

Plasticating Essentials

Screw, Barrel and Front-End Component Fundamentals

1929

Founded as Industrial Research Laboratories in Los Angeles, California, USA

XALOY

1931

Invented the world's first bimetallic casting alloy

1972

Invented the tungsten carbide inlay



1995

Opened Japanese office to reach a growing Asian market



New Castle Industries (NCI) acquired BIMEX

1960

Began screen changer production under the Beringer brand name

1990

Introduced EXTEK screen changer product line

2004

Developed patented Xaloy® Fusion™ Screw Technology

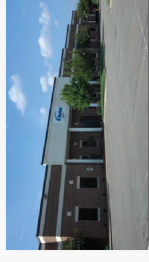


2009
SPIREX

Acquired the screw, barrel and components operations of Spirex

2006

Acquired Dynisco's extrusion products division



2003

Acquired New Castle Industries and expanded screw and roll product offering

2021

Acquired by Altair Investments Inc.

2015

Nordson acquired screw and barrel manufacturer WAFO

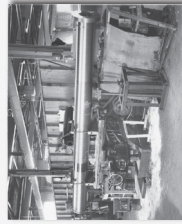
wafo

1934

Invented a casting process for lining cylindrical steel objects with wear-resistant alloys

1938

Delivered the first bimetallic barrel for plastics machinery



1998

Began construction of facility in Chonburi, Thailand



2010

Introduced revolutionary Xaloy® SmartHeat™ Coating Technology



2005

Established sales office in Germany

2016

Introduced revolutionary Xaloy® MPX™ Wear Coating Technology



2018

Consolidation of existing USA facilities into one Advanced Manufacturing Center in Austintown, OH



2012

Acquired by Nordson Corporation



2002

Screw manufacturer Spirex acquired bimetallic barrel manufacturer Bimetalex



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Section 1: Plasticizing Screws

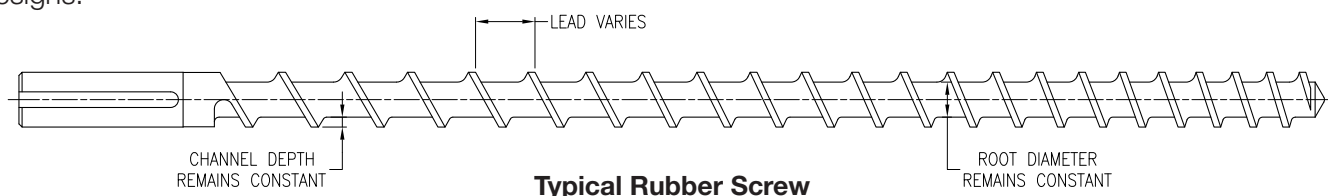


History

History

Thermoplastic materials were not common, large volume commodities until the late 1930's and early 1940's. It was natural to start with equipment developed earlier by the rubber industry. The rubber extruder or "tuber" used a screw, and with modification, these machines would melt and pump thermoplastic materials. Injection machines used the plunger until the early 1960's.

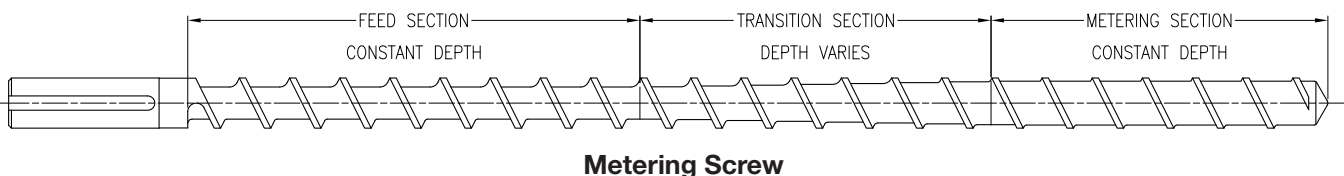
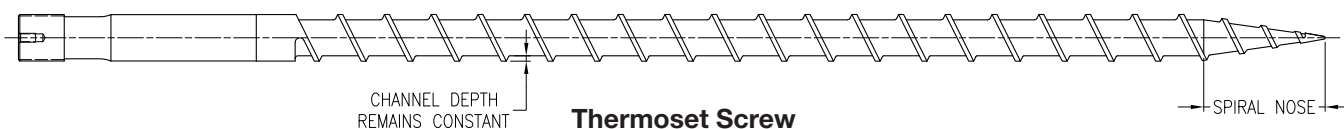
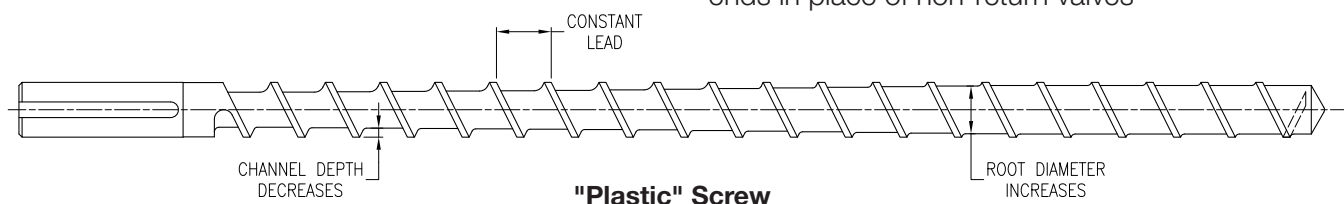
The design of screws for thermoplastic materials gradually changed, and by 1960 most screws were of the "metering" type. The metering screw has a constant depth at the discharge end. This constant depth section or "metering" section was designed to smooth out pressure, temperature, and discharge rate irregularities. It is supposed to meter out the plastic at a uniform rate much like a metering gear pump for liquid materials. The metering screw, with many modifications, is the basis for most present-day extrusion and injection screw designs.



The early thermoplastic screws were called "plastic" screws to differentiate them from rubber screws. "Plastic" screws usually had a constant square pitch (lead=diameter) and no feed or metering section. The channel depth of the screw constantly changed from the feed to the discharge end. This was different from the typical rubber screw which had a constant channel depth but obtained its compression by means of a variable or changing lead.

Until the mid-1960's thermoset materials were molded using compression or transfer presses. About that time, screw injection machines with modifications were developed to run thermosets. These modifications included:

- Low compression
- Deep channel depths
- Short L/Ds
- Spiral down discharge ends in place of non-return valves
- Tool steel construction
- Barrel cooling with heat transfer fluids



Two-stage Screws

Two-stage Screws

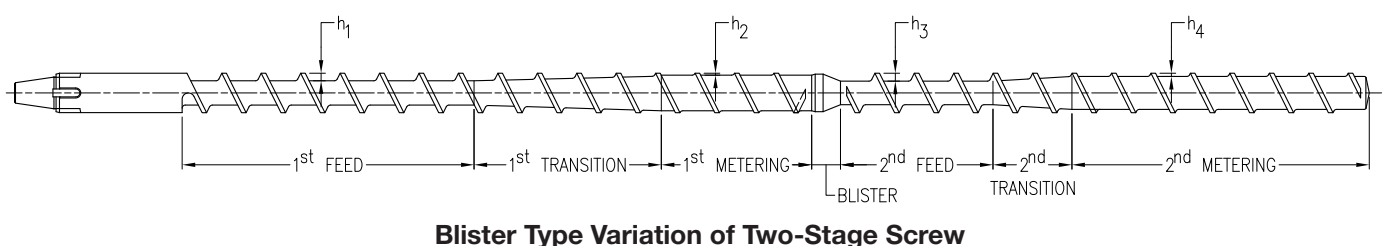
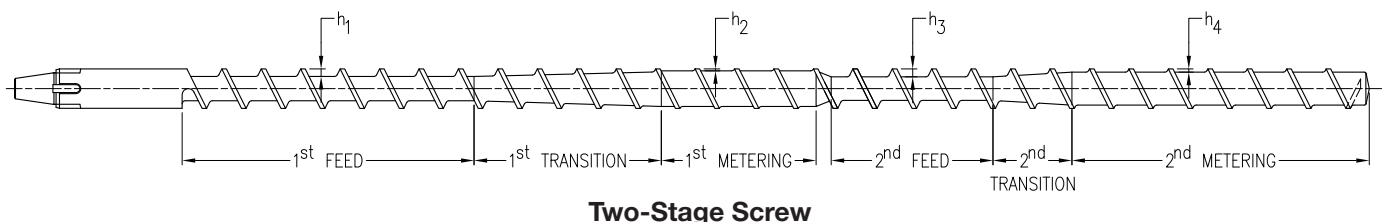
A variation of the metering screw is the "two-stage" or "double metering" screw. This screw can be viewed as two single-stage screws attached to each other. The two-stage screw was first designed to run with a vented extruder. In an extruder, the polymer is melted and pumped by the first stage into the vent or second feed section. In the deep vent section, the melted material is decompressed, or subjected to a vacuum, or atmospheric pressure, and the entrapped volatiles escape, through the barrel. The plastic is then compressed again, or subjected to a vacuum, and pumped through the die by the second stage. In the early 1970s, vented two-stage screws were adapted to injection molding machines.

The two-stage screw has other advantages aside from its venting capabilities. It does some additional mixing because of the tumbling that the plastic receives in the vent section, and because the material is compressed, decompressed, and compressed again. All of this tends to give some added mixing without shear. Adding an additional flight in the vent section does help in the devolatilization of the polymer by exposing more polymer (more surface area of the tumbling polymer) to the vacuum of the vent in the barrel. Because the screw runs partially filled in the vent section and part of the second transition, the torque and horsepower requirements are somewhat reduced for the same output and same screw speed when compared with a single-stage screw of the same diameter and flighted length.

The problem with a two-stage screw in vented extrusion is the difficulty in balancing the first stage output (which can be calculated, and is determined by h_2) with the second stage output (from h_4) as shown in the two-stage screw below. If the first stage delivers more than the second stage pumps through the die, the result is vent flooding. If the second stage tends to take away or pump more than the first stage delivers, the result is instability, or surging of output, pressure, etc. This usually results in unacceptable product size variation.

This can sometimes be adjusted by controlling the feed into the extruder or by valving the output. Problems with one screw design arise because of changes in RPM, resin bulk density variations, die restrictions, and other variables. This is not a problem with a closed vent, and a low pump ratio, using a two-stage screw. The two-stage screw used in injection does not have the surging problem described above, but it is harder to design due to change in screw location relative to the feed and vent ports.

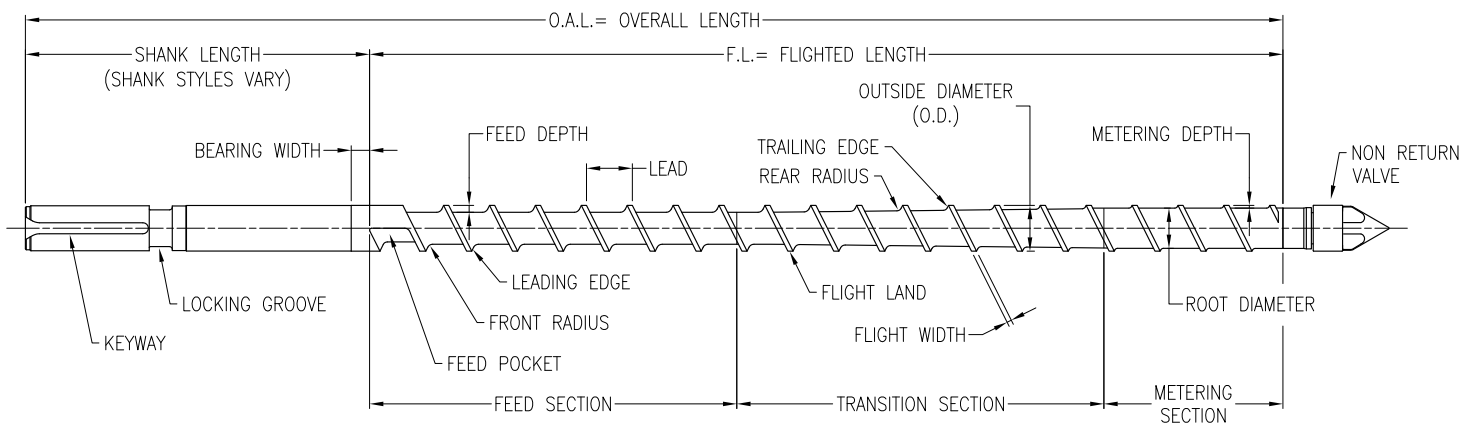
Around 1960, the screw was used in injection machines. The screw gave better mixing than the plunger. Therefore, the part was superior in color dispersion and physical properties. It was also possible to mold at lower temperatures, which resulted in faster cycles and greater profits. The stationary screw extruding into a pot or accumulator was also popular in the early stages, but the reciprocating screw is the most common design used today for injection molding.



Nomenclature: Injection & Extrusion Screws

Nomenclature: Injection Screw

Many people use different terms when describing the various parts of a screw. Here is a sketch of a single-stage injection screw. The parts are labeled as we would do it.



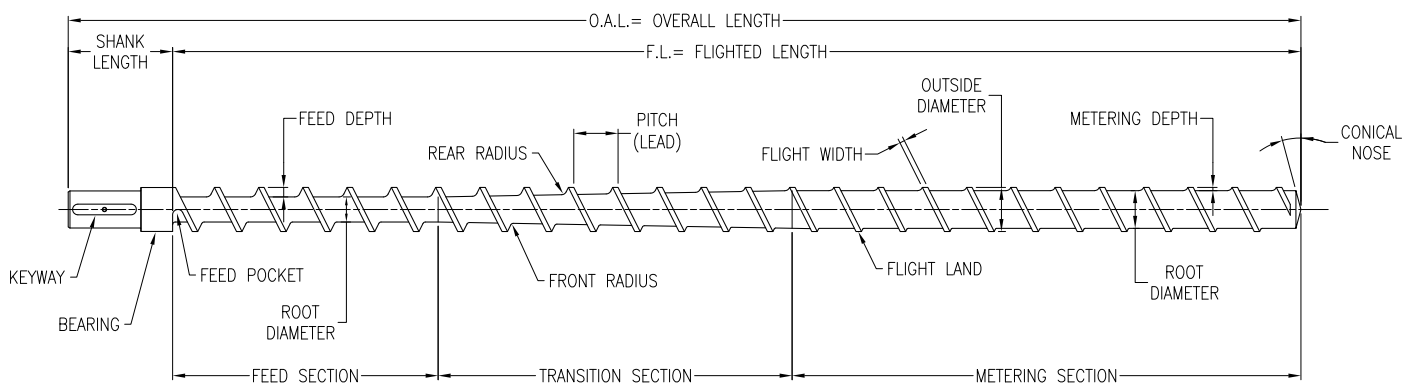
Injection Screw Nomenclature

$L/D = \text{Flighted Length} / \text{Nominal O.D.}$

$\text{Compression Ratio (C.R.)} = \text{Feed Depth} / \text{Metering Depth}$

Nomenclature: Extrusion Screw

Many people use different terms when describing the various parts of a screw. Here is a sketch of a single-stage extrusion screw. The parts are labeled as we would do it.



Extrusion Screw Nomenclature

L/D Ratio

L/D Ratio

The term, L/D ratio is commonly used to describe the relative length of a screw. To calculate the L/D ratio, refer to the sketches on page 7, and use the following formula:

$$\text{L/D Ratio} = \frac{\text{Flighted Length of Screw}}{\text{Outside Diameter of Screw}} = \frac{\text{F.L.}}{D}$$

The nominal diameter "D" is normally used. For example, a typical 2½" diameter screw might have an actual diameter of 2.493", but we use 2.500" for the above calculation. The flighted length (F.L.) is usually described as shown in the sketch on page 7. It does not include the length of the check valve in the case of an injection screw.

There are alternate methods for determining the flighted length for calculation of L/D ratio. In the first method, you consider only the enclosed and flighted portion of the screw and eliminate that portion exposed in the feed port. This means that you must deduct the axial length of the extruder or injection feed port from the flighted length of the screw.

The two methods for L/D ratio calculation are presented here:

Model No. 1

$$\text{L/D Ratio} = \frac{\text{F.L.} - \text{P.L.}}{D}$$

Model No. 2

$$\text{L/D Ratio} = \frac{\text{F.L.}}{D}$$

There are advantages to using a screw and barrel with a longer L/D.

Long L/D Advantages:

1. Allows a screw design for greater output or recovery rate (provided sufficient torque).
2. Screw can be designed for more uniform output and better mixing.
3. Screw can be designed to pump at higher pressures.
4. Screw can be designed for greater melting with less shear and more conductive heat from the barrel.

Compression Ratio

Compression Ratio

The compression ratio is used to determine the amount the screw compresses or squeezes the plastic. The intent is to divide the volume of a flight channel in the feed section by the volume of a flight channel in the metering section. Actually, the standard, simplified method is usually employed where the depth in the feed (h1) is divided by the depth in the metering section (h2).

Here is the calculation:

$$\text{Compression Ratio} = \text{C.R.} = \frac{\text{Depth of Feed}}{\text{Depth of Meter}} = \frac{h1}{h2}$$

This calculation is not accurate if there are any lead changes between the feed and metering sections.

A more accurate method for calculating compression ratio is the volumetric method. This gives a relatively close ratio of volumes, but it is not entirely accurate because it neglects the effect of the radii of the front and trailing edges. The "volumetric" calculation of compression ratio is given here.

$$\text{V.C.R.} = \frac{D^2 - (D - 2(h1))^2}{D^2 - (D - 2(h2))^2}$$

Where: **D** = screw O.D.
h1 = feed depth
h2 = metering depth

The volumetric compression ratio is always a smaller number than the depth compression ratio. The effect is greater with higher compression ratios and with smaller screws. The compression ratio should be high enough to compress the low bulk density, unmelted plastic into the solid plastic without air pockets. A compression that is too low will tend to include bubbles in the melt. High percentages of regrind, powders and other low bulk density materials will be helped by a high compression ratio. A high compression ratio can over pump the metering section. A common misconception among injection molders is that high viscosity engineering and heat-sensitive materials should use lower compression ratios. This is true only if the compression ratio is made less by deepening the metering section and not by making the feed section shallower. The problem of overheating is more related to channel depths and shear rates than compression ratio. Shear rate is discussed on page 33. High compression ratios with certain materials can cause melt blocks in the transition area, leading to rapid wear of the screw and barrel.

Pump Ratio / Transitions

Pump Ratio

The pump ratio applies to two-stage, vented screws and gives a measure of the ability of the second stage to pump more than the first stage delivers to it. Please refer to the two-stage sketch on page 6.

Here is the calculation:

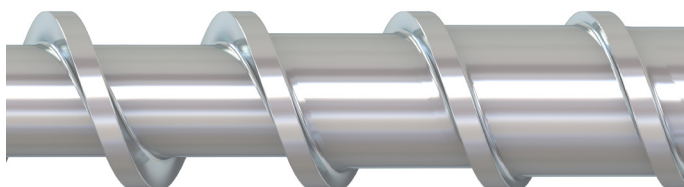
$$\text{Pump Ratio} = \text{P.R.} = \frac{h_4}{h_2}$$

In extrusion, a high pump ratio will tend to surge, and a low compression ratio will tend to cause vent flow.

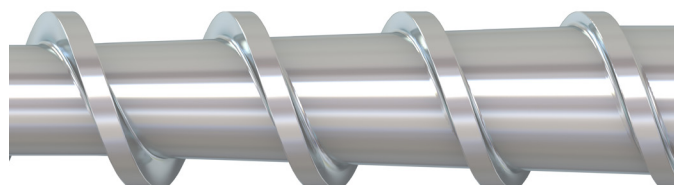
Transitions

Two basic types of transitions are shown below.

The conical transition has a root that is cone shaped and is not parallel to the axis of the screw. The involute transition has a root that is always parallel to the screw axis, and the channel depth varies uniformly. Actually, the use of the word "involute" is not correct in geometric terms, but most people that work with screws are familiar with it. The disadvantage of conical transitions is that they are more difficult to machine and usually are a bit more expensive.



Involute or Spiral Transition



Conical Transition

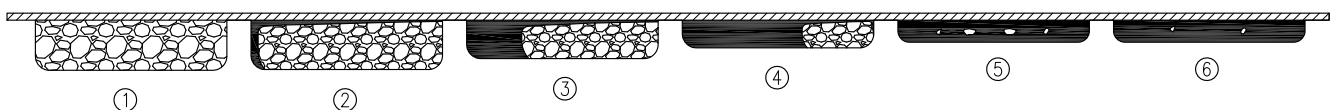
Standard Screws

The basic single flighted screw can be suitable for conveying, melting and pumping most plastic materials, but it does have some limitations. These limitations become particularly important when: (1) The polymer is difficult to melt and the screw controls production rates. (2) Improved mixing of colors or better product uniformity is needed. (3) Greater output is needed, but higher screw speeds will cause excessive shear and overheating. Before we explain the theories of mixing screws, it is best that we understand how a general purpose screw works.

An almost universally accepted model of melting in a single screw extruder has been developed. This model is the basis for most computer simulations. It has been demonstrated to be correct by many "freeze tests". A sketch with our explanation is shown on the next page.

Standard Screws

1. The feed section initiates solids conveying. This is enhanced by sliding on the screw (low friction) and high friction on the barrel. When the plastic sticks to the screw and slides on the inside surface of the barrel, it just goes around with the screw and never moves forward. In the feed section there is also compaction and some heating of the resin.
2. At the beginning of the transition, the resin is further heated and more compression occurs. The solid resin is forced against the barrel, causing a sliding friction. This frictional and conductive heat creates a film of melted polymer on the inner barrel surface.
3. As the plastic proceeds down the transition, there is more melting and more compression. Usually most of the melting takes place in the transition. Here the polymer is divided into three parts: a compacted solids bed, a melt film along the barrel surface, and a melt pool. The melt pool is formed, as the melt film is collected by the advancing flight. Most of the melting continues to be the result of sliding friction of the solids bed against the heated barrel. This is rapid, efficient melting, something like melting an ice cube by pushing it against a hot grinding wheel.
4. The channel depth continues to decrease along the transition. Melting continues and the width of the solids bed decreases while the width of the melt pool increases. As the channel gets shallower, the shear rate increases. Now the melted polymer continues to heat. This may be undesirable.
5. Further down, the solids bed breaks up and the unmelted pellets are distributed throughout the channel like ice cubes in water. The efficient melting by friction of the solids bed against the barrel stops. Now less efficient melting occurs. This is something like heating the water to melt the ice cubes. It will finally get the job done, but it is slow and much less efficient. Heating of the melt continues in the shallow metering section.
6. The plastic continues down the shallow metering section to the discharge. It is possible that unmelted pellets remain, or portions within the melt having higher or lower temperatures and viscosities. With a situation like this, the melt is non-uniform, giving poor properties and color mixing. Greater mixing can be achieved by reducing channel depth but this must be done at the expense of overheating and less output per revolution. The constant depth metering section is not a good mixer. This is because smooth laminar flow patterns are established, causing the different portions of melt to continue to move in a fairly constant circular or "Z" pattern. This does not mix the dissimilar portions of the melt.



Melt Model - Standard Screw

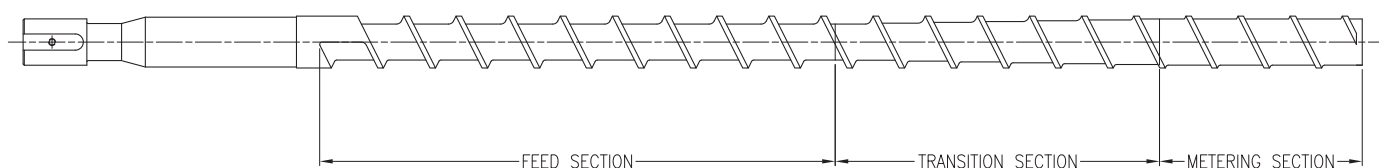
Xaloy® EasyMelt® Injection Molding Screw

Xaloy® EasyMelt® Injection Molding Screw

The Xaloy® EasyMelt® Injection Molding Screw is a multi-purpose three-zone screw. The optimum resin-tailored feed depth, compression ratio and zone lengths allow fully melted material to be delivered to the metering zone, therefore avoiding major causes of intermittent short shots: partially filled flights and pressure instabilities in the metering zone.

Advantages

- Faster screw recovery
- Reduced short shots
- Improved temperature control



Xaloy® EasyMelt® Injection Molding Screw

Marbleizing Screws

Marbleizing or mottling screws are used in instances where little or no mixing is desired. A typical application would be in making cosmetic cases where a swirling effect is desired in the plastic coloration.

This presents a unique situation where the screw must be engineered not to mix the plastic after melting. This is in contrast to the typical molder who wants a screw that will give superior mixing characteristics in order to give a homogeneous melt and proper color dispersion. Quite often, this screw is designed to simulate the effects obtained with a plunger machine.

Typically, the screw will have a very low compression ratio with a good portion of the screw consisting of the feed section, followed by a short taper (low compression) and often times a non-flighted metering section. This design is able to melt, but once melting is achieved, it simply conveys the melt forward with little or no additional mixing.

Other designs also provide multi-flighted screws which convey resin and colorant in different screw channels and introduce them at the discharge, to provide very little mixing action. Xaloy can recommend a design based on the process and equipment available.

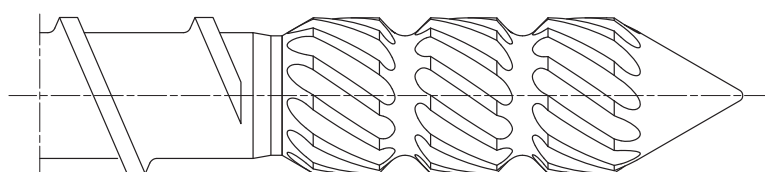
Mixing Devices

Mixing Devices

Mixing devices and mixing screws are all designed to overcome the problems described on page 11. Some common mixing devices are illustrated and described here.

Dulmage

Dulmage Screws have a Dulmage mixing section incorporated as an integral part of the screw, usually located several flights back from the discharge end. The Dulmage Screw was one of the first mixing screws, and was developed by Fred Dulmage of Dow Chemical Co. It has a series of semi-circular grooves cut on a long helix in the same direction as the screw flights. This interrupts the laminar flow, and it divides and recombines the melt many times. In this way, it works something like a static mixer, giving distributive mixing. It is still used on foam screws and other applications.

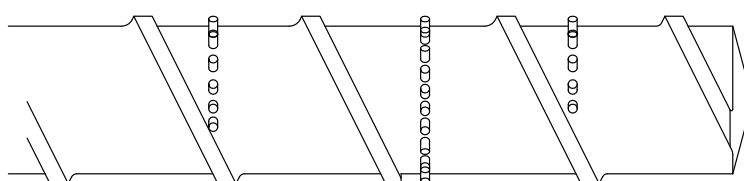


Dulmage Mixer

Mixing Pins

Around 1960, several companies started to place radial pins in the screw root. These pins tend to interrupt the laminar flow and do a little better job of mixing. Because these pins improve mixing, it is also possible to design the screw a little deeper to get some more output with the same degree of mixing. Many patterns and shapes of pins have been used, but in general, they are usually placed in rows around the screw root. They are located in the metering section after most of the melting has taken place. A typical arrangement would have three rows with one row at the beginning of the meter, another one flight back from the end, and the other halfway between.

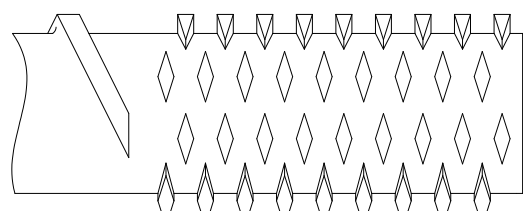
The pins in the drawing to the right are placed so the flight remains intact. The flight may be milled out so the pins can go around the root uninterrupted. This causes a slight loss in drag flow because of the flight interruption, and increased back flow, which could even aid in better mixing.



Mixing Pins

Pineapple Mixer

Pineapple mixers have elements with a rhomboid shape and work similar to pin mixers. They offer chaotic mixing by converging the flow channels at various angles and are useful for mixing of colorants.



Pineapple Mixer

Xaloy® Pulsar® Mixing Screw

Xaloy® Pulsar® Mixing Screw

The Xaloy® Pulsar® Mixing Screw was developed to combat the most common problems encountered in mixing plastic melt. Two of the most common problems include: (1) high shear and the associated excessive melt temperature (from the high compression of shallow depth screws) which result in low production, poor quality, and degraded polymer, and (2) low shear (from the low compression of deeper channel screws) which results in insufficient mixing, trapped air and poor quality.

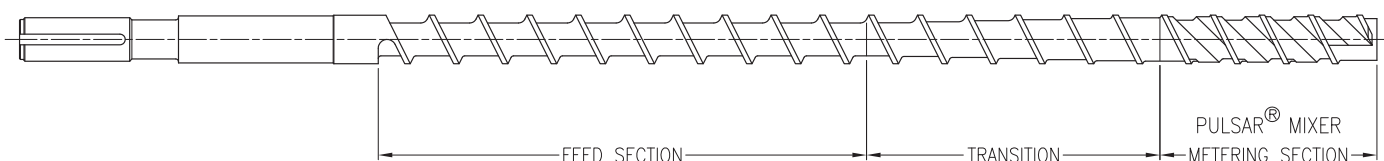
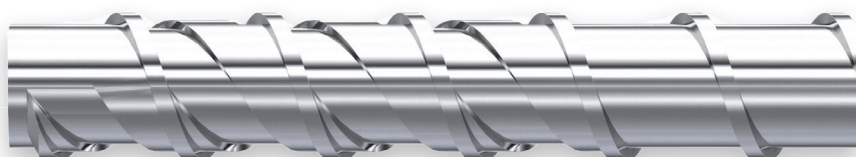
The Xaloy® Pulsar® Mixing Screw is particularly effective with shear-sensitive or temperature-sensitive resins. This screw design provides excellent mixing with little or no temperature rise. In many cases, a lower melt temperature can be achieved. Xaloy® Pulsar® Mixing Screws have been successfully designed to run a wide range of resins.

Some of the applications to date include: ABS, acrylics, HDPE, LDPE, LLDPE, nylon, flexible PVC, polypropylene, polystyrene, urethanes and polycarbonate.

The metering section of a Xaloy® Pulsar® Mixing Screw is divided into alternating sections, which are either deeper or shallower than the average metering depth. The material is forced from one section to another, which causes a gentle tumbling and massaging action. This results in excellent mixing, distribution, and melt uniformity without high shear. This mixer design has no "dead" spots like some mixers, which causes the Xaloy® Pulsar® Screw to be self-cleaning and allows for easy resin changes.

Advantages

- Low melt temperature
- No marbling
- Strong weld lines
- No splay generation
- Less back pressure required
- Quick color and material changes



Xaloy® Pulsar® Mixing Screw

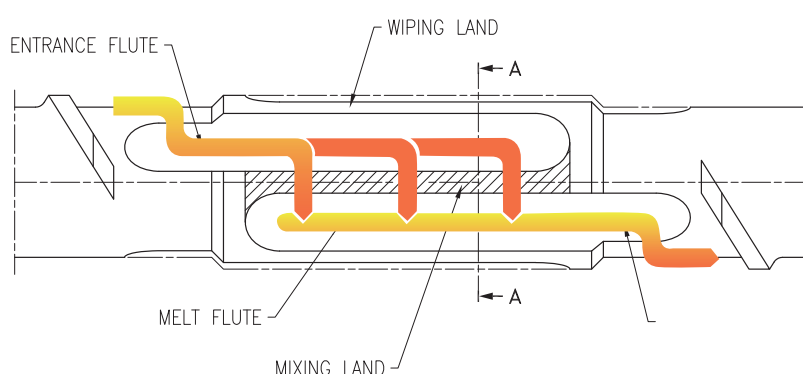
Union Carbide Mixer

Union Carbide Mixer

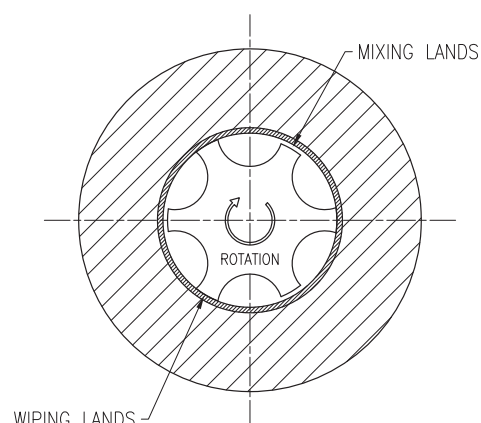
The Union Carbide Mixer is also referred to as the Maddock Mixer. It was patented by Union Carbide and developed for practical use by Bruce Maddock of Union Carbide. The mixer consists of a series of opposed, semi-circular grooves parallel to the screw axis. Alternate grooves are open to the upstream entry. The other grooves are open to the downstream discharge. The ribs or lands that divide the alternating entry and discharge grooves also alternate. These lands are called mixing lands and wiping lands. The resin is forced over the mixing land, which is wide and undercut below the screw O.D. The wiping land is narrow and full diameter, but can be designed for the amount of shear that may be required for the resin blend that you may be processing. This mixer does an effective job of mixing and screening unmelted material.

