CHAPTER 2

Screen printing

Christopher J Hawkyard

2.1 INTRODUCTION

Screen printing is an extension of stencilling. Innumerable children experiment with simple stencils by cutting out shapes from card, and brushing or spraying paint or ink through the holes on to paper beneath. Commercial stencil sets for lettering are made of waxed card or metal, and incorporate ties to hold the solid areas together and to prevent the centres of letters such as O or P from falling out. The ties produce unsightly lines across the stencilled letters.

Centuries ago, when the Japanese developed the stencilling technique for textile printing and brought it to a fine art [1], they overcame this difficulty by using human hair or silk threads as ties. These were so fine that the colour spread underneath them, disguising their presence. By the 19th century, the use of this method for printing fabric had spread far beyond Japan and was used worldwide.

In the mid-19th century, French printers introduced the use of a woven silk fabric to provide a continuous support for the paper stencil. For the best results the support fabric was stretched across a frame, and the combination became known as a screen. The development was important because in this way not only were ties automatically provided, but the amount of colour paste applied could also be controlled. Soon after, the paper stencil was replaced by a durable paint on the screen fabric.

From this time onwards the advantages of screen printing became increasingly appreciated, especially in fashion houses. Designs are relatively easy to transfer to screens and the frame size can be readily varied. The designer, freed from the restrictions of copper rollers, thus had far greater freedom to choose repeat sizes. In addition, the pressure applied in screen printing is much lower than in roller printing with the result that surface prints with an improved ‘bloom’ or colour strength are obtained, and textured surfaces are not crushed.

The development of screen printing to its modern, highly productive form ran parallel with improvements in the screens themselves. Accurate printing of multicoloured designs requires stable screens. Screen fabrics made from hydrophilic yarns, such as silk, cotton, viscose rayon or cellulose diacetate, are apt to sag when in contact with water-based print pastes. The introduction of hydrophobic synthetic fibres such as nylon and polyester, especially the latter, made it possible to manufacture stable screens that maintained tension when wet. Their high tensile strength also allowed the fabric to be stretched more tightly over the screen frame, thus improving the accuracy that could be attained. Further improvement came with the introduction of metal screen frames to replace the wooden ones used hitherto, which tended to warp when subjected to a regime of continually alternating wetting and drying.

Strong, stable screens enabled the hand screen-printing process to be mechanised. The first development was the introduction of a movable carriage, in which the screens are mounted one at a time. The squeegee (a flexible rubber blade used to spread the printing paste across the screen and force it through the open areas) was driven across the screen by a motor attached to the carriage. In this method, which is still in use, the fabric being printed is stuck down on long tables and one colour is printed at a time, just as in hand-screen printing.

The 1950s saw the advent of fully automatic, flat-screen printing, the Buser, Stork and Johannes Zimmer machines being prominent. These machines print all the colours in a design simultaneously along the top of an endless conveyor belt (blanket). The blanket and fabric are stationary while the printing operation takes place and then move on when the screens are raised; hence the fabric movement is intermittent.

Fully continuous printing is best achieved using cylindrical (rotary) screens and many attempts were made to form flat wire mesh screens into cylinders, despite the necessity of a soldered seam. When printing through a cylindrical screen with a seam, a line will show across the fabric once every cylinder circumference, unless the seam can be hidden within the design. This was the approach used in the screens manufactured by A J C de O Barros for the Aljaba machine, first introduced in 1954. Barros has written an interesting description of the Aljaba screens and machines [2].

Wire-mesh screens are too open for printing purposes, and on the early Aljaba screens electrodeposited copper partially filled the holes. This process was later discarded, to be replaced by the use of an outer seamless woven nylon sleeve. Later still, in fact after the closure of the Aljaba company, W Sword introduced a new version of the wire-mesh screen, the Durascreen [3], in which the holes in the mesh were partially filled with a flexible polymer by electrophoretic coating. The same process can also be used on electroformed nickel screens (see section 2.7.3), extending their life considerably, since the flexible polymer coating reduces the risk of creasing.

An important innovation of the Aljaba company was the duplex machine used by some printers to print both faces of curtain fabrics. The fabric ran vertically upwards between pairs of screens, print paste being forced through the screens by metal roller squeegees.

The invention of seamless screens of electrodeposited nickel was the really significant step which heralded the rapid expansion of rotary-screen printing. Peter Zimmer (Austria) introduced the galvano screen in 1961, and Stork (Holland) the lacquer screen in 1963. These screens soon proved to be superior, in many respects, to Aljaba screens. When Stork introduced their machine, based on the lacquer screen, at the 1963 ITMA Textile Machinery Show at Hannover it was an immediate success, so much so that Stork decided to stop manufacturing fully automatic flat-screen machines. Between 1964 and the end of 1972 Stork sold 600 rotary machines throughout the world.

Machines using rod or roller squeegees, such as those manufactured by Peter Zimmer and Mitter, have been very successful in printing wider substrates, such as carpets (see section 4.3.3). Rotary-screen machines have also been used to print paper for the transfer printing process (section 3.2.2). Currently rotary-screen printing is the predominant printing method worldwide, having substantially replaced copper-roller (intaglio) printing (Figure 1.1).

2.2 HAND SCREEN AND SEMI-AUTOMATIC SCREEN PRINTING

The practice of hand screen printing is now mainly restricted in the UK to colleges of art, small-scale units and the high fashion industry, as it is a craft rather than a productive method of printing. Printing is carried out on a flat, solid table covered with a layer of resilient felt and a washable blanket (usually coated with neoprene rubber). Heat for drying the printed fabric may be provided either under the blanket or by hot air fans above the table.

Fabric movement or shrinkage must be avoided during printing in order to maintain registration of the pattern. The fabric to be printed is laid on the table and stuck to the blanket directly, using either a water-soluble adhesive or a semi-permanent adhesive; alternatively it is ‘combined’ with a back-grey. In the latter instance an absorbent fabric is stuck to the blanket and the fabric to be printed is pinned down on top of it. Sometimes fabric and back-grey are combined before fixing to the table using an adhesive and a specially adapted pad mangle. Combining is most suitable for printing lightweight fabrics, where there is a danger of smudging or loss of adhesion caused by the presence of excessive print paste. It can also be advantageous for knitted fabrics.

Before a design can be printed, it must be reproduced on the screens in a suitable form. One screen is required for every colour in the design, except when the fabric is dyed to the background colour (known as the ground) before or after printing, or when a third colour is produced by one colour falling on another. When the background colour is printed it is termed the ‘blotch’. The steps necessary to take an artist’s original design to the stage of being ready for screen printing are detailed (section 2.5).

The printing process consists of forcing a viscous print paste through the open areas of the screen with a flexible, synthetic rubber squeegee. The rubber blade, which is contained in a wooden or metal support, is drawn steadily across the screen at a constant angle and pressure. If the screen is too wide to allow one operator to reach all the way across it, two operators may work together, one on either side of the table. The pressures exerted by the two must be as similar as possible.

The amount of print paste passing through the screen can be controlled in several ways. Factors affecting this are:

- the ‘mesh’ (threads per inch) or ‘raster’ (threads per cm) of the screen fabric; generally a coarse mesh allows more paste to pass through than a fine one
- the fraction of open area in the screen fabric; this depends not only on the mesh but also on the yarn diameter and the effect of subsequent treatments, such as calendering
- the hardness and cross-section of the squeegee blade; a hard rubber squeegee with a sharp cross-section is suitable for outlines, whereas a soft, rounded blade applies more paste and is suitable for blotches
- the hardness of the printing table; if the top of the table is firm a soft squeegee is probably necessary, whereas with a resilient table surface a harder squeegee is preferable
- the viscosity of the print paste; within the constraint of the requirement for good definition, the viscosity can be varied, thinner pastes passing through the screen pores more readily than viscous ones
- the number of squeegee strokes; from two to four strokes are usually applied
- the squeegee angle and pressure
- the speed of the squeegee stroke (see section 2.8.1).

All these variables should be taken into consideration, in conjunction with the nature of the design, when printing the chosen fabric.

Before printing begins, the screens must be carefully positioned on the fabric. The area printed by a screen (screen repeat) must fit exactly alongside the adjacent one, a slight overlap being preferable to a gap. With flat-screen printing this is not automatically achieved (as is the case with rotary printing). The differently coloured areas must be in register and, again, a small overlap is usually allowed. To achieve accurate registration it is common practice to attach to the frame a bracket which locates against fittings, known as ‘stops’, on a guide rail along one edge of the table. The stops are spaced exactly one (lengthways) screen repeat apart along the whole length of the table. Two adjustable screws set the distance of the frame from the rail (Figure 2.1).

As a further aid, repeat crosses known as 'pitch marks' may be incorporated at one or both sides of the screen and the positions of the following screens checked against the first pitch mark. Often registration marks are printed along the selvedge. One such scheme is illustrated in Figure 2.2.

When screen printing is carried out by hand, alternate repeats are normally printed along the full length of the table and then the gaps are filled in. This allows time for the print paste to penetrate the fabric and partially dry before the frame falls on the next printed area. If the design includes an outline this is printed first, to achieve maximum smartness and as an aid to accurate fitting. The screen is then washed and the second screen introduced to print the second colour. The blotch screen, if there is

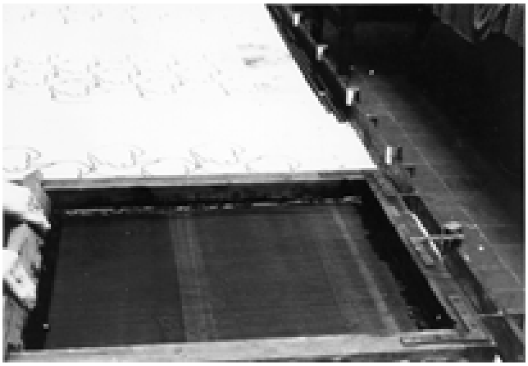

Figure 2.1 Hand screen printing showing stops, rail and bracket

Figure 2.2 Pitch marks: the first screen prints all the circles and a cross in the first circle, the second screen prints colour in the second circle and a cross in the first circle, the third screen prints colour in the third circle and a cross in the first circle

one, is usually left until last as the larger amount of colour is more likely to cause loss of adhesion between fabric and table, with subsequent loss of registration.

