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Editor's Note

Tim Claypole

Welcome to the fourth volume of the TAGA Journal, the premier peer reviewed Journal for all professionals who use printing and related processes to create products. This represents a milestone for the TAGA Journal. Swansea Printing Technology Ltd took over the publication in 2005. This was a dark time for TAGA with worries about its future and much restructuring. One of the possible victims of this need to focus on core activities was the TAGA Journal. Hence, Swansea Printing Technology stepped in to ensure the survival of the TAGA Journal, as the only peer reviewed publication for printing science and technology. Since then TAGA has recovered its strength, delivering one of the premier annual International conferences for those in graphic applications. Thus, TAGA, now successful under GATF stewardship, is in a position to run the Journal.

Volume 5 will be published by GATF on behalf of TAGA. The editorial office, which handles the peer review process, will move from WCPC (Welsh Centre for Printing and Coating, Swansea University) to GATF. Mark Bohan will take over as the editor. Mark as well as being VP Research at GATF has had a long involvement with the Journal. He was one of the group of TAGA members who first formulated the plan for a peer reviewed Journal in San Diego hotel in the early 00's. There is something of a Swansea continuity as Mark at that time was a member of the academic staff in WCPC.

The successful publication of the Journal to date would not have been possible without the work of others. In this regard, I would like to particularly thank my colleagues, Eifion Jewell and David Bould. Many thanks goes to Christine Hammett, the secretary/administrator of WCPC, for the hard work administering the peer review process, particularly chasing reviewers and authors, monitoring progress and formatted the papers.

Finally, my thanks is to the authors who have submitted their work and the reviewers who have ensure the quality of the Journal.

We at the WCPC pass the TAGA Journal back to TAGA and wish it every success in the future.

Tim C. Claypole
Editor
TAGA Journal

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Diffractive glossmeter for measurement of dynamic gloss of prints

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Abstract

Print gloss is an important quality measure for graphic communication papers. In addition, the time evolution of the print gloss immediately after ink has been transferred onto a paper is related to ink-paper interactions that control both paper printability and run-ability of a printing process. However, currently the selection of glossmeters to measure dynamic print gloss reliably is rather limited. Thus in this paper we propose a glossmeter what is believed to be a novel system for dynamic print gloss detection from papers. The intelligent part of the glossmeter is a diffractive optical element, which also makes it easily possible to construct an online measurement device. Experiments proved that the proposed sensor measures print gloss accurately at high sampling rates, and it reveals the behaviour of the ink setting as well.

Keywords: Gloss, print gloss, ink gloss, dynamic print gloss, diffractive optical element.

1 Introduction

The concept of dynamic print gloss has become important factor to characterize print quality in multi-colour technology worldwide in different type of print industry, which covers a wide range of applications such as printing on paper, packing materials, plastic, metals, textiles to name a few.

For instance in printing houses or for press machine manufacturers the quality of multi-colour printing, especially on paper, is controlled by different methods utilizing standard measurement and control technologies. This sets also feedback requirements for the paper makers, including the filler and pigment makers, how to control the standardised quality in physical and optical properties such as CIE whiteness, CIE colour/shade, ISO brightness, moisture, opacity, light scattering coefficient, surface energy, surface roughness, abrasion resistance, dimensional stability, mottle and water absorptivity. Altogether to control and supervise the paper surface quality, and develop novel methods for paper surface research leads to a great variety of issues in paper surface science. Here we refer only to few references, which deal with the recent studies in relation to paper coating [1,2,3,4,5,6,7,8,9,10,11]. In a printing process the properties of ink, such as colour, grind hue, percentage portion of solids, set time, strength, tack, viscosity, water pick-up etc., play an important role. We refer only to basic hypothesis on the mechanism of ink-splitting during printing [12] and few recent references in rheology of ink [13], in tack of ink in substrate [5,7,14,15,16] without neglecting effects of liquid sorption into substrate, or porous structures formed by pigment materials [17,18,19,20,21]. The liquid sorption causes also different type of swelling processes [22].

