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C-FLEX BEARING CO. , INC.

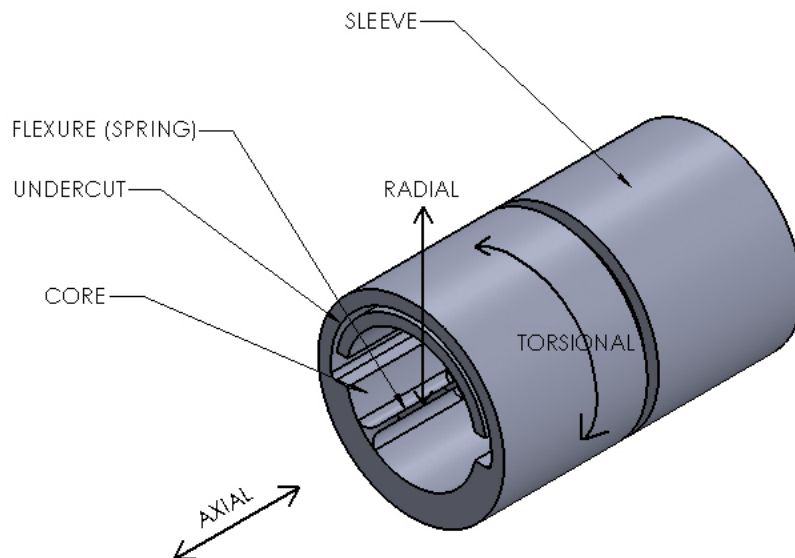# PIVOT BEARING
DESIGN GUIDE

Table of Contents

I. Introduction and Terminology

This design guide is written with both the first time user and the experienced engineer in mind, as they are frequently the same person when it comes to pivot bearings. Due to their unique nature, pivot bearings have many distinct performance features that must be accounted for when compared to traditional bearing styles. Fully understanding these features will allow the user to utilize them to their full potential and reap the benefits of frictionless motion of large loads for long service lives.

The purpose of this guide is to explain the intricacies of using pivot bearings without getting bogged down in reference materials like charts and tables which are available in many locations such as on the C-Flex website and in C-Flex catalogues. It is the hope that this guide will act as a compliment to those tradition resources and explain the proper way in which to use them and the bearings themselves with greater effectiveness.


TERMINOLOGY

II. How Do They Work?

     Critical to understanding how to use pivot bearings is understanding how they function. The bearing itself is made of 2 main elements, the core and the sleeves. The core is the central element containing the springs which allow the bearing to rotate. To get a better feel for how the core functions it's best to start by imagining a thin vertical sheet of metal clamped at the bottom in a vise. If you were to pull sideways on the top edge of the sheet you would notice that the sheet forms a smooth arc as in figure 1. If you then let go of the edge you would notice that the sheet oscillates back and forth, with the top edge following a curved path as in figure 2. That curved path is the basis for the rotational motion of the C-Flex pivot bearing.

figure 1   figure 2
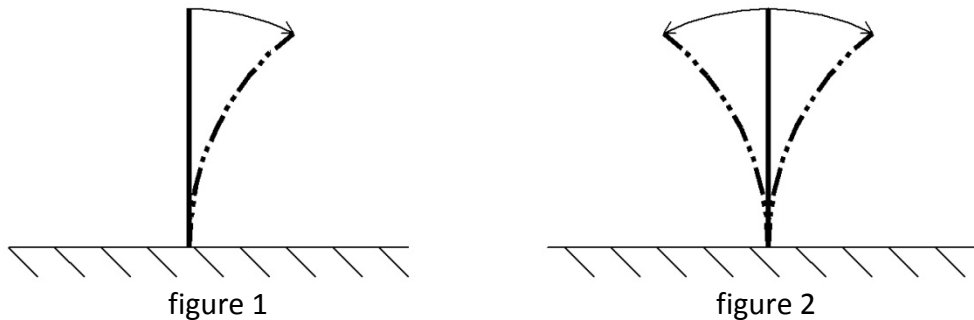
     Since a bearing with a single flat spring would be unstable, we'll add a second flat plate to our scenario above, but perpendicular to the first plate, as shown below. The resulting structure provides the basis for stable limited rotation motion. Since there are no contacting or sliding parts, no lubrication is required and no friction is created.
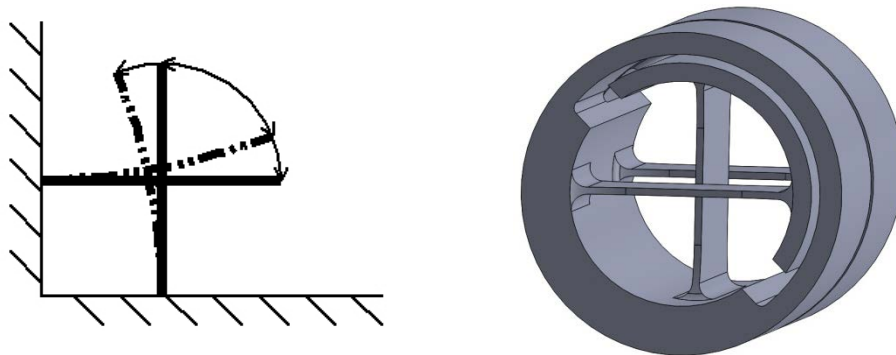
     While the springs create the pivoting motion, it is much easier to utilize pivot bearings in a design when they have a uniform exterior that can be easily clamped onto. This is where the other major element, the sleeves, come into play. The sleeves give the bearing a round exterior that can be mounted easily in a round hole. Since the sleeves do not affect the performance of the springs, it's possible to have many different sleeve combinations of the same bearing such as cantilever or double ended. This allows for a wide range of mounting options that all have the same performance characteristics. Conversely, It's possible to have the same sleeves with a wide variety of spring sizes inside to provide the desired performance characteristics.

