ABB DRIVES

Application guide No. 1

Guide to extruders in AC drives



In the plastics industry there are dozens of different kinds of systems and machinery. The power range is basically from 2.2 kW to 3700 kW. The performance requirement is relatively high. The drive must be able to communicate to overriding systems. It is often preferable that one company can deliver the whole system including drives, motors, interface to overriding system, winding section, etc. ABB is one of the few companies that can handle large systems.

Table of contents

05 **Introduction**

05 General

05 End products

06–17 **Process description**

06–09 Introduction to extruders

- 06 Single-screw extruder
- 07 Extruder barrel and feed section
- 07 Barrel heat input and extraction mechanisms
- 08 Barrel temperature control systems
- 08 Venting
- 08 Screw
- 09 Gearbox and thrust bearing
- 09 Multi-screw extruders

10–17 Extrusion processes and machines

- 10 Compounding
- 10 Profiles
- 11 Pipes
- 12 Fibers
- 13 Blown film lines
- 14 Wire and cable insulation
- 15 Injection molding
- 16 Compression molding
- 16 Blow molding
- 17 Calender and other web-based lines

18 **Drive and motor considerations**

18 Load characteristics

18 Power and speed range

19–21 Dimensioning drive and motor

22 Typical requirements for the drive

23–24 DC drives vs. AC drives

- 23 Performance
- 23 Cost comparison
- 24 How to change from DC to AC

25 **ABB benefits**

25 Requirements

25 ABB solution



Introduction

General

Most end products of the plastics industry are manufactured in a single machine and there is no process flow in the usual sense of the term. The raw material in granular form is supplied to the material hopper of the processing machine, specially designed for the product and the final product is obtained direct from the machine.

In large-scale production with several machines and much the same base material, a central raw material supply system is used together with storage silos and pneumatic transport to the processing machines. In such production the individual machines are sometimes connected to a central control system for supervision etc.

The extrusion process converts raw thermoplastics in powdered or granular form into a continuous melt stream, which is formed by a die into a variety of shapes.

End products

Typical end products include:

- Pellets
- Sheet
- Pipe
- Tubing
- Profile
- Automotive and appliance industries products
- Fibers
- Wire Insulation covering
- Packing material
- Etc.

Process description

Introduction to extruders

Extrusion is the basic process for converting thermoplastic resins into continuous lengths of shapes having uniform cross-section. It is indicated for standard profiles such as sheet, film, tubing, rods, and custom profiles of any shape. The overall processing cycle consists of melting the raw material, usually in pellet form, extruding the molten resin through a die that forms the shape of the final part, and then hardening the continuously extruded shape by cooling it as it emerges from the die. The continuous lengths are then reeled or cut to desired length.

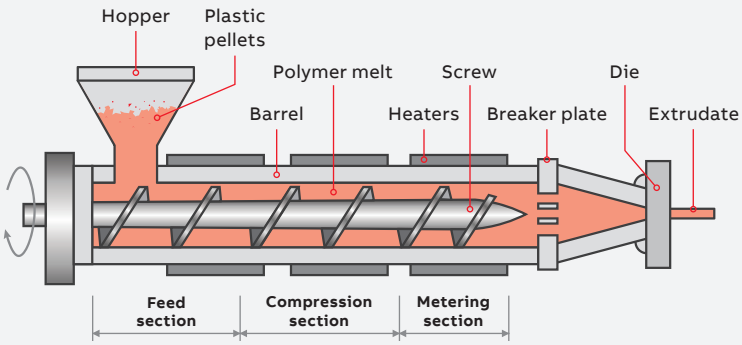
Extrusion generally involves using a screw that advances the raw material or resin from a feeding hopper through a melting zone. The melted material is forced through an orifice in the die that defines the shape of the end product. The extrusion screw provides frictional heat to help melt the resin, and creates the force to form the desired shape in the die with the pressure needed to obtain the necessary product density. External heat is also applied to the extruder barrel as required.

Selection of the feed screw is paramount, since this will dictate whether maximum production rates are achieved, and whether the final product quality is satisfactory.

The two most common methods of heating and cooling the extruder-barrel zones are electrical heating and air-cooling, or electrical heating and water-cooling. Water-cooling is more expensive, but its heat-removal capacity is higher.

Single-screw extruder

By far the most common and most versatile extruder in use today is the single-screw extruder. Single-screw extruders are characterized by two dimensions; the bore diameter (D), and the length of the barrel in bore diameters or L/D ratio. For example, a 65 mm, 20:1. L/D extruder has a barrel bore of 65 mm and a barrel length of 1300 mm. Common commercial sizes of extruders range from 50 - 200 mm. Machines are available as small as 20 mm for laboratory or specialized use, and as large as 600 mm or more on special order. Common L/Ds range from about 5:1 minimum to 40:1 for some multiple venting applications.



