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Hupp, Heike; Dörsam, Edgar

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# Measuring printed special-effect colours
# First experiences with the MultiFX10 spectrophotometer

*Heike Hupp, Edgar Dörsam*

Technische Universität Darmstadt, Fachgebiet Druckmaschinen und Druckverfahren
Magdalenenstrasse 2, 64289 Darmstadt, Germany
E-mails: hupp@idd.tu-darmstadt.de; doersam@idd.tu-darmstadt.de

## 1. Introduction

The printing industry is burdened with price battles and overcapacity. This leads to improvement of the infrastructure and cost reduction on the one hand and introducing new technologies and services on the other hand. To achieve sustained success it is advantageous to introduce new technologies to stand out of the crowd. A new technology, which has been integrated lately, is the printing of special-effect colours such as interference colours.

These kinds of colours are better known in other industries, especially in the automobile industry. Body paintings of cars mostly show metallic effects or a change in colour addicted to the viewing angle as a result of interference. There is a standardisation and different measuring devices to control the quality are established.

For the printing process this proceedings have not taken place jet. Neither the physical background of printed special-effect colours and its interaction with absorption colours nor the possibilities to measure this kind of colours were researched. That is why today no measurement device to measure printed special-effect colours is available. Still, to assess this kind of colours modern printers only have the possibility of a visible inspection, which makes an industrial printing process impossible.

In order to find a remedy it is purpose of this paper to make a technology transfer from measuring devices of the automobile industry to the requirements of the printing industry. For this, a description of measuring device for measuring special-effect colours and the requirements of printing are given fist. Subsequently the multi-angle spectrophotometer Multi FX10 and its attributes are studied. In consequence of this, an adjustment process, using different apertures, occurs with the aim to reach aperture sizes similar to the requirements of the printing industry.

## 2. Preliminary considerations

### 2.1 Measuring special-effect colours

The conventionally used inks like Cyan, Magenta, Yellow and Black consist of absorption pigments. These pigments absorb (or "swallow") a particular wavelength of the oncoming light, Figure 1 left. The colour impression is the remaining part of the white light (complementary colour). Because of their irregular shapes, absorption pigments only show one colour and have no iridescent properties [Merck, 2005]. That is why colour measurement instruments only need one illumination/viewing angle (normally 45°/0° or 0°/45°) to measure these colours.

Metallic inks consist of very thin metallic flakes that act as miniature mirrors, Figure 1 middle. The intensity of these inks changes according to the angle from which they are viewed. Maximum light intensity is achieved near the "gloss" - the angle at which incident light is reflected. Minimum is experienced for an angle far away from the gloss. Factors affecting this flip-flop effect are the shape and the size of the pigment particles and the way they are laid down within the paint [Rodrigues, 1995; Huber, 2000]. To assess the flip-flop effect it is necessary to measure by different viewing or illumination angles. Since the metallic-effect pigments are very often used for automobile varnishes, standardisation process for the illumination and viewing angles takes place in this industry first (DIN 6175-Teil 2).

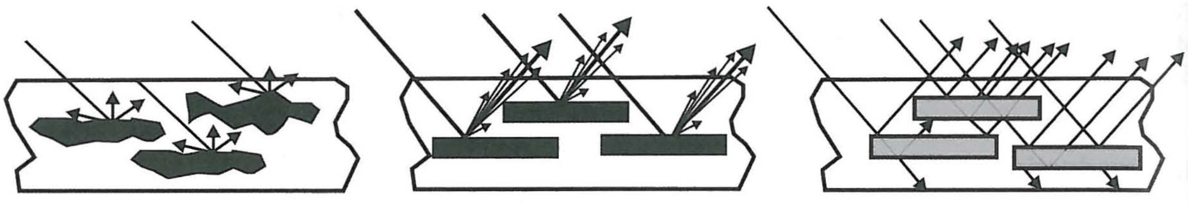



*Figure 1: The three different classes of pigments [Maisch, 1991]*

Interference pigments represent the third class of pigments. In contrary to the other two classes, these pigments are transparent and acquire the colour effects through interference with little or no absorption. The most requested kind of these effect pigments is basically a mica flake coated with single or multiple thin layers of metal-oxide, like $TiO_2$ [Rodrigues, 1995; Huber, 2000], shown in Figure 2 on the left. White light impinging on this type of pigments is partially reflected at its $TiO_2$ surface. The remainder passes (with refraction) through the $TiO_2$ layer until it encounters the surface of the mica. Here it is partially reflected again. This reflected light leaves the pigment parallel to the first reflected light component, but with a shift in the wave compared to the light reflected on the $TIO_2$ surface. A wave peak coinciding with another wave peak will produce a magnified wave, while a wave trough on another wave trough will give a flatter wave. In the simplified interference formula, the resultant reflection colour is a function of the layer thickness of the $TiO_2$, of its refractive index and of the angle from which light impinges [Cramer, 1999]. As the thickness of the layer ($TiO_2$) increases the colour of the pigment changes from silver-white, through yellow, red and blue to green (Figure 2 right) [Cramer, 2001].

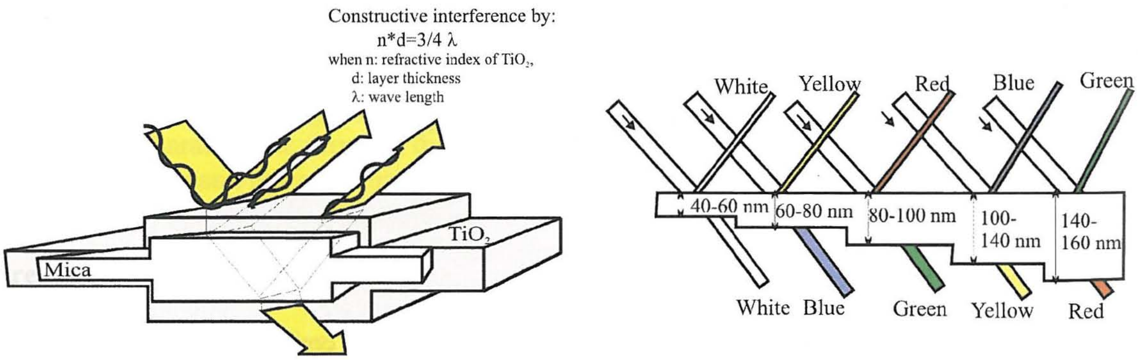



*Figure 2: left: Schematic cross-section through a mica flake pearl lustre pigment [Maisch, 1991] right: Changes in the colour, with respect to the thickness of the $TiO_2^-$ layer [Maisch, 1991]*

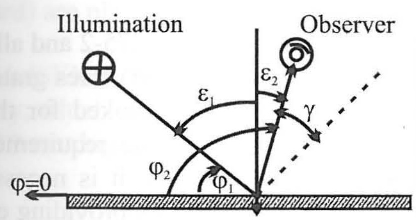
The interference formula expresses the reflection colour as a function of light incidence. Examinations of Cramer and Gabel [Cramer, 2001] have demonstrated that the interference pigments show a marked colour flip-flop effect dependent on the illumination and observation angle. They indicate two discernible fundamental colour shifts of interference pigments. The first is the shift produced by varying the illumination angle and keeping the aspecular angle constant (interference shift). The second is when the illumination angle is kept constant and the aspecular angle is varied (aspecular shift). This leads to the knowledge that a colour measurement system has to provide different illumination and varying viewing angles to measure interference pigment colours [Cramer, 2001].

Recapitulate it could be said, that for measuring the absorption colours only one illumination/viewing angle is necessary. For measuring metallic effect colours a higher effort is needed, so that at least either the illumination or the viewing angle has to be variable. The measurement of interference colours shows the maximum complexity. For this colours varying illumination angle as well as a varying viewing angle are essential.