III. Performance Characteristics

A. Loading

C-Flex Pivot Bearings can be loaded in many different configurations to suit the customer's needs. Properly loading pivot bearings is a crucial step to ensuring that they perform as expected. Load capacities for all bearings are listed in the C-Flex catalogue.

Axial Loading:

In axial loading the force is in line with the axis of rotation causing the springs to experience a shear force. The effect on the bearing is the same whether the load direction is towards or away from the bearing.
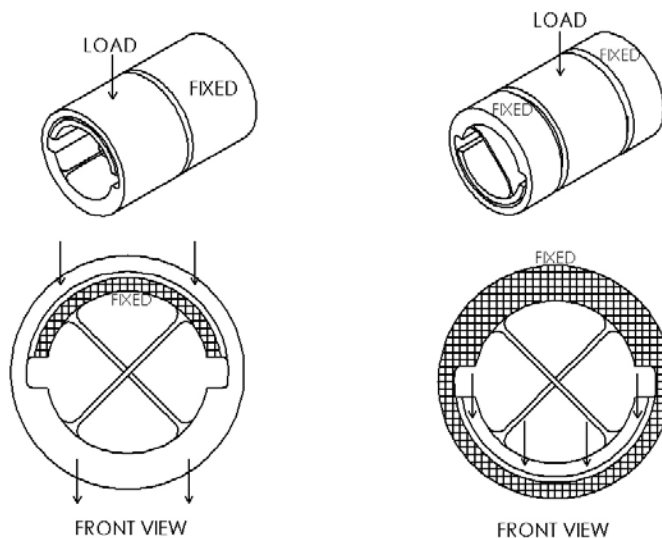

Radial Loading:

In radial loading the force is applied perpendicular to the sleeve. Depending on how the bearing is oriented this can put the springs in either tension or compression. Radial tension and radial compression loading are essentially mirror images of each other, rotating the bearing 180° in its mounting hole will change the loading from one to the other. Compression loading can result in buckled springs, especially with 10-series bearings, at smaller loads than it takes to cause yielding failure when loading in tension. Because of this, radial loading in tension is the preferred mounting orientation when possible.

Radial Loading in Tension (Lt)

Radial tension loading is the preferred method of mounting C-Flex Pivot Bearings and results in the greatest load capacity. An easy check is that if the load is pushing on the thin side of the sleeve then the springs are in tension.

Radial Loading in Compression (Lc)

Radial compression loading results in a lower load capacity, most notably in 10-series bearings. If the load alternates between tension and compression loading then use the compression load capacity when selecting a pivot bearing.
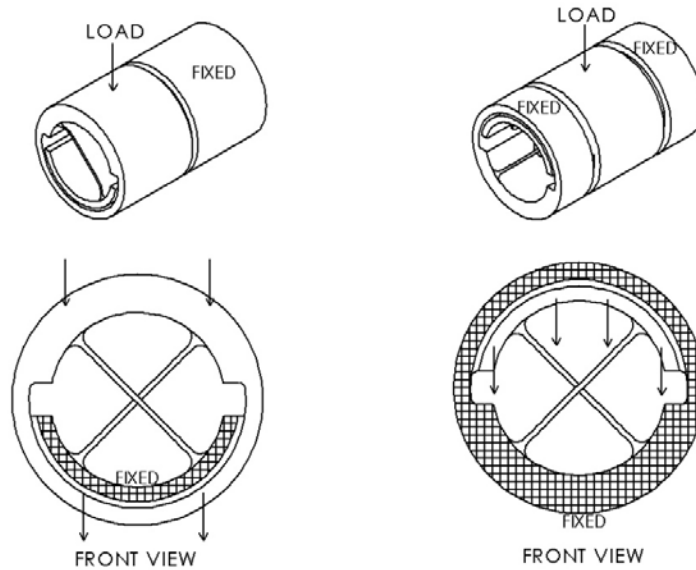
Moment Loading

