Smoothness characterization of printing papers

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INTRODUCTION

Smoothness is one of the most important properties of paper affecting its printability. In a printing press, a printing forme bearing ink on its image portions is pressed against the paper surface for a few milliseconds. When the forme is separated from the paper, the ink transfers to the paper and a print is created. It is evpected that the paper makes complete contact with the inked regions on the printing forme, which in case of half tone images may be millions of tiny dots per square metre of surface. The smoothness of the surfaee controls the ease and the uniformity with which ink transfers to the paper and thus determines the final print quality. It determines how well the paper surface contacts the ink film making printing possible with low ink quantity and low pressure. The requirement of smoothness is most stringent in gravure printing where the transfer of ink takes place from a number of tiny cup-like cells (about 100 μm diameter). It is required that each cell must make contact with the paper to enable the ink to be withdrawn from it during printing. Missing of even a few cells can be detrimental to the quality of the final print. The requirement of smoothness is only comparatively less important in offset printing due to the presence of a deformable transfer roll in this process.

An essential feature of papers is that both the paper itself and its surface are compressible so that the surface becomes smoother under the pressure applied in a printing process. Bristow[1] has shown that two sheets of paper can assume entirely diffferent roughness values under a given pressure even though they have nearly the same initial roughness. Therefore, those paper sur faces which have a higher surface smoothness under pressure conditions similar to those in a printing nip should have a better printability.

Considerable research effort has been devoted to acquiring the ability to predict the printability of paper by measuring its surface smoothness and compressibility

Definition of Smoothness

An ideally smooth surface is one in which all the surface elements lie in one plane. The smoothness of a real surface such as that of paper can thus be easily defined as the closeness of its surface to the plane surface. Roughness, on the other hand, is an inversely related term which implies a deviation from the plane surface. To measure roughness is, however, not as easy as to visualize it as a deviation from a plane surface[1]. Figure—1 shows profiles of a rough surface in relation

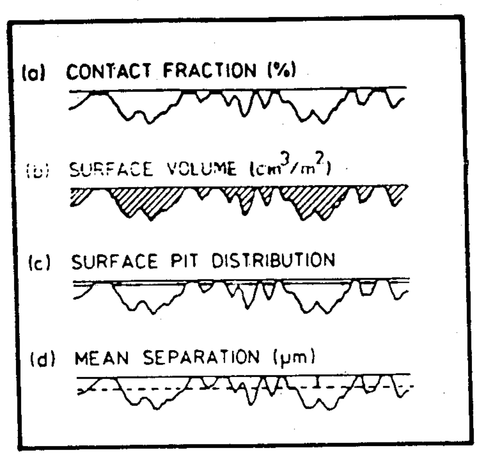

Figure-1 Various ways of defining roughness (Bristow[1])

to a plane reference surfaee, and some of the various parameters which may be chosen to describe quantitatively the deviation between the surface and the reference

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plane. Many more parameters can be defined. Further since the measured quantities show a spatial variation, it is necessary to measure their distributions in order to describe the surface more completely.

Because of the lack of a single parameter which can completely characterize a surface, a large number of methods and instruments have been developed to meet the specific needs in a given situation. The available methods can be divided into the following groups.

1. Air-leak methods.
2. Optical methods.
3. Surface evaluation by ink-transfer
4. Surface evaluation based on liquid film application.
5. Surface profilometry.

Some of these, due to their ease of operation, have become methods of routine measurements, whereas others, though yielding more useful information, are not so regularly used today. The principles involved in most of these methods are presented briefly in the following paragraphs.

AIR-LEAK METHODS

In these methods, the volume of voids between a paper and a plane surface is assessed by measuring the rate of air flow between the two surfaces (Figure-2). Air flow techniques generally involve pressing the test sheet against a flat surface and measuring either the time required for a given quantity of air to flow between them or the volumetric rate of flow of air leaking between them. The smoother the sheet of paper the better will it conform to the surface and the slower will the air pass through the intermediate gap. Hence the measurement of time is said to be a measure of smoothness and the instruments used for this purpose are said to be smoothness testers. On the other hand the air flow rate will increase with decreasing smoothness, hence such instruments are referred to as roughness testers.

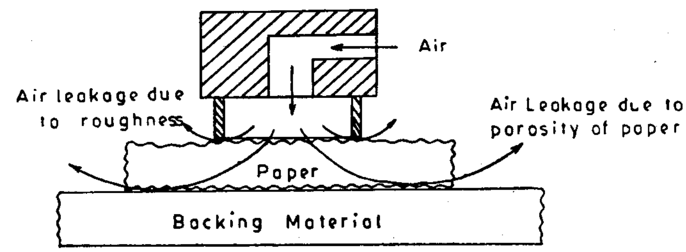

Figure-2 Air-leak method of roughness measurement

Several air leak testers, e.g. the Bekk tester, Gurley-Hill tester, Bendtsen tester, Sheffield tester, Parker Print-surf tester, etc. have been developed over the years. Some important differences between these instruments are given in Table-I.

