thus influences the print-through. Since mineral oil is practically colourless, it does not influence the absorption of light, and the reduction in opacity can thus be explained solely in terms of a change in the light scattering coefficient.

Since the total amount of oil phase added to the paper in multicolour printing is several times greater than that used in single-colour printing, multicolour printing should result in a greater print-through. However, the interaction between paper and printing ink in the printing of several ink layers differs in several important respects from the interaction in the case of a single ink layer, since the first ink layer changes the conditions for both ink transfer and oil absorption, and thus also for pigment penetration, in the printing of subsequent ink layers. The first ink layer has time to be immobilized, i.e. to set and block the pore and fibre network of the paper, and thus influence the absorption of the subsequent inks.

That part of the print-through that is due to oil separation can be investigated by extracting the oil from the printed paper. Reflectance factor measurements made before (R_q) and after extraction (R_qx) of the oil can then be used to calculate the print-through component due to oil separation:

\[
PT_{VS} = \log \frac{R_{qx}}{R_q}
\]
2.2.4 Pigment penetration

News ink consists of a suspension of pigment in oil. These components are separated from each other through the influence of the capillary forces to which the oil is subjected. Pigment particles, with an average size of 2 to 5 µm, are unable to accompany the oil all the way into the structure, and they largely remain in the surface layer. There is a separation of binder from the printing ink and the pigment particles adhere in the surface not only because of their size but also because they very easily form large aggregates and thus find it difficult to accompany the oil into the structure. The pigment penetration which can nevertheless be measured can probably be ascribed to an effect of the linear load applied in the nip to ensure transfer of ink from cylinder to paper. The pigment-penetration component is calculated as:

\[ PT_{pp} = \log \frac{R_{pp}}{R_{qs}} \]  

Since the pigment is a very effective absorbent of light, a strong penetration of the pigment into the structure would have a catastrophic influence on the print-through. However, the pigment is mainly trapped in the outermost region of the structure and only the oil continues to penetrate deeper into the paper. Since the penetration of pigment is small, this component influences the print-through less than the other two components (Dickson et al. 2005).
3 Materials and methods

3.1 Materials

3.1.1 Choice of paper for the laboratory test printing

Print-through measurements on full-scale prints have shown that there are fairly large differences in print-through between newsprints produced on different paper machines. In order to use as diverse materials as possible in the laboratory test printing, three newsprints were chosen from the 10 commercial papers which were included in the full-scale test printing. One newsprint was chosen which on average gave the lowest print-through (paper C) and one which on average gave the highest print-through (paper G). In addition, paper A was chosen since the print-through of this paper appeared to be the most sensitive to multicolour printing, in the sense that the slope of the relationship between print-through and ink amount was greatest for this paper in the full-scale test printing.

![Graph showing print-through for different newsprints](image)

*Figure 2.* Print-through in full-scale multicolour printing for the three newsprints chosen for the laboratory test printing. Print layer 1 was a full-tone black (100% K). Print layer 2 was a full-tone cyan and black (200% C+K). Print layer 3 was a full-tone cyan, magenta and black (300% C+M+K). Paper C: ♦, Paper A: ■, Paper G: ▲.

3.1.2 Optical properties

The average print-through of a full-tone print is influenced by the optical properties of the paper, particularly the opacity and light scattering power of the paper. In general, high opacity and high light scattering give a low print-through. The remaining optical properties of the paper which are considered to be important for the print-through are listed in *Table 1*. A mottle value is also given in the table, since this is related to the formation of the paper which affects the print-through variations.
Table 1. Optical properties and mottle index for the three newsprints used in the laboratory-scale studies.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Grammage g/m²</th>
<th>Opacity %</th>
<th>Scattering m²/kg</th>
<th>Abs. Coeff m²/kg</th>
<th>Brightness %</th>
<th>Y-value %</th>
<th>Mottle 1-8 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>45,1</td>
<td>94,7</td>
<td>57,1</td>
<td>6,48</td>
<td>57,2</td>
<td>62,8</td>
<td>15,2</td>
</tr>
<tr>
<td>A</td>
<td>44,5</td>
<td>94,0</td>
<td>55,8</td>
<td>6,01</td>
<td>57,9</td>
<td>63,3</td>
<td>17,4</td>
</tr>
<tr>
<td>G</td>
<td>45,0</td>
<td>92,4</td>
<td>50,0</td>
<td>5,25</td>
<td>58,0</td>
<td>63,4</td>
<td>20,1</td>
</tr>
</tbody>
</table>

3.1.3 Surface properties

The structure of the paper surface influences the print-through in two different ways. A satisfactory coverage of a rough surface can be achieved either by applying more printing ink to the paper or by increasing the applied printing pressure. Both these measures have a negative effect on the print-through. In addition, a high surface roughness also contributes to an uneven distribution of printing ink over the paper surface and this can lead to a greater variation in the print-through.