Moment loading is similar to radial loading but the force is applied at a distance from the bearing. This multiplies the stress in the springs resulting in a significantly lower load capacity as the load application distance increases. This type of loading should be avoided when possible. A better method is to use two bearings spaced apart from each other. If your application requires moment loading please contact C-Flex to receive the derated load capacity specific to your application.
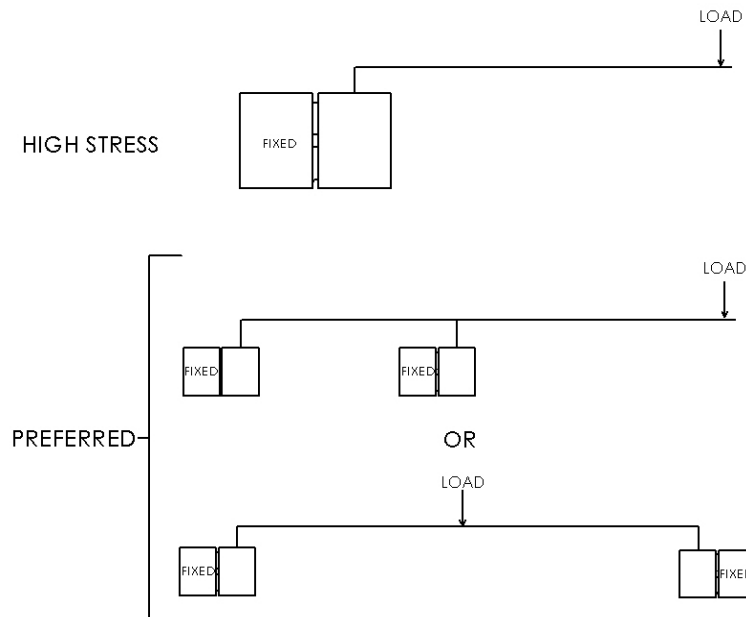
B. Torsional Spring Rate

Torsional spring rate is the amount of torque required to cause the bearing to rotate a certain angle. Larger torsional spring rates equate to stiffer bearings that require more force to rotate. Sleeve configuration has no effect on torsional spring rate so cantilever and double ended bearings of the same size have the same torsional spring rate. Torsional spring rate is a constant for the entire range of motion of the bearing. Typical C-Flex pivot bearings have a torsional spring rate tolerance of +/- 10% of the book value, however tighter tolerances can be provided on request.

EXAMPLE:
How much torque is required to rotate a G-20 bearing 5 degrees?

G-20 TSR = 0.1185 inch*pounds/degree

$$TSR = \frac{TORQUE}{ANGLE} \rightarrow \; TORQUE = TSR \times ANGLE = 0.1185 \times 5 = 0.5925 \; inch * pounds$$

C. Life Expectancy

Because pivot bearings do not have contacting parts they do not experience any wear as other bearing products do. This means that life expectancy is only the result of fatigue on the spring materials resulting from repeated applied loads and rotation angles. Under the proper conditions, C-Flex pivot bearings can be expected to have an indefinite life expectancy. If the application requires rotation beyond the indefinite life rotation angle then a finite and predictable life can be expected. Life expectancy is reduced as load and/or rotation angle is increased.

The life expectancies as provided in the C-Flex catalogue charts are for pivot bearings experiencing full reversing motion about the center position. If non reversing rotation or rotation only to one side is to be expected then contact C-Flex to receive a life expectancy for your application.

EXAMPLE:
Does a G-20 oscillating at +/-11 degrees with a 120 pound radial load in tension have an indefinite life expectancy?

To solve this we will use the life cycle charts as provided in the C-Flex catalogue for a 20 series bearing. First the applied loads must be converted to % of max allowable loads. For the basis of finding life expectancy, max angles are defined as the angle when indefinite life can be expected at zero load and are shown at the top of the life expectancy charts:

20 Series max angle =7.5 degrees   G-20 max radial load in tension (Lt) = 200 pounds

$$\% \ ANGLE = \frac{rotation \ angle}{\max angle} \times 100 = \frac{11}{7.5} \times 100 = \ 146\%$$

$$\% \ LOAD = \frac{applied \ load}{\max load} \times 100 = \frac{120}{200} \times 100 = 70\%$$

The percents found are then plotted on the chart to find a point as shown below.
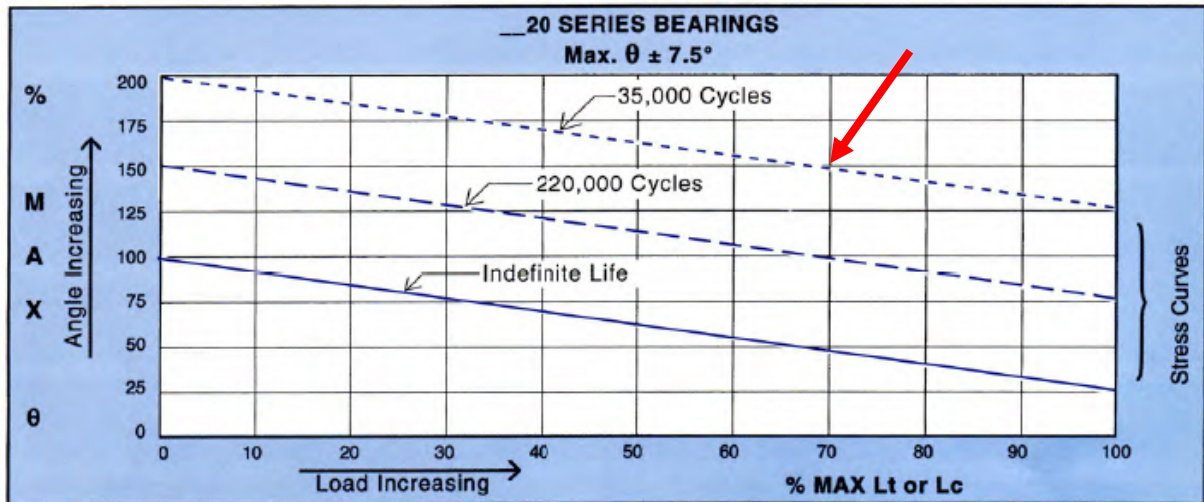
Because the point is above the indefinite life line the bearing will have a finite life expectancy. Since the point falls along the 35,000 cycles line the pivot bearing should be expected to oscillate approximately that many cycles before failure.

