The plastic extrusion process for tube, hose, pipe, and rod.

Contents:

Figures, photos and images.

Figure 1, representative pipe extrusion line, photo courtesy of Davis-Standard.

Figure 2, portable resin hopper-dryer assembly, photo courtesy of Conair.

Figure 3, general extruder assembly, photo courtesy Davis-Standard.

Figure 4, rotary-style continuous screen changer, photo courtesy of Patt Filtration.

Figure 5, melt pump assembly with motor drive, photo courtesy of Zenith Pumps.

Figure 6, in-line spiral tube extrusion die, image courtesy of StreamLine Extrusion.

Figure 7, crosshead extrusion die with spiral manifold, image courtesy of StreamLine Extrusion.

Figure 8, 10-foot free extrusion cooling tank, photo courtesy of RDN Manufacturing.

Figure 9, vacuum sizing and cooling tank, photo courtesy of RDN Manufacturing.

Figure 10, dual-axis laser measurement scanner, photo courtesy of Zumbach Electronics.

Figure 11, three-axis flaw detection scanner, photo courtesy of Zumbach Electronics.

Figure 12, belt puller assembly, photo courtesy of Conair.

Figure 13, fly-knife cutter, photo courtesy of Conair.

Figure 14, top-cut traveling cut-off saw, photo courtesy of RDN Manufacturing.

The plastic extrusion process for tube, hose, pipe, and rod.

Introduction.

Plastic extrusion of tube, hose and pipe is a steady-state process for converting a thermoplastic raw material to a finished or near-finished annular product. The raw material is usually in the form of plastic pellets or powder. The conversion takes place by forming a homogeneous molten mass in the extruder and forcing it under pressure through an extrusion die orifice that defines the shape of the product's cross section. The formed material, or extrudate, is cooled and drawn away from the die exit at a controlled rate. The extrudate can then be wound on a spool, cut to a specified length, or directed into another in-line process.

By contrast with injection molding or blow molding, which are cyclic processes, extrusion is a steady-state process. This steady-state characteristic produces some unique benefits and challenges as a manufacturing process. Extruded products are very long and continuous, and have a cross section that is usually constant with respect to the axis or direction of production. Injection-molded products are discrete items with varying cross sections in each axis. The fact that the extrusion of tube, hose and pipe is a steady-state process will be discussed in many areas of this article.

The terminology used for describing tube, hose and pipe varies from industry to industry. For the use in this article, tube products are 1" in outer diameter or less, and are products that need to be flexible in their use. Examples of tubing include medical catheters or flexible pneumatic tubing. Hose products are generally 1" in outer diameter and greater, and are products that also are flexible in their use. Garden or irrigation hose are good examples of hose products. Pipe products are generally rigid in form when compared to tubing and hose, and can be any diameter in size. Pipe products can range from ¼" diameter water pipe made from CPVC, up to 60" diameter corrugated drainage pipe made from HDPE. These naming conventions are arbitrary and are used for convenience.

Equipment.

The major components of a tube, hose, or pipe extrusion system are often divided into components that are upstream of the extruder, the extruder itself, and those that are downstream of the extruder. Upstream components include resin handling equipment for conveying the raw materials to the extruder, and resin conditioning equipment that will pre-heat the resin, or control the moisture content of the resin before it enters the extruder feed throat. The downstream components include a molten resin filter or screen changer, the extrusion die assembly, the quench or vacuum sizing tank, any product measurement instruments, the extrusion line speed controller in the form of a belt puller or nip roll set, and finally a product cut-off device or winding equipment. There are additional extrusion process methods that will take the extruded product directly into another in-line process for the addition of a reinforcement braiding or for the addition of other coatings or resin layers.

Figure 1 shows a representative pipe extrusion line, including the extruder, vacuum tank, belt puller, and cutoff saw.

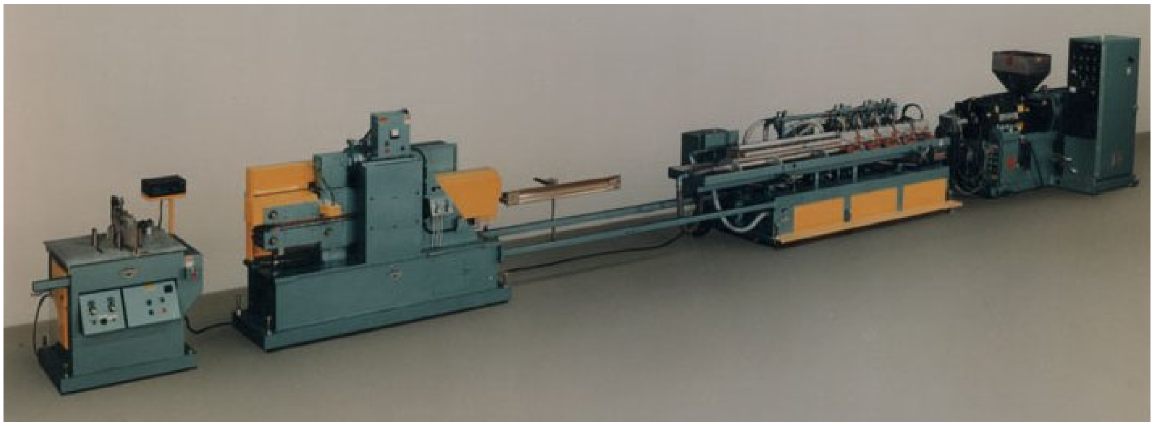


Figure 1, courtesey Davis-Standard

Materials.

Extrusion techniques can be used to process most thermoplastics and some thermoset plastics. The resins most commonly extruded for tube, hose and pipe products include high and low density polyethylene, polypropylene, polyurethane, polystyrene, fluoropolymers, nylon, polyester, ABS, and flexible and rigid PVC. A characteristic that often differentiates extruded resins from injection-molded resins is the melt viscosity of the plastic at normal processing temperatures. Extruded plastics often have a higher melt viscosity, which allows the extrudate to retain the shape imparted to it by the die while the extrudate is in the quenching stages.

Combinations of various resins can be used to gain special physical, biological, or chemical properties. Many additives can be used during the extrusion process to enhance processing characteristics of the polymer or to alter product properties. Such additives include lubricants, thermal stabilizers, antioxidants, radiopacifying agents, and colorants.

Processing Parameters.