The manual process has been semi-automated by mounting the screen in a carriage and driving the squeegee mechanically across the screen (Figure 2.3). Long tables, typically 20–60 m long, are used, and some provision is usually made for drying the printed fabric. Semi-automated flat-screen printing is still very popular where the scale of production is not large, or where capital investment is limited. In both hand and semi-automatic flat-screen printing the colours are printed one after another with time for drying, which means that the situation approaches 'wet-on-dry' printing. Hence sharper results, especially for fall-ons (see section 2.5.3), can be achieved than is possible by printing all the colours in more rapid succession ('wet-on-wet').

Perhaps surprisingly, the level of automation for one-colour-at-a-time flat-screen printing has advanced a great deal recently. Instead of a flat, stationary table, a moving blanket is incorporated, as in fully automatic machines (discussed in section 2.3). The fabric is printed with the first screen, and passes round the end of the table and beneath it before being printed with the second screen, which can be positioned at a second station while the first colour is being printed. Clearly a good adhesive is required to prevent the fabric from becoming detached on its upside-down return journey.

Even more sophisticated developments have been introduced. The Italian company Viero have robotised the process completely. The operative at the console controls the robot, which lifts the screen from its rack (Figure 2.4), positions it accurately in the carriage, fits the squeegee, and then proceeds to collect the bucket of print paste, which it places on a shelf above the screen. It then tips the bucket to pour in the paste. Needless to say, the rest of the process is also automated.

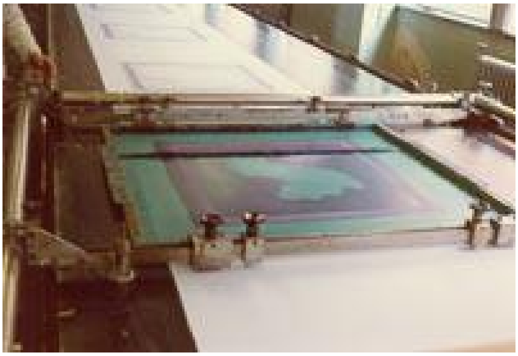

Figure 2.3 Semi-automatic flat-screen printing; in this machine the rod squeegee is rolled across the screen by means of a moving electromagnet under the blanket (Zimmer)

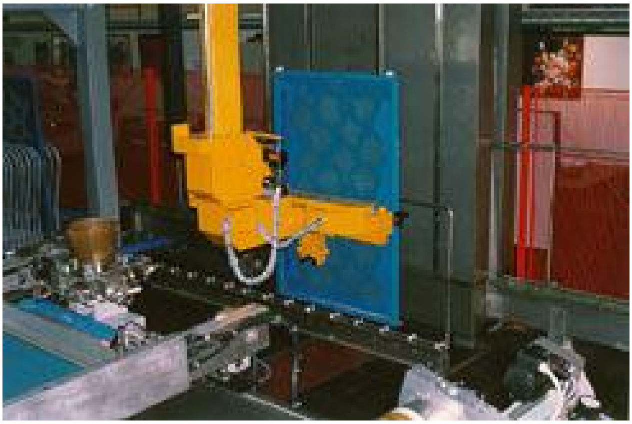

Figure 2.4 Robot lifting a flat screen from the rack prior to fitting it on the printing machine (Viero)

2.3 FULLY AUTOMATIC FLAT-SCREEN PRINTING

In order to increase the speed of flat-screen printing, it was necessary to devise a method of printing all the colours simultaneously. Unfortunately, flat screens are not suitable coloration units for a truly continuous process, and in all the successful machines for fully automatic flat-screen printing the colour is applied through the screens while the fabric is stationary.

The main features of a typical automatic flat-screen machine are illustrated in Figure 2.5 and shown diagrammatically in Figure 2.6. All the screens for the design (one screen for each colour) are positioned accurately along the top of a long endless belt, known as a blanket. A machine intended to print traditional furnishing designs might have space for 15 or more screens. The width of the gap between the areas printed by any two adjacent screens must be a whole number of lengthways design repeats. This need not necessarily be the same as the lengthways screen repeat as there may be several design repeats per screen repeat; for example, where there are three design repeats per screen repeat, the gap between adjacent screens need only be one-third of a screen repeat.

The fabric is gummed to the blanket at the entry end and moves along with the blanket in an intermittent fashion, one screen-repeat distance at a time. All the colours in the design are printed simultaneously while the fabric is stationary; then the screens are lifted and the fabric and blanket move on. When the fabric approaches the turning point of the blanket, it is pulled off and passes into a dryer. The soiled blanket is washed and dried during its return passage on the underside of the machine.

Figure 2.5 Fully automatic flat-screen printing machine (Buser)

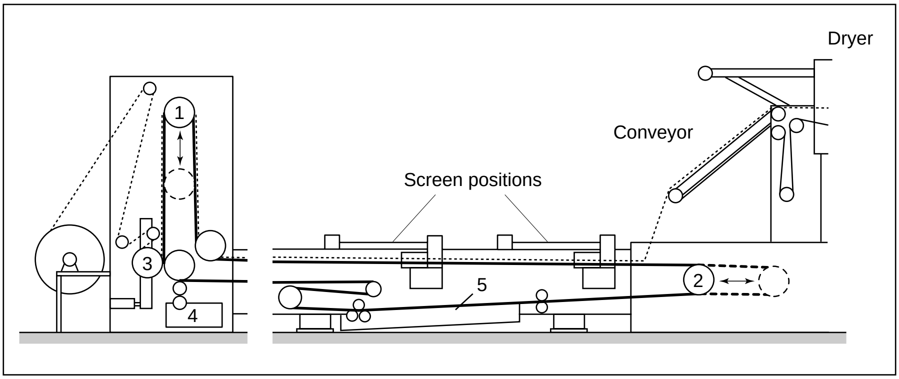

Figure 2.6 Fully automatic flat-screen printing machine (simplified diagram); rollers 1 and 2 move as shown, to maintain the lower side of the blanket in constant motion, 3 is the pressure roller, 4 the temporary adhesive application unit and 5 the blanket washer (Buser)

2.3.1 Adhesive systems

When fully automatic flat-screen machines were first introduced, it was quite common to combine the fabric to be printed with a back-grey, especially if the fabric was lightweight (section 2.2). As adhesives and methods of their application were improved, this practice became less important. The method which then became established, and which is still in use in many plants, is to apply a water-based adhesive to the blanket at the entry end, by means of a brush running in a trough containing the adhesive solution, and to spread the layer more evenly with a rubber squeegee; the fabric is then pressed against the tacky blanket with a pressure roller. A hot-air dryer is sometimes employed to dry the adhesive before the fabric is printed.

The alternative to the continuous application and removal of aqueous adhesive is the use of a tacky semi-permanent or 'permanent' adhesive on the blanket. Such adhesives, often based on acrylic copolymers, can withstand the washing necessary to remove excess print paste without becoming detached from the blanket. Their permanence is limited, however, replacement being required after perhaps two weeks' printing, and permanent thermoplastic adhesives have proved more satisfactory. These adhesives are coated on to the blanket and are only tacky when heated. Heat can be applied either directly to the adhesive layer or to the fabric, in order to achieve the required bond. Such thermoplastic adhesives often remain serviceable during the printing of several hundred thousand metres of fabric.

2.3.2 Squeegee systems

When flat screens are used for printing, the paste can be spread across the screen either along the length, or across the width. The latter has been used more, possibly because this was the tradition for hand printing narrow fabrics, but it also has the advantage that no pressure is exerted on already printed areas at the end of the stroke. One, two or more passes of the squeegee can be made as required. Again, hand-printing practice had an influence. The two most popular squeegee systems are described below.

Double-blade squeegee

This system is illustrated in Figure 2.7. A pair of parallel rubber-blade squeegees is driven across the screen with the print paste in the gap between them. Only the rear squeegee makes contact with the screen, the leading squeegee being raised slightly above it. When the next stroke is made, the leading squeegee for the first pass becomes the rear one for the reverse direction.

The double-blade arrangement is simpler to construct than one utilising a single squeegee that has to be lifted over the pool of print paste at the end of each stroke, although this type is found in some modern semi-automated machines.

Magnetic-rod squeegee

A completely different approach was adopted by Zimmer, who invented a rolling-rod squeegee moved by an electromagnet, driven intermittently under the blanket. This type of squeegee is used in Zimmer flat- and rotary-screen printing machines, except that the electromagnet is stationary in the latter case. In fully automatic flat-screen

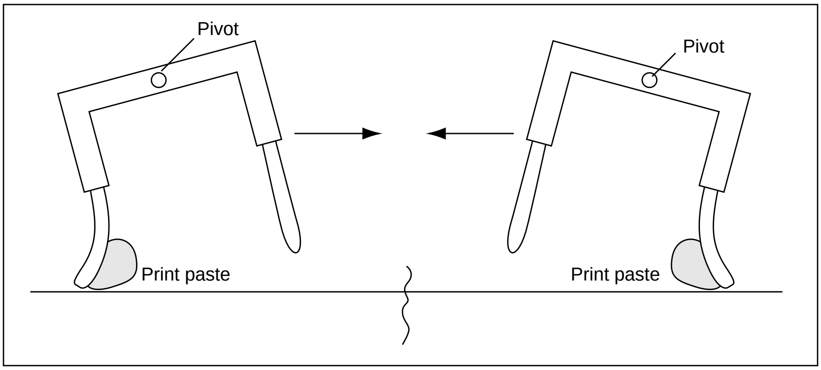

Figure 2.7 Double-blade squeegee arrangement

machines the rod rolls in the lengthwise direction and one passage is usually all that is required for adequate cover and uniformity. The diameter of the rod is usually small enough to allow print paste to flow over and round it at the end of a pass. It is clear that screen distortion and wear are less where rolling rods, rather than rubber-blade squeegees, are used.

