

# Identification of periodic marks in paper and board by image analysis using two-dimensional fast Fourier transforms

## Part 2: Forming and press section marks

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**ABSTRACT:** *The first paper in this series gave details of the two-dimensional fast Fourier transform method used to detect and enhance periodic marks in paper and board caused during manufacture. This second contribution discusses the mechanisms causing marks in the press and forming sections of the machine and their relevance to detection of the resulting pattern. The conclusions drawn are based on 4 years of investigations of real cases of marking including around 100 reports prepared for paper and board manufacturing companies.*

**KEYWORDS:** *Dimensional measurement, forming sections, Fourier analysis, image analysis, marking, paper machines, periodic variations, press sections.*

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The first paper in this series (1) described the basics of how periodic marks can be detected, identified, and enhanced using two-dimensional fast Fourier transforms (FFT). This paper will discuss some of the practical details of the procedure and the interpretation of results in both general terms and with reference to real industrial examples.

There are many possible sources of periodic marks in paper and board ranging from the slice to the calender. In this series of papers, the type of marks due to what could be described as mechanical engineering faults will not be discussed, since they rarely reach the author's laboratory and are dealt with in different ways by different personnel. This excludes barring, both at the wet end and dry end of the paper ma-

chine, and other marking due to vibration, leaving clothing related marking, which is still a broad category including forming fabric, couch roll, wet press felt, drilled and grooved press roll covers, and dryer fabric marks. While marks from all these sources are seen on a regular basis, it is, however, certainly true that some types of marks are more likely than others and that, in practice, some categories of marking must be considered as unavoidable and that it is keeping their intensity to a minimum, which is the goal in these cases. On all occasions, however, it is not the presence of a mark which is a problem but whether it adversely affects the appearance of the paper, and hence its saleability, or suitability for its ultimate purpose by, for example, affecting printability in some way. As paper or board is manufactured, it changes from a very deformable, delicate state to the more robust and resilient final product and, for this reason, the most common sources of marking are in the forming and press sections of the machine.

### Forming fabric marks

In the literature (2, 3), it has long been accepted that forming fabric marks (often called wire marks)

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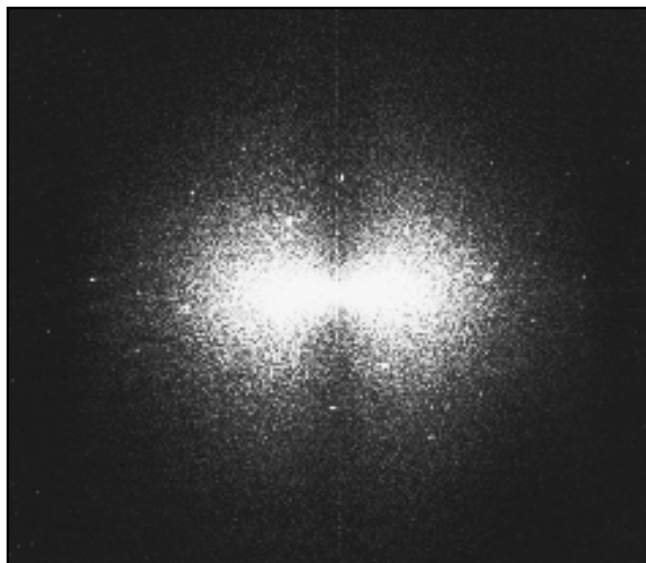
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## Image Analysis

1. Glancing incident light image of the bottom side of a sample of coating base made on a machine with a hybrid twin wire former. MD is vertical, and the field of view is 32 mm x 34 mm.



2. FFT spectrum obtained from the image shown in Fig. 1, with lighter points representing higher intensities. The large scale variation which is highest at the center of the spectrum and fades to zero at the edges is caused by the stochastic variations in Fig. 1 (e.g., formation) and the sharp peaks by periodic features.



originate from the forming pad of fibers being of varying thickness due to the indentations in the surface of the fabric, resulting in differences in mass per unit area from place to place in the pattern of the fabric. However much the surfaces are flattened out in subsequent processing, these differences in local grammage remain. If the surfaces are made completely flat and parallel, the variation will exist as a density difference, the higher grammage sections will thus have a lower specific opacity resulting in an evening out of the appearance of the look-through of the product, although the mark is often still visible. This process is also likely to result in differences of local absorption properties and compressibility, which may both lead to differences in take-up of ink during printing resulting in visible patterns, particularly in continuous colors. In practice, it appears that the surface becomes more even, although not flat in most cases, and the pattern can be perceived by illuminating the surface with low angle light (glancing incident or tangential illumination) or by placing the sample on a light box (transmitted light).

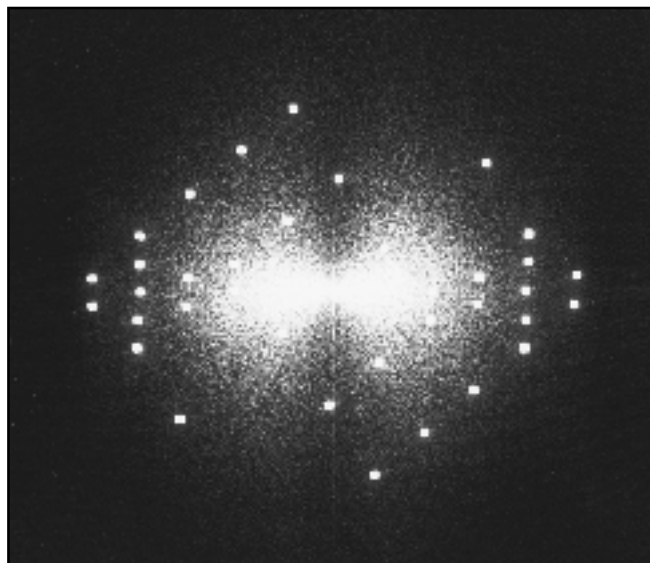
There is also a widespread belief that differences exist from place to place in the forming sheet due to differences in rate of drainage over land and open areas of the fabric. The justification for this is that, in multilayer fabrics, the positions of coarser yarns in the sublayers can be seen in the mark while they could not have affected the shape of the top surface of the fabric. However, an alternative explanation for this might be that the effect of drainage elements and suction boxes is to deform the shape of the fabric such that these yarns do affect the top surface of the fabric. There appears to be no evidence of the existence of these "drainage marks" in the literature although, if the above explanation was correct, then beta (2, 3) radiography would not reveal differences in grammage from place to place in the mark, allowing easy proof.

