

CONTROL OF THE THICKNESS DISTRIBUTION OF BLOWN FILM BY CHANGING THE FLOW CHANNEL GAP OF THE DIE OVER THE CIRCUMFERENCE[†]

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ABSTRACT: The thickness distribution of blown film is conventionally controlled by either changing the temperature or the velocity of the cooling air. This technique cannot be used for the double bubble process, where the film is cooled by water before being reheated and blown up in a second step. A new technique to alter the localized gap of the flow channel at the exit of the die has been developed. It can be used to control the thickness over the circumference of the blown film for both the conventional and double bubble process. The technology is explained and initial test results achieved are presented herein.

KEY WORDS: blown film die, flow channel adjustment, layer thickness, thickness control.

INTRODUCTION

THE ACHIEVED THICKNESS tolerances of blown films affect not only the film quality but also the production cost. This is especially important to consider as the double bubble process is gaining more and more importance. This is due to the fact that the film is first intensively cooled by water and then the stretching is done at lower temperatures as compared to conventional processes [1]. The intensive cooling improves the crystalline structure (smaller spherulites) and stretching at lower temperatures leads to a higher mechanical strength as well as lower haze. In the double bubble process, the melt from the die is first cooled

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down at a diameter which resembles that of the diameter of the die. Therefore, the conventional techniques to control the film thickness with influencing the stretching behavior by cooling the film more or less before it is stretched is no longer applicable. That is why for the double bubble process the possibilities to further reduce thickness tolerances over the circumference or the width of the film are limited.

There are usually a lot of small imperfections that influence the melt stream distribution in the die in a way, which cannot be forecast or calculated. This begins with the fact that the melt that enters into the die is not homogeneous with regard to temperature. At the end of the extruder there is always a slight difference in the melt temperature and thus also in the melt viscosity. In addition, the pressure is also subject to some small variations. The die normally has some slight differences in temperature due to inadequate positioning of the heaters or uneven contact of the heaters to the die body. Finally, the flow channel geometry has tolerances relating to the machining. During the process, the influences of all these imperfections interact in a complex way. As a consequence the resulting films have slight thickness variations around the circumference. Therefore, to further improve the film thickness tolerances a solution has to be developed, which enables a reaction to these factors which cause the variations. This solution will lead to a reduction of production costs.

TECHNICAL REQUIREMENTS

It is clear that only a control system reacting to time-dependent variations can help solve this problem. Establishing a control system for the melt distribution within the die is a precondition to fine tune the relevant geometry of the flow channel in the die automatically. Therefore, it was the goal to design blown film dies, which allow for a sensitive adjustment of the flow channel geometry while the line is running. Consequently, a methodology has to be found to change the position of flow channel walls within the die. Accordingly, the main goal has been to find a method of producing a wall section that is extremely flexible and which thus gives rise to a linear elastic deformation. To meet the required flexibility the following requirements should also be included:

- the connection between the wall and the die body has to be absolutely tight against leakage
- the whole construction should be free of dead spots
- during or after deformation no dead spots are allowed to appear
- the wall has to withstand the internal melt pressure.

Following simple mechanical guidelines, it was obvious that the wall thickness had to be rather thin to allow for the necessary elastic deformation. At the same time the flow channel wall thickness has to withstand the melt pressure – this necessitates a certain thickness value. The basic challenge was to overcome this contradiction.

TECHNICAL SOLUTION

The technical solution entailed taking many single walls that are extremely thin and also extremely flexible. These thin walls were piled up on top of each other until a total thickness was reached, which can sufficiently withstand the internal melt pressure. When this construction is bent, each single wall bends individually, comparable to leaf springs. The critical elongation at the wall surfaces is always very small due to the minimal distance between the neutral layers in the middle of each thin wall. A new production technology was developed. It enables many extremely thin single walls positioned directly on top of each other [2]. There is absolutely no gap between these single thin walls. They join around their entire circumference into a thick solid wall. The thickness of this solid wall is exactly equal to the sum of the thickness of the single walls (Figure 1).

The walls can be shaped three dimensionally. Due to this special construction these single walls support each other. When such a multi-walled flow channel section is deformed by adjusting devices every wall deforms separately. The flow channel geometry alters gradually and thus no dead spots are created by the wall deformation. There exists a neutral layer in every single wall and the two surfaces of each individual wall are extremely close to its neutral layer. This is due to the fact that the separate walls can have a thickness that can be designed down to 0.2 mm (0.008 inch).

