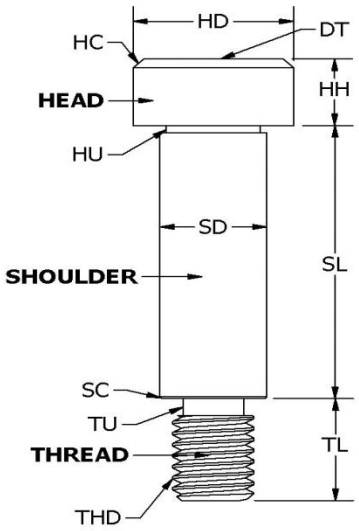
White Paper: Shoulder Screws

Dennis G. Berg, CEO & Chief Engineer
Ondrives.US Corp.
Freeport, NY 11520
www.ondrives.us

Shoulder Screws, also known as Shoulder Bolts and Stripper Bolts, are machine screws with an integral shoulder or journal between the head and the thread. Although they are not readily available in your local hardware or "Big Box" store, shoulder screws are used extensively in industry because of their versatility and unique attributes when installed. They can be found in a vast array of applications from aerospace to toys. (Fig. 1)



Column 1	Column 2
HD	Head Diameter
HH	Head Height
SL	Shoulder Length
TL	Thread Length
SD	Shoulder Diameter
THD	Thread
HU	Head Undercut
TU	Thread Undercut
HC	Head Chamfer
SC	Shoulder Chamfer
DT	Drive Type

Figure 1

Bearings can be mounted on the shoulder to create simple cam followers. Components such as pulleys, gears and sprockets will rotate on the shoulder at moderate speeds. Springs are used on the shoulder to preload components traveling axially along the length of the shoulder. The screws are used as axles for rolling parts, as pivot points, as mounting pins and as guides in sliding elements.

There are two basic shoulder screw categories: "Commercial Grade" and "Precision Grade". Precision grade shoulder screws differ from commercial grade in that they have tighter shoulder diameter and shoulder length tolerances and are ideal for use with ball bearings and other precision components. Both grades of shoulder screws are available in inch and metric sizes.

The shoulder screw is comprised of three main features: The "head" which is the largest diameter, the "shoulder" which is described by its diameter and length and the "thread" whose major diameter must be slightly smaller than the shoulder diameter.

When the thread of the shoulder screw is fully installed, the unthreaded portion extends beyond the thread and creates a journal (Fig. 2). This journal is fully functional as a shaft or dowel for rotating items such as bearings and bushings as well as for sliding applications such as punch and die pins.

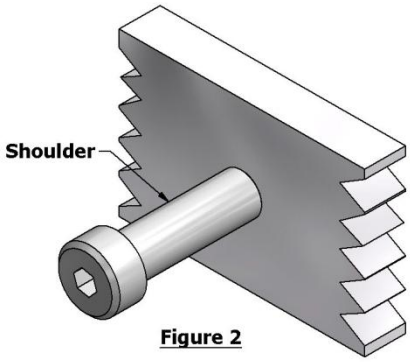


Figure 2

When mounting ball bearings, proper shoulder length and tolerances permit the screw to fix the inner race of the ball bearing and prevent it from rotating while still allowing the outer race to spin freely; thus creating a simple cam follower (Fig. 3). Shoulder screws can also be used to create a pivot point as in the case of a ratchet and pawl assembly (Fig. 4).

Figure 3

Figure 4

In addition, compression springs and sliding components can be mounted on the shoulder to allow axial motion. The sliding component is captured on the shoulder between the head of the screw and the mounting surface.

Unlike most machine screws, which are specified by thread size and thread length, shoulder screws are specified by shoulder diameter and then by shoulder length. Whereas a 1/4" x 1" machine screw describes a 1/4" diameter thread and 1" long under the head, a 1/4" x 1" shoulder screw will have a shoulder diameter of 1/4" and a shoulder length that is 1" long. The overall length of the shoulder screw will include the head height, the 1" shoulder length and the thread length.

A wide range of shoulder diameters are available and each diameter is available in a range of shoulder lengths. Both inch and metric sizes are produced as standards. Custom or made to order screws are offered by a variety of manufacturers. Materials include but are not limited to hardened alloy steel, mild steel, 300 series stainless steels, pre-heat treated 416 stainless steel, 17-4 hardened stainless steel, brass and plastics.