Ideally, then, a forming fabric designed to avoid marking would be perfectly flat and without holes, but this, of course, would not make paper. Forming fabric designers must weigh the need for fast drainage on modern high-speed machines against

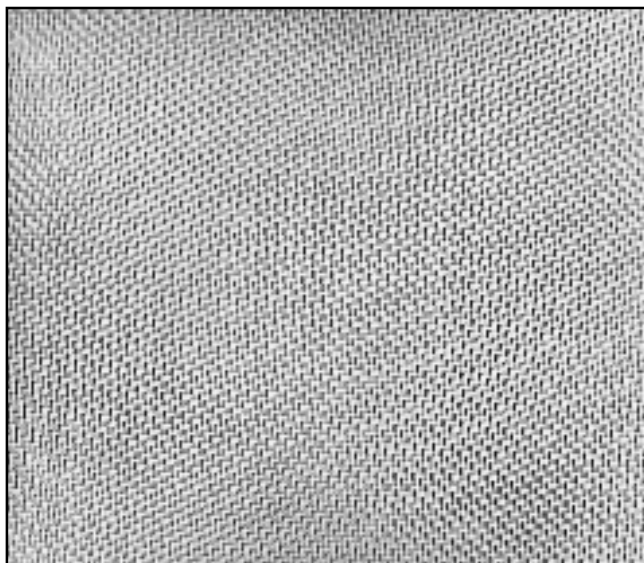
the need for the smoothest possible surface to avoid mark. Modern multilayer fabrics achieve excellent results, but the above arguments mean that there is almost always a detectable mark using the FFT method with appropriate illumination if not with the naked eye. All of the above comments apply equally to board, although forming methods involving cylinder type formers use entirely different fabrics, which are very fine indeed. Even in high-quality coated board, it is usual to be able to detect the presence of a forming fabric mark.

As mentioned above, a map of the grammage over the area of a sample can be obtained using beta radiography in which the beta rays are attenuated in proportion to mass per unit area but are unaffected by thickness. A recent paper by Luner *et al.* (4) provided details of a relatively simple method of doing this by sandwiching a paper sample between an extended beta source and a piece of X-ray film and leaving it to be exposed in a sealed container—a process known as contact beta radiography. The use of this process has been shown by Southern (5) to

3. The spectrum shown in Fig. 2 with the main peaks highlighted. These peaks are all part of a self-consistent geometrical pattern and are thus likely to have been caused by the same source.



4. The result of inverse transforming the spectrum shown in Fig. 2 using only the data corresponding to the peaks highlighted in Fig. 3. This image is a filtered version of Fig. 1, showing only the variations in the image responsible for the highlighted peaks.



allow separation of marks due to grammage variations from others resulting only in indentations (press felt marks in this case). Because forming fabric marks usually leave very fine scale indentations in the paper surface, microcontour ink (6) can often be used to enhance the visibility of a mark not easily visible to the naked eye. This material is spread onto the surface of the sample and then immediately wiped off. None of the ink is absorbed into the paper, but small quantities are trapped in indentations in the surface giving a visible pattern of their locations.

The first paper in this series (1) included an example analysis, which involved the enhancement and identification of a forming fabric mark. This mark was caused by a simple single layer wire and was viewed using transmitted light. The example included here is a mark caused by a more complicated double layer fabric and the illumination is by low angle reflected light, illustrating the clarity of result which can be obtained. To a much greater extent than is the case for transmitted illumination, this type of lighting isolates a

single surface of the sheet allowing, for example, the marks from two forming fabrics to be separately viewed. In addition, since it is the roughness of the surface which allows it to be seen, measurements of the relative variances of the original and the enhanced images allow a quantitative estimate of the intensity of a mark to be made. The sample chosen was a coating base grade made on a machine with a two-wire hybrid former, and **Fig. 1** is a picture of its bottom surface. The field of view is 32 mm x 34 mm, which is small enough for some detail to be resolved but large enough for a reasonable number of repetitions of the pattern of a forming fabric weave to be present. The machine direction (MD) is vertical and the illumination is horizontal. **Figure 2** is the FFT spectrum resulting from this image and shows that both random and periodic variations exist in Fig. 1. The random variations are seen as a smooth change from dark at the edges to white in the center, and the periodic variations are seen as discrete white peaks. Peaks caused by the same pattern in Fig. 1 will form a geometrical arrangement, and it is

this property which is used to identify them. **Figure 3** shows the majority of the visible peaks after they have been interactively selected and highlighted, and it can be seen that they are all part of a diagonal pattern. The identified parts of the spectrum have then been subjected to an inverse FFT, and the result is shown in **Fig. 4**, which shows only the variations in Fig. 1 which were responsible for the highlighted peaks—that is, the periodic parts of Fig. 1. **Figure 4** clearly shows that it is a double-layer forming fabric which is responsible for the indentations in the sample causing the variations in Fig. 1. If there are other periodic variations in Fig. 1, then they are either much weaker or not at a scale which allows them to be detected using this size of field of view.

