The continuous production of endless rubber products is a versatile and extensive application area. The profile geometry, determination and composition of the compound and the process control must be designed and developed to match the application purpose.

For selection of the line components a large number of concepts and alternatives are available. The line layout is therefore designed in close collaboration between the machinery supplier and the product manufacturer.

The decision process for an extrusion line design is explained in the following:

1. Extrusion

The main process component of a production line is the extruder with the connected extrusion head. An extruder basically consists of a screw, a barrel, a feeding device, a drive unit as well as a temperature control unit and a lubrication system.

The barrel and the screw form a technological unit. The screw interacts with the barrel and a feed roll to pull in the compound and compacts, meters and homogenises and then shapes it using a tool.

The cold-feed extruder has generally become accepted for the production of technical rubber goods and is often equipped with a vacuum zone to degas the compound. Hot-feed extruders are used as vacuum extruders to remove volatile materials from the compound.

In rubber extrusion processes with downstream pressureless vulcanisation, cold-feed extruders are used as vacuum extruders to remove volatile materials from the compound. The screw of a vacuum extruder essentially consists of two metering zones connected in series with the deeper-flighted, partly filled, pressureless degassing zone between them (fig. 2). The first screw zone pulls in, meters and plasticises and the second screw zone works as a pressurising metering element for the material output.

Failure-free extrusion is only ensured if the opening of the degassing zone remains unblocked during continuous operation and the second zone after the degassing zone works pulsation-free against the resistance of the tool. The first zone always faces a constant degassing pressure while the second zone operates at different tool resistances. Therefore the vacuum screw is designed for a higher metering capacity in the second zone.

A combination of extruder and gear pump is also often selected for profile extrusion applications (fig. 3). The extruder is the feeding element for the gear pump which

---

* Dr. Tim Pohl
  General Manager Rubber Machinery Division
  Dr. Frank Podzeleny
  Development Department
  Rubber Machinery Division
  Troester GmbH & Co. KG, Hannover, Germany

---

Fig. 1:
GS 90 vacuum extruder with separately driven feed roll (Troester)
ensures constant compound output at a high tool resistance. Due to the volumetric pumping performance of the gear pump, the compound output is proportional to the speed of the gear pump and is virtually independent of the present tool pressure. The advantage of the gear pump which enables a high pressure to be built up with low increase in temperature is therefore optimally paired with the extruder’s homogenization performance.

2. Straining of compounds

Technical rubber products such as wiper blades or weather seals have high requirements with regard to the product surface. Any contamination or inadequately mixed in compound constituents must be removed from the compounds before extrusion. This is achieved by a strainer process, in which the compound is pressed through a fine-mesh screen. The straining can take place at various process steps:
1. Directly after the mixing process with an extruder-gear pump combination.
2. Following storage and upstream of the extruder by means of an independent gear extruder.
3. During extruding upstream of the profile head.

A cold-feed gear extruder (fig. 4) upstream of the extruder enables the greatest process window with respect to output, homogeneity of the compound and maximum allowable processing temperature. The rubber compound is strained through the volumetric pumping of the gear pump under minimum shear stress.

3. Shaping in the extrusion head

Today’s hose and profile designs are increasingly made up of several material components due to the various functions to be fulfilled. In addition, there are textile inlays and metal carriers to reinforce the material, and even today these are mostly still not capable of being adequately replaced by elastomers. An extrusion head must be able to join these different material flows at the required output.

To this end, multiple extrusion heads are used whose flow channels are nowadays optimized by computer-based flow simulations. The head design is determined with regard to the adjusting possibilities of the profile geometry from the outside during production, the quick opening for cleaning purposes when the compound is changed and the guidance of additional media such as supporting air, lubricants or anti-stick agents. Handling of the extrusion heads is made easier by manual or pneumatic quick clamping systems on the extruder.

4. Product transportation

After the tool the product is shaped but not yet stable in its dimensions. The product must be uniformly conveyed with as little contact as possible in the subsequent process steps. If vulcanization immediately follows extrusion, the product is conveyed free of contact up or downwards or horizontally in a catenary line through an infrared shock section. The rapid heating causes surface crosslinking so that subsequent product turns, conveyor rolls or conveyor belt supports do not leave any pressure marks on the product. Figure 5 shows a vertical infrared section for processing silicone to form hoses used in medical technology.
In hose production, the vulcanisation is carried out during a later process step outside the production line. After leaving the extrusion tool, the hose is cooled to approx. 30 °C over the entire cross-section for further processing on the production line. Depending on the application the product is pulled out of the head with a caterpillar to thinner dimensions to achieve the final cross-section of the hose or is conveyed with as little tension as possible if the axial tensile strength is low. Low tension conveyance requires an adjusted extrusion head and tool design.

Caterpillar haul-offs, conveyor belts and roller pairs are used for the further transport. The material from which the transport elements are made and the contact forces and lengths have to be matched to the product to prevent damage to the surface of the product.

5. Vulcanisation

The shaped rubber compound is crosslinked in a subsequent process step. The process takes place continuously or discontinuously in two stages; heating up the product to the vulcanisation temperature and maintaining the temperature until the end of the crosslinking reaction. The temperature control along the heating section must be adjusted to the profile geometry and the properties of the compound.