After printing process the appearance of the print has a great importance, and thus methods to sense the contrast between the paper surface and the printed areas on it have been developed. This relation can be characterized by concept of gloss. In general, the gloss of an object is typically divided into six different indicators, namely specular gloss, sheen, contrast gloss, absence of bloom gloss, distinctness of reflected image gloss and absence of surface texture gloss [23,24]. Typical gloss standards describe the test methods for specular gloss of non-metallic specimens at fixed incident angles of 20°, 60°, and 85°, which are the most popular standard geometries for measuring specular gloss. To sense gloss from paper extra 75° geometry is added in the standard specular gloss measurements to obey the ISO 1223 and TAPPI T480 specifications. Recently NCR has developed a reference goniospectro-photometer to provide high-accuracy traceable measurements of specular gloss at several standard geometries, including 75° for paper samples, haze and absence-of-bloom gloss, and colour appearance of gonio-apparent materials [25].

For pigment coated paper, the print quality and print gloss depend on many factors such as pigment particle size and shape distribution, which control the porosity and surface roughness of the coating layer [26,27,28]. Also binders and especially ink and ink levelling [29,30,31,32,33] have influences to print gloss [34]. In printed matters the evaluation of temporal print gloss may be a useful tool in investigation of ink-paper interaction, since the wet or non-dry ink film layer correlates to final print gloss or paper-ink interface [35]. When the print gloss is monitored as a function of time it is expected that the responses will show different responses as a consequence of complicated ink setting. However, literature lists only few methods and tools to investigate this important mechanism. The print gloss measurements reported by [36] utilize use of goniometric arrangements. Whereas in the print gloss measurements reported by [30] use a laser light incidence in oblique angle of 75^{o} and in the print gloss measurements reported by [10] utilize polarized light reflectrometry at oblique angles (75^{o}) of laser light incidence. In addition, the following authors as [37,38] have reported tentative results concerning the print gloss of paper but not temporal evolution of print gloss. In those experiments a diffractive optical element based geometric arrangement was used.

In this paper we report what is believed to be novel system of dynamic print gloss measurement based on the use of a diffractive optical element based glossmeter (DOG) for the assessment of the dynamic gloss of printed papers. This is a new method for this application and we believe that the measurement of dynamic gloss with DOG will provide new information on ink-paper interactions and ink setting mechanisms. The approach is also easily applicable to on-line measurement of print gloss. Development of gloss is studied in detail with a large sample matrix. Papers with a differing pore structure and a non-absorbing film are used as substrates. Using black as well as coloured inks, and varying the ink amount will provide information about the contribution of ink to development of gloss. Additionally, the measurement parameters of the DOG have been optimised.

2 Materials and methods

A matrix of four coated paper samples having a matte (gloss target 30 during calendering) or glossy (gloss target 70 during calendering) surface finish, and fast or slow ink setting speed were selected for the dynamic gloss experiments. A smooth non-absorbing plastic film was used as the fifth substrate. The four papers, labeled SG (slow glossy), SM (slow matte), FM (fast matte) and FG (fast glossy), were double coated in pilot scale using coating formulations. The differences in the printability and optical properties of the papers are a result from use of different pigment sizes and shapes, which create different microscopic pore and surface structures for the coatings. All the samples were calendered to adjust their gloss and smoothness. The paper samples were printed in laboratory environment by using a black, commercial heatset offset ink (Premoterm 2000, Flint Schmidt). The dynamic print gloss was measured immediately after printing with the DOG sensor. Here we point out that because of the fact that the paper matrix was made in pilot scale the machine and cross direction of paper was not controlled and documented in detail, and thus we were not able to utilize all the potential of the DOG sensor, such as ability to sense directional isotropy or anisotropy of the ink setting as already reported by [38]. In this work only the average dynamic print gloss is reported.

Schematic layout of the DOG system attached to UTP (Universal Test Printer) is shown in Figure 1. Polarized light wavefront from a semiconductor laser (λ_c = 635 nm) is expanded with the aid of a high refractive power lens system by such a way that the wavefront distribution is uniform after passing through a circular aperture stop. Thereafter, the uniform wavefront is focused by a lens system in collimating and focusing unit (C) on the printed ink-paper interface of the sample (S). The ink-paper interface is produced on the paper located on the roller (R) by using the printing unit (P). From the ink-paper interface scattered wavefront is captured specularly on the aperture of the diffractive optical element (DOE). After passing the DOE aperture the wavefront produces a diffraction pattern on the surface of the 2D photo-array of the charge coupled device (CCD).