### Press section marks

The press section is a common source of periodic marks since the pad of fibers still contains a lot of water as it leaves the forming section (approximately 80% moisture content) and is still very delicate. This structure is then pressed against a number of

## *Image Analysis*

periodically varying surfaces at high load before being dried. Press felts have to perform a variety of tasks, and their design and construction involve a skilful balance of properties, which is different for every position. The woven base fabric must be tough enough to withstand continual compression without flattening out, but must be sufficiently permeable to allow water to pass through it. It must be fine enough to ensure good contact with the paper, flexible in the cross machine direction (CD) to make fitting easy, and flat enough to avoid marking. A series of layers of fine fibers (called "batt fibers") is needled onto this base fabric to improve contact with the sheet and water flow from it. This process reduces the probability of base fabric marking but is itself periodic and can produce marks in paper. Drilled and grooved rolls are necessary to remove water quickly from the press nip on modern high-speed machines, but the paper must be protected from them by the press felts. This requirement implies high bending stiffness which is at odds with the need for fine yarns to prevent base fabric marks and the need for low CD stiffness for fitting.

Although the web of fibers is delicate as it enters the press section, it has already lost as much water as possible by natural and forced drainage. This implies that the final relative position of the various components in the x-y plane is fixed by this stage (except those caused by shrinkage during drying) and that any significant changes in the z-direction will be due to consolidation or indentations of things touching its surface. The distribution of mass in the plane of the paper should therefore be unaffected by any press section periodic marks, and Southern (5) has shown that this is true for a limited number of examples. Marks may, therefore, be visible either directly, as indentations in the surface or relatively less pressed

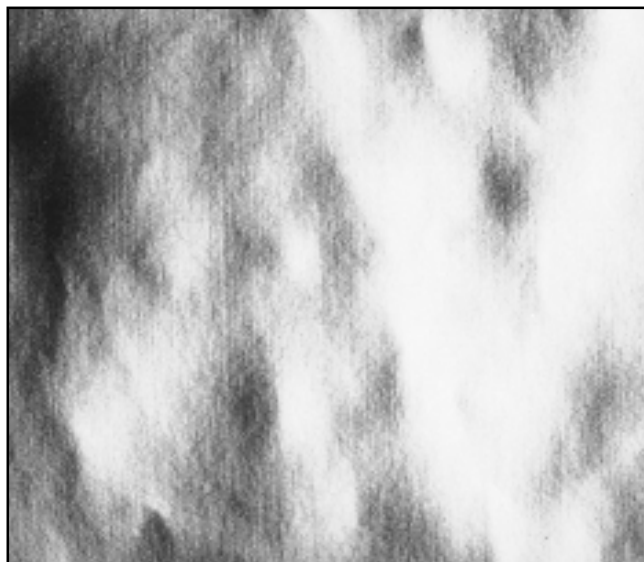
high areas, or as density differences, resulting in areas of high and low opacity (in weakly and strongly pressed areas, respectively). It should also be noted that more strongly pressed areas will be smoother, since it is well known that roughness increases with bulk. The author's laboratory has analyzed in excess of 60 examples of periodic marking in the last year and, in all cases, the above marking mechanism has provided an adequate explanation for the cause of press section marks.

Sometimes explanations for the presence of marks caused in the press section involve "hydraulic" effects in which marks are visible due to textural changes in the surface of the paper or board caused by water being either forcibly extracted from the sheet (at suction presses) or excess water being forced against the paper surface. In the author's opinion, these mechanisms are unlikely and over-complicated, since the marks can easily and consistently be explained by areas of the product being pressed more or less strongly depending on the degree of contact with the felt in the press nip. The "unpressed" areas which result will remain bulkier and rougher in the final product, since the rest of the area has been through one more press. Evidence to support this opinion can be easily obtained by using a method, sometimes used in paper mills, to assess the likelihood of marking at a particular press position. A piece of pressure-sensitive material is passed through the loaded nip at crawl speed. The material used can be pressure-sensitive plastic film (as used by the author's laboratory), carbonless copy paper, or simply two sheets of plain paper sandwiching a sheet of carbon paper in a polyethylene bag. Whatever the material, it experiences the same pressing forces as the paper would, and the result is a map of the relative pressures experienced from point to point by the paper in that

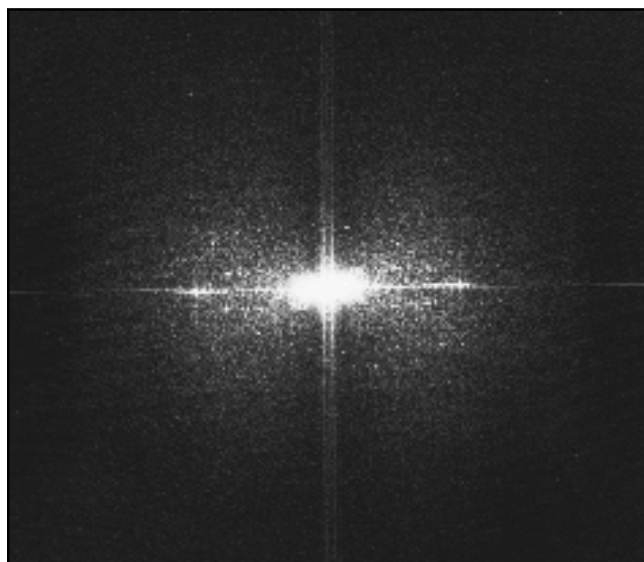
nip. No water is being removed and, equally, there is no reason for there to be excess water present, so no "hydraulic" marking forces can be active. However, at a suction press position, the pattern of the holes in the roll cover can invariably be seen showing that the felt is not stiff enough to bridge the holes and apply an identical pressure to the paper at all places in the nip, which is not, perhaps, surprising when the forces involved are considered. An example is given below where a grooved roll press thought to be causing the second type of "hydraulic" marking is shown to produce clearly visible lines in a slow-speed nip impression obtained in this way.

