ME102B: MINI-PROJECT REPORT
Prosthetic Joint

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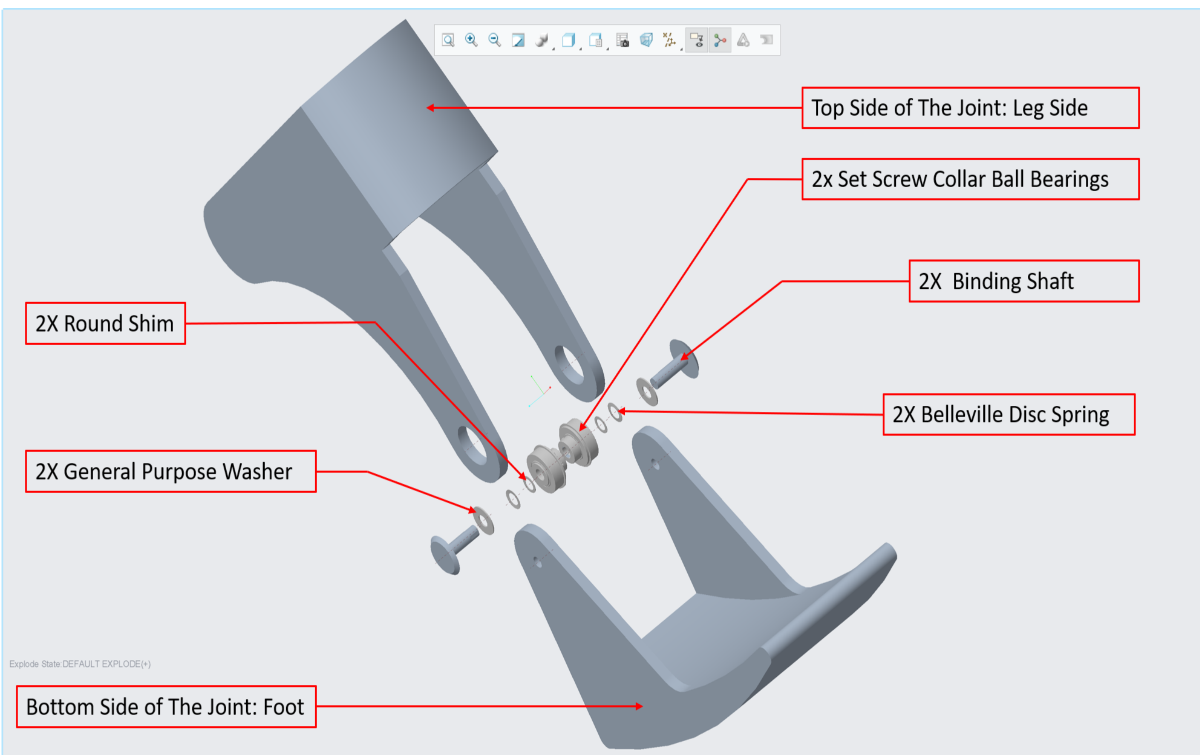
1. Product Description

Prosthetic limbs are one of man's greatest inventions. They come in many different shapes and sizes. The design of prosthetic limbs are usually based on certain important factors which includes the weight of user and activities the user would use it for, say mostly running or mostly walking. The Joint Prosthetic sub-assembly in this design was designed for a 300 lbf male or 1334.47 N. As a sub-assembly, most of the main components are not included in this design such as springs, motor, cables, just to name a few.
That said, this sub-assembly consists of a Top (leg) Side, Bottom (foot) Side, ball bearings, Binding Shaft, Round shim, Disc Springs and General purpose Washer.
Below is an exploded view with all the parts shown.

- **The Prosthetic Joint (Exploded View)**



As shown in the exploded view above, the bottom or foot side of the prosthetic joint is designed to be wider than the top side and wide enough to be used to support the weight. The buttom side is connected directly to the shaft with tolerances for a sliding fit whereas the Top side of the joint is designed to connect directly to the outer race of the ball bearing with a locational clearance fit. The ball bearing is preloaded by placing the shims and disc spring on the shaft between the foot side and bearings. Based on the specific size of the foot, it is able to tightly hold the parts together to preload. The Binding shaft also goes right through all of the assembly and held in places by the set screws on the collar ball bearings. The set screws when tightened holds the shaft at the part of the shaft with flats.
Below are the designed parts of the Prosthetic Joint with dimensions in figures . Engineering and CAD drawings of all parts that will be purchased from a vendor will be purchased can be found in the appendix.