The parameters important to extrusion processing are similar to those of injection molding processes. Resin temperature, resin pressure, resin moisture content, screw speed, and screw motor amperage are usually controlled or monitored to provide a homogeneous melt at a controlled volumetric rate. Quenching temperature and the rate at which the extrudate is drawn are controlled or monitored to provide a controlled product size. Dimension measurements, using a variety of gauging methods, can be taken of the extrudate as it is produced. In contrast to injection molding, extrusion can vary the size of the final product without changing the die tooling. Common extrusion production tolerances or process consistency are held to within 1% of the nominal measured value. As these manufacturing processes involve steady state conditions, any action that can stabilize any parameter or condition is beneficial to the process.

Product Design Considerations.

Extruded tube, hose and pipe products fall readily into two categories: those having just one resin in the product cross section, and those having more than one. The first category includes plain tubing and pipe, or a single layer overcoating. The second category includes tubing or pipe with surface or encapsulated striping, and multilayer extruded products.

Various non-resin materials can also be encapsulated within layers of the extrudate to provide additional properties. Fibers can be braided over an extruded tube substrate in to increase burst strength. Stainless-steel wires can be added to improve kink resistance or to provide electrical conductivity. Fiber-optic bundles can carry images or illumination. Each of these techniques has potential for use in tube, hose and pipe manufacturing.

Upstream Components.

Incoming raw material inspection.

As these product manufacturing processes are steady-state as mentioned before, and will be mentioned again, the consistency of the resin and its processing properties are absolutely critical to the stability and consistency of the manufacturing process. Changing from one batch of resin to another can be like completely changing the type of polymer altogether. Even within a batch of resin, there can be significant characteristic changes that will alter the steady-state nature of the process.

It is very beneficial to be able to measure and verify the physical and processing characteristics of the resin being processed on a regular basis to make sure that the control parameters that have been set for the extrusion line will continue to produce the desired product. It is very unrealistic to make the gross assumption that the processing characteristics of resin in one bag or Gaylord will be identical to that of another. This type of inspection also makes good economic sense as the regular inspection will insure that the resin used in the process will not be converted into useless scrap on the extrusion line. If the extrusion line is not producing good product, making money for the company, it is costing money in lost material, lost wages, and available manufacturing time.

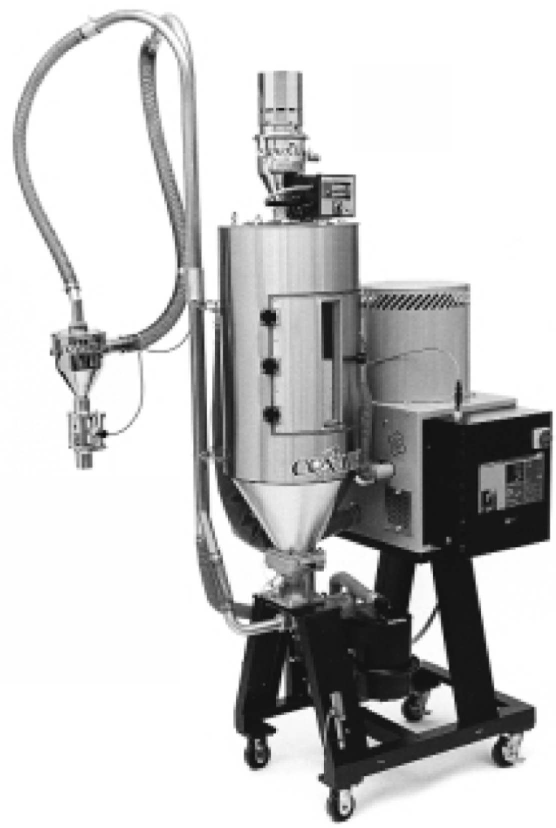
Resin characteristics to be measured and recorded include resin density, melt index, shear rate vs. viscosity data, and tensile strength. Another important visual measurement method is the pressing out of thin resin films on a heated, hydraulic press. This allows a pre-extrusion look at the resin after it has been melted and formed. This method allows a look at clarity or color, the presence and amount of gels, unmelts, or particulate contamination in the incoming resin batch.

The pressing our of resin films prior to extrusion is one of the single most valuable evaluation opportunities that the extrusion line operator has. Every company that does extrusion processing should invest in a small resin analysis lab area that has the proper measurement tools. The resin measurements that are valuable to the extrusion process do not require a high-level individual to make. An average extrusion operator can be trained to perform these basic resin property checks. After all, the extrusion operator is the one that will be responsible at the end of the day for making good extruded product at the end of the extrusion line.

Resin handling for moisture content and temperature.

Another important measurement parameter pair is the moisture content of the resin, and the temperature of the resin just prior to the extrusion process. Some resins are hydroscopic, that is, they absorb water from the surrounding air. Other resins may not be hydroscopic, but they can still collect and harbor surface moisture that will adversely affect the extrusion process continuity. Many companies exist that provide resin drying, heating and conveying equipment. Contact and work with them as necessary to develop the best arrangement for the resin handling for your extrusion process.

Figure 2, photo courtesy Conair



The two important parameters here are temperature and moisture content of the resin. It is an easy mistake to make, to condition the resin prior to extrusion by heating it at a certain temperature, with a certain dryer, at a certain dew point, for a certain amount of time. Unfortunately, this procedure does not tell you the value of the important controlling parameter, that is, the moisture content of the resin. It is certainly easier to say that the resin has been “dryed”, without knowing the important resin parameter of moisture content. Most hydroscopic resin requires a moisture content of .04% by weight. Common hydroscopic resins include nylon, polyurethane, and PET. There are a number of others. This will vary from resin type to resin type. It is also unfortunately possible to "over-dry" the resin. For some resins, a certain amount of moisture is necessary for efficient processing as the moisture can act as a plasticizing agent. By "over-drying" the resin, a condition can be created where the resin won't melt, and the processing viscosity will be extraordinarily high, making the resin unprocessable.

Figure 2 shows a resin dryer with hopper storage.

By preheating the resin prior to extrusion, the extruder is given a consistent requirement of heating, melting, and mixing a resin, beginning its process from the same resin temperature. Remember, a steady-state process. If resin is added to an extruder hopper at 60° Fahrenheit, it will process very differently from resin that is added to the extruder hopper at 90° Fahrenheit. Give the extruder the same job to do and it will do it all day long. Give the extruder different jobs to do, and you will have different results, all day long.

Resin storage and conveyance.

It is always beneficial to store resins in a clean, dry area, away from contamination sources and kept from extreme ambient temperature variation. Some companies store resin in bags, in gaylords, or in silos. When the resin is being prepared for use, it will be conveyed in some way to the extruder hopper.

Gravimetric resin feeding.