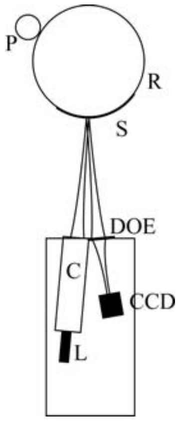

Figure 1: Schematic layout of the DOG system attached to UTP (Universal Test Printer): Diode Laser (L), Collimating and focusing unit (C), Printing Unit (P), Printed paper sample (S), Print roller (R), Diffractive Optical Element (DOE), Charge-coupled device (CCD).

The DOG presented in Figure1 utilizes advances of a diffractive optical element, which are the ability to sense non-coherent and coherent properties of the laser wavefront that scatters from the ink-paper interface in selected solid angle. Moreover, in the DOE artificially 16 separate lenses are integrated. Each lens forms separately spot image in the focal plane of the element. It is also worth to denote that the separate 16 wavefronts interact with each other making this principle active to sense very small phase shifts in the wavefront. Typically the phase differences in the coherent wavefront appear as speckle formation in the far-field regime as shown in the inset of Figure 2a. The difference between the DOG and the conventional laser glossmeter is that the latter cannot sense phase information of the scattered wavefront.

Next we consider the crucial part and the geometry of DOG sensor shown in Figure 2 in more details. The DOE obeys the law of diffraction and principle of hologram imagery [39,40]. To consider and analyse geometric properties of diffracted wavefront we have to determine mean distance.

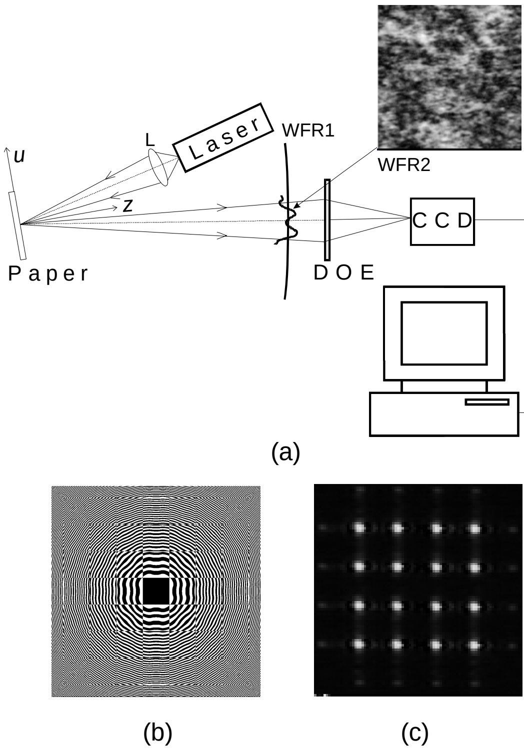

Figure 2: a) DOG sensor, L = lens, WFR1 is the ideal wavefront from a point source and WFR2 distorted wavefront, which is typically caused by appearance of dynamic speckle formation when the ink-paper interface moves with the velocity **u** *perpendicular to direction of the surface normal z. A still image grabbed from a dynamic speckle at DOE aperture is shown in the upper right inset. DOE image (in it's image plane) is captured by a computer controlled CCD device for further analysis, b) Binary DOE element and c) The ideal 4×4 light spot matrix in the image plane of DOE.*

In variables R_r, R_o, R_c, and R_i of point Q and respective angle variables α_r, β_r, α_o, β_o, α_c, β_c, α_i, β_i with respect to the origo (Figure 3).

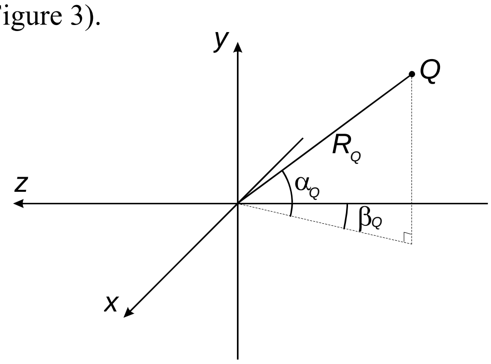

Figure 3: The mean distance variable R_Q with respective angular variables α_Q and β_Q of point source Q.