It is a best practice to select pivot bearings for indefinite life whenever possible. For the above example, if a J-10 was used instead of the G-20 then % angle would be 73% and % load would be 51%. Using the 10-series life expectancy chart these values result in a point along the indefinite life line. As long as the plotted point is on or below the indefinite life line then indefinite life can be expected.

D. Geometric Centershift

Since the pivot bearing rotation comes from the bending of flat springs the resulting motion is not perfectly circular. Because of this, as the sleeves rotate relative to each other they also shift in a radial direction to each other. This motion is referred to as geometric centershift and it causes the sleeves to be parallel, but not concentric. Geometric centershift increases as the rotation angle increases and is zero when the pivot bearing is in the center position. The geometric centershift value is proportional to the bearing diameter, with larger pivot bearings having larger geometric centershift than smaller ones.

EXAMPLE:
What is the geometric centershift of an F-10 at 11 degrees?

Geometric centershift can be found using the centershift chart and the following equation:

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$$Geometric\ Centershift = \frac{diameter\ \times centershift\%}{100} = \frac{0.375\ \times 0.600}{100} = 0.00225\ inches$$

ANGULAR DEFLECTION (Degrees)
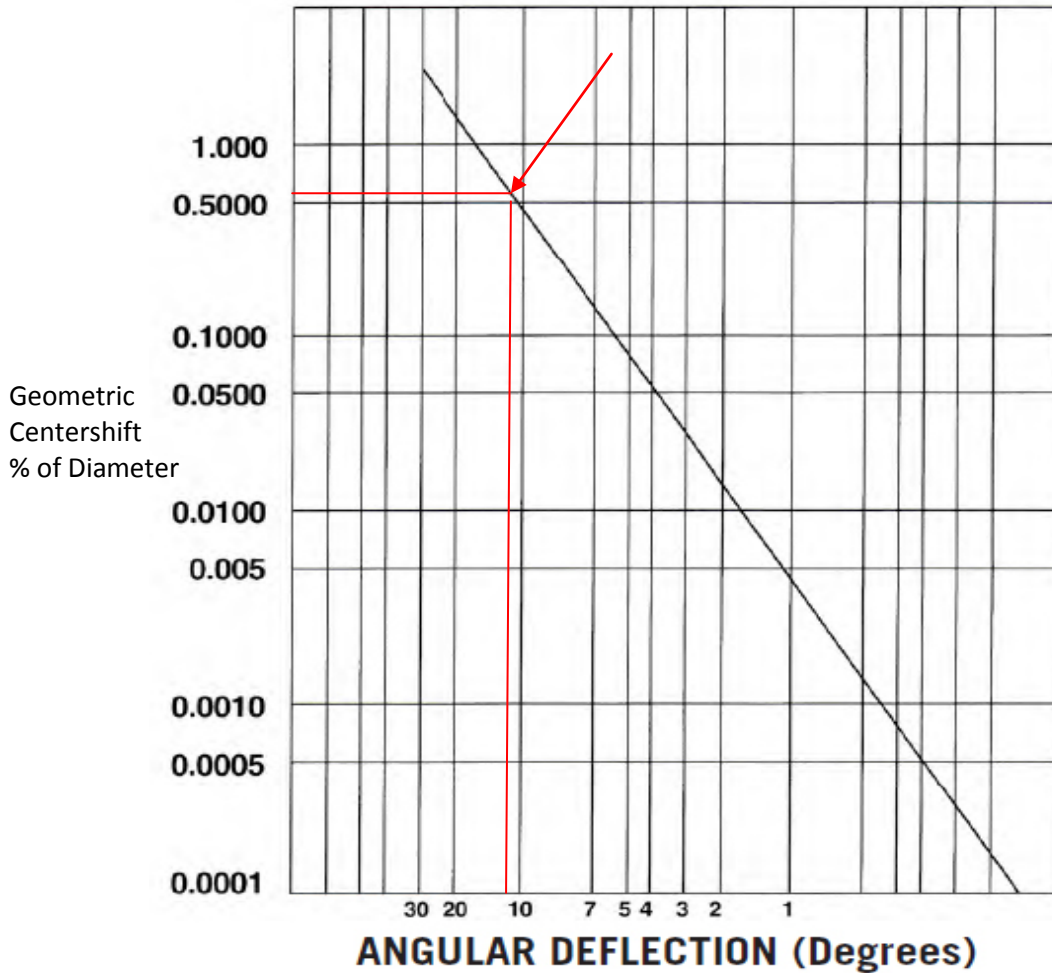
E. Hysteresis