Press section marks require a range of viewing techniques depending on the nature of the mark. Marks caused by a felt base fabric can often be seen most easily using glancing incident illumination to highlight the relatively sharp edges of the indentations caused. Suction, blind-drilled, or grooved roll marks, however, do not, by their nature, have sharp edges and the most effective viewing methods will generally involve highlighting the differences in opacity between the land and open areas of the mark, either by using transmitted light or using diffuse lighting with a black background to show differences in hiding power. Felt surface marks can usually be seen using transmitted or glancing incident illumination. In all cases, Microcontour ink (6) can be useful, as it will not only help to pick out the sharp edges present but will also be retained better (causing the surface to appear darker) on rougher sections due to the presence of bigger fissures at a microscopic scale. Very often, one or the other of the above methods is the logical one to use in analyzing the mark, since it is the one which was originally used by the papermaker when the mark was detected. The size of field of view required for detecting press section marks is usually rather bigger than

**5.** Glancing incident illumination image of a sample of coating base. The field of view is 100 mm x 105 mm, the third press felt side is facing the camera, the MD is approximately vertical and the direction of illumination is horizontal. An MD mark is clearly visible in this image.



**6.** The FFT spectrum obtained from the image shown in Fig. 5. There are a variety of peaks visible in the spectrum, some of which are caused by the obvious mark in Fig. 5, some of which belong to weaker, less important marks.



for forming fabric marks. Although felt base cloths are woven in a similar way to forming fabrics, the scale is much larger, with coarser yarns and bigger spacings. This means that the patterns of the marks produced have a longer wavelength and the peaks produced are nearer to the center of the spectrum than for wire marks, allowing the two to be distinguished. Felt surface patterns caused by needling and marks caused by grooved rolls produce marks at a similar scale to base cloths and they can usually be detected in the same size images, but suction roll patterns are bigger again and require a larger field of view. With so many possible combinations of field of view, sample treatment, and illumination, it is clear that it is not possible to do the full range on every sample. It is necessary to use prior knowledge obtained from the people running the machine and experience of what types of marks are likely for a particular grade to allow the most useful combinations to be used.

The first sample which will be used here to illustrate detection of press section marks was approxi-

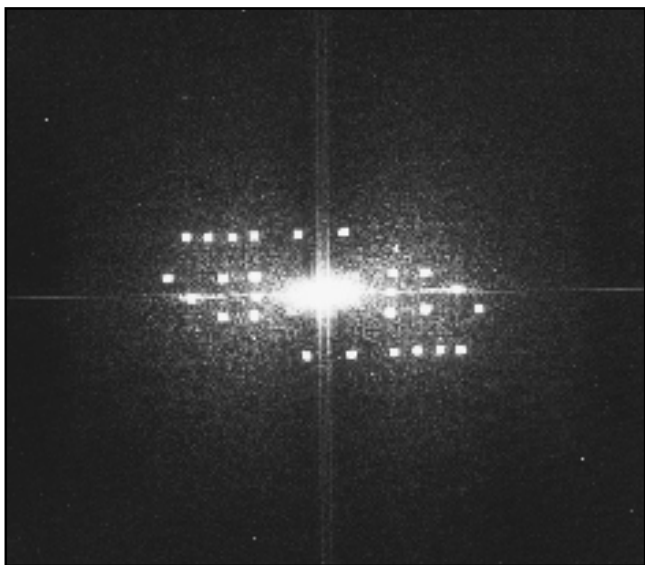
mately 70 g/m<sup>2</sup> coating base and was known to be marked. All those who handled it were easily convinced that it had an MD mark which seemed to be at too large a scale for a forming fabric mark, yet there were two opposing views as to its source. The side on which the mark occurred was only in contact with one press felt (at the third and last press), but it seemed possible that it was caused by either the yarns of the felt base cloth or by the grooved roll at this position. **Figure 5** is a glancing incident illumination image of a sample of the paper using a 100 mm x 105 mm field of view, the MD is vertical and it is illuminated from right to left. An MD mark can clearly be seen.

**Figure 6** is the FFT spectrum of this image, and a variety of peaks are present, confirming that the sample is periodically marked. Of particular interest are the peaks lying on the horizontal line passing through the center of the spectrum (the X axis), which correspond to vertical lines in Fig. 5 with those nearer to the center having longer wavelength. Whichever source of marking was responsible for the MD mark in the sample, it would be expected