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Principle of single-screw extruder.

Extruder barrel and feed section

The barrel of a single-screw extruder usually is a long, thickwalled tube of alloy steel, into which a hard, highly crystalline wear-resistant alloy has been centrifugally cast.

Attached to the feed end of the barrel (often as a separate casting) is an opening into the barrel bore for feeding the raw material. It is usually jacketed for room temperature water-cooling to prevent premature melting of polymer.

Barrel heat input and extraction mechanisms

The barrel must be provided with the means to both add and extract heat. Though heaters vary in design, the most common ones are cast aluminum. The heater halves are clamped to the barrel to provide intimate contact between the steel of the barrel and the aluminum of the heater. The heat sink is either air or a liquid coolant.

The heaters are arranged in zones, e.g. typically 4 to 5 on a 24:1 L/D extruder. Auxiliary systems provide heat sinks for heat absorption. Probably the simplest is a blower mounted under each zone heater to blow air over the surface of the heater, extracting heat from it and transferring it into the plant ambient air. The blower is switched on and off either by automatic controllers or manually.

When greater heat extraction is needed, a liquid-cooled system is used.

Barrel temperature control systems

Each zone of the extruder, and also the head or die, must be controlled to a specific temperature, depending on the process. The temperature is usually sensed with a sensitive thermocouple or resistance thermometer mounted in a hole drilled through the steel of the barrel just to the outside of the wear-resistant layer, close to the melting polymer.

Microprocessors have been used for this control task. One microprocessor-based approach anticipates the effect of heating or cooling on the inner wall of the barrel by mounting a second separate thermocouple in the heat source/sink. This approach provides barrel temperature uniformity.

Venting

Some polymers contain small amounts of volatile monomer, moisture, or entrapped gases, which adversely affect the extruded product. These may be removed through vents in the barrel.

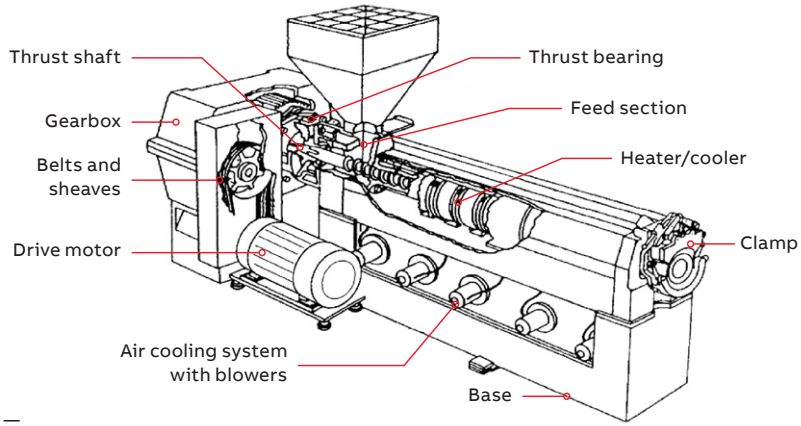
Screw

Inside the barrel is a rotating feed screw that picks up the polymer and advances it into and along the barrel. Most of the extrusion screws consist of three zones:

- Feed zone - 1 to 5 diameters long
- Transition zone - ½ to 9 diameters long
- Metering or pump zone - to complete the length.

The feed zone picks up the resin under the hopper and moves it into the externally heated barrel to begin melting. The transition zone compresses the material, eliminating air pockets and establishing a solid bed of unmelted pellets or powder with melt filling all voids. The conversion of the mechanical energy of the drive to heat occurs to a great extent in this section, an important source of melting energy.

The metering or pumping section of the screw generates the pressure needed to force the polymer through the die system. In the process, the rest of the polymer is melted and refined into a homogeneous mass.



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Single-screw extruder.

Gearbox and thrust bearing

The gearboxes supplied by extruder manufacturers may be horizontal or vertical, cast iron or welded. They may have helical, herringbone or worm gears. Many >65 mm extruders use double reduction helical or herringbone gearboxes.

Multi-screw extruders

Extruders are available with as many as four screws for specialized uses that cannot be optimally met by singlescrew designs. The screws may be intermeshing, co-rotating or counter-rotating; they may be of constant depth or conical in shape.