Standard shoulder screws are offered with pre-selected thread sizes but any thread size can be made to order. The one limiting factor to the thread size is that the thread major diameter must not exceed the shoulder diameter. This is necessary to allow components to pass over the thread and slide onto the shoulder.

Precision versus Commercial

Prior to the 1950's the only standard shoulder screws available were made of hardened alloy steel and supplied with a hex socket drive. The smallest shoulder diameter was one quarter inch. The engineering standard for these shoulder screws is detailed in ASME B18.3 for inch sizes and ASME B18.3.3M for metric sizes.

To the best of my knowledge, sometime in the early 50's, a small company, which has long since gone out of business, introduced a limited range of shoulder screws made from 303 stainless steel. This new line of shoulder screws was made to tighter tolerances on the shoulder diameter and shoulder length. At first, only 1/8", 3/16" and 1/4" shoulder diameters were offered and the complete range included only 27 sizes and they were available only as slotted drives.

To distinguish this new range of screws from the industry standard alloy steel screws, they were marketed as "Precision Shoulder Screws". By inference, the industry standard alloy screws began to be referred to as "Commercial Grade". These classifications persist today and express the basic differences between the two grades. (See the comparison chart on page 4)

Over the years, the range of sizes offered in precision grade shoulder screws has expanded considerably. Both smaller and larger shoulder diameters and their associated range of shoulder lengths have been added. Standard precision grade shoulder screws are available in diameters from 1/8" to ½" diameter. Just a few years ago, a standard selection of "*miniature*" shoulder screws were made available. These have a 3/32" shoulder diameter and lengths from 3/32" to 1/2". A limited list of standard "*low head*" shoulder screws is also available. Both can be found at www.ondrives.us/shlscrew.htm.

Other drive types such as hex socket drives and cross recess (Phillips) drives have become available as standards. The tolerance standards first created by the original manufacturer still persist although there is no established standard for precision grade shoulder screws by a recognized standards organization. A complete list of available standard, precision grade shoulder screws can be found at www.ondrives.us/shlscrew.htm.

The following chart provides the major differences in the two classifications:

Comparison of Commercial Grade and Precision Grade Shoulder Screws

	Type	Commercial Grade	Precision Grade
Engineering Standard and source of data for this table	Inch	ASME B18.3	There is no established standard by a recognized standards organization, however, almost all manufacturers of *precision grade* shoulder screws produce parts to the exact same standards that were first created in the early 1950's. These standards are detailed of this chart and can be found at www.ondrives.us/shlscrew.htm
	Metric	ASME B18.3.3M	
Range of standard Shoulder Diameters	Inch	1/4" to 2"	3/32" to 1/2"
	Metric	6mm to 24mm	2,5mm to 12mm
Shoulder Diameter Tolerance (1)	Inch	Nominal -.002" to -.004"	Nominal -.0005" to -.0015"
	Metric	6.5mm to 10mm dia. -0.013mm to -0.036mm 13mm to 16mm dia. -0.016mm to -0.043mm 20mm to 25mm dia. -0.020mm to -0.052mm	Nominal -0.013mm to -0.038mm
Range of standard Shoulder Lengths	Inch	1/4" to 10"	3/32" to 1-1/2"
	Metric	6mm to 120mm	2.5mm to 40mm
Shoulder Length Tolerance (2)	Inch	Nominal +0.005" to -.005"	Nominal +.0005" to +.0025"
	Metric	Nominal +0.125mm to -0.125mm	Nominal -0.013mm to -0.063mm
Available Head Style		Modified Fillister is the only head type available as a standard	Modified Fillister is standard but almost any head type can be made.
Manufacturing Method (normal) (3)		Cold Headed, Heat Treated, then shoulder ground.	Screw Machined (sometimes referd to as "machined from bar"
Manufacturing Advantage		Mass produced at lower unit cost	Easy to produce in small manufacturing runs and cost effective to produce custom parts
Hardness	Inch	RC 32-43	Varies depending upon material - RB83 thru RC45
	Metric	RC 36-43	
Thread on 1/4" Shoulder Dia.		#10-24	#10-32
Drive Type (normal) (3)		Hexagon Socket	Hex. Socket, Slotted, Cross Recess are standard. Torx, Tamper Proof, External Hex, External Square, etc. can be made to order.
Thread Class		UN 3A	UN 2A
Material		Alloy Steel	303 Stainless Steel and 416 Stainless Steel are the most popular and readily available; but any machinable material can be requested.
Finish		Black Oxide on head and thread, the shoulder diameter is left unfinished.	No finish on stainless steel screws
Manufacturing Differences		The Cold Heading process produces a smooth burr free hex socket cavity.	The hex socket drive is developed by drilling a round hole and then punch broaching the hex. This produces a firmly attached burr at the base of the socket.

