

Diffusion of the Laser Radiation to Characterise the Paper Fibre Orientation and the Paper Sheet Formation

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Abstract — This work concerns the determination of fiber orientation in the paper sheet and possibly the mass density distribution. Both parameters strongly influence the quality of the paper for end uses in printing and converting. The measurement of such parameters is done using different approaches, most commonly indirectly from the determination of the paper's physical properties. The measurement and analysis of the microscopic features of the paper sheet structure, using optical methods based on the laser radiation retro-diffusion and transmission, are the main aims of this work. The proposed method only uses laser light scattered by retro-diffusion from the paper surfaces for surface analysis and the laser light transmitted through the paper for analysis in the bulk. The system can analyze through a scanning procedure point-by-point, one paper sheet to produce a map of both paper surfaces with the selected results.

1. Introduction

The fiber orientation in the paper sheet and mass density distribution strongly influences the quality of the paper for end uses in printing and converting. The measurement of such parameters is done using different approaches, most commonly indirectly from the determination of the paper's physical properties [1] – [4].

One decade ago an optical sensor has been produced by Lippke Cie., called today, Honeywell Automation, giving access to the mean bulk fiber orientation on the paper sheet [5], [6]. More recently another optical sensor has been developed by AccuRay Cie. [7], to measure the fiber orientation on the paper sheet surfaces. Moreover, some attempts are being done to control indirectly this parameter by ultrasonic methods [8]. The paper formation is currently continuously evaluated by beta gage sensors or in some cases by optical sensors unit [9].

None of these techniques can access simultaneously both parameters, i.e. fiber orientation and mass density in the same location of the paper sheet and, furthermore, discretising the fiber orientation on the surfaces and in the sheet bulk. Our work intends to conjugate all these determinations at a microscopic level which is significant for most of the end uses application of the paper, principally for printing. Data integration can give information at a macroscopic level for paper converting applications too.

In this work we use optical methods based on the laser radiation retro-diffusion and transmission in order to measure and analyze the microscopic features of the paper sheet structure.

Previous works enables us the analysis of paper sheet surfaces using the laser light diffraction on paper replicas [10]-[11]. This work proposes an optical method to analyse simultaneously fiber orientation and mass density (Fig. 1) in the same testing point of the paper sheet without using paper replicas.

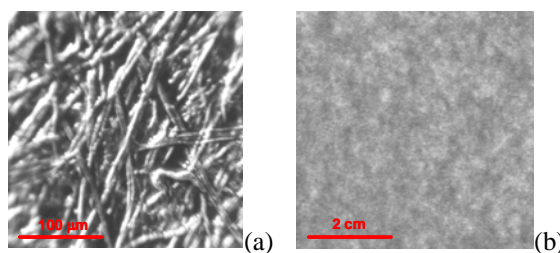


Fig. 1. (a): Fibre network (fibre orientation) and (b): paper sheet (paper formation).

The proposed method uses laser light scattered by retro-diffusion from the paper surfaces for surface analysis and the laser light transmitted through the paper for analysis in the bulk.

A laboratorial prototype has been built to make measurements and analysis in the required conditions. A non-contact data acquisition system have been developed and implemented for both faces of the paper sheet and a software application for scanning control and data processing have also been developed and implemented.

In such way valuable and innovating contributions to the quality improvement of most of the end use applications of the paper such as: printing, converting and metrology, will increase the added value of the wood and paper National resources with corresponding social impact.

2. Principle of the Proposed Method

This work proposes an optical method to analyse simultaneously fiber orientation and mass density distribution in the same testing point of the paper sheet, without using paper replicas. Several techniques are currently in use to analyse such paper parameters but none can access simultaneously both the fibre orientation and the mass density in the same location and discretise simultaneously the fibre orientation on the surfaces and on the sheet bulk, evaluated at a microscopic level lower than 1 mm, which is the necessary resolution for the evaluation of the paper printing quality. The proposed approach uses laser light scattered by retro-diffusion from the paper surfaces, for surface analysis and the laser light transmitted through the paper for analysis in the bulk (see Fig. 2).

In this optical process, the fibres act as light guides spreading the incident light on the paper sheet surface from fibre to fibre and transmitting the light through the fibre structure by scattering and absorption. We observe the light transmission patterns on the opposite surface.

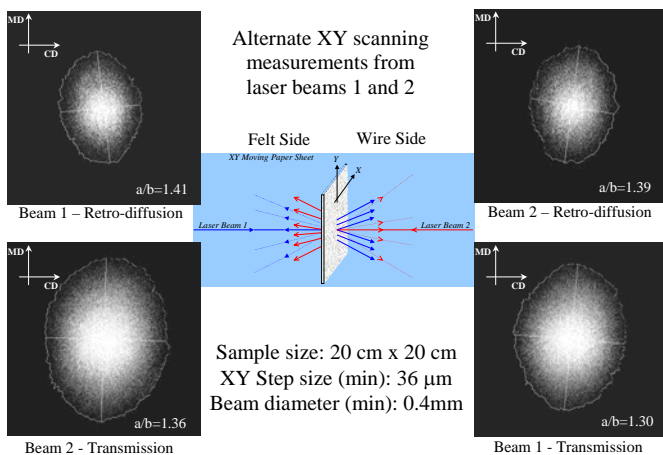


Fig. 2. Scheme of the proposed method.