TABLE—1
Difference between various Air-leak instruments

Instrument	Width of measuring land mm	Air pressure difference kPa	Clamping pressure MPa	Backing material	Quantity measured
Bekk	13.5	50	0.1	Soft Rubber Pad	Time (s)
Gurley-Hill	5.9		0.02	Metal	Time (s)
Bendtsen	0.151	1.48	0.1 or 0.5	Glass	flow rate (ml/min)
Sheffield	0 375	10.34	0.1	Glass	flow rate (ml/min)
Print-Surf	0.051	6.17	0.5	Deform-able	Mean roughness (μm)

Except for the Parker Print-Surf tester (PPS) the roughness in air-leak testers is measured for a relatively free surface. In PPS the clamping pressure can be increased to about 2 MPa which is comparable to those in a printing nip.

A drawback with the air-leak testers is that air leaking la'erally through the sheet is also included in the measurement of roughness. The extent of error caused due to this leakage is dependent on the design of the measuring head, on the type of material backing the paper sheet and on smoothness and porosity of the sheet.

The width of the metering land plays an important role in the measurement of smoothness which can be correlated to the printability of paper. A wide land (e.g the Bekk tester with 13.5 mm leakage path) will create a greater resistance to the flow of air between the paper surface and the measuring land thus inducing conditions of enhanced air leakage through the paper sheet. the instruments with narrow measuring land (for example the PPS tester)are more sensitive to speaks or foreign material. Similarly a greater air pressure difference across the metering land enhances the error due to lateral leakage.

The usual assumption in the design of PPS tester is that there is no loss of air through the bulk of the sheet due to porosity of paper. The tester tries to reduce the effect of lateral air flow by using 1) narrow metering land, 2) deformable backing,3) guard rings in the sensing head which limit the area of paper directly exposed to the upstream air supply to a small value, 1% of the exposed area in some other instruments, 4) measuring flow on the downstream side. However, Mangin and De Grace[2] have reported that in the case of porous papers such as newsprint a significant portion of the total air flow may escape the measure of the roughness as shown in Figure-3.

Air-leak testers are the most widely used ones. The striking feature of these testers is their speed and simplicity in operation. They yield quantitative values which are reasonably reproducible and free from operator error. They have high resolution, and they can be used for different grades of paper and paper Board.

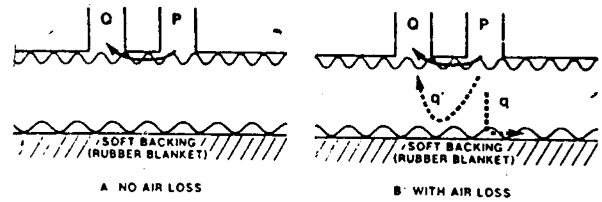

Figure-3 Schematic diagram of the PPS tester showing the possibility of error due to leakage of air through the bulk of the sheet (Mangin and DeGrace[2])

OPTICAL METHODS

In these methods interaction of light and paper surface has been used to evaluate its smoothness. These methods include two basic approaches, namely,

1. Viewing the surface under oblique illumination.
2. Measuring area of contact between a plane glass and the paper surface.

Viewing Surface under oblique illumination

When a rough surface is illuminated by a light beam at a high angle of incidence, 75 to 80°, a pattern of light and shadowed areas can be detected through microscope with a magnification of roughly 20 to 30 times. This method provides a quick qualitative evaluation of the surface. Photographes of the magnified surface give very good visual information about the topography of the surface [3], [4], [5], and they can be used for grading of a limited number of surfaces by a panel of judges.

Based on this principle Scheid[6] developed a tester for the quantitative determination of the smoothness of coated papers. Paper was illuminated by a grazing light beam and viewed normal to the paper surface though a microscope with a magnification of X 30. When the angle of incidence of the illumination is decreased, a decrease in spectral reflectance occurs, and the number of light and shadowed areas and sharpness between them decrease. The angle where this change is most significant can be used to quantitatively determine the smoothness. The largar the angle at which the change occurs, the smoother the surface. The scheid results have, however been found to be operator sensitive.

Viewing of surface under grazing light is a good and quick method for qualitative evaluation of paper surfaces for production control purposes. The quantitative determination is however not easy to standardize due to complicated optical effects. Hull and Rogers[7] observed that the translucency of the paper surface tends to hide some of the contour differences, and variations in translucency of the paper can give an impression of surface roughness.