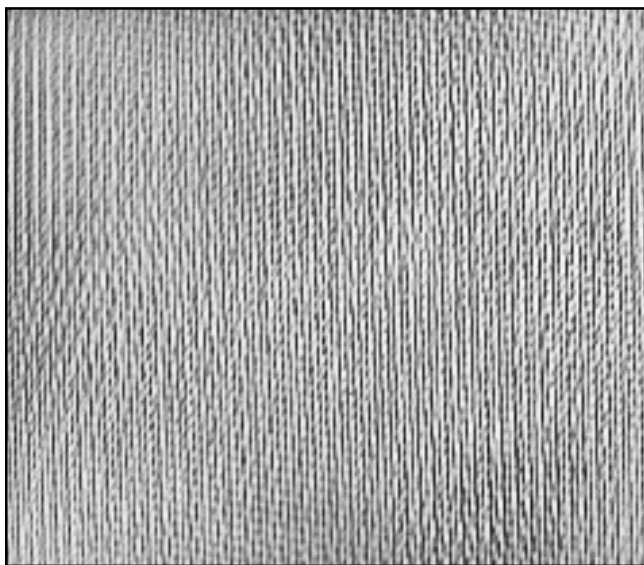
to have some or all of its peaks on this line. The first set of peaks chosen (**Fig. 7**) are a mutually consistent set including the two brightest peaks on this axis and the result of performing an inverse FFT on these data is shown in **Fig. 8**. The spectrum was compared with that of a sample of the base cloth in use at this position (shown in **Fig. 9**), and the correspondence was clear, with the positions of the X axis peaks being particularly strikingly similar. There seemed little doubt then that the main mark visible in Fig. 5 was a felt base cloth mark caused at the third press. However, there were some other peaks along the X axis which were unaccounted for, in particular those highlighted in **Fig. 10**. These peaks did not form part of the pattern of the base cloth and when inverse transformed were found to produce a larger scale MD mark (shown in **Fig. 11**) which was of the right pitch (2.3 mm) to be caused by the grooved press roll. This was not the strongest mark, but it was certainly present. When the sample was viewed by transmitted light (**Fig. 12**), the mark in the paper did not look the same; the mark looked broader.

## Image Analysis

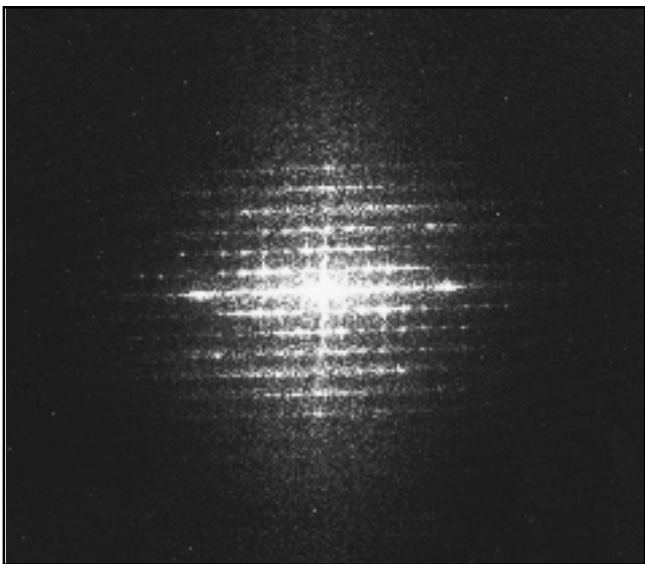
7. The spectrum shown in Fig. 6 with the set of peaks which appear to be caused by the strongest mark in Fig. 5 highlighted. It is the peaks positioned on the horizontal line passing through the center of the spectrum (the x axis) which are caused by vertical lines in the source image. The rest of the peaks are chosen to be consistent with those thought to be responsible for the visible lines in Fig. 5.



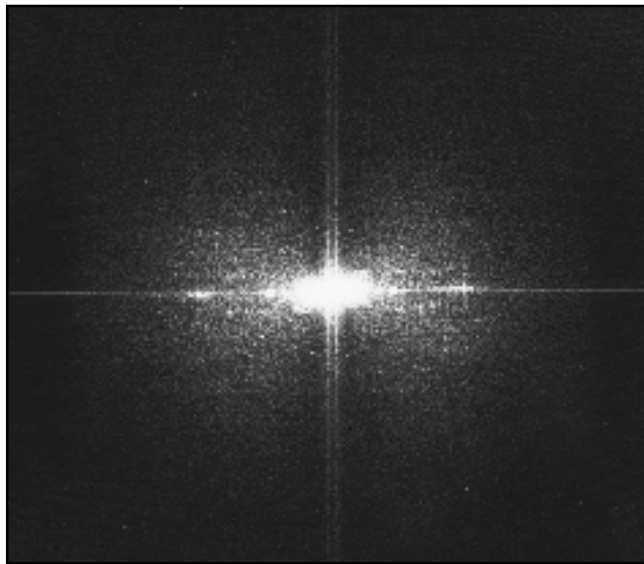
8. The result of an inverse FFT on the spectrum shown in Fig. 6 using the data corresponding to the highlighted peaks in Fig. 7. The appearance of this mark is quite consistent with its being responsible for the visible mark in Fig. 5. Its appearance and the layout of the peaks in the spectrum both point strongly to its being caused by a wet felt base cloth.



9. FFT spectrum obtained from a sample of the base cloth fabric used in the third press felt in use when the sample shown in Fig. 5 was made. Note the close similarity between the positions of the peaks in this spectrum and those responsible for the base cloth mark and, in particular, the positions of the x axis peaks.



10. The spectrum shown in Fig. 6 with another two strong peaks highlighted. These two are not consistent with the mark already extracted but correspond with an MD mark at the pitch of the grooved roll in use on the third press.