## 2.2 Measuring instruments for metallic and interference colours, state of the art

Different manufactures and standardisation commissions endeavour the design and development of measuring devices for measuring metallic effect and newly as well for interference colours. In effort of the automobile industry a standardisation process for measuring metallic effect colours took place. The standardisation DIN 6175-2 defines the viewing and illumination angles to be used for measuring this kind of colours.

Figure 3 demonstrates the definition of these angles ($\varepsilon_1$ illumination angle, $\varepsilon_2$ viewing angle) in this standardisation. However, there is still a discussion about the naming of the angles [Rösler, 2005]. Manufactures and researchers often use the definition of the aspecular angle[1], corresponding to the working group ASTM E-12.12 [Rodrigues, 1996]. Others, like Datacolor, count the angles from the horizontal line ($\varphi_1$ illumination angle, $\varphi_2$ viewing angle), see Figure 3.




| DIN 6175-2 | | | counted from horizontal | |
|---|---|---|---|---|
| illumination angle | viewing angle | aspecular angle | illumination angle | viewing angle |
| $\varepsilon_1$ | $\varepsilon_2$ | $\gamma$ | $\varphi_1$ | $\varphi_2$ |
| 45° | -20° | 25° | 45° | 110° |
| 45° | 0° | 45° | 45° | 90° |
| 45° | 30° | 75° | 45° | 60° |
| 45° | 65° | 110° | 45° | 25° |

*Figure 3: Different possibilities of illumination and viewing angles for measuring Metalic - effect colours [Datacolor, 2006]*

In the following, except for the next two tables (Table I and Table II), the nomenclature of Datacolor, counting the angle from horizontal line ($\varphi_1/\varphi_2$), is used. Table I shows an overview of different portable measuring instruments for measuring metallic effect colours. All these measuring instruments have in common that the illumination angle changes and the viewing angle is fixed or vice versa. The used angles are according to the angles given in DIN 6275-2.

*Table I: Overview of different measuring instruments to measure metallic effect colours, according to DIN 6275-2 [Minolta, 2006; Gretag Macbeth, 2006; Xrite, 2006]*

| Instrument (Name, Manufacturers) | Illumination angle(s) | Aspecular angle or viewing angle | Light source | Aperture size |
|---|---|---|---|---|
| CM-512m3, Minolta | $\varepsilon_1 =$ 25°, 45°, 75° | $\varepsilon_2 = 0°$ | Circumferential pulsed xenon light | ∅12 mm |
| ColorEye 640 & 740, GretagMacbeth | $\varepsilon_1 = 45°$ | $\gamma =$ 15°, 45°, 75°, 110° | Pulsed xenon light | ∅14 mm |
| MA48 and MA 68II Xrite | $\varepsilon_1 = 45°$ | $\gamma =$ 15°, 45°, 75°, 110° | Tungsten lamp 4000°K | ∅12 mm |

[1] Aspecular angle $\gamma$: Viewing angle measured from the specular direction to observer [Rodrigues, 1996]

Since these measuring instruments only give the possibility to measure metallic effect colours, different devices, providing varying illumination and changeable viewing angles, were developed. An incomplete overview of measuring instruments providing changeable illumination and viewing angles is given in Table II.

*Table II: Measuring instruments with changeable illumination and viewing angles, giving the opportunity to measure interference colours [Instrument Systems, 2006; Phyma System, 2006; Murakami, 2006; Gerlinger, 1990; Datacolor, 2006]*

| Instrument (Name, Manufacturers) | Illumination angles | Viewing angles | Aperture size |
|---|---|---|---|
| GON 360, Instrument Systems | $\varepsilon_1$ = 0° to 360° Infinitely variable | $\varepsilon_2$ = -7° to 187° Infinitely variable | ∅10 mm |
| WICO 5&5, Phyma System | $\varepsilon_1$ = 22,5°, 45° (from perpendicular) | $\varepsilon_2$ = 22,5°; 0°; -22,5°; -45°; -67,5° | ∅14 mm |
| GCMS-3, Murakami | $\varepsilon_1$ = 16° to 180° in 1° steps | $\varepsilon_2$ up to 196° (transmission measurement) | ---- |
| GK 311/M, Zeiss | $\varepsilon_1$ = 25° to 155° in 5° steps | Difference angles $\varepsilon_2$ -$\varepsilon_1$ 0° to 110° | ∅15 mm |
| Multi FX10, Datacolor | $\varphi_1/\varphi_2$: 25°/170°; 25°/140°; 45°/150°; 45°/120°; 75°/120°; 75°/90°; 45°/110°; 45°/90°; 45°/60°; 45°/25° | | 69x22 mm (length x width) |

As seen before in Table I and Table II, all measuring instruments according to DIN 6275-2 and all of the devices with changeable illumination and viewing angles have aperture (sample port) sizes grater than the requirements of printing (diameter 3 mm to 4 mm). By this reason, it was looked for the best alternative measuring device, which furthermore could possibly be adjusted to the requirements of printing. For the aim to measure metallic colours as well as interference colours, it is necessary to provide different illumination and viewing angles. That is why all measuring devices providing either a changing illumination or a varying viewing angle can be excluded. The devices of Instrument Systems, Murakami and Zeiss, which allow to illuminate and view in small or rather infinitely variable steps have problems to assure the same illumination/viewing conditions each time of measurement. Beyond this, the Zeiss GK 311/M is not commercially available any longer. For the remaining measuring devices the Multi FX10 presents the best opportunities because of the good repeatability properties, due to the assigned illumination/viewing conditions and the ten sets of illumination/viewing angles. By the reason of the major number of illumination/viewing conditions compared to the WICO 5&5 of Phyma System, the Datacolor Multi FX10 gives the best opportunities to rate interference colours.

### 2.3 Description of Datacolor Multi FX10

The MultiFX10 is equipped with ten sets of illumination/viewing angles which are arranged pair wise on a movable half pipe. The half pipe is associated with a light coupling system connecting a single tungsten halogen lamp with the illuminator optics and the receiver optics to a single spectral analyser, Figure 4 right.

Only one set of optics is active at a given time, by moving the half pipe, and thereby the active illumination/viewing optic, to a position under the sample port. Since only the half pipe moves the angles are always the same and the repeatability is very high. The rectangular sample port is located on the top of the instrument, Figure 4 left. The dimensions of this sample port (aperture) are 69 mm in length and 22 mm width.

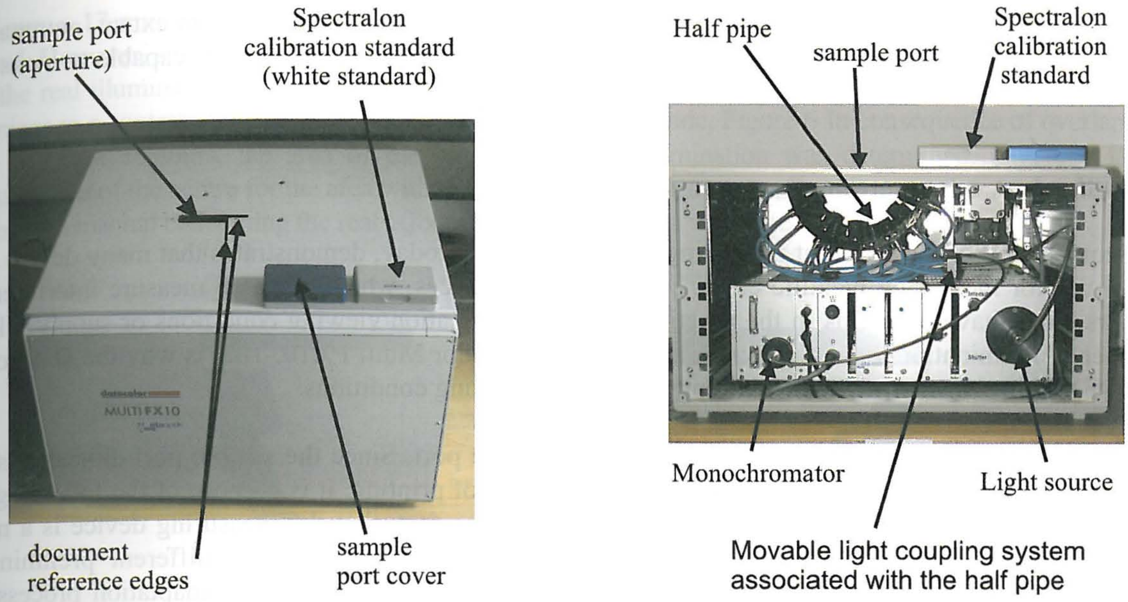



*Figure 4: left: View on the top of the measurement instrument Multi FX10 and declaration of the document reference edges right: View of the device with open front panel*

Figure 4 additionally gives a determination for the document reference edges used in the following. In the right edge of the instrument a sample port cover and the Spectralon calibration standard (white standard) are placed [Datacolor, 2006].