2.3.3 Intermittent movement

The intermittent movement presents a variety of problems for engineers and printers, and these are summarised below.

Accurate movement of the blanket

It was discovered at the development stage that controlled movement of the blanket could not be provided simply by a motor-driven roller at one end of the machine. The blanket tended to slip and overrun, and a more positive control of the movement was required. Stretching of the long rubber-coated, laminated neoprene blanket also introduced inaccuracies. Some early machines incorporated a continuous metal strip along the edges of the blanket to reduce its extensibility and provide accurate edge location, but modern machines more often employ a series of electromagnetically or hydraulically operated clamps which grip the edges and move the blanket precisely one repeat distance without stretching it. The drive for the forward movement is usually hydraulic.

Discontinuity of gumming and washing

When water-based gums are being used, a line of excess gum is likely to be produced each time the blanket stops moving, which in extreme cases may affect the levelness of the print. The blanket, on its return passage, will also receive an irregular degree of washing. The Swiss company Buser have introduced an ingenious method of overcoming these difficulties which enables a blanket to move continuously on the return passage under the machine and in the feed-in unit. Guide drums at both ends act as compensators to allow the simultaneous, intermittent and continuous running of the blanket (Figure 2.6).

Control of fabric speed through the dryer

After the fabric has been printed it passes through the dryer, often being supported on a conveyor belt. Some machines also allow for the fabric to be supported between the end of the blanket and the entry to the dryer, particularly if the entry point is much higher than the blanket. Here also the intermittent movement may cause problems of variable stretching and overdrying. Ideally the fabric should move through the dryer at a constant speed equal to the average linear velocity of the blanket, but this is not always possible. The limits between which the fabric can be lifted off the blanket are the end of the last screen and the end of the top linear surface of the blanket. One technique often employed to maintain the fabric within these limits is to restrict the angle at which the fabric is removed from the blanket with the aid of photoelectric cells and light beams (Figure 2.8). When the fabric reaches light beam A the drive of

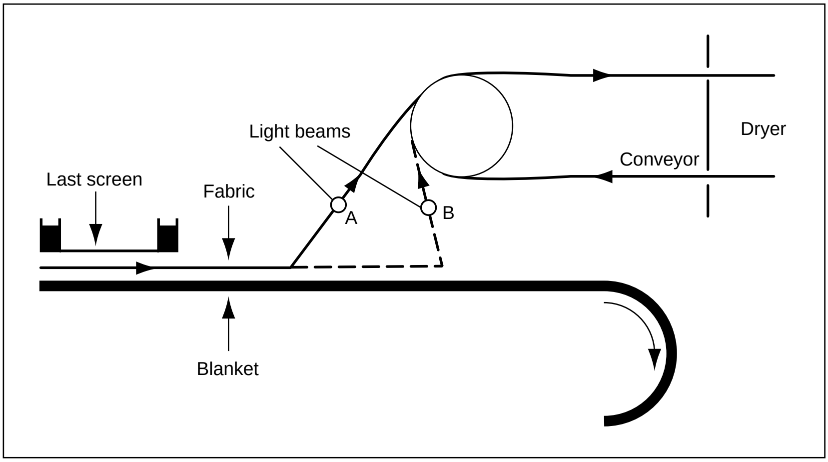

Figure 2.8 Photoelectric device to control dryer conveyor

the dryer conveyor belt is stopped and when it reaches light beam B the drive is started again. Alternatively, a single diagonal beam can be used.

2.3.4 Production rate

The production rate depends primarily on the time interval during which the fabric is stationary. The speed at which the blanket is advanced is much less important, as the blanket is in movement for considerably less time. Speed of advance has to be restricted, as at high speed the system would have so much forward inertia that there would be a tendency for the fabric to overrun the blanket.

The other factors that play an important role in the determination of the overall production rate are listed below.

Number of squeegee passes

Sometimes more than one pass is required to achieve uniformity and adequate penetration, especially in blotch areas. This applies particularly to thick fabrics and those with irregular surfaces.

In some machines the squeegees can be used to make a stroke while the screens are in the raised position (known as a 'flood stroke'). This fills the mesh in the printing areas of the screen with paste before the screen touches the fabric, and more colour is applied with the first stroke when the screen is lowered.

Repeat size

Where the squeegee movement is widthwise, the greater the lengthwise repeat the further the blanket moves forward at each pass; consequently the printing speed is greater. The effect is less marked if the squeegee movement is lengthwise, as the squeegee will take longer to move along the screen where the repeat distances are large.

Efficiency of the dryer

If the dryer is short, or if the temperature in the dryer is too low, the printing speed will have to be reduced in order to ensure that the printed fabric is adequately dried. This is particularly critical for designs in which a high proportion of the total area is printed (high percentage cover).

2.3.5 Printing faults

Some faults in automatic flat-screen prints are due to poor registration (misfitting of the colours in the design); others are associated with screen frames falling on wet areas of the printed fabric.

Registration

It has already been pointed out that accurate movement of the blanket exactly one screen-repeat distance, each time it is advanced, is essential for the correct registration of the colours in the design, and that inadequate adhesion of the fabric to the blanket will cause local misfitting. Another cause is screen distortion due to excessive drag exerted by the squeegee. This is especially likely where rubber-blade squeegees are used and the design contains large repeats.

Frame marks

When printing consecutive screen repeats, the screen frame inevitably falls on part of the area most recently printed and may leave an impression. This is a particularly difficult problem for blotch screens where large amounts of print paste are applied. The problem is reduced in hand screen and semi-automatic screen printing by printing alternate screen repeats and then moving back to fill in the gaps, but this is obviously not possible in automatic machines, since in these the movement of the blanket is always in the same direction. On the other hand, it is more serious in fully automatic screen printing as the printing speed is much higher, so that there is less time for intermediate drying or penetration of the fabric.

One technique used to avoid this fault is known as off-contact printing. The screen frame is lowered to a point only just above the blanket, the gap being so small that, as the squeegee passes and stretches the screen fabric, the printing area of the screen makes contact with the fabric being printed.

A related problem is the crushing of colours by succeeding screens, which is most serious when the screens are close together and the printing speed is high. Off-contact printing obviously reduces the problem and the screens should be spaced out as much as possible. If necessary, the printing speed is reduced. Printing a blotch as the final colour is also normal, to avoid this effect.

Splashing

When screens are lifted symmetrically after printing (that is, with the screen remaining horizontal), print paste in the space beneath the screen can often remain in contact with the screen momentarily and then splash back on to the fabric. This can be avoided, or at least reduced, by lifting the screens at one side just before the other. Inevitably, however, this does slow down the overall printing speed a little.

2.3.6 Current utilisation

In the UK fully automatic flat-screen printing is primarily used for the printing of good-quality furnishing fabrics. The method is well suited to the large repeats and large motifs often used on these fabrics. In addition, the printing speeds are relatively low (300–600 m h^{-1}) compared with rotary-screen or copper-roller printing, and this allows time for any printing faults to be noticed and corrected before much expensive cloth is spoiled.

2.4 ROTARY-SCREEN PRINTING

Fully automatic flat-screen machines cannot be described as operating continuously, because their printing action is in fact intermittent. Continuous movement of the fabric has been achieved by moving the screens along with the fabric while printing (the American Precision Midas machine, for example, is of this type), but the use of rotary-screen machines has proved to be a simpler and more economical means of achieving this goal.

In rotary-screen printing, continuous rotation of a cylindrical screen while in contact with the fabric ensures genuinely continuous printing. Print paste is fed into the inside of the screen, and during printing is forced out through the design areas with the aid of a stationary squeegee. Figure 2.9 illustrates some of the squeegee types in use.

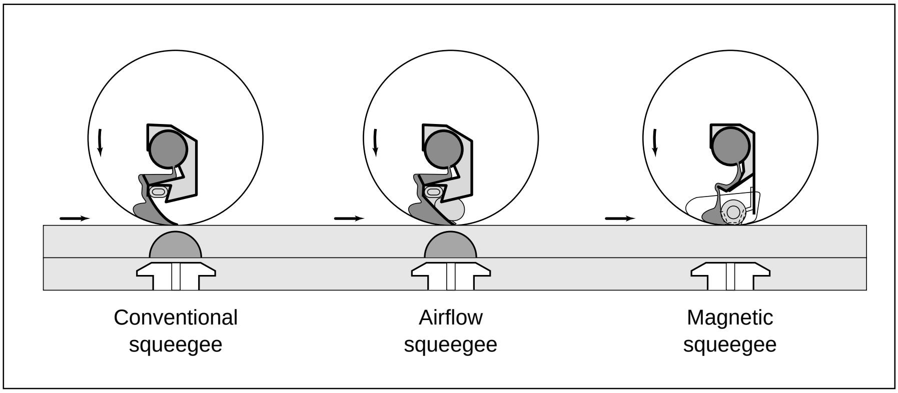

Figure 2.9 Rotary-screen squeegee systems (Stork Screens BV)

In the case of flexible-blade squeegees, the rotation of the screen in contact with the stationary blade builds up the pressure to force the paste through the screen. This is, of course, the converse of flat-screen printing, where the screen remains stationary while the squeegee moves.

A typical rotary-screen printing machine is shown in Figure 2.10. The design of most machines follows the pattern established for fully automatic flat-screen machines: an endless driven blanket, screen positions along the top, and blanket washing and drying effected underneath during the return passage. Provision for the use of a thermoplastic adhesive is common on rotary machines, with a curved-surface heating plate to heat the fabric before it is pressed on to the blanket. The cylindrical screens can be much closer together than is possible with flat screens and so the blanket is shorter (for a given number of colours). The fabric dryer, however, must be longer to enable the printed fabric to be adequately dried at higher running speeds. Typically, speeds of 30–70 m min^{-1} are used depending on the design and the fabric quality. It is quite possible to run the machine faster than this, the limitations often being the length and efficiency of the cloth and blanket dryers and the difficulty of observing printing faults at high running speeds.

