next start-up of the line. However, the success of this method depends on the competence of the operating personnel thus harboring potential difficulties in actual production runs.

Measuring the layer thickness immediately during start-up, detects changes which were made by mistake, for example, during the cleaning of the adjusting device. These changes can be compensated for manually, manually/hydraulically or automatically/hydraulically, depending on the type of equipment used in the extrusion line.

In the production of high and very high voltage cables the current practice of using settings for die centering from the preliminary run for the regular production is to do so only if an identical product is made. That is due to the fact that a die ring with an excentric setting must compensate for the sagging of the melt in the extrusion line (depending on the core geometry, i.e. the ratio of the diameter of the conductor to the wall thickness of the insulation). The die setting also depends on the rotation of the core in the cross-linking tube.

On the other hand, with this new thickness measuring device it is possible to preset the die also for different cores. In that case the measuring system evaluates the position of the conductor and corresponding thickness distribution of the individual layers and either makes the corrections automatically or indicates the correcting measures to be taken. This helps to significantly reduce the amount of scrap even during the first production run.

Altogether, the measurement of layer thickness and the automatic centering of the insulation layers associated with it offer the user the following advantages:

- short start-up time due to the possibility to measure the core immediately after it exits from the extrusion head; no accurate precentering is necessary.
- The accuracy of the system permits an improvement of manufacturing tolerances of the cores. At the same time, the wall thickness of the insulation can be kept at the minimum which results in a reduced material consumption.
- The wall thickness of every layer of plastic material is measured objectively and documented for the purpose of quality assurance.

Translations of captions and terms to figures in the German text (cf. pp. 1349/1351)

Fig. 1. Three-layer extrusion head with a hydraulic die centering and an x-ray instrument for measuring the thickness of each layer

Fig. 2. Display of measured values for the position of the conductor and for the three layers on the monitor screen
Ader Messung = measuring core, Datum = date, Artikel-Nr. = part no., ein = on, Wandstärken = wall thickness data, messen = measure, Zählerzeit = counter time, Messzeit = measured time, Datum = date, Aderlage = core position, Qualität = quality, Exzentrizität = excentricity, Pause = pause, Art. Nr = Article No.

Fig. 3. Effect of the automatic control of wall thickness by means of the thickness measuring system; shown for production start-up of a 20 kV cable with a conductor cross section of 95 mm² (measured data on both sides of the conductor in the x-direction)
a: interior semiconductive layer, b: insulating layer, c: outer semiconductive layer, d: start of the centering control
Dicke der äußeren bzw. inneren Leitschicht = thickness of the outer and interior semiconductive layers respectively, Zeit = time

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Membrane Instead of a Restrictor Bar

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[illegible]

New Perspectives in Flow Regulation for Slit-dies

Translated from Kunststoffe 84 (1994), 10, pp. 1352/1358

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

In the production of sheets and films, the flow design of slit-dies using computer programs is state-of-the-art [1]. Such dies are however not designed for just one operating point or one single material. The need for versatility is high on the list of requirements [2]. To achieve the most uniform possible melt flow across the die width and hence constant thickness distribution in sheets and films, it must be possible to influence the local flow across the die width. In addition to lip adjustment at the die orifice, this purpose has so far been served by the restrictor bar in the interior of the die but this also has the disadvantage of producing undesirable stagnant zones.

Membrane regulates melt flow

If a membrane inside the die is used to influence melt flow instead of a restrictor bar, then neither stagnant zones nor additional dividing surfaces are produced in the flow channel. In the same way as the internal cross section of a rubber hose can be continually altered from the outside with a simple clip, it is also possible to alter the local cross section of a wide, shallow channel with flexible walls by exerting pressure from outside on the channel wall. With a two-channel die (Fig. 1) incorporating a flexible membrane, it has recently been shown that melt streams can be specifically influenced in this way [3].