When resin is fed into the extruder, there are usually two methods of resin feeding used. One is called flood feeding, the other is called trickle, or starve feeding. Flood feeding is the easiest and most commonly used method. With flood feeding, the resin is added to the extruder hopper until the hopper is nearly filled, and the resin falls to the feedscrew by gravity to be conveyed down the extruder barrel. The resin pellets or powder will fill the flights of the feedscrew as it can.

With trickle, or starve feeding, the resin pellets or powder is administered to the hopper, and then to the feedscrew at a known, controlled rate, usually governed by weight. Equipment known as gravimetric feeders are used to control the rate at which the resin is delivered to the feedscrew. Gravimetric feeders are often used in processes that make multi-layer products, especially where the layers of resin are particularly thin and difficult to measure after the product has been extruded.

The Extruder.

Selection criteria.

The performace requirements of the extruder are being successfully met when the desired ouputs are being attained, with adequate resin melting and melt homogeneity, at a constant discharge pressure and melt temperature. When an extruder is selected for a process, the following extruder parameters need to be considered:

Extruder diameter.
L/D raio.
Feedscrew design.
Feedscrew RPM range and interchangeability.
Available torque and horsepower.
Gearbox design and thrust capacity.
The distribution of barrel heating zones.
The type of barrel cooling.
The need for venting the barrel.
The need for feedscrew cooling.
The design of the feedscrew and the hardfacing of the barrel liner.
The control instrumentation arrangement.

Figure 3, photo courtesy Davis-Standard

The extruder is discussed in other areas of this book in great detail. Suffice it to say that for this article that the job of the extruder in the manufacturing of tube, hose and pipe, is to deliver a homogeneous melt material, at a fixed and uniform rate, at a fixed head pressure, and a fixed melt temperature. It is much easier stated than accomplished. As many variables are in action together in this system, as the variables interact, they will cause process variations of greater or lesser magnitude that will manifest themselves in the extruded product quality.

Controlled and monitored parameters.

There are only a few control parameters involving the extruder in the extrusion of tube, hose and pipe. There are also only a few monitored parameters. The controlled parameters usually consist of the temperature control zones for the feed section, the extruder barrel zones, and the extruder clamp area. The other controlled parameter is the speed in RPM of the feedscrew. These two parameters must be held as constant as possible to achieve that ever-elusive steady-state condition. The monitored, or resultant parameters of the extruder include the amperage of the feedscrew motor, the melt temperature at the end of the feedscrew, and the melt pressure at the end of the feedscrew.

Thermocouples and RTDs.

The comparison of the use of thermocouples or RTDs in the extrusion of tube, hose and pipe is nearly endless. The following seems to hold true about this debate. RTDs are more accurate than thermocouples, no question about it. RTD’s are usually accurate and repeatable within 0.1° F. The traditional J-type thermocouple with special limits of error is accurate and repeatable with ±1.0°F. Thermocouples are more physically durable than RTDs, no questions about it. Thermocouples and RTDs, especially for adapters and extrusion dies, tend to get dropped a lot. The thermocouple will tolerate being dropped a lot better than an RTD. RTDs are also four to ten times as expensive as thermocouples; accuracy has a price. If your temperature control instruments cannot display temperature information in 0.1° F increments, an RTD is not providing any benefit for your process. Very few and far between are the extrusion processes for tube, hose and pipe, where temperature control zones need to be controlled to within 0.1°F. Another related issue is temperature repeatablility as opposed to the absolute value of the measurement. The absolute value of the measurement is not as important as the day-to-day repeatability. RTDs and thermocouples are both repeatable to the same relative degree.

Instrument calibration.

It cannot be emphasized enough that the temperature, pressure, RPM, and amperage instrumentation needs to be calibrated on a regular basis. The readings on instruments tend to drift a little over time. If the instruments are not calibrated regularly, you cannot believe what they are telling you and any process documentation that you may have recorded is worthless. You certainly cannot base a steady-state process on them. Most extrusion facilities have the measurement and control instruments calibrated twice per year.

Downstream Components.

Resin filter or screen changer.

At the very end of the extruder barrel is the breaker plate or restrictor bushing, depending on the viscosity and thermal sensitivity of the resin being extruded. Process that extrude resins that are less viscous and more thermally stable will use a breaker plate, otherwise, a restrictor bushing. The breaker plate is nothing more than a disk with a large number of holes. The breaker plate serves several purposes. It acts as a seal between the extruder flange and the downstream adaptor flange, it acts as a source of back pressure to the feedscrew, and also serves as a place to install filtering screen disks called a screen pack. A restrictor bushing, usually for extruding unplasticized polyvinylchloride pipe, provides a free-flowing, controlled-size orifice that produces a fixed back-pressure, or resistance to the feedscrew without causing potential areas of melt degradation or stagnation in the melt flow channel.

There are extrusion processes that can be described as short-run processes in one extreme, and then there are long-term processes on the opposing extreme. Short-run processes, for example, may produce medical tubing, are generally less than 12 hours long. In cases like this, product will be produced during one shift, then torn down for cleaning the next day, and then reassembled for another manufacturing run on the third day. In long-term processes, for example, producing rigid PVC pipe, the extrusion manufacturing operates for 24 hours a day and 7 days per week until the production goals have been reached. Long-term processes provide the best efficiencies as they will usually allow a steady-state condition to be more readily achieved.

Short run processes will use melt filtering in the form of screen packs in the breaker plate. Because of the limited duration of the manufacturing run, a screen pack will provide enough filtering capability to allow the manufacturing run to be completed without changing the screen pack before the line is torn down for cleaning. In the case of the long-term process, especially if the resin quality allows larger amounts of particulates into the resin, some kind of continuous or cyclic melt filter will be installed. Many companies provide these kinds of melt filters, and work closely together with the extruder manufacturers to insure physical compatibility.

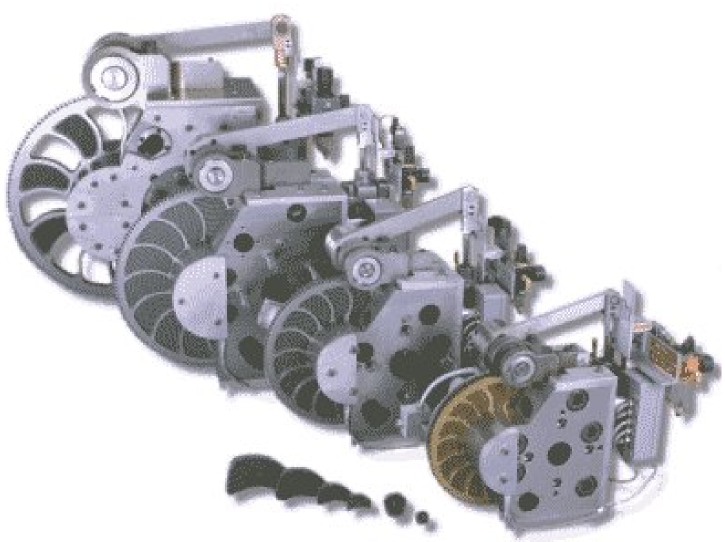


Figure 4, photo courtesy Patt Filtration

Figure 4 shows a rotary-type, continuous screen changer assembly that would bolt to the discharge end of the extruder.