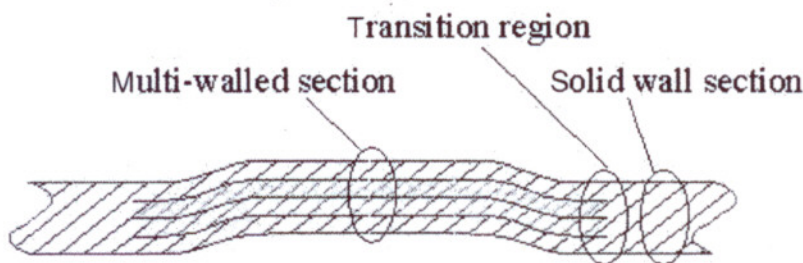


Figure 1. Cross section of a multi-walled flow channel section with seamless transition regions.

PRACTICAL DIE DESIGN

Analogous to flex lip sheet dies for producing cast film, we named the new adjustable circular dies *flex ring dies*. Figure 2 shows a cross-sectional drawing of such an adjustable circular die.

This flex ring die construction gives rise to a sensitive flow channel gap adjustment at the die exit. Such flex ring dies are already successfully used in pipe production [3] and in extrusion blow molding [4] where the adjustment does not need to be very sensitive as the flow channel gap is much bigger. Figure 3 shows an adjustable circular die for producing blown films on a double bubble production line.

In addition to the conventional screws that are used to center the outer ring to the mandrel, it has further fine adjustment capabilities that act on the flexible die lip at the die exit. They are used to fine tune the flow channel gap and reduce existing differences in the local melt flow which emerges from the die. These adjusting screws are manufactured with a 0.25 mm (0.010 inch) pitch for that special purpose. Adjustable circular die technology allows fine tuning of the individual thickness of single coextruded layers. A three-channel test stack die was built having a flexible wall section positioned exactly at the joining point of the middle layer to the inner layer. Figure 4 shows the flex ring disk of the die. The adjustable wall consists of 20 single walls. Each wall has a thickness of only 0.2 mm (0.008 inch).

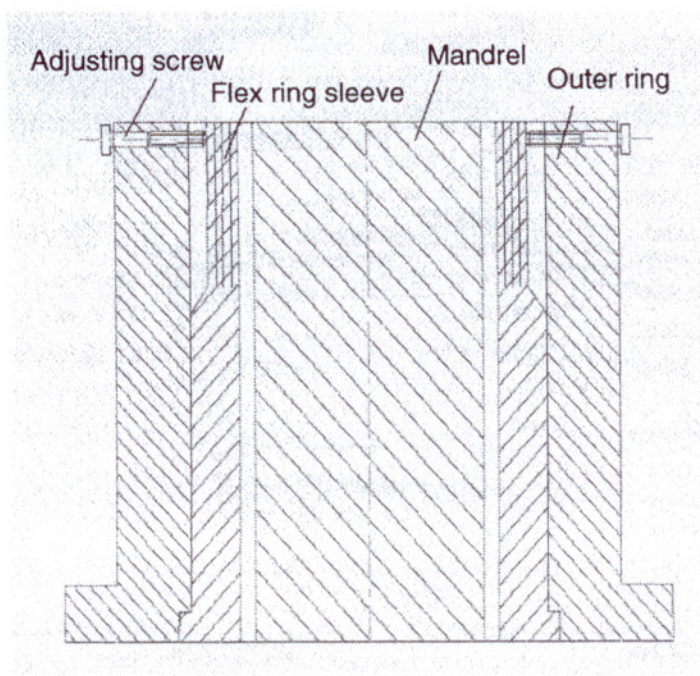


Figure 2. Cross section of a flex ring die that can be retrofitted into nearly any existing annular die by simply modifying the outer ring and inserting the flex ring sleeve.