The MultiFX10 is mainly built for labs in the automobile, textile, and colour recipe calculation industry, which is shown by the dimensions of the measuring instrument (530 mm wide, 470 mm deep and 320 mm high) and the sample port (69 mm long, 22 mm wide).

## 2.4 Demands of the printing industry

Today the printing industry uses generally absorption pigment colours. That is why standardisation of colour measurement, given in DIN ISO 13655, specifies only an illumination/viewing angle of 45°/0° or rather 0°/45°. Special-effect colours like metallic or interference colours are not considered in this standardisation.

Besides this, the printing process places special claims for the size of the measuring fields. On multicolour presses, the application of ink in each printing unit must be monitored and adjusted individually. The fact that several colours have to be printed together in halftone images makes both visual assessment and measurement of the individual inks in the image relatively difficult. The measuring accuracy is limited because the measuring signal is partly superimposed by other inks. Printing so-called colour control bars with measurement patches for the individual colours in the trim-off alongside the image has proven good practise. Colour control bars of this kind are usually printed over the entire sheet width, and the individual patches are positioned so that they are assigned to the ink zones of the ink fountain. This enables targeted adjustment or control of the colour/ink flow [Kipphan, 2001]. Control bars are not a sellable part of the printing product, because they are rarely a part of the image. That is why they have to be as small as possible to reduce waste. Normally they are rarely bigger than 5 mm squared. This leads to the exigencies of ISO 5-4 concerning aperture sizes. This standardisation demands a 0.5 mm to 1 mm bigger measuring field at all edges than the aperture size. Consequentially the outcome of this is a requirement of a maximum aperture size of 3 mm to 4 mm squared or diameter, for measuring printed colours.

Since only the measurability provides the possibility for objective and, to a certain extent, automated quality control in printing, it is necessary to provide a measuring device, which is capable to measure in control bars and allows to rate special effect colours.

## 3. Methods

The comparison of the different measuring devices available today, demonstrates that many device are only built for measuring metallic effect colours. Other devices, which allow to measure interference colours either have problems in the repetition of the illumination/viewing conditions or supply a less number of illumination/viewing conditions than the Datacolor Multi FX10. That is why the Datacolor Multi FX10 is chosen to try the technology transfer to printing conditions.

Main point of this transfer is the dimension of the sample port. Since the sample port dimensions of the Multi FX10 are oversized alluded to the requirements of printing, it is purpose of the following to use a smaller area of the given sample port. In view of the fact, that the measuring device is a new technology and a detailed examination of this instrument is not existing, different preliminary examinations of the measuring device itself are necessary. Especially for the adaptation process to smaller sample port sizes (apertures), it is essential to get further information about how the unmodified sample port of the Multi FX10 is used during the measurement process. Afterwards the actual efforts to adapt the sample port using different apertures of diverse materials and sizes took place. The individual steps and used methods are described consecutively.

### 3.1 Preliminary examinations

For the preliminary examinations following topics were purpose of the research:

- Repeatability of Multi FX10 measurements,
- Allocation of light inside the sample port,
- Location of the centre of illumination and sensor observing,
- Spectral distribution and ratio of luminance in the sample port.

The preliminary examination of the device was based on the appraisal of the accuracy of the measuring results. In order to this, the repeatability was proven. Considering the reference manual, the repeatability has to be tested by measuring the Spectralon calibration standard for 20 times. Thereby the deviation in $\Delta E^*_{ab}$[2] should be less than 0.15 ($\Delta E^*_{ab} < 0.15$) (Datacolor, 2006). To get a statistically firm impression of the metering precision, the repeatability test procedure itself was proven five times.

In the next step the sample port got a closer inspection. As mentioned before the sample port holds a rectangular shape with dimensions of 69 mm length and 22 mm width. The different illumination and viewing angles were realised by moving the half pipe to a given position below the sample port. Since the illumination and sensor optics are positioned on the half pipe along a semicircle, it comes to different illumination/viewing areas, Figure 5.

Figure 5 illustrates exemplary for two different illumination/viewing angles the size of the overlapping area of the optical paths from the illuminant and the sensor. As it could be seen easily that the sizes of overlapping areas are highly dependent on the angles. For the flat angle 25°/170°, the overlapping area is very large. For the steep angle 75°/90°, the smallest overlapping area could be seen. In the operation manual of the Multi FX10 this overlapping area is called effective measuring area. For the angle 25°/170° the effective measuring area is given with 41 mm x 15 mm (length x width), for the angle 75°/90° with

[2] The maximum is declared as CIE 1976 L*a*b* colour difference: $\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$

17 mm x 17 mm. Both declared effective area and schematically acquired overlapping areas are almost equal. However, since the locations of these effective measuring areas are unknown, a further examination of the real illumination and sensoring conditions is needed. To clarify the location of the highest ratio of luminance a contour drawing of all illumination angles was made, Figure 6 In consequence of overlapping the different contours, the area of the highest ratio of illumination was determined. Outcome is the designation of the centre for the area with the highest ratio of luminance. Furthermore, the statements of the operation manual concerning the real effective illumination area were checked.

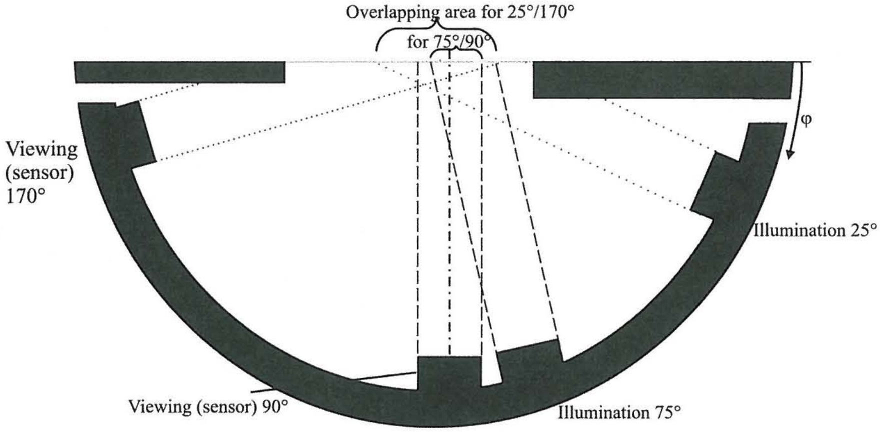



*Figure 5: Shematic illustration of the overlapping areas of illumination and the viewing (sensor), using the model of optical paths*