- **Forces** Not forgeting the fact that this is just a sub-assembly, the metal frames (Leg and foot), ball bearings and shaft will be subjected to forces which are typically the weight of the user. As mentioned early on, male weighing 1334.47 N (300 lbs) will exert that amount of force on the joint during motion. Ideally, in a complete prosthetic limb, the outside metal frame will not be subjected to all the forces. There would usually be a metal rod or any other kind of design in the middle section with springs and motors where the rod may be designed to behave as a dashpot and or with springs the evenly distribute the forces.

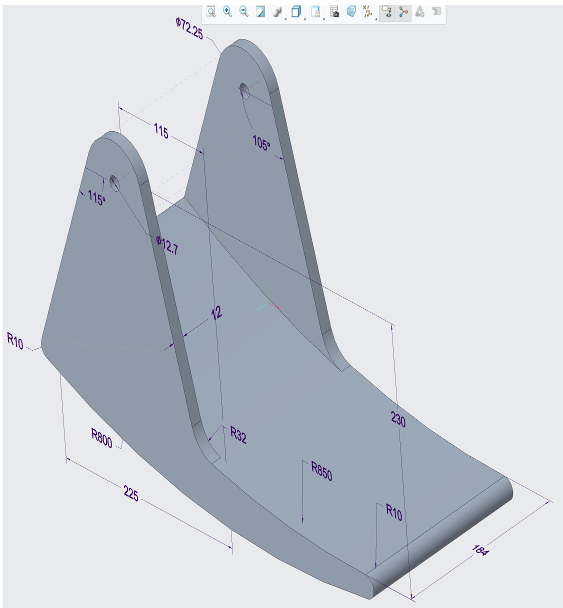


Figure 1: Bottom/Foot Side

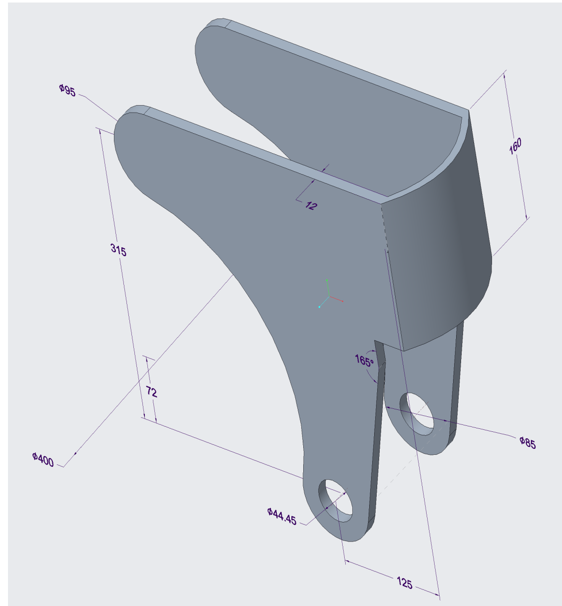


Figure 2: Top/Leg Side

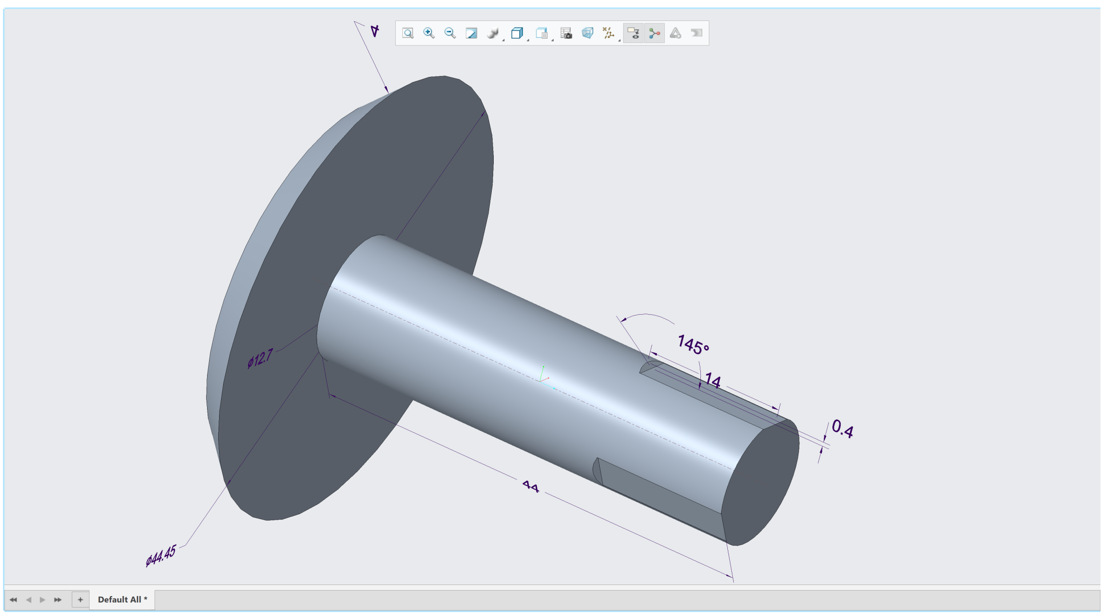


Figure 3: Binding Shaft

For the purpose of this design, it can be assumed as though the force the user would exert on the joint would only be supported by the components shown.
That said, whenever the user walks, this sub-assembly is subjected to the weight of the user intermittently as the other leg will be lifted off the ground whiles the Prosthetic limb supports his weight. The forces in the sub-assembly will therefore be distributed as shown in figure 4 below.

As shown, it can be seen that the forces are evenly applied through the top side unto the two ball bearings, hence

$$F1 = F2 = \frac{1}{2}(1334.47N) = 667.235N \tag{1}$$

These forces F1 and F2, would transmit right through and in turn apply those forces on the shaft then unto the Bottom part. According to newtons third law, the Bottom part also exerts the same amount of force through the to the Ball Bearings hence

$$F3 = F4 = F1 = F2 = 667.235 \tag{2}$$