The system can analyse through a scanning procedure point-by-point, one paper sheet to produce a map of both paper surfaces with the selected results. A software application based on image analysis will select the relevant parameters. A non-contact data acquisition system has been developed and implemented for both faces of the paper sheet. The software application for scanning control and data processing has also been developed and implemented. An optical apparatus make measurements and analysis in the required conditions.

3. Experimental Optical Apparatus

In order to register the transmitted and reflected patterns from paper sheet, for latter processing on a computer, an experimental optical apparatus have been developed and implemented in our laboratory as shown schematically in Fig. 3.

It uses a He-Ne laser beam ($\lambda=632.8$ nm), and two solid state sensors (CCDs) for digital image acquisition purposes. The solid state sensors are connected to a frame grabber, who is installed on a digital computer, in order to record the retro-diffusion and the transmitted patterns intensity distributions as digital images with 512 x 512 pixels and 256 grey levels (8 bit per pixel).



Fig. 3. Experimental optical apparatus for retro-diffusion and transmission analysis.

In terms of acquisition, the experimental optical apparatus was design to perform a controlled scan through a motorised XY table, which holds the paper sheet. The minimum diameter of the laser beam is 0.4 mm. The scanned area goes up to 200.0 x 200.0 mm² and the scan steps can be adjusted between 36 μm and 20.0 mm in a continuous and sequential scan. Random scans are also possible within a predetermined area of scan. Simultaneously, the application program saves all the acquired data corresponding to the performed scan for processing.

Concerning the data processing, several algorithms specifically implemented to evaluate the anisotropy and the fibre orientation can be selected and applied to the recorded data. In general, the basic algorithm applied to analyse each pattern intensity distribution finds the best equi-intensity contour to compute in a few seconds the ellipticity ratio a/b and the orientation of its major axis with respect to the cross direction, CD. The first approach gives a set of possible contours, which is automatically refined in order to give minimal root mean square error of the differences between the contours, and an angle difference between the major and minor axis of the contour nearest to 90°. In figure 1 the best contour found was superimposed to the patterns for display purposes.

3. Experimental Results

In order to establish a comparison between laser diffraction and laser diffusion methods a set of paper samples where prepared in dynamic and isotropic sheet formers, and surface replicas of which one of the papers where obtained [10]. Replicas of paper samples where been used with laser diffraction method to measure the

anisotropy and the fibre orientation distribution at paper sheet surfaces, and the paper sheets where been used to measure the anisotropy and the fibre orientation distribution on the bulk with the described experimental optical apparatus.

The set of paper sheet samples used, from Pine and Eucalypt, includes isotropic and anisotropic one layer sheets and isotropic and anisotropic double-layers sheets, beaten at 19 and 54 °SR.

The experimental optical apparatus have been set for a XY continuous and sequential scanning over the predefined area. The laser beam diameter has set to 0.4 mm and 6.0 mm, respectively.

Four scans where carried out to evaluate the mean ellipticity ratio and the corresponding fibre orientation for each scanned point, and to compute the total average ellipticity ratio and the fibre orientation for the entire sample.

Figure 4 shows a typical fibre orientation map of a complete scan over an area of 78.0 x 78.0 mm² (in this case for laser diffraction). The map displays a segment for each scanned point where its length is proportional to the anisotropy and its direction determines the local fibre orientation. The header of the map states the scan conditions and the global computed results. Thirty minutes is the elapsed time to obtain such map.

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Diffraction Mapping          ptfX@CFG_V4.0 - Wed Jan 24 08:43:38 WET 2001
Source File:                20A.aad      Processed File:              20A.apd
Sampled Area (mm):         78x 78      Offset (mm):               102x 95
Beam Size (mm):           6           Beam Step (mm):           6
Rejection Factor:         25          Smooth Power Factor:       4
Initial Threshold:        20          Final Threshold:          90
Minimum Threshold:        26          Maximum Threshold:        67
Mean Angle:                9.73 deg    Std Angle:                7.44 deg
Mean Ratio a/b:           1.29        Std Ratio a/b:            0.072
Scanned Data Average
  
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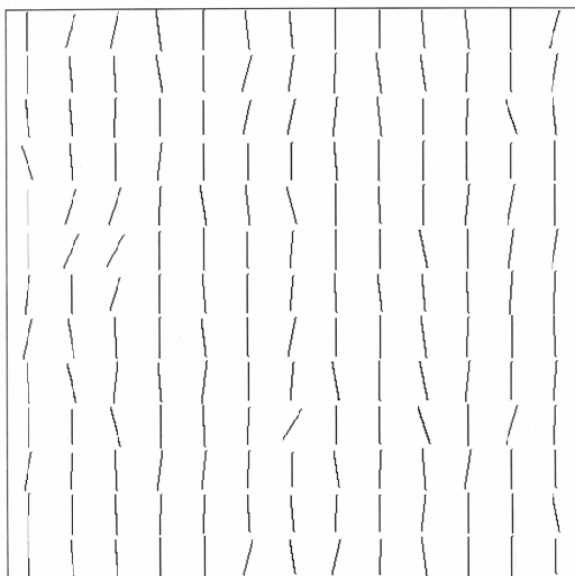


Fig. 4. Fibre orientation map.