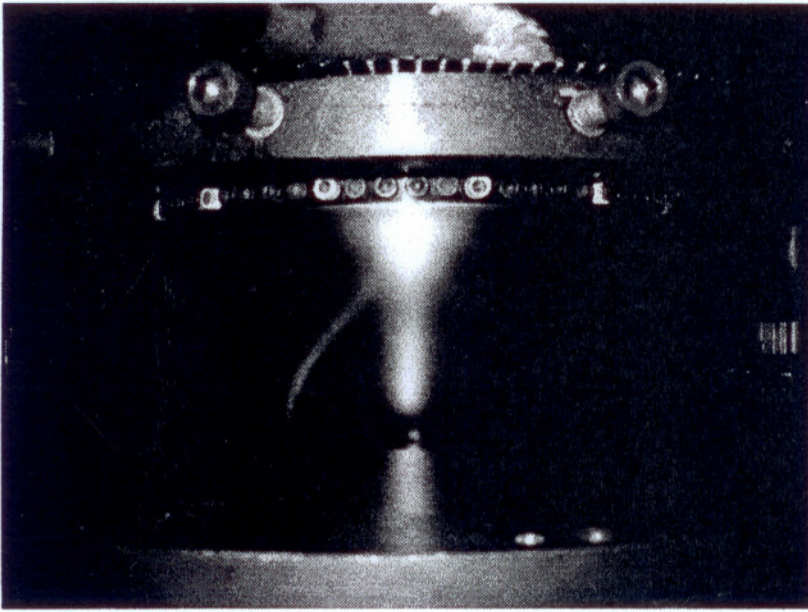


Figure 3. Adjustable circular die having a diameter of 248 mm and 72 adjusting screws over the circumference.

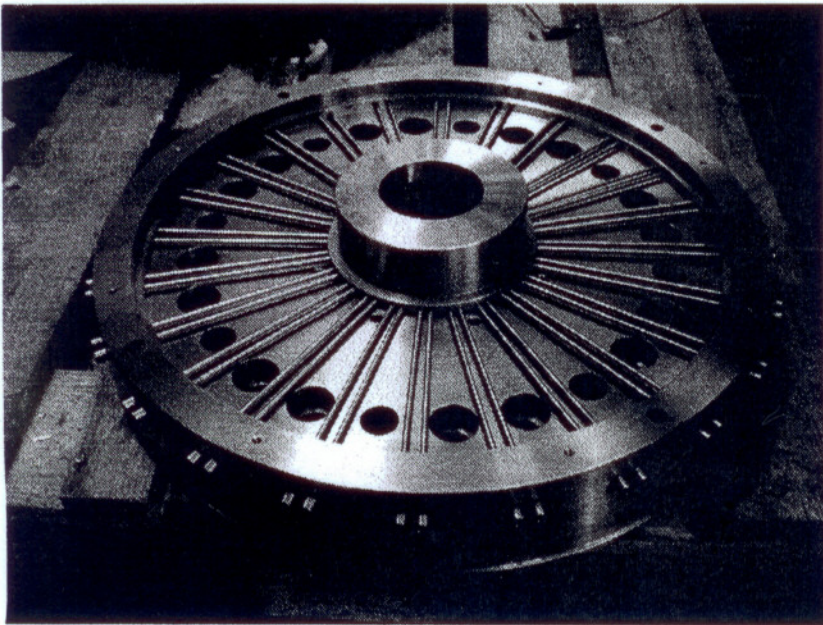


Figure 4. Middle disc of a three-channel stack die having a flexible adjustable wall section to optimize the inner layer flow channel gap with the help of the 48 adjusting screws that are positioned around the circumference.

INITIAL TESTS

In order to reduce the cost in the early stage of the development the first dies (Figures 3 and 4) were equipped with manual adjusting screws around the circumference. The goal was to first get a feeling how the

melt stream is influenced when the flow channel gap is changed at a special location. The first tests were performed on a double bubble production line (Figure 2). During these tests the total film thickness was changed while altering the flow channel gap at the die exit by hand at specific locations. These tests were performed to optimize the primary film (the film just after the water cooling in front of the reheating oven). This was done in order to get rid of stretching effects that have a complex influence on the thickness distribution of the secondary (final) film thickness distribution. The red curve in the polar diagram of Figure 5 shows the starting thickness distribution that was achieved with the ideal round flex ring geometry having a diameter of 230 mm (9.056 inch). The nonsymmetric thickness distribution is a result of a superposition of different insufficiencies during feeding, melting, and conveying of the resin. By a local deformation of the flex ring sleeve at specific regions the thickness variations could be reduced significantly (blue curve). It shows clearly that especially local extremes in thickness can be eliminated with the help of the flex ring die. This is not possible while centering a conventional blown film die.