When considering cyclic or continuous melt filtration systems, there are many companies that have the capability of providing either type, therefore they are able to match the filter type to the process. Cyclic screen changes are usually less expensive, but will contribute less to a steady-state process condition as the filter media will fill with particulates and change the melt pressure over time. Also when the slide plate of the screen changer is activated, there may be a momentary interruption of the melt flow as the new filter media volume is filled. Continuous melt filter systems are usually more expensive, but will contribute more to a steady-state process condition. The goals with any melt filtering system will include: a steady melt pressure contribution, a steady melt temperature, little or no area for melt stagnation and melt degradation, minimal additional melt volume in the melt flow path, and as simple and reliable a mechanism as possible for the melt filter exchange.

Melt gear pump.

Many extrusion processes for tube, hose and pipe will incorporate a melt pump or gear pump in the melt flow path to optimize the consistency of the melt flow delivery rate. Of course, there are benefits and costs for any extrusion line addition of this magnitude. The decision for using a melt pump system will usually reside with the variety of resins that will be processed, and the required accuracy in the final product.

Figure 5 shows a melt gear pump mounted on top of a frame holding the precision motor drive, with an electrical box for temperature control zones.

If many resin types will be used, and it is not efficient to change feedscrews with each resin type change, and high volumetric accuracies are needed, a melt pump may provide a workable solution. Melt pumps do substantially increase the complexity of the mechanical system, the melt flow paths, and the control system in any extrusion process. If a low number of resin types is to be extruded, or ideally, if only one resin is to be processed, the feedscrew design that is used

Figure 5, photo courtesy Zenith Pumps

may be optimized to the point where the feedscrew will provide an extrusion rate accuracy and repeatability that will equal the benefits provided by a melt pump system. In the attempt to keep any extrusion manufacturing system as simple as possible, with as few process variables as possible, it is preferable to try to achieve the required melt delivery accuracy and repeatability without the use of a melt pump system.

Even through the melt pump will provide a uniform volumetric delivery for each turn of the pump, the accuracy of the melt pump drive system will be absolutely critical. The additional temperature control zones will also add their variability to the extrusion system. Also the melt pressure delivery to the melt pump from the extruder will need to become a closed-loop, pressure control system. When incorporating a melt pump into an extrusion system, the primary feedscrew speed control will change from a constant RPM control to a melt pressure feedback control where the inlet melt pressure to the melt pump will be the controlled parameter, no longer the feedscrew RPM. There will usually be the addition of another melt pressure transducer into the process that will be used solely for the melt pressure feedback control system.

As with the melt filtration systems, there are many companies that specialize in the design and manufacture of melt pump systems which can be added to just about any tube, hose, and pipe extrusion line. There are few, if any companies that design and manufacture the equipment for the entire extrusion line. The degree of focus and development on each aspect of the extrusion line and extrusion process has become so concentrated over the years to the point where it has evolved into an industry where no single extrusion equipment company can be the expert in all phases and areas of the extrusion process. The extrusion line owner-operator is guided into the situation of working with many companies to assemble a complete extrusion line. There are some cases where one extrusion equipment company will take the supervisory lead and become responsible for the entire manufacturing line, and then coordinate the activity of the various equipment manufacturers to assemble the entire line for the end user.

The writing of this book faces a similar situation. Many authors are involved, each an expert in there own specialties. There are only a few individuals that are familiar enough with all aspects of the extrusion process that can provide comprehensive information on the entire extrusion process.

Extrusion die assembly.

Many types of extrusion dies are used in tube, hose and pipe product manufacturing that are divided into several main categories or types. These categories include the primary division of crosshead extrusion dies and in-line extrusion dies or extrusion heads. From this point the extrusion die type further divides into sub-categories depending on the number of resins that are involved in the process (co-extrusion), the shape of the final extruded product, if the extrudate will be used as a coating over a substrate or not, and the nature of the resins and how their nature applies to the end product.

The purpose of the extrusion die or extrusion head is to form the molten resin into its final or near-final shape prior to quenching. Extrusion dies have very few moving parts and therefore are comparatively simple machined-metal, electrically-heated assemblies that fasten to the discharge end of the extruder, or the screen-changer, or the melt pump. This simplicity of the extrusion die assembly is made in comparison with the mechanical complexity of equipment like the extruder. The extent of moving parts in an extrusion die is mostly limited to the wall centering adjustment mechanisms.

An in-line extrusion die has an operational centerline that is collinear with the extruder screw axis. A crosshead extrusion die has an operational centerline that is 90° to the extruder screw axis. Both in-line and crosshead extrusion dies can be mounted to an extruder in a number of other ways using various adapter and connection types depending on the requirements of the product manufacturing operation.

Figure 6 shows an in-line, spiral manifold extrusion die assembly for making small diameter hose and tubing, with adjustable wall centering.