Print paste is often poured into flat screens by hand, even in fully automatic machines, but the continuous movement of a cylindrical screen and the restricted access necessitates automation of this operation. The print paste is pumped into the screen through a flexible pipe from a container at the side of the machine; inside the screen, the paste pipe has a rigid structure as it also acts as a support for the squeegee. Holes in the pipe allow the paste to run down into the bottom of the screen; since the paste is pumped in from one end, the holes need to be larger at the end furthest from

Figure 2.10 Rotary-screen printing machine (Stork BV)

the pump to achieve an even spread across the full width of the screen. A sensor (level control) actuates the pump when the paste level falls below a preset height.

2.4.1 Squeegee systems

The first squeegees used by Stork were of the traditional rubber type, but excessive wear of the rubber, due to the continuous movement, and the drag on the inside of the screens, which caused screen distortion, soon led to their replacement with flexible, stainless steel blades.

The curvature of the blade, and hence the angle of contact between the blade and the screen, changes according to the applied pressure, which can be readily altered by adjusting the bearings at both ends of the squeegee assembly.

Sideways movement is also possible so that the line of contact of blade and screen is not necessarily at the lowest point in the screen. Length and stiffness of the blade are also useful variables.

If the squeegee pressure is uneven, the volume of print paste applied across the width will vary, resulting in an unlevel appearance in the final print. This problem is most serious when printing wide fabrics, and special measures are used by some machine manufacturers to overcome it. For example, the Reggiani squeegee system consists of a phosphor bronze blade against which a rod is pressed by an inflated air sack, thus ensuring even pressure.

The Zimmer brothers continued to use the magnetic-rod squeegee system in their rotary machines. In machines with flexible-blade squeegees one boundary of the pressure wedge between rod and screen is stationary, but with rod squeegees both boundaries are moving (Figure 2.11). In most rotary machines there is a resilient bed under the screen position, and with high magnetic-field settings or when large rods are used the screen is likely to be distorted. This increases the contact area of rod and screen and, coupled with extra pressure introduced by the two moving surfaces, results in a higher minimum amount of paste being forced through the screen than with a stationary, metal-blade squeegee [4]. When printing lightweight synthetic fabrics or transfer paper, a metal blade is therefore often preferred to a rod.

Now that the original patents have run out, magnetic-rod squeegees and blades supported by air sacks (such as the Stork Airflow) are being more widely used. A full comparative analysis of magnetic-rod, blade and other types of squeegee used in rotary-screen printing has been carried out by Ferber and Hilden [5].

2.4.2 Setting-up to print

Although the walls of seamless nickel screens are only about 0.1 mm thick, they are

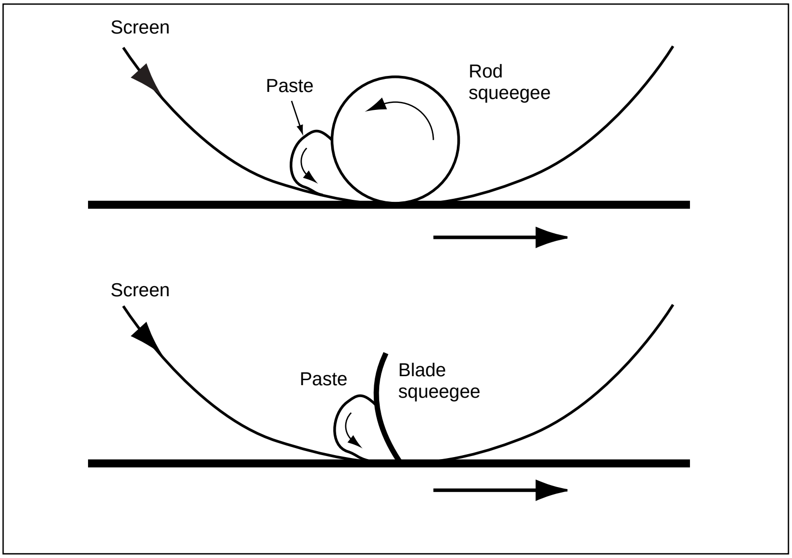

Figure 2.11 Rod and blade squeegees

strong enough to be rotated provided they are put under lengthways tension. Light aluminium alloy end-rings are fitted to the ends of the screen, care being taken that the plane of the ring is at right angles to the axis of rotation of the screen. Notches in the end-rings fit into the mountings (heads) on both sides of the blanket and a turn of the screen locks it firmly in position. Tension is then applied by moving the head furthest from the pump outward. The height of the heads can be adjusted so that the bottom of the screen is either just in contact with the blanket or higher up to allow for the thickness of the material being printed. When all the screens are in position, squeegee assemblies and level controls are fitted, and adjusted, and the flexible colour pipes connected.

Screen end-rings are usually fitted into closed bearings, but Peter Zimmer machines incorporate an open bearing system (Figure 2.12). This allows rapid screen changes, and readily accommodates variations in screen diameter.

When starting to print a multicoloured pattern the screens are adjusted while running in order to achieve registration of all the colours in the design. Several metres of fabric are wasted as a result. This problem has been overcome by German machine makers MBK, who have introduced a laser screen registration system for accurate alignment of rotary screens prior to printing. A red helium/neon laser beam shines down the length of the machine, and the screens are adjusted until the beam shines through the pitch marks.

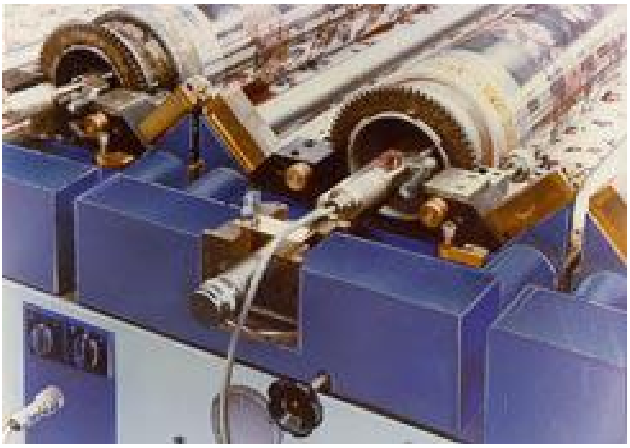

Figure 2.12 Open bearing (Johannes (formerly Peter) Zimmer)

2.4.3 Blanket and screen drives

Some rotary screens are driven from both sides to avoid the danger of twisting and buckling (Figure 2.13). If there is a direct link between the blanket and screen drives, correct fitting should be ensured even during speed changes, provided that the blanket does not slip on the driving rollers. The shorter blankets of rotary machines and their continuous motion substantially reduce the problems of extension and sideways movement often experienced with flat-bed machine blankets. Nevertheless, blankets of low extensibility are required.

The fitting of patterns during an extended printing run is sometimes less than satisfactory, especially with wide fabrics or when printing pile fabrics or carpets. One explanation, put forward by Peter Zimmer, is that these materials exert a considerable drag on the screens so that they are pulled round slightly in advance of their correct position. Eventually, at a seam perhaps, the screens will spring back and the pattern registration will be affected. Zimmer claims to be able to overcome this problem by running the screens at a slightly slower speed than that of the blanket. Stork have also introduced this facility into their most recent machine, which features independent speed control for each screen. MBK also make use of stepper motors for the same purpose.

2.4.4 Large repeats

The standard internal circumference of cylindrical nickel screens for printing textiles is 640.0–640.1 mm. A wide range of screen diameters may be obtained, however, as this

Figure 2.13 Rotary-screen printing machine showing printing heads, screens, connecting columns and screen drive shafts (Johannes Zimmer); one screen end-ring fits into a printing head (foreground) which includes squeegee support and setting fixtures; the end-ring at the far side is also driven by means of a drive shaft (left of screen); rectangular connecting columns on the left and right of the screen enable the position of the heads to be adjusted to suit various screen lengths

dimension depends solely on the diameter of the mandrel on which the screens are electroformed [6]. Rotary screens of circumferences 518, 537, 640, 668, 688, 725, 801, 819, 914 (the most common of the larger screens) and 1018 mm may be obtained as standard. But even the largest screens will not provide as large a repeat as a large flat-screen or a carpet loom. Following the jumper technique used in copper-roller printing, Peter Zimmer solved the problem of large repeats by using a system of intermittent raising and lowering of screens. A particular colour in the pattern might then be printed in sections by two or three screens. The design areas do not fill the complete circumference of the screens, the remaining blank portions being provided so that when the screens are in their raised positions print paste will not drip through them. Other machine manufacturers have also introduced this feature as an option.

2.4.5 Recent developments

Rotary-screen printing machines are expensive, and it therefore pays to keep downtime to a minimum. In their latest machine Reggiani have introduced the idea of washing screens between colourways on the machine. After printing the first colourway excess paste is pumped out of the screens, which are then sprayed with water from the inside while still in position on the machine.

Most manufacturers now offer microprocessor control coupled with computer management packages. All the essential data for a print run are recorded, including machine settings, so that when the design is printed again it can be set up much more quickly.

2.5 DESIGN ASPECTS

2.5.1 Design selection

When planning to produce and market a print, the design and fabric quality must first be selected. The design should suit the end-use envisaged: small motifs, stripes or checks for men's shirting, for example, or larger motifs and repeats for furnishing fabrics. The artist's original design, often called the 'croquis' (a French word), will probably not be drawn in repeat; it may moreover require amendment of scale and of the number of colours. At this point it is necessary to decide which printing method will be used, as the lengthwise repeat is subject to the limitations of the screens or rollers chosen; for example, the repeat is likely to be 64 cm or a simple fraction of this for rotary screens.

2.5.2 Repeat sketch

The individual design units (repeats) must fit together perfectly in order to avoid the appearance of discontinuities that become visible when long lengths of fabric are inspected. To this end, the croquis is redrawn to give a modified version known as a repeat sketch. At this stage the arrangement of repeats must also be fixed. Some common arrangements are shown in Figure 2.14.