(1) *Precision grade shoulder screws* are designed for a more precise fit with ABEC 3 and higher *precision ball bearings* . They are also ideal for use with *precision grade gears* and other precision toleranced components

(2) The shoulder length tolerance is a significant difference between *commercial grade* and *precision grade* shoulder screws. The *commercial grade* tolerance allows the shoulder length to be up to 0.005 inch or 0,125mm below the nominal length. This loose tolerance creates a possible interference when a component with a "thru the bore" length is mounted on a shoulder screw with the same nominal length. The undersize shoulder length may bind with a full sized component and prevent it from rotating freely. The shoulder length tolerance of a *precision grade* shoulder screw is .0005 to .0025" above nominal. It was specifically designed this way allow for free movement of rotating components.

(3) Almost any head type or drive type can be made in either grade, however the cost of tooling for *cold headed* parts normally indicates larger quantities while *screw machined* parts are economical in smaller quantities.

Source:
ASME B18.3
ASME B18.3.3M
Industrial Fasteners Institute - Inch Fastener Standards, 7th Edition
Industrial Fasteners Institute - Metric Fastener Standards, 3th Edition
Ondrives.US Corp - Precision Shoulder Screw Standards
www.ondrives.us/shlscrew.htm

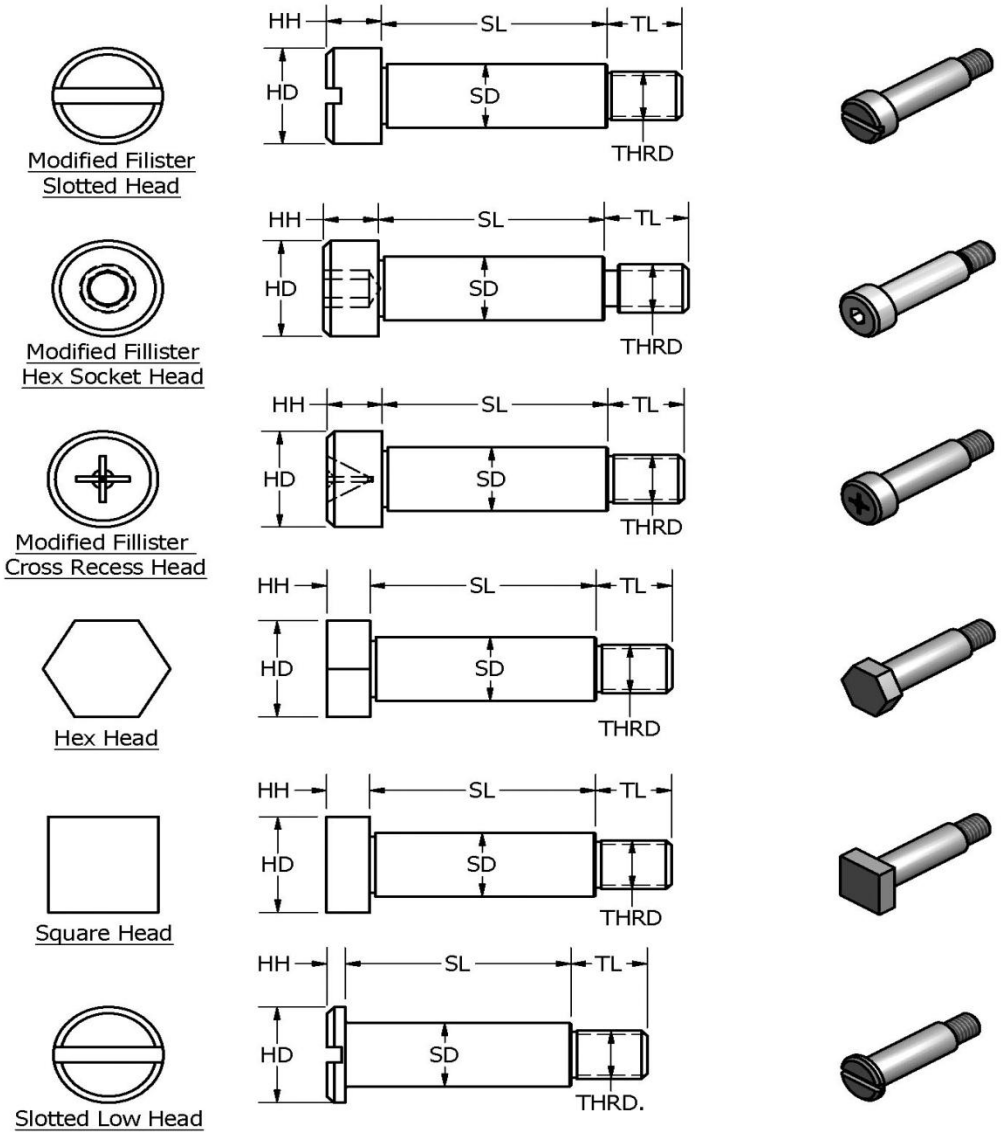
TERMINOLOGY AND FEATURES:

Stripper Bolts:

This is a term often used to specify shoulder screws when used in punch and die mechanisms or plastic injection mold sets. The screws act as linear slides to accurately align the die or mold halves as they open or close.

Drive Types:

Commercial grade, alloy steel shoulder screws are supplied almost exclusively with Hex Socket drives. Precision grade shoulder screws are readily available in Slotted drive and Hex Socket drive and to a lesser degree, in Phillips drive. Torx drive, Star drive, Tamper Proof drives, Square Head drive or Hex Head drives can also be supplied. (Fig. 6)



Other Drive Types and Head styles can be supplied **Figure 6**

Head Types:

The typical head style for shoulder screws is a modified Fillister head in which the head diameter is approximately twice the head height. Unlike the standard Fillister style machine screws, shoulder screws have a flat top with a 45 degree chamfer on the heads outer diameter. Less popular head styles include the Truss head and a Low Head Fillister. External Hex Head and Square Head screws are sometimes made which require the use of a wrench for installation but have an advantage in that they can be made with an extremely shallow head height. (Fig. 6)

Head Diameter:

The head diameter is the largest diameter of the screw (Fig. 1). It is typically twice the head height and 30% to 50% larger than the shoulder diameter. The tolerances used for the head diameter are ± .005" for inch screws and ± 0,127mm in the metric sizes. The Head Diameter on Commercial Grade screws can be supplied with a straight knurl on the head diameter at the manufacturers' option or the customers'

request. (Fig.5)

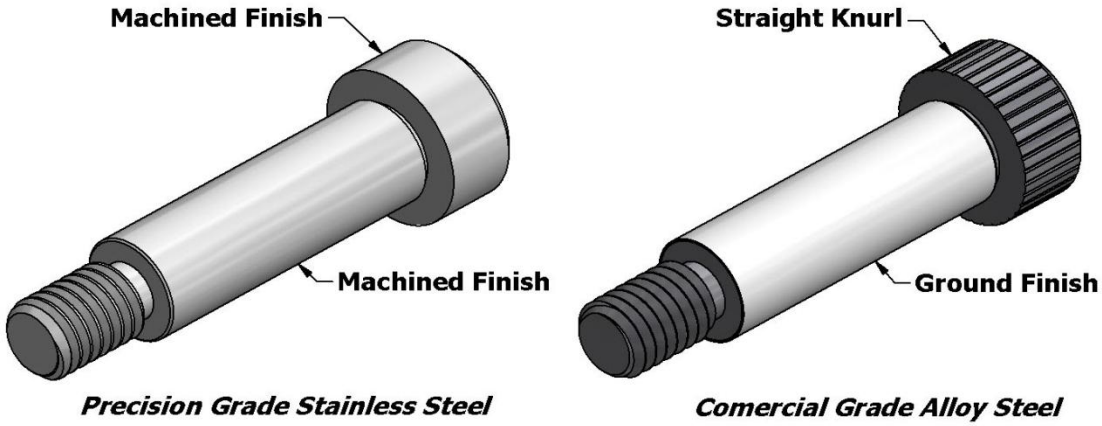


Figure 5

Head Height: Both commercial and precision standard shoulder screws have a head height of half the head diameter. *Head height* tolerances are normally ± .005" for inch screws and ± 0,127mm for metric screws. Special "low head" shoulder screws are available in which the head height is just thick enough to accommodate a flat screw driver slot or the screw head is otherwise made as a square head or hex head.