The character of the paper surface is usually described by determining the surface roughness and topography. The surface roughness was here determined by three different methods: airflow methods, a profilometric method and an optical method. Of the airflow methods, the PPS and Bendtsen instruments were used. The Bendtsen measurements were made at two different applied pressures, 0.1 and 0.5 MPa. The surface profile was determined with a profilometer of the Handysurf E-30A type. Of the seven surface profile parameters (Ra, Pt, Rz, Rt, Rtm, Rpm and Pc) which can be obtained with this technique, only the Ra-value is reported in Table 2.

The topography was determined with the OptiTopo (OT) method, where the paper surface is illuminated alternately with grazing light sources placed opposite to each other. One image is taken when the left-hand light is switched on and a second image is taken when the right-hand lighting is switched on. The exposed area was equal to 16x16 mm, i.e. 256 mm². The two images of the same surface are combined in the analysis which yields a topographical map of the exposed surface. The OT-index given in Table 2 is calculated by a method analogous to the assessment of mottle.

Table 2. The surface structure is described by surface roughness, surface profile and topography data.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Bendtsen 0,1 MPa</th>
<th>Bendtsen 0,5 MPa</th>
<th>PPS µm</th>
<th>Ra µm</th>
<th>OT 1-8 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>128</td>
<td>44</td>
<td>3,84</td>
<td>2,85</td>
<td>21,8</td>
</tr>
<tr>
<td>A</td>
<td>124</td>
<td>45</td>
<td>3,50</td>
<td>2,72</td>
<td>17,0</td>
</tr>
<tr>
<td>G</td>
<td>92</td>
<td>33</td>
<td>3,56</td>
<td>2,63</td>
<td>11,2</td>
</tr>
</tbody>
</table>
3.1.4 Absorption properties
The absorption properties can play an important role in the development of print-through in both single and multicolour printing. All the published literature considers oil absorption to be the key parameter. This is natural since the oil absorptivity of the paper influences both the rate of setting of the ink and the oil separation, and both these processes affect the print-through, particularly the oil separation.

The manner in which the fountain solution used in the lithographic print process influences the print-through has not been scientifically investigated. Studies of water absorption by the fibre structure have shown that significant structural changes may arise after the application of water to the surface (Aspler and Beland 1994; Huynh 1987; Skowronska 1988; Åslund 2004). It can be assumed that water transferred to the paper surface in the non-image areas leads to similar structural changes. In multicolour printing, these changes will consequently influence the ink transfer in subsequent press nips. In the case of single-colour printing, this effect is practically negligible, due to the absence of the water in the image areas of the rubber blanket. Neither oil nor water absorption has been specifically investigated in this study.

3.2 Methods
In order to evaluate the print-through, two different test printing methods were used. First, a full-scale test printing was carried out in a four-colour print in order to investigate the print-through development in multicolour printing under realistic offset process conditions. Some of the same paper material was then used in a laboratory test printing in order to study the print-through development under well-defined laboratory printing conditions, and to evaluate possible differences between these two ways of studying print-through.

3.2.1 Full-scale test printing
In the full-scale test printing, newsprint from 10 different paper machines was used. After an initial run corresponding to a few thousand sheets, all the papers were test printed under almost identical conditions. The ink and water dosage was then changed and after the ink-moisture balance had been reached, all the papers were again printed in the same way with this new adjustment. The procedure involving a change in the ink-moisture settings was repeated five times. Samples for print-through studies were always taken at the end of each print run before printing began on the next paper grade.

3.2.1.1 Printing press
The full-scale test printing was carried out in a Heidelberg Speedmaster sheet offset press with A2 paper format. In the printings, a news ink and fountain solution which are generally used for newsprint in a cold-set-web-offset process were used. The printing order in the test printing was CMYK, i.e. cyan, magenta, yellow and black.
3.2.1.2 The layout of the printing plate

The printing plate contained full-tone areas, screened areas and tone scales. Over-printing, i.e. two or three printing inks printed on top of each other "wet-in-wet", was carried out only in full-tone areas. In the report, an over-print is indicated by a combination of two or three letters. The combination C+M indicates a full-tone cyan followed by a full-tone magenta. The combination C+M+K indicates a full-tone cyan followed by a full-tone magenta and finally a full-tone black. Figure 3 shows that the printing included several combinations of two and three ink layers. In this study, however, only one of each combination has been used, viz.:

K for one layer
C+K for two layers
C+M+K for three layers

Figure 3. The layout used in the full-scale four-colour offset test printing. The image areas used for the evaluation of the print-through were produced with full-tone prints with one (100% K), two (100% C+100% K) and three (100% C+100% M+100% K) layers of ink.