Optical Contact Area Measurement

A good measure of the smoothness of paper surface can be the fractional area of contact between a level reference surface and the paper surface in question under pressure equivalent to those expected during real printing. A number of instruments to measure this contact fraction based on optical principles have been developed [8], [9], [10]. Among these the FOGRA-KAM (10) received the maximum attention. In this instrument, Figure-4, the paper sample is pressed against a glass prism by means of a hydraulic press. The bottom surface of the prism is illuminated at an angle greater

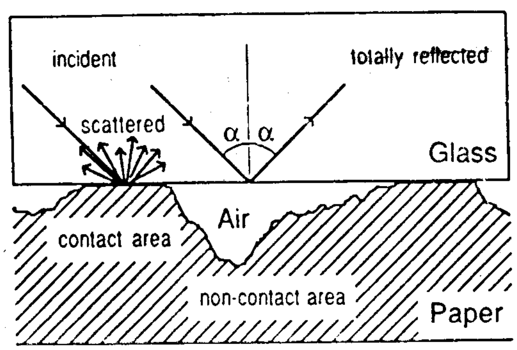

Figure-4 Light distribution at contact and non-contact areas in the FOGRA tester

than the angle of total reflection (about 50°). The light is totally reflected by the prism if the bottom surface is in contact with air. This totally reflected light is measured by a photocell positioned at an angle equal to the angle of incident light. On the other hand, when the prism is in contact with a paper surface, the light enters into the paper since the cellulose has nearly the same refractive index as that of the glass, and is diffusely reflected at all angles into the prism. Only a very small fraction of this light reaches the photocell. Thus the light reaching the photocell indicates primarily the regions of non contact. The ratio of the intensity of the light reaching the photocell to that of the incident light gives the fractional non-contact area.

When viewed normal to the paper surface, only the scattered light coming from the paper surface reaches the eye, and the portions of the paper surface not in contact with the prism appear black. An image of the contact distribution is obtained. Photographs can be taken for further evaluation of surface features of paper.

Bliesner [11], Blokhuis and Kalff [12], and Lyne[13] have discussed optical contact area measurement under dynamic pressure conditions.

The Chapman or FOGRA testers determine the fraction of the paper surface which comes in optical contact with the prims, but give no measure of the depth of surface cavities which are not able to contact the prism. In case of actual printing, the ink film is flexible, as opposed to the hard surface of the glass prism), and can even contact portions of the surface which do not come in optical contact with the prims. Information about the depths of the gaps between the prism surface and the paper can be obtained by varying the wavelength of the incident light. When internal reflection occurs, the light waves penetrate slightly into the air beyond the prism boundary before being reflected, the depth of penetration being proportional to the wavelength of the light. The phenomenon is called frustrated total reflection (FTR) and it influences what is registered as optical contact. A surface region not in physical contact with the prism may thus be interpreted as being in contact by light of wave length λ_2 but not by light of wave length λ_1, as shown in Figure-5. If the optical contact area is determined with light of different wave lengths, the fractional area of paper within a depth from the surface of the prism corresponding to each wave length can be calculated and hence the topographical structure of the paper surface can be estimated. A dynamic smoothness tester based on this principle has been developed in Japan[14].

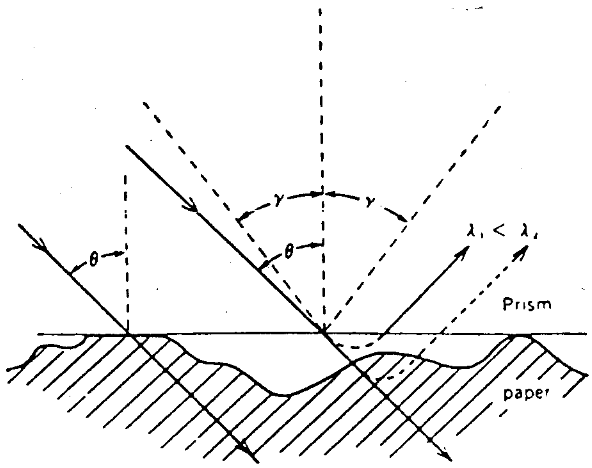

Figure-5 Effect of wavelength of light in discriminating contact and non-contact areas

METHODS BASED ON TEST PRINTING

Most laboratory smoothness measuring methods differ from actual printing conditions. The important differences being :

1. Printing occurs under dynamic forces, as against the application of static pressure used in most instruments.
2. The paper surface is required to contact a flexible ink film on the printing forme rather than a hard surface.
3. The entire paper surface should achieve perfect contact with the ink layer on the forme. Methods giving average values may often not give enough weight to those surface defects in the paper which are detrimental to its printability. Poor prints are obtained at defective positions notwithstanding what the average values are.

Obviously' the evaluation of paper surface smoothness should be more relevant from the printability viewpoint if it is based on a method in which the paper is actually printed under conditions similar to those encountered in real printing. A number of such studies have been reported in the literature. In most of these methods the paper is printed on a laboratory printability tester under controlled conditions of ink film thickness, pressure and speed of printing. A number of ways have been reported to analyse these data.

Minimum Ink Demand for Complete Coverage

When the paper is printed with a small amount of ink, the paper surface does not establish complete contact with the ink layer on the printing forme. The ink from the forme is transferred to those portions of the paper which make contact and results in a discontinuous print on the paper. As the amount of ink is increased on the forme, more and more of the paper surface receives ink during printing The minimum amount of ink required on the forme to give continuous coverage is reported to be a good measur of printing smoothness[15,16,17,18]

Since the term "ink film thickness" is not relevant in gravure printing, the number of dots per square inch which do not transfer from a half tone with a screen ruling of 100 lines per inch has been found to be a good roughness index (18).