The basic idea of the flexible membrane is to provide a wall in the adjustable region of the flow channel so thin that it can be deformed. This idea has already been accomplished in practice by *Johnson* [1] in an extrusion die by milling away an area in the reverse side of the flow channel. With this solution, however, the adjusting screws, even at low membrane deformation, produce a tensile stress over the whole thickness of the membrane.

A membrane can be used however if the region to be adjusted is not subjected to tensile stress over the whole thickness during deformation. This can be achieved in a relatively simple manner if the originally flat membrane is curved three-dimensionally and thus is predominantly under flexural stress. An exploratory FEM analysis showed that a curved membrane is suitable for relatively long adjusting paths and that the deformation remains in the linear-elastic region of the material (Fig. 2) [4].

Practical implementation

After this positive result, the total three-dimensional deformation of the membrane was optimized by FEM analysis. Fig. 3 shows membrane deformation at a melt pressure of 100 bar with an adjusting screw setting of 1 mm. The FEM network for the stress calculations reproduces the rounded geometry of the wall thickness transition regions in order to obtain the most precise information on the stresses occurring there.

In the die body, the membrane must be clamped on all sides to ensure that it seals off the melt. The geometrical design of these critical edge areas was also optimized by FEM analysis.

It became apparent that optimization of the geometry of the actual membrane was not in itself sufficient. For reliable functioning, it is also necessary to include the geometry of the opposite side of the flow channel in the optimization. This was ultimately designed so that when the adjusting screws were on maximum setting the underside of the membrane touched the surface on the opposite side of the flow channel in the edge region [5]. In this way, it is possible to alter the flow width of the coextrusion channel from outside during operation.

This possibility is very useful in adapter coextrusion in order to prevent the undesirable enclosure of one melt layer by another melt layer. To this end, shortly before the point at which the two melt streams unite, the potentially enclosing layer is influenced by the membrane in the edge regions in such a way that enclosure no longer takes place.

Integration of the membrane into the slit-die inevitably necessitated some new design solutions. As a result, a new overall design was created which prevents the sealing problems which frequently occur at points where melt streams divide. The reasons for such sealing problems range from design weaknesses through operating errors to incorrect cleaning or installation of the dies.

The new design reduces these problem sources by minimizing the number of dividing surfaces required. Fig. 4 shows a two-channel die with a very sensitive system of adjustment ready for operation in a laboratory at the Institut für Kunststoffverarbeitung, Aachen. When the heating plates and locking bolts are removed, it can be seen from the open die in Fig. 5 that this die consists of only three parts. It possesses only two dividing surfaces which run parallel to the flow channel. This die is easy to dismantle, clean and refit.

Membrane permits flow regulation

The main advantage of the new technology is the high flexibility of the membrane integrated into the flow channel. Even in the flow channel of the laboratory die, which is only 150 mm wide, the melt stream can still be crucially influenced. Because of the curve in the membrane and its minimal wall thickness, only low forces are required for deformation. This makes it possible to use small adjusting screws and to arrange them at intervals of only 20 mm.

Fig. 6 gives three examples showing layer thickness in relation to the setting of the adjusting screws in a trial coextrusion of PP onto PE-LD. The examples show that the adjustable membrane (with nine adjusting screws) can influence layer thickness within wide limits.

When the die was first tried out [3], each adjusting screw was fitted with its own sub-miniature motor. The maximum adjusting torques measured were 3 Nm. So the right conditions have been set to control the total melt stream or separate streams inside a flow channel. The systems of measurement necessary for continuous, selective sensing of separate melt streams are available on the market [6].

Through the use of a membrane it is now possible to regulate melt flow via geared motors. This control system operates without downtimes and requires very little energy. It is thus superior both technically and commercially to control with the aid of thermal expansion pieces (state-of-the-art technology in plastic film production).

Another important advantage of membrane technology is the fact that there are no stagnant areas in the restricted flow zone. The flow channel in the die changes continually; there are no longer any dividing surfaces perpendicular to the flow direction. A die with membrane adjustment is therefore suitable for thermally unstable and sensitive materials.