Hysteresis in C-Flex pivot bearings is defined as the difference of null positions when the bearing is deflected to a plus angle and then relieved, and then deflected to an equal minus angle and then relieved. The angle of hysteresis is the angle formed between the two relieved positions. Hysteresis angle has an exponential relationship to rotation angle and is extremely small at small angles of rotation. Bearings with thinner flexures will exhibit less hysteresis than bearings with thick flexures. Charts for hysteresis angles of 10, 20, and 30 series pivot bearings can be found in the C-Flex catalogue.

F. Stiffness

C-Flex pivot bearings exhibit different degrees of stiffness depending on the direction of force and bearing orientation. 30 series bearings are stiffer than 10 series bearings of the same

size and larger bearings are stiffer than smaller bearings of the same flexure series. Stiffness is given in the C-Flex catalogue as inches of deflection per pound of load at zero degrees rotation, so smaller numerical values equate to stiffer bearings.
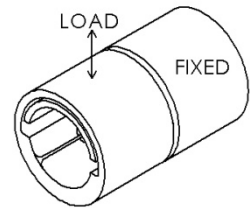
AXIAL STIFFNESS
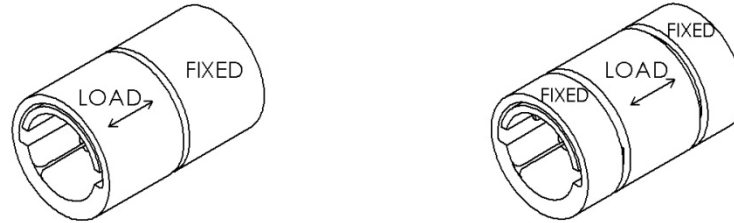
Axial stiffness is the same for cantilever and double ended pivot bearings. Axial stiffness is also the same whether the load is compressing or pulling the bearing.
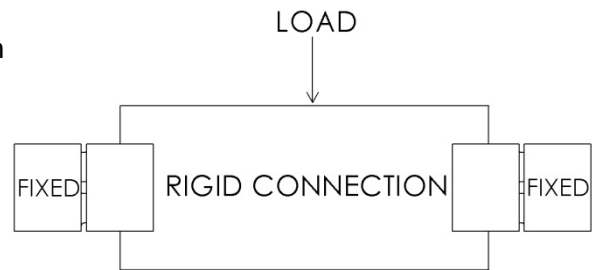
RADIAL STIFFNESS

Single Cantilever

The radial stiffness values given in the C-Flex catalogue are for cantilever bearings which are fixed at one end and loaded radially at the mid-point of the other sleeve. Lc is the stiffness when the load puts the flexures under a compressive force. Lt is the stiffness when the load puts the flexures under a tensile force.

Tandem Cantilever

When the system uses two cantilever bearings rigidly connected as shown to the right, then the resulting radial stiffness for the system is 1/3 that of the values in the catalogue. For example, a pair of rigidly connected tandem mounted B-10s would have a stiffness of:

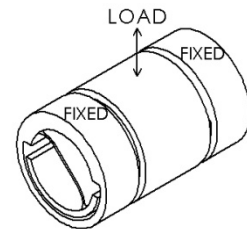$$Lc = \frac{0.00033}{3} = 0.00011 \; inches/pound$$
$$Lt = \frac{0.00050}{3} = 0.00017 \; inches/pound$$

Double Ended

Double ended Bearings are twice as stiff radially as cantilever bearings, so the catalogue values should be divided in half. For example, a BD-10 would have a radial stiffness of:

$$Lc = \frac{0.00033}{2} = 0.00017 \; inches/pound$$
$$Lt = \frac{0.00050}{2} = 0.00025 \; inches/pound$$

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IV. Selecting a Bearing

C-Flex Bearing Company offers two types of pivot bearings in 10 sizes with 3 spring series for each size resulting in 60 different standard parts in addition to a large number of custom pivot bearings. Due to the fact that some of these bearings have overlapping properties it can be a confusing process to select the right pivot bearing. The following procedure is a basic method for narrowing down the many options available to arrive at the proper bearing for a particular application. There may be situations where one element of your device is predetermined such as a mounting hole diameter or a driving motor torque capacity in which case some flexibility will have to be taken when selecting a bearing. If any assistance is required in selecting a bearing or if confirmation of a selected size is desired please contact C-Flex Bearing Company and we will be happy to assist you.

A. Cantilever or Double Ended?

The first decision to be made when selecting a C-Flex pivot bearing is what type of bearing to use, cantilever or double ended. The answer to that will depend on the application and how the bearing will be mounted.