With the three variables R_r, R_o and R_c it is possible to determine the location of point source Q. The subscripts r, o, c, i indicate reference, object, reconstruction and image -terms of mean distance variables, respectively. According to Gaussian image properties the mean distance variables and respective angle variables of point Q relate to each other as follows

$$\frac{1}{R_i} = \frac{1}{R_c} \pm \frac{\mu}{m^2}\left(\frac{1}{R_o} - \frac{1}{R_r}\right), \tag{1}$$

$$\sin\alpha_i = \sin\alpha_c \pm \frac{\mu}{m}\left(\sin\alpha_o - \sin\alpha_r\right), \tag{2}$$

$$\cos\alpha_i \sin\beta_i = \cos\alpha_c \sin\beta_c \pm \frac{\mu}{m}\left(\cos\alpha_o \sin\beta_o - \cos\alpha_r \sin\beta_r\right), \tag{3}$$

and

$$\mu = \frac{\lambda_c}{\lambda_o}, \tag{4}$$

where m is a scaling factor (here m = 1). In the Equations (1-4) the factor μ denotes the ratio of the reconstruction and recording wavelengths. The (±)-sign is + for a virtual image and - for a real image. In the case of the DOE, the reconstruction source is infinity and thus the respective angle variables are $\alpha_r = 0$ and $\beta_r = 0$.

The geometry obeying hologram imagery including geometric and chromatic aberrations of the DOE used in DOG is considered in details by [41]. The DOE element, used in the realisation of the DOG-meter was calculated by using the Rayleigh-Sommerfield diffraction integrals [42], is an on-axis binary amplitude diffractive element (Figure 2b). The element is focusing type and its focal length is planned to be 100 mm at λ_o = 632.8 nm. The planar DOE produces a 4 × 4 light spot matrix in its focal plane (Figure 2c). Because of the large number of light spots (16), it is possible to use statistical analysis in order to increase the accuracy and reliability of the gloss measurement. The size of the aperture of the DOE is 4mm × 4mm, and the respective image area of 0.5mm × 0.5mm including the 16 light spots with the distance of 125 micrometers between nearest adjacent light spots in the focal plane when the reconstruction source locates in infinity. The DOE's wave optical principle was analysed in details by using diffraction based wave-optical treatment [43]. After geometric and wave optical analysis the DOE was fabricated by sputtering a 120 nanometer thick layer of chrome on a fused silica substrate. Next, a positive electron-beam resist was spin-coated onto the chrome layer. This resist was exposed using an electron beam writer. After the resist was developed, the chrome layer was wet-etched. More details of DOE in materials inspection are described in the references [44,45].

After passing the DOE aperture the distorted wavefront performs a diffraction pattern on the surface of the 2D photo-array of the charge coupled device (CCD). Thus also the ideal 4×4 light spot matrix, as shown in Figure 2c, is distorted and its brightness is reduced as a consequence of roughness as shown in Figure 4a. In the numerical analysis of the DOG sensor image to get measure for the dynamic print gloss, the total irradiance over pixels locating in the signal window (denoted by dashed area in Figure 4b) is calculated by using the following formula

$$I_{TOT} = \frac{1}{N_{SW} M_{SW}} \sum_{i_{SW}=1, j_{SW}=1}^{N_{SW}, M_{SW}} I_{i_{SW}, j_{SW}}, \tag{5}$$

where N_{SW} and M_{SW} are the dimensions of the DOE image in x- and y-direction and $I_{i_{SW}, j_{SW}}$ is the image irradiance observed by the $(i_{SW}, j_{SW})^{th}$ element of the CCD camera array. The ink-paper interface is not smooth in optical sense and thus the irradiance of the peaks is reduced. However to be absolutely sure that the irradiance of peaks (denotes coherent response) does not make any uncertainties, the irradiance portion of peaks should be subtracted from the total irradiance of that DOE image as follows

$$I_{NC} = \frac{1}{N_{SW} M_{SW}} \sum_{i_{SW}=1, j_{SW}=1}^{N_{SW}, M_{SW}} I_{i_{SW}, j_{SW}} - \frac{1}{N_{pks} M_{pks}} \sum_{i_{pks}=1, j_{pks}=1}^{N_{pks}, M_{pks}} I_{i_{pks}, j_{pks}}, \tag{6}$$