3.2.1.3 Print density

The amount of ink transferred in the full-scale test printing was changed in two different ways, by increasing the amount of printing ink applied to the printing plate and by printing more than one colour, i.e. several layers of ink, on top of each other.

The amount of ink has been changed from a low to a high level in five stages, the amount of ink being controlled by on-line measurement of the print density. Five different density levels have been aimed at. To avoid toning, the fountain solution dosage was increased when the ink amount was changed. The lowest density level was about 0.6 and the highest was about 1.0.

In the multicolour printing, full-tone (100 %) areas were printed on top of each other. The maximum amount of ink transferred to the paper corresponded, in this investigation, to a print density of about 1.0 and a transfer of different inks in three layers i.e. 300 % tone. The
five different amounts of ink in each ink layer in the different colours meant that printed areas with increasing print densities were also obtained in the multicolour printing. If the water emulsified into the ink is disregarded, the amount of ink which gives a print density of 1.0 is approximately 1.0 g/m². Assuming that the transfer of ink to the paper is the same in all the nips, the amount of ink in three layers will be approximately 3 g/m².

3.2.1.4 Measurement of print-through
The average print-through for the full-tone prints printed with one (K), two (C+K) and three (C+M+K) ink layers on the different papers was determined with the help of an Elrepho 2000 reflectometer. The print-through was evaluated at a print density of 0.90 in the print on the front and in the three different ink layers.

3.2.2 Laboratory test printing
The print-through measurements made on the full-scale material were used as a basis for the choice of paper for the laboratory test printing. The newsprint having on average the lowest print-through (paper C) and that which on average had the highest print-through (paper G) were chosen. Paper A was chosen as the third paper. The print-through of this paper appeared to be the most sensitive to multicolour printing, in the sense that the slope of the relationship between print-through and ink amount was greatest for this paper.

3.2.2.1 Multi-layer printing in a Prüfbau laboratory press
The laboratory test printing was carried out in a printability tester of the Prüfbau type. The same printing ink as in the full-scale test printing was used in this study. To avoid the influence of different rheologies which are characteristic of different colours, only the black ink was used in these printings.

3.2.2.2 Procedure
The ink was distributed evenly over the printing disc during 60 seconds. After this time, the printing disc was placed on the shaft in the printing unit and the ink was transferred to the paper samples with a width of 50 mm, an applied load of 600 N and a speed of 2 m/s. The printing disc and inking cylinders were cleaned and the procedure was repeated with approximately the same amount of fresh ink. The mean ink transfer in these two printings was then calculated. Thereafter, the procedure was repeated with a higher amount of ink. In this way, printed samples were produced with 5 different amounts of transferred ink.

After the printing, the printed samples were hung vertically and allowed to dry in a standard climate (25° C and 55 % RH) for 24 hours. The print density (Gretag) and print-through (Elrepho 2000) were then measured.

The principle of the multicolour printing in Prüfbau is shown schematically in Figure 4. The different ink layers in the figure are shown with different colours in the figure, but these colours do not indicate the inks used. The same black ink was used in all the test printings. The single-colour printing was carried out with the ink amounts a₁-a₅. The two-colour printing was carried out with the amounts a₃ (in the first layer) and b₁-b₅ (in the second
layer). The three-colour printing was carried out with the amounts $a_3+b_3$ (in the first two layers) and $c_1-c_5$ (in the third layer).

![Figure 4. Schematic description of the printing in several ink layers.](image)

The first layer of ink was thus transferred to the newsprint in five different amounts, $a_1-a_5$. For each amount, the printing was repeated twice and the mean of these two values was plotted in the diagrams shown in the results section. The amount of ink in the first layer was increased from 0.2 g/m² to 4.5 g/m².

In the printing of the first layer, the ink amount $a_3$ (ca. 2.5 g/m²) was chosen and a couple of dozen strips were printed with this ink amount. After drying for 24 hours, a second ink layer was applied on this first ink layer with 5 different ink amounts, $b_1$-$b_5$. The amount of ink in the second layer $b$ was increased from ca 0.3 to 4.0 g/m². In this way, a set of two-colour prints was produced with the ink amount $a_3$ in the first layer in each case and the ink amounts $b_1$-$b_5$ in the top layer. The total amount of ink in this two-colour printing varied from 2.8 to 6.5 g/m².