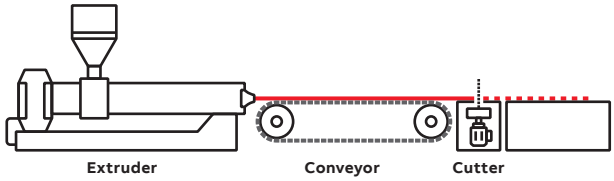
Although multi-screw extruders can be used with any thermoplastic, their added complexity is normally acceptable only when required for special characteristics such as lower sheet heat. Common multi-screw applications include e.g. large diameter rigid PVC pipe, compounding of certain polymers, and processing of heat-sensitive materials or materials that must leave the die at relatively low temperatures.

Unlike single-screw extruders, which are sized by L/D ratio, multiscrew extruders are sized by kg/hour output for rigid PVC.

Extrusion processes and machines

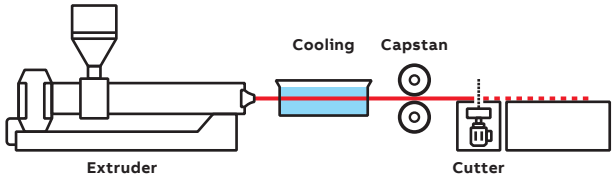
There is an almost infinite number of variations of different kinds of extrusion processes and machines in the plastics industry. This chapter briefly describes some of the processes and machines.

Compounding



This is the simplest form of extrusion, as the end product is pellets. The extruder pumps the melt into a die, the face of which has a series of holes, and from there to a cutting device. Alternatively, the polymer may be extruded as a flat sheet, quenched and then diced.

Profiles



The range of profile extrusions is almost infinite. The extrudate is often sized as it is cooled, cut to length and sold as raw material for further finishing operations.

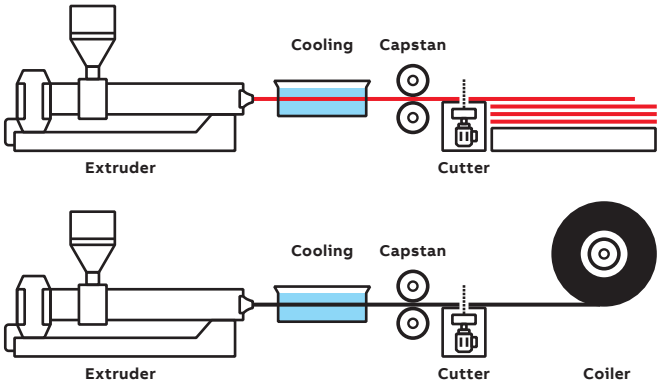
The shape of profile dies differs from that of the finished product, because the extruded polymer swells upon leaving the confines of the die and the flow rate varies in dies with complex shapes.

After exiting the die, the shape may be drawn into a water quench trough. It may be sized with intensely cooled vacuum sizing tools or be shaped into its final form with any of an assortment of jigs and fixtures. The profile shape is usually drawn off with some form of capstan or puller.



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Extruder for the production of polyethylene pipes.

Pipes



Pipe extrusion differs very little from profile extrusion except that the shape is round, hollow and uniform. Wall thickness and ultimate polymer strength are critical factors when it comes to meeting codes and assuring failure-free use based on standard design criteria.