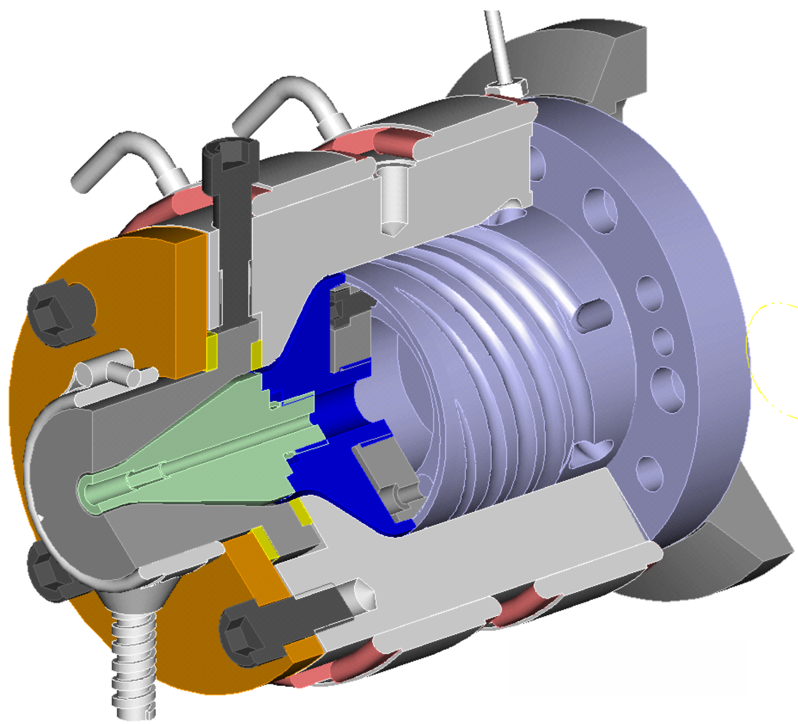


Figure 6, image courtesy of StreamLine Extrusion

The importance and involvement of the extrusion die in the extrusion process is as great as every other piece of equipment that contributes to the process. There is no such thing as a minor piece of equipment in an extrusion process. All of the pieces of equipment are major contributors to the process. The extrusion die can be compared to the injection mold in the injection molding process, or the blow mold in the blow molding process, in that the extrusion die is responsible for imparting the product size and shape. The extrusion die or the tooling set in the extrusion die can be readily changed in order to make different product types or sizes. A significant difference between the extrusion die and the injection mold is that the injection mold can make only one part shape, where the extrusion dies and tool sets are capable of making various product sizes with one tool set.

With extrusion die assembly types, another selection method or decision tree can be constructed as selecting between an in-line design or crosshead design, processing one resin or more than one resin, and if you are coating a substrate or not. It is most preferable to extrude product with an in-line configuration if at all possible. The in-line method contributes the least disturbance and shear history to the melt flow. Unfortunately, the in-line extrusion method is not agreeable with all product manufacturing types.

In-line extrusion can be used most often for single layer plain tube, or single layer plain tube with a single surface stripe or single encapsulated stripe. In-line extrusion die types include spider-type, spiral-type, or strainer-basket type assemblies. Resins and products that are often extruded with in-line extrusion heads include cold water plumbing pipe made from white, rigid PVC or a fluoropolymer medical catheter with a spider-type head; and natural gas pipe or electrical conduit from high-density polyethylene with a spiral-type or strainer basket-type extrusion head.

Crosshead extrusion is most often found in coating applications such as wire-coating (described in detail elsewhere in this book), multiple-layer tube, hose or pipe coextrusion processes, striping coextrusion processes with either surface stripes or encapsulated stripes, and extruded profiles that have a round outer shape, but contain multiple openings or lumens of specific shape to carry multiple fluids.

Figure 7 shows an extrusion crosshead assembly with a spiral melt flow manifold and adjustable wall centering.

When resin enters the extrusion die from the extruder, screen changer, or melt pump, the melt flow channel is usually in the form circular supply orifice. It is the job of the extrusion die to convert this rod of resin into an annular (tubular) shape to form the tube, hose or pipe. This conversion from a rod to an annulus is done by the manifold, or flow channel type that is designed into the extrusion die.

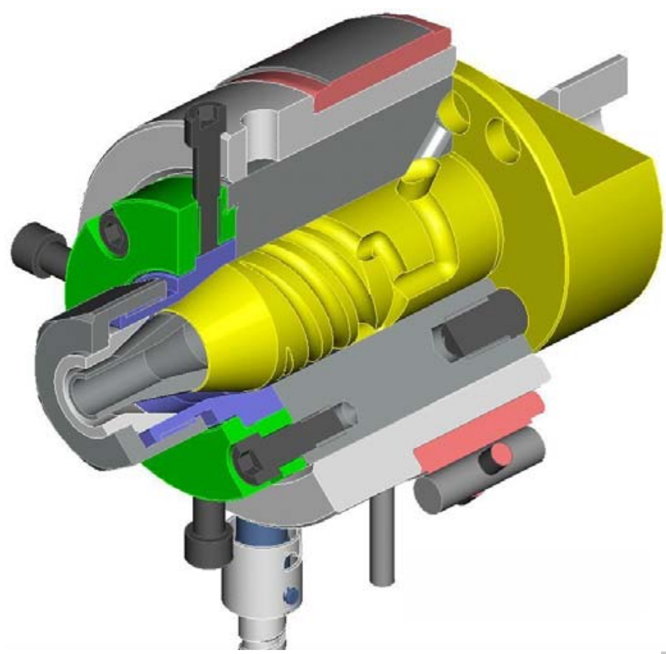


Figure 7, image courtesy of StreamLine Extrusion

Some special extrusion die arrangements that have been developed for specific product types include extrusion dies for HDPE corrugated pipe, FPVC/RPVC spiral wound swimming pool hose, and Y-block manifold arrangements that connect more than one extrusion die to one extruder in order to take advantage of the output capacity of an extruder when making smaller diameter products.

Another special tube and hose extrusion process is referred to as tandem extrusion. This coextrusion process involves two or more extruders with as many extrusion dies. There are many cases where coextrusion within one extrusion die assembly is not possible because of resin processing temperature incompatibility, or because the addition of a braided reinforcement needs to be applied between hose layers. It is in this case where two extrusion dies will be located closely together in a single process, where extruded product travels from one extrusion die to the other for sequential coating. There are cases where the die to die spacing is merely inches in distance. There are other cases, for example the addition of the braided reinforcement, where one resin layer goes through a quench tank and is cooled, before entering the second extrusion die for subsequent coating.

The air gap and quench entry.

In between the extrudate exit of the extrusion die and the entry to the quench tank is a critical area known simply as the air gap. This is the area in which the extruded resin is first seen by the outside world. There are many things going on in this area, although if correct extrusion processing is taking place, it will be difficult to tell that anything is happening there at all. The air gap should appear to the human eye as a completely motionless area. If you can see or detect any kind of motion in the air gap, there is probably a processing problem going on. This goes back to the concept of extrusion being a steady-state process. Going along with steady-state condition, in the air gap, is the concept of the extrudate being visibly motionless while passing through the air gap.

Phenomenon that takes place in the air gap include: die swell, die buildup, melt orientation, melt fracture, and draw resonance. These events are detailed in an earlier part of this book under the topic of extrusion dies.