New processing possibilities

The flow channels free from dividing surfaces and stagnant areas which can be obtained with membrane technology prevent melt stagnation in the die. In the case of materials which cause problems with degraded particles after prolonged operation, it is possible to achieve longer operating times. Dies with a membrane are also suitable for thermally sensitive materials such as PVC.

When a feed unit is supplying different flow channels, the quantity ratio of the individual melt streams can be specifically adjusted by integrating several membrane restrictors. If, for example, in producing twin-wall sheets, the “flanges” and the “web” are fed from one extruder, the pressure in each flow channel can be influenced during the extrusion process by membranes. In this way, unnecessary localized thickening of costly individual layers can be prevented. For example, in twin-wall panels made from polycarbonate, the top and bottom “flanges” are coextruded with a costly UV-stabilized layer to provide weathering protection. Uniform layer thickness distribution is difficult to achieve without a restrictor because of the complex geometry of the flow channels.

If, in a single-channel die, the restrictor bar is replaced by a membrane, the melt flow distribution across the die width can be much more precisely fine-tuned. With sub-miniature geared motors, it is possible to achieve continual thickness controlling in sheet extrusion with very low energy requirement. As a result, large sheet extrusion plants can produce saleable products, even during the unstable start-up phase, which normally lasts several hours.

In coextrusion, membrane technology makes it feasible for the first time to construct small multi-channel dies for laboratory operation. Such comparatively inexpensive laboratory dies permit development work to be carried out with low material and labour costs. The low material requirement is a particular advantage if costly trial materials have to be used or only a small quantity of trial material is available.

Multi-channel dies with membranes are likely to acquire greater importance in future at the expense of the feedblock solution because of their trouble-free overall design and impressive adjustment capability in coextrusion. These dies enable considerably better adjustment of individual layer thickness to be achieved. Since they also permit automatic layer thickness control, they open up new perspectives in terms of attainable layer thickness tolerances.

In feedblock coextrusion, the membrane feedblock (Fig. 7) is logically continuing the development which began with the fixed feedblock (Dow system) and progressed through the Cloeren and Reifenhäuser feedblock systems [7] to the Röhm lamellar feedblock system [8]. The latter patented system was the first to permit layer thickness regulation in feedblock coextrusion but is not available on the market. The numerous dividing surfaces which are so difficult to seal in the lamellar feedblock and the stagnant areas caused by the lamellae projecting into the flow channel are eliminated in the membrane feedblock.

In feedblock coextrusion, attaining the most uniform possible layer thickness continues to be the greatest problem [9]. Hence the advantages of an externally adjustable feedblock system are obvious. The membrane can be used for widely varying material combinations without any need for remachining to modify flow channel geometry or for exchange of inserts. Optimization trials, which have previously taken several days, now require only a few hours because the feedblock can be adjusted while the line is running. With the membrane feedblock, rapid manual or automatic adjustment can be carried out in response to changes in thickness distribution produced by batch variations. This permits layer thickness tolerances to be reduced in feedblock coextrusion.

Future prospects

In sheet and film coextrusion, membrane technology opens up many new processing possibilities. A membrane die offers an ease of maintenance previously unknown and high operating reliability. For this reason, it is likely that membranes will rapidly become established as restrictors in single- and multi-channel dies and in coextrusion feedblocks.

Thickness adjustment or regulation with sub-miniature motors improves the efficiency of extrusion both in terms of the control costs and the material savings which can be achieved during start-up and material change over by the new system of regulation.

The possibilities for fine-tuning flow channel resistance and hence influencing the flow of melt streams using a membrane, as described here with the example of extrusion technology, will open up new perspectives in many other areas of plastics processing as well.