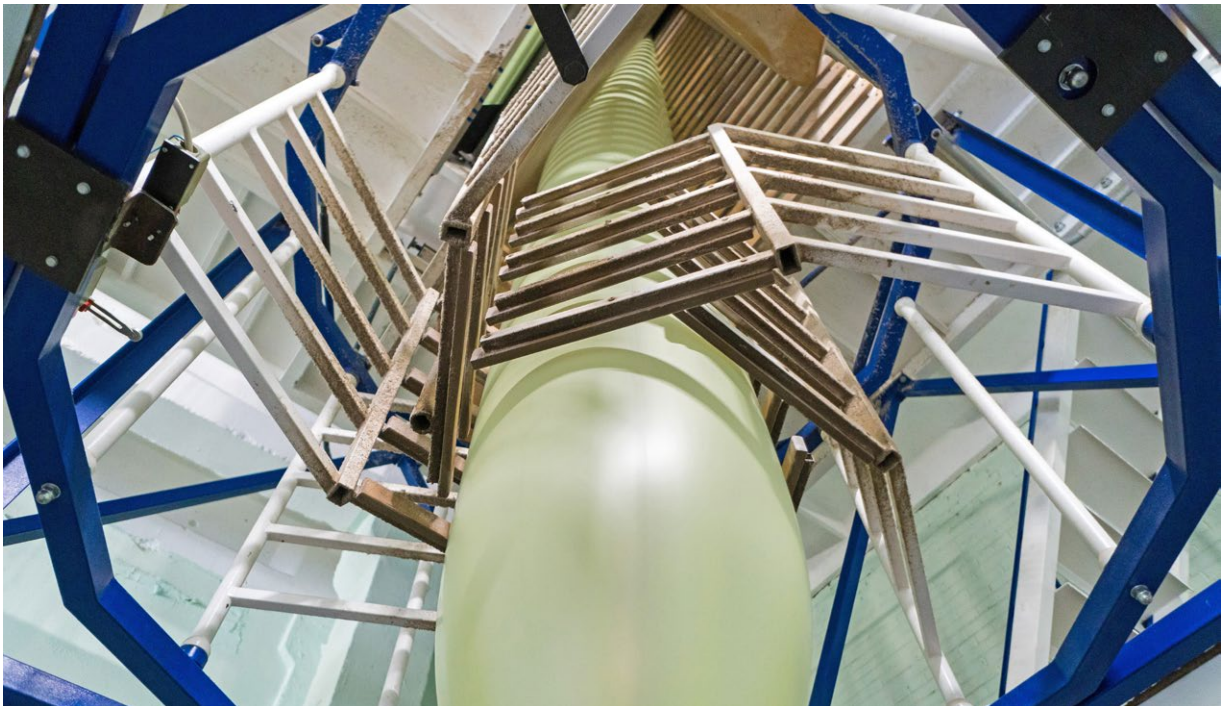
After exiting the die, the extrudate is vacuum-sized and quenched in a water trough. Rigid pipes, such as PVC exiting from the quench/cooling tank, are cut to lengths of 3-6 meters by traveling table saws. Flexible pipes, such as black PE pipes, are usually coiled in much greater lengths.

Fibers

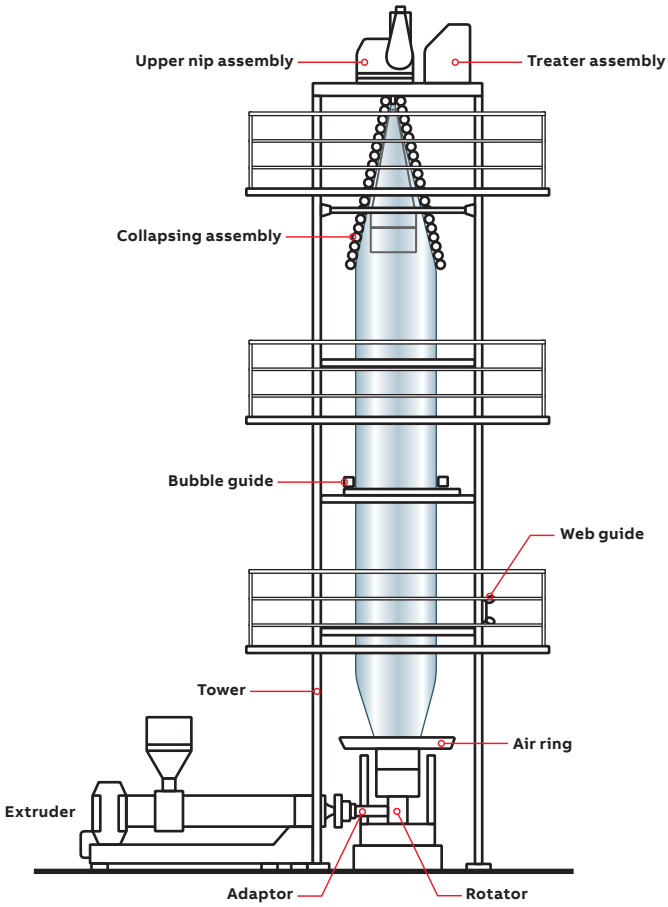
Fiber extrusion ranges from monofilaments, such as fishing lines, to literally hundreds of fibers extruded from one die, drawn to the diameter of the finest hair, often twisted, sometimes crimped for added bulk, and wound on beams. Except for the heavier gauges of monofilaments (which may be considered as specialty profiles), the fiber extruder usually only acts as a melt pump, and not as a metering device.



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The machinery and processes that go into making strong, flexible, and durable synthetic fibers, such as nylon, polyester, and acrylic.



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Blown film extrusion machine.



Blown film lines

Though there are several processes with vertically downwards or horizontally blown extrusions, the vast majority of film is blown vertically upwards.