It is beneficial to keep any random air currents from impinging on the air gap area as these air currents will adversely affect the uniform cooling of the extrudate. The air gap distance should also be held constant. The air gap distance will determine the rate of elongation that the melt cone or extrudate, experiences in the air gap. Usually, the air gap distance will be kept as short as possible to minimize the area where the extrudate can be negatively affected. There are some extrusion processes, like the extrusion of fluoropolymer tubing, where the air gap is several inches in length, and protected from air drafts. This is because fluoropolymers can be elongated, or drawn down from the extrusion die in great amounts, sometimes as much as 100:1 by cross-sectional area.

As the extrudate is drawn through the air gap, another motionless area is the extrudate entry into the quench tank. This is quite challenging as the quench tank entry is occupied with running water. The water is usually under strict control by the use of dams, diaphragms, and wiers to keep the water flow as constant as possible to prevent unstable or unsteady water contact with the melt cone. This area is quite important, as the area where the extrudate first makes contact with water from the quench tank creates an irreversible condition in the product as the outer surface of the extruded product is altered from a high-temperature viscous liquid state to a solid state.

Extrudate quench and cooling.

In the extrusion of tube, hose and pipe, there are two main types of product quench and cooling. One type is called free extrusion, and the other type is called vacuum sizing. We have already presented a small portion of the quench tank area in the previous paragraph as the extruded product is drawn through the air gap and into the cooling water of the quench tank entry interface. Most extrusion process quench and cool using water as the main thermal transfer media. Some processes use controlled air streams as the thermal transfer media when the product is very sensitive to cooling, or needs to be cooled very slowly. Some other processes use more aggressive thermal transfer media such as liquid nitrogen to move heat more quickly.

Free extrusion describes the method of extruded product quenching and cooling where the entire product cooling process takes place at ambient pressure. No vacuum effects are exerted on the product outer diameter to assist in quenching the product and controlling the size. In free extrusion there is frequently the addition of very low air pressure to the inner diameter of the extruded product in order to help define the inner diameter dimension and to assist in the product cooling of the inner diameter. There are no hard and fast rules about which products should be vacuum sized, and which products should be free extruded. Generally speaking, smaller, flexible products, like thin-walled medical catheters are free extruded. Larger, rigid products, like heavy-walled PVC pipe products are quenched with vacuum sizing. In free extrusion, there is usually no tooling of any kind at the quench tank entry that controls the size of the extruded product, as there is in vacuum sizing processes.

Figure 8, photo courtesy of RDN Manufacturing

Figure 8 shows a 10-foot long cooling tank that can be used for free extrusion, and can be adapted to immersion or spray cooling.

A concept worth remembering is that extruded products, when drawn through a quench tank or a vacuum sizing tank, cool and solidify from the outside of the wall to the inside of the wall. For an extruded tube, hose, or pipe to cool completely, all the heat energy stored within the wall of the product must be transferred to the water of the quench tank on the outside of the product. The thinner the wall of the final product, the faster it will cool to room temperature. The heavier the wall of the product, the slower it will transfer heat and cool to a uniform solid state.

Also, plastics are a poor thermal conductor, that is, they absorb and relinquish heat fairly slowly. After spending quite a bit of time being heated in the resin hopper, then heated and sheared in the extruder, and then formed into shape in the heated extrusion die, the product will take quite a bit of time to give up that stored heat. The thermal conductivity of the resin is a fixed value, heat will only be transferred so fast, no matter how cold the water in the quench tank may be.

In vacuum sizing, the extruded product is drawn through the air gap and into a wall of water to begin drawing heat away from the outer surface of the product, forming a skin, or thin portion of the outer wall as a solid, or near solid surface. The product is further drawn into a chamber of the tank that is exposed to a controlled level of vacuum. This vacuum chamber can be as short as 1 foot in length to as much as 6 feet in length. This negative-pressure environment causes the extruded product diameter to expand slightly and to make contact with a series or rings or a sleeve that is referred to as vacuum sizer tooling. There are different vacuum sizer tooling types, styles, and lengths for various products and materials. The vacuum sizer tooling allows the extruded product to be fixed at controlled outer diameter. The wall thickness of the product is then controlled and varied by the extruder output. A vacuum sizing tank can also be often used as a free extrusion tank, but a free extrusion tank is always a free extrusion tank.

Figure 9, photo courtesy of RDN Manufacturing

Figure 9 shows a vacuum sizing tank for small tubing that can be adapted to immersion or spray cooling.

Within the quench tanks, there is usually one of two types of extruded product cooling, one is immersion cooling, and the other is spray cooling. In immersion cooling the extruded product is held under water, completely immersed as it is cooled by the water media. Rollers or other holding methods are used to keep the tube product under the water surface. The extruded product will tend to want to float to the water surface in immersion cooling conditions and needs to be controlled. The shape of the roller or other product holding method should conform to the round shape of the extruded product so that the round product shape is not distorted accidentally into an oval shape. If the product is allowed to float to the surface, an unbalanced product cooling condition will occur, where the bottom of the product is being cooled by the water, but the upper portion of the product that is exposed to air is not being cooled.

Also in immersion cooling, the cooling effect will be limited by the laminar effect of the water in the tank. The water that is directly in contact with the extruded product tends to be drawn along with the surface of the product and is heated by the energy coming out of the product. As the cooling efficiency of the tank is dependent upon the temperature of the water in contact with the product, the warmer the water in contact with the product surface, the poorer the cooling efficiency. In order to disrupt the laminar condition of the water that surrounds the product, different wiping methods or walls are used to exchange the water that is in contact with the product outer diameter.

With spray cooling, the immersion portion of the tank is exchanged for a tank area that houses a set of spray nozzles that will cause water to be sprayed all around the surface of the extruded product. This method of cooling the product is more efficient by 20-40% compared with the immersion cooling method. This is because the laminar effect in the immersion cooling method does not exist, and there is continuous exchange of cooled water applied to the surface of the product.

When a wall thickness measurement system is used, the measurement sensors will often be placed in the water volume of the quench tank. This will be further covered in the next section on product measurement instrumentation.

At the end of both quench and cooling tank types is a short tank section that houses an air wipe, or water blow-off. This device removes the water from the surface of the products so that when the product outer diameter is measured, no water droplets will interfere with or distort the optical-based measurement. Also the air wipe helps confine the water to the quench tank, keeping the workplace floor free of water puddles for the benefits of operator safety. Air wipes are often selected by the efficiency of compressed air usage, and how quietly they operate in the manufacturing plant environment.

Product measurement instruments.