A dozen printed samples with two ink layers and ink amounts $a_3+b_3$ (ca. 2.5 + 2.5 g/m²) were prepared and, after drying for 24 hours, these were printed with a third ink layer in 5 different amounts, $c_1-c_5$. The amount of ink in the third layer was increased from ca 0.3 to 4.0 g/m². The total amount of ink in this three-colour printing thus varied from 5.3 to 9.0 g/m².

### 3.2.2.3 Extraction of oil

The oil was extracted from the printed samples in two stages in a series of baths containing petroleum ether. This solvent dissolves the oil completely, whilst the pigment and the paper remain unaffected (Larsson. 1969).

The printed sample was dipped in the first bath of solvent and was carefully rocked to and fro. After most of the oil had been extracted from the printed sample, the sample was moved to bath No 2 containing clean solvent to extract the remaining oil in the sample. After the extraction, the sheet was air-dried and reconditioned for a few hours. Thereafter, density and print-through measurements were made in the same way as on the printed samples before extraction.

In order to check that the optical properties of the paper were not changed by the extraction, a reference sample of unprinted paper was also extracted. The paper was measured before and after extraction with an Elrepho 2000 instrument.
# Results and discussion

## 4.1 Full-scale test printing

### 4.1.1 Print density

The print density has been measured with an on-line densitometer. An increase in the amount of ink applied to the printing plate gave a similar response in print density. Figure 5 shows the print density for the five different ink amounts. Single-colour (K) and two-colour printing (C+K) gave practically the same print density, but the print density was significantly greater after printing of the third layer (C+M+K).

It should be noted here that the colour order in the printing gives different conditions for both print density and print-through in the different ink layers. Since the printing order was CMYK, the single ink layer (K) was applied to a paper surface which had already passed through three press nips where it had been moistened three times with fountain solution. Since the surface structure is influenced by moistening (Hoc 2005), this moistening probably also influences the ink transfer and consequently also the ink absorption.

The two-colour printing described here has been produced by first printing with cyan onto the original surface of the paper. There it probably forms a barrier which influences the transfer of fountain solution in the next two nips before the second ink layer (K) is printed in the fourth nip. A slightly higher print density after the two-colour printing, particularly for papers G and C, can be seen in the figure, but the difference between one and two ink layers is hardly significant.

In the three-colour printing, cyan is printed first and thereafter magenta. These two ink layers provide a fairly safe barrier against the absorption of fountain solution in the third nip before the black ink (K) is transferred in the fourth press nip. On all the papers, the three-colour print had the highest print density. The development of density in the three ink layers indicates that the moistening of the surface influences the ink transfer. This circumstance is one reason why it is difficult to relate the results of laboratory printings to the behaviour in commercial printing.

![Figure 5. The development of print density for three different papers printed with several layers of ink at five different ink levels. The comparison here has been made for one, two and three ink layers. One layer 100 % (K: •). Two layers 200 % (C+K: ■). Three layers 300 % (C+M+K: ▲).](image-url)
4.1.2 Print-through in full-scale printing

The print-through increased both with increasing amount of ink and with the same amount of ink applied in an increasing number of ink layers, see Figure 6.

It has previously been possible to show that the first ink layer printed on a newsprint partly blocks the pore system in the paper. This blocking means that the ink transferred from the rubber blanket in the printing of a subsequent ink layer will be concentrated in the surface layer of the print. The fine-scale structure of the paper is therefore important for a better understanding of the interplay between paper, ink and printing nip. Since a large part of the print-through in a full-tone print is due to a migration of the liquid vehicle of the ink, the ability of the fibre material to take care of this oil is very important for the print quality. This is of increasing importance in the printing of several ink layers on top of each other, since the absorption of one ink layer printed on another previously printed ink layer influences not only the print-through but also to a high degree the smearing in the form of set-off.

Figure 6 shows how the print-through increases with increasing density with three ink layers on three different newsprints. The penetration of oil from the first ink layer has a decisive influence on extinguishing the internal scattering surface of the paper and this makes the greatest contribution to the print-through. At a print density of 0.95, the contribution to the print-through from the first layer is 60-80 %. At the same density, layer two contributes 10-20 %, and layer three contributes 5-10 %.

Figure 6. Average print-through in the printing of one, two and three ink layers on top of each other. The evaluation was made at five different density levels. One layer 100 % (K: ♦). Two layers 200 % (C+K: ■). Three layers 300 % (C+M+K: ▲).

4.1.3 Print-through variation

The print-through is a mean value of a certain number of reflectance factor or density measurements. The reflectance factor measurements are made with an instrument where the measurement area is usually several cm², so that a single print-through value can be regarded as a mean of the local print-through values.