The Ball Bearings however based on it's dimensions, can withstand huge amounts of force upto 2550lbs under dynamic loading and 1000lbs under static loading. Based on these numbers, the ball bearing would survive a 300lbs man. I also designed the shaft to have a reasonable diameter to be able to withstand the shear forces during walking. The shaft however could be a place where I would expect failure when considering the fact that there is not other component to support the weight. As a result, prototyping this design would be a great way to further investigate the design.
I also designed the Bottom part such that with a spring attached, would initiate motion hence the circular looking shape. And for the Top and Bottom to also be able to withstand the forces, I designed them to have 12mm thickness (almost the same diameter as the shaft) and just like the shaft, as they are made of steel (As the material for the final product) they can withstand really high force.
After a few prototypes and testings, the sizes and materials could be adjusted and changed to optimize the performance of the join. However, based on the capabilities of the Ball Bearings, it may be over designed and hence changes could be made to produce the final product.

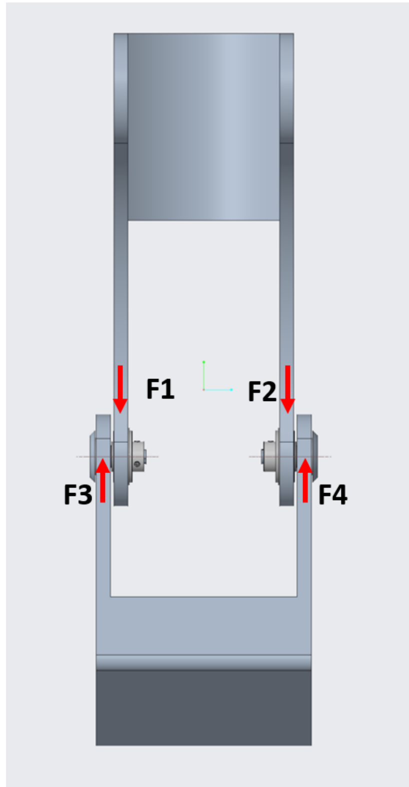


Figure 4: Force distribution

2. Fabrication and Parts And Tools List

- **Fabrication**
  Although there may be several ways to fabricate the prosthetic sub-assembly joint, The best way to fabricate for the purposes of prototyping, 3D printing the designed components will be the best way. Given the designed components, the design is not too complicated and therefore easily achievable with a 3D printer. However when it comes to the tolerances and agility, the 3D printed components may not be able to give the precision needed for all the parts to fit perfectly together and to support the a 300lbf male or 1334.47N which it was designed for.
  Besides the main parts being 3D printed for the purposes of prototyping, all other parts such as the ball bearings, shim and disc spring will be purchased from McMaster-Carr. In the table below is a list of the components, parts and tools that make up the prosthetic joint sub-assembly. In addition, the quantity needed, vendor and materials they are made of are listed in the table.