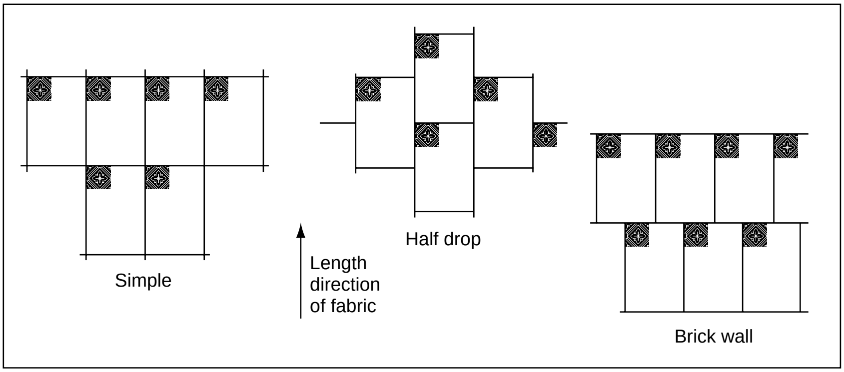

Figure 2.14 Repeat arrangements

During the preparation of the repeat sketch for a simple repeat, a repeat rectangle is often produced. This is halved vertically and horizontally, top halves then being moved to the bottom and left to right. The outer areas are then in repeat, and the central part has to be redrawn.

The boundary of the repeat in the final version is usually disguised by following the edges of motifs as much as possible – the 'line of least resistance' (Figure 2.15). It is particularly important that the boundary should not run through the middle of a blotch, as it would show up as a dark line in the final print. This is because a touch fit is very difficult to achieve, and so an overlap would have to be used (see below).

2.5.3 Colour separations

Once the repeat sketch has been produced, the next step is to separate the colours in the design. This is done by reproducing the design areas of each colour separately on a clear (or translucent) dimensionally stable film. The colour separations (or diapositives, as these painted films are termed) were usually hand-painted positives produced using opaque paint. This laborious process has now been automated by using programmed photoelectric scanners (see section 2.6.1).

Figure 2.15 The 'line of least resistance'; the broken line indicates how the edge of the repeat skirts motifs and cuts across the shortest gap when the design includes a blotch

At this stage decisions must be taken with regard to the juxtaposition of the various colours in the design.

Overlap

Adjacent colours in a design for screen printing are usually made to overlap slightly, the degree of overlap depending on the type of design, the printing width and the nature of the fabric to be printed. If this precaution is omitted, unsightly gaps appear when registration errors occur during printing. The overlap is kept to a minimum as the third colour, formed when two colours overlap, can also be unsightly. In copper-roller printing a slight gap (or 'allowance') is left between colours at the diapositive stage (see section 1.3.3).

Design interpretation

In certain designs, particularly those containing tonal areas such as flower petals, it is advisable to print one colour on top of another. The result is known as a 'fall-on'. Usually, however, a space on the fabric is reserved (or 'saved') for each colour.

2.5.4 Step and repeat

Once a single repeat of the design has been redrawn in a suitable form it must normally be replicated in the correct arrangement (see above) so as to fill the screen, and cover the full width of the fabric to be printed. In flat-screen printing the design area should not reach the frame, as there must be room for the paste reservoir at the ends of each stroke of the squeegee, and at the sides the blade is unlikely to fit the width of the screen precisely. Such considerations do not apply to rotary screens, and here a whole number of repeats has to fit around the circumference. Thus for a 64 cm circumference screen, for example, the repeat must be 64 cm or a whole number fraction of this (32, 21.33, 16 cm and so forth).

When flat screens are being photopatterned multiple exposures of the positive for a single repeat are carried out directly on to the coated and dried screen, using a 'screen step-and-repeat' machine (see section 2.7.2). This method cannot be used for a cylindrical screen, and so for rotary screens (and for photogravure) the step-and-repeat process is carried out at the film stage. The single-repeat colour separation positive must first be converted into a negative, after which multiple exposures are made on to a large piece of photographic film. In both cases the borders round the single repeat must be carefully masked, so as to protect unexposed screen or film.

2.5.5 Registration

It is essential to include registration lines or crosses on each colour separation film during its preparation; often they are added in blue ink so that they do not show after exposure of the screen to blue light. They are lined up when the completed separations are checked for registration by placing them one on top of another over a 'light table' (a glass-topped table illuminated from beneath the glass). Pitch marks (Figure 2.2) are often used to check registration during printing.

2.6 COMPUTER-AIDED DESIGN

By far the most important developments in printing of recent years have been in the field of computer-aided design (CAD). Associated with these advances has come laser engraving, and also the proofing of designs on paper or fabric before screen engraving. All these depend upon the successful digitisation of the design, that is, the conversion of design information into binary code in a form that can be stored in the memory of a computer.

Until recently customers have generally placed orders after strike-offs have been submitted. (A 'strike-off' consists of a few metres of the correct fabric printed with each colourway of the design.) These are normally produced on a sample table so as to avoid interrupting work on the large-scale machine. Unfortunately, many of the designs that reach this stage are never printed in bulk, and so the expense of screen engraving has been wasted. The use of CAD substantially reduces the time taken to produce repeat sketches, colour separations and colourways; when the design system is linked to an ink-jet printer for proofing (see section 2.6.4), this may allow the decision to engrave screens to be delayed until orders are forthcoming [7].

2.6.1 Scanning

Although it is now possible to create a design on the colour graphics monitor of a CAD system using a 'Paintbox' or similar software package with a pressure-sensitive stylus or a mouse, most designs are still produced in the traditional manner, with paintbrushes or airbrushes on to paper or card. The original artwork is then digitised by means of a scanner. Design information is stored in the computer memory, one pixel (picture element) at a time. A scanner analyses the design one line (that is, one row of pixels) at a time, converting analogue colour information into digital form.

For small designs up to A3 size, a flat-bed desktop scanner will suffice. Typically such scanners use a single CCD (charge-coupled device) sensor for detecting the light reflected from parallel filtered red, green and blue fluorescent lamps, with a maximum scanning resolution of 300 dpi (dots per inch). The scanning speed varies with the resolution, but the maximum is 30 ms per line. At this speed an A4-sized design takes 99 seconds to scan.

Larger designs require rotating-drum scanners, one of which is shown in Figure 2.16. This scanner utilises a xenon light source with red, green and blue interference filters, and a photomultiplier sensor. The width of the drum is 1160 mm and its circumference 1168 mm. The drum rotates at up to 900 rev min^{-1} and the resolution for colour work is 3–33 dots mm^{-1} horizontal and 5–80 dots mm^{-1} vertical. Digitised design information from the scanner is sent to the CAD system.

2.6.2 Colour reduction

The normal procedure is to scan a design at relatively low resolution, and then display it on a colour monitor. At this stage any variations in colour, whether intentional or not, will show, and the software allows the design to be divided into a large number of colours. The next step is colour reduction, whereby the design is simplified into a manageable number of colours. After further editing the design is then rescanned at a higher resolution.

2.6.3 CAD operations

A typical CAD software package will allow a large number of manipulations to be carried out. Options would probably include:

– putting the design into repeat, e.g. quartering for a simple repeat
– scaling the design to fit screens

Figure 2.16 Drum-type colour scanner interfaced to CAD system (Stork Screens BV)

– drawing and brushing
– Mirror, Inverse and Replicate functions
– overlap
– fall-ons
– capturing, copying, moving and scaling motifs
– zooming in on small areas in order to edit them
– filling in colours
– changing colours
– shading and stippling
– colour separation
– dot removal (deleting stray dots in a colour separation).

Optical discs are becoming the most common way of storing design information, replacing magnetic tape. The capacity of currently available optical discs is up to 600–650 Mbytes, while a typical design may require 20–100 Mbytes.

When the designer is satisfied, design information can be downloaded to a film plotter or laser engraving machine via an Ethernet link, but more often it is quicker to transfer the disc by hand. Nowadays, more and more screens are being engraved without the need to produce colour separations on film [7].

2.6.4 Proofing

The hardware associated with most CAD systems will include a colour printer. 'Proofing' is the term used for the production of initial coloured hard copy in the graphics industry, and it is becoming accepted in textile CAD parlance.

There are several varieties of computer-controlled colour printer, including ink-jet, thermal and sublistatic. Of these, ink-jet printers are the most widely used. Jet printing has been thoroughly reviewed by Dawson [8]. The manufacturers of ink-jet printers use various methods of creating a large 'palette' of colours, but they all utilise the subtractive primaries (cyan, magenta and yellow) and, usually, black for the ink colours (so-called CMYK printing).

An extended range of colours can be produced by the following means:
– using several concentrations or jet diameters for the primary inks (for example, the Canon FP 510 has three levels each of cyan and magenta, and one of yellow and black)
– varying the dot size (for example, the Stork Ink-Jet uses streams of tiny charged droplets, and up to 32 of these coalesce as a dot on the paper)
– using a 'dither pattern', that is, a spatial arrangement of dots of the primaries within a grid or 'matrix'.

When a dither pattern is used there has to be a compromise between the number of squares in the matrix and the resolution of the printed design. Thus, if a 2×2 matrix is used the number of colours in the palette is smaller than if a 4×4 matrix is used, but the resolution is twice as high.

Proofing with ink-jet printers is currently being heavily promoted, but there are two major drawbacks. In charged-drop printers the ink is flowing continuously; thus a small design on a large white ground uses as much ink as a design with 100% cover. As a result, expensive ink is wasted if the design requires no ink at a particular point. The other problem is that jets can get blocked, and care must be taken to flush out with solvent when the printer is not in use.

The resolution of paper printers is often as high as 400 dpi, much higher than the mesh in rotary screens. The quality of hard copy obtained from CAD systems using ink-jet printers is high, and a wide selection of colourways and design variants or coordinating designs can be presented to customers. Matching the colour of the paper print (under specified lighting) to the colour on the display requires the printer to be calibrated (characterised) [9]. Colour fidelity from screen to fabric is best achieved via synthetic reflectance curves and computer match prediction [10,11].