The polymer is pumped into the inlet groove and as the screw rotates, the undercut mixing land passes under it. The melted material ends up in the outlet or discharge groove. As it goes over the undercut mixing land, it is subject to high shear but for a very short interval. The material is then pumped out of the discharge groove as new material enters over the mixing land, and cannot escape over the full diameter wiping land.

Because the Union Carbide Mixer screens out unmelted materials, it can be designed deeper to give greater output. In most cases, a screw can be designed to give improved output over a conventional single-stage screw but still give equivalent or better mixing. This mixing device was developed for low density polyethylene film. It is also used for many other extrusion applications. Injection screws for polypropylene and HDPE also use this section. Many screws have been retrofitted with a UCC Mixer on the discharge end. The drawback for this mixing device is that it cannot be used for shear-sensitive materials unless the barrier clearance is deepened, in which case performance is sacrificed. Union Carbide Mixers can be thought of as a type of barrier screw with multiple barriers parallel to the screw axis.



Union Carbide Mixer



Section A-A

Xaloy® Pulsar® II Mixing Screw

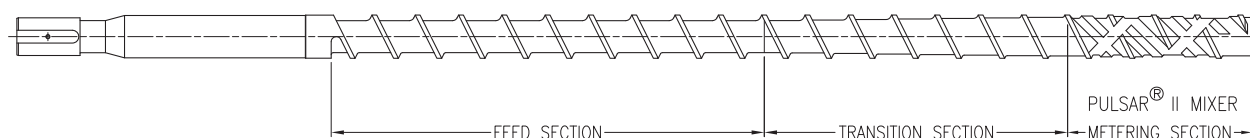
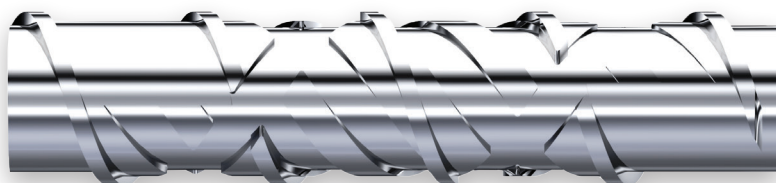
Xaloy® Pulsar® II Mixing Screw

The Xaloy® Pulsar® II Mixing Screw is a modification of the previously patented Xaloy® Pulsar® Mixer. The Xaloy® Pulsar® II was developed after a need for more intense distributive mixing was required. In studying the geometry of the Xaloy® Pulsar® Mixer, it became apparent that by cutting a reverse interrupting channel through the pockets of each "pulse" section, more chaotic mixing could be developed, plus the elimination of any dead spots that may occur at the beginning and end of each "pulse" section. This advanced design also allows for more streamline channeling, further eliminating any dead spot areas.

The Xaloy® Pulsar® II has been found to work very well with both crystalline and semi-crystalline polymers. Just like its predecessor, the Xaloy® Pulsar® processes shear sensitive materials such as ABS and polycarbonate very well and gives excellent distributive mixing. This distributive mixing allows for superior melt homogeneity also.

Advantages

- Low melt temperature
- Low fiber breakage
- Versatile with all amorphous materials
- Less back pressure applied
- Strong weld lines



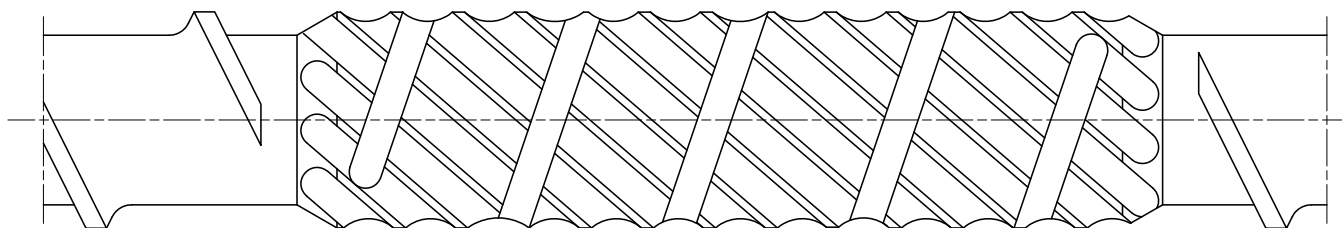
Xaloy® Pulsar® II Mixing Screw

Saxton Mixer / Double Wave Screw

Saxton Mixer

The Saxton Mixer has proven to offer good distributive mixing for a wide range of resins. The mixer was developed by Ronald Saxton and was patented in 1961. The section is designed with a plurality of minor flights and channels on a helix angle which is normally greater than that of the primary flight. The minor flights and channels are interrupted by major channels which are cut with an opposite hand lead. These channels and interruptions help in distributive mixing by separating and recombining the resin, thus breaking up the laminar flow. The one drawback of this type of mixer, or any type which has non-flighted interruptions, is that the resin no longer has the positive forward conveyance other than the pressure flow, although the interruptions on a helix are much better than tangential grooves as some barrel wiping action still takes place.

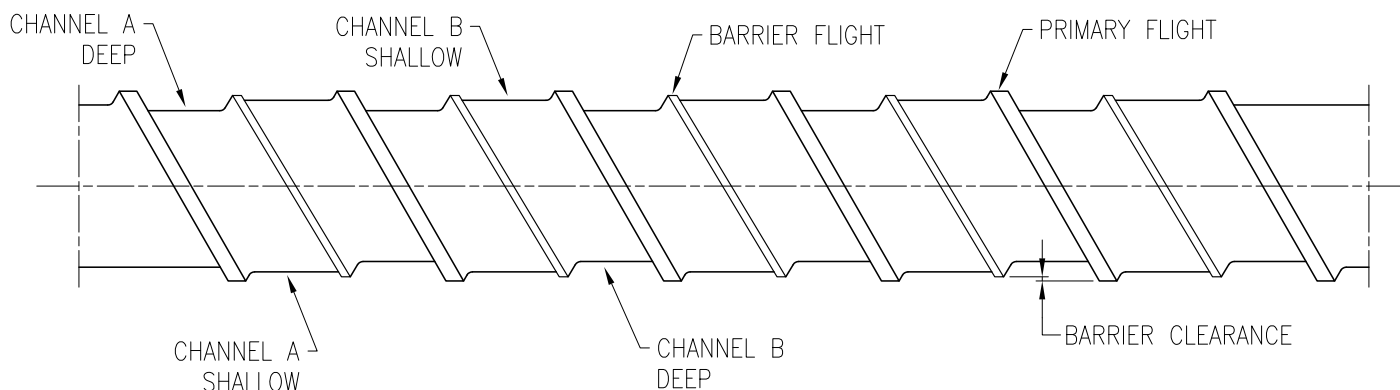
The Saxton can be designed for various resins and mixing actions by varying the total length, number of minor flights and channels, number of interruptions, helix angles, depths, etc.



Saxton Mixer

Double Wave Screw

The Double Wave Screw has two equal width channels separated by an undercut barrier flight. The roots of each channel go up and down like a wave. The channel depth on one is shallow while the channel across the barrier is deep. This continually reverses, forcing melted polymer back and forth across the barrier. The material in the channel is alternately subjected to high, then low, shear. Usually these Double Wave mixing sections are located in the metering section where the plastic has already been melted. The channels are open at both ends and run parallel. The Double Wave was patented by HPM Corporation. (See drawing below).



Double Wave Screw

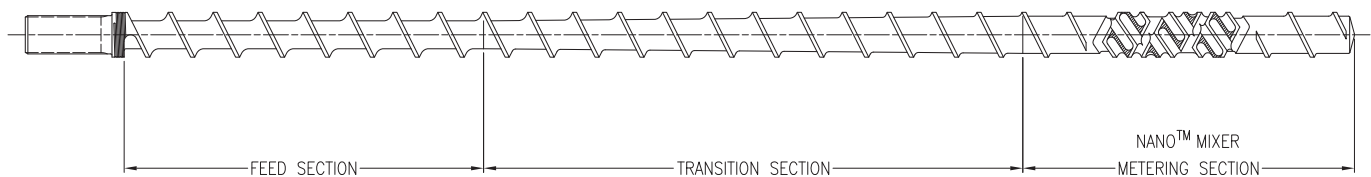
Xaloy® Nano™ Mixer Extrusion Screw

Xaloy® Nano™ Mixer Extrusion Screw

The Xaloy® Nano™ Mixer Extrusion Screw combines very intensive dispersionary mixing of colorants, fillers and additives with excellent temperature control. The unique, patented geometry of the Xaloy® Nano™ Mixer provides exponential mixing action. Its melt channels have multiple inlets and outlets that divide, reorient and recombine the melt stream.

Advantages

- Improved product quality through break-up of color, filler and nanoclay agglomerates into fine particles and superior dispersion throughout the polymer melt
- Self-cleaning
- Multi-pass mixing
- Eliminates un-melts in stiff viscosity materials with minimal melt temperature
- Less back pressure required
- Increase and improved temperature homogeneity



Xaloy® Nano™ Mixer

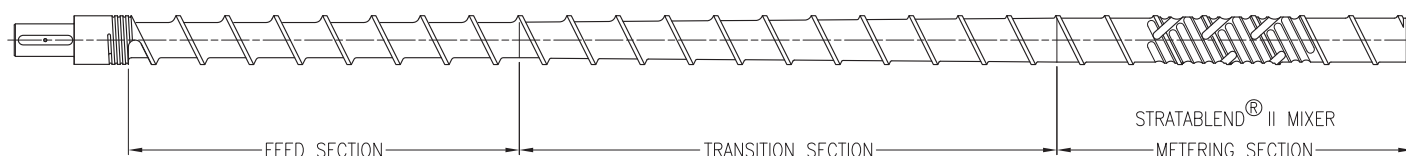
Xaloy® Stratablend® II Mixer Screw

Xaloy® Stratablend® II Mixer Screw

The Xaloy® Stratablend® II Mixer Screw is designed for intensive chaotic and distributive mixing in molding and extrusion applications, but with low shear and little or no temperature rise. The unique, proprietary screw geometry and cut-through channels for highly effective mixing cut-through melt channels allowing backflow for chaotic mixing effects.

Advantages

- Improved color uniformity
- Enhanced effects of additives, fillers and reinforcements on product properties
- Debundled glass fibers with minimal breakage
- Homogenized melt temperature
- Faster material/color changeover due to self-cleaning action



Xaloy® Stratablend® II Mixer

Xaloy® Z-Mixer™ Screw

Xaloy® Z-Mixer™ Screw

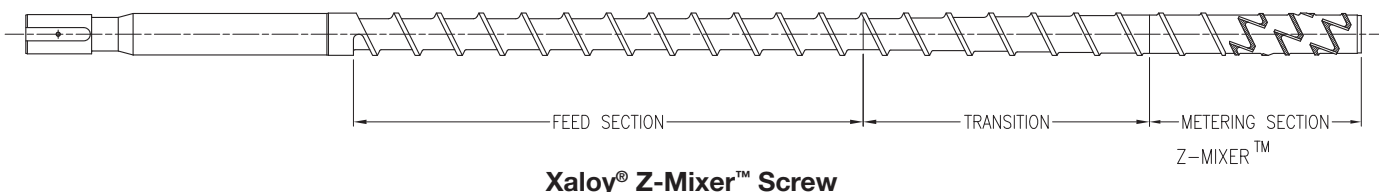
The Xaloy® Z-Mixer™ Screw is a very unique, dynamic mixing element. It has the capability of both dispersive and distributive mixing which is quite uncommon to most dynamic mixing elements. Most mixing elements are usually one type or the other; few have the capability of performing both functions.

A brief description of how the Xaloy® Z-Mixer™ is able to perform both of these functions is that at the start of the Xaloy® Z-Mixer™ the single flow of polymer coming out of the metering section is divided into multi-channels. The size of the screw determines the number of channels that the polymer is distributed into. The polymer will be either divided into two, three or four distinct channels and separated by a full diameter primary flight, as can be seen in the photo below. Then, each division of polymer passes over a barrier in each of its distributive channels. With the passing of the polymer over the barrier, shear or work is applied to the polymer. The shear that is applied to the polymer is required to give good dispersive mixing and the breaking up of conglomerates. After the dispersive mixing takes place, the polymer is distributed again by means of cross flow from one distributive channel to the next through the flight interruption in the primary flight of the mixer. Then the cycle repeats itself. The amount of mixing can be controlled by the height of the barrier gap, the size of the flight interruption, or the number of Z's that are placed in each distributive channel. Empirical studies have shown that typically three cycles are used to give satisfactory mixing.

This mixing device has been found to work very well on polyolefins and other non-shear sensitive polymers. It has also been found that the Xaloy® Z-Mixer™ performs very well when color concentrates are added to the virgin polymer, either in a master batch or blended at the feed throat.

Advantages

- No marbling
- Strong weld lines
- No unmelts
- Best color dispersion in the industry



Xaloy® V-Mixer™ Screw

Xaloy® V-Mixer™ Screw

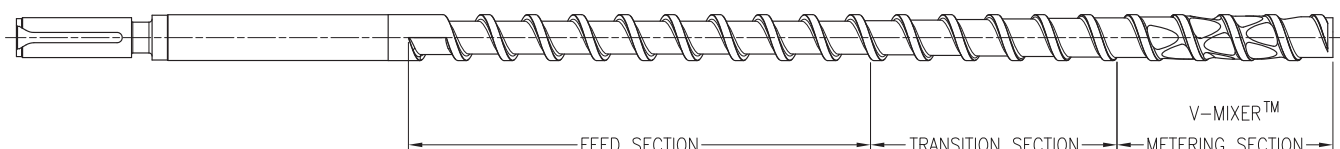
The Xaloy® V-Mixer™ Screw design is unique because it is a dispersive and distributive mixing device that is installed near the discharge end of the screw. The feeding and pumping mechanism is the same as a single flighted screw; however, the melting and mixing effects are superior to a single flighted non-mixing design as well as many other mixers. The Xaloy® V-Mixer™ has many different faces. Nine different versions were tested, and all assist in the melting phase by having a shallower channel depth, thus delivering a degree of increased shear and melting capability.

The homogenizing effect is accomplished by a chaotic mixing action by creating a high shear rate with a side-to-side (wavy wall) movement of the flow as well as an up-and-down (wavy root) movement. By controlling these depths of the channels and creating this flow action, the Xaloy® V-Mixer™ yields a superior dispersionary melt quality.

This distribution delivers a more uniform, homogenized melt with minimal temperature differential. The more uniform the polymer, the more consistent the viscosity and hence the potential for consistent repeatable flow through the die or into the mold. The more repeatable the flow, the greater the molecular orientation, which determines the physical properties of the component being manufactured.

Advantages

- Process a variety of materials
- Low melt temperature
- Less back pressure required
- Quick color change ability
- No marbling

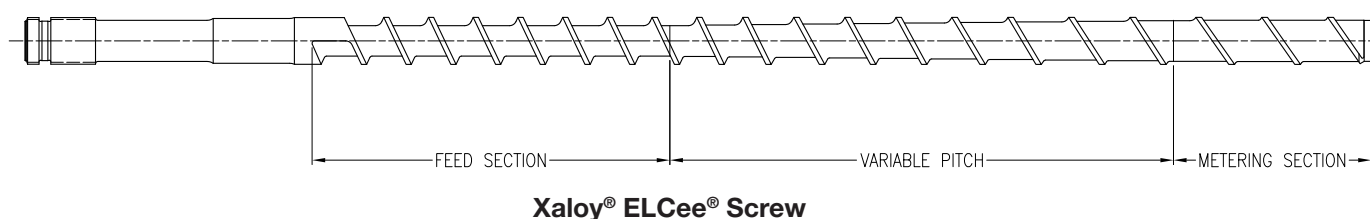


Xaloy® V-Mixer™ Screw

Xaloy® ELCee® Screw / Barrier Screws

Xaloy® ELCee® Screw

The Xaloy® ELCee® Screw was developed by DuPont® and is designed to reduce recovery times with amorphous and crystalline resins. When designing the Xaloy® ELCee® Screw, rheological properties of the resins processed are considered, and mass flow through the screw is optimized. This makes the screw more efficient with each turn, resulting in controlled shear which reduces material degradation and allows for higher screw speeds. Screw recovery time is reduced and a homogeneous melt is realized. Lower shear stress in the polymer results in stronger molded parts. Balanced material flow reduces pressure in the screw channels, extending wear life.



Barrier Screws

One of the most important developments in screw design was the "barrier" screw. There are many different patented barrier screw designs, but it is our feeling that they all come under the broad claims of the Geyer or Uniroyal U.S. Patent No. 3,375,549, which expired in 1985. Many of the other screws shown here have patents of their own. Xaloy has its own modified barrier screws shown on the following pages, which have proven very successful.

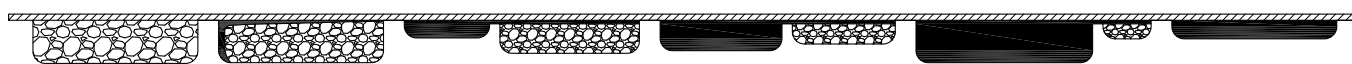
All barrier screws have at least two channels in the barrier section, which is mostly located in the transition section. A secondary flight is started (usually at the beginning of the transition), creating two distinct channels - a solids channel and a melt channel. The barrier flight is undercut below the primary flight, allowing melted plastic to pass over it. The theory of most barrier screws is best understood by referring to the drawing shown on page 23. It is best to also refer back to the melt model of the conventional screw (page 11).

1. The feed section establishes solids conveying in the same way as a conventional screw.
2. At the beginning of the transition (compression), a second flight is started. This flight is called the barrier or auxiliary flight, and it is undercut below the primary flight O.D. This barrier flight separates the solids channel from the melt channel.
3. As material progresses along the transition, melting continues as the solids are pressed and sheared against the barrel, forming a melt film. The barrier flight moves under the melt film and the melt is collected in the melt channel. In this manner, the solid pellets and melted polymer are separated and different functions are performed on each.
4. The melt channel is deep, giving low shear and reducing the possibility of overheating the melted polymer. The solids channel becomes narrower and/or shallower, forcing the unmelted pellets against the barrel for efficient frictional melting. Break-up of the solids bed does not occur to stop this frictional melting.
5. The solids bed continues to get smaller and finally disappears into the back side of the primary flight.
6. Now, all of the polymer has melted and gone over the barrier flight. Melt refinement can continue in the metering section. In many cases, mixing sections are also included downstream of the barrier section. In general, the melted plastic is already fairly uniform upon exit from the barrier section.

Barrier Screws

Barrier Screw Sketches

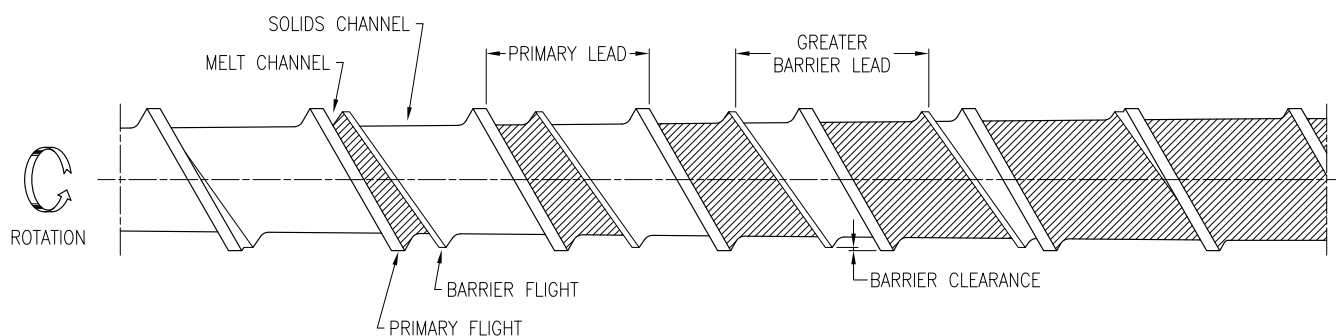
Barrier screws have been around for over 40 years. They were developed for extrusion but then were designed to solve problems in injection. There are a great number of patents and designs. Some barrier screws work better than others, but all require knowledge and experience to design properly. The primary reason for a barrier screw is to eliminate the problem of solids bed breakup for more efficient melting. We have selected some of the more important and most popular barrier screws. We do not have space to describe every type of screw in this booklet.



Melt Model - Barrier Screw

Uniroyal Screw

The Uniroyal Screw is the original barrier screw. The barrier flight starts on the front side of the primary flight at a greater lead, and it disappears into the back side of the primary flight. The channels are basically close-ended, and the depths on either side of the barrier are usually the same. There are many ways the channel widths and depths can vary. This screw is also sometimes referred to as the Maillefer Screw.



Uniroyal Screw

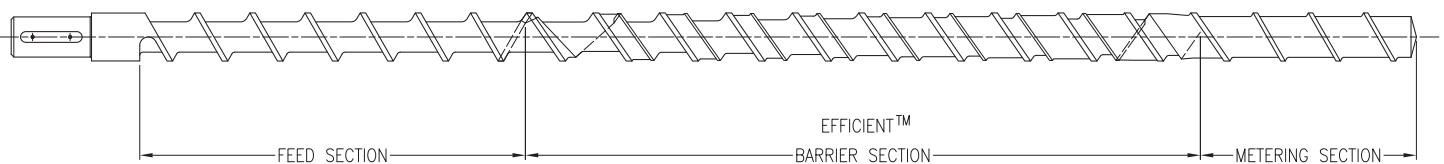
Xaloy® Efficient™ Extrusion Screw

Xaloy® Efficient™ Extrusion Screw

The Xaloy® Efficient™ Barrier Screw design was one of the first patented screw designs in the history of plasticating screw technology. Through the years, the design methods and techniques have been refined to the point where it has become the most modifiable barrier design in the Xaloy screw offering. The Xaloy® Efficient™ Barrier Screw typically delivers up to 20% more output than conventional screw designs, while offering better melt temperature control and homogeneity.

Advantages

- Increases melting efficiency due to elimination of premature solids bed break-up
- Enhances melt homogeneity from moderate shear created by the barrier flight
- Increases melting rates and throughput resulting from "Efficient™" management of the solids bed geometry
- Improves melt temperature control due to lower, post melt shear stresses



Xaloy® Efficient™ Extrusion Screw

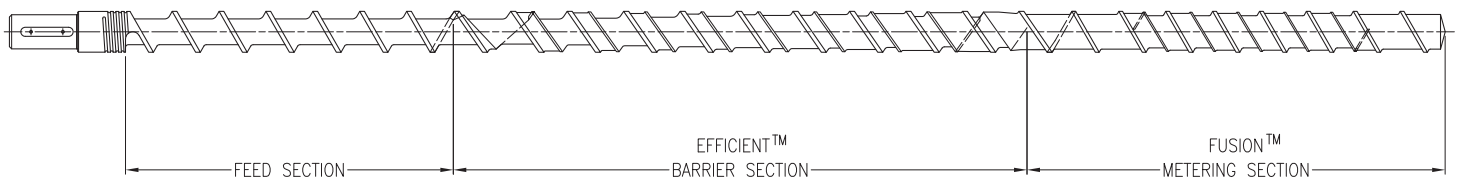
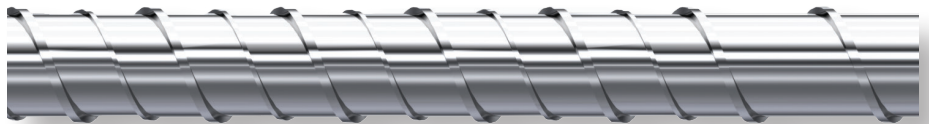
Xaloy® Fusion™ Screw

Xaloy® Fusion™ Screw

The Xaloy® Fusion™ Screw is based upon the Dray-Lawrence U.S. Patent No. 3,650,652, which originated in April 1972. The new technology implements the benefit of the advanced lead in the barrier section, which allows maximizing of the solids bed width at the barrel wall. This, in turn, allows for the greatest melting rate to be achieved. By combining barrier technology for the ultimate melting rate of the polymer, along with wavy root technology to minimize the shear rate of the polymer, a new technology was developed, which produces high recovery rates at very low melt temperatures. These attributes of the new technology have produced a screw design ideal for processing most polyolefin resins to obtain quickest overall cycle times.

Advantages

- Improved product quality
- Increased production
- Lower melt temperature
- Lower drive motor load



Xaloy® Fusion™ Screw

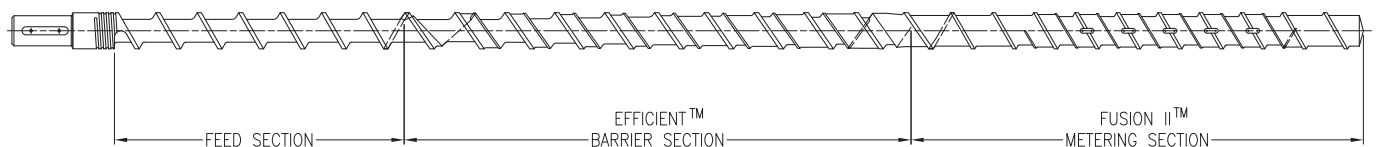
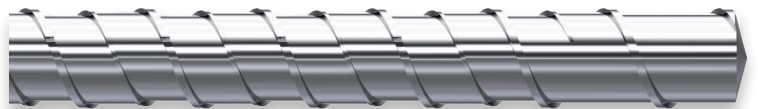
Xaloy® Fusion™ II Extrusion Screw

Xaloy® Fusion™ II Extrusion Screw

The Xaloy® Fusion™ II Screw delivers enhanced chaotic mixing while retaining the productivity benefits of faster plasticizing and lower melt temperature provided by the original Xaloy® Fusion™ Screw. Like the original Xaloy® Fusion™ Screw, this screw has also two barrier zones. The first melts and meters the material forward to a homogenizing transition zone. This zone is followed by a second barrier zone with grooved flights, which allows materials in adjacent melt channels to mix together, enhancing the intensive, chaotic mixing action produced by the screw's undulating root profile.

Advantages

- Improved product quality
- Lower melt temperature
- Lower drive motor load
- Improved dispersion of color and additives in the melt and enhanced melt homogeneity through grooved flight design
- Increased plasticizing rate

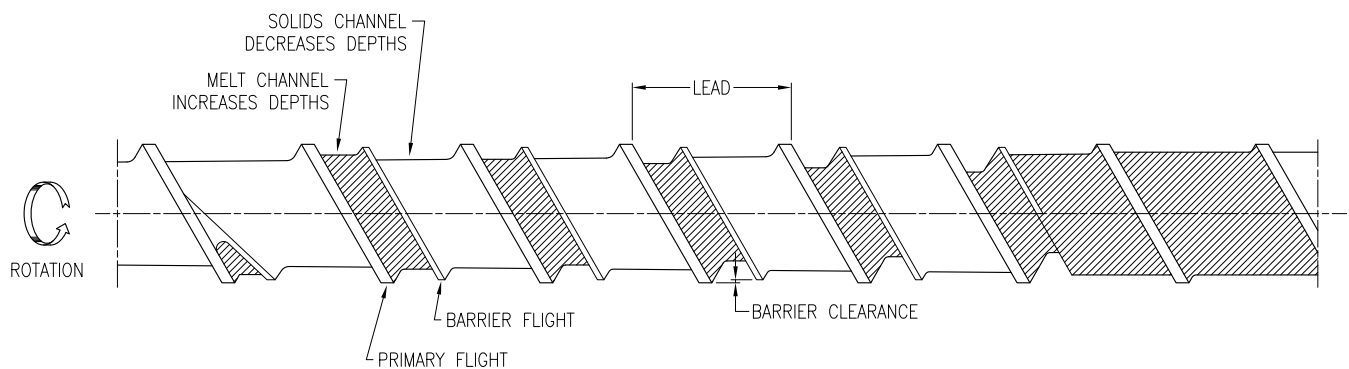


Xaloy® Fusion™ II Extrusion Screw

MC-3 Screw

MC-3 Screw

The MC-3 Screw starts the barrier flight from the front side of the primary flight just like the Uniroyal Screw. The greater lead of the barrier makes it move away from the primary flight, creating the melt channel. After it has gone a certain distance the lead changes back to the same lead as the primary flight, and the two flights run parallel for most of the barrier section. The melt channel becomes deeper and the solids channel becomes progressively shallower. At the end the barrier flight is terminated, and all depths equal the metering depth. The solids channel is open at the discharge end.



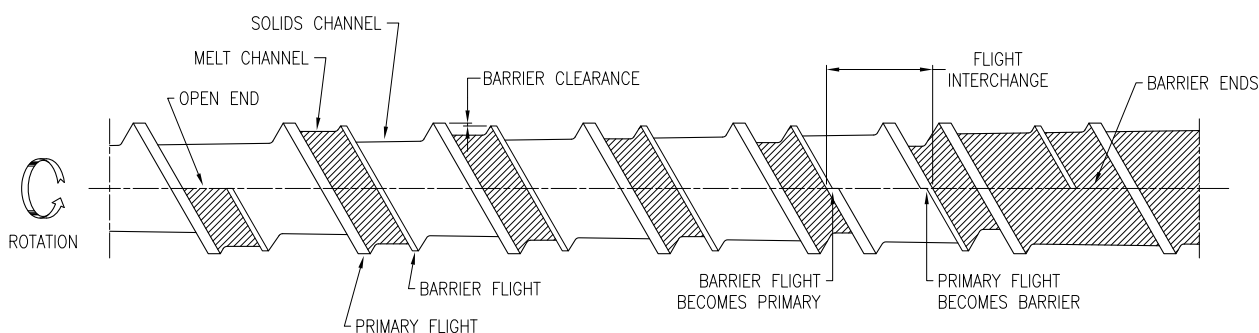
MC-3 Screw

Barr II Screw / Barr E.T.® Screw

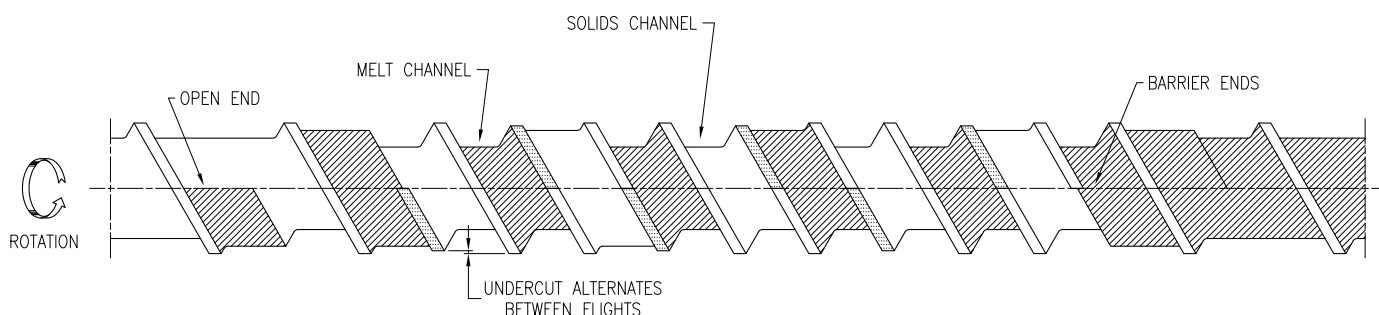
Barr II Screw & Barr E.T.® Screw

The Barr II Screw begins the barrier flight from the root of the screw at the beginning of the transition. The open-ended melt channel is created, and the flights run parallel to the end of the mixing section. The depth of the solids channel decreases, and the depth of the melt channel increases. Near the end there is a flight interchange where the primary flight becomes the barrier flight and vice versa. This promotes mixing. The barrier flight disappears into the channel root, and the melt channel is open-ended.

