A New Technique for Measuring Periodic Patterns Within a Paper Sheet

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Abstract: A new technique, based on Fourier analysis, has been developed to detect and measure periodic patterns within the sheet formation. This technique detects patterns from small scale (e.g. forming fabric marks) to medium scale (streaks with wavelength up to 10 mm) and determines their orientation, period and intensity. These patterns can be caused by felt marking, roll marking, headbox rheology, etc., and are specific to each paper machine. Their characterization provides a useful tool for quality and process control.

In the papermaking process it is common for a sheet of paper to have periodic or pseudo-periodic patterns within its structure. For example, fabrics and felts may generate small scale patterns. Other phenomena, such as headbox rheology or roll marking, may generate larger scale periodic marks. A periodic mark that is too strong compromises the quality and the value of the product. It also often indicates some problem on the machine (a felt in need of change, a roll problem, etc.). Thus there is an incentive to detect and quantify these periodic marks for quality control and process control.

To that purpose methods based on fast Fourier transform (FFT) spectrum analysis have been used during the last 20 years [1-3]. However, these techniques have serious limitations, as discussed below.

Experimental

This paper introduces a new method based on a modified Fourier analysis that characterizes periodic and pseudo-periodic marks, which vary in size from about 0.4 mm to 10 mm. The method determines their size, orientation, and intensity. The results of this method are compared to that of a standard FFT method.

The analysis uses light transmission images of paper sheets acquired by the Paper PerFect formation analyzer. These 480 x 480 pixel images cover a 69 x 69 mm sheet area and have a 8-bit pixel depth (256 grey levels).

Figure 1 presents an image of a newsprint sample with a complex series of patterns: large, almost vertical streaks at 85 degrees, smaller oblique streaks at 43 and 53 degrees, and almost horizontal streaks at 4 degrees that are strongest at the lower left corner of the image. The directions of these patterns are summarized in Fig. 2. There are also two small forming fabric marks, almost vertical, that cannot be seen on Fig. 1.

Figure 3 shows the resulting power spectrum for Fig. 1 obtained using a standard FFT method. The usual characteristics (and usual limitations) of a standard power spectrum appear.

- Poor resolution at low frequencies (centre of the spectrum): at frequencies lower than about 20, corresponding to a wavelength of about 3.5 mm, the spectrum becomes a cloud from which it becomes difficult to identify peaks, unless they are very strong. For frequencies below 10, this becomes almost impossible. This spectrum noise which increases at low frequencies is due to the presence in the signal of low and very low frequency patterns which are not complete, thus creating difficulties for the FFT as it tries to "match" them with sinusoidal waves. This problem is common in FFT analysis and, when present, reduces its field of application to medium and high frequencies.

- Parasitic peaks: Another, less obvious difficulty is the presence of "parasitic" peaks in the spectrum at medium and high frequencies. This question was discussed by l'Anson [1,2]. A periodic mark in the sheet usually generates several peaks on the spectrum, along a line or along several parallel lines (l'Anson describes them as "self-consistent" series of peaks). This multiplication of results makes automatic detection of patterns delicate.

We developed an enhanced FFT-based method that significantly diminishes the impact of these two problems. This is carried out by filtering from the formation image the low and ultra-low frequency components that might result in the cloudy spectrum centre mentioned above, and by increasing the resolution of the discrete spectrum to better isolate the specific peaks from the signal, thereby decreasing the parasitic peaks. The resulting spectrum is shown on Fig. 4.

The enhanced spectrum presents significant improvements from the standard one as the peaks are much clearer. The enhanced FFT significantly reduces the noise created by the ultra-low frequency, thus the signal-to-noise ratio (obtained by divid-
ing the intensity of the peak by the average intensity of the same frequency) is higher, allowing easier detection. This is especially striking at low frequencies: the peak related to the large, almost vertical streaks of Fig. 1 has a signal-to-noise ratio of 1.17 on the standard spectrum (meaning that the peak is only 27% stronger than the spectrum noise), and of 5.8 on the modified spectrum (meaning that the peak is almost six times stronger than the spectrum noise). Thus with the standard FFT the peaks of the large streaks are almost undetectable, while they are very clear on the enhanced FFT.