Additionally similar tests [5] have been performed on a conventional blown film lab line in the Institute for Plastics Processing (IKV) to adjust the individual inner layer thickness of the interior of a three-channel stack die while running a three-layer film using the middle disk shown in Figure 4. These tests clearly demonstrated that the thickness

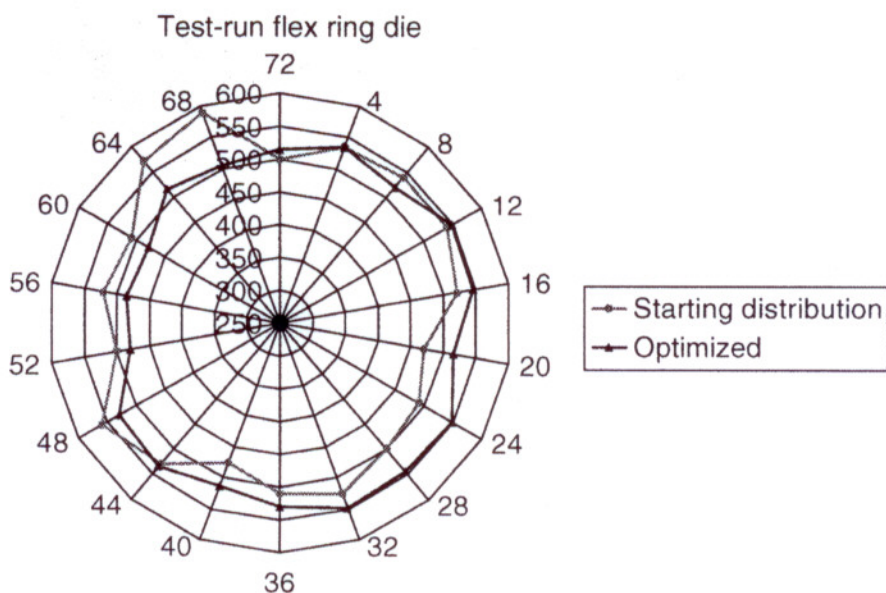


Figure 5. Polar diagram showing the primary film thickness (values in μm) distribution vs. the circumference (screw numbers) in a double bubble line before (red curve) and after adjusting the local flow channel by deforming the flex ring sleeve (blue curve).

over the circumference can be fine tuned not only at the exit of a one-channel die, but also in the interior of a three-channel die. To visualize the capability of the flex ring solution a three-layer PE-film where the inner black layer was covered with a transparent covering layer on both sides. Figure 6 shows a film section where the height of the flow channel was reduced by closing one single adjusting screw. Apart from some small flow instabilities in the film, a clear light line resulted at that specific location where the screw has been closed.

Prerequisite for that is that the die has a flow channel section that has a flexible adjustable section [4]. So flex ring dies are the first solution that allow for an adjustment of the individual thickness of a coextruded layer while the line is running. However, a high degree of training and skill of the operator is required to fine tune the screw positions in order to improve the thickness variation.

Encouraged by these results both projects have entered into the next phase. At IKV, a 2-year research project has started with the goal to establish a closed-loop control for the middle layer of a three-layer film. The adjusting screws will be controlled by stepper motors. Additionally, an on-line thickness measuring system to monitor the individual inner layer has to be added to the line. This is necessary in order to be able to check the difference between the set value with the actual value. Finally, the software for the controller has to be written. For the second project a new one-channel flex ring die was built and equipped with 28 adjusting drives (Figure 7) to fine tune the flow channel gap at the die exit.

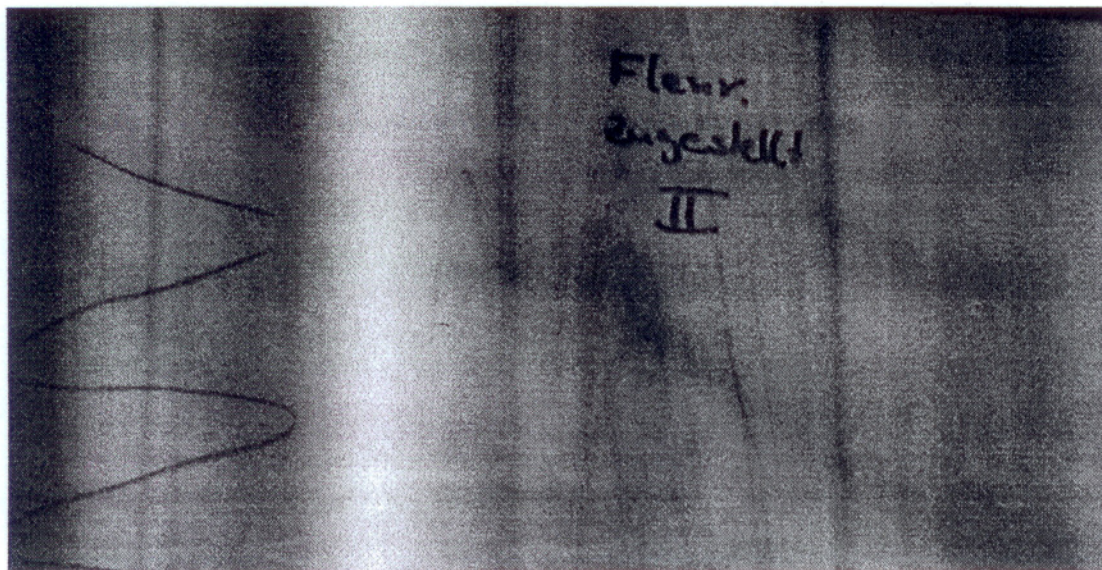


Figure 6. Section of a three-layer PE-film where the thickness of the black inner layer had been reduced over a small width (light line in the left half) by closing one adjusting screw slightly.