where N_{pks} and M_{pks} are the total numbers of pixels in the DOE spot image in *x*- and *y*-direction and $I_{i_{pks},j_{pks}}$ is the image irradiance observed by the $(i_{pks},j_{pks})^{th}$ element of the DOE spot image (region of spots: dark-grey areas in Figure 4b). The light-grey areas enable the calculation of visibility factor $V=(V_{\max}-V_{\min})/(V_{\max}+V_{\min})$ for *x*- and *y*-directions to estimate the anisotropy of the ink-paper interface as already reported for print gloss of paper with clear separation of machine (MD) and cross-direction (CD) without temporal evolution of print gloss [38]. However in this paper we present only the average dynamic print gloss arisen from the reasons as already stated in the first section of this chapter. Finally, the gloss can be calculated from the relation

$$G=\frac{I_{ink-substrate}}{I_{reference}}\times 100\,. \tag{7}$$

where $I_{ink\text{-}substrate}$ and $I_{reference}$ are measured from an ink-substrate interface and from the gloss reference.

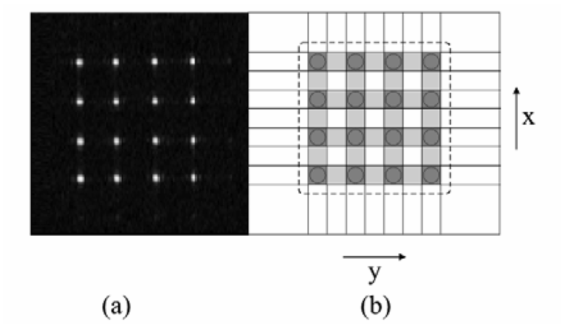

Figure. 4: (a) Image pattern of 4 × 4 light spot matrix produced by DOE from print, (b) minimum (light grey) and maximum (dark grey) intensity areas of the DOE image pattern. The area used for calculation of the total irradiance is marked by dashed line.

In calibration of the DOG equipment for print gloss measurements, the gloss base line is measured by using a gloss reference (black gloss standard). The non-uniformities of ink-paper interface affecting different types of distortions in the scattered wavefront are thereafter captured specularly on the aperture of the diffractive optical element (DOE) according to the arrangement of Figure 1.

Table 1: Additional parameters of the DOG-meter used in dynamic print gloss measurements.

Subject	Notes
Incidence angle of laser beam (α_c, β_c)	(4.8, 0) deg.
$\mu=\lambda_c/\lambda_o$	1.0035
Gloss reference	Black gloss standard
Measurement area	ca. 5 mm x 5 mm
Measurement frequency	ca. 100 ms
Measurement period	300 s

When the incidence angle of the laser beam (α_c, β_c) = (4.8 deg, 0 deg) is used in the DOG equipment, the deviation of the DOG spot image of 1mm, on the 2D photo-array of the CCD device, can be accepted caused by the wobbling of the paper web by 11.9 mm in the normal *z*-direction (Figure 2a). Theoretically this limitation can be calculated using the Rayleigh criteria ($z_R=\pi w_o^2/\lambda_c$, where w_o denotes the minimum radius of the focused laser beam waist). The other additional parameters of the DOG-meter used in the dynamic print gloss measurements contain the following specifications as shown in Table 1. The correlation between the industry standard gloss and the DOG gloss can be found, e.g., from following references [46,47]. The receptor angle of the present DOE sensor geometry is rather small, moreover, the DOE element itself acts as a spatial filter for coherent light (coherent components diffract towards the peak area, where the gloss is measured), and thus it is no need to use an extra bandpass filter in the DOG sensor to cancel the harmful effects of background irradiance away.

3 Results and discussion

In the dynamic print gloss experiments the responses, printed with constant slow/black ink volume of 0.3cm^3 ink on rolls, showed distinctive separation from sample to sample when different type of papers were used in the test (Figure 5). In this experiment slow/black ink on slow/glossy and fast/glossy papers showed (monotonic increasing) gloss evolution as a function of time, the gloss of slow/glossy