PARTS AND TOOL LIST			
PART N0.	**PART NAME (QTY)**	**MATERIAL**	**VENDOR/MACHINE SHOP**
4768K11	Set Screw Collar Ball Bearing (2)	Steel, Plastic,Rubber	McMaster-Carr
97022A240	Round Shim (2)	316 Steel	McMaster-Carr
94065K44	Belleville Disc Spring	High Carbon Steel (2)	McMaster-Carr
MS-1	Binding Shaft (2)	Stainless Steel	Machine Shop
MS-2	Bottom Side of Joint (Foot) (1)	Stainless Steel	Machine Shop
MS-3	Top Side of Joint (Leg) (1)	Stainless Steel	Machine Shop
90107A033	General Purpose Washer (2)	Stainless Steel	McMaster-Carr
5020A33	Ball-End L-Key	Stainless Steel	McMaster-Carr

3. **Assembly Procedure**

To Assemble the prosthetic joint, double check the list above to make sure you have all the parts and tools needed to complete the assembly. After confirming all parts and tools,

- Get the Top/Leg side ready and by applying pressure on the outer race, carefully install the Ball Bearings in the holes of the Leg, such that the ring on the outer diameter of the Ball Bearing touches the inside of the Leg. It may take a sizeable amount of force to install the bearing. Do this with both bearings.
- When the ball bearing is properly installed, the inner race should be outward and the parts with the set screws will be on the inside.
- After this, install the general purpose washers unto the Binding Shaft such that it touches the head of the shaft.
- The following procedures may require two people to correctly perform the Assembly otherwise a holding device may be required for one person to perform the Assembly.
- After this, align the holes in the Belleville Disc Spring with the Round Shim then with the holes in the Ball Bearing such that the Round Shim and Disc Spring comes in contact with the inner race of the Ball Bearing and does not touch the outer race at all.
- Holding the aligned parts in position, align the holes in the the Bottom part with the aligned holes.
- Note that based on the design of the Bottom part, it may be difficult to get the holes to align as the Bottom side is designed with just the right dimension to barely hold components together.
- In this holding position with all the holes aligned, Carefully push the shaft through all the holes such that it appears on the other side of the Ball Bearing.
- By ensuring that the flat on the shaft is positioned such that the Set Screws in the Ball Bearing sits directly on top of the flat.
- By applying a reasonable amount of force on the head of the shaft to preload the bearings, use the L-key to tighten the Set Screws to hold the Shaft in place.
- Repeat Steps above to install the other Binding shafts.

APPENDIX:

Data Sheet and 2D drawings of Parts To Be Purchased From Vendor

- **Ball Bearings**

McMASTER-CARR.