Phillips drives and hex socket drives are not appropriate for low head shoulder screws due to manufacturing and design difficulties. In a "low head" screw, a Phillips drive or hex socket drive will closely approach the head undercut and create a potential fracture point. The manufacturing process of punching or broaching these drives would frequently cause the heads to break off.

Head Chamfer:

The head chamfer on standard modified fillister head shoulder screws is 30 to 50 degrees from the plane of the top of the head. The chamfer may be slightly rounded. Other head styles may or may not be chamfered. Occasionally a chamfer or radius is supplied on the bottom of the head.

Head Undercut, (also called Shoulder Neck Diameter):

There is an undercut on the shoulder diameter just below the head (Fig. 1). This allows mating components to mount flush against the head. The width of the undercut is included when measuring the shoulder length.

On Precision shoulder screws, there are no dimensional standards for the depth of this undercut but most manufacturers keep it to a minimum. Generally the undercut diameter is .006" to .015" below the shoulder diameter.

Commercial shoulder screws have standard shoulder neck diameters established in ASME B18.3 and ASME B18.3.3M. (Fig.7)

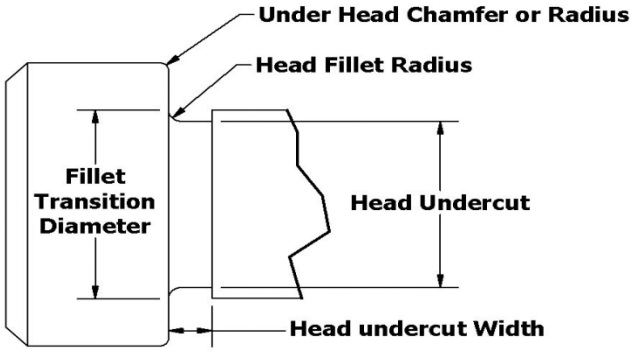


Figure 7

Head Fillet Radius:

There is a fillet where the head undercut meets the head. The high point of this radius may not exceed the shoulder diameter. Commercial shoulder screws have standard *head fillet radius* established in ASME B18.3 and ASME B18.3.3M. The *head fillet radius* is generally not used on precision grade shoulder screws. (Fig. 7)

Fillet Transition Diameter:

The *fillet transition diameter* is the maximum diameter created by the head fillet radius. (Fig. 7)

Full Head Radius:

A *Full Head Radius* is used in place of a *head undercut*. The *head undercut* is eliminated and a radius between the shoulder diameter and the bottom of the head is supplied. This option is used infrequently. If the full radius makes contact with a component mounted on the shoulder it may prevent the component from seating properly or rotating smoothly. (Fig. 8)

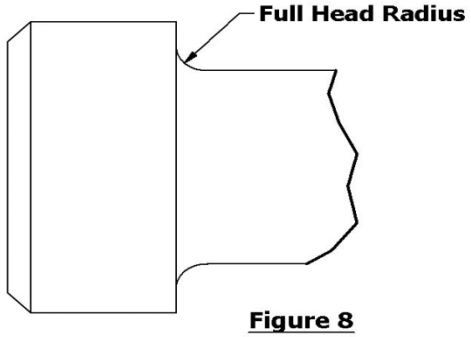


Figure 8

Head Undercut Width, (also called Shoulder Neck Width):

The *Head Undercut Width* is the maximum width (length) of the *head undercut* .

On Precision shoulder screws, there are no dimensional standards for the width of this undercut but most manufacturers keep it to a minimum. Small shoulder diameter screws may have an undercut width of .025" while larger diameter screws may have a width of .042" or even slightly larger.

Commercial shoulder screws have standard *head undercut width* dimensions established in ASME B18.3 and ASME B18.3.3M. (Fig. 7)

Under the Head Chamfer or Radius:

The *under the head chamfer or radius* refers to an optional edge break on the bottom of the head. ASME B18.3 and ASME B18.3.3M specify a maximum dimension for this chamfer or radius. Generally precision grade shoulder screws do not have an *under the head chamfer or radius.* (Fig. 7)

Shoulder Diameter:

Various shoulder diameters are offered as standards in inch and metric in both precision grade and commercial grade. Any diameter can be made as a custom part.