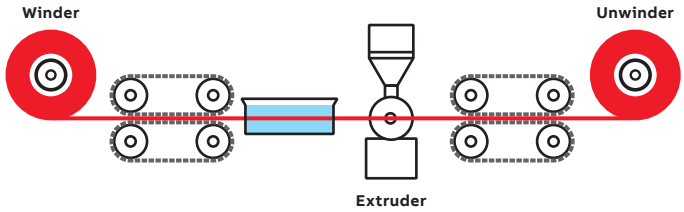
A rotator, or rotary union, is usually fitted above the elbow so that the die above it can either rotate continuously in one direction or oscillate back and forth. The die distributes the polymer into an annular ring. The polymer is forced to flow uniformly up and out in the shape of a tube, much like an extruded pipe except that the wall is thin. The die is provided with a passage to feed compressed air into the approximate centre of this ring of flowing polymer.

At start-up, the ring of molten polymer is drawn together by hand, sealed to form a generally hemispherical bubble on top of the die, the internal compressed air line is opened and the bubble is hauled away at a rate of speed generally greater than that of the polymer flow, thus orienting the film in the machine direction. As the bubble approaches a nip roll above the die, it is converged by wooden slats, a rack of rollers or a similar mechanism to change the shape from the tubular bubble to a flat, two-layer sheet.

These types of machine are used for foils from 0.005 mm up to 0.3 mm. The total width of the foil varies from 0.5 m to 16 m.



Wire and cable insulation



The great bulk of electrical wire and cable today is insulated using one or more layers of extruded elastometric or thermoplastic insulation. A number of forms are possible:

- Several layers may be successively put on single wire strands.
- Pairs or other multiples of pre-insulated wires may be covered to form a single cable.
- Many bare wires may be fed into a die, side-by-side, and insulated to form ribbon cable.

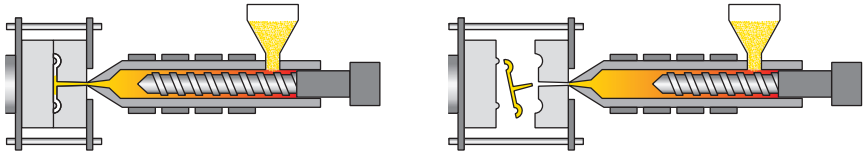
Because the cable to be insulated must flow through the die in a straight line, the die is most often arranged perpendicular to the axis of the extruder. Such a die is called a crosshead.

The crosshead directs the flow of polymer from the extruder, around an internal core tube, through which the bare wire is fed. The core tube is designed with helical flow paths and varying gap or length flow restrictions to direct a uniform thickness of insulation around the wire or cable.

A complete wire or cable extrusion line has a number of major wire handling components upstream and downstream of the extruder. These include payoffs, capstans, cooling troughs, spark testing equipment, diameter controllers, legend imprints and take-ups.

Injection molding

Injection molding is the basic process for converting thermoplastics into finished molded parts. The main steps include blending the raw-material pellets with colorants, additives, etc., drying the mixed blend, feeding the blend into the injection molding press through a hopper, melting the blend, injecting the molten material into the cool mold and ejecting the molded parts from the press. The melting and injection cycle may have several stages.



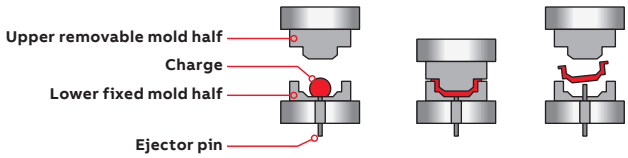
Molds for injection molding presses may contain a single cavity or a number of similar or dissimilar cavities, each connected to flow channels or runners that direct the flow of melted plastic to individual cavities. The fast heating/cooling cycle of this process makes it one of the most economical systems for mass-producing a single item. Plastic parts taken from the mold are, in most cases, finished products ready for use. Molding cycles are relatively fast, and the process readily lends itself to varying degrees of automation.

The mold clamp of a press must have sufficient locking force to prevent the force of the fluid plastic moving at high pressure from separating the halves of the mold. If the mating surfaces of the mold are forced apart by even a few thousandths of an inch, plastic will flow across the mating area, and flash material will become an unwanted part of the product. The magnitude of the clamp's locking force depends on the projected area of the molded part.

Methods used for clamping the mold are, in general, variations on a few basic types: straight hydraulic ram, hydraulically actuated toggle for closing speed with a secondary hydraulic ram for final lockup, and mechanical clamp with crank-type bull gears. The first two are commonly used.



Compression molding

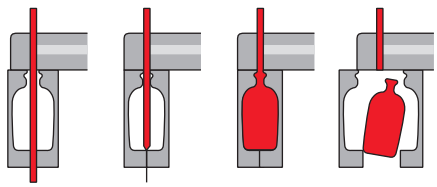


Compression molding is the oldest method of manufacturing molded plastic objects.