The E.T. (energy transfer) screw was patented by U.S. Patents 4,000,884 and 4,405,239 and was invented by Robert Barr and sold by Barr Inc. The E.T. section is incorporated at the downstream end of the Barr II Screw, a conventional single-stage screw, or a two-stage screw for vented applications. The E.T. section is double flighted with parallel flights that are alternately deep then shallow. Neither flight is primary or secondary. Undercuts in the flights are provided at numerous places allowing both melted polymer and unmelted pellets to pass into the adjacent channel and mix with and be melted by the already melted polymer. This causes the melted polymer not to overheat and assists in melting the pellets. There is also distributive mixing by the frequent changes in channels and direction.



Barr II Screw



Barr E.T.® Screw

Xaloy® MeltPro™ Barrier Screw

Xaloy® MeltPro™ Barrier Screw

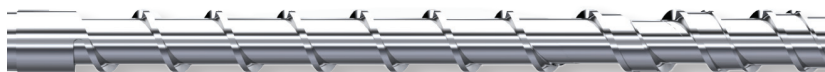
The Xaloy® MeltPro™ Barrier Screw uses a greater than square pitch lead in the feed section and increases the primary flight pitch even greater when the barrier flight starts, and continues this primary pitch the entire screw. The barrier flight comes off the front of the primary flight pitch, continues away until a set width is established and thereafter runs parallel with the primary flight. The melt channel depth continually increases as the solids channel depth decreases, until at the end of the barrier where both channels merge at the metering depth.

Here is a description of the operations of the Xaloy® MeltPro™ Screw:

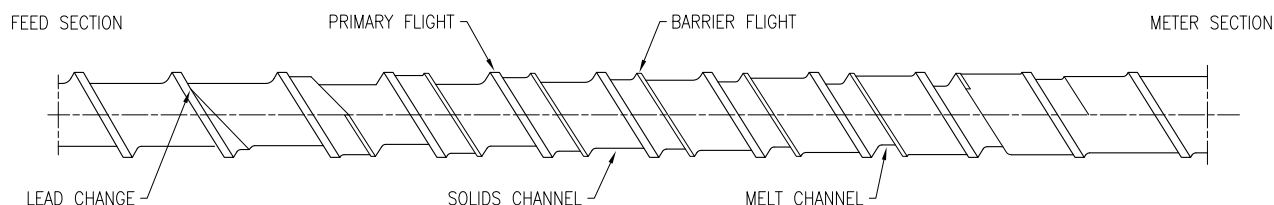
1. The feed section establishes solids conveying in the same way as a conventional screw.
2. At the beginning of the transition (compression) a second flight is started. This flight is called the barrier or intermediate flight and it is undercut below the primary flight O.D. The barrier flight separates the solids channel from the melt channel.
3. As material progresses down the transition, melting continues as the solids are pressed and sheared against the barrel, forming a melt film. The barrier flight moves under the melt film and the melt is collected in the melt channel. In this manner, the solids pellets and melted polymer are separated and different functions are performed on each.
4. The melt channel is deep, giving low shear and reducing the possibility of overheating the melted polymer. The solids channel becomes shallower, forcing the unmelted pellets against the barrel for efficient frictional melting. Breakup of the solids bed does not occur to stop this frictional melting.
5. The solids bed continues to get shallower and finally disappears into the back side of the primary flight.
6. Now, all of the polymer has melted and gone over the barrier flight. Melt refinement can continue in the metering section. In some cases, mixing sections like a patented Xaloy® Pulsar® section are also included downstream of the barrier section. In general, the melted plastic is already fairly uniform upon exit from the barrier section.

Advantages

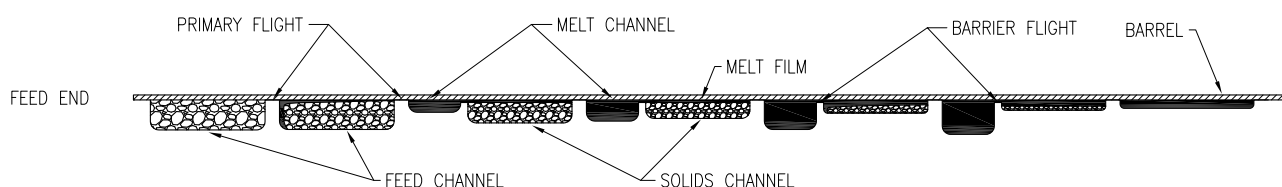
- Low melt temperature
- Highest throughputs in the industry
- Highest efficiency of any screw design
- Versatile - melt quality can be controlled by varying the barrier gap
- Less back pressure required



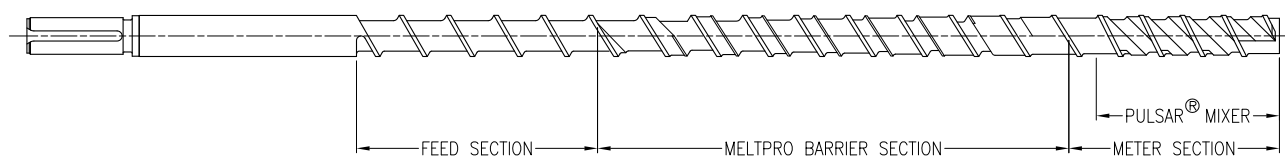
Xaloy® MeltPro™ Barrier Screw



Xaloy® Meltpro™ Barrier Screw



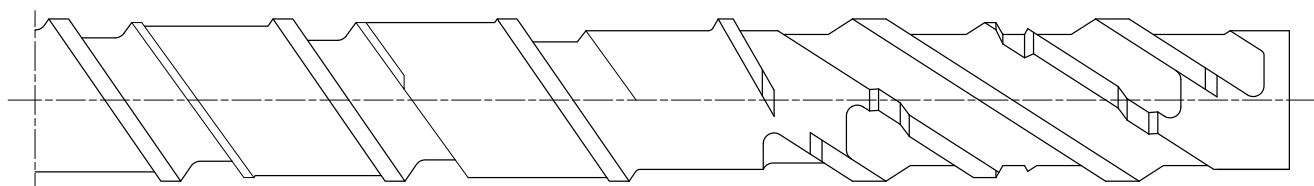
Melt Model - Xaloy® Meltpro™ Barrier Screw



Xaloy® Meltpro™/Pulsar® Barrier Screw

Eagle® Barrier Screw

The Eagle® Barrier Screw, a low shear mixing screw, is supplied by Reiloy Westland Corporation and was patented under No. 5,215,764. It is reported to provide outstanding color mixing and melt quality without increasing melt temperature, burning or degradation while running at very high RPM. It utilizes wiping lands (flights) with large helix angles to rapidly convey the melt either over alternating barrier lands or through mixing notches in the barrier lands. A reduced root diameter allows the mixer to accept substantially all (over 95%) of the melt volume available to it without creating a pressure drop or causing excessive shear.



Eagle® Barrier Screw

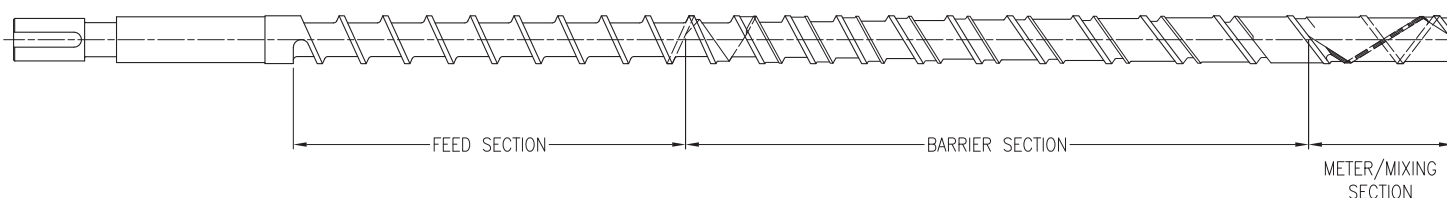
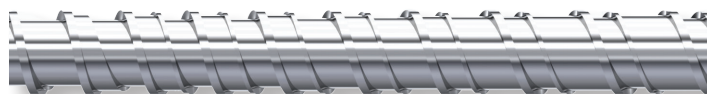
Xaloy® Quantum™ Injection Screw

Xaloy® Quantum™ Injection Screw

The Xaloy® Quantum™ Injection Screw is rated as an ultra-high performance barrier screw, targeted to recovery limited, thin wall processes utilizing polyolefin resins. The innovative barrier screw design of the Xaloy® Quantum™ plasticizing system approximates a mass balance throughout the screw that compensates for the conversion between feedstock bulk density and resin melt density, thereby controlling shear rates and shear stresses throughout the melting process for a remarkably homogeneous melt quality.

Advantages

- Optimum plasticizing rate and recovery times.
An improved screw recovery time by 10-15% over existing barrier designs is possible, dependent upon process parameters
- Maximized melting efficiency through controlled shear forces of the polymer
- Optimized melt quality in high speed applications
- Decreased percentage of scrap produced
- Yields a rapid return on investment



Xaloy® Quantum™ Injection Screw

Output of Screws

Output of Screws

There is no easy way to calculate the output of injection and extrusion screws. A multitude of factors affect this output. Many capable people are spending the majority of their time working on mathematical models and analysis of screw performance. They have developed sophisticated computer simulation programs that can be of considerable assistance in predicting performance of a certain screw. Even with all of this knowledge and computer assistance, exact answers to a specific problem can be difficult. We have computer systems and screw simulation programs that we feel are helpful to us. These simulation programs are most helpful making modifications from existing designs and results. There are also some simplified formulas that can lend some assistance in certain cases.

Here is a simplified formula that gives the drag flow output of the metering section of a conventional square pitch (pitch = diameter) screw:

English

$$R = 2.3D^2hgN$$

Where: **R** = Rate in lb/hr
D = Screw diameter in inches
h = Depth of the metering section in inches
g = Melt density, grams/cm³
N = Screw speed in RPM

Metric

$$R = 0.064D^2hgN$$

Where: **R** = Rate in kg/hr
D = Screw diameter in cm
h = Depth of the metering section in cm
g = Melt density, grams/cm³
N = Screw speed in RPM

This formula does not take into consideration "back flow" or "leakage flow" over the flights. This is not usually a large factor unless the resin has a very low viscosity at process temperatures and shear rates. Leakage flow becomes a significant factor when screws or barrels become severely worn. The formula also assumes pumping against zero pressure at the head or die. It also assumes no over or under pumping from the feed section, and gives no consideration to melt quality.

With all these and other limitations, the formula can still give us guidance as follows:

1. A general guide to the output of screws.
2. If the actual output of the screw is significantly greater than calculated, it is caused by high compression ratios that over pump the metering section. Sometimes this is desirable but it can lead to surging and rapid screw wear if it is excessive.
3. If the output is a lot less it usually indicates a feed problem, a worn screw or barrel, or exceeding the ability of the screw to melt at higher screw speeds. The screw or barrel wear problem can be determined by measurement. A feeding problem can, on occasion, be corrected by changes in barrel temperature settings. More often, the problem is caused by other factors such as screw design, shape and bulk density of the feedstock, surface condition of the screw root and barrel I.D. in the feed area, feed throat design and screw temperature.

Shear Rate

Shear Rate

Most of the energy that a screw imparts to the plastic material is by means of shear. The plastic is sheared between two surfaces moving in relation to each other. These surfaces are the barrel I.D. and the root diameter of the screw. The rate of energy imparted to the plastic increases as the shear rate increases. The shear rate increases as the relative speed of the two surfaces increases and as the distance between the surfaces becomes less. Knowledge of shear rate can be useful when there are problems with excessive shear causing high melt temperatures and burning of heat sensitive materials. Low shear rate can cause poor mixing, low melt temperatures, and unmelted material. The actual shear rate at any single point along a screw can be calculated using the following formula:

English

$$S = \frac{DN}{19.1 h}$$

Where: **S** = Shear rate in reciprocal seconds
D = Screw diameter in inches
N = Screw speed in RPM
h = Screw channel depth in inches

Metric

$$S = \frac{DN}{19.1 h}$$

Where: **S** = Shear rate in reciprocal seconds
D = Screw diameter in mm
N = Screw speed in RPM
h = Screw channel depth in mm

Feeding Problems

Feeding Problems

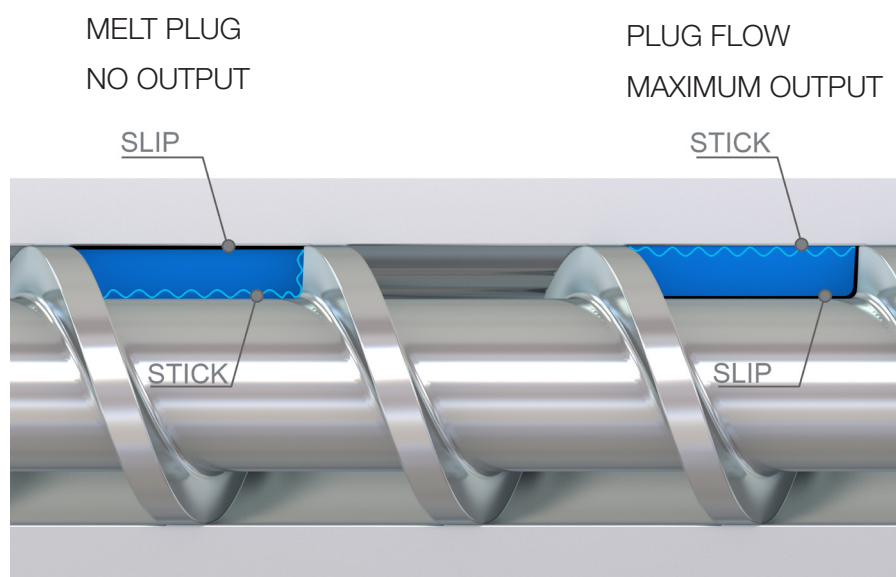
The mechanism that pushes solid particles forward in the feed section of a single screw extruder or injection machine has always been one of the weakest features of these machines. This forward feeding force near the feed hopper is often weak and erratic and is classified as "non-positive". It can be so tenuous that a specific screw/barrel combination will feed virgin but little or no additions of regrind, or one feedstock shape but not another, and often one family of resins but not another. Non-uniform feed will result in poor production rates, non-uniform output (surging), and poor product quality.

This solids feeding mechanism is dependent on the surface friction of the screw surfaces and the inner surface of the barrel. The easier the solid particles of plastic slide on the screw, the better the screw will feed. Also, the greater the friction or resistance to sliding on the barrel wall, the better it will feed. This is perhaps best visualized by considering the worst condition where it slides on the barrel and sticks to the screw. In this case, the plastic will merely go round and round with the screw and never move forward along the barrel.

The processor has several medium cost solutions that may help. It is possible that a redesign of the screw by recut or replacement will cure the problem for a specific situation. It is also possible that the surface of the feed section of the screw can be altered to decrease friction. Chrome plating or other low friction coatings can help. The most immediate tool available to the processor is finding the optimum barrel temperature settings.

This optimum setting will give the best feeding temperature at the inside of the barrel for that RPM and resin combination. These feed critical settings are the rear ones and will vary depending on many things, including RPM, barrel wall thickness, depth of thermocouple and other items. The intent is to obtain an inside barrel wall temperature which will be hot enough to provide a viscous sticky melt film early without overheating to make the plastic too fluid so that it flows easily.

An important consideration in all of these "feed" problems is that many are improperly diagnosed and are actually melting problems. Every screw design and resin combination has a practical limit for the rate at which it can melt the material. If the screw is run at an RPM which exceeds the ability of the screw to melt material at that rate, solids blocks will form with surging and the appearance of poor feeding. This is particularly true of resins with high specific heats such as the polyolefins. If you obtain low and erratic output in conjunction with temperature override in the transition, the problem is usually melting, not feeding.



Extrusion Screws

Extrusion Screws

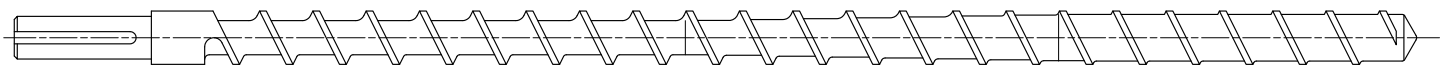
Extrusion screws are multi-functional devices. The screw must be divided into three basic components: feeding, melting and pumping. All three of these components must work simultaneously with each other.

The primary function of the feed section is solids conveying - the forward movement of the pellets from the feed throat opening and into the electrically heated barrel. The main theory of solids conveying is that the material must stick to the barrel and slip on the screw to have good plug flow. Plug flow must be established to insure that the feedstock has been properly compacted into a solids bed. As the feedstock nears the end of the feed section, a melt film begins to develop and the melting process begins.

Once the polymer enters the transition section of the screw, the melt pool develops on the push side of the flight. As the polymer begins its gradual transition up the taper of the screw to the metering section, the polymer is forced against the barrel wall. As the polymer continues up the transition, the solids bed becomes smaller and the melt pool becomes larger until it enters the metering section of the screw. At this point, solids bed breakup occurs, and any remaining unmelted pellets are dispersed throughout the already melted polymer. The final completion of metering in the metering section is primarily done by means of convected heat from the molten polymer into the remaining unmelt particles.

The metering section of the screw is essentially the pumping section. In the metering section, the final melting takes place and enables the screw to overcome the pressure resistance caused by the die. The ability of the screw to pump is basically dependent on the depth of the screw channel in this section, the viscosity of the polymer, and the speed at which the screw is rotating.

If the extrusion screw is designed properly and feeding, melting and pumping occur in a harmonious state, uniform extrusion of the polymer will occur. These three mechanisms are the basics of good screw geometry. Once these requirements have been met, it may be necessary to investigate the possibilities of maximizing the throughput by utilizing all, or at least 90% of the horsepower available, or improving the mixing by adding some type of dynamic mixing device. These requirements illustrate the necessity for understanding the elements of good screw design.



Single-Stage Screw

Twin Screws / Mechanical Requirements

Twin Screws

Twin Extrusion Screws are high-performance screws suitable for processing and conveying a wide range of polymeric materials. Precision engineered, parallel (co-rotating and counter rotating) and conical (counter rotating), intermeshing and non-intermeshing, they can be custom tailored to the processing requirements with kneading blocks, conveying elements, reverse conveying elements and gear mixing elements etc. and show therefore exceptional mixing capabilities and great process flexibility.

Advantages

- Improved productivity
- Desired results
- Consistent melt quality
- Increased output at reduced shear rates
- Greater process flexibility
- Reduced down time
- Extended working life



Mechanical Requirements

Screws always run inside a stronger, more rigid barrel. For this reason they are not subjected to high bending forces. The critical strength requirement is resistance to torque. This is particularly true of the smaller screws with diameters of 2½" and less. Unfortunately, the weakest area of a screw is the portion subject to the highest torque. This is the feed section, which has the smallest root diameter. A rule of thumb is that a screw's ability to resist twisting failure is proportional to the cube of the root diameter in the feed section.

The maximum torque that can be applied to a screw can be calculated by the following formula:

English

$$T = \frac{5252 \text{ (HP)}}{\text{(RPM)}}$$

Where: **T** = Torque in foot pounds
HP = Horsepower of drive motor
RPM = Lowest screw speed in RPM at which the drive delivers max. horsepower

Metric

$$T = \frac{9549 \text{ (kW)}}{\text{(RPM)}}$$

Where: **T** = Torque in Nm
kW = Power of the motor in kW
RPM = Lowest screw speed in RPM at which the drive delivers max. horsepower

Mechanical Requirements

(Caution: some variable speed drives can deliver full horsepower at less than full speed.)

Once we have the maximum torque, we can determine whether the screw can take the torque, or we can use the information, or we can use that information to determine the feed depth. Other feeding characteristics are also important. Here is an approximate formula used to determine the minimum root diameter of the screw:

English

$$D_{min} = \sqrt[3]{\frac{102T}{S_t}} + d^3$$

Where: **D** = Root diameter in inches (feed section)
T = Torque in foot pounds
d = Diameter cooling hole in inches
(use d = 0 if no hole)
S_t = Tensile yield strength in psi

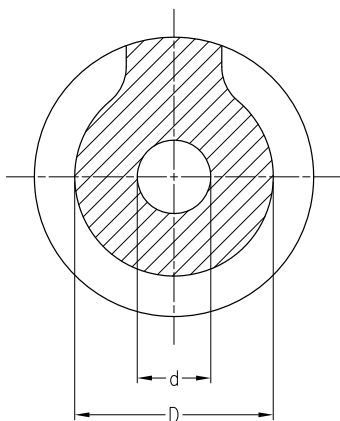
Metric

$$D_{min} = \sqrt[3]{\frac{8509T}{S_t}} + d^3$$

Where: **D** = Root diameter in mm (feed section)
T = Torque in Nm
d = Diameter cooling hole in mm
(use d = 0 if no hole)
S_t = Tensile yield strength in N/mm²

At Xaloy, we have finite element analysis (FEA) available for more accurate determination of stress levels.

This formula is intended strictly as a guide and is not exact for a number of reasons. (1) We assume that torsional shear strength is 60% of the tensile yield. Torsional shear strength is inexact at best, and there are very few places where you can find this data. (2) We do not take into consideration the added strength provided by the flight. We merely calculate the section as a cylinder. This gives a built-in safety factor. (3) There is no consideration given to rapid shock loads which can be a significant factor. (4) Stress concentration factors can vary widely depending on the radius at the bottom of the flight. (5) All strengths given in the tables and in most other places are at room temperature. They are bound to be less at operating temperatures. Again this is only a guide. The amount of added safety must be determined by the user.



Screw Cross Section

If you do not wish to go through the step of calculating torque, on the next page are some formulas to calculate:

1. Minimum root diameter
2. Minimum screw RPM at full HP
3. Maximum HP that can be applied to a screw with known dimensions.

These formulas have the same limitations as the above formula for torque.

Mechanical Requirements

English

$$D_{min} = \sqrt[3]{\frac{535,000 \text{ (HP)}}{(\text{RPM}) S_t}} + d^3$$

Metric

$$D_{min} = \sqrt[3]{\frac{81,144,000 \text{ (kW)}}{(\text{RPM}) S_t}} + d^3$$

English

$$\text{RPM}_{min} = \frac{535,000 \text{ (HP)}}{(D^3 - d^3) S_t}$$

Metric

$$\text{RPM}_{min} = \frac{81,144,000 \text{ (kW)}}{(D^3 - d^3) S_t}$$

English

$$\text{HP}_{max} = \frac{(D^3 - d^3) (\text{RPM}) S_t}{535,000}$$

Metric

$$\text{kW}_{max} = \frac{(D^3 - d^3) (\text{RPM}) S_t}{81,144,000}$$

Screw Materials

Screw Materials

Please refer to the table on page 41 for a summarized comparison of materials used for screw construction. We are also giving a description of these materials here:

AISI 4140

This alloy steel is by far the most common screw material. It probably accounts for in excess of 80% of all extrusion and injection screws. 4140 is readily available and is purchased in the heat treated condition (28-32 Rc) and stress relieved. It has good strength and can be flame hardened or hard surface welded. It is important to make sure that special, easy-to-machine grades are not selected. These grades usually contain either lead or are re-sulphurized. This makes them, for all practical purposes, impossible to rebuild by hard surface welding due to extreme porosity and stress cracks. 4140L is a grade of 4140 modified by the addition of lead, which makes it easier to machine, but impossible to rebuild.

AISI 4340

This alloy is similar to 4140, but includes nickel as an alloying element plus a greater percentage of molybdenum. This gives a slightly higher strength but the major difference is the greater penetration of heat treatment. This gives superior mechanical properties at the core of the bar. It is most beneficial for screws that have very deep flights and smaller diameter screws where strength is more critical.

Nitralloy 135-M

A number of manufacturers produce a steel similar or identical to Nitralloy 135-M, but this is the name best known. Nitralloy is similar to 4140, but is slightly lower in physical properties. The major difference is the inclusion of a small portion of aluminum which forms aluminum nitrides in the nitriding process. See the table on page 41 for more details.

300 Stainless

A number of 300 series stainless steels including 304 and 316 are occasionally used to manufacture screws where corrosion resistance is of primary importance. These materials have relatively poor strength and abrasion resistance. They cannot be flame hardened and must have the flights hard surface welded. A better selection is a precipitation hardening stainless steel such as 17-4 PH which gives similar corrosion resistance, but mechanical properties superior to 4140.

17-4 PH Stainless

This is a trade name of Armco Steel Corp., but similar products are available by other steel makers. They are much stronger than 4140 and have corrosion resistance similar to the 300 series of stainless steels. 17-4 PH is an excellent selection for smaller screws where strength is important. This material eliminates the need for frequent stripping and chrome plating.

D2 and H13 Tool Steels

These standard grades of tool steel have been primarily used for high wear applications caused by abrasion. The uses include components for non-return valves, nozzles, endcaps/ nozzle adapters, barrel sleeves, and for plasticizing screws. Both grades require a heat treating process to obtain maximum wear properties. D2 offers a good degree of corrosion resistance by virtue of the large amount of chromium present.

Screw Materials

CPM Tool Steel

CPM is a designation of materials made by Crucible Specialty Metals Division and stands for Crucible Particle Metallurgy. These CPM materials contain very high portions of alloying elements usually not possible in conventional processes starting with ingot casting. The HIP process is used to make these special CPM alloys. HIP stands for Hot Isostatic Pressure and is a process where powdered metals are combined at extremely high temperatures and pressures to make very dense bars or other shapes with superior properties not possible by older methods.

Xaloy pioneered the use of CPM materials for the manufacture of extremely abrasion resistant screws. Now a variety of CPM materials are used in all types of plastic related machinery components. They include screws, barrels, barrel sleeves, non-return valves, cutter and pelletizer knives, and molds. CPM materials are particularly useful as resistance to wear caused by abrasive fillers such as fiberglass. CPM is not a coating but exhibits its abrasion resistance throughout the entire part. This protects screws in the root surfaces where glass erosion is the most severe. Here are some of the current CPM products now used for plastic machinery components:

CPM 10V

A high-vanadium, high-carbon alloy with extreme abrasion resistance. Used for barrel liners and some screws. This alloy exhibits the highest wear resistance available in the particle metal series.

CPM 9V

Slightly less vanadium and carbon giving a little less abrasion resistance but improved toughness over CPM 10V. This is now the standard CPM material for screws by virtue of properties at elevated temperatures.

CPM S90V

This is a high-vanadium, high-chromium tool steel for applications requiring both high wear resistance and good corrosion resistance similar to 400 series stainless steels. Wear resistance is comparable to CPM 9V.

CPM M4

A CPM steel made using the HIP process with chemistry similar to conventional M4 tool steel but having superior wear properties due to the denser structure.

Hastelloy C-276

Hastelloy C-276 is a special nickel alloy with outstanding chemical resistance. It is lower in strength than 4140 and is very expensive. The tensile yield strength can be improved from 50,000 psi (3,500 bar) to 80,000 psi (5,500 bar) by cold reduction, but this is even more expensive and will extend delivery. Cold reduction also increases the stresses formed in the bar. For good wear, the flights should be hard surfaced with a nickel-based hard surfacing material.

Inconel

Inconel 625 and 718 are nickel-chromium alloys with excellent corrosion resistance. These alloys retain good strength at high temperatures. The flights should be hard surfaced with a nickel-based weld.

Common Screw Materials

COMMON SCREW MATERIALS

	Yield Strength psi	Hardness as Machined Rc	Availability of Case Hardness Rc	O.D. Wear Resistance	Root Wear Resistance	Corrosion Resistance Material	Material Availability	Ease of Machining	Cost
ALLOY STEELS									
AISI 4140	100,000	28-32 Rc	48-55 Rc ¹	Fair ¹	Poor	Poor	Excellent	Fair	Low
AISI 4130	100,000	28-32 Rc	48-55 Rc ¹	Fair ¹	Poor	Poor	Fair	Fair	Low
Nitralloy 135-M	85,000	33 Rc	60-65 Rc ²	Good ³	Good	Poor	Fair	Fair	Low
STAINLESS STEELS									
17-4 PH	175,000	38 Rc	42 Rc ³	Poor ³	Fair - Poor	Good	Fair	Fair - Poor	Low
TOOL STEELS									
CPM 10V	300,000	98 Rb	58-60 Rc	Excellent	Excellent	Fair	Fair	Fair	Medium
CPM S90V	300,000	100 Rb	55-57 Rc	Excellent	Excellent	Good	Poor	Fair	Medium
CPM 9V	285,000	100 Rb	52-55 Rc	Excellent	Excellent	Fair	Fair	Fair	Medium
D2	>300,000	96 Rb	58-60 Rc	Good	Good	Fair - Poor	Good	Fair	Low
H13	>300,000	96 Rb	50-60 Rc	Good	Good	Poor	Good	Fair	Low
Elmax	335,000	96 Rb	58 Rc	Good	Good	Excellent	Fair	Fair	High
Vanadis 10	>300,000	100 Rb	58-60 Rc	Excellent	Excellent	Fair	Fair	Fair	Medium
SPECIALTY MATERIALS									
Hastelloy C-276	80,000	86 Rb	86 Rb ³	Poor ³	Poor	Excellent	Good	Poor	High
Inconel 625	40,000	163 Br	N/A	Poor	Poor	Excellent	Good	Fair	Medium
Inconel 718	110,000	352 Br	N/A	Poor	Poor	Excellent	Good	Fair	Medium

⁽¹⁾ Flame or induction hardened

⁽²⁾ Nitrided

⁽³⁾ Usually improved by hard surfacing

Heat Treatments

Flame Hardening

This is probably the oldest method to increase wear resistance of the tops of flights. AISI 4140 steel is usually purchased by screw manufacturers in the heat treated condition. Normally, this condition is 28-32 Rc (269-321 BHN) which gives good mechanical strength of around 100,000 psi (6,900 bar) tensile yield. It is still readily machinable in this condition. The flights can be further flame hardened to around 48-55 Rc. This cannot be done with low carbon steels. Approximately 0.4% carbon content is needed to achieve this result on a practical basis. The process employs an open gas/oxygen flame followed by rapid quenching. The usual depth of hardness is around 1/8" (3 mm), but the hardness tapers off as you go deeper from the surface.

Induction Hardening

This process gives the same result as flame hardening but uses induction heat created by magnetic flux reversals rather than a flame.

Nitriding (Ion or Gas)

A very hard outside case can be obtained by subjecting screws or barrels to a high nitrogen atmosphere (usually ammonia gas) at elevated temperatures. The temperature is around 950°F (510°C). This comparatively low temperature gives minimal distortion but a very high case hardness of around 55 - 65 Rc. The depth of case is approximately .020 - .024" (0.508 - 0.6096 mm). This thin case diminishes in hardness from the outside, causing the screw to wear rapidly once any significant wear has occurred. Allowance for .0005 - .001" (0.0127 - 0.0254 mm) of growth must be considered when designing parts before the nitriding process. The high hardness is caused by the formation of metallic nitrides. A proper nitriding steel such as Crucible Nitriding 135 or Ryerson Nitralloy 135-M should be used in order to develop maximum hardness from the process. These steels are similar to AISI 4140 in their chemistry, but they have 0.95 - 1.30% aluminum added to form very hard aluminum nitrides. Alloy steels such as 4140 can also be nitrided but they give a slightly lower hardness, and a slightly increased depth of case. Nitriding is usually done over the entire flighted area including the root. This gives some improved wear resistance to abrasion by glass filled materials. It is best to nitride screws and barrels in a vertical oven in order to minimize distortion. The nitriding process can cause some problems with screw rebuilding.