In density measurements, the measurement area is considerably smaller and approaches the scale of the local variations in print-through. The resolution in this case is only a few mm². Since density measurements carried out with a densitometer are much simpler, the measurement is repeated many more times.
than a reflectance measurement. In this case, the print density is reported as a mean value with an associated standard deviation. Since the print-through density is very low, a densitometer is not suited for such a measurement. More accurate values are obtained with reflectance factor measurements made with a suitable optical instrument.

Further information about the print-through can be obtained by measuring the print-through mottling. In principle, the method used is the same as that used to measure the formation of a paper with the help of a scanner. As mentioned previously, print-through mottling is considered to be more disturbing than the average print-through.

![Print-through mottling as a function of print density for one ink layer (100% K) and three ink layers (300% CMK).](image)

**Figure 7.** Print-through mottling as a function of print density for one ink layer (100% K) and three ink layers (300% CMK). The print-through mottling increases with increasing print density for all three papers. Paper G (▲) has the highest unevenness throughout, for both one and three ink layers. Papers A (■) and C (♦) showed the same unevenness in both single and three layer printing.

The increase in unevenness in the print-through in multicolour printing was fairly marginal at a print density of 0.95. The increase from one to three ink layers was only about 0.2 units of print-through mottling. This indicates that print-through mottling certainly increases with multicolour printing, but that this increase does not have a disturbing effect on the print quality.

4.2 Laboratory test printing

The mechanisms prevailing in multicolour printing, i.e. the transfer of printing ink in several layers, can best be studied in some kind of laboratory test printing machine. For this study, the Prüfbau printability tester was chosen. In this apparatus, the transfer of printing ink to the paper can take place under well-defined printing conditions, but it suffers from the disadvantage that not only is there no ink-water emulsion, but the transfer of ink takes place discontinuously and the test print covers only a very small area of the paper.

In spite of these disadvantages, laboratory test printing is preferable since, in full-scale printing or in some other realistic test printing, it is not possible to
weigh the ink and print density has to be used as an indicator of the amount of ink transferred. Different newsprints and other paper substrates can however have different ink requirements to give the same print density, which means that in a study based on printing to the same density, different amounts of ink may be transferred to the different substrates. Another factor which makes the scientific evaluation of the print-through in a realistic test printing more difficult is that the inks used in multicolour printing differ from each other with respect to their rheologies.

Another factor which can influence the print-through in realistic printing is that, in multicolour printing, the paper surface is subjected to one or several treatments with fountain solution. In the black printing unit (K), the paper surface is exposed to moisture three times in the preceding printing units if the printing order is CMYK. The extent to which this moistening affects the print-through has not been investigated.

To avoid the effects of different ink rheologies, only one ink was used in this study. Since the black printing ink is consumed most in newspaper production (circa 3 times more than any of the chromatic colours), a black news ink was used for all the printings (Carleson 2005).

Multicolour printing was thus simulated by transferring black ink to the paper in one, two and three layers on top of each other. The amount of printing ink in the underlying ink layers was held practically constant, but the uppermost ink layer was printed with five different amounts of ink in all cases. This made it possible to investigate how different paper surfaces react to an increasing amount of ink in each ink layer.

### 4.2.1 Print density

The design of the laboratory printing has made it possible to study the development of print density according to two different procedures. Figure 8 shows for the two-colour printing (a) in the left-hand diagram, the print density as a function of the amount of ink transferred in the top layer and (b) in the right-hand diagram, the print density as a function of the total amount of ink transferred in both the underlying and the top layers.

The total amounts of ink are high here, since the underlying ink layer was ca. 2.5 g/m². In a commercial printing, ca. 1 g/m² of ink is transferred in each press nip, so the laboratory printing was carried out with more than twice the amount of ink commonly used in commercial printing.
24 Print-through in multicolor printing
NRP 28

Figure 8. Print density for the three different papers as a function of the amount of ink transferred in the second printing (left-hand diagram), and as a function of the total amount of ink transferred to the paper in the first two printings. Paper C: ♦, Paper A: ■, Paper G: ▲.

The development of print density in the first ink layer, Figure 9, shows the difference in ink requirement between the three papers. Papers A and G have almost the same ink requirement for a given print density, while paper C lies slightly higher. The differences do not begin to appear until ink amounts exceeding 2.5 g/m² are reached. Below this level, all the papers can be regarded as having the same ink requirement. A low ink requirement has a favourable effect on the printing process. Not only is the ink consumption lower, but the fountain solution dosage can also be held at a lower level. The final result is a higher print contrast, which is positive from a print quality viewpoint.