In general, cantilever bearings are easier to install and are best suited when the bearing has to fit into a blind hole such as on an optical assembly or when a lever must be supported from only one side. A system using a single cantilever bearing is the most economical way to utilize C-Flex pivot bearings. Cantilever bearings can also be used in tandem pairs where they are axially concentric as shown in the radial stiffness section. This setup provides many advantages including higher load capacity since the load is shared between two bearings as well as providing the greatest radial stiffness possible. Tandem mounted cantilever bearings also offer more flexibility in regards to the connecting rod width compared to using a double ended bearing where the connecting rod width cannot exceed the center sleeve length.

Double ended bearings are best suited for applications such as a rocker arm or platform where the arm width is the same as the center sleeve length and both outer sleeves are fixed. The main benefit of double ended bearings is that they are radially stiffer than cantilever bearings where only a single bearing is used. Double ended bearings are also useful in forced oscillation applications where the center sleeve is used as the fixed point. Here an oscillation creating device can be mounted to one outer sleeve and the assembly to be oscillated can be attached to the other sleeve. This allows for a setup with a minimal number of components.
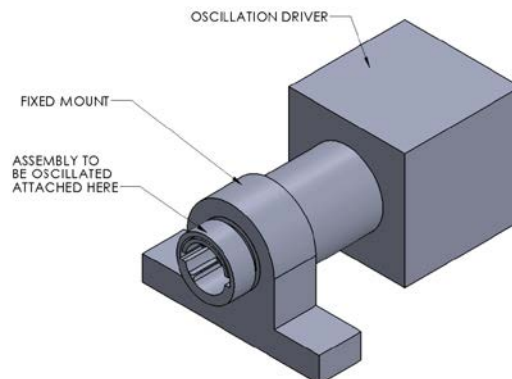
B. Spring Series

Once the bearing type has been selected the next step is to select the spring series, either 10, 20 or 30. The decision on spring series should be based on required range of motion and stiffness required. 10 series bearings have thinner springs giving them the largest range of motion and low torsional spring rates but are offset by having lower load capacities and being less stiff. 30 series bearings have thick springs giving them a smaller range of motion and large torsional spring rates but have higher load capacities and are stiffer. The ranges of motion for the different series are shown below:

SPRING SERIES	INDEFINITE LIFE ANGLE	MAX ANGLE BEFORE DAMAGE
10 SERIES	+/-15°	+/-30°
20 SERIES	+/-7.5°	+/-15°
30 SERIES	+/-3.7°	+/-7.5°

The primary consideration when selecting spring series should be the rotation angle. If possible, select the spring series so that the largest angle you expect to use the bearing at is less than the indefinite life angle. For example, if your application will rotate +/-10°, a 10 series would be best as indefinite life is probably possible. A 20 series would work as well although with a limited life. A 30 series could not be used at those angles.

C. Size

After deciding on a pivot bearing type and spring series the final step is to determine the size needed. C-Flex offers 10 standard sizes with fractional inch diameters ranging from the 1/8 inch A to the 1 inch J. The size bearing to use will be based on the load that is expected on the bearing and how stiff the system needs to be. In general it is best practice to use the smallest bearing size which has sufficient load capacity and stiffness for your application as this will be the most economical solution.

D. Example Selection

A pivot bearing is required to support a 5 pound optical assembly that will be mounted to one side of a support plate in a blind hole. The optical assembly is balanced and will be rotated by a servo which will be sized at a later time. The bearing will be mounted so that the weight of the optical assembly puts a radial tension load on the bearing. The assembly will have to rotate +/- 5° at 10 Hz for extended periods of time in a difficult to access location. Low centershift is a priority along with stiffness to prevent inaccurate reading from the assembly.

Step 1: Bearing Type
Since the bearing will have to fit into a blind hole while supporting the assembly on only one side a single cantilever bearing will be used.

Step 2: Spring Series

Since the pivot bearing will be rotated up to 5 degrees then either a 10 or 20 series bearing can be used while providing indefinite life. A 30 series could possibly be used but since the bearing will be rotating at a high frequency for long periods of time this brings a life cycle issue into play which would require periodic replacement of the bearing and the possibility of a fatigue failure at an inopportune time. For these reasons a 30 series bearing should only be considered if the stiffness conditions becomes a higher priority than not having to schedule replacement of the bearing periodically.   Since this application is in a difficult to access location it would be a good idea to not use the 30 series springs unless this becomes absolutely necessary to reduce maintenance time. Because high stiffness is a priority the 20 series springs would be a better choice over the 10 series springs for now. Once a size is found we will come back to check life expectancy since indefinite life is based on angle and percent load.

Step 3: Size

Now look at the [cantilever performance properties](#) page in the [C-Flex catalogue](#). Since the load is in the radial tension direction scroll down the Lt load capacity column looking at the 20 series values for each size as picked in the previous step until a value larger than 5 pounds is found. Based on the catalogue an A-20 can support a radial tension load of 12.7 pounds, more than sufficient to hold the 5 pound optical assembly.

Checking the geometric centershift of an A-20 at 5 degrees we see that it is only 0.8% of the bearing diameter of 1/8 inch or 0.001 inches total. This meets one of our priorities but there are still life expectancy and stiffness to contend with.