The plastic material in the form of a press mat, press mass or pellets is placed in the heated lower form half. The upper form half is lowered on to the lower half and heat and pressure are applied. The material softens and becomes “plastic”, filling the space between the form halves. A chemical reaction caused by the heat results in the hardening of the plastic.

After a certain time, depending on the thickness of the material and the hardening time of the plastic, the form halves can be separated and the finished object removed.

Blow molding



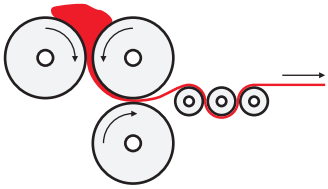
Blow molding is an important method for the production of hollow objects such as tubes, bottles and containers of different thermoplastic materials.

An extruder supplies a tube of suitable dimensions through an angled mouthpiece into a separable form.

The form is closed, thereby welding the lower end of the tube, the upper end being formed to a neck at the same time. Compressed air is introduced and presses out the warm and plastic tube against the walls of the form space, where it is cooled.



Calender and other webbased lines



Calendering is a method for the manufacturing of thin thermoplastic film of both softened and stiff vinyl chloride plastics in different colors and patterns. Soft film is mainly used for rainproof clothing, curtains, bags and upholstery material. Stiff film is mainly used for packaging.

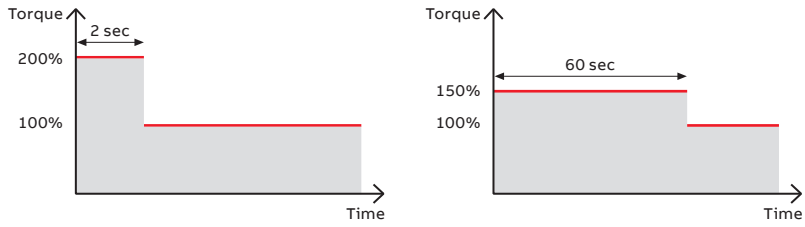
In addition to the extruder lines and calender lines described elsewhere, there are other types of web-based line. Most of these machines are used for finishing, decorating, printing, etc. Coating lines are one example.

Coating is a method of providing woven textiles, paper and other materials with a plastic surface. Plastic-coated textiles of this type have a wide range of uses, e.g., for rainproof clothing, protective work clothing, furniture, vehicle upholstery, wallpaper, tablecloths and luggage. The plastic most frequently used is vinyl chloride mixed with a considerable amount of softener.

Drive and motor considerations

Load characteristics

An extruder is a constant torque application. Overload ability is needed when the raw material is cold. For example, when there is a production shutdown the melted raw material has time to cool off and congeal. Such starts can require as much as 200% of rated torque.



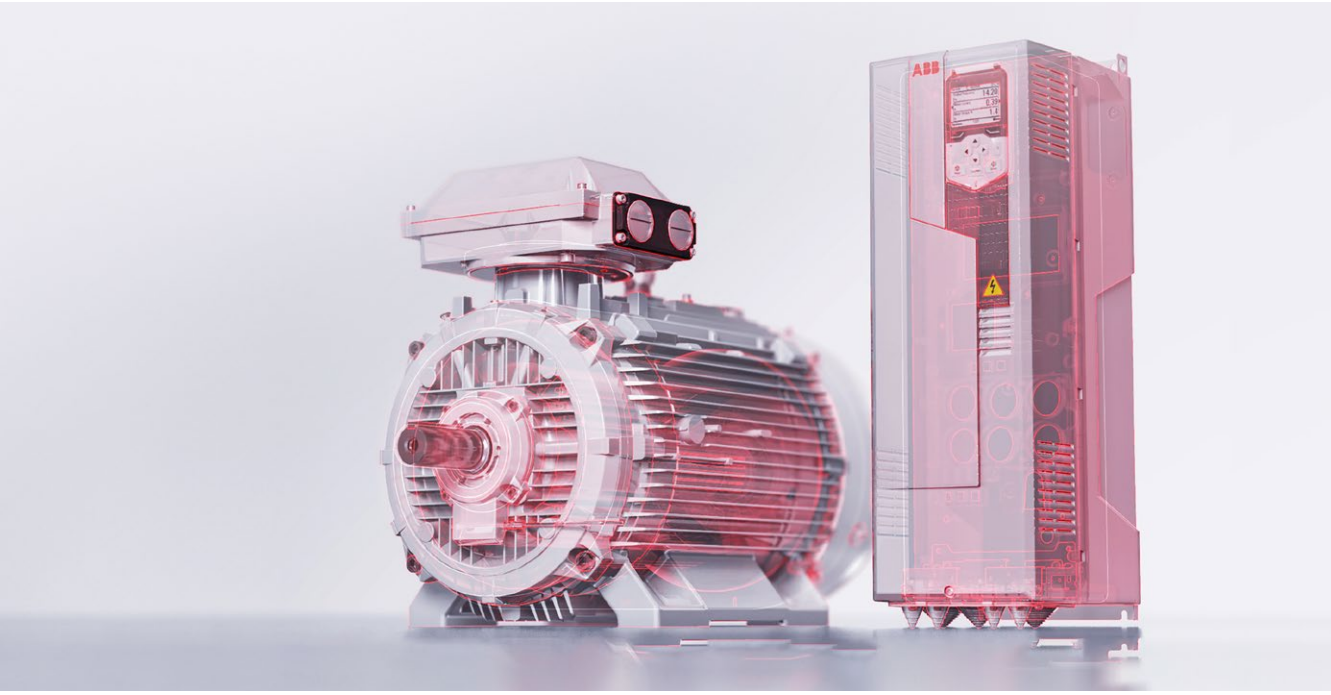
Typical extruder load characteristics.