Figure 9. No significant difference in ink requirement was observed for the different papers at low or normal ink amounts. At a high amount of ink, paper C showed a slightly higher ink requirement than papers A and G. Here, the print density was measured with a Gretag densitometer. Paper C: ♦, Paper A: ■, Paper G: ▲.

The densities calculated from reflectance factor measurements (Elrepho 2000), Figure 10, showed much greater differences between the papers than the densities measured with a Gretag densitometer.
Paper C has the highest ink requirement while paper A has a lower and paper G the lowest ink requirement. The trend is the same for both two and three ink layers. It is here evident that multilayer printing does not greatly increase in the print density. In the printing with two ink layers, the amount of ink on the paper has increased by 2.5 g/m², but the print density increased by only ca. 0.05 units and, in the printing with three ink layers, the print density increased by only a further 0.05 units. Nevertheless, Figure 10 does suggest that printing a given amount of ink in three layers leads to a higher print-through than would be achieved by printing the same amount of ink in a single layer. The results here gave approximately the same result as those obtained in the full-scale test printing, where the density of the three-layer print was approximately 0.1 units higher than the density for a single ink layer.

Figure 10. Print density after transfer of one, two and three layers of ink on three different papers. The total amount of printing ink transferred is shown on the abscissa. Paper C: ♦, Paper A: ■, Paper G: ▲.

4.2.2 Extraction of oil

The extraction of oil from the print always gives a slightly higher print density measured on the printed side. No explanation of this phenomenon has yet been put forward. The light absorption in the ink layer presumably increases owing to the fact that the ink layer collapses slightly in the thickness direction after all the oil has been extracted. The same phenomenon can be observed in a commercial newsprint after the print has been extracted in the same way with a solvent. The unprinted paper can perhaps also become lighter as a result of the extraction. Figure 11 shows an example of the increase in print density after extraction. The increase is the same for different papers and is greater with high ink amounts. The diagram shows the change in print density for a single ink layer.
Figure 11. The print density is slightly higher after the oil of the printed sample has been extracted with petroleum ether. The diagram shows the relationship between the amount of ink and the print density of the different papers. Print density before (♦) and after (■) extraction.

The same effect was noticed in the prints made up of several ink layers. Figure 12 shows the print density in the prints made up of two ink layers as a function of the total amount of ink on the paper. The amount of ink in the first layer was ca 2.5 g/m² and the amount in the second layer was varied from ca 0.3 g/m² to 4.0 g/m².

Figure 12. The print density before and after extraction. The diagram shows the print density as a function of the total amount of ink transferred in two-colour printing (100 % K + 100 % K). The print density is in all cases slightly higher after (■) than before (♦) extraction.

The difference between print density before and after extraction decreases with multilayer printing. In three-layer printing, the difference is almost negligible, particularly with high ink amounts. It seems that the increase in light absorption which takes place as a result of the extraction of oil is reduced by the previously printed ink layer.

Figure 13 shows the print density as a function of the amount of ink transferred in three ink layers. To total amount of ink on the paper is equal to the amount shown plus the amounts applied in the first and second ink layers, i.e. 2.5 + 2.5 g/m².
4.2.3 Print-through in multi-layer prints

In this investigation, the print-through has been evaluated in order to be able to compare the results of the simulated laboratory multicolour printing with the results of the full-scale multicolour test printing. In contrast to the full-scale test printing, the amounts of ink in each ink layer are known in the laboratory printing. The evaluation can be made either with the same amount of ink in all the ink layers, or with different amounts in different layers. In the first case, either a low or a high amount of ink can be chosen for the evaluation. If the ink amount is too low, the difference between the different papers is far too small to be statistically significant. If the ink amount is high, the uncertainty increases since the differences between different papers are concealed in the high ink applications.

In the second case, different amounts of ink in the different ink layers can be chosen for the evaluation. This method of evaluation best simulates the situation which prevails in full-scale test printing. If it is assumed that the ink film thickness in each press roll nip corresponds approximately to 1 g/m², then two layers consist of 1+1 g/m² and three layers consist of 3 g/m².