Surface Evaluation by Partial Coverage Printing

In this technique (19), the paper to be studied is printed with a small quantity of ink under a light pressure in order to provide a print with only partial coverage. The prints obtained present the surface structure in a manner suitable for useful visual examination (Figure-6) The prints obtained are similar to photomicrographs taken under grazing illumination. but these prints present the picture of the surface as it meets the inked printing forme in a dynamic printing nip and are free from the complications of optical effects, exposure times, devloping conditions etc. At the same time, the area examined is much larger than that which is measured by most of the smoothness measuring heads. The method provides two dimensional details. Since the printing experiments are carried out with varying amounts of ink on the printing disc, strips of different papers with almost the same fractional area of the surface coveredby ink can be chosen for the purpose of close comparisons. An experienced observer should be able to judge whether the features observed are likely to be detrimental to print quality in the intended printing process, and also what the likely causes are. The following may be observed :

1. The contrast between adjacent areas. A low contrast signifies smoother surfaces.

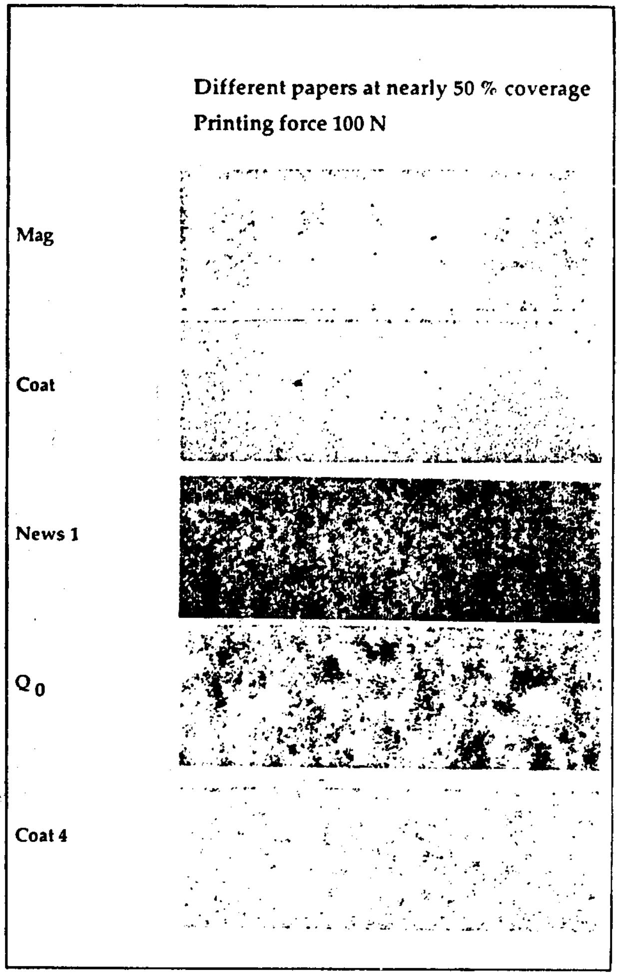

Figure-6 Typical prints on different grades of paper

2. Wiremarks, calender or coater streaks or any other type of marks. Such marks become more pronounced in the final prints and spoil their appearance.
3. The degree to which uneven features are oriented in the surface. A pronounced orientation may indicate a poor printing surface.
4. Fineness or coarseness of structure. A coarser structure gives rise to a greater print unevenness.

The prints obtained in this technique may be further analysed by an image analyzer to determine a number of surface characteristics in numerical terms. An image analyser is a system in which an image is digitized and stored in a computer for numerical analysis of the image. In such systems the image is stored in terms of a number of small picture elements called pixels. Numerical values of CIE colour coordinates are recorded for each pixel of the picture, In case of black and white images only a greytone value of pixel is required to be recorded. The range of greytone scale between white (unprinted) and black (completed covered with ink) will depend on the sensitivity of the system. In this study (19), the prints were viewed in a TV camera under uniform illumination and the image was converted to a 512×512 pixel matrix recording 256 grey levels for each pixel in a Kontron IBAS image analyser. The recorded images were used to:

1. assess the fractional area of the surface covered by the inked regions.
2. assess the number and mean length of chords of inked regions along parallel lines on the prints.
3. Determine the spatial distribution of variance of grey levels of the inked regions and to assess the typical wavelength of the printed patterns.

In the assessement of fractional coverage area and the distribution of chords lengths, the images were treated purely binary, i.e., consisting of either completely black regions or completely white regions. Whereas, in the determination of grey level variance, the image was not treated as binary.

For a given amount of ink on the disc a greater degree of surface coverage is achieved on a smoother paper than on a rougher paper. The coverage can also be increased by increasing the pressure in the printing nip. To compare different papers standard conditions were adopted in which the speed was 1 m/s and the printing force was 100 N on a 31.5 mm wide strip of paper.

The amount of ink required for 50 percent coverage of the surface at a given printing smoothness index. The choice of 50 percent coverage has the advantage that the area measurement techniques are most accurate in this range. The gradient of the coverage area versus amount of ink on the disc may also have different values for different papers although the ink requirement for 50 percent coverage is the same. This gradient is a measure of the shallowness of the cavities in the paper surface. The shallower the cavities, the more rapidly will they be filled when the ink thickness on the disc is increased and the greater will the gradient at 50 percent coverage be.