Most extrusion lines producing tube, hose and pipe products have an on-line gauging system that measures, at least, the product outer diameter with a laser-based scanner. Such laser gauging systems have a very high measurement accuracy and a very high scanning rate for measurement averaging. These gauging scanners are usually placed in the extrusion line after the air wipe and before the belt puller or nip roll. As product moves from equipment to equipment in this portion of the line downstream of the quench tank, it is important to maintain as visually motionless a product as possible. Sometimes if the product is unsupported for a long enough distance, the product can develop a bounce or vertical-plane oscillation that can detract from the product stability. When viewing the product as it travels from the quench tank to the gauging scanner, to the belt puller, to the cutter, the product must appear visually stable and motionless. Any sign of motion, bounce, or vibration is indicative of a disruption in the steady-state condition that needs to be rectified.

The next step beyond an ordinary laser measurement scanner is a dual-axis scanner measurement system. When using a single axis scanner, the possibility exists for the measurement plane to be in an orientation where the average diameter is not measured due to extruded product ovality. A dual-axis laser measurement scanner uses two laser scanners, with measurement planes that are 90° apart. By having the scanners mounted in this way, and by taking the average of the measurements from the two scanners, any ovality that exists in the extruded product can be taken into account and a measurement that represents the true diameter of the product may be produced and displayed.

Figure 10 shows a dual-axis laser scanner for tube and hose. Note the 90° relationship of the scanning paths.

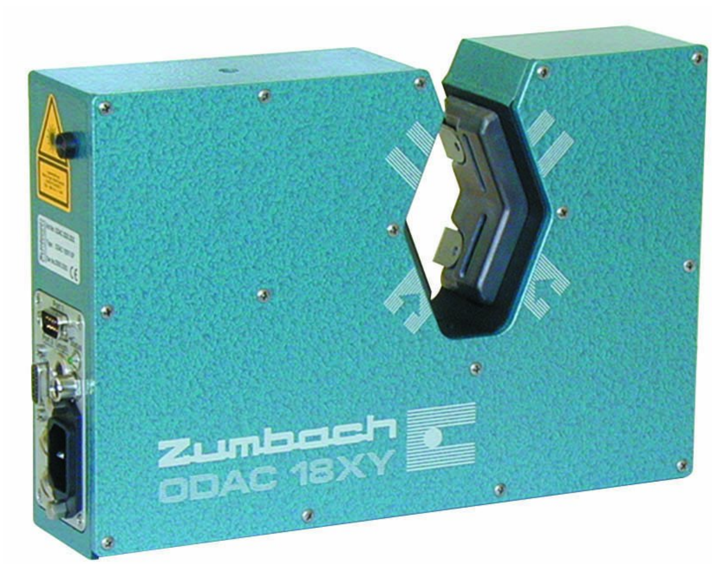


Figure 10, photo courtesy of Zumbach Electronics

Another in-line inspection parameter is known as flaw detection. This is different than outer diameter or wall measurement parameters because flaw detection looks for short-term variations on the surface of the product, there is no dimensional measurement made. For example, if there is a piece of particulate matter on the outer diameter of the product, the flaw detector will announce or record that a surface flaw has been detected, and collect a count of flaws over time or distance. The limitation here is of the scanning field and the size of the flaw. There are limits to how small a flaw can be detected, and the coverage of the flaw detection scanner. Sometimes multiple flaw detection scanning beams will be arranged around the product to gain additional detection coverage.

Figure 11 shows a flaw detector assembly with three axes of detection coverage.

Figure 11, photo courtesy of Zumbach Electronics

The third step or level in product measurement is the measurement of the wall thickness of the extruded tube, hose or pipe. This is most often accomplished with a series of four ultrasonic sensors that are mounted to a frame in the quench tank. The water environment is necessary as it is used as the conductor for the ultrasonic energy used for the measurement. These four sensors are located at four places, equally spaced around the product diameter. In the most simple description, the ultrasonic sensors emit bursts of ultrasonic energy that impinge on, and then penetrate the surface of the extruded product. Two echoes are created, one from the outer surface of the product and the second from the inner surface of the product wall. By knowing the velocity of the ultrasonic energy, and by measuring the time between the echoes, a wall thickness value can be obtained. The four sensors produce a picture of the product wall thickness in four, 90 degree increments. These wall thickness measurements, combined with a dual-axis laser scan of the outer product diameter, provides a very good look at the important dimensional values of the extruded product.

It is important to remember that with all dimensional measurements taken during the manufacturing process, the final product size may still change from the value measured while on-line. This is because the product may not have attained an equilibrium room temperature. Measurements taken when the product is hot, will be different than when the product has been completely cooled. Also the orientation, or stretching of the product while in the melt state through the air gap can produce a condition where the product will shrink in the axial direction. The shrinkage in the axial direction of the product will change the dimensional values of the product diameter and wall. In some medical product applications, tubing will be cut to length and then attached to a metal frame to fix the ends of the tube, and then place the frame with the fastened tubes in a hot air oven to allow the product to anneal. This is like trying to hit a moving dimensional target. What is helpful is that any axial shrinkage will usually be the same throughout the production run, and although the wall thickness measurement values may not be accurate in absolute value, they will be able to confirm the condition of a uniform wall thickness by having a common value around the product.

Once the product dimensional measurements are being taken, they can be used to assist in controlling different parameters in the extrusion line to maintain a setpoint dimensional value. This is very much like a temperature control zone on the extruder barrel or the extrusion die. One example of closed-loop dimensional control involves the tracking of the dual-axis measurement of the product outer diameter, and then varying the belt puller speed up and down slightly to allow a setpoint diameter value to be met and held stable. When the belt puller speed increases, the product diameter decreases, and vice versa. The laser gauging system will then increase or decrease the belt puller speed to achieve the product diameter setpoint. In the manufacturing of rigid pipe, the vacuum level on the vacuum tank can be used as a controlled parameter to increase or decrease slightly the product outer diameter. There are also cases where the extruder speed, or the gear pump speed will be varied up or down slightly to increase or decrease the amount of resin being pushed out of the extrusion die.

Another next step in product dimensional measurement and control involves the use of the ultrasonic wall thickness measurement, and using this information to vary and control the wall thickness or wall centering of the extruded product. The ultrasonic information is used in a control algorithm that will be directed to a mechanically driven adjustment system at the extrusion die. Newer designs of extrusion dies can be adjusted for wall centering while in operation and can be driven by the ultrasonic sensor information to produce a product that has a wall thickness consistency that is only limited by the accuracy and the repeatability of the measurement sensor. Extrusion dies that are controlled for wall centering with ultrasonic sensors have actually been in use for about 20 years, but hade been limited to very large extrusion dies that make larger diameter pipe products. Large extrusion dies that produce flat sheet products have been using heated bolts to vary the wall thickness of the sheet from place to place across the exit front of the sheet die for many years. The most recent developments have been accomplished in the areas of smaller extruded products. For example medical tubing, automotive fuel hose, or high-speed wire coating processes. Prior limitations in extrusion die design have been overcome and now the closed-loop wall-centering of extruded products has been achieved to be coupled with the dual-axis diameter measurement and control.