Print producers have, however, always shown a reluctance to accept representations of designs on paper. Process inks designed for printing on chalky coated paper do not print very satisfactorily on to fabric. As a result Stork, in conjunction with ICI (now Zeneca), have developed a new ink system designed for printing on to fabric [12]. The inks contain highly purified reactive dyes, and are suitable for printing on to specially prepared cotton, rayon, wool and silk fabrics. The strike-offs or ‘proofs’ are steamed and washed off as usual. The Trucolor printer was launched by Stork at the 1991 ITMA machinery show. No doubt other jet printers will follow, using disperse dyes of low r.m.m. (molecular weight) for transfer printing on to synthetic fibres.

Conventional direct printing of textiles, however, does not use half-tone CMYK techniques, but instead involves every colour in the design being printed through a separate screen. The question therefore is bound to be whether the proofs, even when printed on to fabric, adequately resemble the final production printed through screens.

2.7 SCREEN PRODUCTION

2.7.1 The photochemical process

Some polymers, in the presence of a sensitiser, will crosslink when exposed to blue or ultraviolet light and so become insoluble. The polymers most used in the preparation of textile printing screens are mixtures of poly(vinyl alcohol) and poly(vinyl acetate), sensitised with a dichromate salt such as sodium or ammonium dichromate, or a ‘diazo resin' (condensation product of formaldehyde (methanal) and *p*-diazodiphenylamine). The poly(vinyl acetate) is added as a dispersion and acts as a cheap filler, but also increases the solids, improves the edge quality and imparts some water resistance to the finished stencil.

Other photosensitive polymer systems have been used for screen making, notably the stilbazole system developed in Japan [13].

In the photochemical method for preparing a textile-printing screen, the screen is coated with photosensitive polymer solution, dried, exposed through the positive and washed with water, all under dark-room conditions. The areas of unexposed polymer coating are washed out of those parts of the screen fabric through which the print paste will pass.

The term 'engrave' is commonly used for the photochemical process described above, but perhaps 'photopattern' would be preferable, since strictly speaking 'engraving' usually implies etching a metal surface.

2.7.2 Flat screens

Screen frames for commercial use are usually made of steel, or a lighter metal, with a hollow cross-section to provide rigidity with minimum weight. The coarser screen-mesh fabrics are usually woven from polyester multifilament yarns, which are cheaper than the monofilaments preferred for fine-mesh screens. Screen fabrics used for printing on to paper, in the graphics industry, are sometimes calendered to reduce the open area and thickness, and are often coloured red or orange to reduce the level of light scatter during exposure, but this degree of sophistication is rarely necessary for textile printing. The choice of screen fabric depends on the fabric and design to be printed. Table 2.1 provides a guide.

In many screen-printed fabrics the edges of the printed areas appear serrated,

Table 2.1 Choice of screen fabrics

	Threads/cm^{-1}	Open area/%
Terry towelling	19–34	47–43
Large blotches, furnishing fabrics	4–49	47–40
Large blotches on smooth fabrics	43–55	43–39
Small motifs	49–62	41–34
Details and outlines on coarse fabrics	55–62	41–34
Outlines, half-tones, fine fabrics, synthetic fabrics	55–100	41–27

although they were smooth curves or straight lines at the colour separation stage. This is known as the ‘saw-tooth effect’ and is an almost inevitable consequence of the design area consisting of a regular array of threads and spaces. The boundary of any motif that is not exactly parallel with the threads in the screen fabric will be stepped, since the holes between the threads are approximately square. Spread of the paste underneath the threads is essential for successful coverage of the fabric, and this tends to reduce the effect; nevertheless it is often visible, especially when coarse screen fabrics are used. The use of fine-mesh screens enables small quantities of low-viscosity paste to be applied, giving rapid but limited penetrations, good colour yield, unbroken fine lines and geometrical objects with minimal saw-tooth effect.

The selected screen fabric is cut to size and stretched, for which pneumatic tensioning equipment may be used. It is then fastened to the frame with a suitable adhesive and degreased (for example, by soaking with 5% caustic soda solution, rinsing and neutralising with dilute acetic acid). A flat screen is coated by standing it against a wall and applying the layer of viscous polymer solution with the aid of a smooth, straight-edged trough by moving the tilted trough from the bottom to the top. The coated screen is dried in a dark cupboard, ideally on a horizontal shelf, with a draught of cool, dust-free air. The coated screen is sensitive to light, and photographic dark-room conditions with safe lights are required during the exposure and developing stages.

Frequently, a number of repeats are to be reproduced on a screen and in these cases it is normal to use a step-and-repeat machine. A positive of the single repeat is fixed to the glass of a light table and the remaining area of glass is blacked out with opaque paper. The coated screen is mounted on a carriage, the sideways movements of which are carefully monitored. After one exposure the screen is moved the exact distance required for the next repeat and a second exposure is carried out, and so on until the screen is completed. (The contact between positive and coated screen is often improved by employing a flexible cover and reducing the pressure between glass and cover.) The screen is then soaked in a tank of water and lightly sprayed to remove the unexposed polymer. After drying and painting out any small holes (pinholes), it can then be reinforced with lacquer (cellulose or polyurethane), the lacquer being removed from the printing areas by suction. As an alternative, some photosensitive polymeric coatings can be further hardened after ‘photopatterning’ by a second exposure to light or by a heat-curing process.

A method of photopatterning flat screens without the use of colour separation films has been developed by Gerber Scientific in the USA. A computer-controlled printer applies an ink containing a water-soluble polymer and a black pigment to a previously coated screen, the coating being the conventional light-sensitive type. The screen is then exposed to light and washed in the usual way.

2.7.3 Rotary screens

Lacquer screens

Lacquer screens, introduced by Stork in 1963 but now available from several manufacturers, have uniformly spaced hexagonal holes arranged in lines parallel with the axis of rotation of the cylinder and offset in alternate lines, as in a honeycomb, for maximum strength. The walls of the holes through the thickness of the screen are sloping, so that the holes are larger on the outside of the wall than on the inside (Figure 2.17). In the screens used for printing textiles the open area, measured on the inside of the screen, varies between 9 and 13% of the total.

Lacquer screens are manufactured by electrodeposition of nickel on to a mill-engraved mandrel [6]. The mandrel is a cylindrical steel roller which is coated with a thin layer of copper by electrodeposition and engraved with the required hexagons using a milling machine. The mill is a small, hardened steel cylinder with the design standing out from the surface (see section 1.3.3). It is pressed against the polished copper and moves along the length slowly while the mandrel and mill are rotated, producing a spiral pattern with no seam.

The hexagon-shaped recesses must next be filled with a polymer which acts as an electrical insulator, after which the copper surface is protected by nickel (or chromium) plating followed by a further filling in of the recesses up to the outer plating level. If the mandrel is nickel-plated it is then passivated (coated with a thin layer of oxide) with chromic acid, in order to prevent it from fusing to the nickel screen. It is then immersed in the nickel-plating bath where it becomes the cathode, while the anode consists of nickel lumps held in nylon bags contained in titanium baskets along the sides of the bath. The composition of the plating bath has not been published, but the nickel compound used is usually nickel sulphate or nickel sulphamate. Other

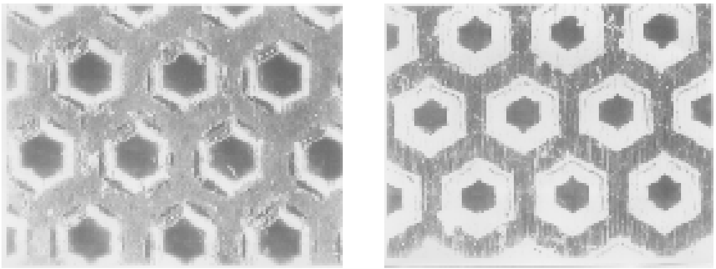

Figure 2.17 Holes in lacquer screens, seen in reflected light (× 50); (left) outside: the sloping sides of the holes are in shadow and barely visible; (right) inside: the holes show as black areas, those areas where the insulator has been bridged during electrodeposition (see Figure 2.18) appear grey, and those where the nickel has been in contact with the mandrel appear white

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common constituents are boric acid and an organic compound such as saccharin, which helps to reduce stress in the electrodeposited layer.

When the nickel layer is about 0.1 mm thick the mandrel is removed from the bath and hosed down, and the nickel screen detached from the mandrel.

As the thickness of the nickel layer builds up it gradually bridges across the insulator (Figure 2.18) so that eventually the holes are blocked. This means that it is not possible to produce screens finer than 100 mesh (holes per linear inch) by this technique, and the finer the mesh the thinner is the wall. The most popular screen meshes are 60 mesh for blotches and motifs and 80 mesh for outlines and synthetic fabrics.

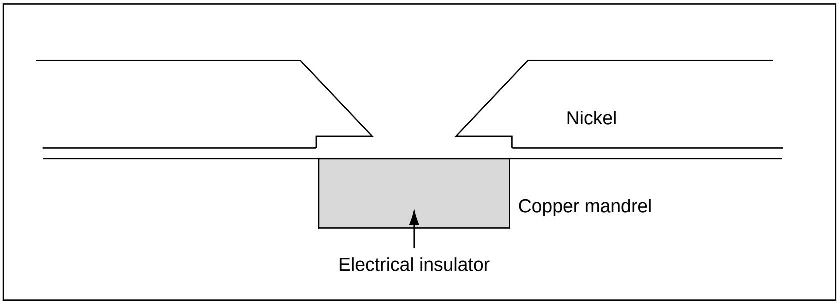

Figure 2.18 Bridging of insulator

Manufacturers of rotary screens have been fully aware of their deficiencies [14]. In particular, the relatively coarse mesh, compared with the fine-mesh fabrics which are available for flat screens, meant that the definition left room for a great deal of improvement, in particular that of fine lines and at the edges of motifs and stripes.

This kind of consideration prompted Stork to modify their electrodeposition procedures. Screens made by the process described above are often described as 'electroformed'. It is widely believed that in the production of finer-mesh electroformed screens the screens are removed from the mandrel and then reimmersed in the plating bath – the so-called 'electroless' process. Stork have introduced lacquer screens known as PentaScreens [15], and more recently, NovaScreens. The two variants are shown in Figure 2.19, and their specifications are given in Table 2.2.