Furthermore, on the enhanced FFT spectrum the parasitic peaks are either non-existent or weak enough not to be confused with the “real” one. Thus a simple threshold can be used to automatically detect the pattern-related peaks.

Table I summarizes the periodic patterns detected on Fig. 1 with the enhanced FFT method, with their period, orientation (angle from horizontal, counterclockwise) and relative intensity (signal to noise ratio, as defined above). Figures 5 and 6 show the two largest patterns of Fig. 1 sample, of respective periods 10 mm and 1 mm, as recreated from the FFT spectrum results of Table I.

A NEW APPROACH: THE CARTESIAN SPECTRUM
Standard FFT spectra in polar coordinates such as that shown on Figs. 3 and 4 are difficult to read for non-specialists as the human brain is not adapted to such coordinates. An easier way to carry out the information is to transform such polar spectra into Cartesian ones, where the abscissa represents the angle, from 1 to 180 degrees, and the ordinate the frequency. Fig. 7 represents the enhanced FFT spectrum from Fig. 4 in Cartesian coordinates. (The standard FFT spectrum could also be represented in Cartesian coordinates but due to its poor angular resolution at medium and low frequencies this would present little interest). Thus a peak at coordinates (x,y) represents a pattern at angle x and with a frequency y.

The Cartesian spectrum is very convenient to provide a quick overview of the patterns that are in the sheet, or to compare the patterns of different samples.

ANOTHER EXAMPLE: TISSUE PAPER
Depending on the papermaking process, sheets may have very different formation
and very different patterns. Fig. 8 shows an image of tissue, with two clear oblique patterns. They appear on the Cartesian spectrum, Fig. 9. Thus each papermaking process and each paper machine will present a different spectrum fingerprint.

**APPLICATIONS AND FUTURE WORK**

As the periodic patterns within a sheet can come from various sources, their analysis can provide useful information on the several steps of the papermaking process. Small scale patterns
can be used for monitoring felt aging, while medium and larger scale streaks may indicate a roll marking or a headbox rheology problem. The precise determination of the frequency of a specific pattern can be helpful to identify the underlying cause in the papermaking process (e.g. a vibration). Also, the set of patterns in a sheet is specific to the paper machine that has produced the sheet and is the fingerprint of this machine. This can be used, for example in benchmarking, as an additional tool to identify the origin of a sample. Finally, the analysis of the changes in the size of the forming fabric marks across the CD profile provide information on the non-uniformity of shrinkage, thus on non-uniformity on drying, which can later cause problems of curl, etc.

SUMMARY AND CONCLUSION
This new method for detecting periodic patterns within the sheet formation constitutes a considerable improvement over previous techniques that relied on standard FFT power spectrum analysis. The precise identification and quantification of these patterns provides a helpful tool to the papermaker for determining their origin. As such patterns usually must be kept below some threshold to ensure good product quality, this new method can be used for product quality control and in a process control loop.

REFERENCES

Résumé: Nous avons développé une nouvelle technique de mesure des marques périodiques dans la formation de la feuille, qu’elles soient à petite échelle (marques de toile, de feutre) ou de plus grande taille (marques de rouleau, bandes dues à la flocculation dans la caisse de tête). L’orientation, la taille et l’intensité de la marque sont déterminées. Ces marques sont spécifiques à chaque machine. Leur détermination permet un suivi de la qualité du produit ainsi que le contrôle de l’opération de la machine.


Keywords: SHEET FORMATION, PERIODIC PATTERNS, FOURIER ANALYSIS, FELT MARKS, FABRIC MARKS, QUALITY CONTROL.