Shoulder Diameter Tolerance:

Precision grade shoulder diameters have a tolerance of minus .0005" to minus .0015" below the nominal size. Precision grade metric screws are minus 0,013mm to minus 0,038mm below nominal. They are intentionally toleranced this way to accommodate a close, but free fit with nominal sized components such as bearings and pulleys. Commercial grade screws have a larger tolerance range. They are .002" to .004" below nominal diameter. Commercial grade metric screws are made below the nominal diameter but the tolerance increases as the diameter increases. Refer to ASME B18.8.3M or to the comparison chart on for exact tolerances.

Shoulder Length:

Shoulder screws of a single shoulder diameter are offered in a range of incremental shoulder lengths. Shoulder lengths are measured from under the head to the bottom of the shoulder. This includes the *head undercut* dimension. (Fig. 1)

Shoulder Length Tolerance:

A significant difference between Commercial and Precision shoulder screws is the *shoulder length tolerance*.

Precision grade shoulder lengths are made plus .0005" to plus .0025" above the nominal length and metric screws are plus 0,013mm to plus 0,063mm over nominal allowing for a free fit with nominal sized mating components.

Commercial shoulder screws have a *shoulder length tolerance* that is ± .005" or ± 0.125mm. This can cause a binding condition when a full width component is mounted on a shoulder screw that was made on the short end of the allowable tolerance. For this reason, designers must properly size the "through the bore length" of the mating component when using a commercial grade shoulder screw.

Thread:

Inch threads are specified by major diameter and threads per inch. Metric threads are specified by major diameter and pitch. The major thread diameter of a shoulder screw must not exceed the shoulder diameter.

Thread Length:

Thread length is the distance from under the shoulder to the end of the thread. This includes the Thread Undercut dimension. Shoulder screws have relatively short thread lengths but can be produced to any required dimension. As in machine screws, thread lengths are always held to a minus tolerance and vary slightly from among manufacturers. (Fig. 1)

Thread Class :

In an odd reversal of what would be expected; *commercial grade* shoulder screws have UNC class 3A threads and *precision grade* shoulder screws, regardless of head or drive type, have UNC class 2A threads as standard. Precision shoulder screws can be manufactured with class 3A threads as a custom made part.

Thread Undercut:

The *thread neck diameter* and *thread neck width* together are often referred to as the *thread undercut*. Both Precision Grade and Commercial Grade screws have an undercut between the shoulder and the thread. It is slightly below the minimum thread diameter. (Fig. 1)

This undercut is necessary for manufacturing and permits the shoulder to seat flush with the threaded component however the *thread undercut* reduces the diameter of the screw at that point and it is the weakest point of the screw. When the screw is over torqued it will normally fracture at this point.

Thread Neck Diameter:

On precision shoulder screws, there are no dimensional standards for the depth of this undercut but most manufacturers keep it to a minimum. Generally the *thread neck diameter* is between .002" to .005" below the minor thread diameter.

Commercial shoulder screws have standard *thread neck diameters* established in ASME B18.3 and ASME B18.3.3M. (Fig. 9)

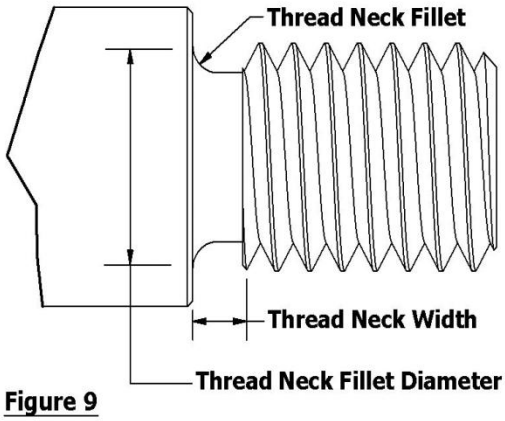


Figure 9

Thread Neck Width;

Thread neck width is the maximum width of the undercut between the shoulder and the thread. In precision grade shoulder screws the width is equal to the width of 1-1/2 threads. Commercial grade *thread neck widths* are established in ASME B18.3 and ASME B18.3.3M. (Fig. 9)