The coverage area could be related to the amount of ink on the disc by the following equation (coef. of determ. >97%),

$$A/(1-A)=kx^n$$

where A = fraction of the surface covered by the ink

x = amount of ink on the printing disc, g/m^2

k and n are constants for paper.

The two constants k and n are not correlated. The constant k is basically a smoothness parameter. There is a correlation between k and the Parker-Print-Surf roughness values. It is difficult to assign any structural significance to the constant n, but it is noteworthy that it is not greatly changed by calendering which may indicate that it is related to structural features which are not directly associated with the roughness.

It has been found empirically that the square root of the product of x and 1/(da/dx) at 50 percent coverage is very close to the Parker-Print-Surf roughness value. Thus by calculating both x and dA/dx the information provided by the Parker-Print-Surf measurement is broken down into two complementary components representing different features of the paper surface and structure.

The mean chord size for a given area of coverage varies slightly for different papers. The subsequent calendering of paper leads to a shorter mean chord length and an increased number of counts for a given area of coverage. Thus the mean chord length provides additional information concerning the nature of the surface.

The spatial distribution of the variance in the grey tone levels has been studied and a typical wavelength with which the greatest variance is associated has been determined.

The coefficient of variation in the greylevel increass with increasing area of coverage but the coefficient of variation at 50 percent coverage is a parameter characterizing the roughness and correlates reasonably with the PPS value. The coefficient of variation decreased with increasing extent of calendering.

A typical wavelength is different for different papers and, for a given paper, it is almost independent of the degree of coverage and of calendering treatment. Thus the typical wavelength is independent of roughness in the sense measured by air-leak and similar methods. This typical wavelength may provide important additional information describing the pattern of structure and texture of the surface as it is influenced by other bulk properties of the paper, e.g, formation, rather than the surface roughness alone.

SURFACE EVALUATION BASED ON APPLICATION OF LIQUID FILMS

Drawdown Tests

Drawdown tests were initially devised for the inspection of inks. In these tests a small quantity of ink is drawn down on a sheet of bond paper with the help of a knife to a thin film suitable for colour comparison. Hull and Rogers[7] found that the technique was equally useful for the study of the texture of the paper surface under the ink film. They found that a number of paper characteristics could be studied by varying the design of drawdown blade and the type of ink used.

In a rigid-blade drawdown test the paper sample is placed on a flat glass plate and the drawdown is made with a thick blade with relatively blunt edge. A load equivalent to 0 5-2 MPa is applied by putting a weight at the centre of the blade. A specially formulated, pigmented ink is used for these tests. This ink is short non-drying, and of the correct pigment strength to show maximum differences in the surface, In flexible blade drawdown tests, the paper sample is backed by a soft material like a pad of rubber or paper and the drawdown is made with a thin flexible blade similar to the doctor blade used in a gravure press. The load applied is of the order of 0.5 MPa. A relatively longer ink is more suitable for flexible drawdowns.

The patterns obtained on the paper surface from these drawdown tests vary in darkness with the weight on the blade, the speed of the blade and the angle at which the blade is held. These factors are not, however, found critical for showing the contour variations on the surface but they may need to be standardized for the purpose of comparison of different paper samples.

A drawdown at 45° to the machine direction is optimum because it emphasizes marks is both machine and cross directions.

The pattern shown by the rigid-blade drawdown test indicates the variation in thickness and hardness of the paper examined. Thin spots are dark and thick spots are light. When these drawdowns are made on opposite sides of the paper the pattern is roughly duplicated on both sides of paper confirming that the variation is in the formation of the paper and not limited to the surface alone. The flexible-blade drawdown test shows a much finer pattern with usually no relation to the large rigid-blade pattern. The pattern is not the same on both sides of the paper and is not caused by the absorption properties. The test essentially shows the surface characteristics of the paper. Holes in the coating, surface fiber structure, wire marks and other similar characteristics which can be identified under oblique illumination are made visible by these tests.

Wipe Tests

Wipe tests are a variation of the drawdown tests. The inks are spread in a thin layer on the paper sample by means of a spatula. They are allowed to remain there for a specified time (0-2 min) and the excess is then wiped off using cleaning tissues. Patterns produced by pigmented inks indicate surface contours and those produced by dye-base inks indicate a combination of roughness and absorption.

The microcontour ink which contains a blue pigment suspended in a colourless oil is used particularly for suaface evaluation. Upon application of such an ink, the soild phase pigment stays in the surface cavities and the oil is absorbed in the paper. When the excess ink is wiped from the surface a mottled blue stain is left. An intense colouration of the stain indicates a high roughness of paper. The microcontour value of a stain is calculated from the reflectance values using the following equation (20) :

$$Q = 100 (R\infty - R)/R$$

Where Q = microcontour value for a paper
R = reflectance factor of the stain
$R\infty$ = intrinsic reflectance factor of the paper

There appears to be a general agreement between the microcontour value and the PPS - roughness but there are nevertheless significant deviations indicating that the two methods compliment each other in their characterization of the surface[19]. For very smooth papers, however, the microcontour value seems to show a greater resolution than the PPS value.

