Because of its various advantages, it can be predicted that the CQC method will have a similar future to that currently enjoyed by SPC methods, since it has eliminated their known weaknesses. It is of particular advantage for this development that, as a result of modern SPC, the necessary knowledge of statistical processes is already available in many processing shops, and the acceptance of model-supported quality control processes has increased and their necessity been recognized.

Translations of captions and terms to figures in the German text (cf. pp. 1540/1546)

Sorting-box lid of ABS

Fig. 1. The sampling analysis
Prozeßwissen = process knowledge, Bemusterungsplan = sampling plan, Mustern und Optimieren = sampling and optimization, Formteilprüfung = testing the mouldings, Prozeßkurvenverläufe = process curves, Prozeßkennzahlen = process characteristic values, Prozeßmodelle = process models, On-line-Qualitätsüberwachung = on-line quality control

Fig. 2. Fully automated production line with measuring instrument and CQC system

Fig. 3. Comparison of quality measured and quality computed
Länge gemessen/berechnet = measured/computed length, Abweichung Messung‹-›Rechnung = deviation between measurement and computation

H. Gross, Rossdorf

Small Forces – Thin Films

Production of Thin Two-side-Polished Films – Must Methods be Rethought?

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NOTE: For figures and literature see German text; translations of captions and terms appear at the end of this article

The most economic method of plastics film manufacture is the bubble process. If the film to be produced must have at least one high-quality surface, it is necessary to switch to the more costly chill-roll method. Market requirements and uses for films of high surface quality on both sides is certainly increasing.

Only a polishing roll stack, as used in the manufacture of sheet, can meet these end-user requirements [1]. Two-side-polished films down to 200 µm are state-of-the-art today. But practical, matter-of-fact considerations show that one cannot get much further in this direction with sheet technology.

Sheet-polishing technology conventional

Plastics sheeting 1 to 15 mm thick can be made without problems on conventional units (Fig. 1). But the further down the thickness range one attempts to move, the greater the difficulties become. In order to explain the problems at small thicknesses it is necessary to look more deeply into the production process. Fig. 2 gives a schematic side view of the most important features of the sheet-polishing process. For the purposes of explanation, a horizontal polishing stack with vertical introduction of the melt is employed, since this hitherto rather unusual procedure has distinct technical advantages.

The melt curtain (2) emerging from the slot die (1) falls into the gap (4) formed between the two polishing rolls (3). It has turned out to be both advantageous and advisable to work with a certain size of melt bead (5) on the roll stack above the narrowest gap. This bead ensures that two roll surfaces always stay in contact with the incoming melt. By means of locking cylinders that act on the journals of the two rolls and run against an end stop, it is possible to keep the size of the roll gap approximately constant. Consequently, the size of the bead remains constant as long as the flow of melt passing from the die into the roll gap does not change during the polishing process.

On the assumption that there is no departure from a chosen sheet width, the result throughout is that with various bead sizes the polishing effect is equally good, so that certain changes in the size of the bead, at any allowable frequency of change, do not affect the end result unfavourably. It is clear, however, that with the gap constant and an increasing size of bead, or with stronger cooling [2], the forces in the gap increase. At the same time there is also an unavoidable increase in roll deflection, arising from the greater gap forces. An essential precondition for good polishing is, of course, that melt should always be present within the running web on the line of the narrowest gap, meaning that the two solidification fronts running inwards from the two cooled roll surfaces at this point should not meet in the middle. This is always so with sheet, since thicknesses are greater and because the thermal conductivity of plastics is poor. The gap forces and any associated roll deflections are small, since the melt within the gap is still deformable. As a rule, the resulting variations in sheet thickness are also found to be small in relation to the overall thickness, and are usually tolerable.

Film polishing in the roll gap

In the past, this proven method, adapted with detail changes from sheet technology, has been used as the basis for making even thinner films with two polished surfaces. The effort involved and the costs of such roll stacks increase out of all proportion to the reduction in thickness of the film that can be made. But it is not just the costs of such units that increase so greatly; the problems of running them do so as well, and the efficiency of the production process is lost progressively with further reduction in film thickness. The causes of these problems are easily stated.

As the thickness of the film of melt passing through the roll gap decreases, so the thickness of the molten core within the narrowest gap – this molten core is essential for the polishing process – also diminishes until the solidification fronts finally meet in the middle. Inevitably, larger forces are required in the gap to eliminate the rather large thickness variations across the width of the melt curtain below the die. Since the forces can be brought to bear only through the external roll journals, the flexural stiffness of the rolls has to be increased. The possibilities of achieving this by means of special roll designs are limited. Thus one has no choice but to increase the roll diameter, in order to keep bowing within acceptable limits.

But the consequence of this measure is that there is also a further worsening of the boundary conditions. Fig. 3 provides a schematic comparison of conditions in the gaps between rolls of large diameter and rolls of small diameter (blue). It is easy to see that with a larger roll diameter the result must be that the dwell time of the melt before it reaches the narrowest gap is necessarily longer, since the contact length on the large roll (Lg) is quite clearly longer than that on the small roll (Lk). With thin films, the solidification fronts (not shown in the sketch, for the sake of clarity) have met well before the narrowest gap, so that the conventional smoothing process is not possible because the normal melt cushion in the middle of the web is absent. The best evidence for this occurrence is the many hardened roll surfaces that have been destroyed in these trials by solidified melt in the gap.

Small bead

One experiment that remains to be done is to control the size of the bead. To allow this, rather laborious measurement procedures are employed [3]. A second possibility rests on raising the rotational rate of the bead. Both activities are aimed at the doubtful possibility of retaining a melt cushion in the narrowest gap.