Typically the extruder load increases linearly as speed increases. However, the load type can still be characterized as a constant torque load type. Injection molding and other molding machines are typically hydraulically operated. In these machines the electrical drive system spins a hydraulic pump having quadratic load characteristics. In injection molding there is potential for energy savings due to the quadratic load characteristics.

Power and speed range

The typical power range is from 4 kW to 630 kW.

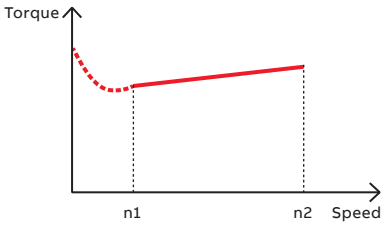
Speed range is often 1:10. Typically there is a gear reducer and a belt that may also act as a speed reducer. The induction motor speed range is typically 200 rpm to 2000 rpm. With the speed reducer(s) the motor speed is reduced to screw speed, simultaneously increasing the torque.



Dimensioning drive and motor

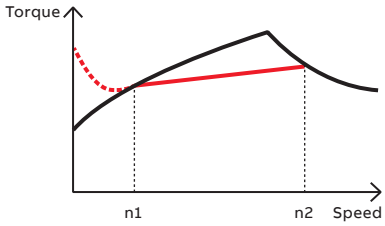
Once the typical operational characteristics are known the drive and motor dimensioning follows these general guidelines:

- Check the speed range and torque requirement.
- Check the starting torque requirement. Remember that the starting torque only needs to last a short time. The starting torque may affect the drive current rating but doesn't usually affect the diode supply unit's (where applicable) or supply transformer's dimensioning since mechanical power is very small at low speeds.

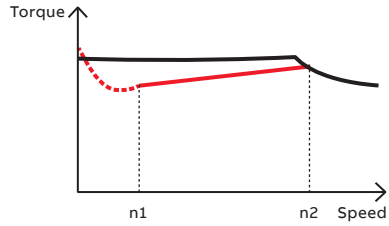


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Torque requirement over the specified speed range.

- Select the motor so that torque is below the thermal load ability curve. Compare separately and self-ventilated motor types.

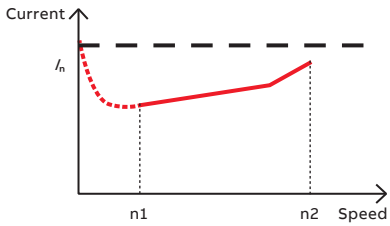


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Self-ventilated motor.



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Separately ventilated motor.

- Select the proper drive based on load current. Remember to utilize the short-term current capabilities of the drive. If high overloadability is not needed the nominal current rating can be used in constant torque applications.



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Drive selection is based on the motor nominal current and process current requirement.

Example:
The extruder speed range is 500-1100 rpm. The load at 1100 rpm is 90 kW. There is no starting torque requirement. The motor is a 6-pole 400 VAC self-ventilated induction motor. Motor thermal load ability is 90% at 1100 rpm and 85% at 500 rpm.

Solution:
The constant torque requirement is:

$$T = \frac{9550 * P[kW]}{n[rpm]} = \frac{9550 * 90}{1100} Nm = 781.4 Nm$$

Motor thermal load ability is 85% at 500 rpm. The nominal torque of the motor must be at least:

$$T_n \geq \frac{781.4}{0.85} Nm = 919.3 Nm$$

The minimum motor nominal power is:

$$P \geq \frac{919.3 * 1000}{9550} kW = 97 kW$$

Drive selection is based on the motor nominal current and load current. Now the motor load would be roughly 85%. In this case the drive could be selected using normal rating since high overload (150% … 200%) isn't required.