This should be taken into consideration when selecting a new screw. Nitrided screws are rebuilt by hard surface welding. This welding process can cause the nitrides to bubble at the intersection of the base material and the hard surface overlay. Special steps must be taken to avoid these bubbles.

The nitriding process is still used for injection barrels. These barrels usually do not last as long as the bimetallic barrels, and they should be avoided where chemical resistance is an important factor.

Precipitation Hardening

Precipitation hardening is a low temperature process used to harden certain grades of stainless steels. 17-4 PH stainless steel is an example of this type where the PH stands for precipitation hardening. These grades are usually supplied in Condition A (Solution Treated) which is similar to being annealed. The bar is then machined and hard surfaced before precipitation hardening.

Coatings

Chrome

Screws are often chrome plated in the flighted area. Plating has several benefits. They are: (1) Screws are much easier to clean after removal from the machine. This can be important when frequent color changes are needed. (2) The feeding characteristics of the screw remain constant over a longer period, because the root surface in the feed section does not change rapidly. (3) There is some minor improved wear resistance in the root when running abrasive materials. This, however, is minimal.

Chrome plating is often applied to improve corrosion resistance. A misconception is that all shiny screw surfaces are chrome plated. Chrome plating does not make screws shine, it helps to keep them that way. A highly buffed screw will have the appearance of a chrome plated screw. The best way to test for chrome is to apply a solution of copper sulphate. If a copper color appears the screw is not plated. If the test is negative, the screw is plated, or you are testing a stainless or hard surfaced area.

Chrome plating is usually applied .001" - .003" (0.025 - 0.076 mm) thick but it can be applied to almost any thickness and expense. It is not normally applied to the tops of the screw flights.

Nickel

Nickel plating is sometimes used for the same reasons as chrome plating. In most cases corrosion resistance is better than chrome. In other cases it is not as good, depending on the specific chemicals involved. Nickel is always softer and has less wear resistance. Nickel can be electroplated in a process similar to chrome, giving a pure nickel deposit. The bond of this electroplating is usually not sufficient for screws. The better method, electroless nickel plating, gives an alloy of nickel with up to 15% phosphorous. The advantages of electroless over electro nickel are: (1) Uniform in thickness, even in deep recesses; (2) Non-porous; (3) Some ability to obtain higher hardness by baking; and (4) Better adhesion. The disadvantages are higher cost and greater difficulty in obtaining thick coatings. In either case, the bond is not as good as chrome.

Tungsten Carbide

Tungsten carbide is a very hard crystalline compound of tungsten and carbon, made by reacting the two substances at high temperatures. It has a melting point of 5,198°F (2,870°C). As fine gray or black powder it can be pressed and formed into shapes and has considerable advantages in the production of wear-resistant machinery parts; tungsten carbide is considered twice as strong as steel. Xaloy uses tungsten carbide in a nickel based alloy for the Xaloy® X-8000™ Screw Encapsulation. For this innovative screw encapsulation, Xaloy applies this nickel-based alloy with high tungsten carbide content to the entire screw geometry in a high-velocity oxy-fuel (HVOF) coating process. Then the alloy is fused to the parent metal of the screw in a two-step method that forms a metallurgical bond, rather than the purely mechanical bond formed by standard HVOF coatings, therefore achieving exceptional wear resistance.

Conventional Hardsurfacing

The wear surfaces (primarily of flight lands) are usually protected by welding special wear resistant alloys over these surfaces. The most familiar of these alloys are Stellite and Colmonoy, but many other good materials have been developed in recent years. These materials contain various metal carbides in a matrix of cobalt or nickel. Stellite materials are cobalt based and Colmonoy materials are nickel based. Typical materials used to hard surfaced screws are given in the chart on page 49.

Coatings

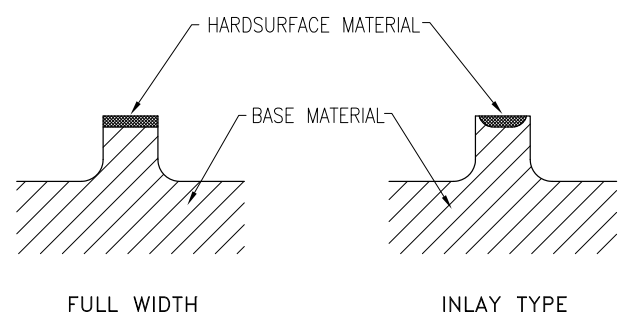
Similar materials are available from other suppliers of welding materials. They are applied by the following methods: TIG (tungsten inert gas), PTA (plasma transferred arc) and oxyacetylene (stick). These hardsurfacing materials generally outlast flame hardened or nitrided screws by a factor of 3 or 4 to 1. The final thickness of the hard surfacing materials is usually around 1/16" (1.59 mm). Wear resistance does not appreciably decrease as wear progresses until the hard surfacing is gone. The screw should be rebuilt before that point is reached. The materials described above are the same materials that are also used to rebuild the flight lands when the screw is rebuilt. Most of these materials are also highly corrosion resistant because of the nickel or cobalt base. For the same reason, the hard surfacing portion does not plate well at all. The result is the formation of a wavy line at the intersection of the welded material and the base screw material. This problem can be eliminated by the use of an inlay. Shown below are two basic hard surfacing geometries. Inlays only apply to new screw manufacturing.

Stress cracks are fine hairline cracks that run across the top of the hard surfaced flights at a right angle to the flight. These cracks are very small and are not normally cause for concern. They are caused by the hardsurfacing materials (usually nickel or cobalt based) having a different rate of thermal expansion and contraction. The temperature of the welding melt pool is also much higher than the temperature of the base screw. For this reason, the hard surfacing has a need to cool and contract more. These cracks can be minimized, and in some cases eliminated, by proper preheating, and post heating of the bar and other welding techniques. In general, the higher the carbon content of the hard surfacing material, the greater its tendency to crack and the better its wear characteristics. Cracks in the hard surface material that are suspicious are the ones that start at the top of the flight and travel down to the bottom of the weld and then turn in a circumferential direction. Actually, screws using the high carbon, more abrasion resistant hard surfacing materials that do not have some hairline stress cracks can be suspect. They may not have cracks because the hardsurface material has been over diluted, with the base screw material, giving a softer flight land which will wear rapidly.

Laser Hardsurfacing

Another method for hardsurfacing, is laser hardfacing on flight lands. All the common hardsurfacing materials listed in the chart on page 49 are available, along with tungsten carbide composites. The tungsten carbide particle can be spherical or angular in shape.

The key benefits of the laser process are the low heat input, the low dilution of the deposited alloy, the large variety of hardfacing compositions (powder fed), and the overlays are metallurgically bonded and impervious. All these attributes lead to very high quality overlays (no cracks, minimal porosity and high hardness values). For example, a Colmonoy 56 PTA powder was laser deposited with hardness values into the low 60's Rc. The final thickness achievable for highly crack sensitive materials ranges from 0.015" to 0.055". The final thickness achievable for less crack sensitive materials like Stellite 6 is not limited because multilayer deposits can be done. This product is available on new screws, while the rebuilding or repairing of used screws is evaluated on a case-by-case basis.



Two Hardsurfacing Geometries

Xaloy® Wear Coating Technology

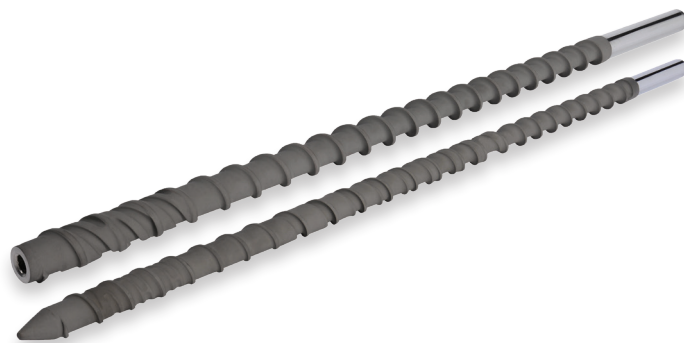
Xaloy® MPX™ Wear Technology for Screws

Xaloy® MPX™ Wear Coating is a newly engineered, tungsten carbide coating with improved abrasive and corrosive wear performance and higher bond strength than conventional High-Velocity Oxy-Fuel coatings (HVOF).

- Proprietary thermal spraying technology, different from anything in the market today
- Controlled plasma spheroidization of very small particles using specially produced equipment
- Higher particle velocity than standard HVOF technology
- Specialized spray equipment developed to spray fine particles
- ASTM testing for abrasive, sliding wear and bond prove Xaloy® MPX™ Wear Coating is superior to standard HVOF materials and processes

Advantages:

- Higher return on investment than commonly used standard HVOF wear technologies driven by reduced particle size, improved density and bond strength
- Estimated 3 - 4 times longer abrasive wear life than nitrided case hardened screws
- Improved corrosion resistance over nitride and standard HVOF coatings. Near zero porosity Xaloy® MPX™ Wear Coating survived more than 1,000 hours in Salt Fog Test validating superior corrosion resistance vs standard HVOF coatings

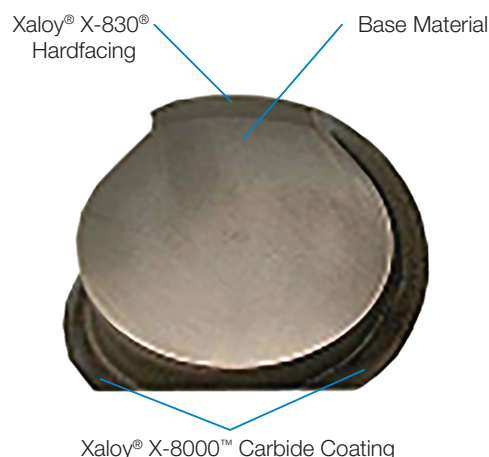


Xaloy® X-8000™ Encapsulated Screws

The Xaloy® X-8000™ Coating is a thermal spray coating applied to the screw. This material complements Xaloy's high abrasive resistant Xaloy® X-830® overlay and is well suited for processing highly filled or corrosive resins, providing a 100% metallurgical bonding to the screw base material. It can be applied for the full flight length or only on isolated areas of the screw that are more susceptible to wear.

Advantages:

- Tungsten carbide cladding – improved wear and superior corrosion resistance
- Metallurgical bond (typical bond strength 280 MPa) – no chipping or delamination issues associated with HVOF carbide coatings
- Rebuilt screws – Xaloy® X-8000™ is repairable and can be applied to rebuilt screws



Rebuilding & Repairs

Rebuilding & Repairs

Screws and barrels are expensive components. When they are damaged or worn it is often desirable to repair rather than replace. It is a common practice to rebuild a worn screw with hardsurfacing materials described on page 49. The various steps in the rebuilding process are shown on page 47. The larger the screw diameter, the more economical screw rebuilding becomes. The rebuilding of a 4½" (114.3 mm) diameter 24:1 L/D screw is approximately two-thirds the price of a new, flame hardened screw, and half the price of a new screw, welded with Stellite. It usually does not pay to rebuild 2" (50 mm) diameter and smaller screws. The repair of the internal thread at the front of an injection screw is practical, provided the thread is small and the metering depth is shallow. The front is bored out to a larger diameter and a solid plug is shrunk with an interference fit. A new thread is then machined. If this is done properly there is no chance of the thread pulling out. A drawing illustrates this on page 49.

When the wall is too thin to install a bushing, the front end can be repaired by stubbing. The screw is cut off behind the threads. A pilot is cut in the remaining screw and a stub front end is welded in. The external flights are then machined and a new thread and pilot are cut. Usually this also requires stripping the screw, and re-chrome plating, after the above repairs. A drawing of this repair is shown on page 48.

Many splines become damaged and unrepairable by constant pounding or sometimes improper installation of the suck back device. In most cases, a satisfactory repair can be made by stubbing a new section in a larger diameter area in front of the spline. The new spline is then machined as shown on page 48.

Strip/Polish/Plate

After some service, most screws become scratched, carbonized, and discolored. They are hard to clean and tend to lose their original feeding characteristics. If they have been plated, the chrome may be gone in some places or peeling in others. It is best to refurbish a screw in this condition by stripping the old chrome, polishing, buffing, plating and buffing again. The screw will look a lot better, and should also perform better for little cost and a short delivery. Most screws that are rebuilt are also stripped, polished and plated.

Screw Inspection / Repair Process

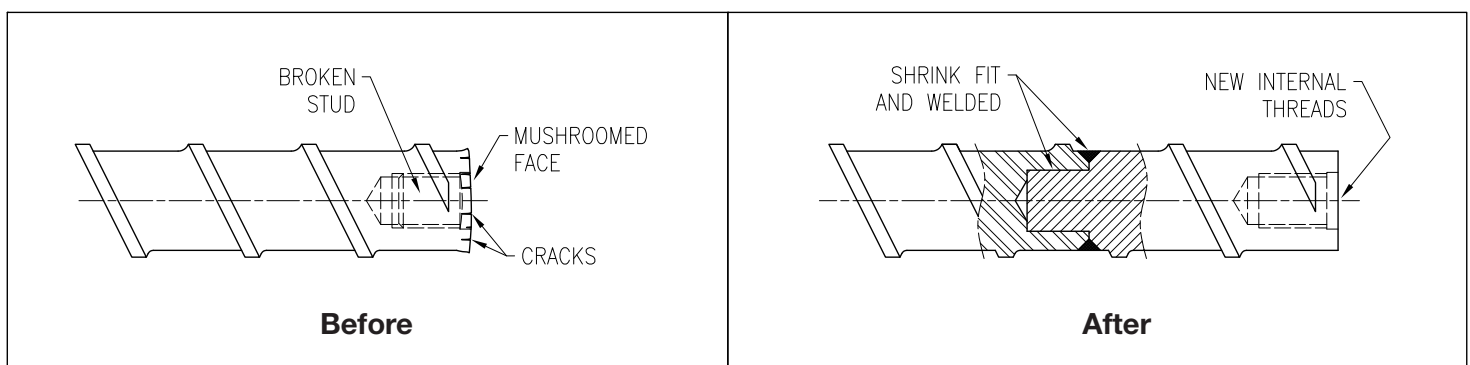
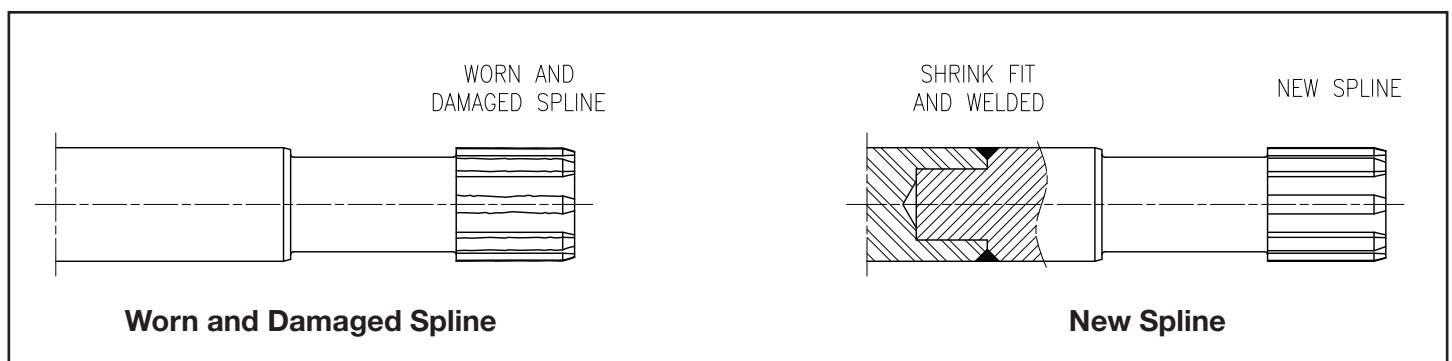
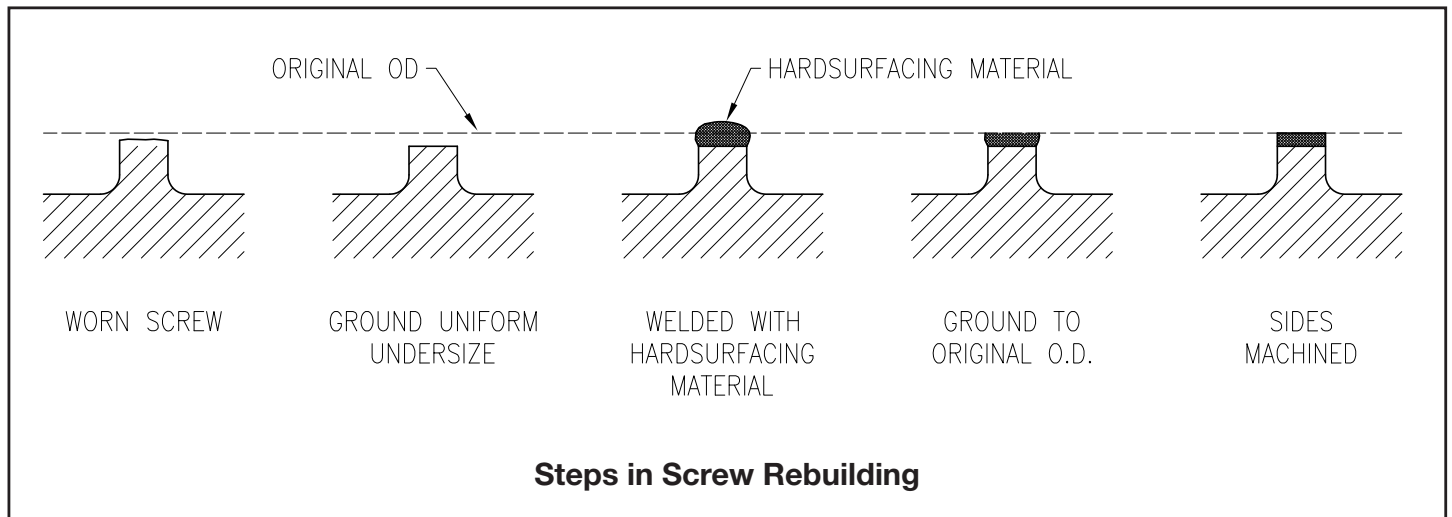
Screw Inspection Process

1. Wear determination: abrasive, adhesive or corrosive.
2. Visual inspection on rollers.
3. Measurement of the root diameter or outside flighted diameters using specialized equipment.
4. Channel depth measurement using a screw depth indicator.
5. Check straightness and concentricity.
6. Measure the pilot I.D. (for injection screws) using a digital bore gauge.
7. Test the hardness using an electronic hardness tester.
8. Measure the surface finish using a profilometer.
9. Issue an inspection report as well as a quotation.

Screw Rebuilding Repair Steps

1. The screw is set up in a lathe and a center is found. At this time it is also checked for straightness and concentricity.
2. It is then polished and prepped for stripping off the existing chrome; entire screw is submerged in an acid bath to remove the chrome plating.
3. Screw then moves to the grinder where it is ground undersize.
4. Screw flights are welded with a hard surface material, i.e. Colmonoy 56 or Stellite 12.
5. Back to the grinder for rough grind after weld; at this time, screw is also checked for straightness; and root runout.
6. Screw is sent to the flight grinder to trim the sides of the flight.
7. A rough polishing follows at the polishing booth.
8. The screw is then inspected and buffed for chrome plating if needed.
9. Chrome plated coating of .001"-.003" thick, is applied to the entire root and bearing surface.
10. Buffing follows after chrome.
11. Grinding to final O.D. specification follows.
12. Final polishing and buffing follows as needed.
13. Grind front face, size register and board the O.D. follow.
14. A final inspection will be complete this process.

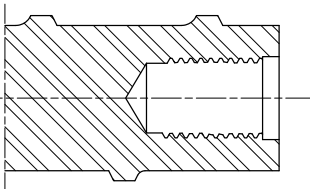
Screw Inspection / Repair Process



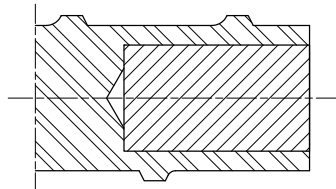
Common Hardsurfacing Materials

COMMON HARDSURFACING MATERIALS

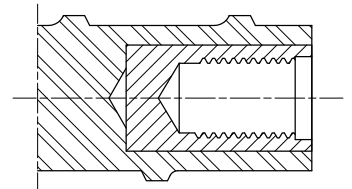
	Base Material	Typical Applied Hardness*, RC	% Carbon	% Chromium	% Tungsten	% Boron
PRODUCT						
Xaloy® X-183®	Nickel	48-52	0.5-1.2	16-20	--	1.8-2.5
Xaloy® X-830®	Nickel	48-55	1.7-2.4	18-22	34-42	0.9-1.8
Colmonoy 56	Nickel	46-52	0.9	18.0	--	1.9
Colmonoy 57	Nickel	47-52	0.5	11.5	16	2.5
Colmonoy 83	Nickel	43-55	2.0	20.3	34.0	0.9
Colmonoy 88	Nickel	59-63	0.8	15	17.3	3.0
Stellite 6	Cobalt	37-42	1.2	28.5	4.6	≤1.0
Stellite 12	Cobalt	43-55	1.4	30.0	8.5	≤1.0
Hardness range for single and double pass						



Worn Thread



**Brushing Installed
by Shrink Fit**



New Thread

Screw & Barrel Wear

Laser Alignment Service

Injection machines and extruders usually are aligned properly by the manufacturer prior to shipment. They can become misaligned during shipment, during installation, and by accidental impacts and other reasons over the years. An angular misalignment will generally cause wear uniformly around the diameter of the screw in a fairly localized portion of the screw. The barrel will be worn around the entire I.D. in that area. If the barrel is bent, the screw will be worn all around near the center and near the discharge. The barrel will be worn on one side, usually near the center.

Screw & Barrel Wear

Wear on screws and barrels can be categorized into three categories: Abrasive, Adhesive and Corrosive.

Abrasive Wear

Abrasive wear on screws and barrels is caused by fillers such as calcium carbonate, talc, glass fibers, barium ferrite (used in magnetic strips), and even titanium dioxide pigments used in all white and pastel shades. The mechanism of abrasive wear is much the same as emery cloth on metal. The very hard and fine particles scour off a little metal from the screw or barrel each time they make contact. They can wear any part of the screw or barrel exposed to the plastic.

Glass fibers particularly abrade the root of the screw at the leading edge, and in severe cases can even undermine the screw flight completely, leaving no flight at all. This usually happens in the transition or compression area of the screw where the fibers have been exposed and the partially melted pellets are squeezed against the screw and barrel.

Adhesive Wear

Adhesive wear or galling is caused by metal-to-metal contact. Certain sensitive metals can momentarily weld to each other due to very high localized frictional heating. As the screw continues to rotate, the weld separates and metal is pulled from screw to barrel or vice versa. This type of wear can normally be avoided by proper clearance, proper alignment, compatible screw and barrel materials, and proper hardness. It is important to be certain that the screw design allows the screw's melting capacity to keep up with the actual process demands. If this is not done, solids blocks will form, forcing the screw against the barrel and causing rapid adhesive wear.

Corrosive Wear

Corrosive wear is caused by chemical attack of the screw and barrel surfaces. It is usually the result of a corrosive chemical given off when polymers degrade due to overheating. A typical example is the hydrochloric acid released when PVC degrades. Corrosive chemicals can also be released by: ABS, polycarbonates, cellulose, polysulfones, fluorocarbons, flame retardant materials, fiber sizing agents, and many other materials. Corrosive wear usually shows a pitted appearance, and is more pronounced at the downstream end of the screw where the material had a chance to overheat. This type of wear can be controlled by proper operating procedures. Don't let the machine sit at operating temperatures for any length of time. Proper screw design and selection of corrosion resistant screw and barrel materials are the best answers.

Corrosive chemicals can also penetrate between the non-return valve and the front face of the screw, entering and destroying the internal threads. Stainless steel screws and/or screw tips are the best remedy for this.

Screw & Barrel Wear / Inspection Screws

Typical Factors Affecting Component Wear

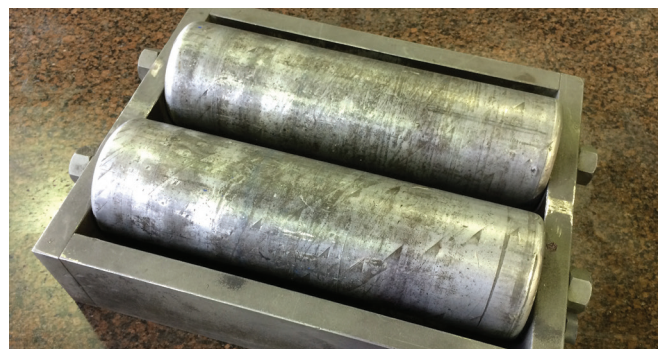
- Screw, barrel and drive alignment
- Straightness of screw and barrel
- Screw design
- Uniformity of barrel heating
- Material being processed
- Abrasive fillers, reinforcing agents and pigments
- Screw surface materials
- Barrel liner materials
- Combination of screw surface and barrel liner
- Improper support of the barrel
- Excessive loads on barrel discharge end
- Corrosion caused by polymer degradation
- Corrosion caused by additives such as flame retardants
- Excessive back pressure or injection recovery
- High screw speeds (RPM)

Inspection (Screws)

Screws do not have a continuous outside diameter. This requires special techniques in manufacturing and inspection. Over the years, we have settled on some methods we feel give reliable results and save time. We are presenting these methods here.

Inspection Rollers

Proper visual inspection of a screw or barrel requires that it be turned many times in order to see all sides. Screws and barrels are often heavy and difficult to turn when supported by the usual means. A simple but useful device as shown in the photograph to the right. We use two sets of double conveyor rollers supported by multi-slotted angle irons.



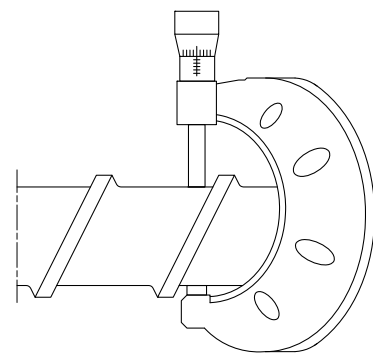
Diameters

The shank and many other diameters are easy to measure by the usual methods. Other diameters, such as the root diameter or the outside flighted diameter require special methods. Measuring the root diameter is not always a reliable way to obtain channel depths. There is also a problem of the micrometer sitting on the radius on both sides, giving a false reading. If the O.D. is severely worn, this method is still best to determine the correct channel depths.

This problem is worse with less than square pitch or very deep channels. The best way to obtain root diameter is to find the O.D. then subtract the channel depths.

Inspection Screws

The O.D. is measured with the assistance of a parallel bar spanning two flights. The thickness of the bar is subtracted from the measurement obtained. The usual technique is to place the bar on top and hold the anvil of the micrometer against the flight at the bottom with the left hand. The right hand adjusts the micrometer while making rocking motions across the screw. The bar will rock with the micrometer as the final setting is reached. At Xaloy, we use a 1/2" (12.7 mm) thick by 3/4" (19 mm) wide precision ground parallel. It is essential that the bar be straight and of uniform thickness. It is best to check the O.D. at 90° from the original set of measurements because screws can be manufactured egg-shaped or become worn that way.



Root Diameter Measurement

Depth

The channel depth of small screws can be easily checked with a standard depth micrometer. As the size of screws becomes larger, the depth micrometer will not span from flight to flight. If you intend to check many screws, it is best to make a "screw depth indicator". The screw depth indicator consists of a wide angle "V" block with a dial indicator mounted on top and the probe extending down through the center of the "V". The indicator is placed with the "V" resting on top of the screw and the probe on top of the flight. The gage is then adjusted to zero. When the tip moves down into the root, the dial gives an accurate indication of channel depth. It is also very fast, allowing many measurements to be made very rapidly, and it can give continuous readings as the screw is rotated. This last feature is also helpful in locating the starting and ending points of the various sections of the screw such as feed, transition, and metering. This is not easy to do without the inspection rollers described on page 51. The original channel depths of a severely worn screw are difficult to determine by this method. In this case it is best to use the root diameter method. Sometimes deep jawed calipers can help if micrometers are running on the radii.

Straightness and Concentricity

Checking straightness is difficult for the average plastics processor. If a good, long granite inspection table can be found, it will be helpful in checking concentricity and straightness. A preliminary check for straightness is possible just by rolling the screw on the table. If the screw is not straight, it will roll unevenly and show light under the flights in the low areas. This presumes that the screw is not worn. The approximate amount that the screw is bent can be determined by feeler gauges. This is not totally accurate because the weight of the screw will tend to straighten it against the table. Most injection screws can be mounted between centers on a lathe and checked with an indicator as it rotates. This assumes an accurate center on both ends. Extrusion screws usually do not have a center on the discharge end, requiring that a center be installed and then re-welded after testing and possible straightening. Checking the runout on the flighted portion is done by using a "T" bar that spans

Inspection Screws

at least three flights. The bar leans against the flights and an indicator measures the movement of the bar. Straightness and concentricity can be determined on screws that don't have centers, by rotating them in "V" blocks on an accurate inspection table. This is done with the help of a height gauge. This is particularly useful in inspecting the pilot at the discharge end of injection screws.



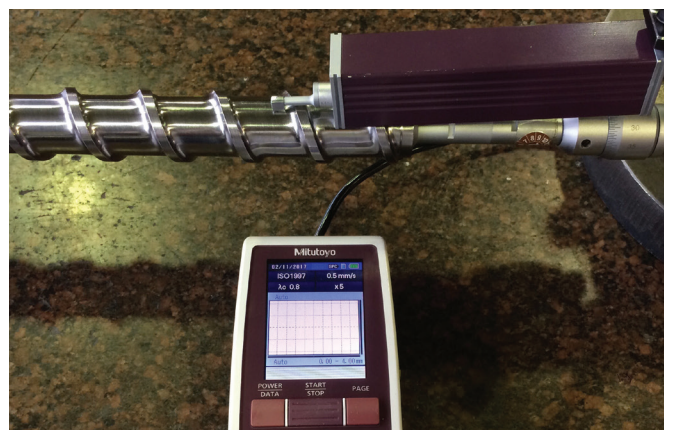
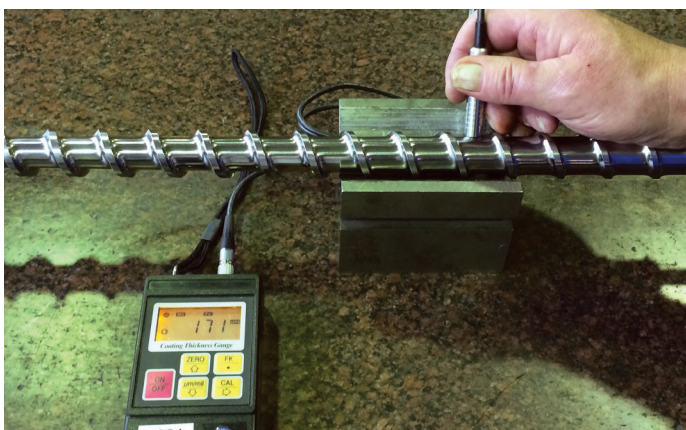
Hardness

The hardness of most portions of a screw is difficult to measure because the screw is usually too large to test in a stationary Rockwell type tester. Also, the curved surfaces of the screw present a problem, and it is undesirable to make penetration marks on the surface. At Xaloy, we have had good results with an electronic hardness tester.



Finish & Coating Thickness

Finishes can be verified by a number of profilometers. A portable thickness tester can test for chrome plating thickness or, with experience, nickel and other nonmagnetic coatings. Photographs of these tests are shown below.



Screw Manufacturing Tolerances

Xaloy adheres to the S.P.I. "Recommended Dimensional Guidelines for Single Screws", as a minimum. This guideline is presented in the Appendix for your convenience.