Translations of captions and terms to figures in the German text (cf. pp. 1352/1358)

Fig. 1. Two-channel slit-die for coextrusion with the adjusting membrane integrated into the secondary channel
a: adjusting screws for the flexible lip, b: adjusting screws for the membrane

Fig. 2. Deformation behaviour of a unidimensionally curved membrane calculated by the finite element method (thin line: original contour)

Fig. 3. FEM calculation of the three-dimensional deformation of an adjusting membrane at 100 bar melt pressure and 1 mm setting of the adjusting screw

Fig. 4. Fully assembled coextrusion slit-die with internal membrane ready for operation

Fig. 5. Opened-up view of the die shown in Fig. 4 after removal of the heating plates and locking bolts

Fig. 6. Relationship between the setting of the adjusting screws (z) and the layer thickness distribution (d) achieved in co-extrusion of PP onto PE-LD
A: adjusting screws on neutral setting, B: deliberate creation of a thin point in the centre by suitable adjustment of the membrane, C: adjusting screw settings for optimum layer thickness distribution; because of the low-viscosity outer layer, a very shallow flow-channel depth must be set at the edges
Schraubenstellung = screw setting, Schraubenposition = screw position, Schichtdicke = layer thickness

Fig. 7. Diagram showing the principle of a coextrusion feedblock with adjusting screw b and integrated membrane a

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A Concept for Modern Injection Moulding Production

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

Just-in-time production is the magic formula that large industry is using to reduce its costs. This method necessarily affects injection moulding factories. Low-manned shifts or unmanned shifts at weekends are among the most important efficiency measures in this industry. Some prerequisites first have to be fulfilled, however, as described below.

It is no wonder that plastics processors, in particular, are thinking about how best they can counteract increasing wage costs and further reduce working times. The times are long past when we could gain high profits by producing plastics mouldings because we were able to gain a clear technological lead over our competitors or competitor countries.

The competitive environment

The European market in injection moulding technology is particularly hotly contested. The opening up of the European internal market will further intensify the competitive situation for producers of plastics mouldings, particularly in the German-speaking countries.

Producers of injection mouldings in East European countries should also not be underestimated as competitors. Considerably lower labour costs, lower energy costs and longer working hours significantly affect the finished-part price – particularly of injection mouldings that require a high amount of manual assembly work.

Countries and continents that have petrochemical raw materials and are being increasingly industrialized or already have a high technical standard are also developing more and more into competitors to be taken seriously.

If we consider the weekly working hours, annual and public holidays and absences of an industrial worker in the most important industrial countries (Fig. 1) and also compare the labour costs in the processing industries (Fig. 2), pressure on German processors to rationalize is unmistakable. There is only one large potential reserve for this:

- The full utilization of the capacity reserves of all machines and systems, combined with shorter throughput times.

In the modernization of injection moulding factories, the prime potential for cost reduction is, according to Fig. 3, the reduction of throughput times. This is true irrespective of the fact that genuine just-in-time production should only be considered when the factory is organized according to the criteria of optimum material flow and balanced operations.

For production it is true in general that the more bulky and more expensive the finished mouldings, the more sense it makes to have short throughput times from raw materials purchasing through to delivery of the finished mouldings. Such large mouldings take up high amounts of warehouse space and the storage costs have a direct effect on the mouldings price. Furthermore, cost-intensive finished mouldings in the warehouse tie up a high amount of capital; this can lead to bottlenecks in liquidity.

Correctly determining economical batch sizes

Despite all the tempting arguments in favour of just-in-time production, a decision must be made from case to case as to whether production and warehousing should be preferred. Before this decision is made, it is necessary to clarify the situation by calculating the economical batch size.

The question of what is the economical batch size is raised time and again for many injection moulders:

- Is it better to produce a larger quantity than is currently needed and store the excess in the warehouse, or
- is it more economical to produce only the amount needed for the next delivery order?

The economical batch size is determined by

- the lost marginal costs due to the retooling of the injection moulding machine,
- the required annual quantities,
- the warehousing costs,
- the capital costs.