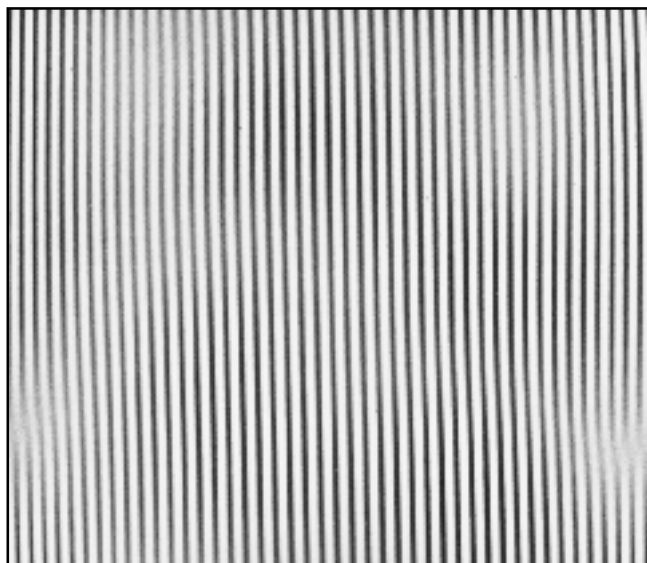
The FFT spectrum (**Fig. 13**) looked different too; the “base cloth” peaks were weaker and the brightest peaks were now those attributed to the grooved roll. So, it appeared that the base cloth mark was stronger when viewed by reflected light, but

the grooved roll mark was stronger in transmitted light. This is consistent with what has been said above about the need to choose illumination carefully depending on the source of mark which is suspected. It is hardly surprising that, when

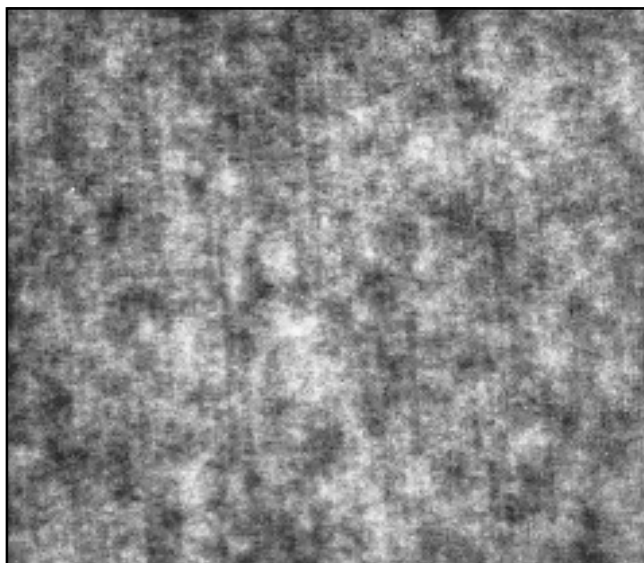
viewing the sample in a mixture of lighting conditions, the various parties could not agree on the source of the mark, particularly if they had a vested interest!

Felt surface marks are caused by the needling process, which is used

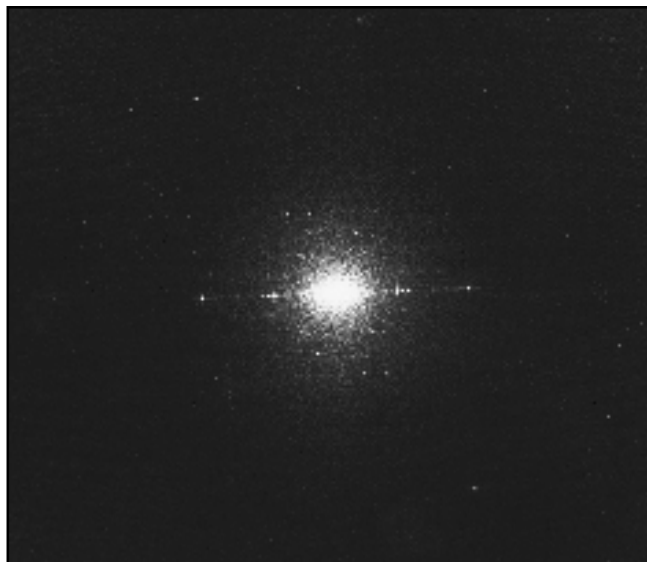
**11.** The result of inverse transforming the spectrum shown in Fig. 6 using only the data corresponding to the peaks indicated in Fig. 10. It is thought that this mark has been caused by the third press grooved roll.



**12.** A transmitted light image of the paper sample already shown in Fig. 5 using reflected light. Size and orientation are identical (100 mm x 105 mm, MD vertical, third press side up). An MD mark can still be seen in this image but it appears to have a bigger pitch.



**13.** FFT spectrum of the image shown in Fig. 12. Peaks similar to those in Fig. 6 are visible, but those shown below to correspond to a roll mark are now brighter and more easily visible than those corresponding to the felt base cloth mark. The situation has now been reversed and the roll mark is the more intense.



**14.** Glancing incident illumination image of the wire side of a sample of 80 g/m<sup>2</sup> printing paper. Field of view is 100 mm x 105 mm, MD is vertical and illumination is from right to left.