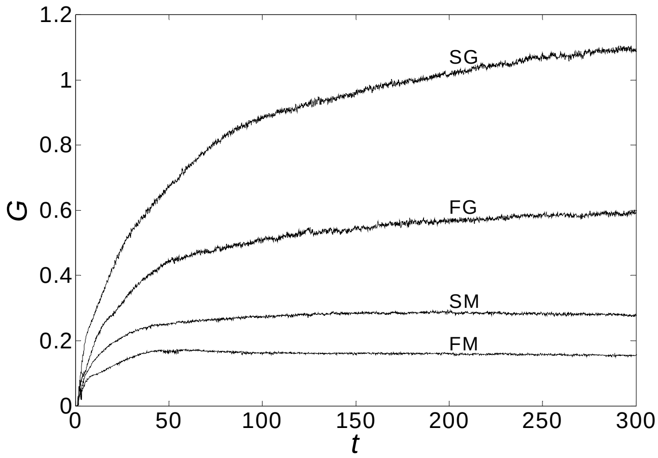

Figure. 5: Dynamic gloss curves in gloss unit as a function of time in seconds from four different paper samples print with 0.3cm^3 ink amount. SG=slow/glossy, FG=fast/glossy, SM=slow/matte and FM=fast/matte paper.

in the above paper being two times as high as that of the fast/glossy paper. This behaviour indicates long time gloss formation with a high time constant τ (at 0.9G_{SAT} –level, where G_{SAT} is gloss saturation), whereas in the slow/matte and in the fast/matte papers the gloss formation is faster with smaller time constants than in the previous cases. The time constants for the gloss dynamics shown in Figure 5 are listed in the Table 2. The results of the second experiment, where the slow/black ink volume on rolls varied on the above paper surfaces, showed interesting phenomena in ink-setting (Figure 6). In the ink amount experiments we confined only to three different ink amonts (0.15, 0.30 and 0.50 cm^3) caused by the huge number of paper samples. In slow/ matte (Figure 6a) and fast/matte (Figure 6b) papers the ink- setting contributes low gloss, and reaches maximum gloss magnitude with 0.3 cm^3 volume of ink on rollers, whereas the at the higher volumes the gloss will decrease significantly. The behaviour implies that the ink may unify the non-isotropic structure of ink - matte paper interface as already tentatively stated by [38]. This dynamic gloss evolution confirms the previous findings.

Table 2: Time constants of gloss evolution for four papers shown in Figure 3, when the slow/black ink of 0.3cm³, was used in the printing.

Paper	Time constant τ in second at $0.9G_{SAT}$ –level
Slow/Glossy	170
Fast/Glossy	140
Fast/Matte	60
Slow/Matte	35

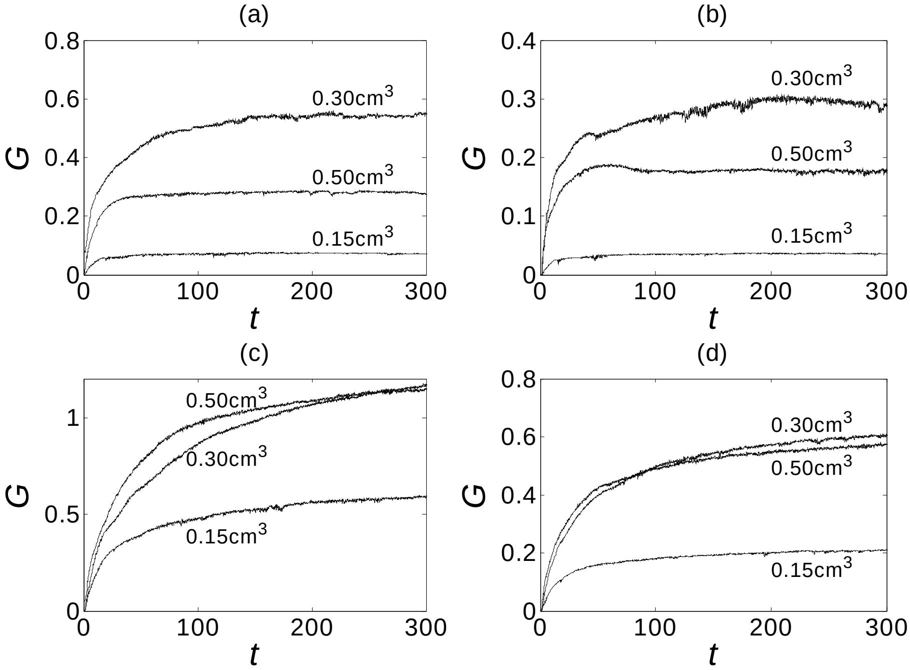

Figure 6: Dynamic gloss curves in gloss units as a function of time in seconds from four different papers printed using 0.15, 0.30 and 0.50 cm³ ink amounts (a) slow matte, (b) fast matte, (c) slow glossy and (d) fast glossy paper.