The 125 mesh PentaScreen has a percentage open area similar to the original 60 mesh screen, and the 185 mesh the equivalent to the 80 mesh screen. The profile of each hole from inside to outside is rather different, being narrowest in the centre of the wall, like that of an hour glass. With the new screens it is possible to print a line 0.12 mm thick, which is half the minimum width obtainable previously.

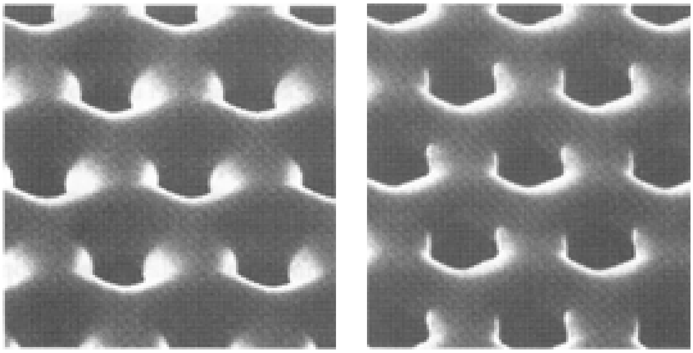

Figure 2.19 Stork PentaScreens (left) and NovaScreens (right) (Stork Screens BV)

Table 2.2 PentaScreens and NovaScreens

PentaScreens		NovaScreens	
Mesh	Open area/%	Mesh	Open area/%
125	15	135	24
155	16	165	21
185	11	195	18
255	7		

NovaScreens feature a combination of high mesh counts and holes that are larger than in equivalent PentaScreens. This favours half-tones (see section 2.7.4), and also allows printing with pastes with high pigment loadings, such as whites and metallics. NovaScreens are slightly thicker than PentaScreens, which makes them less subject to creasing.

The method of introducing the design on to the screens is similar to that used for flat screens, except that the shape of the screens necessitates modifications in the details. A full-size (full-out) positive is usually prepared for rotary screens to avoid the need for multiple exposures of the screen on a step-and-repeat machine.

Stork introduced the annular squeegee for coating screens by hand with photosensitive polymer, starting at the bottom and moving upwards. Modern screen-coating units, however, apply one thick layer of highly viscous emulsion, starting at the top and moving down (Figure 2.20). Besides poly(vinyl alcohol), the lacquers used contain other polymers that promote good adhesion to nickel, such as melamine formaldehyde resin.

Figure 2.20 Semi-automatic rotary-screen coating machine (Stork Screens BV)

The coated and dried screen is placed on an inflatable rubber tube and the full-size positive wrapped round it. The film is carefully positioned on the screen with the aid of the reference lines, using a sliding pointer attached to the exposure machine. This allows the other positives to be aligned correctly on their respective screens. Special care is taken that the junction is accurate, and in this respect greater precision is achieved if the join is nonlinear, as sideways slippage is thus avoided. The rubber tube is then inflated to ensure good contact between screen and positive and the assembly is rotated while the screen is exposed to an ultraviolet light source.

Galvano screens

The other type of rotary nickel screen, called the galvano screen by Peter Zimmer, is manufactured quite differently. The design is introduced at the same time as the nickel is electrodeposited. This means that the nondesign areas are solid nickel instead of a uniform mesh filled with a thin layer of lacquer. They are therefore stronger and less susceptible to pinholes.

A mandrel similar to that used for the manufacture of lacquer screens can be used for the preparation of galvano screens, but Peter Zimmer designed a thin, inflatable nickel tube, known as a matrix, to replace the mandrel. The matrix (or mandrel) is first coated with photosensitive polymer. A full-size negative of the colour separation is required. This is wrapped round the hollow matrix together with a second film on which the required grid pattern is reproduced (Figure 2.21), and the matrix is inflated to provide close contact. The coated matrix is then exposed and washed in the normal way. At this stage the nondesign areas and the supporting mesh in the design areas are free from polymer. Besides defining the design areas, the polymer also acts as a dielectric resist (insulator). The matrix is then mounted in a nickel-plating bath and the nickel screen built up in the same ways as for the lacquer screens. Bridging of the insulator is a more serious problem with galvano screens, and a nominal 80 mesh screen is the finest that can be reliably manufactured.

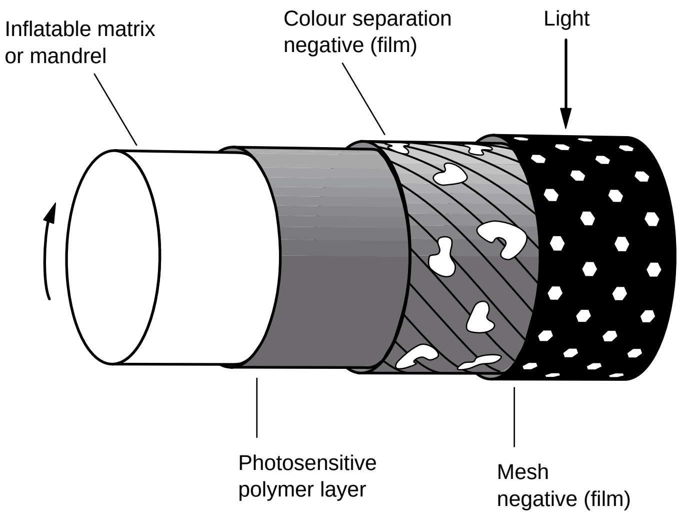

Figure 2.21 Galvano screen manufacture: the exposure step

The pros and cons of the two types of screen are well balanced. For narrow fabrics and fine patterns lacquer screens are probably the best choice, whereas the extra strength of galvano screens has advantages for wide-width printing, especially for rigorous conditions such as those encountered in carpet printing. In this case the wall thickness is 0.35–0.4 mm, instead of the 0.08–0.1 mm used for textiles, and the mesh is much coarser.

2.7.4 Half-tone and multi-tone printing

Half-tone printing (that is, a gradation of tones within one coloured area) is not easy to achieve by screen printing, although it is a common feature of copper-roller prints both on paper (gravure) and fabric (intaglio). Confusion is sometimes caused by the use of the term in the textile field, where it often indicates just two tones, one roughly twice as dark as the other. Half-tone illustrations for screen printing on paper are prepared with the aid of a cross-screen grid which breaks up continuous tones into rows of dots of different sizes, large dots for dark areas and small dots for paler areas. When half-tone positives produced in this way are used to prepare printing screens, interference patterns, known as moiré patterns, are likely to occur unless the angle of the positive relative to the printing-screen mesh is carefully adjusted.

In recent years, with the advent of fine-mesh screens and laser engraving, tonal printing with rotary screens has become possible.

2.7.5 Laser engraving

Laser light (the acronym comes from 'light amplification by stimulated emission of radiation') is highly monochromatic, polarised, coherent and powerful. The use of high-powered lasers for engraving screens is a development from their use for engraving rubber-covered flexographic printing rollers (discussed in section 3.2.2).

The leaders in the laser engraving field have been the British company ZED and Schablonentechnik Kufstein (STK) of Austria. Initially the process was restricted to lacquer-type rotary screens, carbon dioxide (infrared) lasers being used to burn away the lacquer. A thin, even coating of a nonphotosensitive lacquer is applied to the screen, usually starting at the bottom of the cylinder. Electrophoretic coating can also be used [3]. The term 'engraving' is more satisfactory for this method of putting the pattern on to a screen.

More recently, however, flat-screen laser engraving has been introduced by Luscher (Switzerland) and Meccano Systeme (Italy), the development work having been carried out by Mografo A/S (Denmark). The polyester mesh of flat screens would be burned away along with the lacquer by a carbon dioxide laser, and so a photosensitive lacquer is exposed to a computer-controlled argon ion laser (blue-green).

A typical rotary-screen laser engraving machine is shown in Figure 2.22. It features a 1000 watt class 4 industrial laser, sufficiently powerful to allow the machine to be employed for stripping all the lacquer off used screens so that they can be used again.

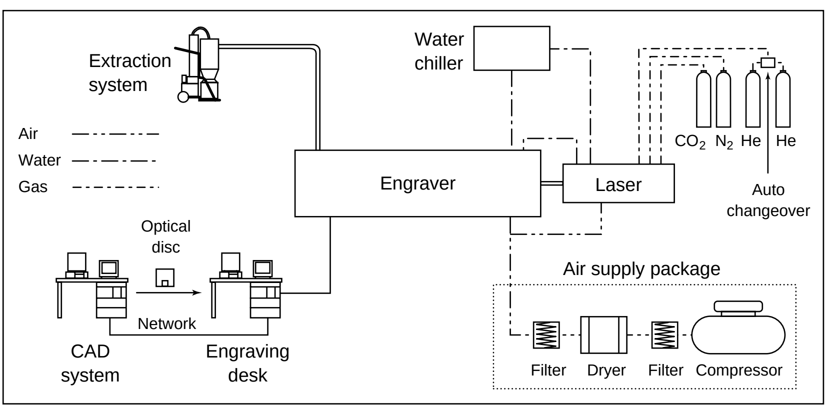

Figure 2.22 Typical configuration of a laser engraving unit (ZED Instruments)

The laser requires supplies of nitrogen and helium as well as of carbon dioxide, and the infrared beam (10.6 μm) is passed from the generator (on the right in Figure 2.22) down the length of the engraving unit. It is deflected at right angles by a mirror and focused by a lens on to the screen. Care is taken to remove all the degraded lacquer with a powerful suction and filter unit, so as to avoid contamination of the optical system.

The coated screen, having been mounted in the engraving unit, must be held precisely in position while it is being engraved. A moving hardened steel guide ring with a diameter slightly larger than the screen has been patented by ZED. The ring runs in three roller bearings which are mounted on the same carriage as the engraving head (Figure 2.23). When a screen is being loaded or unloaded the guide ring is concentric with the screen position. For engraving, the guide ring is moved off-centre, away from the engraving lens. This brings the ring into contact with the screen under light pressure. As the screen is rotated the ring turns at the same speed, so there is very little friction between screen and ring, but it is sufficient to hold the screen securely in position. During engraving the ring moves with the carriage, in front of the beam.