Line speed controller in the form of a belt puller or nip roll set.

The governing parameter of extrusion line speed is performed by either a belt puller or a nip roller device. The goal of the line speed controller is to provide a constant, controlled rate of speed for the product as the product is drawn away from the extrusion die, and to do so without damaging the product by crushing, distorting, or causing any aesthetic defects. The primary difference between belt pullers and nip rollers is the degree of contact with the product through which the pulling and frictional force can be applied. Nip rollers will have a very small contact area with the product and so are limited in the size of product they can control without damage, and they are also limited to the pulling force that can be applied to the product to draw it downstream from the extrusion die. Belt pullers have a much greater contact length by using pairs of belts held apart by motor-driven rollers. Between the rollers are plates that create and maintain contact of the belt to the product.

Figure 12 shows a 2-belt product puller, or catapuller for medium size tube and hose products.

A wide variety of materials are used to cover or coat nip rolls and puller belts with the intention of creating a situation of constant speed, sufficient grip and surface friction to prevent slipping, and sufficient hardness/softness to prevent damage to the product. Again there are many companies that specialize in these pieces of equipment and the materials coating the belts or rollers. Belt and roller covers can range from hard, solid urethane materials which have very high surface friction, to extremely soft, foamed neoprene materials, and everything in between. The belt puller or nip roller must be able to overcome any frictional forces that may be applied to the extruded product

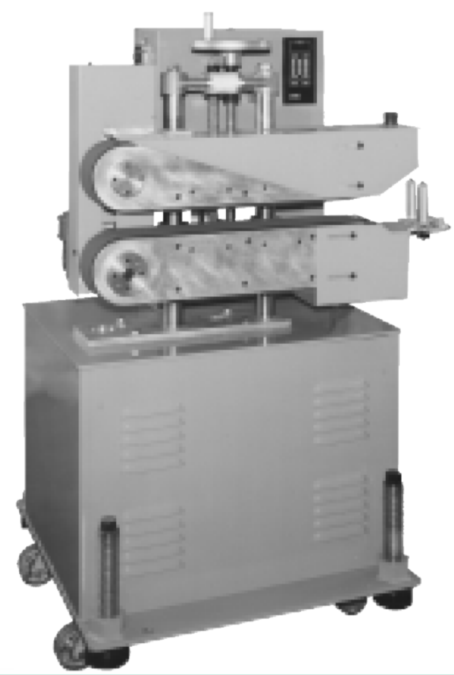


Figure 12, photo courtesy of Conair

beginning at the extrusion die exit, and through the quench tanks. For example, in products that are vacuum sized, the friction of the sizing sleeves and any rubber seals in the vacuum system must be overcome, in addition, the resistance to drawing of the melt cone due to melt viscosity of the resin in the melt cone must be overcome. Usually the free extrusion process will have much less friction for the belt puller or the nip roller to overcome.

With speed control of the extruded product as the primary goal of the belt puller or nip roller, much work has been done in applying highly accurate motor drives and mechanical drive systems that control the speed of the belt or roller. The mechanical stability of the structure of the machine also receives a lot of attention so as to avoid mechanical vibration, and to provide a reliable, firm platform for pulling the product downstream.

Product cut-off device or winding equipment.

When the extruded tube, hose or pipe is brought to this stage of production a decision needs to be made whether to cut the product to a specific length, or to wind it up on a spool or reel. Of course, with rigid pipe products, the process is often limited to a cut-off device in the form of a fly-knife cutter for smaller products, or a traveling saw for larger products. If the product is too rigid to be wound on a spool or coiled, it must be cut to length. If the product is flexible, there can then be a choice of cutting or winding.

Figure 13 shows a fly-knife cutter for flexible tube products where high length accuracy is required.

Winding products must be done with the consideration of the product taking a set, or curve of the spool during winding and subsequent storage. Many extruded products can be wound on a spool where either the curvature imparted to the product is of no consequence, or the product resists taking a curvature set enough so as not to create a quality problem. Spools for winding can be quite small, for example for medical tubing, or quite large, for example for corrugated drainage pipe. Winders can be as simple as a single motor-driven shaft with a removable spool, or as complex as having multiple shafts with automatic product cutting and transfer from spool to spool. Product tension control also can come into play with flexible products and smaller diameter products so that the product is not accidentally stretched and distorted while on the spool.

Figure 13, photo courtesy of Conair

Figure 14 shows a cut-off saw assembly for rigid pipe products.

When cutting products to length, the length is normally determined by either an encoder that is connected to the belt puller or nip roller to define the length, or by an optical sensor that actuates the cutter when activated by the product. Accuracy of the cut length can vary from fractional inches to thousandths of an inch. Here is another case where the accuracy and repeatability of the cut length are strongly dependent upon the continuing axial shrinkage of the product after extrusion.

Figure 14, photo courtesy of RDN Manufacturing

A tremendous amount of time and effort has gone into the design and process development for cutting extruded products. The design of fly-knife cutting blades and the blade drive mechanisms have seen great changes over the recent years. The intention is to create the perfect cut, where there are no particulates created during cutting, and where there is no distortion of the product diameter on either side of the cut. Many lubricants and lubricant delivery systems have been incorporated into tubing and pipe cutters to assist the cutting process and to increase blade longevity.

Common tube, hose, and pipe product types.

Medical devices / Pharmaceutical products.

Electrical / conduit.

Plumbing.

Irrigation.

Natural gas distribution.

Municipal water and sewer / corrugated pipe.

Swimming pools and spas.

Writing instruments.

Lawn and garden.

Automotive.

Consumer products / packaging.

Appliances.

Marine.

Industrial hose.

Conclusion.

The extrusion of tube, hose and pipe is one of the simpler plastics forming processes when compared to injection molding, blow molding, or blown film processing. The key to successful, efficient extrusion processing is found in taking every parameter that can affect the manufacturing system, and identifying it, controlling it, or monitoring it. There is no such thing as insignificant parameters in the extrusion process. Remember that the extrusion of tube, hose or pipe is a steady-state process. Anything that happens that alters the steady-state condition will disrupt the steady-state condition and create variation in the product quality.