4768K11

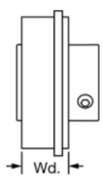
Set Screw Collar Ball Bearing

with Steel Ring, Trade No. 7608-2RS, for 1/2" Shaft Diameter

Each

ADD TO ORDER

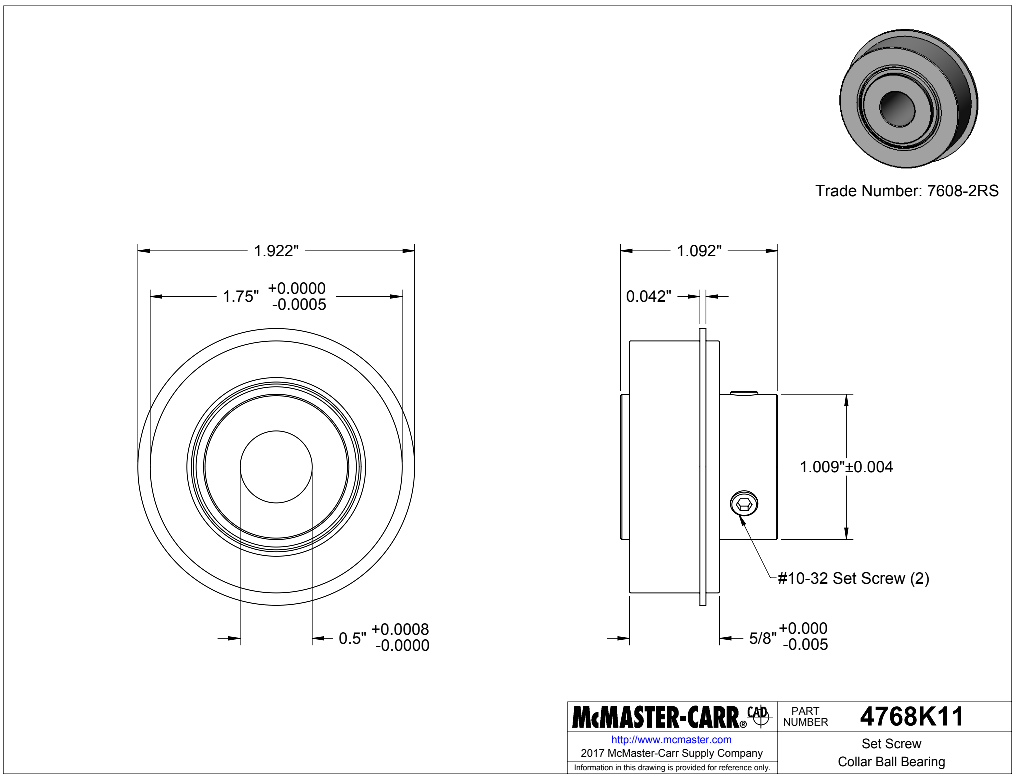
In stock
$37.88 Each
4768K11



Bearing Type	Ball
For Load Direction	Radial
Construction	Single Row
Inner Ring Type	Extended
Ball Bearing Type	With Retaining Ring
Trade No.	7608-2RS
For Shaft Type	Round
For Shaft Diameter	1/2"
ID	0.5"
ID Tolerance	0" to 0.0008"
For Housing ID	1 3/4"
OD	1.75"
OD Tolerance	-0.0005" to 0"
Width	5/8"
Width Tolerance	-0.005" to 0"
Inner Ring	
OD	1.009"
Min. OD Tolerance	-0.004"
Maximum OD Tolerance	0.004"
Width	1.092"
Retaining Ring	
OD	1.922"
Thickness	0.042"
Ring Material	Steel
Ball Material	Steel
Cage Material	Nylon Plastic
Seal Type	Sealed
Seal Material	Buna-N Rubber
Radial Load Capacity, lbs.	
Dynamic	2,550
Static	1,000
Maximum Speed	5,000 rpm
Lubrication	Lubricated
Lubricant	Grease
Shaft Mount Type	Set Screw
Set Screw Thread Size	10-32
Number of Set Screws Included	2
Temperature Range	-20° to 250° F
ABEC Rating	Not Rated
Radial Clearance	0.0002" to 0.0012"
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2020, 209 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States

Slip these bearings onto a shaft and secure with the included set screws, no special tools required. All have an extended inner ring for additional shaft support. A removable retaining ring holds the bearing inside a housing.

Sealed bearings block out dust and other contaminants better than shielded bearings.