The ZED machine engraves at up to 1.2 m s^{-1}, with a rotation speed of 1000 rev min^{-1}, resolution being typically 100 μm for blotches, and 50 μm for fine lines and fine-mesh screens. Fast conversions of the data formats from a range of CAD systems are available.

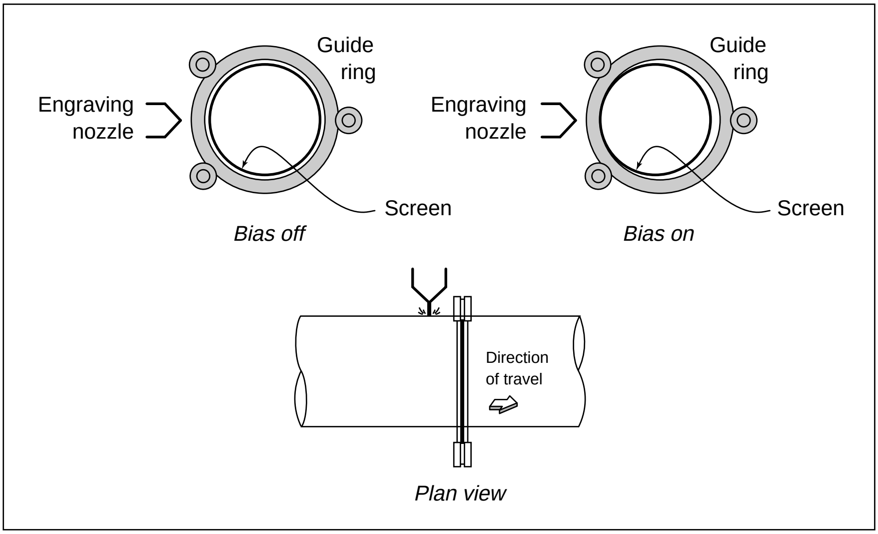

Figure 2.23 ZED Instruments guide ring system (ZED Instruments)

2.8 THE FUNDAMENTAL MECHANISM OF SCREEN PRINTING

In all screen-printing processes a hydrodynamic pressure is developed in the wedge of print paste that lies between the squeegee and the screen. Where a rod or roller squeegee is used, two moving surfaces bring their boundary layers of paste into the wedge and the pressure is higher than with a comparable blade squeegee, other factors being equivalent (Figure 2.11). However, the quantity of paste finally applied to the fabric depends not only on the magnitude of the pressure, but also on the restrictions imposed by the holes in the screen and by the receptivity of the fabric being printed.

2.8.1 Hydrodynamic pressure in the paste wedge

The downwards force *F* (Figure 2.24) on the squeegee is necessary to produce the required angle and to prevent the blade being lifted off the screen, but otherwise has little effect on the hydrodynamic pressure in the paste wedge except that due to any distortion of the screen which may alter the effective squeegee angle.

The hydrodynamic pressure is increased by:

– decreasing the squeegee angle (hence sharp squeegee blades apply less colour than rounded ones)
– increasing the base length of the pressure zone *b*
– increasing the speed of movement of the squeegee *v*
– increased paste viscosity η
– reduced screen-pore radius *r*.

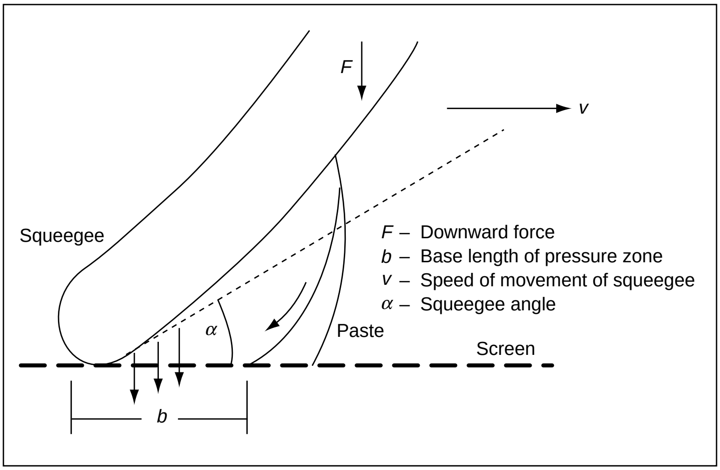

Figure 2.24 Pressure profile of the paste wedge

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2.8.2 Flow of paste through screen pores

Simple flow through holes in screens can approximately be described by the Poiseuille relationship (Eqn 2.1):

$$Q = \frac{Pr^4}{8\eta l} \qquad 2.1$$

where Q is the quantity of the paste flowing through a hole of length l (related to the screen thickness) and radius r, and P is the pressure drop across the hole.

The variables r and η appear in this expression twice, since the pressure drop is produced by the hydrodynamic pressure in the paste wedge and, as has been observed already, this also depends on r and η. The hydrodynamic pressure is inversely proportional to the radius (or to a power of the radius not likely to exceed 2) and thus Q is proportional to r^3 (or r^2). Hence, pore radius has a large effect on the quantity of paste that will flow through a screen.

The hydrodynamic pressure is probably directly proportional to the paste viscosity η, in which case its effect on the quantity of paste flowing through the screen is likely to be negligible.

In addition to the pore size, the percentage of open area (porosity) of the screen has a direct effect on the quantity of paste flowing through a screen, more open screens allowing more paste to pass through.

2.8.3 Uptake of paste by fabric

A variable not mentioned so far, except in discussing the choice of screen mesh, is the nature of the fabric being printed. The three-dimensional form of the fabric (that is, the amount of free space between yarns and fibres), the absorbency of the fibres and penetration between yarns will all affect the uptake of paste. Penetration occurs through the thickness of the fabric, mainly due to the pressure and kinetic energy with which the paste leaves the pores, but sideways spread due to surface tension forces is restricted by the higher viscosity of pseudoplastic pastes under low shear conditions (see section 7.7.3). Some work has been carried out on the fundamentals of the flat-screen printing process [14,16,17], and also on rotary-screen printing [4,5].

2.9 NONTEXTILE APPLICATIONS OF SCREEN PRINTING

The versatility of screen printing is well illustrated by the diversity of applications for which the technique is used. Examples include the production of advertising posters,

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ceramics, wallpaper, packaging and printed circuits. The explanation for this diversity is the wide range in the type and quantity of ink that can be applied through screens.

2.9.1 Screen printing paper

Less ink is required for adequate coverage when printing the relatively smooth surface of paper than for a more markedly three-dimensional textile. The manufacture of fine-mesh monofilament polyester screen fabrics, which can be calendered to reduce the open area still further, allows the successful application of smaller quantities of ink.

Solvent-based inks are usually employed for paper printing, as these dry sufficiently quickly to allow rapid production. The use of solvents in inks has disadvantages, however, as photosensitive screen lacquers having good solvent resistance must be used and solvent sprays are necessary to remove ink from screens after printing.

In the graphics industry the images that are printed on to paper must be as sharp and clear as possible. The use of indirect stencils [21] has catered admirably for this requirement. The technique entails the use of a photosensitive coating, usually gelatin-based, on a clear plastic film. After exposure to actinic light, through a positive of the design, the coated film is washed in warm water and, while still damp, is brought into contact with a prestretched screen mesh. Drying produces good adhesion, after which the plastic support film can be peeled off and the screen is ready for use. The chief advantage of this approach is the excellent image resolution obtained due to the fact that no mesh interference takes place while the stencil is being exposed.

Screen printing of transfer paper

Since the advent of transfer printing, rotary-screen machine manufacturers have gone to some lengths to show that it is possible to print paper without intermediate drying on these machines. The amount of paste applied by the method is much greater than by gravure or flexographic printing (Table 2.3), and heavy (about 70 g m^{-2}) absorbent paper is required.

Table 2.3 Approximate quantities of ink applied to paper

Printing method	Ink applied/g m^{-2}
Gravure	5
Flexographic	7
Rotary screen	15

The new generation of fine-mesh screens, such as Stork PentaScreens [15] and the more recent NovaScreens (see section 2.7.3), have proved very useful for this process. It was pointed out earlier that blade squeegees apply less paste than rolling rods, and should therefore be more suitable for printing transfer paper. Zimmer, however, are still promoting magnetic-rod machines for transfer paper printing [22], particularly for wide widths. They have also designed a machine bearing a resemblance to the Aljaba duplex machine, with the paper being printed while vertical, with support rollers behind each screen, and no blanket (Figure 2.25). This competes with gravure machines for quality of printing, but at widths up to 2.2 m.

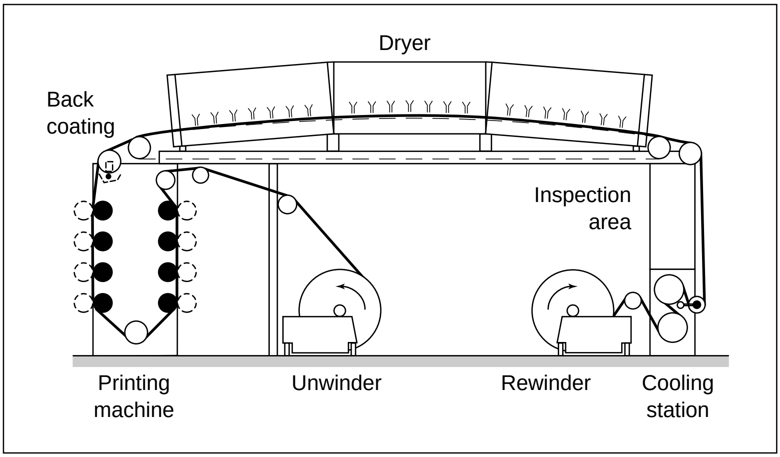

Figure 2.25 Rotary-screen printing machine for transfer paper (Johannes Zimmer)

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