Questionnaire



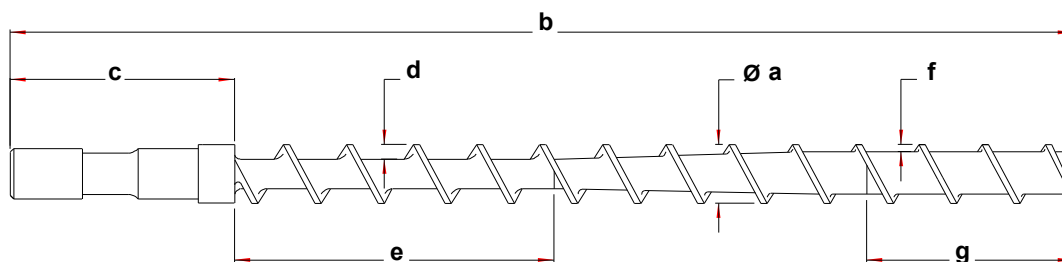
XALOY® INJECTION SCREW QUESTIONNAIRE

Name _____ Title _____
 Company _____ Address _____
 City _____ State/ Province _____ Postal Code _____
 Country _____ Email _____
 Phone _____ Fax _____ Date _____

SCREW RECOMMENDATION FOR INJECTION PROCESS (Please Supply The Following Information So that XALOY May Reply To Your Request)

MACHINE SPECIFICATIONS

O.E.M _____ Injection Unit # _____
 Model # _____ Serial # _____ Year Mfrd. _____
 Rated Shot Size Styrene _____ Clamp Tonnage _____ Stroke of Injection Unit _____
 Max. RPM _____ Max. Injection Pressure _____



DIMENSIONS

a) _____ c) _____ e) _____ g) _____
 b) _____ d) _____ f) _____

EXISTING SCREW DATA

☐ Single Stage ☐ Two Stage ☐ Other _____

Screw Construction Materials _____

If there is a particular problem that you are having with a resin or resins, please explain the process conditions. We may have a product(s) to solve your problem.

PROCESS CONDITIONS

Resin(s) Processed _____ Fillers, Additives _____

Overall Cycle Time _____ Shot Size (with runner, grams) _____ Recovery Time _____

Cooling Time _____ Operating Injection Pressure _____

Barrel Temperature Settings

(Set Point): Rear _____ Center _____ Front _____

(Actual) Rear _____ Center _____ Front _____

Back Pressure (bar) _____ Screw Speed (RPM) _____ Melt Temperature _____

Melt Decompression? ☐ Yes ☐ No If yes, distance _____ Scrap Level _____

List Current Problems and Goals? _____

PLEASE EMAIL YOUR COMPLETED QUESTIONNAIRE to info@xaloy.com

Questionnaire

Page 1 of 3

Date _____

Extruder Data Collection



Company Name _____

Xaloy LLC.
375 Victoria Rd.
Austintown, OH 44515, USA

Address _____

City _____ State _____ Zip _____

Tel. +1.330.726.4000

Contact _____ Email _____

www.xaloy.com

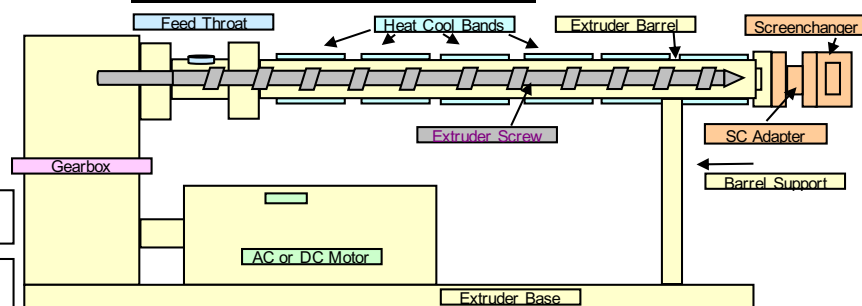
Ph _____ Ext: _____ Fx _____

Return To: _____

Extrusion Process? Sheet _____ Wire/Cable _____ Profile _____ Blown Film _____ Cast Film _____ Compounding _____

Scrap Reclaim/Pelletizing _____ Pipe _____ Other _____

EXTRUDER MECHANICAL INFORMATION



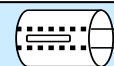
Type: OEM or Processor

OEM type?

Dia _____

L/D _____

Does the barrel insert through the Feed Block? Y___ N___



Barrel Cooling - Water _____ or _____ Air

Please submit Current Barrel Zone Temperature Settings:

1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____ 7 _____ Adapter _____ Die _____

Are you using screw cooling? Feed Length _____ Full Length _____ No Cooling _____

Drive Motor Info

HP _____
Max Amps _____
Type - AC
Motor RPM _____

Gearbox Reduction Ratio

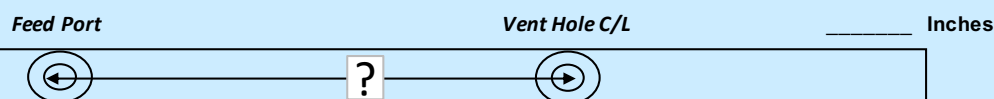
_____ : 1
Max Screw RPM: 0 to _____

Head Pressure Range

_____ psi to _____ psi

Using a Melt Pump? Yes _____ No _____ If Yes, What is the suction pressure? _____

If Vented Barrel is used - then provide vent location from back of Feed Opening to centerline of vent hole?



Questionnaire

Page 2 of 3

Process Data Collection



Is there a	YES	NO	Feed Section	YES	NO
Groove Feed Throat?			Water Cooled?		

IF YES - then provide I.D. Groove Geometry

Straight?		Spiral?		Tapered?	
	# of Grooves		# of Grooves		# of Grooves
	Width		Lead		Width
	Length				Length
	Depth				Starting Depth

CURRENT OPERATING PARAMETERS

Current Output in Lbs/Hr

Primary Resin

Lbs/Hr

Secondary Resin

Lbs/Hr

at what Melt Temperature?

°F

°F

at what Screw RPM?

RPM

RPM

at what Motor Amps?

Amps

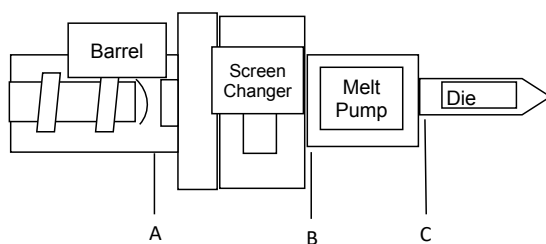
Amps

at what Head Pressure?

PSI

PSI

Pressure and Melt Temp. Measurement



	Press.	Temp.
Position A		
Position B		
Position C		
Position D		
Position Other		

Melt Temp. measured by? Hand Held _____
In-Line _____

DESIRED OPERATING PARAMETERS

Desired Output in Lbs/Hr

If unknown indicate Max Rate

Primary Resin

Lbs/Hr

Secondary Resin

Lbs/Hr

at what Melt Temperature?

Reference Supplier recommended Melt Temperature

°F

°F

at what operating Screw RPM?

We calculate for 90% of full speed usage

RPM

RPM

at what Head Pressure variation? +/- 10% psi

Stability variation below 5% requires a melt pump

PSI

PSI

Questionnaire

Page 3 of 3

Project Goals and Materials



Clearly describe project goals and objectives:

Process Resins and Additives

Materials Used: (PP, PE, Nylon, etc.)

*If PVC: Rigid _____ Flexible _____

*PVC Shore Hardness and scale _____

Melt Index if known

Resin Manufacturer: (Dow Chemical, Equistar, etc)

If resin numbers are unknown please provide samples of materials with MSDS Sheets to be processed. (Zip Loc Bag size)

Resin Number(s): (Dow 5150, Eastman 6763, etc)

Using Regrind? What %?

Advise if reprocessed or flake.

Regrind Bulk Density?

If unknown - provide blended sample (zip loc bag size)

If color - Concentrate or Liquid

% Color(s)

Are you using any of these additives?

% Fillers

% Other

Are you drying any of the materials?

If so at what temperature and how long?

_____ °F / _____ Hrs

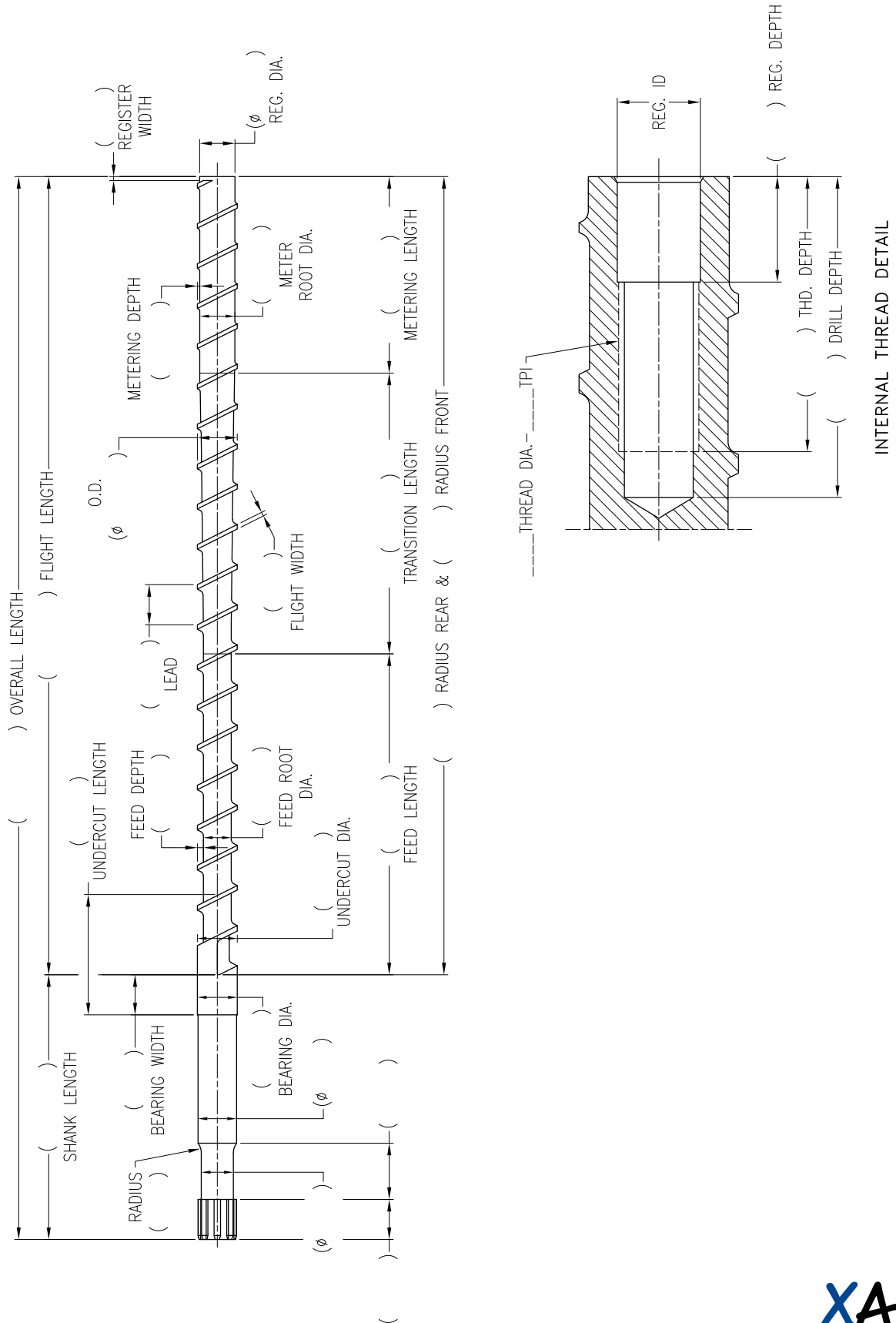
_____ °F / _____ Hrs

Sketches

The sketches on the next three pages (Injection Screw, Drive Ends and Extrusion Screw) are provided to assist you in defining a screw that you wish to duplicate. Simply copy this page and then fill in as many of the blanks as you can. You will probably wish to provide an auxiliary sketch showing special reversing grooves, blisters, mixing pins and other items. This is particularly true of the shank area where screws have similar shapes. In most cases your information will confirm that the screw you have is the same as one of our trusted drawings.

Injection Screw Sketch

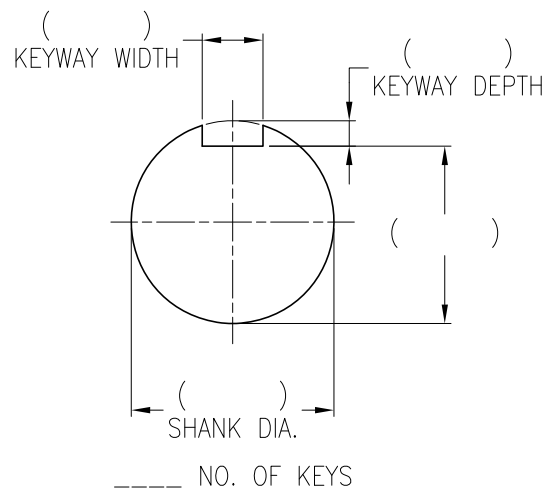
Injection Screw Sketch



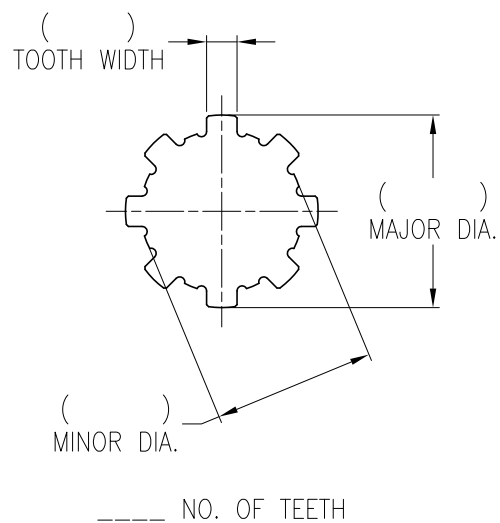
Drive End Sketches

Drive Ends

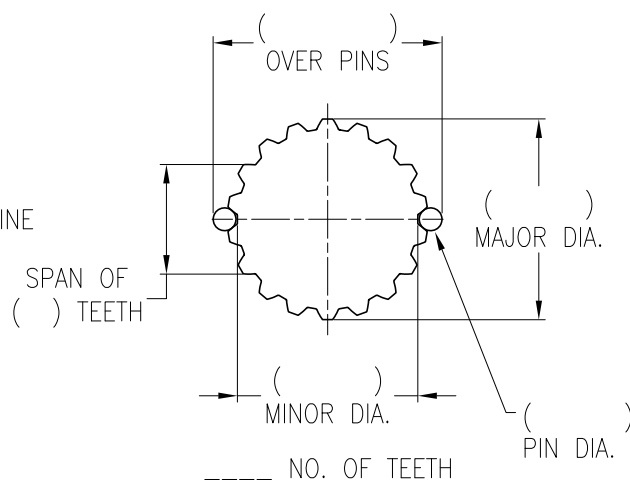
KEYED SHANK



STRAIGHT SIDED SPLINE

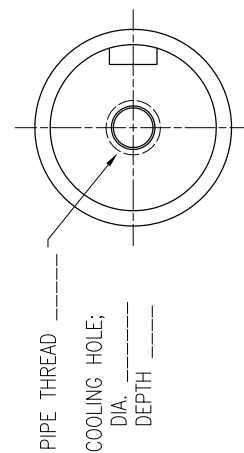
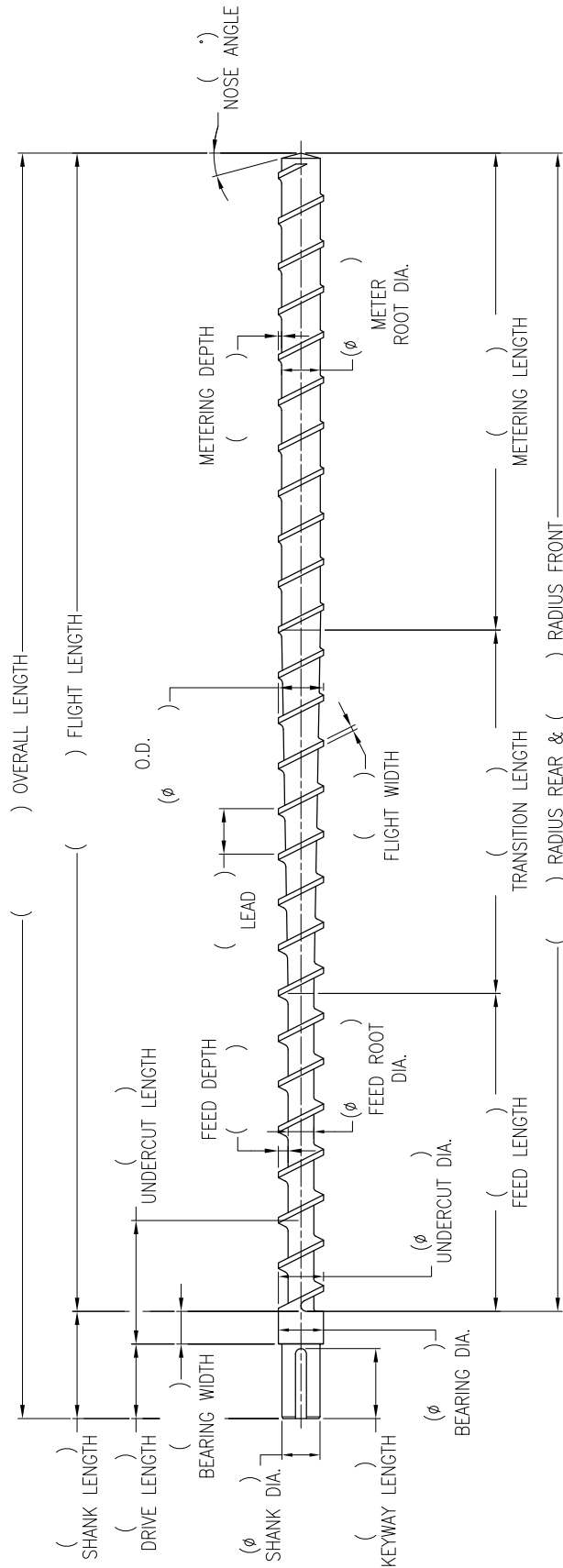


INVOLUTE SPLINE



Extrusion Screw Sketch

Extrusion Screw Sketch



Section 2: Barrels



Barrels (Cylinders)

History

The original extruder barrels were used for rubber and were nitrided steel or special steel alloys. One of the early products was HC-250. This was a one-piece design with a very high chromium content. Many foreign extrusion and injection barrels are still nitrided, but the trend continues toward bimetallic.

Industrial Research Labs developed the first bimetallic barrels in 1939. The product was called Xaloy® 100 and it was a centrifugally cast, abrasion resistant liner material inside an alloy steel outer shell. These bimetallic liners were originally used as mud pump liners in the oil fields.

Industrial Research Labs was owned by Honolulu Oil Company and Xaloy® was the brand name of their bimetallic cylinder. In 1963, the bimetallic cylinder business was sold, and Xaloy® became a division of International Rectifier. The major global manufacturers of bimetallic barrels are: Wexco Corporation, USA; OMG, Italy; Hitachi Metals Ltd., Japan; Reiloy, Germany; Tanstar, Taiwan; Huaye, China; Bernex, Switzerland; Xaloy, USA. Xaloy has acquired a number of barrel manufacturers, Bimex, Spirex, Bimetalix, Wafo, IDM.

Barrel Materials

Nitrided

Please see our discussion of nitrided materials in the screw section, page 42, for general information on nitrided materials. Nitrided barrels are rarely used on U.S. machines, but are more prevalent in Asia and for select applications in Europe. They do not wear as well as bimetallic barrels, and because the case hardness is thin, wear becomes progressive after it starts. In general, corrosion resistance is not as good as any of the bimetallic grades. Nitrided barrels are a very poor selection for machines that will run a lot of glass or other abrasive filled materials. Honing to a uniform oversize is not usually economical due to the high cost of re-nitriding.

Bimetallic - Abrasion Resistant

Reiloy R121, Hitachi N100, Wexco 666 and Xaloy® 102® are the standard grades of general purpose abrasion resistant bimetallic cylinders. They are grades used for most standard extrusion or injection applications. They are very similar in chemical composition. Unless otherwise specified, these are the grades implied when someone refers to bimetallic barrels. Here is a typical composition for this type of liner: carbon 4%, nickel 4%, chromium 3-6%, boron 1%, molybdenum 1%, and the balance iron.

Bimetallic – Corrosion Resistant

The corrosion resistant grades are usually nickel/cobalt based materials. They give improved chemical resistance but sacrifice some wear resistance. Here are the chemically resistant grades offered by domestic suppliers: Wexco 555, Reiloy R115 and Xaloy® 306®. A typical composition for a corrosion resistant grade is: nickel 40%, chromium 8%, boron 4%, and the balance cobalt. These liners are recommended for use with corrosive materials such as rigid PVC, Saran, and some fluorocarbons.

Barrel Materials

Bimetallic Carbide Type

The increasing use of resins with abrasive fillers created a demand for an even more abrasion resistant barrel than the standard iron/boron type. The use of glass reinforced compounds for injection molding has been the single most important factor. This need has been successfully answered by the development of liner materials containing metallic carbides such as tungsten carbide, titanium carbide and tantalum carbide.

These finely divided carbides are suspended in a matrix of nickel, cobalt, chromium, boron, or some combination of those corrosion resistant materials. The domestic designations for carbide type bimetallic barrels are: Wexco 777 and Xaloy® X-800®. They cost more as an initial investment, but they will outlast the general purpose type many times over. They are also more corrosion resistant than the standard bimetallic barrels. If a lot of glass filled compounds are expected, the carbide type is a must. Selection of a proper screw material is critical with these carbide-type cylinders. Some of the screw hardsurfacing materials such as Stellite 6 will pick up or gall when used in combination with some of these barrel materials. This will cause catastrophic wear. It is best to consult with us before using an unproven combination.

CPM 10V

Please see our discussion of this very abrasion resistant material on page 40. We have found CPM 10V to have moderate abrasion resistance and poor corrosion resistance. Its performance is positioned between general purpose bimetallic alloys and carbide-containing bimetallic alloys. The cost for larger diameter barrels >800 mm is quite high.

Others

Tool steels such as D2 are used occasionally for complete barrels (not recommended by Xaloy) and for re-sleeving. Hastelloy C-276 is used in some cases for fluorocarbons where extreme corrosion resistance is required. With Hastelloy, abrasion resistance is poor and the strength of the barrel is not good.

Injection Barrels

On page 66 is a drawing of a typical centrifugally cast injection barrel. Note the feed port is an opening cut through the barrel. Injection barrels are subjected to very high pressures at the very end of the injection stroke and in front of the non-return valve. This pressure is up to 20,000 psi (138 MPa) as a standard and can go to 30,000 psi (207 MPa) on special machines. This requires special considerations for the final few inches at the discharge end. Some barrels have "bell" ends to accommodate the pressure, some incorporate a high pressure sleeve, and some have both. The backing material is usually a medium carbon alloy steel. It does not, however, give the strengths possible with such a steel because it anneals in the high temperature spinning oven followed by slow cooling. The high pressure sleeve is made of stronger heat treated alloy steel material and is shrunk over the already centrifugally cast barrel. A technology improvement by Xaloy has allowed some barrel manufacturers to eliminate the high pressure sleeve. By using special alloyed steels they are able to achieve 50% higher pressure carrying capacities, thus allowing for a single-piece construction on injection barrels. The injection barrel usually slides into a separate water-cooled feed housing. The barrel is held in place by a split collar or a large nut at the rear of the feed housing. There is also a key or machined flat to insure against turning with the screw. On the other end, the barrel has a circular flange with a bolt circle pattern to attach the endcap or nozzle adapter. The discharge flange of the barrel has a counterbore to center the endcap.

Sealing is accomplished on the vertical surface inside the pilot, extending from the endcap.

Extrusion Barrels

Extrusion barrels differ from injection barrels in several important ways. They are usually longer because the modern extrusion barrel has an L/D of 30:1 minimum and can go as long as 36:1 or even greater, while the

Barrel Materials / Barrel Machining

injection barrel is usually 22:1 with an occasional 25:1. A few vented injection barrels are 25:1 but the trend is toward shorter and Xaloy is supplying 18:1 or 20:1 vented barrels on a regular basis. The extruder barrel is usually designed to withstand lower pressures of 10,000 psi (69 MPa) maximum. This means a thinner wall and eliminates the high pressure sleeve or bell end. Extrusion barrels normally do not have an integral feed port, but are fastened to a separate water-cooled feed throat casting. At the rear, there is a large diameter flange with a bolt circle to attach the barrel to the feed throat.

The extrusion barrel connects to the die adapter at the discharge end, but the seal is made in a manner slightly different than the injection barrel and endcap. The barrel flange has a female counterbore just like the injection barrel, but the die adapter has a counterbore instead of a pilot. The counterbore is called a breaker plate recess, and it allows space for a breaker plate or sealing ring to make the seal. Attachments for the die adapter are designed for more rapid removal than in injection. This allows for ease of screen changes, screw changes and die changes. The most common closures are split "C" clamp, swing gate or bolt circle.

Twin bore barrels are extrusion barrels designed for high load applications and in particular PVC for pipe and profile. These barrels have two intersecting bores forming a figure 8 configuration which is precision machined to fit the corresponding twin screw pair. The predominant metallurgy used for these barrel types is a nitride steel which provides sufficient life for mild or less abrasive and corrosive resins. With the addition of more fillers and additives the lifespan can drop dramatically. Xaloy introduced a pioneering method of fabricating and inserting a bimetallic figure-8 liner inside a steel housing which provides a far superior wear resistant surface than nitride steel. The other benefit is these bimetallic inserts can be replaced which brings the cost of replacement way down.

Much like the bimetallic single bore barrels as written about in this handbook, the metallurgy of the bimetallic inlay for the twin barrels is the same. The Xaloy® X-800® bimetallic twin barrels feature a barrel lining with a composite consisting of superhard tungsten carbide particles uniformly dispersed in a nickel alloy matrix, providing superior wear resistance. Screw-barrel compatibility is especially critical in twin-screw extrusion because of very high screw-to-barrel loading and the potential for adhesive and abrasive wear at the interface. Any screw material that has a carbide coating on it must therefore have a carbide barrel matched with it.

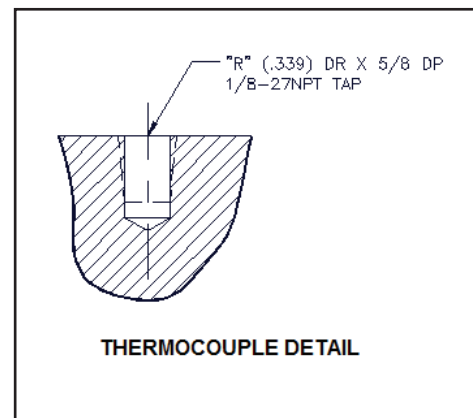
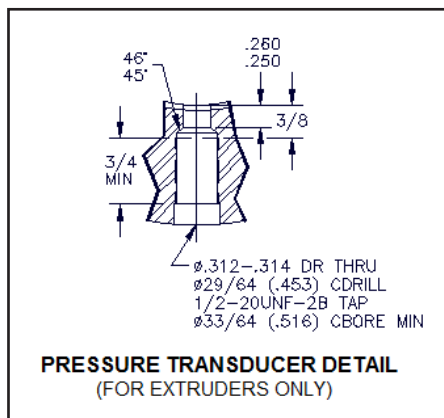
Barrel Machining

The various barrel holes required for measurement and control are mostly standard. They are designated as thermocouple holes and pressure transducer holes. Thermocouple holes are blind holes used for a temperature measure and controlling the exact heat profile the processor desires. The second hole detail is for extrusion applications only, this is the standard machined hole to accept pressure transducers to measure the pressure of the melt stream. These are typically found at the discharge end of the extruder just before the screen changer or die. This same hole can be used to insert a thermocouple to measure the melt stream temperature via a flush melt thermocouples or immersion melt thermocouples (not in the area wiped by the screw or valve). It is difficult to drill any of the rough holes without chipping the brittle liner material and causing a dead spot. It is best to EDM (electrical discharge machining) these holes.

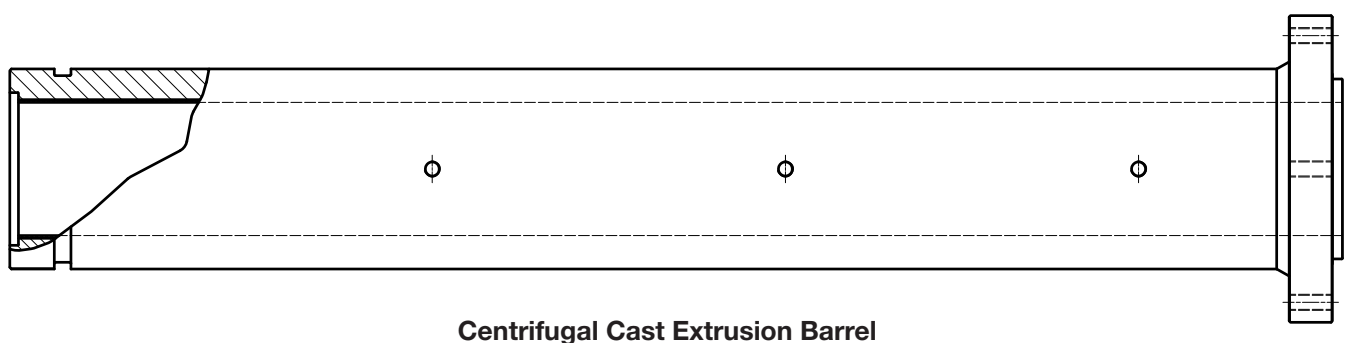
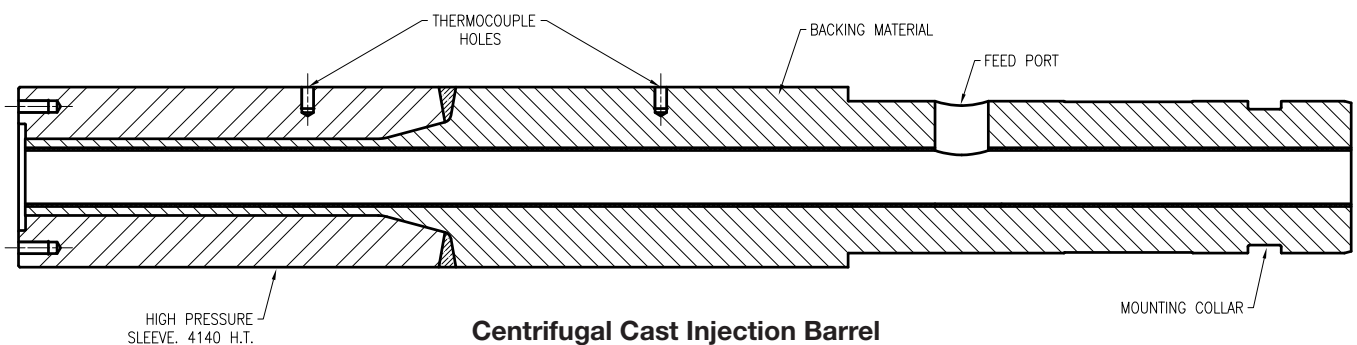
The depth of thermocouples is an important factor for control and measurement. A deep hole closer to the inside diameter measures the metal temperature closer to the plastic, and therefore a temperature closer to the plastic temperature. The problem with this deep location is the temperature lag causing control problems. The thermocouple senses a low temperature and tells the heater to pour more heat into the outside of the barrel. By the time this heat penetrates a thick barrel and heats the deep thermocouple, the outside is very hot. This causes an overshoot and wide swings in barrel temperature. This is more pronounced in thicker barrels.

Barrel Machining

Conversely, the shallow thermocouple gives the best control but set temperatures can be very different from the inner barrel temperature. Actually, the set temperature that produces the best processing results is more important than the one that is closest to the actual plastic temperature. Some compromise in thermocouple depth is desirable, but shallow is usually better than deep. A good alternative solution is the paralleling and averaging of the output of a shallow and deep thermocouple.