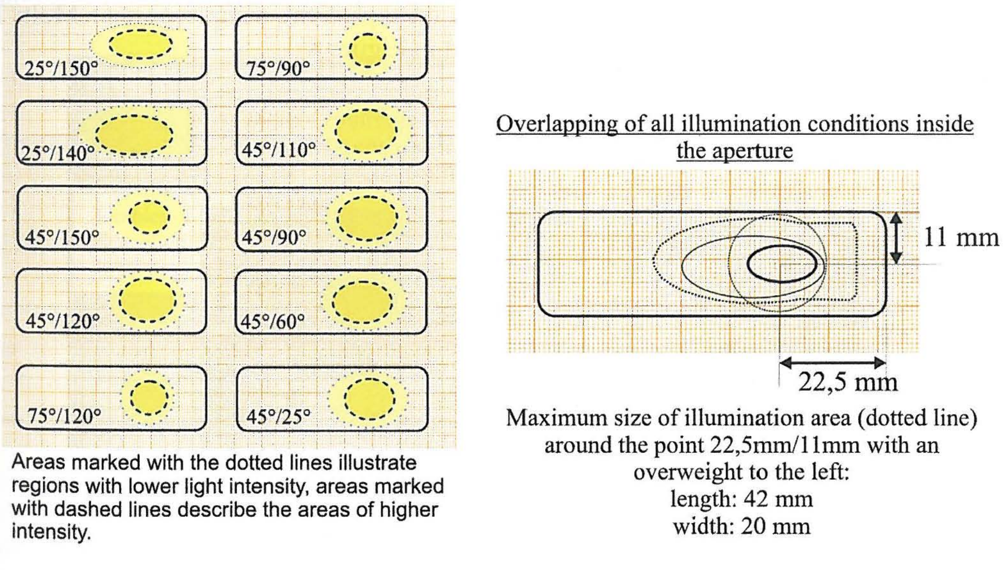



*Figure 6: left: Illumination conditions inside the aperture of the MultiFX10*
*right: Overlapping of all illumination conditions and determination of the centre*

Since the area observed by the sensor is not observable, the location of the "sensor centre" has to be found by measuring. For this a 5 mm wide strip of white paper in front of a black background was moved to the different positions shown in Figure 7 The positions with the highest remission ratio appropriate the area of the highest sensor sensitivity and therewith the centre of the measuring area.

By combining the different centres of illumination and sensor observing it is possible to accumulate a point inside the sample port, in which the middle of a sample has to be located to get the best measuring results.

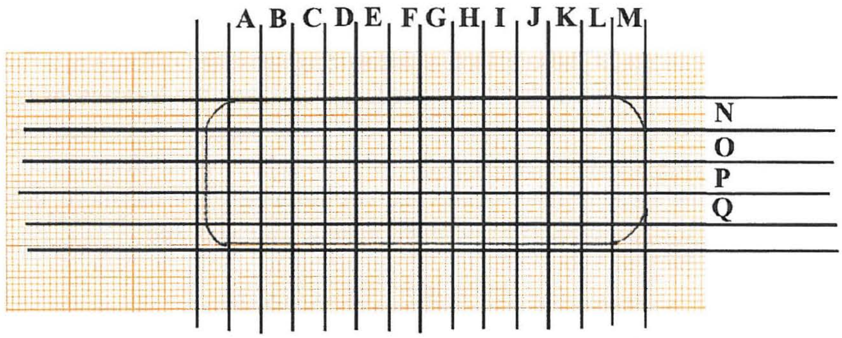



*Figure 7: Positions to find the optimum measurement area inside the aperture*

Besides this, to get a better impression of the measurement device and the illumination conditions the spectral distribution and the illumination ratio of the light were measured in the beforehand acquired location, Figure 6 left. For this examination, the spectrophotometer EyeOne Beamer of Gretag Macbeth and the light measuring instrument MiniLux of MX-Electronic were used.

### 3.2 Adapting process for the sample port of Multi FX10

After the preliminary examinations and with the knowledge of the location for the centre of illumination and sensor observing inside the sample port or rather the centre of the aperture, the actual adjustment process took place. For this different apertures were built using different materials and varying the hole sizes of the apertures. Exemplary an on top of the sample port of Multi FX10 fix aperture as well as diverse other apertures are illustrated in Figure 8.

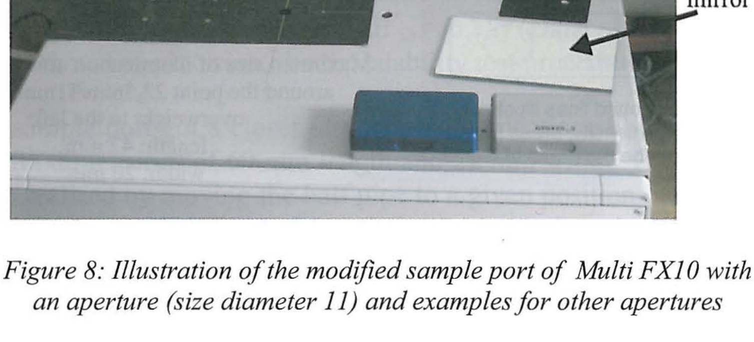



*Figure 8: Illustration of the modified sample port of Multi FX10 with an aperture (size diameter 11) and examples for other apertures*

The sizes of the apertures varied from the size of the overlapping area of illumination found before to typically used sizes in the different industries, diameter 3 mm for printing and diameter 8 mm and 12 mm for the automobile industry. In the following "d" is been used for the abbreviation of the diameter.

Following researches to adapt the sample port of Multi FX10 to printing conditions, described in detail subsequently, were done:

- Influence of the calibration method,
- Influence on the measuring results of absorption and interference colours by attaching different black-paper apertures on the sample port,
- Comparison of the measuring results of Multi FX10 with unmodified and adapted sample port with other measuring instruments,
- Adapting the sample port using a mirror as aperture.

The influence of the apertures cohesive the calibration and the results measuring the calibration standard were considered first. For measuring colour, it is necessary to calibrate the measuring instrument first. In this coherence, a 100%-reflection calculation is used. This means that the outcome of measuring the white standard during the calibration process is set to 100% at all wavelengths. In a CIELAB assessment the result for an ideal white standard has to be $L^* = 100$, $a^* = 0$ and $b^* = 0$. By the reason of this knowledge, it is easy to get a first impression of the impact using apertures to reduce the size of the sample port. If here a huge influence on the measuring results is established, this way of adjusting the size of the sample port could be excluded. In the next step, the measuring results of different print substrates and printed absorption and interference colours were regarded. For this, different black paper apertures were fixed on top of the sample port with the centre of the aperture at the location found before. For sample two different papers (LumiArt of Stora Enso and a paper for copier), the absorption colours "Cyan", "Magenta", "Yellow" and "Black" as well as the interference colours "LithoYellow", "LithoRed", "LithoBlue", "LithoLilac" and "LithoGreen" were consulted. The samples for the absorption colours were taken from the colour compendium IRIODIN® /IRIODINBRONZE® [Merck, 1993]. The samples for the interference colours derived from the IRODIN®/AFFFLAIF® Offset colour effects fan of Merck [Merck, 2006], Figure 9. The measuring results of these colours, determined using different apertures, were compared.


*Figure 9: Used samples for absortion and interference colours*

To improve the quality of the Multi FX10 and adjustment process, a comparison with measuring results of other measurement devices were made. For this, commonly used measuring instruments of different industries, such as the printing and the automobile industry, were used, given below:

- Techkon Spectrodens, a common used portable spectrophotometer for the printing industry, with a sample port of diameter 3 mm and ($\varphi_1/\varphi_2$) 45°/90°- Geometry [Techkon, 2006],
- Minolta CM-2600d, a portable spectrophotometer, mostly used in the automobile and textile industry, with a sample port of diameter 8 mm or 12 mm and a diffuse illumination [Minolta, 2006],
- Minolta CM512-m3, a portable multi-geometry spectrophotometer, for measuring especially automobile metallic colors, with geometries of ($\varphi_1/\varphi_2$) 45°/90°, 45°/110° and 45°/60° [Minolta, 2006].