Thread Neck Fillet:

ASME B18.3 and ASME B18.3.3M specify the Max. and Min. fillet to be supplied on the thread neck. The maximum diameter of the fillet may not exceed the major diameter of the thread or it may interfere with a flush fit of the shoulder against the mating component. (Fig. 9)

Head and Drive Types:

Hexagon Socket (Also called Hex Socket):

Hex socket refers to a hexagon shaped cavity in the screw head used in connection with a hex key to drive the screw into place. Standard hex socket size is established for all standard shoulder screws based on the shoulder diameter. Refer to ASME B18.3 and ASME B18.3.3M for commercial grade shoulder screws and to www.ondrives.us/shlscrew.htm for precision grade shoulder screws. Key Engagement is the minimum amount that the hex key engages in the socket cavity. Most standard shoulder screws have a minimum key engagement of 75% of the hex socket size. (Fig.10)

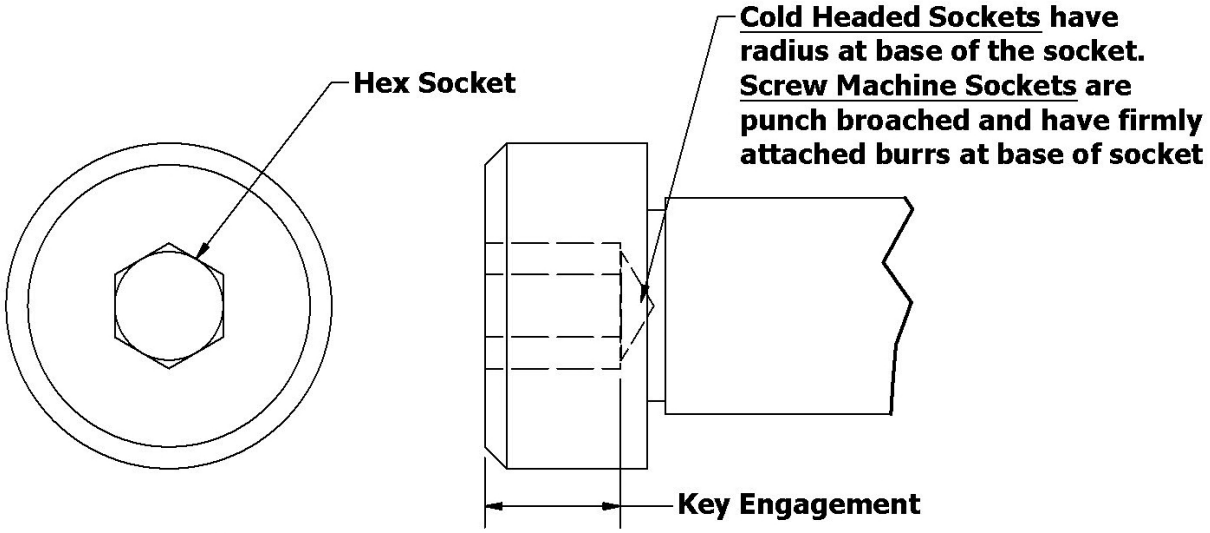


Figure 10

Slotted Drives

As a standard part, slotted drives are available only on precision grade shoulder screws and not on commercial grade. Dimensions can be found at www.ondrives.us/shlscrew.htm.

Cross Recess or Phillips Drives

Cross recess drives are also only available on precision grade shoulder screws as a standard. Drive sizes standards are established for each shoulder diameter and can be found at www.ondrives.us/shlscrew.htm

Custom Heads and Drives:

As previously discussed, any number of head styles and sizes as well as drive types can be produced.

Materials:

303 Stainless Steel in a cold drawn condition is the most prominent material of the precision grade shoulder screws. It provides excellent corrosion resistance. It is an Austenitic material and cannot be hardened by heat treatment. It may be mildly magnetic due to work hardening. 18-8 stainless is also specified which permits a manufacturer to use any 300 series stainless steel. 303 stainless steel shoulder screws have an approximate hardness of Rockwell B83 and the tensile strength is 75 to 90 ksi.