Thermocouple Drawings



Barrel Inspection

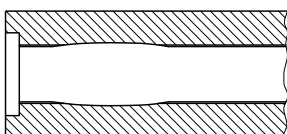
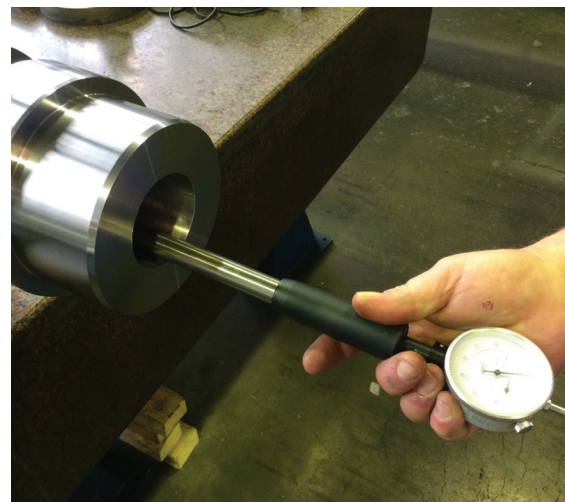
Barrel Repairs & Alterations

Sleeving

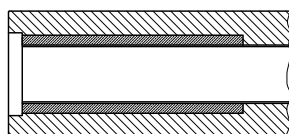
Injection barrels become worn in the front 4 - 5 diameters where the ball check or sliding ring valve reciprocates. In other words, a 3" (76.2 mm) I.D. barrel would normally become worn in the front 12" (304.8 mm) to 15" (381 mm). With wear in the front only, an economical and reliable (if done properly) repair is accomplished by sleeving. Wear from glass fibers or other abrasive fillers will cause barrel wear in the middle where the screw transition reciprocates. In order not to waste money, it is important to check the remainder of the barrel before sleeving the front. This can be done accurately with a bore gauge or close enough with a cylinder gauge. It is also important that the bore of the new bimetallic sleeve be aligned with the remainder of the existing I.D. This requires special procedures because the new sleeve must be installed accurately with the proper interference fit in order to eliminate any possibility of movement in operation. We can provide full length sleeves on some barrels, but the cost is close to, or more than, a new bimetallic barrel.

The very front of a barrel can be measured with inside micrometers but this is limited and will not show deep enough to be of much use. An inexpensive cylinder gauge can be rigged up with a long handle to slide the full length. Such a device is accurate enough to determine the need for replacement or repairs. It is not accurate enough for machining purposes.

A cylinder gauge that ranges 2-1/10" to 6" (53.34 to 152.4 mm) is a good choice. There are a number of bore gauges available. These gauges measure accurately at great depths and have the indicator outside the barrel for easy reading. Xaloy uses a number of these gauges for different sizes. One of these is also shown on the right.



Worn Injection Barrel



Repaired Injection Barrel

Straightness & Concentricity

Barrel straightness is difficult to determine by conventional methods. The I.D. and O.D. are not usually concentric. The first method is to set up the barrel on a lathe, indicate both ends and run in an indicator on a long rod. This is limited in length. Tolerances allow deviation from a straight barrel to accumulate to a total allowable indicated runout. The second method is the use of a test bar usually about 70% of the barrel length. This is a slotted and chrome plated bar that is precision ground to approximately mid-range of the normal screw size tolerances. In theory, if the test bar slides easily through the barrel, the screw will also. In addition, this will catch rapid changes or kinks that would otherwise be allowed under the accumulation of tolerances. A different bar size is needed to test each I.D. Because these bars are quite expensive, it is impractical for most organizations other than barrel manufacturers. An optical or laser bore gauge is the best method for determining barrel straightness.

Barrel Inspection

Laser Alignment Service

Laser systems offer significant accuracy advantages compared to traditional optic bore scopes and transits. The laser gives a resolution of 0.5 micron with plane flatness of 0.0000155"/ft or 0.001 mm/M.

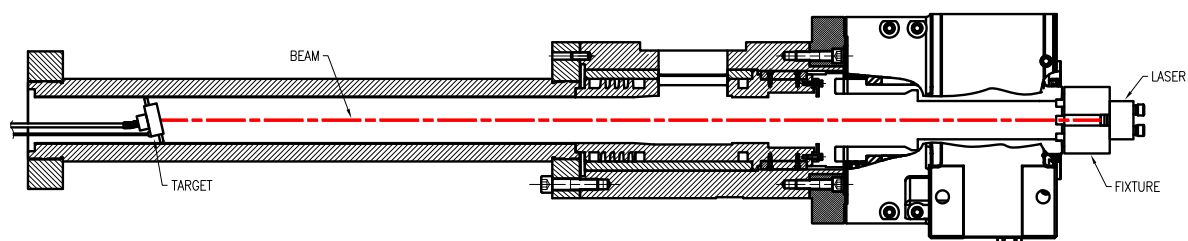
Laser systems are expensive, so most companies will have to contract the laser alignment to a qualified company. Correct barrel alignment is vital for optimum performance of extrusion equipment. Factors such as wear, vibration, metal fatigue, environmental effects, relocation, repair and replacement of components impact machine alignment. A negative change in alignment can evidence itself in reduced throughput, surging, shortened screw and barrel life, increased amperage load, increased vibration, friction heat, noise and ultimately component failure.

Proper alignment also influences the process. Tolerances between the barrel and screw average a .008" (0.2032 mm) total clearance or .004" (0.1016 mm) on all sides. The feedscrew is designed to work in harmony with the barrel to feed, compress, shear, melt, and mix the plastic materials to uniform temperature and viscosity. If the output end of the barrel is out of alignment, then the screw rubs against the barrel. The rubbing creates friction heat and work load in-balance. This results in melt inconsistency and surging. If feed housing and barrel are aligned to the thrust shaft centerline then friction is alleviated. This allows proper machinery operation to extrude a uniform melt flow.

Proper alignment involves pre-inspection to ensure: a correct mounting of machine to foundation & barrel to feed housing, available adjustment points, levelness, alignment supplies, and equipment needs. The laser emitter is mounted at the drive end (gear box) then adjusted to the center of axis rotation. A self-centering target is inserted into the bore (barrel output) and moved through the length of the barrel. Instrument readings determine misalignment in both the horizontal and vertical plane. Based on the readings, the technician determines where to make adjustments such as at barrel supports, machine base, mounting flange and/or gearbox. The adjustments establish that the barrel bore is in exact alignment performance and prolongs productive life of machinery and components.

Barrel Hardness

Obviously, the standard hardness testers are not able to get inside a barrel to measure hardness. The instrument most commonly used for this purpose is the Internal Mobile Hardness Tester. When testing and comparing the hardness of a bimetallic liner, it should be remembered that absolute hardness, as measured, is not necessarily in direct proportion to wear resistance. Sometimes you may be measuring the softer matrix rather than the wear-resistant carbides. The degree of lubricity or how well the screw and barrel slide against each other is very important. This is not always related to hardness, but it is very critical to barrel and screw wear.



Barrel Composition

Barrel Composition

The chemistry and hardness information for various types of domestic barrels is supplied in tabular form below. The chemical information is for the "as cast" condition. The actual chemistry may vary widely after final machining is complete. It is important to note that the chemistry and hardness are not necessarily indicative of wear resistance. Other very important factors are how these elements are combined and where they are located relative to the bore.

Barrel Tolerances

The S.P.I. "Recommended Dimensional Guidelines for Single Barrels", are located in the Appendix at the end of this booklet. Xaloy has a state-of-the-art bimetallic barrel plant that can manufacture a full line of extrusion and injection barrels, feedthroats, liners and water-cooled barrels. Xaloy can also manufacture tool steel barrels (CPM 10V, D2, etc.).

Abrasion Resistant					
These alloys are for general purpose, unfilled resins.					
	Xaloy	Wexco	Reiloy	Bernex	Hitachi
Name	Xaloy® X-102®	666	-	A110	N100
Alloy Type	Fe/B	Fe/B	-	Fe/B	Fe base
Hardness	60 - 64	60 - 65	-	58 - 65	55 - 65

Abrasion Resistant + Corrosion					
These alloys are for general purpose with some corrosion protection.					
	Xaloy	Wexco	Reiloy	Bernex	Hitachi
Name	Xaloy® X-220®	-	R121	AC333	-
Alloy Type	Fe/B	-	Cr/Ni/Mo/B	Fe/CR-B	-
Hardness	60 - 64	-	65	62 - 69	-

Corrosion Resistant					
These alloys are for very corrosive resins (PVC, fluoropolymers, etc.).					
	Xaloy	Wexco	Reiloy	Bernex	Hitachi
Name	Xaloy® X-306®	555	R115	C242	H503neo
Alloy Type	Co/Ni/Cr	Co/Ni	Co/Cr/B	Ni/Cr-Boride	Ni Base
Hardness	48 - 56	50 - 55	47 - 49	48 - 56	50 - 60

Extreme Abrasion Resistant					
These alloys are for highly filled resins where extreme abrasion resistance is required.					
	Xaloy	Wexco	Reiloy	Bernex	Hitachi
Name	Xaloy® X-800®	777	R215	ACW800	H70neo
Alloy Type	Ni/Cr/B + WC	Fe/B	Co/W/Cr/B	Ni-B/WC	Ni+carbide
Hardness	60 - 64	60 - 65	59	58 - 66	55 - 64

Downsizing / Upsizing

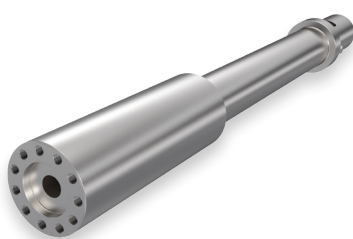
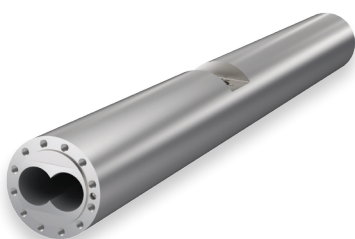
Downsizing

Very few of the installed machines run shot sizes anywhere near the full shot size capacity of the injection unit. Typical usage is from 25 - 60%, but in many cases it is even less. Most suppliers of injection machines offer several sizes of injection units for any given press tonnage. At the time of purchase, the thinking regarding the injection unit is to "make sure we have enough". The problem of having too much shot capacity can render some injection machines unusable for certain materials and applications. One related problem is excessive residence time for the polymer and it applies to most of the engineering materials. Any polymer that will degrade when held at injection temperatures for long periods will have problems with small shots, long cycles and large injection units. Some of the materials that have this problem are: polycarbonates, ABS, nylon, acetals, cellulose, PES, and most fire-retardant grades. Another problem associated with very large injection units and small shot sizes is relative to the plasticizing screw design. In order to properly plasticize the resin, the screw should impart approximately 40% of the energy needed to melt the resin via the drive motor. If the screw RPM is too low and the meter zone flight depth is too deep relative to the throughput needed, very little energy will come from the screw drive. This situation will result in very poor homogenization of the melt pool which will lead to poor part quality. When the injection unit is too large, the travel of the screw needed to fill the mold is also very short, sometimes not allowing the machine hydraulics and electronics to be utilized effectively. One solution is to purchase a completely new, smaller injection unit from the original machine supplier. This is expensive, both in investment and labor.

Xaloy has developed a regular business of downsizing existing injection units. We supply a new barrel, screw, valve, endcap and either a screw/quill adapter or a new drive quill. In some cases, the existing heater bands can be used after considering barrel wall thickness. Often it is possible to utilize greater injection pressures acquired through the downsize process. If not, the injection pressure relief valve must be adjusted to make sure excessive pressure is not developed at the discharge end and screw drive motor. All of this is a lot less expensive than a new injection unit. Consideration to limiting torque to the hydraulic screw drive motor should also be given to reduce breakage of the smaller screws.

Upsizing

Upsizing can also be done to increase shot size. A number of items have to be considered for the upsizing process, such as: barrel wall thickness, resultant screw L/D, injection speed reduction, screw drive torque, and injection pressure drop. Before considering the upsizing process, one has to determine whether the molds can be filled properly using the decreased pressure and injection speeds. The injection pressure and speeds will decrease directly proportional to the difference in the barrel I.D. projected areas. If this poses no problems, the L/D and structural integrity of the cylinder have to be considered before proceeding. At Xaloy, we can help you make these assessments and develop quotes associated with the upsizing process.



Shot Size

Shot Size

The proper selection of screw diameter and L/D is critical to the manufacture of high quality parts at economical cycle times. Generally, 20 - 60% of the full stroke of the particular injection machine is considered a good operating range. This figure is probably valid if the full stroke of the machine is approximately four diameters long for a 20:1 L/D screw. Many machines have either shorter or longer total strokes. A better determination of a good range for the stroke is 20 - 60% of a four diameter full stroke on a 20:1 L/D screw. This gives a two diameter stroke length as mid range. This is appropriate when recovery time is approximately 50% of the overall cycle and given a screw/barrel combination with proper design to melt/mix the succeeding shot.

Relative to the previous paragraph, we are talking about residence time of the resin within the barrel. This is the amount of time that the pellets have to come up to melt temperature and be discharged from the injection unit. According to some research done by Bernie Olmstead, if the machine injection stroke is four diameters or more, you must multiply the rated shot capacity of the machine by a factor of 1.4 to get the approximate resin inventory. If the screw stroke is three diameters, the multiplication factor is 2.0. This assumes that the screw has a 20:1 L/D with general purpose compression and flight depths.

To figure residence time, use the formulas below:

M	=	rated machine shot size (oz. PS)
R	=	M x (1.4 or 2.0) total resin weight (oz. PS)
S	=	shot size of the part being molded (oz. PS)
C	=	cycle time of the part being molded (in seconds)
Tr	=	total residence time (in seconds)
Tr	=	$\frac{R}{S} \times C$

If a different resin is being used other than styrene, use the melt densities on page 93 to calculate relative shot weights. To be more precise than the general statement made that 20 - 60% is a good operating range, figure out the total residence time (Tr) and ask for a suggestion from the resin supplier. If the residence time is too short (less than 1.5 minutes), the resin is probably not melted adequately and may result in unmelts and great thermal differentials within the melt pool. If the residence time is too long, it is possible to thermally degrade the polymer. In most cases, if the residence time is too long the screw diameter is too large for the shot being molded. This situation is discussed in further depth in the "Downsizing" section on page 70.

Here are some formulas on the next page to calculate shot weight, stroke, and desirable screw diameter.

Shot Size

1. Shot Weight

To determine the shot weight given a screw/barrel diameter, specific gravity of the resin at melt temperature (melt density), and the stroke selected.

$$S_E = \frac{D_E^2 G_E (L_E - T_E)}{2.2}$$

$$S_M = \frac{D_M^2 G_M (L_M - T_M)}{1273}$$

2. Stroke

To determine the stroke required to obtain the desired shot weight, given the screw/barrel diameter and melt density of resin at melt temperature.

$$L_E = \frac{2.2 S_E}{D_E^2 G_E} + T_E$$

$$L_M = \frac{1273 S_M}{D_M^2 G_M} + T_M$$

3. Diameter

To determine an ideal screw/barrel diameter size for a given shot weight, the following formulas will be helpful. This assumes a stroke of 2.0 diameters in length and a recovery time that is approximately 50% of the overall cycle time.

Where:

SE	=	shot weight in ounces
DE	=	screw diameter in inches
GE	=	melt density in g/cm ³
LE	=	length of stroke for this part in inches
TE	=	travel of the sliding ring in inches (usually 1/8" for 1" dia. to 1/4" for 6" dia.)
SM	=	shot weight in grams
DM	=	screw diameter in mm
GM	=	melt density in g/cm ³
LM	=	length of stroke for this part in mm
TM	=	travel of the sliding ring in mm (usually 3 mm for 20 mm dia. to 6 mm for 150 mm dia.)

$$D_E = \sqrt[3]{1.1 S_E}$$

$$D_M = \sqrt[3]{637 S_M}$$

Barrel Grooving

Remedial Grooves

Barrel grooves can be specified when ordering a new machine when it is anticipated that difficult materials will be processed. Unfortunately, this is usually learned after the fact. Grooves can usually be installed on an existing machine to solve a feed problem. Again it is important to determine if it is a feed problem or a melting problem. If the problem is melting, grooves will only make it worse.

Barrel Inspection & Repair

Barrel wear usually occurs in two locations. With filled materials (glass, mica, etc.), the wear starts near the end of the feed and continues through the transition section of the screw, in the middle of the barrel. With unfilled materials, the wear occurs at the discharge end where the valve reciprocates. Both types of wear can be repaired.

Barrel Inspection Process

1. Inspect the inside diameter with an inside micrometer or cylinder gauge.
2. Check straightness and concentricity using either an optical or bore gauge.
3. Issue an inspection report as well as a quotation.

Barrel Rebuilding Process

1. The barrel is identified and inspected with a bore gauge for I.D. wear and visually for any additional damage.
2. The barrel is then set up in a boring machine where the I.D. is bored oversized to a uniform size. Before boring, the I.D. is checked against the O.D. for concentricity.
3. The barrel is then cleaned, honed and prepared for sleeving.
4. The I.D. of the cylinder is then heated to approximately 600 - 700°F (315 - 371 °C). At the same time the liner is packed in dry ice.
5. After the barrel reaches the necessary temperature, the liner is removed from the dry ice and is dropped immediately into the cylinder.
6. After the barrel is cooled, the front register is ground to O.E.M. specification.
7. If the barrel is relined full length, it is then set up to have the feed pocket cut out. This procedure is normally done with an EDM machine.
8. The barrel is then checked for straightness and honed to final size.
9. A final inspection completes the process.

Innovative Barrel Heating Technology

Xaloy® SmartHeat™ Coating

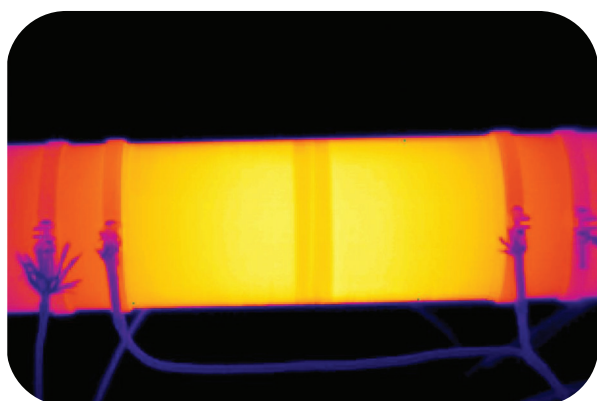
The Xaloy® SmartHeat™ Coating is a fairly new technology. An innovative, robust metallized-ceramic heater coating where plasma is sprayed to the surface of the barrel, which virtually eliminates melt-stream energy losses, ensures uniform heating and provides responsive control for superior processing.

Advantages

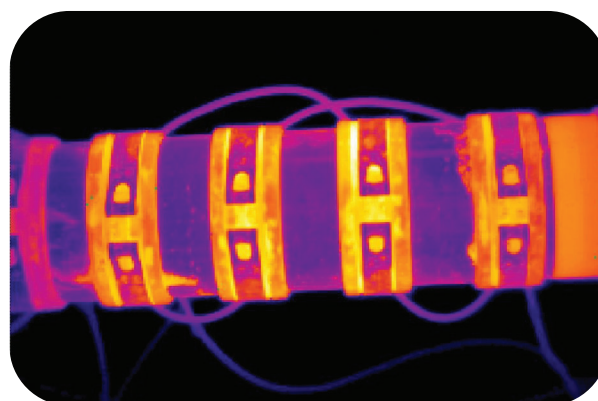
- Enhanced product quality and significant reduction of material defects through precise and rapid temperature control
- Increased productivity due to elimination of heater band maintenance
- Faster start-up and reduced cycle times
- Reduced downtime through easy to clean surfaces
- Maximized operator safety with elimination of exposed wires and cool-to-the-touch surface
- Improved ROI
- Improved process control
- Superior energy savings, 30 - 60% compared to typical heater bands
- Standard thermocouples for easy installation



Comparison Xaloy® SmartHeat™ Coating versus Band Heaters



IR Camera - Xaloy® SmartHeat™ Coating
Uniform, Responsive Heating



IR Camera - Band Heaters
Non-uniform, Sluggish Heating

Section 3: Front End Components



Valves

Valves

Non-return valves, check valves or, as they are sometimes referred to, screw tips, are used on most injection and injection blow molding machines. The exceptions are rigid PVC and thermoset resins; although in some cases, sliding ring valves are used with rigid PVC. The check valve works in the same fashion as a check valve in a hydraulic system, allowing fluid to pass in only one direction. Most industry standard check valves could be divided into two categories: (1) Ball Check Valves and (2) Sliding Ring Valves. There have been advancements in this area, some with positive shutoff mechanisms and others which are said to operate via improved design logic, both claiming more positive shut-off characteristics.

We will explain the mechanics involved and list the valves that both led the way historically and are being used today. Here are some comparisons:

Ball Check Valve

Advantages

- More positive shut-off
- Better shot control
- Less expensive than sliding ring valve

Disadvantages

- Most designs are less streamlined, resulting in degradation of heat-sensitive materials
- More barrel wear, and a potential for galling
- Greater pressure drop creates more heat
- Harder to clean
- Not suitable for high viscosity resins

Sliding Ring Valve

Advantages

- Greater streamlining for less degradation of materials
- Best for heat-sensitive materials
- Less barrel wear
- Less pressure drop across valve
- Easier to clean

Disadvantages

- Less positive shut off, especially larger sizes > 4" (100 mm)
- Less shot control
- More expensive than front discharge ball check

Valves

Ball Check Designs

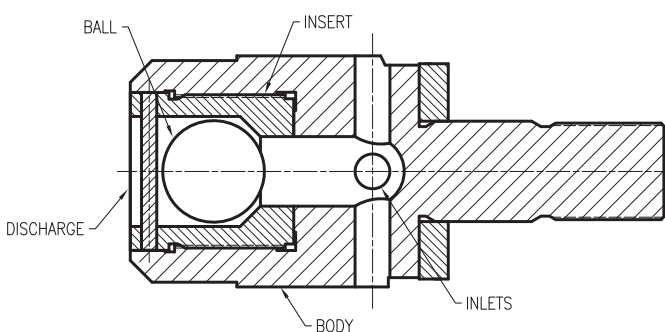
There are two basic types of ball check valves: (1) Front Discharge and (2) Side Discharge, with modifications to the ball and seat sizes which determine flow rates. The body and hence the O.D. rotate with the screw, and have to accept a compressive load during plasticating.

The Front Discharge Ball Check is a positive and accurate valve design. Most have a removable insert or pins so the ball and wear parts can be replaced.

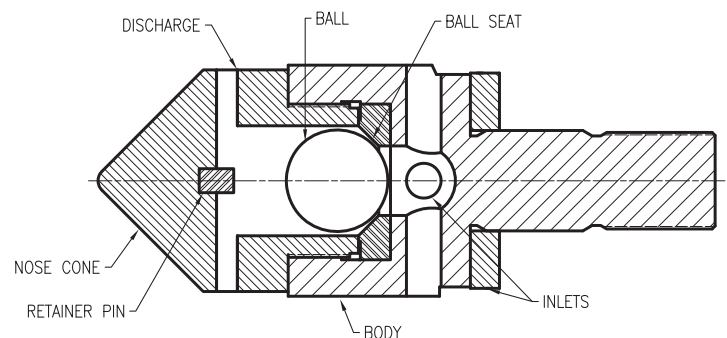
The Side Discharge Ball Check is also a positive and accurate design which has better self-cleaning characteristics over the traditional ball check valve. The nose cone angle matches that of the endcap/nozzle adapter which should lend itself to quicker color changes. The nose cone is normally removable to replace internal components.

The Xaloy® Poly-Check® Valve provides improved performance over the traditional ball check valve without the usual disadvantages. This starts with the design. In order to eliminate unnecessary shear stress in the resin, it is designed with large inlet holes angled as much as possible.

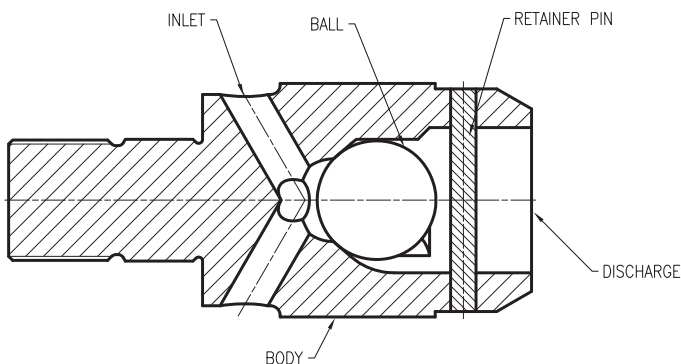
You can achieve amazing part weight repeatability for the price of a ball check valve.



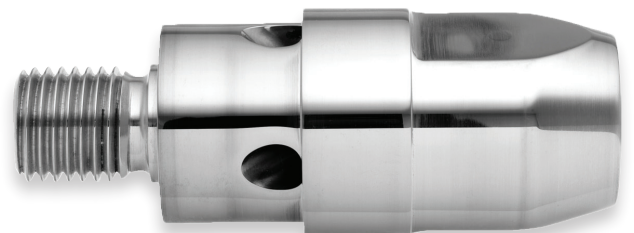
Front Discharge Ball Check



Side Discharge Ball Check



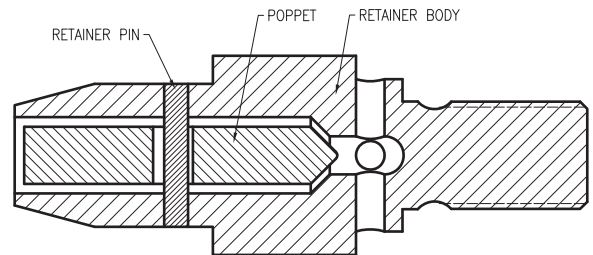
Xaloy® Poly-Check® Valve



Valves

Poppet Valve

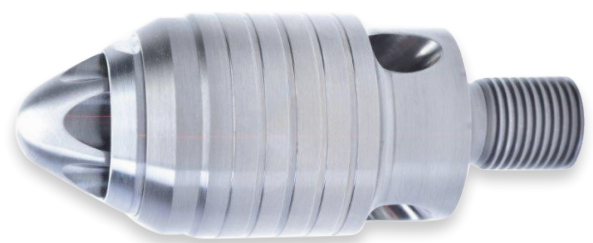
The Poppet Valve is a derivative of the ball design, while using an internal poppet for shut-off. The poppet can be designed with flutes or grooves for more mixing. This poppet valve has excellent shutoff characteristics and is used with low viscosity resins.



Poppet Valve

Glycon QSO™ Valve

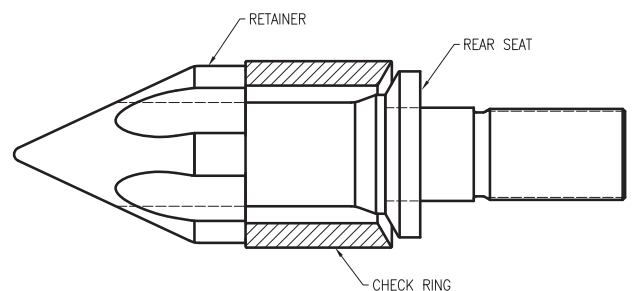
The Glycon QSO™ "Quick Shut-off" Valve delivers both high flow and quick shut-off. This unique combination of benefits ensures molders of rapid material shut off for part weight consistency; and a smooth, high-flow profile to prevent material degradation. The result is higher quality parts, fewer rejects, improved yield, and a better return on every pound of material.



Sliding Ring Valves

Sliding Ring Non-Return Check Valves are the workhorse of the industry. There are many variations of the design, but as the name implies, a check ring is used to provide the shut-off. There are many valves supplied by numerous manufacturers. We are showing drawings of some common valves.

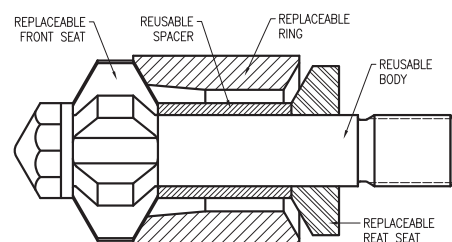
The "free flow" valve creates very little pressure drop, while the flow paths are streamlined for processing heat sensitive and viscous materials. If the design is too "free flowing", it may experience shut-off problems with less viscous materials and larger diameters.



3-Piece Free Flow Valve

CMD Valve

The CMD valve has individual replacement parts for the wear areas. The front seat can also be reversed for continued wear. Pressure drop is low and the design is streamlined. This is a design patented by CMD Corporation.

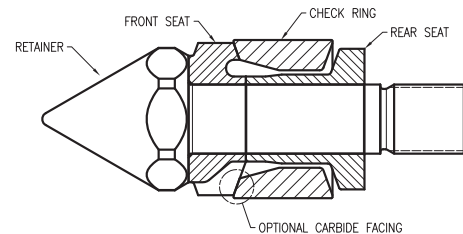


CMD Design

Valves

4-Piece Mallard Design

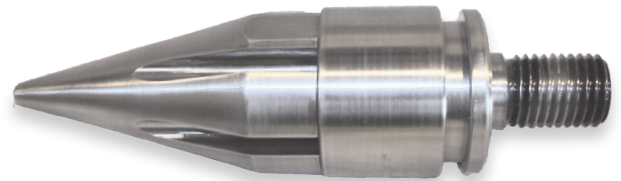
The Zeiger Industries 4-piece Mallard valve has replaceable wear parts and is made with a combination tip/stud that has ductile threads. The wear parts are made from D2 or CPM 10V. The valve is streamlined and shuts off well.



4-Piece Mallard

Sliding Closure Design

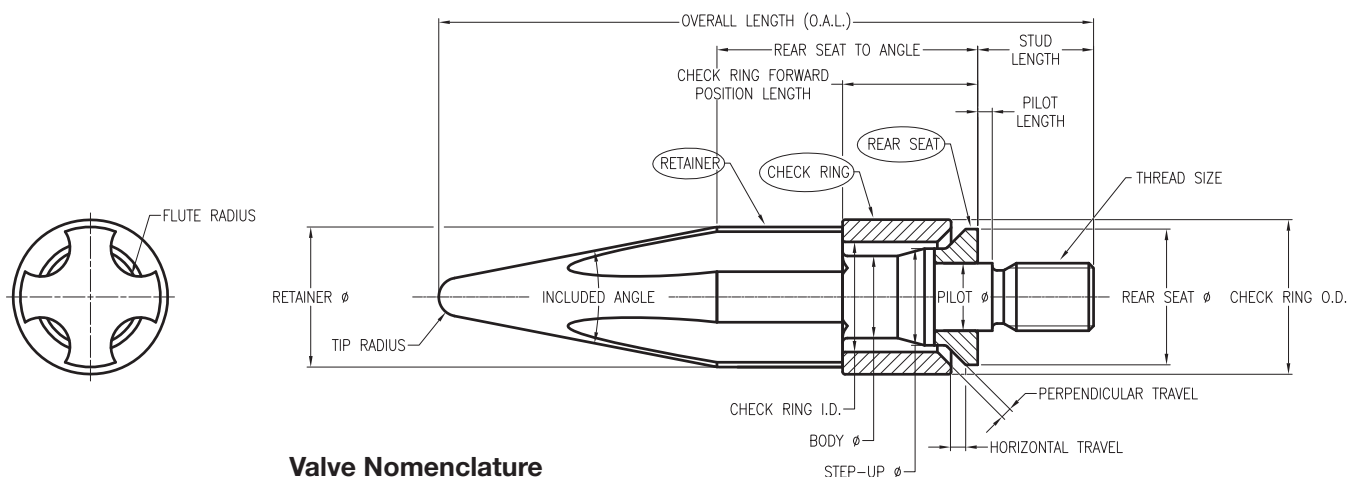
The APV family of closure valves (R. Dray Manufacturing) utilizes a sliding closure design, requiring no fast initial velocity to close the valve. This design provides faster closure and more consistency and is suitable also for low viscosity polymers.