The rigid-blade drawdown, the flexible-blade drawdown and the wipe tests differ in the frequencies and sizes of the irregularities indicated. The rigid-blade drawdown tests indicate variations in the surface features in the wavelength range 2.5 mm to 25 mm which are mainly affected by formation and thickness variations in the paper. The flexible-blade drawdown test indicates a medium surface structure with a wavelngth range of 0.25 to 2.5 mm and the wipe tests show fine surface structures at wavelengths less than 0.25 mm. According to Hull and Rogers, the wipe tests indicate roughness of the same order as that which affects the gloss of the paper.

These tests are fairly easy and quick to perform, but they have the disadvantage that experience and skill are required in interpreting the results. The tests are good only for the comparison of paper which have nearly the same absorptivity and optical properties.

Spreading of Liquid

Several apparatus have been developed in which a certain liquid film is spread over the paper surface. A part of the liquid applied penetrates into the paper depending on its absorptivity and a part of the liquid remains in the valleys of the paper surface This latter quantity is determined and is used to express the smoothness of the paper[21,22,23].

The Sweerman[22] apparatus is shown in Figure-7 The paper is drawn at a uniform velocity past a rectangular slit filled with liquid During this movement, the liquid fills in valleys of the paper surface and at the same time penetrates into the paper. The total quantity transferred to the paper per unit area is expressed as

$$Y = R + K (\gamma t \cos\theta/\mu)^{1/2}$$

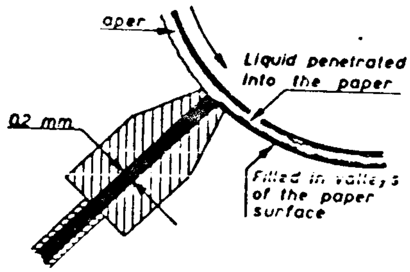

Figure-7 The Sweermen apparatus for liquid application (Sweerman[22])

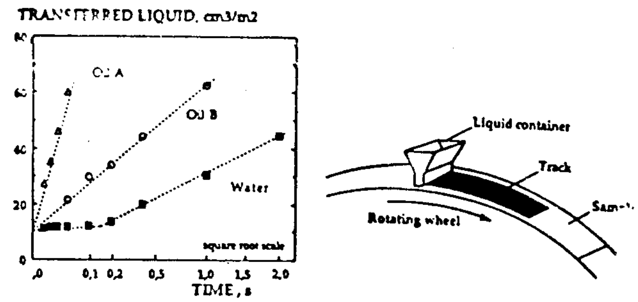

Figure-8 The Bristow absorption tester (Bristow[23])

where R equals the liquid quantity that remains in the valleys of the paper surface and the second term represents the liquid that has penetrated into the paper. Here γ is the surface tension of the liquid, μ is the viscosity of the liquid, t is the penetration time and θ is the contact angle of the liquid on the paper, K is a measure of the porosity of the paper.

Sweerman used paraffin oil as the testing liquid with $\gamma = 25 - 30$ mN/m, $\mu = 1.5$ to 60 mPa.s, $t = 0.04$ to 0.002 s and $\cos\theta = 1$. The pressure exerted on the paper by the edges of the slit was about 100 kPa.

A plot of Y against $\sqrt{t}$ should give a straight line and the intercept of the line with the Y axis gives the roughness index.

The disadvantage of the Sweerman method is that it still requires a long time and great experience to get reliable results. The external pressure appropriate to each sample could only be found by trial and error and this was a time-consuming process.

Bristow[23] developed an apparatus which is more suitable for routine test purposes. The principal of liquid spreading in the Bristow apparatus is shown in Figure—8.

SURFACE PROFILOMETRY

The technique which provides the most exhaustive description of the surface topography involves recording surface profiles by a fine point stylus traversing the surface.

The technique was originally developed for the evaluation of very smooth surfaces in the metal industry and was later adopted in many other fields including the topographical study of paper and paper-board surfaces. A number of workers have reported that the results obtained using the profiling methods show high correlations with the performance of paper in actual printing operation[24-35]. Most other methods of measuring smoothness lack resolution for very smooth papers whereas the profiling instruments are fairly sensitive to surface imperfections in such papers. Moreover, the technique provides information of a fundamental nature not readily obtainable by other methods. The technique is useful because:

1. the profile of the surface can be drawn with different magnifications on the vertical and horizontal axes allowing a clearer visual assessment of the surface.

2. the actual size and shape of the surface irreqularities are measured rather than obtaining merely a single average value.

3. a distinction is made between periodic and irregular surface features.

Recording of Surface Profiles

The paper surface is scanned by a fine point stylus which moves over the surface at a constant speed. The vertical motion of the stylus is measured by means of a positional transducer which generates a voltage proportional to its vertical displacement. In early instruments, the voltage generated was magnified by a calibrated amplifier and fed to a direct linking oscillograph. In modern instruments the output is digitized at close time intervals and the data are stored in a computer. This has the advantage of avoiding errors due to mechanical inertia which may arise in a real time recorder.