Even though it is still theoretically possible, the attempt to make ever thinner polished films is frustrated finally and conclusively by the manufacturing tolerances of the roll stack. Even if the most accurate manufacturing techniques are employed and specially selected bearings used for the rolls, and if expensive tempering methods are employed for bearings and journals, one still has to accept rotational tolerances of about 5 µm, at least, on each roll. Given that the rolls run against each other, the resulting maximum change in the size of the gap is 10 µm. Thus, for example, if a 100 µm film polished on both sides is required, the change in the size of the roll gap will be about 10 %. The slightest speed difference between the two rolls results in all intermediate states appearing during a production run.

The result, with thin films, of these relatively large changes in roll gap is that there are considerable alterations of the forces operating in the gap. It can be readily understood that a stable production process is impossible under these conditions, since roll deflection changes with gap force. In the technological sense with the conventional polishing process, at this point at the latest, one is up against limits that remain impregnable for the moment.

If, nevertheless, one wishes to produce still thinner polished films then it appears advisable to rethink the whole concept entirely and take a completely different route.

Rethought

The considerations related to the circumferential tolerances on the roll stack, which for the moment cannot be reduced further, make it abundantly clear that the problem cannot be overcome with higher clamping forces.

On the other hand, possibilities are opening up as a result of improvements in measurement and control technology [3], as well as in the area of design of extrusion dies [4], that enable the extrusion of a homogeneous melt curtain. The rolls no longer have to smooth out thick spots in the gap. The basic precondition for this is that thick edges, resulting from lateral contraction as the melt curtain is drawn down from the die, must be avoided. What happens in practice is that thin bands are produced at the edges of the melt curtain by reducing the die-gap locally to balance edge thickening, and these eliminate the normal thick edge bands that act as roll separators.

In this situation the polishing stack loses its function of equalizing the molten film thickness across the width of the roll. Also it is no longer necessary to operate with high clamping forces, and the bending forces therefore become smaller. It is then possible to return to smaller, more advantageous roll diameters, and the duration of melt contact with the roll can then be short; the result is that gap forces are so greatly reduced that roll deflection becomes negligible [5].

With such a procedure the size of the gap, and thus the film thickness, is determined only by the thickness of the incoming curtain of melt, rather than by a roll stack whose rolls are set against limit stops. At the same time, a solution to the very critical problem of rotational tolerances in the polishing stack becomes available. Since the roll axles are subject to only minimal forces, they can be pushed apart if there is roll eccentricity and if a minimum gap were to be set because of this. In consequence, the actual roll gap does not vary much and the forces in the gap remain almost constant. However, the precondition for this is that particular attention must be paid to providing the best possible friction-free bearing system of the axle of the roll in the side plates of the frame. This is absolutely necessary, otherwise the small holding forces will be insufficient to keep continuous contact between the melt and the roll surfaces. With conventional methods of mounting the roll axle on the side plate, the frictional forces in the side plates are many times greater than the minimimum holding forces, and so the axles cannot reposition themselves.

Fig. 4 is a schematic side view of a polishing stack embodying the new principles. It consists of a fixed roll (3a) and a second roll (3b) carried in sideplates (9) running on linear bearings (10). The clamping force is applied by a simple helical spring (11) with a flat compression characteristic. The pretensioning required in each case can be set by means of a threaded bush (12). A cylinder (13), which closes and opens the roll gap on line start-up and shut-down, is mounted at the end of the clamping device.

The flat characteristic spiral spring in association with the linear-bearing guide of the adjustable roll ensures that gap forces are kept constant during the polishing process, in a very simple and cost-effective way. All immediate efforts by plant manufacturers concerning more precise methods of production, stiffer frame construction, and still-larger clamping forces, thus become superfluous. As to line operators, the risk of damage to extremely expensive roll surfaces, by locally exceeding the permitted surface pressure, is eliminated.

There are always sceptics about

Finally, if the new ideas presented here are to be successful, total rethinking is needed. The roll-polishing stack that up to now, with very costly modifications, played the decisive role, has lost its central importance. The principal target must surely be concentrated on the current, but not for the moment exhausted, possibilities of equalizing the thickness of the melt curtain emerging from the die. The use of the latest techniques of die design is needed here, especially of dies with really sensitive, flexible lips (thickness of lip walls 4 mm over the full width of the lips). Additional improvements can be achieved by the use of the most up-to-date techniques of measurement, and of open and closed-loop control: in this context, especially, by the use of bead measurement techniques of die control. Correspondingly, there has been success in equalizing the thickness of the melt curtain entering the die gap, and thus the construction of polishing rolls for producing thin polished films will in future be simpler and more reliable. Sceptics will cast doubt upon the assertion that trials have confirmed this to be so. If, in fact, the effort and the potential success of the two concepts are compared, the prospects are optimistic about the new ideas, in spite of this doubt, not only for accommodating them theoretically but, most certainly, practically as well.

Translations of captions and terms to figures in the German text (cf. pp. 1548/1551)

Fig. 1. Horizontal arrangement of polishing-roll stack

Fig. 2. Schematic diagram of a polishing unit for manufacturing high-quality sheet
1: slot die, 2: melt curtain, 3: polishing and cooling roll, 4: roll gap, 5: bead, 6: solid, 7: roller conveyor, 8: haul-off

Fig. 3. Comparison of rolls of different diameters; blue = small roll diameter, black = large roll diameter; 2: melt curtain, 3: polishing and cooling roll, 4: roll gap, 5: bead, 6: solid

Fig. 4. Schematic layout of a polishing stack specifically designed for operating with minimum roll-clamping force
1: slot die, 3a = fixed roll, 3b = adjustable roll, 9 = side plate, 10 = linear bearing, 11 = helical spring, 12 = adjustment of clamping force, 13 = cylinder for opening and closing the roll gap