Interlocking (Castle) Design

The Interlocking (or Castle) design has tabs that interlock with slots on the retainer. This requires the ring to turn with the screw, eliminating wear between the ring and front seat. Side loading is applied to the interlocking components, making this interface critical.

Xaloy has developed a similar version of the Castle design concept and labels the valves, F-LOC and S-LOC. With the F-LOC we have incorporated more generous flow paths with larger radii to prevent shear problems. The S-LOC is designed to run with materials having very low viscosity.



Valve Nomenclature

Valves

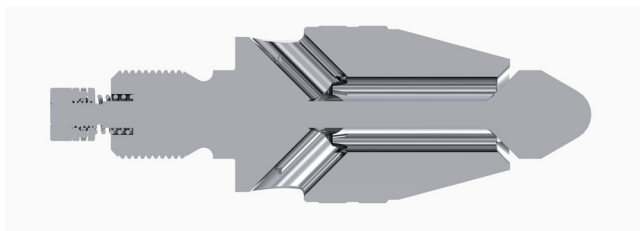
Xaloy® Auto-Shut™ Valve

Xaloy has designed a valve that has been statistically proven to provide extremely consistent shot-to-shot repeatability with many difficult to process resins. The Xaloy® Auto-Shut™ valve has a positive shut-off, is versatile with most all resins, and is free-flowing, yet self-cleaning. To accomplish this, we made the shut-off mechanism independent of the travel of the screw. This allows us to have generous flow paths without sacrificing quick and positive shut-off.

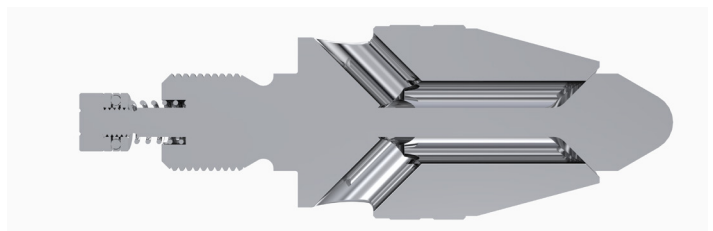
The mechanics of the Auto-Shut are:

1. As the screw turns, pressure is built up behind the assembly which forces the poppet off of its seat, allowing plastic fluid to flow through the valve. A thrust bearing is placed to accept the load applied when the polymer is flowing and prevents any wear that would occur between the adjacent surfaces. The volume through the valve decreases slightly in the flow direction, creating a self-cleaning action. The stroke of the poppet is generous, which creates very little pressure drop and, hence, a free flowing valve assembly. The screw retracts in a normal fashion.
2. When the screw stops, the pressure gradient equalizes in the system, the poppet retracts and forms a positive shut-off. The spring supplies the force required to close the poppet. This action takes place instantaneously and is independent of the viscosity of the resin. The valve is now closed and is ready for the next phase of the process...injection. (3) During the injection phase of the cycle, the customary "time lapse" or "response time" required to shut-off industry standard valves no longer exists. This can be significant with some resins, and may even require the processor to change valve designs. The versatility of the Auto-Shut Valve is thereby increased and becomes more "universal".

Auto-Shut Valve (open position)



Auto-Shut Valve (closed position)



All industry standard valves have a potential wear problem between the front seat and ring components. This problem is magnified when high screw speeds and back pressure are used. With the Xaloy® Auto-Shut™ design, this potential wear area no longer poses a problem and should experience a long service life in high RPM applications. Construction materials of the assembly are chosen to be compatible with one another as well as with the industry standard cylinders used today.

In addition, materials and components are selected to cover temperature ranges up to 750°F (400°C) (continuous operating temperatures). Size ranges include 35 mm diameter and larger.

Delivering more consistent shot-to-shot repeatability means better dimensional and mechanical properties, assuring greater profitability to all molders.

Valve Materials

Valve Materials

Valve materials are as diverse in the industry, so we are listing the materials that Xaloy uses.

Standard Wear

H13, D2

High Wear Resistance

CPM 9V, CPM 10V, carbide faced materials.

Corrosion & Abrasion Resistance

CPM S90V

Xaloy can take base materials with high corrosion resistance (stainless steel) or Inconel and carbide face the wear surfaces to give extremely high wear resistance without sacrificing the properties of the base material.

FRONT END COMPONENT TECHNOLOGY Common Construction Materials

	Yield Strength psi (Mpa)	Hardness as Machined	Availability of Case Hardness	Uses	Wear Resistance	Corrosion Resistance Material
ENDCAP MATERIALS						
AISI 4140	100,000 psi (690 Mpa)	28-32 Rc	48-55 Rc ¹	General	Poor	Poor
AISI 4150	100,000 psi (690 Mpa)	26-30 Rc	48-55 Rc	General/Large	Poor	Poor
17-4 PH	175,000 psi (1,200 Mpa)	38 Rc	42 Rc ³	Corrosive	Fair - Poor	Good
Hastelloy C-276	80,000 psi (550 Mpa)	86 Rb	86 Rb ³	Corrosive	Poor	Excellent
NON-RETURN VALVE MATERIALS AND HARD FACING						
17-4 PH	175,000 psi (1,200 Mpa)	38 Rc	42 Rc ³	F, D	Poor ³	Good
CPM 10V	300,000 (2,100 Mpa)	98 Rb	58-60 Rc	A	Excellent	Fair
CPM S90V	300,000 (2,100 Mpa)	100 Rb	55-57 Rc	A	Excellent	Good
CPM 9V	285,000 psi (1,950 Mpa)	100 Rb	52-55 Rc	A, B, C	Excellent	Fair
D2	300,000 (2,100 Mpa)	96 Rb	58-60 Rc	B, C	Good	Fair - Poor
H13	300,000 (2,100 Mpa)	96 Rb	50-60 Rc	A, C, E	Good	Poor
Stellite 12	N/A	N/A	41-45 Rc	D, F	Good	Excellent
Colmonoy 56	N/A	N/A	46-52 Rc	A	Excellent	Fair
Titanium Nitride	N/A	N/A	67 Rc	E		
Tungsten Carbide	N/A	N/A	>70 Rc	E	Poor ³	Excellent
Electroless Nickel	N/A	N/A	45 Rc	G	Poor	Excellent
Chrome Plating	N/A	N/A	50 Rc	G	Poor	Excellent
Hardlube	N/A	N/A	90 Rc	E, A	Good	Good

⁽¹⁾ Flame or induction hardened

⁽²⁾ Nitrided

⁽³⁾ Usually improved by hard surfacing

A) Retainer

B) Ring

C) Seat

D) A.S. Poppet

E) A.S. Poppet Shaft

F) A.S. Body

G) Endcap



Endcaps / Nozzle Tips

Endcaps/Nozzle Adapters

The discharge or downstream end of an injection barrel uses an endcap or nozzle adapter to connect the barrel to the nozzle. This is an important component because it is subject to very high internal pressures up to 23,000 psi (1600 bar) as a standard, and 43,000 psi (3,000 bar) on special machines. This requires that the endcap be made of a high strength alloy steel hardened properly to achieve the high strength, but ductile enough not to initiate or propagate cracks readily. A grade that through hardens well is also desirable. We use AISI 4140, AISI 4150 or 17-4 PH stainless, depending on the requirements. We use tool steels and Hastelloy C-276 for special applications. All internal surfaces contacting the resin should be polished to 8 -16 RMS and nickel plated, chrome plated or nitrided, depending on the application.



Nozzle Tips

The revolutionary design of the patented Xaloy® Eliminator® Nozzle Tip can control or eliminate stringing, drooling and cold slugs with molders' specific resins and applications. It is constructed of hardened steel, and comes in a wide range of sizes and orifices within the 1/2" (12.7 mm) and 3/4" (19.05 mm) radii. With it, molders can decrease rejects, down time and mold repair costs while increasing profits.



Section 4: Miscellaneous



History

History

When processing thermoplastics in an injection molding machine, it is important to maintain a minimum pressure during injection of the melt to avoid forming microscopic or submicroscopic cavities in the molded part. As the melt cools, the bubble grows, which in turn decreases the mechanical properties of the molded part. The majority of the cavities formed is a result of water vapor present on the surface, as well as imbedded in the plastic particles themselves. When these bubbles appear at the surface of the molded part, it is called "splay". An increasing amount of today's engineering thermoplastics are hydroscopic and thus absorb moisture during storage. In some molding compounds a chemical reaction called hydrolysis leads to a decrease in the average molecular weight accompanied by a decrease in physical properties.

It is necessary to pre-dry hydroscopic materials at a temperature below the softening point, for the reasons mentioned above. However, because of the limited drying temperatures, the poor thermal conductivity of the plastic, and the resistance to diffusion within the pellets, several hours are required for drying. Add to this the thermal efficiency of the dryers which is in the order of $E=0.17$, and you have a very costly and inefficient process.

Since the early 1960's, a concerted effort by raw material and machinery manufacturers has been made to simplify this expensive method of preparation. The vented barrel, reciprocating screw, injection molding machines were developed to remove this moisture from materials without the need to pre-dry them. Around 1970, the use of the vented injection machine became more widespread in the U.S. and in Europe. This technology was previously practiced in the non-reciprocating process of extrusion.

Most of the vented barrels being used today have an L/D ratio of at least 24:1. The theory behind the longer than standard L/D is: (1) To prevent reduction in the plastication of material (screw recovery). (2) To prevent an uneven return stroke of the screw. (3) To prevent extrudation of melt from the vent opening. (4) Proper plasticizing of the polymer without added shear. A majority of these theories have been proven otherwise, and units using a much shorter L/D have been operating with great success. The determining factor is an advanced screw geometry. Xaloy has been supplying vented barrels of both longer and standard lengths.

The molding operation, when using a vented molding machine, differs slightly from a conventional, non-venting machine. There are a few conditions to be concerned about. First, because of the shorter second metering and transition section, screw back pressure should be kept to a minimum. A small amount of pressure can cause vent bleeding on some machines. Additional back pressure is present throughout the system leading back to the tank. With excessive back pressure the screw cannot build up enough head pressure to allow the screw to recover, but forces the material to flow back through the vent hole. Secondly, a greater awareness of melt temperature is necessary. Excessive melt temperature or barrel heat imbalance can also cause vent bleeding.

It must be pointed out that although a small amount of bleeding may occur if the vent hole is still open, proper and efficient devolatilization will take place.

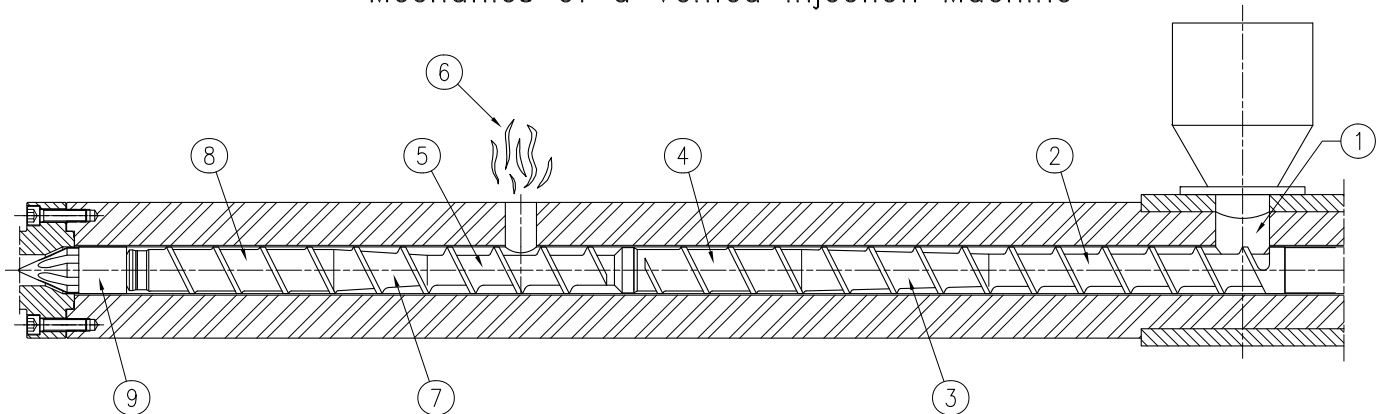
Temperature profiles on a vented system are expected to be different than conventional, especially on a short conversion. The length of the screw available for melting is usually shorter. Therefore, heat must be applied more rapidly to the pellets. This usually does not represent any problems, but in order to assure that feeding is not disturbed, the application of heat should be concentrated on the compaction or transition section.

A vented screw should have the screw speed adjusted so that practically all the time available for screw rotation is used. This is important because: (1) it provides a good melt without excessive shear; and (2) it increases the time that the melt is tumbled in the vent zone continually exposing new surfaces to allow escape of volatiles.

When keeping these items in mind, with a properly designed screw and barrel assembly, a vented barrel can offer many advantages.

Vented Injection

Mechanics of a Vented Injection Machine



Here is a Simplified Version of the Mechanics of a Vented Injection Machine:

1. Wet material enters from a conventional hopper or through a controlled feeding device.
2. The pellets are conveyed forward by the screw feed section and are heated by the barrel and by some frictional heating. Some surface moisture is removed here and escapes rearward through the feed opening.
3. The compression or transition section does most of the melting.
4. The first metering section accomplishes final melting and evens flow to the vent section.
5. Resin is pumped from the first stage metering section to a deep vent or devolatilizing section. This vent section is capable of moving quantities well in excess of the material delivered to it by the first metering section. For this reason, the flights in the vent section run partially filled and at zero pressure. It is here that volatile materials such as water vapor and other non-desirable materials escape from the melted plastic. The vapor pressure of water at 500°F (260°C) is approximately 690 psi (48 bar). These steam pockets escape the melt and travel spirally around the partially filled channel until they escape out the vent hole in the barrel.
6. Water vapor and other volatiles escape from the vent.
7. The resin is again compressed and pressure is built in the second transition section.
8. The second metering section evens the flow and maintains pressure so that the screw will be retracted by the pressure in the front of the non-return valve.
9. A low resistance, sliding ring non-return valve works in the same manner as it does with a non-vented screw.

Vented Injection

1. Xaloy® Two-Stage Screw

This unique, length conserving design is successful on a great variety of engineering materials, both filled and unfilled. Xaloy offers many materials for screw construction and coating, including: 4140, 17-4 PH stainless, Stellite, Colmonoy, nitrided, chrome or nickel plated, and tungsten carbide coated for resistance to glass abrasion.

2. Vent Deflector

The Xaloy® vent deflector is designed to prevent vent weepage and to drag material back into the barrel. Our deflectors are made of special materials for durability and maximum heat conductance which minimizes vent hole seal off.

3. Vent Chute

Materials that escape from the vent during startup must be kept from the barrel, heaters and heater wiring. The Xaloy® chute is constructed of heavy-gauge stainless steel and is easy to clean.

4. Barrel Machining

The barrel hole is accurately machined and honed to prevent side wall leakage. The deflector is pin-located to prevent incorrect orientation. The deflector is honed in position to match with the barrel I.D. and eliminate dead spots.

5. Free Flow Check Valve

A special, low resistance sliding ring valve is supplied to give optimum venting characteristics. The tip, check ring, and rear seat are made of H13 for long life and abrasion resistance. All flow passages are streamlined for engineering polymers.

6. Ceramic Heater

A thermally efficient ceramic heater is provided to go around the barrel behind the vent. This high quality heater is designed to operate easily at the high temperatures required by the newer materials. A thermocouple hole for individual vent zone control is provided for use if desired. A safety terminal box with both 220V and 440V connections is standard.

Heater Bands

Heater Bands

Electric heat is used on all types of plasticizing equipment to soften and melt plastic material. The type of heater and the power output (wattage) used depends on the material being processed, the cycle time expected, and the amount of material being molded. The following paragraphs will outline the different types of heaters currently available and provide a guideline for selecting the correct heater.

All electric heaters are constructed from resistance wire, an electric insulating material, and steel sheath. Insulating materials include ceramic, mica, and magnesium oxide (MgO). The element is supported by a metal sheath and power is connected through various electrical terminations. Heaters are rated according to total wattage output over the surface area of the heater or watts per square inch. For example a mica band heater 3" ID x 2" W at 300 watts is rated at $300 / (3 \times 3.1416 \times 2)$ or 16 watts per square inch.

There are three methods of heating: radiant, convection and conduction. Radiant heat is used primarily in thermoforming applications, convection for drying material, and conduction for melting. The types of heaters mentioned in this article are all conduction heaters since conduction heat is the most efficient way to get electric heat into the plasticating process.

Energy efficiency is defined as the energy absorbed into the process versus the energy (wattage) put into the heater. Energy efficiency impacts the overall cost of running the heaters and the response time of the process to the heaters. Obviously, the more heat that conducts from the Nichrome element into the process the lower the cost and the shorter the response time. Energy efficiency is determined by the conductive characteristics of the heater, the fit between the heater and the surface, and the loss of heat to the air. Conductive heaters include mica insulated, ceramic insulated, cast aluminum, tubular, mineral insulated and heat/cool assemblies.

Mica Heaters

Mica insulated heaters are constructed from 20 - 24 gauge rust resistant steel, Nichrome resistance wire, and plate mica. The resistance wire is wound onto the plate mica and supported by the metal sheath. These heaters are capable of a maximum operating temperature of 900°F (483°C) and are typically rated from 25 to 50 watts per square inch. Since these heaters transfer energy through conduction, tight fit between the heater and the barrel or nozzle is critical. The higher the watt density the more critical the fit becomes. Any voids, holes, or grooves in the surface being heated can cause hot spots and burn out the element. The advantages to this type of heater is its lower cost, durability, quick response times, and design flexibility. Mica heaters can be made in a wide variety of shapes including round, rectangular, cone, and plate all with different electrical connections and lock-ups. The disadvantages are the lower operating temperature which make it unsuitable for many of the newer high temperature resins and its lower energy efficiency. Without an insulating shroud or blanket as much as 40% of the wattage input into the heater is lost to the surrounding atmosphere.

Mica bands are flexible in design but stiff in construction. They should not be opened up to wrap around the barrel but should be slipped on over the end. Flexing can damage the mica sheet and cause premature failure. Mica bands can be made in 2, 3, and 4-piece segments. All mica bands which are larger than 20" (508 mm) diameter should include compression springs to help take up the expansion of the element under heat. Mica heaters should be slightly undersized to insure a tight fit on the surface being heated. They should be retightened after the first heat up. Lastly, mica bands can be made up to 24" (609.6 mm) wide but they tend to work better and last longer when the width is held to 3" (76.2 mm) or less. Mica bands are best suited for applications where the melt/process temperature is less than 550°F (288°C).

Heater Bands

Ceramic Heaters

Ceramic heaters are constructed from 24 - 26 gauge stainless or aluminized steel. The element is a helically wound nichrome resistance wire which is supported by interlocking ceramic blocks. Depending on the application the ceramic blocks are made from either a cordierite, steatite, or silicon carbide material. A ceramic fiber insulating material is sandwiched between the ceramic pieces and the outer steel shell to insulate against heat loss. The insulating blanket is typically 1/4" (6.35 mm) thick but can be manufactured up to 1" (2.54 mm) thick to provide additional energy efficiency and conservation, as much as 30 - 40% over standard mica bands.

Besides being more energy efficient, ceramic band heaters have a maximum operating temperature of 1,400°F (760°C) and are typically rated at 35 to 50 watts per square inch. Ceramic heaters heat through both conduction and radiation and therefore do not need as integral a fit as mica bands. This characteristic tends to give ceramic heaters a longer service life than mica. They are flexible in construction and can be opened up to wrap around a barrel or die. The disadvantages are the higher cost (50% more than mica) and that ceramic heaters are prone to contamination. Ceramic heaters are best suited for applications requiring high process temperatures 500°F (260°C) and higher, faster cycle times, or in locations with high electric rates. Ceramic heaters can also be made in 2, 3, and 4-piece segments but given the flexibility of the band this is usually unnecessary. Larger ceramic bands (>20" ID) should include compression springs in the lock up. Ceramic heaters are commonly manufactured in widths greater than 3" (76.2 mm) to take advantage of the insulating blanket. They can be made with either lead wire or screw terminals however given the high operating temperatures, screw contacts help extend service life.

Mineral Insulated Heaters

Mineral insulated heaters are manufactured using a stainless steel sheath with a sinuated Nichrome element sandwiched between thin layers of mineral insulation. The mineral insulation is a magnesium oxide material pressed into sheet form. Once the heater is assembled it is pressed to compact the sinuated element into the sheet, then shaped into a cylinder and finally baked to remove any organic binders from the mineral insulation. This process creates excellent heat transfer properties allowing for high operating temperatures and high watt densities. Mineral insulated heaters can operate up to 1,400°F (760°C) and are rated as high as 230 watts per square inch. With low mass and high watt densities, mineral insulated heaters heat up and cool down very quickly. The disadvantages are that magnesium oxide is a hygroscopic material which can reduce dielectric strength. Further mineral insulated heaters are stiff and limited in design variations. Lastly, mineral insulated heaters have energy efficiencies similar to mica heaters.

Tubular and Cast-in Heaters

Tubular band heaters are constructed using either stainless steel or Inconel tubing. A helically wound element is stretched the length of the tube. The heater is filled with magnesium oxide for insulation and compressed. The heaters are then shaped into a cylinder. Lastly, a stainless-steel strap is used to tighten the heater onto the die or barrel. Similar to the mineral insulated heaters, tubular heaters have good heat transfer characteristics and because of the tubing they are highly resistant to contamination. Tubular heaters can reach operating temperatures of 1,200°F (649°C) and are rated up to 100 watts per square inch. Watt density is limited by application and heat transfer.

Heater Bands

The disadvantage to tubular heaters is that while the heat will radiate from the element efficiently, it radiates 360 degrees from the surface of the element. The heater only makes tangential contact with the surface being heated. This creates a very inefficient heat transfer from the element to the surface and most of the energy is lost to the open air. To overcome this problem the tubular heaters can either be set into an aluminum extrusion which is formed into a cylinder or it can be cast directly into molten aluminum. Using either of these variations creates a heater with an excellent heat profile. The heat will be transferred uniformly across the width of the heater. Also, these heaters are very rugged and have quick heat up and cool down times. However, they are the most expensive heaters on the market and have a maximum operating temperature of 650°F (343°C). At 650°F, the aluminum starts to get soft and will melt at 750 - 800°F (400 - 427°C).

Tubular heaters without the aluminum extrusion or casting are best suited for applications with high levels of contamination and or fumes that would quickly attach the nichrome wire and cause failure in standard mica or ceramic heaters. Cast-in heaters are best suited for situations that require good heat profiles like blown film dies and extrusion barrels where cooling is required.

Heat/Cool Applications

The extrusion process generates heat through friction as the screw shears the resin against the inside of the barrel. Heaters are used at start-up to get the process going and then in many applications cooling is required to offset the heat generated by the shear affect. Cooling is accomplished with either water or forced air. Air cooled units use either cast aluminum or ceramic heaters. The heaters are enclosed in a sheet metal shroud, and a blower is attached. Water cooled heaters are cast aluminum heaters with cooling tubes cast into the heaters. Water lines are attached to the cooling tubes. Water cooled units cool more efficiently than air cooled. However, the piping can be messy and leak water, and the cooling tubes can get clogged with mineral deposits. Ceramic air cooled units are capable of higher operating temperatures than cast aluminum and are lower cost.

Heater Selection Guide

HEATER SELECTION GUIDE					
Style	Insulation	Max. Temperature °F (°C)	Max. W/in ² (W/cm ²)	Advantages	Drawbacks
Mica	Plate Mica	900°F (482°C)	50 W/in ² (7.75 W/cm ²)	Low Cost Versatility	Low Temperature
Ceramic	Cordierite Steatite Silicon Carbide	1,400°F (760°C)	51 W/in ² (7.75 W/cm ²)	High Temperature Flexibility Energy Efficiency	Prone to Contaminants
Mineral Insulated	MgO	1,400°F (760°C)	230 W/in ² (35.65 W/cm ²)	High Temperature Response Time	Cost Versatility Energy Efficiency
Tubular	MgO	1,200°F (649°C)	100 W/in ² (15.50 W/cm ²)	Durability	Energy Efficiency
Cast Aluminum	MgO	650°F (343°C)	35 W/in ² (5.43 W/cm ²)	Uniform Heat	Cost Low Temperature
Cast Water Cooled	MgO	650°F (343°C)	35 W/in ² (5.43 W/cm ²)	Durability Cost	Cost Water Leaks Sealing
Cast Air Cooled	MgO	650°F (343°C)	35 W/in ² (5.43 W/cm ²)	Cost	Cost
Ceramic Air Cooled	Steatite	1,200°F (649°C)	50 W/in ² (7.75 W/cm ²)	High Temperature	Cooling Efficiency

Variations of OHM's Law

VARIATIONS OF OHM'S LAW

VOLTS

$$\text{VOLTS} = \sqrt{\text{WATTS} \times \text{OHMS}}$$

$$\text{VOLTS} = \frac{\text{WATTS}}{\text{AMPERES}}$$

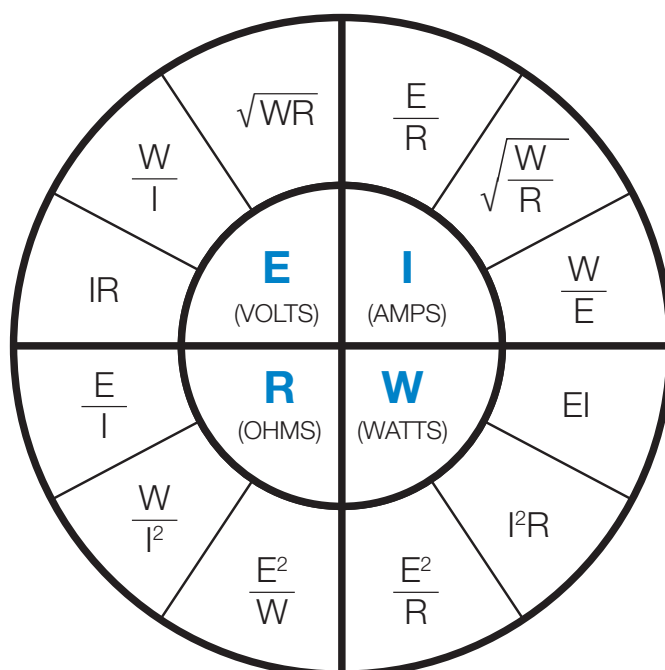
$$\text{VOLTS} = \text{AMPERES} \times \text{OHMS}$$

OHMS

$$\text{OHMS} = \frac{\text{VOLTS}}{\text{AMPERES}}$$

$$\text{OHMS} = \frac{\text{WATTS}}{\text{AMPERES}^2}$$

$$\text{OHMS} = \frac{\text{VOLTS}^2}{\text{WATTS}}$$



AMPERES

$$\text{AMPERES} = \frac{\text{VOLTS}}{\text{OHMS}}$$

$$\text{AMPERES} = \sqrt{\frac{\text{WATTS}}{\text{OHMS}}}$$

$$\text{AMPERES} = \frac{\text{WATTS}}{\text{VOLTS}}$$

WATTS

$$\text{WATTS} = \text{VOLTS} \times \text{AMPERES}$$

$$\text{WATTS} = \text{AMPERES}^2 \times \text{OHMS}$$

$$\text{WATTS} = \frac{\text{VOLTS}^2}{\text{OHMS}}$$

WATT DENSITY CALCULATION FOR BAND HEATERS

$$\text{WATTS/IN}^2 = \frac{\text{WATTAGE}}{\text{DIA.} \times 3.1416 \times \text{WIDTH}}$$

Section 5: Appendix

Resin Data

RESIN DATA														
	Crystallinity	Hydroscopic	Approx. Density at Room Temperature, g/cm ³	Approx. Density at Process Temperature, g/cm ³	Melt Temperature °C	Extrusion Temperature °C	Injection Temperature °C	Drying Temperature °C	Drying Time h	Circumferential Speed m/s	Specific Heat kJ/kgK	Specific Heat BTU/lbs/F	Water Absorption % in 24 HRS.	Maximum Water Content Allowable for Molding
ABS	A	Y	1.05	0.97	220 - 260	224	260	70 - 95	2 - 4	0, 20 - 0,40	1.30	0.40	0.40	0.20
ASA	A	Y	1.09	0.98	250			80	2 - 4	0, 20 - 0,40				
CA	A	Y	1.28	1.09	218	193	232	70	6	0, 20 - 0,40	1.50	.36	2.50	
CAB	A	Y	1.19	1.10	200			70	6	0, 20 - 0,40	1.60	.38	2.40	0.20
CAP	A	Y	1.22	1.10	218	193	218	70	6	0, 20 - 0,40	1.70	.40	1.70	
CPVC	B	N	1.50	1.30	195		91							
ECTFE	C	N	2.11	1.49			288				0.92	.22		
EVA	B	N	0.95	0.93										
FEP	C	N	2.11	1.49		316	316				1.17	.28		
FPVC	B	N	1.30	1.20	200					0,10 - 0,50	1.10	.25		
HDPE	C	N	0.96	0.72	245						2.30	.55		
HIPS	A	N	0.96	1.04		232	227				1.40	.34		
Inomomer	B	Y	0.95	0.73	215	260	216				2.26	.54	0.20	
LCP	B	Y	1.40	1.20	290			130	2 - 4	0.80				
LDPE	B	N	0.92	0.70							2.30	.55		
LLDPE	B	N	0.92	0.70										
PA 11	C	Y	1.04	0.97	270	238	232				1.26	.30	0.30	0.10
PA 12	C	Y	1.01	0.97	280	232	229				1.26	.30	0.40	0.20
PA 6	C	Y	1.13	0.99	240	271	288			0.50	1.70	.40	1.60	0.15
PA 6/10	C	Y	1.08	0.97	235		232				1.70	.40	0.40	0.15
PA 6/12	C	Y	1.07	0.97	260	246	260				1.70	.40	0.25	0.10
PA 6/6	C	Y	1.14	0.97	280	266	266			0.50	1.70	.40	1.50	0.15
PBT	B	Y	1.31	1.11	250 - 260		238	120 - 140	3 - 4	0.30				
PC	A	Y	1.20	1.02	280 - 320	288	302	120	2 - 4	0.20 - 0,40	1.26	.30		
PC / ABS	A	Y	1.14	0.97	240 - 290			100 - 110	2 - 4	0.20 - 0,35				
PC / PBT	B	Y	1.20		250 - 270			110 - 115	2 - 4	0.20 - 0,35				
PC / PET	B	Y	1.21		260 - 280			110 - 120	4 - 6					
PEEK	B	N	1.24		350 - 370									
PEI	A	Y	1.27	1.12	370 - 410			150	4 - 10	0.16 - 0,26				
PES	A	Y	1.37		340 - 360			135 - 160	2 - 4	0.16 - 0,26				
PET	A, B	N	1.31	1.10		249	254				1.70	.40		
PET	B, C	Y	1.30	1.15	270 - 290			120	4 - 6	0.34	1.70	.40		
PETG	A	Y	1.30	1.15	270 - 290			120	4 - 6					
PPA	C	Y	1.45		329 - 350			120	4					
PMMA	A	Y	1.18	1.06	220 - 260	193	232	70 - 95	2 - 3	0.20 - 0,40	1.47	.35	1.50	0.15
POM	C	N	1.42	1.20	220		199			0.50	1.46	.35	.025	
PP	C	N	0.90	0.75		232	254				2.10	.50		
PPE, PPO	B	Y	1.10	0.92	280 - 310			100 - 120	2 - 3					
PPS	B	Y	1.35	1.12	280			140	4					
PS	A	N	1.05	0.97	240	210	218				1.34	.32	0.10	
PSU	A	N	1.24	1.16	360	343	360				1.17	.28	0.30	0.15
PUR	C	Y	1.20	1.13	205						1.70	.40	0.10	0.03
PVDF	C	N	1.78		210 - 230					0.15				
RPVC	B	N	1.40	1.14	195					0.10 - 0,20	1.05	.25		
RPVC	B	N	1.40	1.14	195					0.10 - 0,20	1.05	.25		
SAN	A	Y	1.08	1.00	240	216	243			0.20 - 0,40	1.30	.31	0.03	0.02
SB	A	Y	1.05	1.00										
TPE	C	Y	0.95	0.82	205	199	204				1.90	.46	0.01	
TPU	C	Y	1.15	1.02	210			100 - 110		0,20 - 0,40	1.90	.46		

***N** = non-hygroscopic

Y = hygroscopic

****A** = amorphous

B = amorpho-crystalline

C = crystalline

These are strictly typical, average values for resin class. Consult your resin supplier for values and more accurate information. We have not included many of the newer engineering materials because they vary considerably within a family of materials and mostly they have fillers such as glass fillers which affect all of the data considerably.