Table 1 compiles the fibre anisotropy results for the paper samples using the laser diffraction method for surfaces, and laser transmission for the bulk. The laser beam impact is referred to the wire or felt side. The side

refers to the paper sheet face on which the laser beam is impinging.

We can observe that the dynamic sheet former gives different fibre orientations for both sides of the sheets due to the effects of the turbulence during the sheet formation close to the wire of paper machine.

Table 1. Paper sheet fibre anisotropy: Ellipticity (a/b)

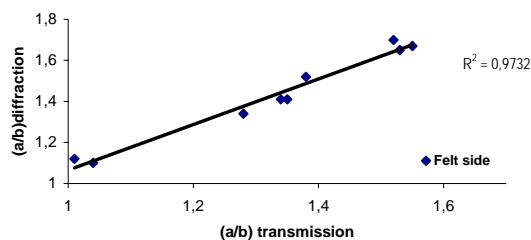
Paper Sample		Transmission			Diffraction		
		Wire	Felt	Mean	Mean	Wire	Felt
MK	19 °SR	1.08	1.04	1.06	1.11	1.12	1.10
	54 °SR	1.04	1.01	1.03	1.14	1.17	1.12
DF E 850	19 °SR	1.23	1.38	1.31	1.33	1.14	1.52
	54 °SR	1.33	1.35	1.34	1.30	1.19	1.41
DF R 886	19 °SR	1.49	1.52	1.51	1.61	1.52	1.70
	54 °SR	1.50	1.55	1.53	1.59	1.50	1.67
DF R 1339 54 °SR		1.49	1.53	1.51	1.45	1.27	1.65
DF50%E+50%R 54° SR		1.38	1.34	1.36	1.50	1.58	1.41

DF – Dynamic former
MK – Isotropic former

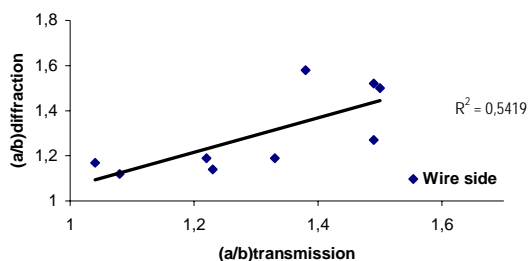
Graphs 1 and 2 shown the correlation between optical diffraction and optical transmission analysis results for the felt and wire sides.

The correlation between the two methods for the felt side is quite good ($R^2=0.973$), while the correlation for the wire side is less clear ($R^2=0.542$). The dispersion is high probably because the effects of the turbulence during the sheet formation close to the wire.

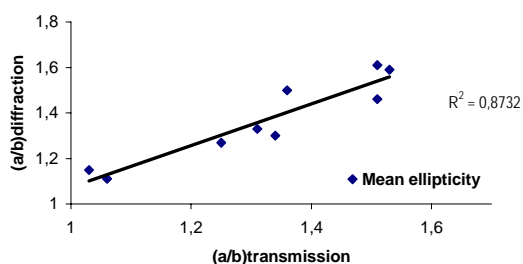
If we consider the mean values of the ellipticities the correlation (graph 3) appears good enough ($R^2=0.873$) even if the laser beam impacts for the two presented methods are quite different: 0.4 mm for the laser transmission analysis and 6 mm for the laser diffraction analysis.



Graph 1. Correlation between optical diffraction and optical transmission analysis: felt side.



Graph 2. Correlation between optical diffraction and optical transmission analysis: wire side.



Graph 3. Correlation between the mean values of the ellipticity obtained by optical diffraction and optical transmission analysis.

The mean ellipticity looks a little bit lesser in the transmission analysis: this come from the effect of homogenisation of the fibres substrate which scatters the light after the first impact of the light on the surface. In the case of the diffraction analysis we measure only two fibre distributions in extreme positions at the paper surfaces without further attenuation by the scattering.

4. Conclusions

Light diffraction analysis gives us access to the fibre orientation distribution at the paper surfaces, while light transmission analysis give us access to the fibre orientation distribution of whole structure of the paper sheet.

The fibre orientation distribution is higher at paper surfaces than in the bulk. This is due to the fibre homogenisation inside the paper sheet.

The results obtained by light transmission agree with previous works made in split paper sheets [12].

Relatively to the results obtained for wire side, we can conclude that the marks produced by the wire of the paper machine affects strongly the fibre orientation at the surface.

The optical methods presented here are easy to apply and have high resolution and reproducibility.

Future work will be dedicated to the analysis of the retro-reflected light from the surfaces, and to the comparison with previous results from diffraction and transmission, and to the development of the study of the mass density distribution in paper sheets.

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