The outcome of this comparison is the appraisal of the possibilities of reducing the sample port of Datacolor Multi FX10.

After the comparison a new adaptation process, this time using a mirror as aperture, occurred. In the first step of this process, the effectiveness of measuring a mirror with Multi FX10 unmodified sample port was tested. After that, the absorption and interference colours were measured using different sizes of mirror-apertures.

## 4. Results

### 4.1 Results of the preparatory examinations

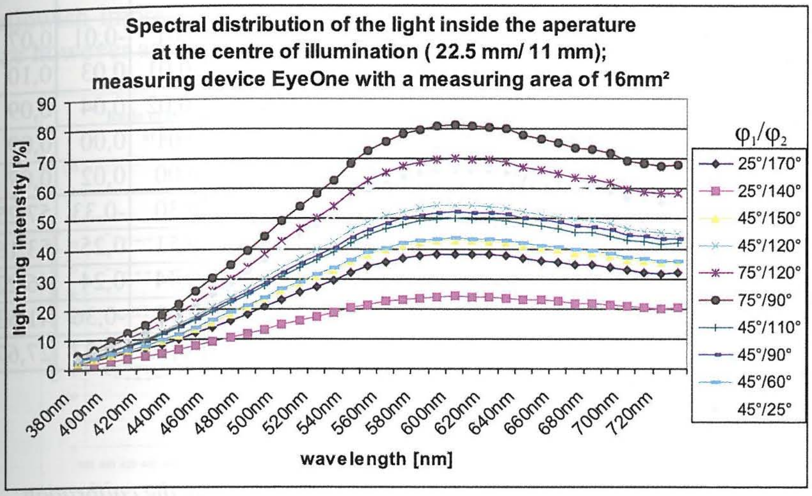
As told before, the repeatability of the Multi FX10 was tested first. Based on 20 reads of the Spectralons calibration standard, the deviation has to be smaller than $\Delta E^*_{ab} < 0.15$ [Datacolor, 2006]. The accomplished repeatability test, repeated five times, indicates that 3.5% of all measurements were outside the maximum range of $\Delta E^*_{ab} < 0.15$. These errors predominantly occur for the illumination/viewing angles of 45°/60° and 45°/25°. In consequence, it was necessary to take more than one measurement in the present work to exclude the measurement errors and calculate the average.

Figure 6 illustrates the contour drawings of the distribution of light inside the sample port. As it could be seen, the illuminations areas of highest ratio of illuminance for the varying angles have almost the same size as predicted by the operation manual and the theoretical considerations out of the optical paths. For example, the illumination area by an illuminant at the angle 25°/170 ($\varphi_1/\varphi_2$) should theoretically have a length of 46 mm and a width of 19 mm. The contour draw exhibits the dimensions for the illumination area with highest ratio of luminance of 38 mm x 13 mm (length x width) and a bigger area (43 mm x 18 mm) included regions of lower intensity. Thus the theoretical considerations can not include the different allocation of the light intensity, but gives a good appraisal for the covered area. Similar circumstances established for the other illumination angles. By overlapping all illumination areas of highest intensity a centre at the point 22.5 mm from the right edge of the sample port and 11 mm from the upper edge of the sample port is found, Figure 6 right. Besides this results a maximum illumination area of 42 mm length and 20 mm width, located around the centre, by measuring the length and the width of the overlapped counter draw.

The following search of the "sensor centre" confirms the assumption of the centre located in the area around the same point like the centre of illumination (22.5 mm / 11 mm). Between the vertical positions "I" and "J", as well as between the horizontal positions "O" and "P" (Figure 7, the maximum of remission is located.

Subsequently, the precise illumination conditions in the centre of illumination, found before, were studied. Since the operation manual does not give any details on the illumination ratio and the spectral distribution, this data was acquired next. For this measurement, the sample port abides unmodified. Concerning the different measurement devices and their aperture sizes, used to measure the illumination ratio and the spectral distribution, the acquired areas of light around the centre of illumination of the sample port (22.5 mm / 11 mm) were different. Figure 10 left shows the measured spectral distribution of the light in the centre of illumination inside the aperture. The table in the same figure right illustrates the different illumination ratios for the different illumination/viewing angles in the same point.

For the illumination angle of $\varphi = 75°$ the highest ratio of illumination exists. For the very flat illumination angle of $\varphi = 25°$ the illumination ratio decreases to 30%. As expected, because of the light coupling of all illuminator optics with the halogen lamp in the half pipe, the spectral distribution for all illumination/viewing angles shows the same tendencies. Only the illumination intensity decreases in the same way as the ratio of illumination. The distributions show a high share in the green-red sector and a very low intensity in the blue sector. Looking at the colour temperature, not illustrated in the figure, the measurement shows a colour temperature of approximately 3560 K for all angle combinations.




| Illumination/ viewing angle ($\varphi_1/\varphi_2$) | MiniLux measured area 95 mm² Illumination ratio [lux] |
|---|---|
| 25°/170° | 1530 |
| 25°/140° | 1240 |
| 45°/150° | 2240 |
| 45°/120° | 2970 |
| 75°/120° | 3530 |
| 75°/90° | 5370 |
| 45°/110° | 2790 |
| 45°/90° | 2860 |
| 45°/60° | 2730 |
| 45°/25° | 4340 |

*Figure 10: left: Spectral distribution of the light inside the aperture at the "optimum" position right: Ratio of illumination at the different illumination/viewing angles measured at the "optimum" position*

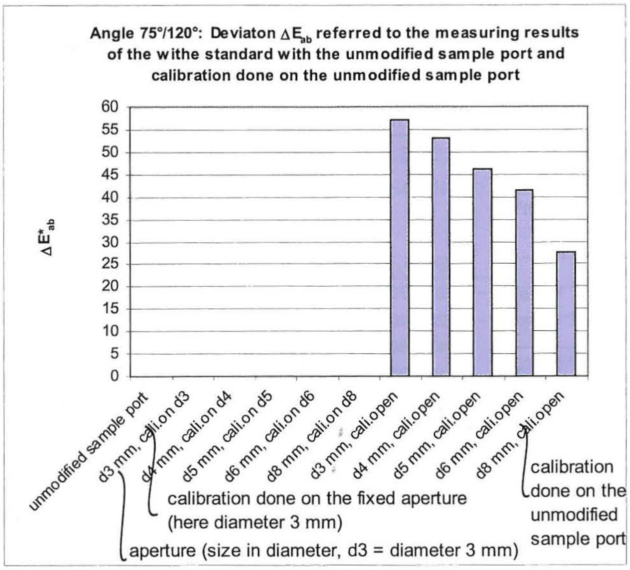
### 4.2 Results of adapting the sample port to measurement conditions of printing

With the different apertures of black paper, fixed on top of the sample port (Figure 8), the illumination conditions were checked again. For this the centre of the apertures was located on the position of the centre of highest illumination ratio (22.5 mm / 11 mm). The results, Figure 10, indicate a reduction in the illumination ratio of 75% in all illumination/viewing angles with respect to the open unmodified sample port by using an aperture of diameter 3 mm. By enlarging the aperture size, the illumination ratio gets higher again. For an aperture size of 15 mm x 15 mm the same lightning conditions could be measured as within the unmodified sample port. Meanwhile, the reduction of the aperture size does not influence the spectral distribution. With the knowledge of the aperture size influence on the illumination conditions, it is of interest, if the different apertures influence the colour measurement in the same way.

Figure 11 illustrates, on the example of black paper apertures for the illumination/viewing angle of 75°/120°, the influence of different aperture sizes while calibration is done on the unmodified sample port or on the aperture.