Figure 14 shows the development of the print-through for the first printed layer, divided into three components, as a function of the amount of ink for the three newsprints investigated. With an ink application less than 3 g/m², a laboratory test printing gives the same trend as the full-scale test printing. Paper C has the lowest print-through, paper G has the highest, and paper A lies midway between these two papers. With high amounts of ink applications, the different papers give the same print-through. The division of the print-through into its components shows that paper C had the lowest \( PT_{ST} \) (show-through) and as low a \( PT_{VS} \) (vehicle oil separation) value as paper A. Paper G, on the other hand, had not only a high \( PT_{ST} \) but also a very high, \( PT_{PP} \) (pigment penetration) value. It appears that the pigment penetration was the decisive factor to the disadvantage of this paper.
The results from the two-layer printing, Figure 15, showed that papers A and paper C behaved fairly similarly with respect to $PT_{VS}$ and $PT_{PP}$, but that paper G showed a lower $PT_{VS}$ and a higher $PT_{PP}$ than the other two papers. This indicates that the fibre structure in paper G has a good ability to limit the oil penetration but a poor ability to be able to keep the pigment on the surface. In spite of the higher pigment penetration, paper G gave a slightly lower total print-through in the two-layer prints.

The $PT_{VS}$ and $PT_{PP}$ components increased slightly as a result of the printing of the second ink layer, but the increase did not correspond to the total amount of ink transferred in the two-layer as opposed to the a single-layer printing. An increase in the amount of ink by ca. 80 % to a total of 5.5 g/m$^2$ increased the print-through by only slightly more than 30 %. It seems that the decisive contribution to the print-through is made with the first ink layer.

The third ink layer was printed on top of 2.5+2.5 g/m$^2$ ink in the two underlying layers. The print-through did not increase in proportion to this amount. Both the $PT_{VS}$ and $PT_{PP}$ components increased to approximately to the same extent as was observed in the case of the second ink layer. This printing confirms that the greatest contribution to the print-through is in the printing of the first ink layer.
Paper G was again found to have the ability to effectively limit the oil penetration in multi-layer printing. In spite of the increase in pigment penetration, the total print-through was slightly lower for this paper than for paper C and A.

**Figure 16.** Mean print-through of the three-layer prints. The difference between the print-through before (♦) and after (■) extraction is approximately the same as in the single-layer and two-layer printing.

Table 3 shows print-through divided into the three different components for the three papers. In this evaluation of the print-through, an ink amount of 3.0 g/m² in the uppermost ink layer was chosen. This means that in two-colour printing, the total amount of ink was 2.5+3.0 = 5.5 g/m² and in three-colour printing, 2.5+2.5+3.0 = 8 g/m², since the amount of ink in the underlying ink layer had an ink amount of approximately 2.5 g/m². The total amount of ink transferred was not used in this evaluation, since the transfer of the second and third ink layers was made after 24 and 48 hours, respectively, which makes it possible to regard the surface printed with ink as a new paper surface.

The print-through development in the printing of the first ink layer was similar in papers C and A, but paper G had a higher pigment penetration. Together with a high $PT_{ST}$ value, this paper gave the highest print-through, in agreement with what was observed in full-scale printing. The application of an additional ink layer did not give the same good agreement with the full-scale printing. Here paper G showed a good ability to inhibit oil penetration. In the printing of both the second and the third ink layer, this paper developed the lowest print-through. Papers A and C showed approximately the same oil penetration but a slight difference in the pigment penetration component, to the detriment of paper A. Together with a slightly higher $PT_{ST}$ value, this gave paper A a higher print-through than paper C. The development of the print-through followed the same pattern in the printing of the third ink layer. Paper G still showed a good ability to inhibit oil penetration $PT_{VS}$, while paper A had a higher $PT_{VS}$ value than C. Due to this increase, paper A showed the highest sensitivity to full-scale multicolour printing.
Table 3. Print-through for three papers evaluated at 3 g/m² in the uppermost ink layer divided into three components: $PT_{ST}$ = show-through, $PT_{VS}$ = vehicle separation and $PT_{PP}$ = pigment penetration.

<table>
<thead>
<tr>
<th>Components</th>
<th>Paper-C</th>
<th>Paper-A</th>
<th>Paper-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. layer</td>
<td>0.011</td>
<td>0.014</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>0.050</td>
<td>0.051</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>0.019</td>
<td>0.019</td>
<td>0.030</td>
</tr>
<tr>
<td>2. layer</td>
<td>0.011</td>
<td>0.014</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>0.088</td>
<td>0.086</td>
<td>0.067</td>
</tr>
<tr>
<td></td>
<td>0.031</td>
<td>0.034</td>
<td>0.042</td>
</tr>
<tr>
<td>3. layer</td>
<td>0.011</td>
<td>0.014</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>0.121</td>
<td>0.123</td>
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</tr>
<tr>
<td></td>
<td>0.046</td>
<td>0.044</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Figure 17 shows the percentage proportions of the three components in the total print-through. The figure shows both the sizes of the print-through components and the changes in these which takes place in the printing of one, two and three ink layers. $PT_{VS}$ gave by far the greatest contribution to the print-through, amounting to between 50 and 70%. The first ink layer had the greatest effect on the print-through. The printing of a single ink layer thus gives a sufficiently good indication of the development of print-through in multicolour printing.