5 pounds is 39% of the max load for an A-20 and 5° is 67% of the max angle. Checking these values on the 20 series life expectancy chart we find that this point is just below the indefinite life line, a good result. Because larger sizes have higher load capacities, the percent load shrinks as larger sizes are used. Because our load is fixed at 5 pounds and even the smallest size has an indefinite life expectancy, it becomes clear that any 20 series bearing would have an indefinite life expectancy in our application.

An A-20 has a radial stiffness in tension of 0.00050 inches per pound. With the 5 pound optical assembly this will create a sag in the assembly of 0.0025 inches. Depending on the particular application this may be tolerable, but improvements might be possible.

If instead of an A-20 we decide to "oversize" the bearing and use a B-20 some advantages come to light. Geometric centershift goes up marginally to 0.00125 inches because the B-20 has a larger diameter than the A-20. However, a B-20 has a radial tension stiffness of 0.00025 inches/pound, resulting in a sag of only 0.00125 inches, half of what it was with the A-20. Therefore the max misalignment from Geometric centershift and stiffness combined can be reduced from 0.0035 inches with an A-20 to 0.00245 with a B-20. If we continue this process we'll find that a C-20 has a max misalignment of 0.00235 inches, improvement still. However there comes a point where the geometric centershift from using larger bearings overshadows the gains in stiffness. Using a D-20 the geometric centershift alone rises to 0.002 inches and combined with the stiffness the total max misalignment goes back up to 0.00255 inches.

Therefore in our scenario the appropriate bearing to use is a C-20.

V. Simulating

    C-Flex can perform a Finite Element Analysis simulation of your application on request or when non-standard performance features must be found. If customer produced simulations are required for regulatory requirements or customer use please use the following material properties.

420 Stainless Steel Simulation Material Properties	
Elastic modulus	29000000 psi
Poisson's ratio	0.28
Shear modulus	11167905 psi
Mass density	0.281793 lb/in^3
Tensile strength	294000 psi
Compressive strength	230000 psi
Yield strength	197000 psi
Thermal expansion coefficient	6.111111159e-006 /°F
Thermal conductivity	0.000240746 BTU/(in*sec*°F)
Specific heat	70.2207 BTU/(lb*°F)

    Note that while the sleeves and part of the core are not 420 SS, C-Flex recommends the entire bearing be simulated as a single part of solid 420 SS. Spring failure is the primary mechanism of bearing failure by a large margin and simulating the entire bearing as a single piece of 420 SS gives reliable results for spring failure while reducing computational resources. Failure of braze joints or sleeves are extremely rare and typically only occur from unusually high frequency vibrations. If you believe your application may encounter these conditions please contact C-Flex for more information.

VI. Installing In Your Application

A. Clamping

   C-Flex Pivot bearings can be installed in many different ways. The most commonly used method is to have a smooth hole with a set screw. Mounting holes should be 0.0005 to 0.0010 inches larger in diameter than the bearing.

Recommended Installation Methods
Set Screws
   Cup point style set screws should be used. Set-screws must be positioned so as to apply pressure to the heavy (solid) section of the bearing sleeve. It is not recommended to position set screws over the undercut section of the sleeve, as buckling or collapse of the sleeve may occur.

Bearing Series Size	Max. Holding Torque Required (Lb-In) (-30 series brg)	Recommended Set-Screw Size	Tightening Torque (In-Lb)	Torsional Holding Power of Screw
A	0.082	#0	1.0	3.125
B	0.164	#1	1.5	5.076
C	0.268	#3	5.0	11.250
D	0.658	#4	5.0	20.000
E	1.314	#5	10.0	31.250
F	2.220	#8	20.0	72.190
G	5.264	#10	35.0	135.000
H	10.512	1/4"	80.0	312.500
I	18.098	5/16"	160.0	562.500
J	43.301	3/8"	275.0	1000.000

Clamp Screws
   Take care to not over-tighten the clamp and crush the sleeve

Epoxy
   If possible, inject the epoxy around the outside of the bearing after it has been positioned in the mounting hole. Make sure that no epoxy gets into the core or between the core and the sleeves of the bearing.

Shrink Fit
   Cool the bearing to -100 °F using liquid nitrogen and heat the mounting hole. Quickly locate the bearing in mounting hole and hold in position until temperatures equalize and bearing is secured. Shrink fit is typically permanent and cannot be undone without damaging bearing.

DO NOT PRESS FIT BEARINGS, SPRING DAMAGE IS VERY LIKELY WHEN PRESS FITTING

B. Preventing Damage

Overloading

Exceeding the rated load capacity is the most common cause of failure for pivot bearings. Consideration must be taken not only for the standard loads experienced during operation but also for shock loading that may occur during installation, usage or transport. The designer must also remember to take into account factors that reduce the bearings load capacity such as moment loading scenarios and how the combination of load and angle affect life expectancy.