Continuous methods are more efficient compared to discontinuous methods. However, several profiles have to be crosslinked in a high pressure regime so that any air or moisture inclusion does not result in voids and bubbles in the product. In such a case the crosslinking section must be sealed off from the surroundings, which is only usual for simple profile geometries such as cables (fig. 6) or hoses.

The crosslinking system of the compound and the cross-section of the product limit the vulcanization methods available. In the case of peroxide crosslinked materials the vulcanisation must take place in a salt bath with exclusion of oxygen, as atmospheric oxygen makes the surface of the compound sticky and therefore incapable of being transported.

Small profile volumes of sulphur crosslinked rubber profiles are processed on a hot air, infrared or even salt bath line. If the product is heated by several consecutive sections arranged in series, they should be close together to avoid a temperature drop of the product at the transits between the channels.

Heating large volume profiles by means of convection is not economical. The energy input takes too long. Here the hot air is assisted by the microwave radiation penetrating deep into the profile material. Microwave-absorbing substances must be added to the rubber. Combined heating with hot air and microwave energy is common practice, especially in the automotive seal and gasket sector. The task of the hot air is to maintain the surface temperature of the product and remove the gaseous emissions. The uniform heating of the profile’s cross-section by microwave radiation enables uniform crosslinking of the rubber material and a homogeneous pore pattern in sponge rubber compounds.

The combined heating and heat addition is complicated in process terms due to the large number of alternative settings. To avoid time-consuming setting up of the vulcanisation line, Troester has developed a program for calculating the optimum operating parameters. The simulation program takes into account the precise 2D geometry and the material data of the profile design. This approach enables the temperature distribution to be calculated and therefore the degree of crosslinking, even in complicated profile cross-sections. Figure 7 shows the temperature and the degree of vulcanisation at three characteristic points in the product cross-section while the profile is being transported through the line.

6. Cooling

The product is cooled to 25 to 40 °C, depending on its application, to make it easy to handle for further processing. In general, spray cooling is used as this is more effective than film or immersion cooling. The spraying angle and the hole diameter of the
spray nozzles and thus the spraying width is adjusted to the product range to be cooled.

7. Cutting and winding

At the end of the production line the product is either deposited or wound up. Deposit systems with cutting equipment have their own feed caterpillar which is responsible for guiding the product in the correct position. The cut is made in the stopped or moving product. If the cut is made at a stop, the product is accumulated in front of the caterpillar, usually in the form of a dancer loop. At higher line speeds the cutter is running along and cutting the product. The cut quality here is improved. Downstream of the cutting device a take-off belt removes the cut pieces. The pieces are removed by the operator or are sorted into different containers via ejectors. At the same time the product’s surface is visually checked.

There are winding units for collapsible reels, drums or turntables. Figure 8 shows a double collapsible reel winder with automatic winding function. The product is tangentially wound on at the winding point and is therefore wound tension-free. The product is fed by a belt haul-off. After the winding length has been wound the cut is initiated by a length counter. The wound product is transported into the discharging position by rotation. At the same time a new reel is automatically generated at the winding point.

Furthermore, steps such as drilling, gluing, bending, coating or cross-cutting can also be integrated into the process.

8. Line control

Automatic process control is increasingly part of a production line. To this end, production data are recorded, providing information on the stability of product properties such as the dimensions and surface temperature of the product, the extrusion temperatures and pressures and the temperatures of heat transfer media. In most cases the extruder output, the line speed and the process temperatures are controlled.

To ensure the automatic production sequence and recipe-controlled reproducible machine settings, all the line’s settings concerning the dimensional stability and product quality must be electrically controllable.

An important aspect is the choice of suitable measuring positions and sensor types for continuous product monitoring. Contactless operating systems with optical, capacitive or ultrasonic sensors are increasingly used.

The so-called PLC (programmable control) has established itself worldwide as the line control hardware components. The actuators and transducers are connected to the central PLC. The corresponding operating system ensures that the current state of the transducers is always available to the application software. This information can be used by the application software (fig. 9) to guide the actuators so that the machine or line functions in the required way. A different control

Fig. 7: Diagram showing the temperature and vulcanisation curves with heating, temperature maintenance and cooling processes at various points in the profile

Fig. 8: Double collapsible reel winder (Troester)

Fig. 9: Overview screen of a line control with access to the line components
concept is used during the line production starting procedure to enable a stable production process to be achieved rapidly.

Apart from the core control purpose, PLC modules also perform other tasks such as visualization, alarms, recipe management and recording of all process event signals. Nowadays the sensors and actuators are connected to the PLC via a field bus and no longer discretely. This reduces the wiring required. Finally, the line is also increasingly linked to the administration computer so that up-to-date data concerning the production status are always available.

9. Conclusion and outlook

Present day rubber machinery has improved in many details. Separate drive units for the extruder feed rolls, more effective vulcanization and cooling zones, transport elements which handle the product carefully and automated winders are only a few examples of these. As the demand for higher quality products and low production costs will never cease to be topical or relevant, in future auxiliary process resources such as simulation programs or control modules for controlling the starting process will become even more important. They will enable the line operator to achieve reliable, reproducible and faster manufacture of their products.