The contribution of the pigment penetration component $PT_{PP}$ was much lower in this investigation and amounted to 10-20%. Although this component is small, the pigment penetration is a significant print-through component and even a small increase in the pigment penetration can have a very negative effect on the print-through.

Although it is relatively small, the show-through component is at least as important as the other components. A good paper must have a low $PT_{ST}$ value to give good conditions for low print-through. Since magnitude of this component is independent of the amount of ink at normal ink levels, the percentage contribution is dependent on the total print-through. At a low print-through, the $PT_{ST}$ contribution is greater and it will consequently decrease with increasing print-through.

Figure 17. Print-through for three papers evaluated at 3 g/m² in the uppermost ink layer, divided into the three components of the total print-through: $PT_{ST}$ = show-through, $PT_{VS}$ = vehicle separation and $PT_{PP}$ = pigment penetration. The columns are from the left: paper C, paper A, and paper G.
5 Conclusions

The investigation has illustrated the complexity which prevails in the development of print-through in multicolour printing. The results have shown that a laboratory test printing with a single ink layer gives a good indication of how the print-through may develop in full-scale multicolour printing. If the investigation is supplemented with the measurement of the $PT_{ST}$ component, a sufficiently good certainty is obtained in the results. The printing of additional ink layers is of only a more or less academic interest and need not necessarily be applied.

The proportions of the print-through components are extremely different in different papers. The relationship between the components in this investigation according to the method of evaluation applied was on average: 65% for $PT_{VS}$, 25% for $PT_{PP}$ and 10% for $PT_{ST}$. Even though the contributions of these components are extremely different, these differences should be observed with caution, since the components can show differences in their influence on the print-through. It has been mentioned previously that the pigments are effective with respect to the absorption of light and this is no doubt influenced by the transparency of the pigments (a magenta pigment which shows a high $PT_{PP}$ does not give as high a print-through as a black pigment with a lower $PT_{PP}$).

Full-scale test printing is of course the most realistic test method. However, a disadvantage of this is that the printing is controlled by the print density, which means that there may be different amounts of ink on different papers if the materials differ with respect to their ink requirement. Another important factor is that in multicolour printing, fountain solution is transferred to non-image areas in the press nips. In CMYK printing, a fountain solution is, for example, transferred three times to the surface before it receives the black ink (K). To what extent this moistening and the colour order in multicolour printing affect the print-through has not been investigated.

The disadvantages of a laboratory test printing are its discontinuity and the lack of fountain solution both emulsified into the ink and moisture applied to the surface before the ink transfer.
6 Proposals for further work

Information about the influence of the fountain solution and its quality on the development of print-through in multicolour printing would bring a greater understanding to print-through studies. Test printings with water emulsified into the ink would show how these small amounts of water influence the print-through components.

A study with fountain solution could be carried out with repeated moistening of the surface of the material before the ink transfer takes place. This would provide information as to how the print-through is influenced by one, two or three moistenings with alcohol or a surfactant-containing solution before the ink transfer.

It is known that the fines in the pulp influence the print-through. The significance of the distribution of fines in the surface and consequently the influence of the finest surface structure of the paper on print-through mottling and on the print-through components is less known.
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Title
Print Through in multicolour printing

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Abstract
This report presents an evaluation of print-through on different newsprints. The print-through was studied in two different ways: through full-scale test printing in a four-colour sheet-fed offset press and through laboratory test printing with a printability tester of the Prüfbau type. In both these studies, the print-through was evaluated in full-tone prints consisting of one, two or three ink layers printed on top of each other. The full-scale test printing was carried out in multicolour printing (CMYK) at five different density levels. In order to study the ability of the paper to absorb the ink components, test printings were carried out on a laboratory scale with three layers of black ink (KKK).

The penetration of oil from the first ink layer greatly reduces the internal light-scattering surfaces in the paper and gives the greatest contribution to the print-through. At a print density of 0.95, the contribution of the oil penetration to the print-through from the first layer is 60-80 %. At the same density, layer two contributes 10-20 % and layer three contributes 5-10 %.

In the laboratory test printing, the same result was obtained as in the full-scale printing with respect to the first ink layer. The print-through in the first ink layer combined with the paper’s show-through gives a good indication of the development of the print-through to be expected in multicolour printing. The print-through components contribute to the total print-through to different degrees. The greatest contribution, 65 %, comes from the oil separation component. The pigment penetration contributes ca. 25 % and the show-through component ca. 10 %.

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