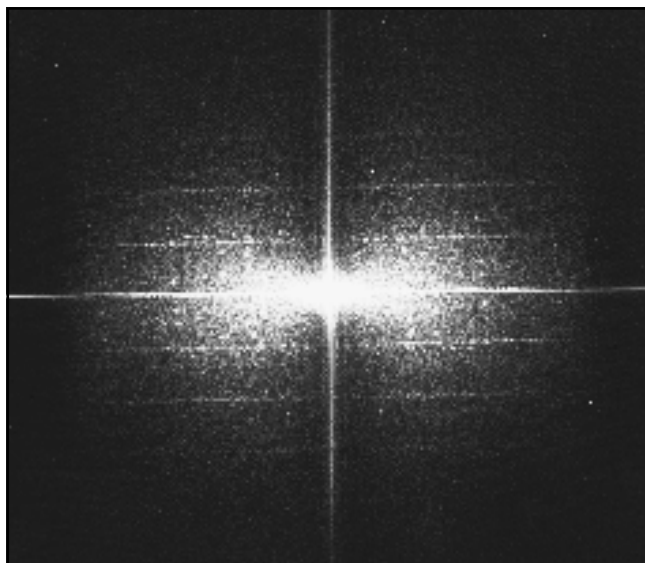
to anchor layers of fine “batt” fibers to the structure of the base cloth. The layers of loosely connected fibers are laid onto the woven fabric, and the two are passed through a needle loom, in which a board of barbed needles forces the batt into

the base cloth. Inevitably the distribution of the batt fibers is affected by the positions of the needles, but a great deal of trouble is taken to arrange the needles on the board so that visible patterns are avoided. However, it is the amount by which

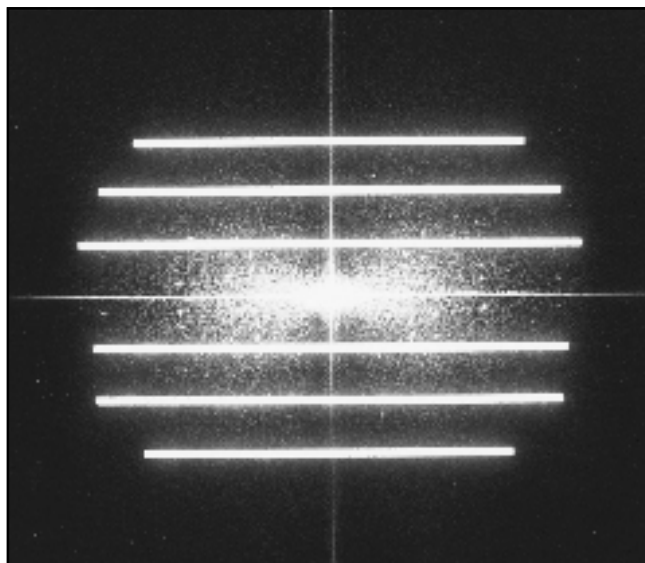
the felt is advanced between strokes of the needle loom which inevitably introduces a periodic variation into the distribution of material in the surface since, by definition, points in the running direction of the felt separated by a distance of a whole num-

## Image Analysis

**15.** FFT spectrum obtained from the sample in Fig. 14. There are a number of discrete peaks present, which are probably caused by a wet felt base cloth, but there are also some horizontal bands. Bands of this type are caused by the needled surface of a wet felt.



**16.** The spectrum shown in Fig. 15 with the positions of the horizontal bands thought to be caused by the needled surface of a wet felt highlighted. The position of these bands is consistent with a needling operation performed at 2.3 mm advance per stroke, although this does not take into account any dimensional change of the paper during drying.



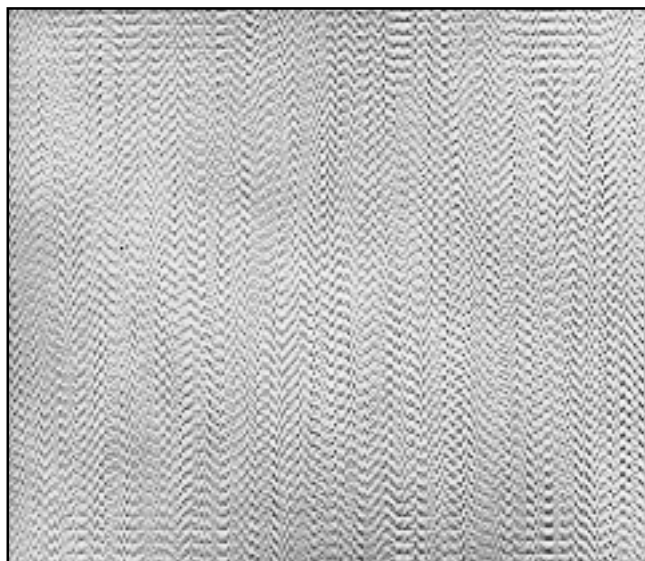
ber multiple of the advance per stroke have been treated in exactly the same way. The pattern is usually also periodic in the cross machine direction (CD), since the needles are evenly spaced in this direction, but at a much longer wavelength. The resulting pattern in the FFT spectrum (if the MD of the paper is vertical) consists of horizontal bands of very closely spaced peaks (often indistinguishable from each other). The vertical separation of these bands is controlled by the advance per stroke (around 2–4 mm) and the horizontal separation of their component points is controlled by the needle separation (around 10 mm). Subsequent passes through the needle loom can usually completely eradicate the patterns caused in the surface of the felt in this way, so that it is usually only the last pass which is detected in the paper surface. **Figure 14** is an image of the surface of a sample of 80 g/m<sup>2</sup> printing paper illuminated with glancing incident light, the field of view is 100 mm x 105 mm, and the MD is vertical. A certain MD graininess can be perceived in this image but the source is

unclear. **Figure 15** is the FFT spectrum obtained from this image, and there are a number of features present which show that the paper sample is certainly periodically marked. Of particular interest here are the parallel horizontal bands which are entirely typical of those produced by the needled surface of a wet felt. In this case, the separation of the bands indicates that the part of the needling process which caused the mark, presumably the last phase, has been performed at 2.3 mm advance per stroke (note that any dimensional change of the paper during subsequent pressing and drying operations has been ignored in calculating this figure). The bands of peaks have been highlighted in **Fig. 16**, and these parts of the spectrum have been subjected to an inverse FFT to produce **Fig. 17**, which is effectively a filtered version of Fig. 14 showing only the part associated with the selected areas of the spectrum. It is immediately noticeable that Fig. 17 looks very similar to the surface of a needled wet felt, confirming that it is the needling process which is responsible for the