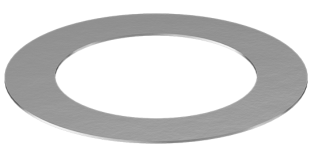
- **Round Shim**

McMASTER-CARR

97022A240

316 Stainless Steel Ring Shim

0.025" Thick, 1/2" ID



Packs of 10

ADD TO ORDER

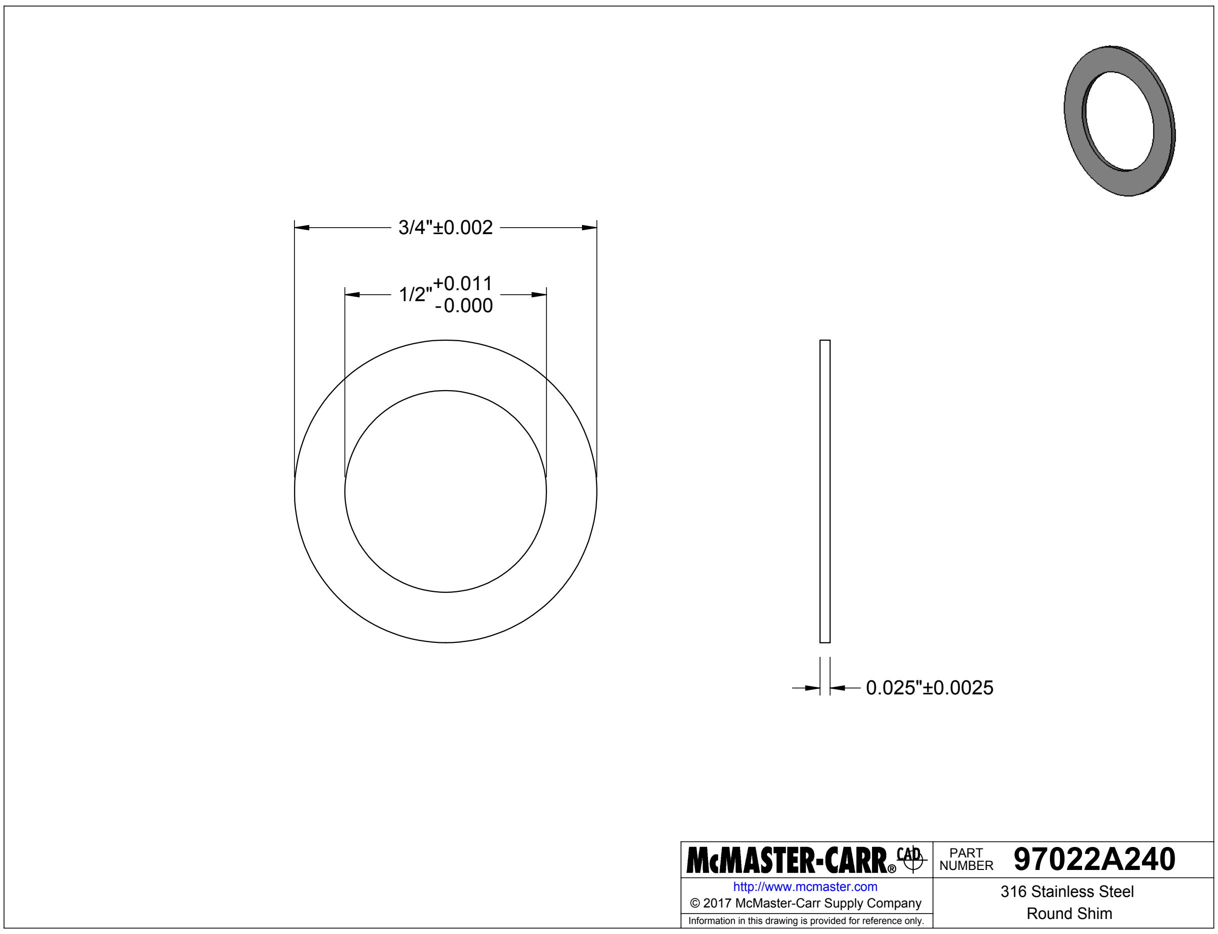
In stock
$5.69 per pack of 10
97022A240

Shape	Ring
System of Measurement	Inch
Thickness	0.025"
Thickness Tolerance	-0.0025" to 0.0025"
ID	1/2"
ID Tolerance	0" to 0.011"
OD	3/4"
OD Tolerance	-0.002" to 0.002"
Material	316 Stainless Steel
Min. Hardness	Rockwell B70
Specifications Met	ASTM A240
Magnetic Properties	May Be Mildly Magnetic
Passivation	Not Passivated
Individual/Set	Individual
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2020, 209 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States

Precisely align, level, and adjust spacing on fasteners, shafts, and machinery with these shims.

For accurate leveling, choose materials such as steel or stainless steel, which are hard enough to resist scratching and deforming. Softer shims, like copper or aluminum, can be used as wear plates between components that rub together, preventing damage to equipment.

Stainless steel shims are more corrosion resistant than steel shims. 316 stainless steel shims have the best corrosion resistance of our stainless steel shims.



- **Belleville Disc Spring**

McMASTER-CARR

94065K44

Belleville Disc Springs

for Ball Bearing Trade No. R6, 0.539" ID

ADD TO ORDER

94065K44

Compressed Ht. at Working Load

Thick.