Figure–9 shows a typical surface profile in which 1500 points were recorded with an interval of 13.5 μm between two adjacent points. The data can be treated to yield a number of statistical quantities. These can be broadly divided into two groups, the amplitude parameters, and the spatial parameters.

Amplitude Parameters

Amplitude parameters are definded to describe the magnitude of heights and depths of the surface features[38] some of the commonly used parameters are shown in Figure–10. These are.

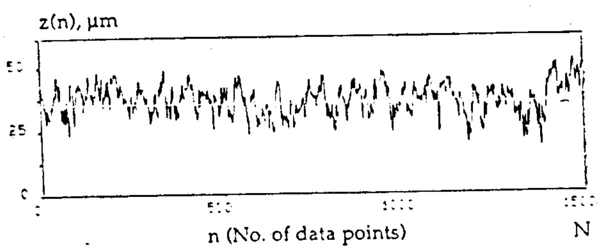

Figure-9 A typical surface profile

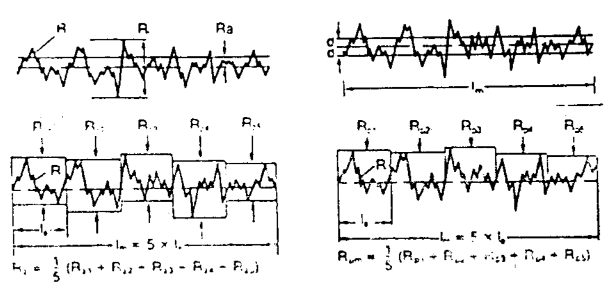

Figure-10 Definition of amplitude roughness parameters

1. The arithmetic mean of the departure of the profile from the mean line (Ra).
2. The variance or the root mean square roughness (Rq).
3. The maximum profile depth, i.e., the vertical distance between the highest point and lowest point. (Rt),
4. Average value of the individual roughness depths in 5 sampling lengths (R_z).
5. The profile height from the mean line within a a sampling length (R_p). The mean value of R_p over 5 sampling intervals (R_{pm}).
6. The Swedish height parameter which is similar to R_t but which excludes extreme values by evaluating the surface between two reference lines positioned to exclude the top 5% of the plane length provided by the extreme peaks and the bottom 10% of the plane length provided by the extreme valleys. The height parameter is the vertical distance between the two lines.

All these amplitude parameters will have small values for profiles of smooth surface By far the variance is the most commonly used roughness parameter.

Spatial Parameters

The amplitude parameters provide information on the depth of cavities but give very little information about their shape. In most printability studies some measure of cavity width distribution is also included in surface characterization parameters.

If the profile curve in Figure-9 crosses the mean line frequently this indicates the presence of narrow irregularities in the surface or a profile variation of a small wavelength. If, on the other hand, the curve crosses the mean line less often this indicates the presence of wider cavities or variation of longer wavelength. A glance at a paper profile reveals that a paper surface contains variations of no definite amplitude or wavelength. It can be regarded as consisted of a large number of waves of varying wavelengths and amplitudes. It is possible to decompose a profile into its components[19]. Figure-11 shows how an original profile decompose into four components of different wavelength bands. The residue after this separation contains wavelength components longer than 81 data points. When all these components are summed, they give a profile equal to the original profile. It has been observed that the first four bands contain information about the roughness of the surface and the residue contains the waviness of the surface. Now the amplitude roughness parameters can be determined for each component of the profile. In Figure—12 tne variance in four bands has been plotted for an uncalendered-paper and for the same paper calenderd at three different pressures. The figure shows that the variance decreases in all these bands, as a result of smoothing effect of calendering, but it is interesting to note that the greatest reducton is in the bands 3 and 4 and that three is little reduction in the first two bands. Information of this type is potentially valuable in the study of the printability of paper.

