while it is not necessary to relinquish the helpful self-optimizing strategies for the adjustment of control parameters. To the contrary, new possibilities arise, such as e.g. automatic turning on the extrusion line via PC.

As a whole, the integrated control strategies help the user to achieve a better control of the manufacturing conditions that can further lead to improved (lower) tolerances in the dimensions of the extrudate at the same time. This further helps to reduce the consumption of material and supports the machine operator in his efforts to maintain the highest possible extrusion speeds. Moreover, the recipes stored in the system contribute to a much quicker changeover. The inclusion in the control system of the gravimetric feed, a feature being used with ever-increasing frequency, is a great help in accomplishing that since that way the proper composition of the delivered raw materials will be monitored. (100822)

Fig. 1. Coextrusion line for the manufacture of PVC sheets by freefoaming
Photo courtesy of Cincinnati Milacron Austria, Vienna/Austria

Fig. 2. Tandem extruder with an increased cooling capacity for the manufacture of foamed sheets
Photo courtesy of Battenfeld Gloucester, Gloucester, MA/USA

Fig. 3. Sheet smoothing by a steel belt
Photo courtesy of Reifenhäuser, Troisdorf

Fig. 4. Design of the device for the compensation of bearing play
Lagerspiel bei unbelasteter Walze = bearing play of an unloaded roll; Lagerspiel bei Belastung aus Spaltekräften aus Spalt 1 oder 2 = bearing play under loading by cleaving forces from nip 1 or 2
Illustration courtesy of Seide Engineering, Buchholz

Fig. 5. Screw for the processing of metallocene polymers
Photo courtesy of Black Clawson, Fulton, NY/USA

Fig. 6. Process constant filter system with a screen wheel
Photo courtesy of Gneuß Kunststofftechnik, Bad Oeynhausen

Fig. 7. Process visualization with the system Eurotherm PC3000
Photo courtesy of Eurotherm, Limburg

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Extrusion Dies for Sheets and Films

Developments in Flat Sheet Dies and Coextrusion Adapters

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Today, in the development of special extrusion dies, usually intended for the production of a single specific product, 3D simulation programmes for the layout of the flow channel geometry are used. In the area of universal dies and coextrusion adapters the developments focus mainly on the improvement of profitability in their use.

In many plants dies ten years old or older are still in use. And often it happens that the operating personnel swears by these old dies. The majority of extrusion companies face the innovations in a rather reserved manner. Generally, the risk attached to the use of new technology is seen rather than the expected long term economical benefit. Therefore, there is no wonder that new, improved designs from the die makers are accepted for practical applications only very slowly. This presentation of the current status in the field of extrusion mould making will also try to examine the implementation into practical use in production.

The Requirement Profile in Changing Overall Economical Conditions

The development process in the manufacture of extrusion dies is influenced by the overall economical conditions. After the diversification theories of the eighties were replaced by concentration on the core business, the demand for special dies, which are designed to make a single specific product has become stronger. However, this happens only then, when there is large enough market volume for this product to keep the whole line fully occupied. This trend is particularly pronounced in the area of production of oriented films. The efforts to reduce inventories and the demand for just-in-time delivery associated with it have caused smaller production lots and forced most of the operators of extrusion plants to frequent production changes on their lines. In these cases, opposite to the trend towards special dies, the need is for universal design of extrusion dies which affords flexibility in production. Accordingly, the die makers work to find solutions which widen the application range of universal dies even more. This means such designs that allow processing of a wider range of melt viscosities at enhanced possibilities to adjust the die accordingly and which are able to produce a wider range of gauges and widths.

Special Dies for the Manufacture of a Single Product

Particularly in the production of films and sheets, dies are intended to be used exclusively for the processing of a single plastic material with an exactly specified throughput. Such dies in most cases do not have any extreme adjustment devices. Also, particularly in multi-channel dies for coextrusion the previously often used restrictor bar is in the meantime integrated less and less frequently. Since the number of individual parts used for the production of a die has been already consistently reduced for the sake of reliable operation, the development activities concentrate on the application of increasingly more complicated and consequently more accurate simulation programmes for a more precise layout of each flow channel. Thus Extrusion Dies Inc., (EDI) in Chippewa Falls, WI/USA has been using the three-dimensional Finite Element Program (FDIP) under the licence from Fluid Dynamics in Evanston/USA for the optimization of the design of flow channels in dies for some time. With this technique, new shapes of manifold channels are also being developed such as, for example, the "Hybrid Coathanger" manifold channel (Fig. 1). Among other things, it decreases the length of the die thus reducing the problem of die widening due to melt pressure.

Special dies designed for a single set of operating conditions certainly represent in mould marketing the optimum for minimizing production breakdowns and increasing reliability of operation. However, in the practical production setting, problems can

occur when over the years the line is optimized and production throughput is further increased and consequently moves away from the original running condition used in the design of the die or when another raw material is used.

Universal Dies for the Production of Films, Sheets and Slabs

The heart of universal dies are the adjustment systems which are used to change the cross-section of the flow channel while the unit runs. In film extrusion dies, there are manually or automatically adjustable flex-lips and in sheet extrusion dies restrictors bars and, recently, adjusting membranes are used.

Film Dies with Flex-Lips

In the past the flex-lips from different diemakers differed only in some minor details. The new thinking is not only to enlarge the attainable adjustment range but also to substantially increase the flexibility of the lips in order to increase the adjustment range of the lips alone and to be able to influence even the slightest differences in melt flow in a more sensitive and effective way [1]. Thus, Sauer & Sohn, Dieburg/Germany, has been offering dies with superflexible lips since 1995, which by now are built up from special steel spring strips arranged one over the other (Fig. 2). Sauer & Sohn has delivered a laboratory die for a special application and soon thereafter two production dies with such superflex lips.