Nested Stack | Inverted Stack | Nested and Inverted Stack

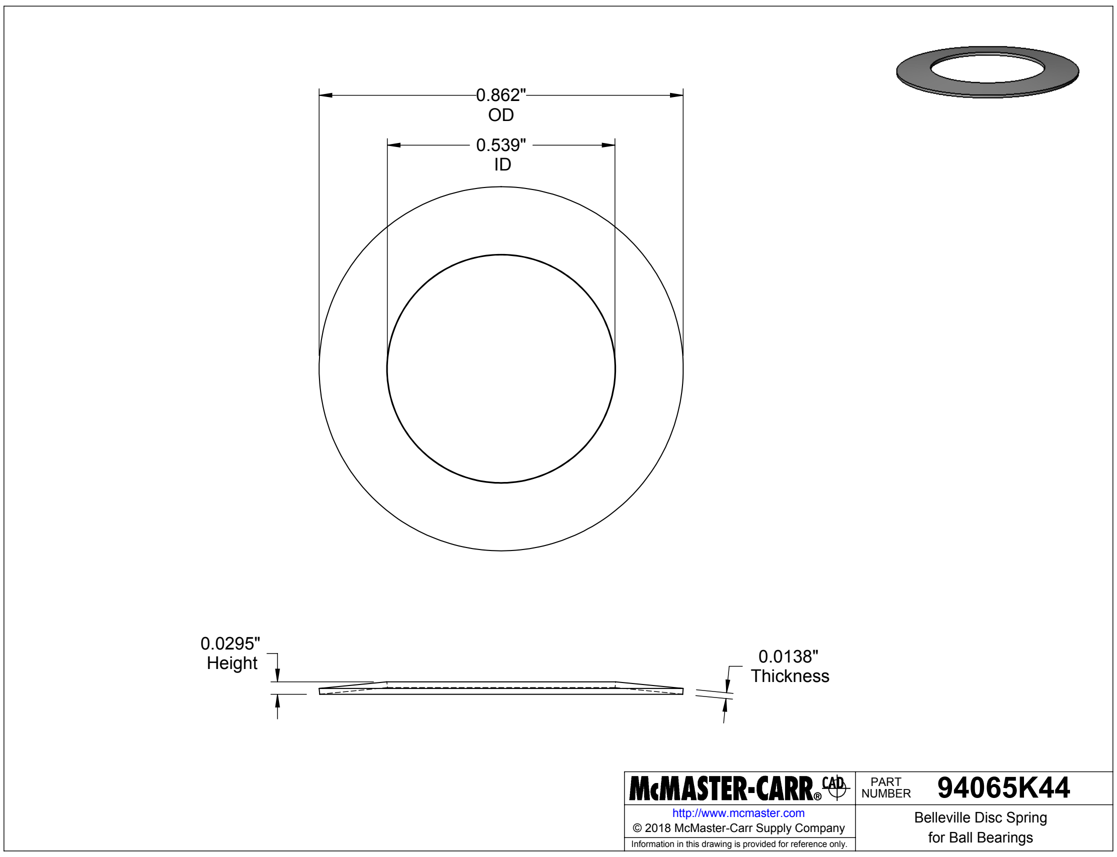
Stacking Configurations

Spring Type	Disc
Disc Spring Type	Belleville
For Bearing Type	Ball
For Bearing Trade Number	R6
ID	0.539"
OD	0.862"
Thickness	0.0138"
Height	0.03"
Compressed Height @ Working Load	0.018"
Deflection @ Working Load	0.012"
Working Load	11 lbs.
Flat Load	Not Rated
Material	High-Carbon Steel
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2020, 209 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Peoples Republic of China

Install these springs, also known as bearing preload washers, against ball bearings to reduce noise and unwanted movement along the shaft. Unlike Belleville washers, they return to their original height once working loads are removed.

Deflection is the distance a spring compresses under load. Flat load is the load at which the spring is completely compressed.

Springs may be stacked to increase working load and deflection. In a nested stack, working load is multiplied by the number of springs used, while deflection remains unchanged. In an inverted stack, deflection is multiplied by the number of springs used, while the working load remains unchanged. In a nested and inverted stack, both load and deflection are increased.