Typical requirements for the drive

Requirements for most extruders include:

- Relatively high speed accuracy
- Static speed accuracy is always important but low speed ripple is often even more crucial
- High starting torque, especially at restart
- Constant torque operation
- Stall protection for protecting the expensive screw
- Accurate torque limitation. Possibility to replace mechanical torque limiters or protection devices.
- Typical power range from 4 kW to 630 kW
- Typical basic I/O features include:
  - analog speed reference
  - digital motor potentiometer for operator tuning
  - external fault input
  - run enable/disable
  - emergency stop

The ABB industrial ACS drives can fulfill all the Plastic Machinery requirements and offers well-proven Direct Torque Control (DTC) technology with excellent motor control performance at all motor technology type (SCIM; SynRM; PMSM; Torque motor), together with a wide variety of standard features and easy programmability.

Naturally, if the customer is determined to use a DC drive based solution ABB can offer the best quality in that technology, too.

DC drives vs. AC drives

The future of extruders is definitely AC. Many plants that are modernizing their equipment are already now considering changing from DC to AC. The trend with OEMs is for a rapid change from DC to AC.

ABB can support both DC and AC with world-class products. However, we need to do what customers want. We should still encourage the customers towards modern AC solutions but still provide a DC solution if required.

Performance
There is no difference in performance. The DTC controlled ABB ACS drive is perfectly comparable in performance to old DC drives. ABB ACS drive encoderless operation is practically made for extrusion. The speed range and load/overload characteristics are optimal for a high-performance drive as ABB ACS drive. Most OEMs have used since decades both AC and DC solution and the result was confirmed to be able to meet right quality product output with best productivity meeting decarbonization targets.

Cost comparison
At higher power ratings the DC drive becomes less expensive. The cost of the motor in the drive & motor package is, however, somewhat higher for DC. If a spare motor is included the purchase cost for an AC drive & motor package may even be lower.

A standard AC squirrel cage motor requires very little service beyond bearing lubrication. The AC drive's power factor is also high, fundamental power factor being 0.97, which also reduces longer time period operating costs compared to DC. A higher power factor also saves money in the dimensioning phase.

The installation and maintenance costs for AC drives are lower than for DC drives. A DC motor typically requires several annual inspections, brush replacements and filter replacements.

To summarise, the initial cost with a DC system may be lower, but in the long run an AC system may be the more economical solution.

How to change from DC to AC
Converting a system from DC to AC is relatively easy. Typically the information needed is:
- Base speed or nominal speed. This is the typical operating speed
- Minimum speed
- Maximum speed
- Overload requirements
- Torque characteristics
- Power

If power is not known it can be calculated from armature voltage (U_a) and armature max. continuous current I_a). The power is $P = U_a \times I_a \times \eta$, where η is typically 0.7-0.9.

With this information the AC drive system is dimensioned to meet the requirements set by the old DC system.

The speed range of the DC drive system can sometimes be extremely long. In this case the AC motor selected can be a special low-inertia rotor type AC motor with a wide field weakening range. The other option is to dimension the standard AC motor to meet the requirements (e.g. select a 4-pole motor instead of a 6-pole motor). In most cases an equivalent AC option can be found. It is extremely important to concentrate on the torque characteristics and speed range needed.

If there is a requirement for the shaft height to be the same as in an existing DC motor there is the possibility to use a specially designed motor designed for retrofit in old DC drive systems and for replacing DC motors in OEM installations. The dimensions of these special motors are made equivalent to the same size DC motors.

ABB benefits

Requirements

In the plastics industry there are dozens of different kinds of systems and machinery. The power range is basically from 2.2 kW to 3700 kW. The performance requirement is relatively high. The drive must be able to communicate tooverriding systems. It is often preferable that one company can deliver the whole system including drives, motors, interface to overriding system, winding section, etc.

ABB solution

ABB is one of the few companies that can handle large systems. We can deliver all the components and also pay attention to obtaining the most cost effective solution by:

- Correct selection of drives and motors
- Correct dimensioning of a drive system
- Taking the environmental conditions into account
- Responding to regulatory requirements

ABB can succeed in this challenging task worldwide. The benefits of having ABB as a supplier are:

- ABB has lengthy and broad experience with drive systems
- ABB has lots of references in the plastics industry
- ABB emphasizes relations with OEMs and end-customers
- CE, UL, cUL, CSA approvals
- Capacity to deliver the whole package
- Worldwide service network
- ABB Channel Partner Network
- Local representation all over the world
- ABB respects the wishes of the customers

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