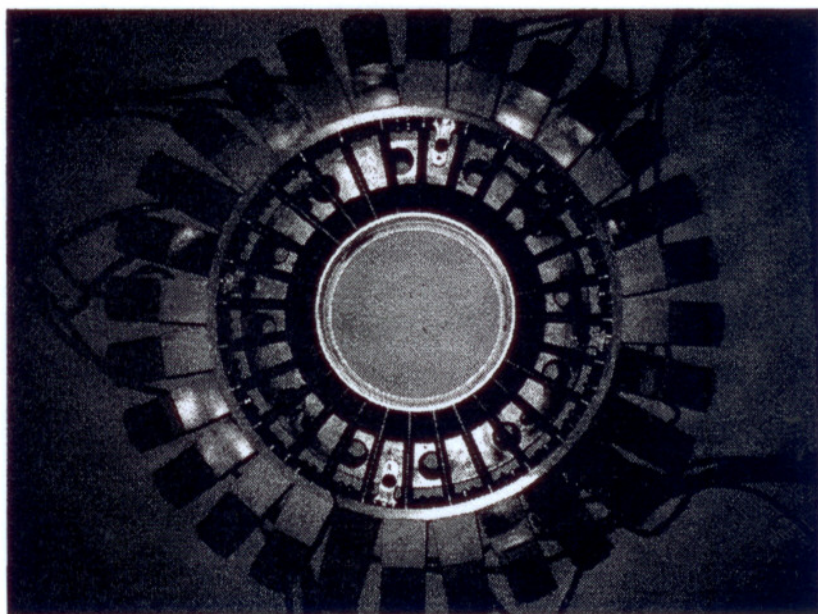


Figure 7. Arrangement of 28 linear stepper drives for a sensitive automatic adjustment of a flex ring sleeve having a diameter of 180 mm (7.09 inch).

For this project special stepper drives with a linear traveling axis have been built. These drives were designed to reach adjusting paths down to 300 nm (1.2×10^{-5} inch) with a high degree of reproducibility. The die is ready to be tested in a double bubble line as well as in a conventional blown film line. But before the test can start the control software has to be available. With flex lips the flow channel gap gradually reduces in the neighborhood of a position where the lip has closed. Contrary to this, flex rings always open the flow channel gap slightly after a certain distance from the position where it has been closed. This is due to the fact that the flex ring circumference is constant. So if it is closed under the adjusting bolt it opens to the right and left from this position. Compared to existing solutions this is a new situation. That is why a totally new software strategy has to be implemented which will control the thickness of a blown film produced with a flex ring die.

SUMMARY

A new manufacturing technique was developed, which enables the production of adjustable circular dies which for the first time have flow channel sections that are multi-walled and thus are adjustable while the line is running. This enables control of the thickness of blown film by varying the local flow resistance in the die similar to cast film flex lip dies. Adjustable circular dies can also be used to adjust the thickness

distribution of single layers in coextruded blown films. With an adjustable circular die a closed-loop control of individual layers can be established. A precondition is that the single layer can be measured online. In both cases special software is necessary, which takes into account that the flex ring acts differently compared to a flex lip when being adjusted.

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BIOGRAPHY

Dr Ing. Heinz Gross

Heinz Gross studied mechanical engineering at the RWTH Aachen with concentration on plastics processing and graduated in 1979. Thereafter he worked with Prof. Menges at the Institut für Kunststoffverarbeitung (IKV), where he passed his PhD in 1983.

He started to work for Röhm GmbH as head of R&D for extrusion processes and extruded products and in 1990 became head of R&D of the technical products group. In 1993, he left Röhm and founded Gross Kunststoff-Verfahrenstechnik that mainly develops improved processing technologies in the field of extrusion with concentration on downstream equipment. Gross holds several patents dealing with new die constructions like the Membrane Technology for slit dies and the Flex Ring Technology for annular dies. In 1997, he additionally founded the Gross Messtechnik to develop new on-line extrusion systems to improve quality of plastic extrusions, sheets, and films.