If the calibration is done on the open aperture, huge colour differences $\Delta E^*_{ab}$ appear. The colour differences between the different aperture sizes become greater by smaller aperture sizes. It almost shows a linear tendency. If calibration is done on the apertures and the calibration standard is measured again, the colour difference $\Delta E^*_{ab}$ is very small, almost zero. Therefore, it was determined for the following to calibrate directly on the corresponding aperture.

Since the measuring results of the white standard, after calibration is done on the aperture, match the measured values acquired by the unmodified sample port, the adaptation process was continued. This time different printing substrates, absorption and interference colours were measured with the different apertures. The measurements of two different papers (LumiArt of Stora Enso and a Copy paper) strengthened the conclusion that measurements will have the same result as measurements on the unmodified sample port.




| measurement | L* | a* | b* | $\Delta E^*_{ab}$ |
|---|---|---|---|---|
| unmodified sample port | 100,08 | -0,01 | 0,00 | |
| d3 mm, cali.on d3 | 100,01 | 0,01 | -0,01 | 0,07 |
| d4 mm, cali.on d4 | 99,98 | -0,01 | 0,03 | 0,10 |
| d5 mm, cali.on d5 | 99,99 | -0,02 | 0,04 | 0,09 |
| d6 mm, cali.on d6 | 99,99 | 0,01 | 0,00 | 0,09 |
| d8 mm, cali.on d8 | 100,01 | 0,00 | 0,02 | 0,07 |
| d3 mm, cali.open | 42,83 | 0,30 | -0,33 | 57,25 |
| d4 mm, cali.open | 46,92 | 0,51 | 0,25 | 53,16 |
| d5 mm, cali.open | 53,86 | 0,34 | 0,24 | 46,22 |
| d6 mm, cali.open | 58,55 | 0,03 | -0,36 | 41,53 |
| d8 mm, cali.open | 72,41 | -0,10 | -0,27 | 27,67 |

*Figure 11: Visualisation and table of $\Delta E_{ab}$ for different black paer apertures influenced by the calibration; "cali on" stands for measuring and calibrating on an aperture, "cali open" stands for measurering on an aperture but calibration on the unmodified sample port. $\Delta E_{ab}$ refers to the measurement measured and calibrated on the unmodified sample port*

Figure 12 and Figure 13 illustrate the remission curves of the absorption colour "Yellow" and the interference colour "LithoYellow" for two different illumination/viewing angles. This remission curves were measured firstly on the unmodified sample port and secondly with different apertures. Other absorption and interference colours were measured for all illumination/viewing angles as well and show the same attitude. The diverse apertures were built of different papers with different sizes. Depending on the used paper, the thickness and the colour of the aperture the shape and attitude of the remission curves change. The curves with the rhomb show the measuring results of unmodified sample port. They mark the reference for rating the quality of the adjustment. As it could be seen, the remission curves show different behaviours in dependence to the aperture size and the illumination/ viewing angle. The absorption colours have the same remission curves for all illumination/viewing angles measured on the unmodified sample port tendentious, only the intensity for the very flat angle is lower. Thus, the measurement with the unmodified sample port demonstrates the independency of the illumination/viewing angle of the absorption colours. On the other hand, the influence on the colour impression of interference colours can be seen in Figure 13. As during a visual inspection, the interference colour "LithoYellow" exhibits a yellow colour impression for very flat angles, Figure 13 left. For angle combinations according to DIN 6175-2 with aspecular angles greater than ± 15°, as illustrated in Figure 13 right, the impression of the interference colour gets more colourless and even white.

As shown in Figure 12, the remission curves of absorption colours measured with apertures feature higher intensities. This behaviour does not change according to the illumination/viewing angle. Contrary to this, the interference colours change their behaviour with the illumination/viewing angle if apertures are used. For flat angles the measured curves with reduced aperture sizes lay below the remission curve measured with the unmodified sample port. As the illumination angle gets steeper, the remission curves of interference colours will lay above the remission curve of the open aperture. Besides, it could be seen that the differences between the diverse remission curves decrease with steeper illumination angles.

Beside the illustration of the remission curves, the software of MultiFX10 gives the possibility to compare two different measurements for all illumination/viewing angles in one CIELAB colour space diagram. In Figure 14 the differences of the measuring results using the aperture (diameter 3 mm) compared to the unmodified sample port are easily visible. As the behaviour of a visual inspection, the measurements by the unmodified sample port designate a colour flop from a red impression near the specular angle (light violet for the very flat angle 25°/170° through pure light red, 45°/150°) to alight the yellowish impression far away from the specular angle. The measurements with the reduced aperture size however assign an even lighter (whiter) colour impression.

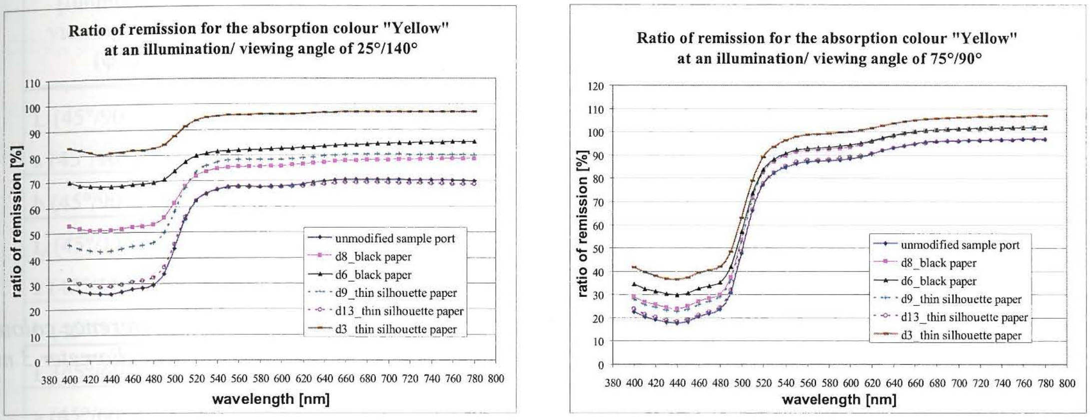



*Figure 12: Remission curves of the printed absorption colour "Yellow" for two different illumination/viewing angles ($\varphi_1/\varphi_2$); left: 25°/140°; right: 75°/90°*

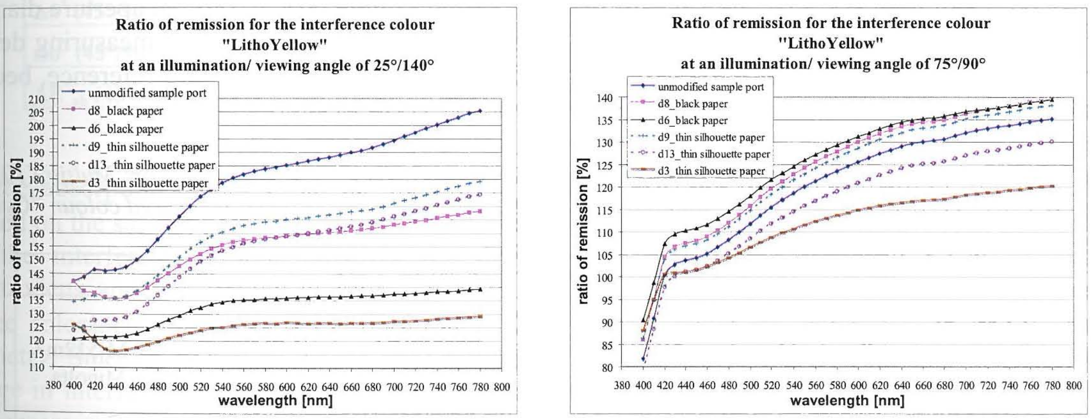



*Figure 13: Remission curves of the printed interference colour "LithoYellow" for two different illumination/viewing angles ($\varphi_1/\varphi_2$); left: 25°/140°; right: 75°/90°*

Another possibility to demonstrate the differences between the diverse aperture sizes is the CIELAB colour difference $\Delta E^*_{ab}$. Table III gives the achievement for the colour differences of the measuring results using apertures versus the measuring results of the unmodified sample port. Displayed are the colour differences for the absorption colour "Cyan" and the interference colour "LithoGreen" and the two aperture sizes diameter 8 mm and 3 mm. The colour difference of both colours is higher if the aperture size is reduced. For the absorption colour, this effect is heightened.