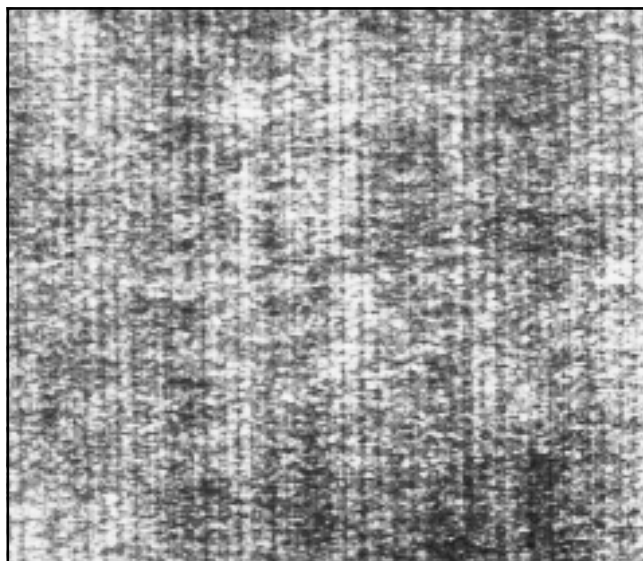
strong bands of peaks in the spectrum. Detailed comparison of Figs. 14 and 17 reveals that some of the visible individual grooves which contribute to the impression of MD grain seem to be associated with areas of Fig. 17 which are strongly marked. These widely separated and randomly positioned grooves, although easily visible, could not be associated with the needling process of an individual press felt if the sample were studied by conventional means.

**Figure 18** is an image of a 100 mm x 105 mm area of a “dynamic nip impression” obtained from the fourth press of a high speed fine paper machine. This impression was taken by the papermaker using a sheet of carbon paper between two sheets of plain paper sealed into a polythethylene bag. This combination was fed through the loaded nip at a slow speed during a brief break in papermaking, so that the felt was still wet and conditions in the nip were as near as possible to those used in papermaking. Figure 18 is clearly far from even, showing that pressing is different from place to place in the nip, and the fact that

**17.** The result of performing an inverse FFT on the spectrum shown in Fig. 15 using only the data corresponding to the areas highlighted in Fig. 16. This is the mark in the paper surface which has been caused by the needled surface of a wet felt and is remarkably similar in appearance to a felt surface.



**18.** 100 mm x 105 mm image of a “dynamic nip impression” made at the 4th press of a fine paper machine. Very strong MD lines can be seen in this image.



some of these variations are periodic is demonstrated by the FFT spectrum of this image shown in **Fig. 19**, which contains a variety of peaks and bands. In particular, the strong MD lines caused by the grooves of the press roll (pitch 2.54 mm) can be seen in Fig. 18 and have produced strong *X* axis peaks in Fig. 19. Bands of peaks due to the felt surface and discrete peaks due to the base cloth can also be clearly seen. Since the explanations for “hydraulic” marking are clearly not relevant in this case, it seems reasonable to suppose that these are mechanically caused marks due to differences in pressing pressure from place to place. When the paper web is pressed in this nip, it will experience similar forces (as well as any others), and it seems reasonable to suppose that the degree of unevenness of pressure demonstrated in Figs. 18 and 19 would be sufficient to mark the paper. There is no need to invent complicated hydraulic mechanisms for marking when nip pressure variation can adequately account for any mark. Another comment which should be made here is that such

tests almost invariably demonstrate that there is a potential for marking, but very often the paper shows no evidence of mark at the reel. This suggests that marks can be eradicated at subsequent presses and may relax out during drying.

## Conclusions

There is a great deal of mystery surrounding clothing related marking on paper and board machines. Without using a method such as the one described here, it can be difficult to identify the source of a mark and even more difficult to identify why it has occurred. Using the two-dimensional FFT method, it is usually possible to identify visible marks, allowing proper action to be taken to improve the situation. The work presented here is the result of a large number of such investigations allowing a number of conclusions to be drawn.

Forming section marks are caused by differences in grammage from place to place in the forming sheet due to the shape of the forming fab-

ric. Such marks are very common but are often not a problem.

There are big differences in local pressure from place to place in a press nip, a situation which felt construction can improve but not eradicate. These differences in pressure frequently leave indentations in the surface of the pressed web, but often these have disappeared by the reel. All sources of marks are best explained in the above manner, with “hydraulic” effects apparently causing unnecessary complication.

Forming fabrics need to be completely smooth but still permeable, if mark is to be completely avoided. Press felts need to have a completely homogeneous structure, even under load, but need to retain permeability as well as other mechanical and hydraulic attributes, which is again clearly impossible. Where grooved or drilled rolls are used, the felt needs to be as stiff as the material of the roll cover to prevent low pressure over the open areas and therefore mark, but this also sounds rather unlikely. Perfect, nonmarking paper machine clothing is still some distance away!

## Image Analysis

Clothing which is currently in use works very well. There are many other considerations besides mark in the design of suitable fabrics and improvements are regularly made. Use of the FFT method is now allowing more rapid evolution of clothing because the performance of particular fabrics on particular positions can be monitored in an additional way, allowing faults to be more quickly identified and corrected. 

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**19.** FFT spectrum of the "dynamic nip impression" shown in Fig. 18. There are very strong peaks indicating that the grooved roll has contributed to the pattern as well as bands of peaks caused by the needled surface of the felt and discrete peaks caused by the base cloth.