316 Stainless Steel is similar to 303 but has better corrosion resistance. It is ideal for marine applications. It is an Austenitic material and cannot be hardened by heat treatment. The Rockwell hardness for 316 Stainless Steel is B83 to B90. Tensile strength rums between 75 ksi and 90 ksi. 316 stainless steel shoulder screws are not available as standards but may be made to order. Screws made of 316 Stainless are considerably more expensive than 303SS due to more difficult machinability.

17-4 PH Stainless Steel is a Martensitic precipitation hardening material heat treatable up to the mid Rc 40's. 17-4 stainless steel is nonmagnetic and will appear brown in color due to the heat treat process. When 17-4PH stainless steel is heat treated to an H900 condition after machining it achieves a minimum hardness Rc40 and a minimum tensile strength of 150 ksi.

416 Stainless Steel is stronger and harder than 303 and 316 stainless steel but is not as corrosion resistant and may develop surface corrosion. 416 stainless steel is highly magnetic. 416 stainless steel shoulder screws are generally machined in a pre-hardened, Rc 26 minimum condition offering a minimum tensile strength of 123 ksi.

Alloy Steel is the prominent material of the commercial grade shoulder screw. Most screws are made of a high strength alloy such as 4140. Rockwell hardness is C32-43 with a minimum tensile strength of 144 ksi. The hardening process turns the screw black but the shoulder is ground after hardening which leaves this surface bare steel. Alloy screws are heat treated by oil quenching from above the transformation temperature and then tempered at a temperature not lower than 650 degrees F.

Mild Steel: Any number of mild steels can be used to manufacture shoulder screws. They can cover a range of hardness and tensile strengths. They will be magnetic and are frequently plated to improve corrosion resistance or appearance. Unhardened mild steel shoulder screws are often chosen as a less expensive alternative to stainless or hardened steel screws in light duty applications.

Brass is a soft material and it is specified for light duty applications. Because it has a natural lubricity, it works well with rotating or sliding components. It also has the advantage of being totally non-magnetic.

Plastics: Numerous plastics can be used for shoulder screws. Plastic screws most often have reduced surface hardness and tensile strength compared to metal screws. Most plastics will be electrically non-conductive. Some plastics are injection moldable and can be manufactured in large quantity and at considerable cost savings. Precision grade tolerances cannot easily be held on most plastics leading one to understand that plastic screws, whether molded or machined, are considered commercial grade.

Materials verification: All reputable manufacturers will supply "raw material certifications" if requested.

300 series stainless steels, 400 series stainless steels, mild steels, unhardened alloys steels and plated brass can look alike. If there is a need to verify the material, the following may be helpful:

- 300 series stainless steel will be non-magnetic or very slightly magnetic due to work hardening. Generally the 300 series parts will not be able to hold the weight of a decent sized magnet. All other steels mentioned above are highly magnetic.
- To isolate magnetic 400 series stainless steel parts from non-stainless parts, a quick dip in a saturation solution of cupric sulfate will instantly show the difference. Cupric sulfate acts on non-stainless steel parts by discoloring them copper, brown or black. All stainless steels are unaffected.
- Brass with chrome plating looks like stainless steel. It is non-magnetic and will not react to the cupric sulfide. To distinguish it from 300 series stainless it is necessary to grind away an area of the plating and look for the brass color beneath.

Options:

Shoulder screws are often supplied with an anti-vibration thread locking element on the threads. Certain materials can be plated for corrosion resistance or appearance.

* * * * *

Commercial grade shoulder screws, in standard sizes, are available from most fastener and bearing distributors. Non-standard sizes, when produced by the "cold heading" method, are not economically feasible unless they are produced in rather large quantity, i.e. tens of thousands. Commercial grade shoulder screws were the "Industry Standard" but are being replaced in many applications by Precision Grade screws.

Designers are given much more versatility when they source shoulder screws from precision manufacturers. Standards are available in a variety of materials and drive types. Smaller shoulder

diameters and lengths are offered as standards and the tighter manufacturing tolerances assure non-interference fits when assembled to components.

Because of the different methods of manufacturing, screw machined versus cold headed, custom screws are quickly and inexpensively produced in any quantity. Almost any variation can be supplied. Non-standard shoulder diameters, shoulder lengths, head types, drive types and thread sizes can be manufactured in most materials. The designer can specify every characteristic that he or she desires rather than trying to make a standard screw fit in the application.