Dies for Slab Extrusion

The number of possible variations and the multitude of offered solutions is certainly greatest for dies for extrusion of sheets. These dies have either none or very different systems for lip adjustment. In addition, they have, as a rule, an adjustment inside the flow channel that allows the change of resistance to flow in order to adjust it to different thermoplastic materials or else to changing throughputs. The concept of restrictor bars used exclusively for this purpose in the past has a competition in a new design presented on the occasion of the 17th Colloquium on Plastics Technology at the IKV (Institut für Kunststoffverarbeitung – Institute for Plastics Processing) in Aachen, 1994. This die has a thin membrane integrated in the flow channel that can be deformed from the outside.

Since then, there are seven licensees for this patented system (Fig. 3) which has the advantage of a sensitive locally restricted adjustability and of the ability to eliminat dead spots as well as imperfect seal. Since the membrane is welded solid into the die, it should provide a greater reliability and fewer breakdowns in production than the restrictor bar. Forerunner for this new design was the US company EDI which brought to the market a membrane design called "Flexible Preland Technology" in 1996. At the end of this year it is estimated that there will be about 20 membrane dies used in industrial applications.

Adjustment of the Lip Gap of the Sheet Dies

While the most widely used method of adjusting the gap between the die lips to obtain the required sheet thickness in the past was by bolts, by now dies with one fixed and one movable lip have gained acceptance. The gap of such dies can be adjusted in the range < 10 mm. The forerunner in this case was again EDI with the "Fast Gap" technology; about 100 dies of this design have been delivered. Today, almost all of the established manufacturers, such as, for example, Verbruggen N.V., Temse/Belgium ("Duoflex"), Production Components Chippewa Valley Die Inc., Eau Claire WI/USA ("Uni-Flex", Fig. 4) or also Reifenhäuser, Troisdorf/Germany, ("ISR") offer similar designs of adjustable lips. These dies make lip adjustments possible during production runs and thereby reduce or even eliminate the established startup procedures during the change of thickness. The newest developments with welded-on lips made from spring steel strips, make adjustments up to 20 mm possible. However, the requirement for a parallel die land zone at the exit from the die is relinquished.

Adjustment of Width at the Outlet

In the field of width adjustment at the exit of the die which is, of course, is recommended only for the processing of thermally insensitive thermoplastics, the development moves towards systems that allow the change of width faster or even while the unit is running. Fig. 5 shows a deckling device from EDI which can be folded away for the width change. Production components offers "Power Wedge Deckling" – a system that can be adjusted in operation and thus eliminates the stoppage and subsequent startup of the unit for the change of width.

Automatic Adjustment Systems for Flat Sheet Dies

The use of heat expandable lip bolts for automatic adjustment of the lip gap has been and still is today the state-of-the-art. Recently, there is an increasing number of efforts to replace heat expandable bolts by servomotors (Fig. 6). The advantage of servomotors is their low operating cost, large range of adjustment and fast reaction times. The servo-devices are especially interesting for the adjustment of membranes and also for superflexible lips, since those systems require small forces for adjustment and therefore smaller motors with a smaller torque can be used. On the other hand, neither the heat expandable bolts nor the occasionally used translators can provide the large adjustment paths required by membranes and superflex lips. Servomotors were used for the first time in 1994 in connection with the demonstration of the first membrane die on a running laboratory unit at IKV. IKV is at present working intensively on the control system for the production of sheets in which a membrane die equipped with servomotors should be controlled through signals from the measuring the bead in front of the nip of the roll stack also newly developed by IKV. Plans are to demonstrate this technology for the first time in March 1998 on the occasion of the 19th IKV Colloquium on a pilot unit. During K'95 Kuhne, Sankt Augustin/Germany and Reifenhäuser also displayed dies with servomotors. However, the acceptance by the processors has been rather small according to statements made by both companies. Thus the dies after own first successful trials are being engaged in long term evaluation at their manufacturers facilities or wait for someone interested to evaluate it in his production.

Multi-Manifold Die for the Production of Coextruded Sheets and Slabs

In the past, multi-manifold dies were designed as special dies with flow channels that could not be adjusted and were calculated for single specific set of operation conditions. By now, there are companies that replace consistently their multiple channel dies on hand by those having an integrated membrane for adjustment. The membrane can be quite easily integrated into a multi-manifold die as shown in a cross-sectional sketch from EDI built two-channel die (Fig. 7), without creating dead spots in the flow channel. It offers the processor the possibility of a precise adjustment of the thickness distribution or to be able to react to fluctuations in batches or changes in running conditions in individual cases. The production trials of the first multichannel membrane dies were so positive that the licensees of the membrane technology have currently more than fifteen orders for such dies worldwide.

Coextrusion Feedblocks

The multitude of coextrusion feedblocks offered on the market is considerable. EDI alone offers three different systems. The trend here is also clearly toward systems which in different shapes and forms can be adjusted with the extrusion line running. ER-WE-PA Davis-Standard GmbH in Erkrath/Germany has integrated rotary pins similar to those known from the Cloeren Feedblock in their further development of the original Dow Chemicals patented lamellar feedblocks system (Fig. 8). Reifenhäuser now offers their slide feedblocks, similar to the restrictor bar; an feedblock with a five-part slide that is intended for special applications. As an option, two additional slides can be used for encapsulated edges. Omipa S.p.A in Morazzone/Italy offers an feedblock system for seven or more layers in which the melt stream relationships for the individual layers can be changed among themselves. An entirely new and unconventional approach is taken by EDI in their "Proteus" feedblock (Fig. 9)