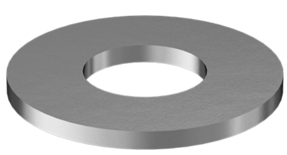
- **General Purpose Washer**

McMASTER-CARR

90107A033

316 Stainless Steel Washer

for 1/2" Screw Size, 0.531" ID, 1.25" OD



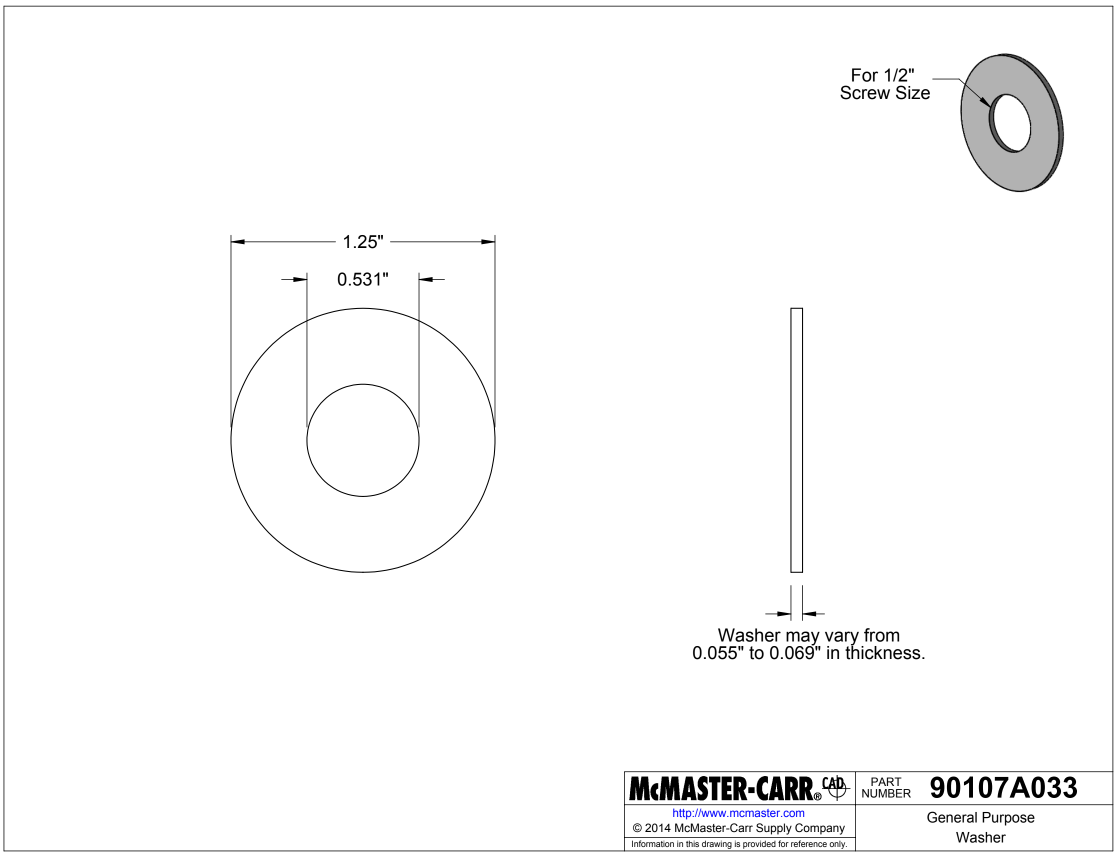
Packs of 25

ADD TO ORDER

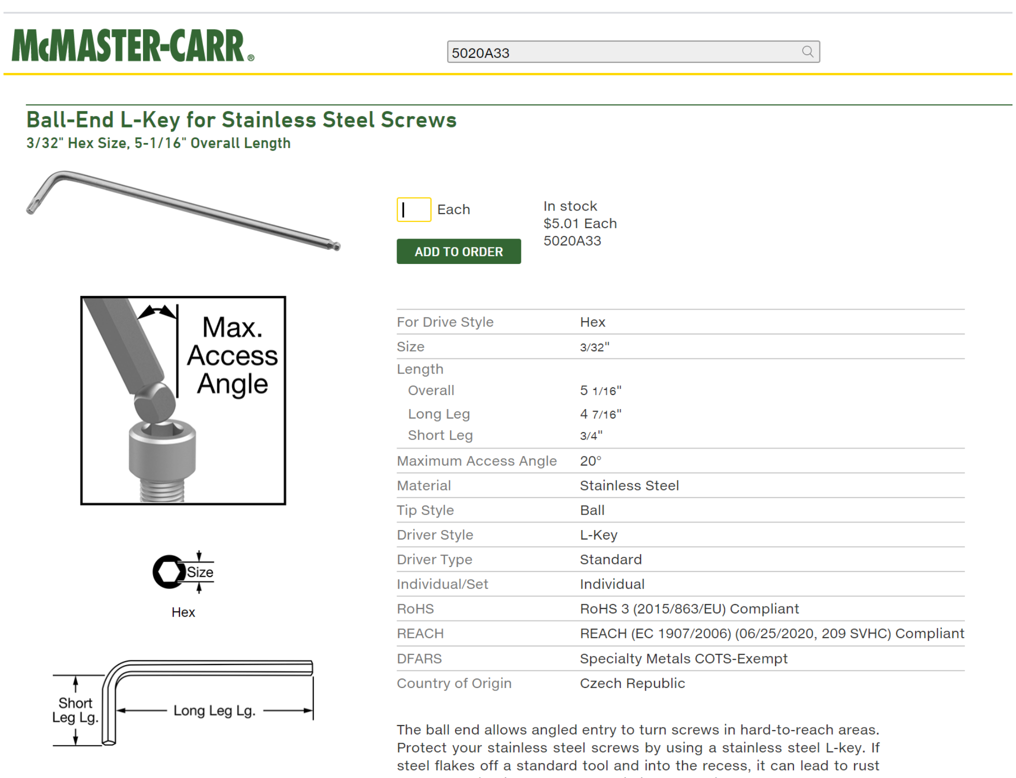
In stock
$8.16 per pack of 25
90107A033

Material	316 Stainless Steel
For Screw Size	1/2"
ID	0.531"
OD	1.250"
Thickness	0.055"-0.069"
Washer Type	Flat
System of Measurement	Inch
Hardness	Not Rated
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2020, 209 SVHC) Compliant
DFARS	Not Specialty Metals Compliant
Country of Origin	India, Peoples Republic Of China, or Taiwan

316 stainless steel washers have excellent resistance to chemicals and salt water. They may be mildly magnetic.



- **Alan Key**



For Drive Style	Hex
Size	3/32"
Length	
Overall	5 1/16"
Long Leg	4 7/16"
Short Leg	3/4"
Maximum Access Angle	20°
Material	Stainless Steel
Tip Style	Ball
Driver Style	L-Key
Driver Type	Standard
Individual/Set	Individual
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2020, 209 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Czech Republic

The ball end allows angled entry to turn screws in hard-to-reach areas. Protect your stainless steel screws by using a stainless steel L-key. If steel flakes off a standard tool and into the recess, it can lead to rust and contamination. These keys eliminate that risk.