*Table III: Colour differences $\Delta E^*_{ab}$ of the measuring instrument MultiFX10 referred to the open aperture*

| | Absorption colour: "Cyan" | Interference colour „LithoGreen“ |
|---|---|---|
| Unmodified sample port | reference | reference |
| d8 mm | 4,9 | 2,25 |
| d3 mm | 14,39 | 7,4 |

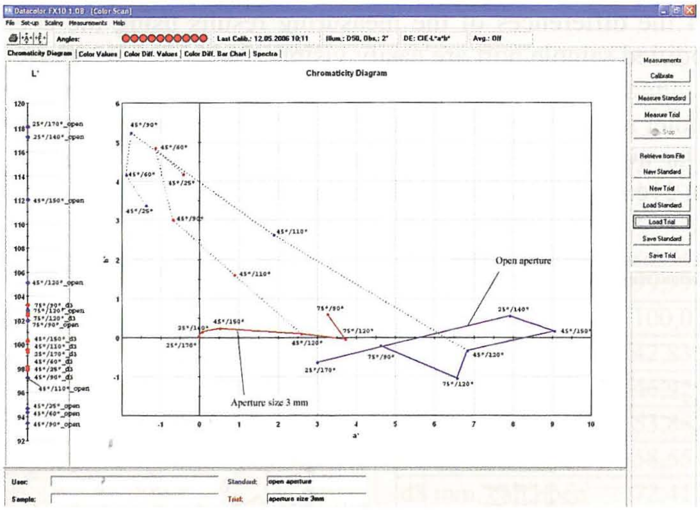



*Figure 14: Comparison in the CIELAB colour space of the measuring results for the interference colour "LithoRed", measured by the unmodified aperture and a black paper aperture with the size diameter 3 mm*

Further, a comparison with measuring results of other measuring instruments took place. For this, the CIELAB colour space and the colour differences $\Delta E^*_{ab}$ (D65 and 2° observer) are used. Table IV and Tabel V show the results for the absorption colour "Cyan" and the interference colour "LithoGreen". For this comparison, the measuring results of the unmodified sample port and for an aperture diameter 3 mm were consulted. The table indicates colour differences between the different measuring devises referred to the measuring results of Techkon Spectrodens. This device is taken as a reference, because it represents a device of the printing industry.

*Table IV: Comparison of the measuring results of different measuring instruments [Datacolor: MultiFX10 with open aperture; Techkon: Spectrodens; Minolta: CM-2600d; Minolta: CM-512m3]; measured colour "Cyan"*

| | Absorption colour "Cyan" | | | | |
|---|---|---|---|---|---|
| L*, a*, b* (illumination/ viewing angle); ($\varphi_1/\varphi_2$ | Spectro-dens Techkon | Unmodified sample port Multi FX 10 Datacolor | aperture d3 for Multi FX 10 Data-color | Cm-2600d Minolta (exclu-ding glance) | CM-512m3 Minolta |
| L (45°/90°) | 82,66 | 82,08 | 91,95 | 82,37 | 81,1 |
| a (45°/90°) | -14,37 | -14,62 | -6,08 | -14,63 | -14,06 |
| b (45°/90°) | -11,17 | -10,74 | -4,67 | -9,88 | -12,7 |
| L (45°/110°) | ---------- | 86,71 | 94,12 | ---------- | 82,88 |
| a (45°/110°) | ---------- | -12,7 | -4,57 | ---------- | -14,16 |
| b (45°/110°) | ---------- | -9,21 | -3,39 | ---------- | -12,56 |
| L (45°/60°) | ---------- | 79,79 | 87,47 | ---------- | 84,5 |
| a (45°/60°) | ---------- | -14,62 | -11,01 | ---------- | -13,76 |
| b (45°/60°) | ---------- | -12,28 | -8,03 | ---------- | -12,74 |
| **$\Delta L^*$ (45°/90°)** | | **-0,58** | **9,29** | **-0,29** | **-1,56** |
| **$\Delta a^*$ (45°/90°)** | | **-0,25** | **8,29** | **-0,26** | **0,31** |
| **$\Delta b^*$ (45°/90°)** | | **0,43** | **6,5** | **1,29** | **-1,53** |
| **$\Delta E^*_{ab}$ (45°/90°)** | | **0,76** | **14,04** | **1,34** | **2,20** |

*Table V: Comparison of the measuring results of different measuring instruments [Datacolor: MultiFX10 with open aperture; Techkon: Spectrodens; Minolta: CM-2600d; Minolta: CM-512m3]; measured colour "LithoGreen"*

| | Interference colour "LithoGreen" | | | | |
|---|---|---|---|---|---|
| L*, a*, b* (illumination/ viewing angle); $(\varphi_1/\varphi_2$ | Spectro-dens Techkon | Unmodified sample port Multi FX 10 Datacolor | aperture d3 for Multi FX 10 Data-color | Cm-2600d Minolta (exclu-ding glance) | CM-512m3 Minolta |
| L (45°/90°) | 93,09 | 93,03 | 92,9 | 93,64 | 91,25 |
| a (45°/90°) | 0,3 | 0,23 | 0,05 | -1,21 | 0,23 |
| b (45°/90°) | 1,67 | 2,66 | 2,96 | 4,31 | 0,08 |
| L (45°/110°) | --------- | 98,28 | 98,14 | ---------- | 95,53 |
| a (45°/110°) | --------- | -2,26 | -2,23 | ---------- | -1,4 |
| b (45°/110°) | --------- | 3,93 | 4,32 | ---------- | 1,27 |
| L (45°/60°) | --------- | 93,88 | 93,34 | ---------- | 94,61 |
| a (45°/60°) | --------- | 1,06 | 0,35 | ---------- | 0,08 |
| b (45°/60°) | --------- | 1,74 | 3,11 | ---------- | 0,3 |
| **$\Delta L^*$ (45°/90°)** | | **-0,06** | **-0,19** | **0,55** | **-1,84** |
| **$\Delta a^*$ (45°/90°)** | | **-0,07** | **-0,25** | **-1,51** | **-0,07** |
| **$\Delta b^*$ (45°/90°)** | | **0,99** | **1,29** | **2,64** | **-1,59** |
| **$\Delta E^*_{ab}$ (45°/90°)** | | **0,99** | **1,32** | **3,09** | **2,43** |

For the absorption colour Cyan the measuring results measured with the aperture diameter 3 mm applied on the sample port of the Multi FX10, the greatest colour differences $\Delta E^*_{ab}$ could be identified. For the interference colour however the difference between the measuring result of Techkon Spektrodens and the applied aperture on Multi FX10 is within the range of normal measurement device tolerances ($\Delta E^*_{ab} \leq 1.2$); [Dolezalek, 2005]. This could be explained by the measuring geometry. Since the Techkon device only measures with an illumination/viewing angle of 45°/90°, the change in interference colours could not been seen. For this, the other illumination/viewing conditions are necessary. For absorption colours in contrast, a reduction of illumination intensity caused by the aperture for every illumination/viewing condition affects the remission curves and thereby the colour difference a lot.

Furthermore the table demonstrates the influence of the measurement geometry for the other measurement devices. The multi-angle spectrophotometer Minolta CM 512m3 has the greatest colour difference compared with the Techkon device for the absorption colour. Especially for the interference colour, the Minolta CM 2600d shows a high colour difference compared with the Techkon device. This could be explained by the diffuse illumination and the measurement excluding glance, which plays a big roll in the case of interference colours.