Appendix 1

Appendix 1

**S.P.I. Single Screw and Barrel
Recommended Dimensional Guidelines
By
The Society of the Plastic Industry's
Machinery Component Manufacturers Division,
(now Plastics Industry Association)**

Guidelines for Single Screws

The Society of the Plastic Industry's Machinery Component Manufacturers Division

Recommended Dimensional Guidelines for Single Screws

The following recommendations for single screws of injection molding machines and extruders have been prepared as a guide to manufacturers and processors. These guidelines have been developed to provide working tolerances that produce effective performance with economy of manufacture. Manufacturers are encouraged to meet or exceed these guidelines and processors are entitled to expect screws that they purchase to be in conformance with the guidelines.

Lengths

The following tolerances apply to most linear dimensions of a screw including, but not limited to the **overall length** of the screw, the **flighted surface** and the **drive**. The tolerances increase with the linear dimension involved.

English Measurement		Metric Measurement	
<u>Linear Dimension</u>	<u>Tolerance</u>	<u>Linear Dimension</u>	<u>Tolerance</u>
To 12"	± .010"	To 300 mm	± .25 mm
12 - 60"	± .030"	300 - 1,500 mm	± .75 mm
60 - 120"	± .045"	1,500 - 3,000 mm	± 1.00 mm
120 - 200"	± .060"	3,000 - 5,000 mm	± 1.50 mm
Over 200"	± .090"	Over 5,000 mm	± 2.25 mm

Flight Width

The tolerances set forth below relate to the **screw flight width** at any point in the length of the flighted surface. The tolerances increase with the size of the screw and, therefore, the width of the flight.

English Measurement		Metric Measurement	
<u>Specified Flight Width</u>	<u>Tolerance</u>	<u>Specified Flight Width</u>	<u>Tolerance</u>
To .500"	± .015"	To 12 mm	± .38 mm
500 - 1.000"	± .020"	12 - 25 mm	± .50 mm
Over 1.000"	± .030"	Over 25 mm	± .75 mm

Guidelines for Single Screws

Channel Depth

The tolerance guidelines set forth below are for the **channel depths** of the **feed** and **meter sections** of a screw. As the channel depth increases, the tolerance also increases.

English Measurement		Metric Measurement	
<u>Channel Depth</u>	<u>Tolerance</u>	<u>Channel Depth</u>	<u>Tolerance</u>
To .100"	± .003"	To 2.5 mm	± .08 mm
.100 - .500"	± .007"	2.5 - 13.0 mm	± .18 mm
Over .500"	± .012"	Over 13.0 mm	± .30 mm

Barrier Flight Undercut

The barrier flight (or secondary flight) in a barrier screw is undercut (or a reduced diameter) from that of the primary flight, permitting the flow of melted polymer over it. The undercut is expressed as the difference in radius of the barrier flight from the primary flight. This **barrier flight undercut** has a greater tolerance in screws with larger diameters, as follows.

English Measurement		Metric Measurement	
<u>Screw Diameter</u>	<u>Tolerance</u>	<u>Linear Dimension</u>	<u>Tolerance</u>
To 6.0"	± .002"	To 152 mm	± .05 mm
Over 6.0"	± .003"	Over 152 mm	± .075 mm

Screw Section Lengths

Screw section lengths (also referred to as **zones**) such as the feed, transition or meter sections, are defined by their length and also toleranced by a fraction of a turn (or diameter). The tolerance for screw sections for all sizes of screws, expressed in turns (or diameters) is **± 1/8 of a turn**.

Keyway tolerances for all sizes of screws are recommended as follows:

English Measurement	Metric Measurement
Specified Depth + .005"	Specified Depth + .13 mm
Specified Width + .002" - .000"	Specified Width + .05 mm - .00 mm

Spline tolerances are recommended as set forth in the table on the next page, using metric measurements.

Guidelines for Single Screws

d (mm)	Designation	Teeth	D (mm)	B (mm)
11	6 x 11 x 14	6	14	3
13	6 x 13 x 16	6	16	3.5
16	6 x 16 x 20	6	20	4
18	6 x 18 x 22	6	22	5
21	6 x 21 x 25	6	25	5
23	6 x 23 x 28	6	28	6
26	6 x 26 x 32	6	32	6
28	6 x 28 x 34	6	34	7
32	8 x 32 x 38	8	38	6
36	6 x 36 x 42	8	42	7
42	8 x 42 x 48	8	48	8
46	8 x 46 x 54	8	54	9
52	8 x 52 x 60	8	60	10
56	8 x 56 x 65	8	65	10
62	8 x 62 x 72	8	72	12
72	10 x 72 x 82	10	82	12
82	10 x 82 x 92	10	92	12
92	10 x 92 x 102	10	102	14
102	10 x 102 x 112	10	112	16

Guidelines for Single Screws

Basic Size		B (d10)	D (a11)	d (f7)
From	To			
0	3	-.020 to -.060	-.270 to -.330	-.006 to -.016
3	6	-.030 to -.078	-.270 to -.345	-.010 to -.022
6	10	-.040 to -.098	-.280 to -.370	-.013 to -.028
10	14	-.050 to -.120	-.290 to -.400	-.016 to -.034
14	18	-.050 to -.120	-.290 to -.400	-.016 to -.034
18	24	-.065 to -.149	-.300 to -.430	-.020 to -.041
24	30	-.065 to -.149	-.300 to -.430	-.020 to -.041
30	40	-.080 to -.180	-.310 to -.470	-.025 to -.050
40	50	-.080 to -.180	-.320 to -.480	-.025 to -.050
50	65	-.100 to -.220	-.340 to -.530	-.030 to -.060
65	80	-.100 to -.220	-.360 to -.550	-.030 to -.060
80	100	-.120 to -.260	-.380 to -.600	-.036 to -.071
100	120	-.120 to -.260	-.410 to -.630	-.036 to -.071
120	140	-.145 to -.305	-.460 to -.710	-.043 to -.083
140	160	-.145 to -.305	-.520 to -.770	-.043 to -.083
160	180	-.145 to -.305	-.580 to -.830	-.043 to -.083
180	200	-.170 to -.355	-.660 to -.950	-.050 to -.096
200	225	-.170 to -.355	-.740 to -1.030	-.050 to -.096
225	250	-.170 to -.355	-.820 to -1.030	-.050 to -.096
250	280	-.190 to -.400	-.920 to -1.240	-.056 to -.108
280	315	-.190 to -.400	-1.050 to -1.370	-.156 to -.108
315	355	-.210 to -.440	-1.200 to -1.560	-.062 to -.119
355	400	-.210 to -.440	-1.350 to -1.710	-.062 to -.119
400	450	-.230 to -.480	-1.500 to -1.900	-.068 to -.131

B = d10

D = a11

d = f7

Guidelines for Single Screws

Hollowbores

In some cases, a screw is cored for cooling by boring a hole from the drive end of the screw well into the flighted section of the screw. The tolerance for the cored length (or hollowbore) is the same for all sizes of screws.

English Measurement

Specified Length $\pm .030$ "

Metric Measurement

Specified Length $\pm .76$ mm

Nose Thread Pilots

A nose thread pilot is an internal cylindrical surface at the meter end of a screw used to accurately locate a non-return valve or other attachment connected to the end of the screw. The tolerance for the length of the pilot is especially important on an injection screw which will be fitted with a valve. The tolerance is the same for all sizes of screws.

English Measurement

Injection
Extrusion

Specified length $\pm .005$ "

Specified length $\pm .015$ "

Metric Measurement

Specified length $\pm .13$ mm

Specified length $\pm .40$ mm

Flight & Bearing Diameters

The diameters of the flighted section and the bearing surface of the screw are vital to the performance of the screw. The flight diameter is the outside diameter of the screw flights. The bearing diameter (or Hub) is the diameter of the screw immediately behind the flighted length which prevents the escape of material and provides a seal between the screw and the barrel. The tolerances for these two diameters is stated below:

Screw Diameter

To 6.0"
Over 6.0"

English Measurement

$+.000$ $-.002$ "

$+.000$ $-.004$ "

Metric Measurement

$+.00$ $-.05$ mm

$+.00$ $-.10$ mm

Shank Diameter

The shank is the non-flighted section of the screw, also referred to as the drive end. The tolerance for the diameter of the shank is the same for all sizes of screws.

English Measurement

$+.000$ $-.002$ "

Metric Measurement

$.000$ $-.50$ mm

Hollowbore Diameter

The tolerance for the length of the hollowbore is stated in a previous paragraph. The tolerances for the diameter of a hollowbore are dependent upon the size of the screw, as shown below.

Screw Diameter

To 3"
3" to 6"
Over 6"

English Measurement

$\pm .020$ "

$\pm .040$ "

$\pm .060$ "

Metric Measurement

$\pm .5$ mm

± 1.0 mm

± 1.5 mm

Guidelines for Single Screws

Nose Thread Pilot Diameter

The depth of the nose thread pilot is stated in a previous paragraph. The tolerances for the diameter are the same for all sizes but differ between injection and extrusion screws.

	English Measurement	Metric Measurement
Injection	+.001" - .000"	+.025 - .000 mm
Extrusion	+.002" - .000"	+.050 - .000 mm

The tolerance for injection screws is particularly important because they will be fitted with valves.

Concentricity of Outside Diameters

Concentricity of cylindrical surfaces of a screw exists when all of the cylindrical shapes share the same axis (and the axis is the true center of the screw). The deviation in the concentricity of one surface to another is measured as the maximum reading on a dial indicator, also referred to as Total Indicator Reading (TIR). The tolerance in concentricity deviation (also known as runout) varies with the length of the screw, as follows:

English Measurement		Metric Measurement	
<u>Screw Length</u>	<u>TIR</u>	<u>Screw Length</u>	<u>TIR</u>
To 100"	.004"	To 2,500 mm	.100 mm
100 - 200"	.006"	2,500 - 5,000 mm	.150 mm
200 - 300"	.010"	5,000 - 7,600 mm	.250 mm
Over 300"	.015"	Over 7,600 mm	.400 mm

These tolerances apply to the concentricity of the **outside diameter** of the screw, the **bearing surface** and all portions of the **screw drive**. The concentricity of diameters in flighted sections cannot be accurately measured due to the interrupting effect of the flight. Flight depth variations taken from a true OD are used as a measure of concentricity in this area.

Concentricity of Inside Diameters

The tolerances for inside diameters are the same for all sizes of screws. However, there is a different tolerance for the register of the screw as compared with the other inside diameters.

Nose Thread Pilots, Nose Threads and Hollowbores

English Measurement (TIR)	Metric Measurement (TIR)
.001"	.025 mm

Screw Register

English Measurement (TIR)	Metric Measurement (TIR)
.0005"	.013 mm

Guidelines for Single Screws

Flight Radii

Unless otherwise specified, the flight radii connecting the flight with the root of the screw should not be less than ½ of the flight depth, up to a 1" or 25 mm radius. The tolerances should be as follows:

English Measurement

Specified $\pm .030"$

Metric Measurement

Specified $\pm .75$ mm

Perpendicularity & Parallelism

All **flights**, unless otherwise specified, should be perpendicular to the screw axis from the root radius to the OD on both sides. Other surfaces perpendicular to the screw axis can be tested by use of a surface plate and an adjustable height table indicator or a precision square. Other perpendicular surfaces would include the **register face** and the **rear drive face**. The tolerances for these surfaces are the same for all sizes of screws and may be measured in distance or degrees, as follows:

English Measurement

$\pm .001$ in./in.
.006°

Metric Measurement

$\pm .0025$ mm/mm
.006°

Parallel surfaces can be determined by TIR or by using a surface plate and an adjustable height gauge. All dimensions meeting the concentricity and/or flight depth guidelines are considered acceptable.

Screw Threads

The variation in threads used in the manufacture of screws is too broad to be addressed by these recommendations. It is suggested that whenever thread selection is made, either ANSI or ISO standards are observed for ease of measurement and compatibility.

Surface Finish

Surface finish tolerances are different for plated vs. unplated surfaces, as indicated below:

Chrome-plated Surfaces

English Measurement

Metric Measurement

Channel	16 microinches	.40 micrometers
OD	32 microinches	.80 micrometers
Bearing / shank	32 microinches	.80 micrometers

Unplated Surfaces

English Measurement

Metric Measurement

32 microinches	.80 micrometers
----------------	-----------------

Hard Surfacing

All hard surfacing materials should be specified as to alloy, width or weld, and depth of weld.

Measurement Temperature

All measurements should be taken at room temperature of 72°F ($\pm 20^\circ\text{F}$) or 22°C ($\pm 11^\circ\text{C}$).

Guidelines for Single Barrels

The Society of the Plastic Industry's Machinery Component Manufacturers Division

Recommended Dimensional Guidelines for Single Barrels

The following recommendations for single bore barrels for extrusion/injection machinery have been prepared as a guide to manufacturers and processors. These recommendations have been developed over many years and provide working tolerances that produce effective performance with economy of manufacture.

Lengths, Depths & Widths

The following tolerances apply to most linear dimensions of a screw including, but not limited to the overall length of the screw, the flighted surface and the drive. The tolerances increase with the linear dimension involved.

I. Most linear dimensions

English Measurement

To 12"	± .010"
12 - 60"	± .030"
60 - 120"	± .045"
20 - 200"	± .060"
Over 200"	± .090"

Metric Measurement

To 300 mm	± .25 mm
300 - 1,500 mm	± .75 mm
1,500 - 3,000 mm	± 1.00 mm
3,000 - 5,000 mm	± 2.25 mm
Over 5,000 mm	± 2.25 mm

II. Counterbore Depths or Pilot Lengths

English Measurement

All sizes ± .005"

Metric Measurement

All sizes ± .125 mm

Diameters

I. Bores (including counterbores)

English Measurement

To 1½"	dia. (<60" long)	+ .001" - .000"
1½ - 3"	dia. (>60" long)	+ .002" - .000"
3 - 5½"	dia. (<120" long)	+ .002" - .000"
3 - 5½"	dia. (>120" long)	+ .0025" - .000"
5½ - 8"	dia. (<180" long)	+ .0025" - .000"
5½ - 8"	dia. (>180" long)	+ .003" - .000"
8 - 12½"	dia. (<180" long)	+ .003" - .000"
8 - 12½"	dia. (>180" long)	+ .004" - .000"

Guidelines for Single Barrels

Metric Measurement

0 - 38 mm	dia. (<1,500 mm long)	+ .025 mm - .000 mm
3 - 75 mm	dia. (<1,500 mm long)	+ .050 mm - .000 mm
25 - 75 mm	dia. (>1,500 mm long)	+ .038 mm - .000 mm
75 - 140 mm	dia. (<3,000 mm long)	+ .051 mm - .000 mm
75 - 140 mm	dia. (>3,000 mm long)	+ .063 mm - .000 mm
140 - 200 mm	dia. (<4,500 mm long)	+ .063 mm - .000 mm
140 - 200 mm	dia. (>4,500 mm long)	+ .076 mm - .000 mm
200 - 315 mm	dia. (<4,500 mm long)	+ .076 mm - .000 mm
200 - 315 mm	dia. (<4,500 mm long)	+ .102 mm - .000 mm

II. Outside diameters except pilots

English Measurement

All sizes and lengths $\pm .005"$

Metric Measurement

All sizes and lengths $\pm .102$ mm

II. Pilot diameters

English Measurement

All sizes $\pm .001"$

Metric Measurement

All sizes $\pm .038$ mm

Concentricity of Diameters

Concentricity between all inside and outside diameters should be held within .002" TIR or .051 mm TIR within one bore diameter of each end. Concentric diameter dimensions further inside of one bore diameter from the ends should be avoided and/or specially tolerated when required.

Straightness

Straightness is generally specified for the bore of the barrel and is measured by TIR.

English Measurement

1 - 3"	bore diameter (≤ 24 l/d)	.008" TIR
1 - 3"	bore diameter (≥ 24 l/d)	.010" TIR
3 - 5½"	bore diameter (≤ 24 l/d)	.010" TIR
3 - 5½"	bore diameter (≥ 24 l/d)	.012" TIR
5½ - 8"	bore diameter (≤ 24 l/d)	.012" TIR
5½ - 8"	bore diameter (≥ 24 l/d)	.015" TIR
8 - 12½"	bore diameter (≤ 24 l/d)	.014" TIR
8 - 12½"	bore diameter (≥ 24 l/d)	.016" TIR

Guidelines for Single Barrels

Metric Measurement

25 - 75 mm	bore diameter (≤ 24 l/d)	.203 mm TIR
25 - 75 mm	bore diameter (≥ 24 l/d)	.254 mm TIR
75 - 140 mm	bore diameter (≤ 24 l/d)	.254 mm TIR
75 - 140 mm	bore diameter (≥ 24 l/d)	.305 mm TIR
140 - 200 mm	bore diameter (≤ 24 l/d)	.305 mm TIR
140 - 200 mm	bore diameter (≥ 24 l/d)	.380 mm TIR
200 - 315 mm	bore diameter (≤ 24 l/d)	.355 mm TIR
200 - 315 mm	bore diameter (≥ 24 l/d)	.406 mm TIR

To prevent short "kinks" to which the screw could not conform, any two successive measurements taken less than twice the bore diameter apart should have no more than 1/2 the total allowable TIR.

Bar Test

A second way to check both straightness and bore size is by using a precision ground test bar. This method is detailed in the appendix 1.

Finish

The following surface finishes apply unless specified otherwise.

Outer diameters	125 RMS
Counterbores	32 RMS
Pilots	32 RMS
Cylinder bores	8 - 32 RMS
Feed ports	125 RMS
Vent ports*	32 RMS

*Required within 1/4" of cylinder bore.

The bore shall be free from visual surface defects in the bore over its entire length.

Parallelism & Perpendicularity

Parallel surfaces can be determined by TIR and all dimensions meeting the concentricity recommendations are acceptable. Perpendicular surfaces to the cylinder bore can be tested by placing the barrel on a surface plate and indicating with an adjustable height table indicator or with a precision square. All mating surfaces should be perpendicular as follows:

	English Measurement	Metric Measurement
Pilots and counterbores	.0015" TIR	.038 mm TIR
Flanges	.001 TIR per 10" of dia.	.038 mm TIR per 250 mm of dia.

Threads

The variation in threads used is too broad to be addressed in these recommendations. It is suggested that whenever thread selection is possible that either ANSI or ISO standards are adhered to for ease of measurement and compatibility.

Guidelines for Single Barrels

Venting

The following warning label should be affixed to a vented extruder or injection barrel supplied without a venting plug. **Warning:** This vented injection/extrusion barrel was designed for operation with the vent OPEN ONLY. Operation of this machine with the vent plugged or otherwise closed off may result in serious injury to persons in the vicinity. Check with your supervisor if this vent is intentionally or unintentionally plugged.

Downsizing Injection Barrels

When downsizing (reducing the barrel/screw bore size and resultant shot capacity) an injection molding machine must have the pressure capability reduced or be redesigned for the new resultant pressure. This is necessary to reduce the screw thrust pressure in proportion to the reduction in area of the bore to prevent the barrel from being over pressurized. All units that are downsized should be equipped with a warning label on the barrel where it can be easily seen.

Barrel Construction

Bimetallic Centrifugally Cast and Hot Isostatically Pressed Barrels

The inlay thickness is to be 1/16" (1.6 mm) nominal, with a 1/8" (3.2 mm) maximum and 1/32" (0.8 mm) minimum. Hardness standards are those of the manufacturer and are based on the arithmetic means of five hardness measurements taken at random points along the bore. The hardness values vary greatly with the type of inlay. The inlay should have a 100% metallurgical bond at all points determined by ultrasonic techniques.

Nitrided Barrels or Other Single Metal Barrels

Depending on the material used in the outer tube and the bore hardening method, both the hardness and depth of hardness will vary. As a result, the hardness standards are those of the manufacturer.

Sleeved Barrels (New)

All sleeves should be inserted by either shrink fit or press fit with no less than the interference required to maintain the stress levels applying to all barrels detailed in the appendix. In all cases a minimum interference of .001" (.025 mm) diametral shrink per inch of diameter should be used. Hardness standards are those of the manufacturer and vary with the material and hardening method selected for the sleeve.

Sleeved Barrels (Relined)

The liner material should have a co-efficient of thermal expansion within + 30 % of the base (outer tube) material from room temperature through to maximum expected operating temperature. All internal sleeves should blend to any remaining bore with no visible lip and with no more than the following mismatch in TIR.

English Measurement

To 2"	bore dia. .001"
2 - 3½"	bore dia. .002"
> 3½"	bore dia. .003"

Metric Measurement

To 50 mm	bore dia. .025 mm
50 - 90 mm	bore dia. .051 mm
> 90 mm	bore dia. .076 mm

In the case of injection barrels, relining of the discharge end should extend a minimum of 2" (50 mm) past the maximum backward travel of the rear edge of the check ring on the non-return valve.

Barrel / Test-Bar Screw Clearance

Appendix 1

Barrel / Test-Bar Screw Clearance

Clearance specified in the two tables on the next page are based upon a minimum of .001" to a maximum of .0015" per inch of diameter between the barrel inside diameter and the screw flight outside diameter. The test-bar outside diameters are sized to the midway point between the screw flight outside diameter and the barrel inside diameter. The lengths of the test-bar specified are based on approximately 15 - 20 times the nominal screw/barrel diameter. All table dimensions are based on the parameters established in the first sentence of this criteria.

Barrel / Test-Bar Screw Clearance

Nominal Diameter	Specified Barrel ID Size	Specified Diameter Test Bar	Specified Screw OD Size	Test Bar Length	Barrel/Test Bar Diametral Clearance	Barrel/Screw Diametral Clearance
1 - 1/8"	1.125+001/.000	1.1235/1.230	1.1225/1.220	22"	.0015/.003	.0025/.004
1 - 1/4"	1.250+001/.000	1.2485/1.2480	1.2475/1.2465	24"	.0015/.003	.0025/.0045
1 - 1/2"	1.500+001/.000	1.4985/1.4980	1.497/1.496	26"	.0015/.003	.003/.005
1 - 3/4"	1.750+001/.000"	1.7480/1.7475	1.7465/1.7455	30"	.002/.0035	.0035/.0055
2"	2.000+001/.000	1.9980/1.9975	1.996/1.995	36"	.002/.0035	.004/.006
2 - 1/4"	2.250+001/.000	2.2480/2.2745	2.246/2.245	38"	.002/.0035	.004/.006
2 - 1/2"	2.500+001/.000	2.4975/2.4970	2.495/2.494	42"	.0025/.004	.005/.007
2 - 3/4"	2.750+001/.000	2.7475/2.7470	2.745/2.744	46"	.0025/.004	.005/.007
3"	3.000+001/.000	2.9970/2.9965	2.994/2.993	50"	.003/.0045	.006/.008
3 - 1/4"	3.250+002/.000	3.2465/3.2460	3.2435/3.2525	56"	.0035/.006	.0065/.0095
3 - 1/2"	3.500+002/.000	3.4965/3.4960	3.493/3.492	60"	.0035/.006	.007/.010
3 - 3/4"	3.750+002/.000	3.7465/3.7460	3.743/3.742	62"	.0035/.006	.007/.010
4"	4.000+002/.000	3.9960/3.9955	3.992/3.991	68"	.004/.0065	.008/.011
4 - 1/4"	4.250+002/.000	4.2460/4.2455	4.242/4.241	72"	.004/.0065	.008/.011
4 - 1/2"	4.500+002/.000	4.4960/4.4955	4.491/4.490	76"	.004/.0065	.009/.012
4 - 3/4"	4.750+002/.000	4.7455/4.7450	4.741/4.740	82"	.0045/.007	.009/.012
5 - 1/4"	5.250+002/.000	5.2445/5.2440	5.240/5.238	90"	.0055/.008	.010/.014
6"	6.000+002/.000	5.994/5.9935	5.988/5.986	96"	.006/.0085	.012/.016
8"	8.000+002/.000	7.993/7.992	7.984/7.982	108"	.007/.011	.016/.021

Nominal Diameter	Specified Barrel ID Size	Specified Diameter Test Bar	Specified Screw OD Size	Test Bar Length	Barrel/Test Bar Diametral Clearance	Barrel/Screw Diametral Clearance
30 mm	1.181+001/.000	1.1795/1.790	1.1785/1.780	22"	.0015/.003	.0025/.004
35 mm	1.378+001/.000	1.3765/1.3760	1.3750/1.3745	24"	.0015/.003	.003/.0045
38 mm	1.496+001/.000	1.4945/1.4940	1.493/1.492	26"	.0015/.003	.003/.005
40 mm	1.575+001/.000"	1.5735/1.5730	1.572/1.571	28"	.0015/.003	.003/.005
50 mm	1.969+001/.000	1.9670/1.9665	1.965/1.964	36"	.002/.0035	.004/.006
60 mm	2.362+001/.000	2.3595/2.3590	2.357/2.356	38"	.0025/.004	.005/.007
65 mm	2.559+001/.000	2.5565/2.5560	2.554/2.553	42"	.0025/.004	.005/.007
70 mm	2.756+001/.000	2.7535/2.7530	2.751/2.750	46"	.0025/.004	.005/.07
75 mm	2.953+001/.000	2.9500/2.9495	2.947/2.946	50"	.003/.0045	.006/.008
80 mm	3.150+001/.000	3.1465/3.1460	3.1435/3.1425	56"	.0035/.005	.0065/.008
90 mm	3.543+002/.000	3.5395/3.5390	3.536/3.535	60"	.0035/.006	.007/.010
100 mm	3.937+002/.000	3.9330/3.9325	3.929/3.928	68"	.004/.0065	.008/.011
105 mm	4.134+002/.000	4.1300/4.1295	4.126/4.125	72"	.004/.0065	.008/.011
115 mm	4.528+002/.000	4.5240/4.5235	4.519/4.518	76"	.004/.0065	.009/.012
120 mm	4.724+002/.000	4.7195/4.7190	4.715/4.714	82"	.0045/.007	.009/.012
135 mm	5.315+002/.000	5.3095/5.3090	5.305/5.303	90"	.0055/.008	.010/.014
150 mm	5.906+002/.000	5.990/5.8995	5.894/5.892	96"	.006/.0085	.012/.016

Flange Construction Methods

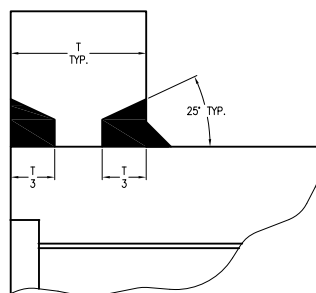


FIG. 1 - DOUBLE "J" GROOVE WITH FILLET

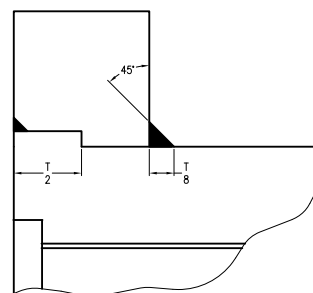


FIG. 2 - STEP WITH DOUBLE FILLET

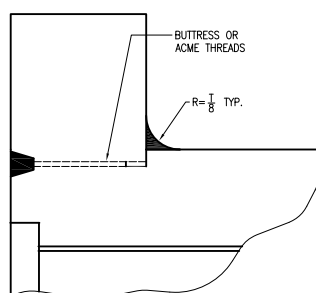


FIG. 3 - THREADED WITH DOUBLE SEAL WELD

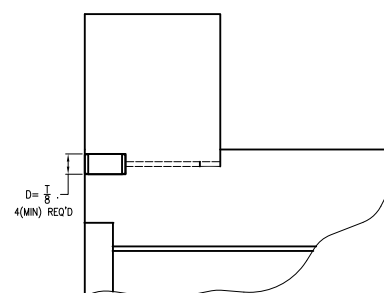


FIG. 4 - THREADED WITH DUTCHMAN

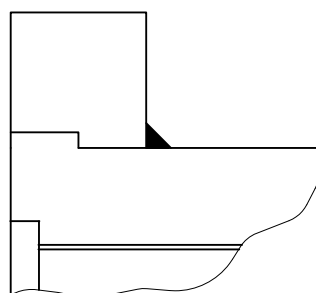


FIG. 5 - STEP WITH SINGLE FILLET

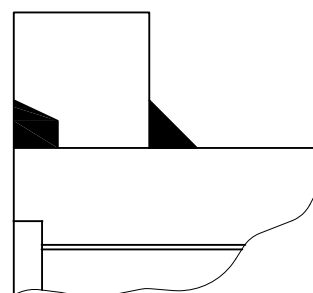


FIG. 6 - SINGLE "J" GROOVE WITH FILLET

Hardness Conversion Table

HARDNESS CONVERSION TABLE							
Brinell Indentation Dia. mm	Brinell Hardness No. 10-mm Tungsten Carbide Ball, 3,000-Kg Load	Rockwell Hardness No.			Diamond Pyramid Hardness No., Vickers	Shore Solero-scope Hardness No.	Tensile Strength (Appx) in 1,000 psi
		C Scale 150-Kg Load Brale Penetrator	B Scale 100-Kg Load 1/15-in Dia. Ball	A Scale 60-Kg Load Brale Penetrator			
2.25	745	65.3		84.1	840	91	
2.30	712						
2.35	682	61.7		82.2	737	84	
2.40	653	60.0		81.2	697	81	
2.45	627	58.7		80.5	667	79	
2.50	601	57.3		79.8	640	77	
2.55	578	56.0		79.1	615	75	
2.60	555	54.7		78.4	591	73	298
2.65	534	53.5		77.8	569	71	288
2.70	514	52.1		76.9	547	70	274
2.75	495	51.0		76.3	528	68	264
2.80	477	49.6		75.6	508	66	252
2.85	461	48.5		74.9	491	65	242
2.90	444	47.1		72.2	472	63	230
2.95	429	45.7		73.4	455	61	219
3.00	415	44.5		72.8	440	59	212
3.05	401	43.1		72.0	425	58	202
3.10	388	41.8		71.4	410	56	193
3.15	375	40.4		70.6	396	54	184
3.20	363	39.1		70.0	383	52	177
3.25	352	37.9	(110.0)	69.3	372	51	171
3.30	341	36.6	(109.0)	68.7	360	50	164
3.35	331	35.5	(108.5)	68.1	350	48	159
3.40	321	34.3	(108.0)	67.5	339	47	154
3.45	311	33.1	(107.5)	66.9	328	46	149
3.55	293	30.9	(106.0)	65.7	309	43	141
3.60	285	29.9	(105.5)	65.3	301		138
3.65	277	28.8	(104.5)	64.6	292	41	134
3.70	269	27.6	(104.0)	64.1	284	40	130
3.75	262	26.6	(103.9)	63.6	276	39	127
3.80	255	25.4	(102.0)	63.0	269	38	123
3.85	248	24.2	(101.0)	62.5	261	37	120
3.90	241	22.8	100	61.8	253	36	116
3.95	235	21.7	99.0	61.4	247	35	114
4.00	229	20.5	98.2	60.8	241	34	111
4.05	223	(18.8)	97.3		234		
4.10	217	(17.5)	96.4		228	33	105
4.15	212	(16.0)	95.5		222		102
4.20	207	(15.2)	94.6		218	32	100
4.25	201	(13.8)	93.8		212	31	98
4.30	197	(12.7)	92.8		207	30	95
4.35	192	(11.5)	91.9		202	29	93
4.40	187	(10.0)	90.7		196		90
4.45	183	(9.0)	90.0		192	28	89
4.50	179	(8.0)	89.0		188	27	87

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