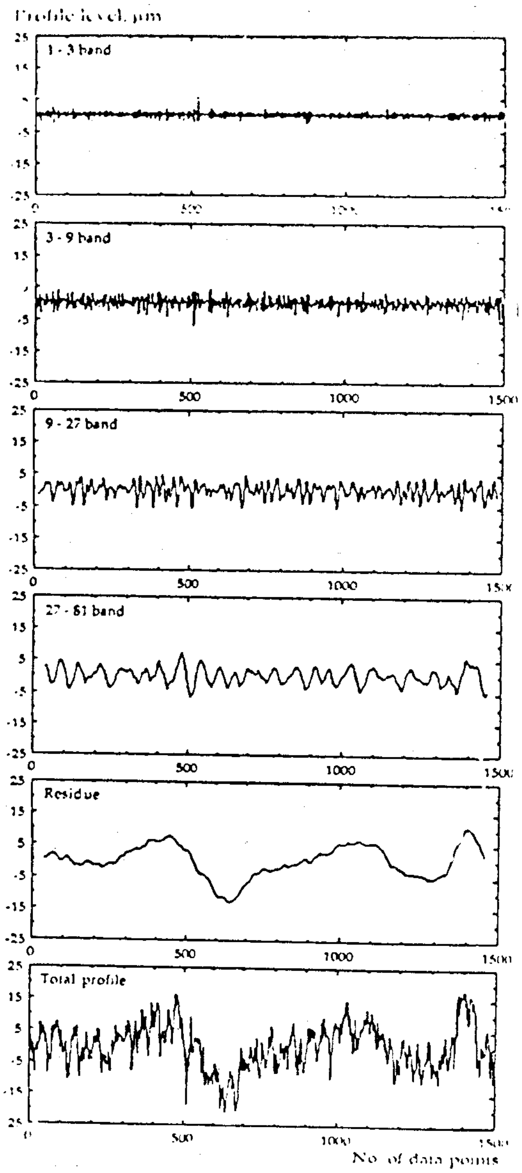

Figure-11 Components of a paper surface profile

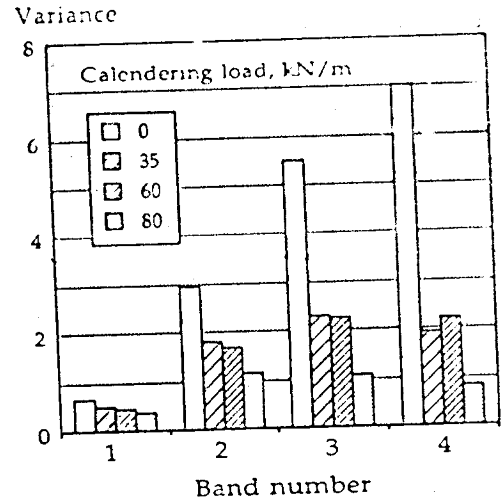

Figure-12 Effect of calendering on the variance of the profile in the four wavelength bands

Autospectrum

A variance distribution obtained by the method of moving averages has only four or five bands with successively increasing bandwidth. The technique is quite simple and useful for the characterization of the paper surfaces. But when an analysis of the wavelength components with narrower bands is required, the technique of determining the autocorrelation and autospectrum has a greater efficiency[19]. These latter techniques also provide means of determining the presence in the profile, of any periodic components, their amplitude and periods.

The detailed discussion on the determination of autospectrum of a profile is beyond the scope of this review. In brief we can say that autospectrum of a profile presents the distribution of the variance in the profile data at different frequencies. The variance of a random series is uniformly distributed over the entire frequency range, smooth series has most of its variance at high frequencies. If the series contains a periodic component, the variance tends to concentrate at the frequency of that component. Conventionally, the autospectrum is calculated as a function of frequency, but for paper since the wavelength is better related to the physical nature of the surface, a wavelength spectrum can be computed using the method suggested by Norman and Wahren[34]. Figure-13 shows the autospectra of profiles of two paper samples 'REFA' and 'RGN'. The paper REFA was found to be smoother than the paper RGN when measured by Parker-Print-Surf roughness tester.

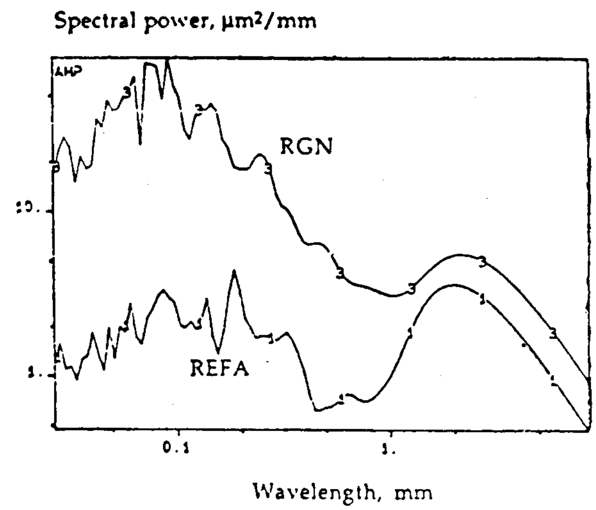

Figure-13 Comparison of autospectra of two paper profiles

CONCLUSIONS

These various methods were used to characterize surfaces of handsheets of three different types of mechanical pulps, namely stone groundwood (SGW) thermomechanical pulp (TMP), and chemithermomechanical pulp (CTMP). The smoothness rankings of the handsheets of these pulps as evaluated by different methods are shown in Table—II.

TABLE—II

Smoothness ranking* of handsheets by different methods

	CTMP	SGW	TMP
1. PPS	2	1	3
2. FOGRA—KAM	2	3	1
3. Partial coverage print	3	1	2
4. Microcontour ink stains	1	1	2
5. Autospectra of profile	1.5	1.5	3

* 1 = smoothest

The lack of agreement between different methods clearly shows that they do indeed measure different properties of paper surface. More work needs to be done before the complexity of the relationship between various tests can be explained. Until then it may be important that the various tests must always be used with caution and with thought in order to derive the best possible interpretation.

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