The adjustment process using black paper apertures of different sizes and exhibit a huge influence on the measuring results. Since the absorption colours and the interference colours show different behaviours for the different illumination/viewing angles, further examination was done with a mirror as aperture. Characteristic of a mirror is the reflexion in specular direction only. Since all illumination/viewing angles of the MultiFX10 are positioned not in specular direction the remission of the mirror has to be zero for all illumination/viewing angles. To prove this statement a measurement of the mirror is done for all illumination/viewing angles, see Figure 15. The highest intensity of the measured remission occurred for an angle of 45°/150°. Since the intensity of remission is very low, almost zero, the assumption is proven.

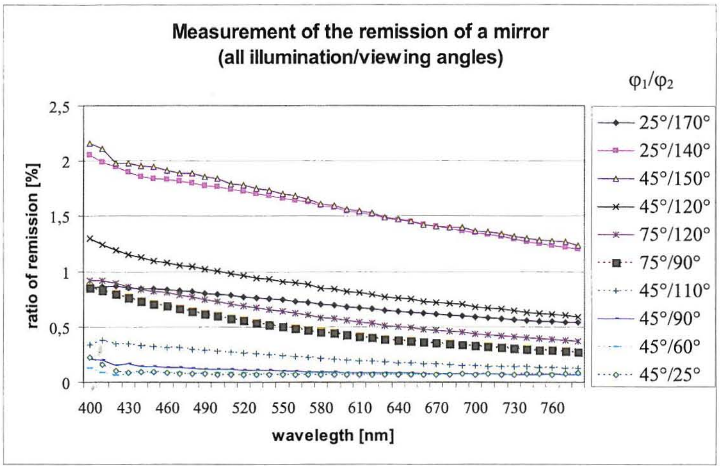



*Figure 15: Results of the measurement of a mirror for all illumination/viewing conditions*

In the next step it was looked for the smallest possible size of the aperture when using a mirror. The upper part of Figure 16 left illustrates the results of the measurement by different aperture sizes for the absorption colour "Cyan" and right for the interference colour "LithoRed".

In the lower part of the figure the accumulated quotient based on the results of the measurement with unmodified sample port is shown for both colours. It could be seen that for aperture sizes greater than 15 x 15 mm the results based on the unmodified sample port almost coincide. For aperture sizes smaller than 15 x 15 mm a relation to the remission curve measured by an unmodified sample port size could be seen, but they do not give the same outcome. For a better validation the quotient based on the remission curve for the unmodified sample port was accumulated, see equation 1.1.

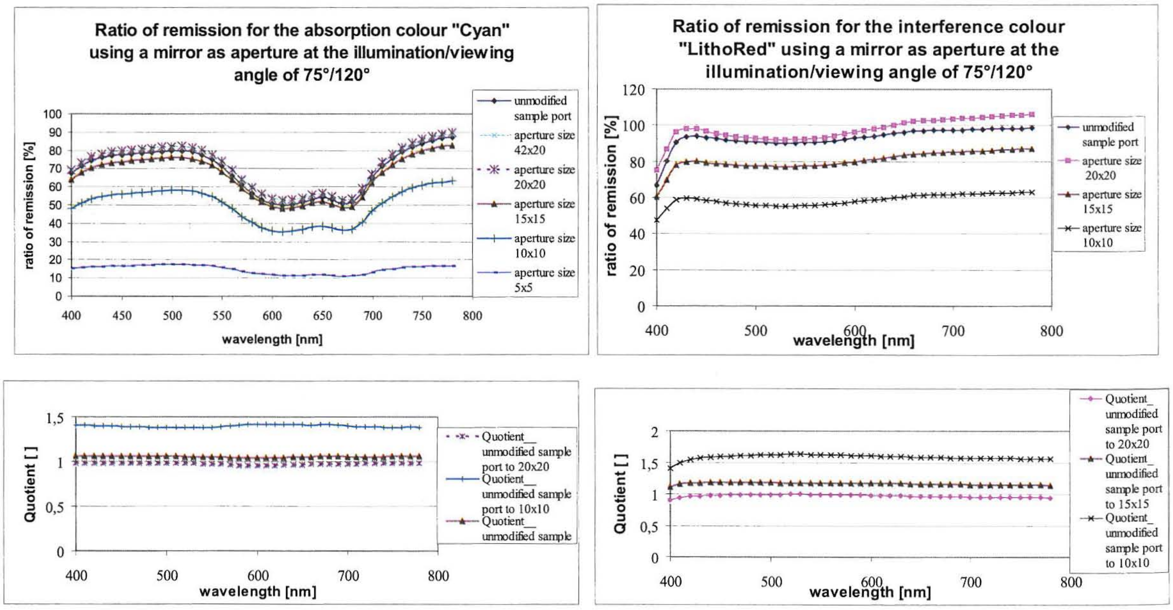



*Figure 16: Measured ratio of remission for the angle 75°/120° using a mirror as aperture upper part left: Ratio of remission for the absorption colour "Cyan"; right: Ratio of remission for the interference colour "LithoRed" lower part: Accumulated quotient of the ratio of remission unmodified sample port and the mirror-apertures for both colours*

$$Quotient = \frac{remission\ curve\ measured\ by\ unmodified\ sample\ port}{remission\ curve\ measured\ by\ mirror - aperture} \quad (1.1)$$

Looking at this quotient for all different illumination/viewing angles it can be seen that this quotient is almost equal for all measured colours (absorption and interference colours) for aperture sizes greater or equal 15 x 15 mm. For smaller apertures no relation between the measuring results of the unmodified sample port and the apertures could be found.

## 5. Conclusion

Multi FX10 offers a device for measuring metallic and interference colours. Since this measuring instrument is not developed for the printing industry, the sample port of this device is not suitable for measuring in print control bars. The researches describe the process of adapting the sample port to demand measurement conditions of the printing industry.

In detail, addict following results:

- Multi FX10 shows in context of the repeatability test bigger uncertainties than given in the operation manual. That is why die measurement results have to be proven each time assiduously. As best way for statistically firm measurement results is to repeat each measurement at least three times and accumulate the average.
- The distribution of light inside the sample port of Multi FX10 is addicted to the illumination angle and the size of the illuminator optics. Furthermore it does not show a consistent distribution of light intensities.
- Inside the sample port a centre of the illumination and the sensoring was found and accumulate the centre of the adapting apertures.
- The comparison between the different measuring instruments on absorption colours demonstrate that the measuring results measured with the MultiFX10 (unmodified sample port) are within normal tolerances of $\Delta E^*_{ab} \approx 1.2$. Hence, the measuring results of this instrument achieved by an unmodified sample port can be used as reference.
- The adaptation using black paper apertures of different sizes was dissatisfactory, because the measured colour values (L*, a*, b*) as well as the remission curves are highly dependent on the aperture size and differ intense to the measured values of the unmodified sample port. Also no uniform tendencies (increase or decrease of the remission curve) respectively a conversion factor significant for absorption colours as well as for interference colours could be found.
- The adaptations with the mirror apertures in contrast show better results. With this it was possible to reduce the size of the aperture to 15 x 15 mm. Smaller sizes of apertures are not possible because no quotient valid for both absorption and interference colours could be found. Since the measuring results by the unmodified sample port of MultiFX10 and the mirror aperture do not coincide, a factor was found to randomize the measuring results. The dimension of this factor depends on the illumination/viewing condition.

In conclusion, this paper shows that it is not feasible to adjust the aperture size for measuring fields in print control bars (diameter 3 mm). Since the printing process has difficulties to print huge solid patch with constant film thickness the adaptation of the sample port using a mirror aperture with a size of 15 x 15 mm nevertheless gives advantages in measuring printed interference colours.

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