Load capacities listed in the C-Flex catalogue are for cantilever pivot bearings loaded at the mid-point of the sleeve and with no rotation. Listed load capacities tend to be conservative, about 30% below the yield point of the springs, however that does not guarantee good performance above the listed values and C-Flex recommends against using pivot bearings beyond their rated values. If your application will utilize a pivot bearing at or near its listed load capacity it is good practice to use the next largest size if possible.

Improper Loading

C-Flex pivot bearings are intended to be loaded at the mid points of the sleeves in either a radial or axial direction. Improper loading of the bearings either due to moment loading or improperly combining several different forces is the most common cause of pivot bearings that failed "within their rated values".

Over-rotation

C-Flex pivot bearings should never exceed their max angles of rotation +/-30, 15 and 7.5 degrees for 10, 20 and 30 series bearings respectively. Even at these angles, hysteresis will typically be large and life expectancies will be short. It is good practice to only rotate bearings to their indefinite life angles when possible. Do not rely on the core travel slots as limit stops because the bearing will pass the max angle of rotation before the travel slots contact.

Excessive speed

All pivot bearings have an inherent natural frequency of free oscillation. Typically this frequency is extremely fast and most users will not experience any speed issues. While it is possible to force rotation of the bearings faster than this frequency, care must be taken as harmonic waves can appear in the springs resulting in premature spring failure. Very advanced vibration simulations must be analyzed in this scenario.

VII. Customizing

C-Flex Bearing Company can provide a vast array of custom alterations to the standard pivot bearings. If you have an application where a standard pivot bearing will not suffice then see if one of the alterations we offer below will suit your needs. If you have a requirement that can't be met with the options listed here feel free to contact C-Flex and we can work with you to create a custom product just for your application.

A. Materials

C-Flex Pivot Bearings can be made out of a wide variety of metals to meet your material property requirements. DFARS compliant and made in USA materials are available on request. Please note that not all sizes may be available when using certain materials.

All 420 Stainless Steel and other stainless steels
Inconel
Titanium
Beryllium copper
Hast X
And more...

Various material treatments are available as well including:
Electropolishing
passivating
vacuum baking
And more...

B. Clamping Options

There are many options available for when standard clamping methods do not provide enough holding power or positioning accuracy for your application.
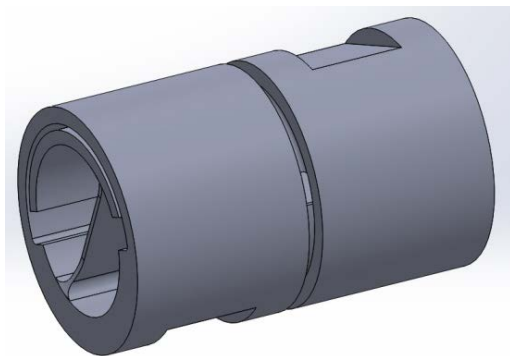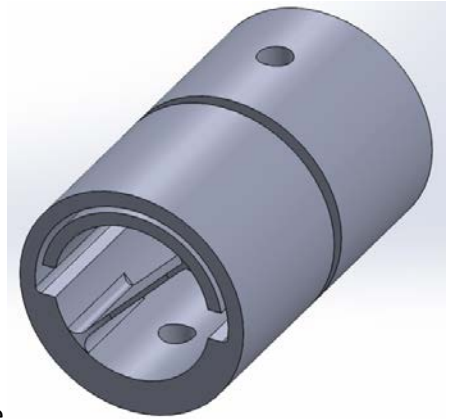

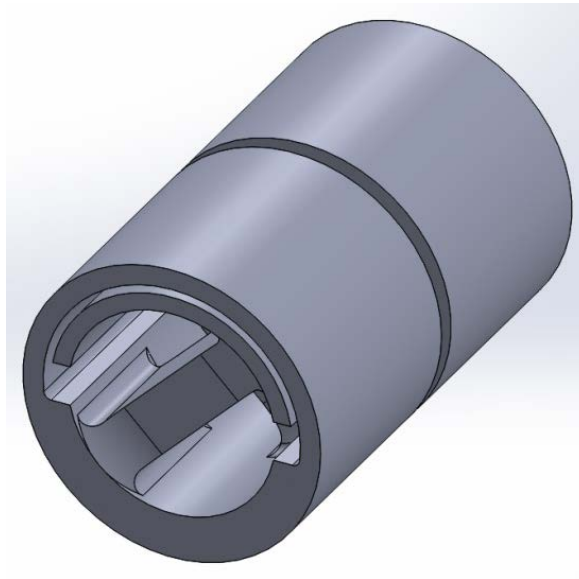Locator Flats

Radial Pins

Axial Pins

Pin/Screw Hole

Adhesive Grooves

C. Spring Stiffness/Geometry

Spring thickness and geometry can be altered to provide a custom torsional spring rate or increased load capacity.

D. Sleeve Geometry

The sleeves of C-Flex Pivot Bearings can be altered in an almost unlimited number of ways to provide the proper fit for your application. Adjusting the sleeve lengths and/or outside diameters are common custom alterations.

E. Labeling

Parts can be laser marked with logos, lot numbers, part names, serial numbers and orienting marks.

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