The decrease of the gloss at high ink amounts can be related to formation of large ink filaments, which are not levelled out by the surface tension prior to the final setting of the ink film. This is supported by the observation that the final print gloss values are higher on papers designed to have slow ink-setting speed. Also the changes in effective refractive index may also have some insignificant contribution to decrease of gloss when ink volume increases. It may also be possible that the gloss will decrease as a consequence of evolution of surface roughness, which may appear at the formation of high ink coverage. This phenomenon is observed for different type of papers [48] and for imprints [49]. On the contrary in slow glossy (Figure 6c) and fast glossy (Figure 6d) papers the increase of ink from 0.3 cm^3 to 0.5 cm^3 do not cause significant changes in uniformity of ink-paper interface, and the dynamic gloss responses coincide as shown in Figure 5. This may indicate that the ink has achieved saturation, and the addition of extra ink does not change the gloss. Although the dynamic colour measurements were not performed simultaneously the observation by naked eye revealed that adding of more ink increased the perceived colour. This subjective observation may cause by the coupling of illuminating light through the air-ink interface into paper. The same type phenomenon appears on the Nordic lakes in the spring when the scattering of daylight from ice surface reduces as a consequence of coupling of daylight through ducts of water in ice into underlying lake water, and the ice surface become dark.

As the general note all of the DOE measurements showed rather good repeatability from paper to paper used in the test. Here we point out that the repeatability of DOG mesurement has been observed to be 0.26% measured from high gloss metal plate [50]. However, there should be a bit higher deviation in the present measurement, since the printing properties of labprinter also vary. Also amount of ink on roller is rather difficult to control. As an example, we report here the responses (Figure 7) performed with aid of the slow/black ink and fast/ matte paper as it is the case in Figure 6b.

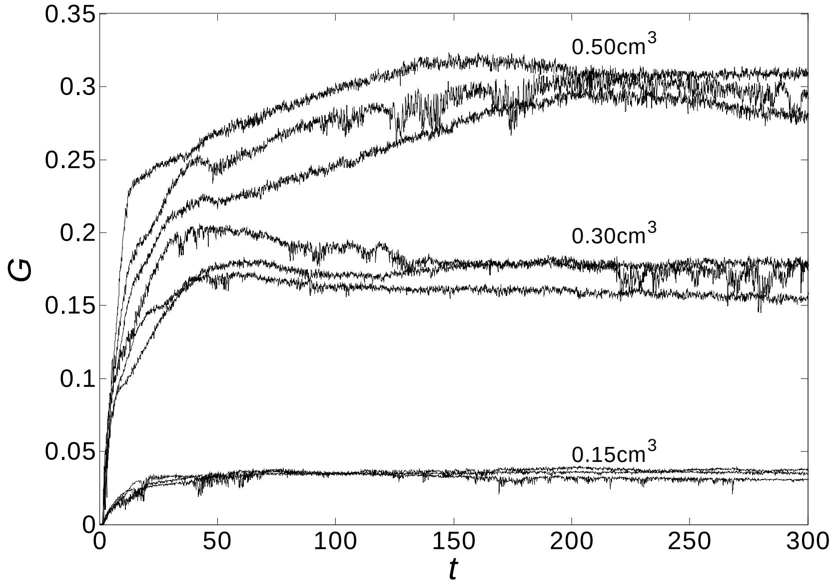

Figure 7: Repeatability of dynamic print gloss measurement.

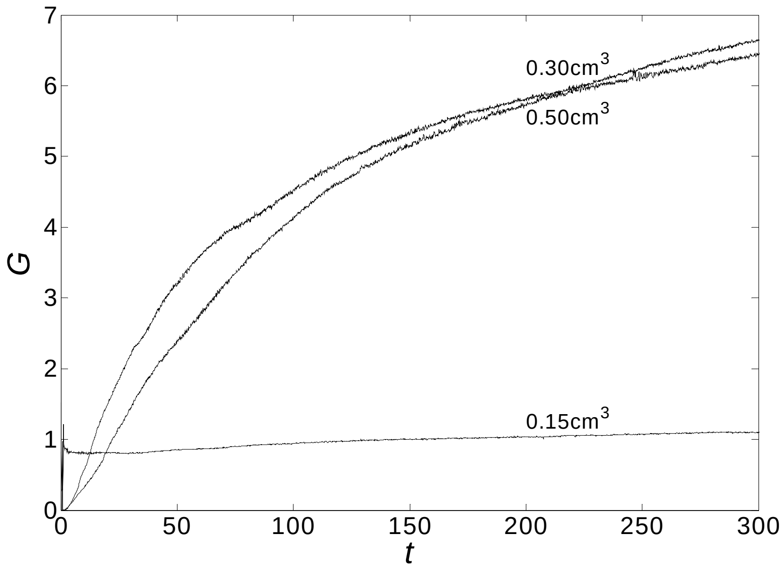

Figure 8: Dynamic gloss development of slow/black ink on non-absorbing plastic film.

On the plastic film the dynamic gloss values from slow ink – plastic film interface (Figure 8) are roughly five times as high as from the slow ink – slow glossy paper, and roughly ten times higher as from ink- matte papers and fast glossy paper (Figure 6). The increase of dynamic gloss is believed to be caused by the higher smoothness, lower porosity and better isotropy of the air-ink-film interface than is the case with the pigment coated papers.

As an additional discussion concerning the gloss, which may have public interest, we point out that the gloss depends on the reflectivity, which relates to the complex refractive index, on the angle of incidence of light and on the texture of surface including the surface roughness. In the case of DOG the normal incidence of probe light is usually used in the experiments to cancel out the effects caused by the polarization but it is also possible to use oblique angle of light incidence. The use of probe light close in normal direction of paper surface, which is possible by using the DOG sensor without loosing the specular signal as it the case with the reflectance measurements with laser light, allows also deeper penetration of the light compared with the oblique angle geometry, which in turn may be an influencing factor to reveal a fall in gloss with higher ink levels. Since the colour will change during the print run also the gloss will change as a consequence of refractive index change and possible change of roughness [49]. The same principle of gloss is also valid for the transparent inks and coatings as plastic, varnish and glass etc. [45,51]. The DOG gloss values correlate with the gloss values drawn out by commercial devices, and the studies with human perception has been carried out but not reported yet. In this paper we have introduced the dynamic gloss properties of the DOG sensor, the anisotropy parameters related to DOG gloss we have already introduced in several publications [6,37,38,49,52]. The wider and deeper insight to the basis of the DOG method and to the merits of the DOG sensor can be find, for instance, from the following references [41,50].

4 Conclusion

The DOG sensor, working in neighbourhood of normal incidence, was observed to be capable of sensing dynamic print gloss. The sensor reveals the behaviour of the ink setting as a function of time giving information from the remodelling of ink-paper interface also at low inking level. In contrast to the conventional online paper glossmeters working at oblique angles of incidence as already mentioned in introductory part of this article, the DOG sensor does not require a flat sample surface due to its controlled waist cross section of the focused laser beam. Moreover, from the geometrical reasons, the gloss meters working at the oblique angles of incidence (20^o, 60^o, 75^o and 85^o) are sensitive for paper-web flutter. At low inking levels, the paper properties, surface roughness and absorption are important for the gloss evolution, and in that purpose the DOE element can acts as a crucial multifunction tool in measurement of dynamic print gloss development at various level of inking.

Acknowledgement

This study was performed in the Molecular Understanding of Printability Project (MOLPRINT), which is part of Network of Competence in Formation of Surface Properties (NETCOAT), funded by the Finnish Funding Agency for Technology and Innovation (Tekes).

Nomenclature

λ = wavelength
R_r, R_o, R_c, and R_i = mean distances from point Q, and
α_r, β_r, α_o, β_o, α_c, β_c, α_i and β_i = respective angles, where subscripts *r, o, c, i* indicate respective reference, object, reconstruction and image –terms
m = scaling factor (here $m = 1$)
μ = ratio of the reconstruction and recording wavelengths
I = irradiance
V = visibility
G = gloss
z_r = Rayleigh regime
w_o = minimum radius of the focused laser beam waist

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