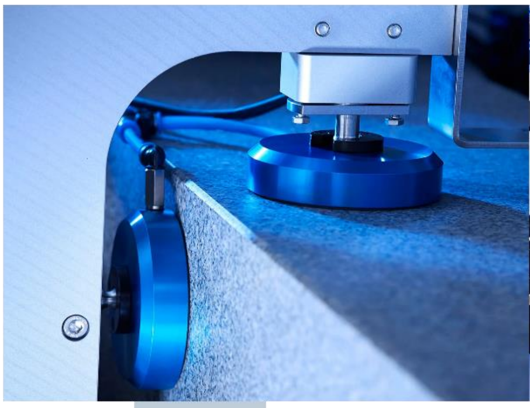
Air Bearing Application and Design Guide



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1 PART I: UNDERSTANDING AIR BEARINGS

1.1 Introduction

Bearing technology represents one of the age-old problems for mechanical engineers. Rolling element bearings developed in the last century were a revolutionary improvement over the plain bearings that had been pushed to their limits in applications like electric motors and automobile wheels. Similarly, rolling element bearings are today being pushed to their technical limits by the demands of applications like semiconductor manufacturing, high resolution scanning, and high-speed machinery.

Air bearings represent the next logical step in bearing design. Air bearings in general have a proven track record having been employed in coordinate measuring machines for 20 years. The many technical advantages of air bearings such as near zero friction and wear, high speed and high precision capabilities, and no oil lubrication requirements are powerful advantages for today's machine designers. However, these benefits have not been more fully utilized to date because air bearings are difficult to manufacture and they have not been commercially available until recently. New Way Precision was founded ten years ago to pioneer the use of porous media technology and make air bearings that are robust, simple to use, inexpensive, and available off-the-shelf.

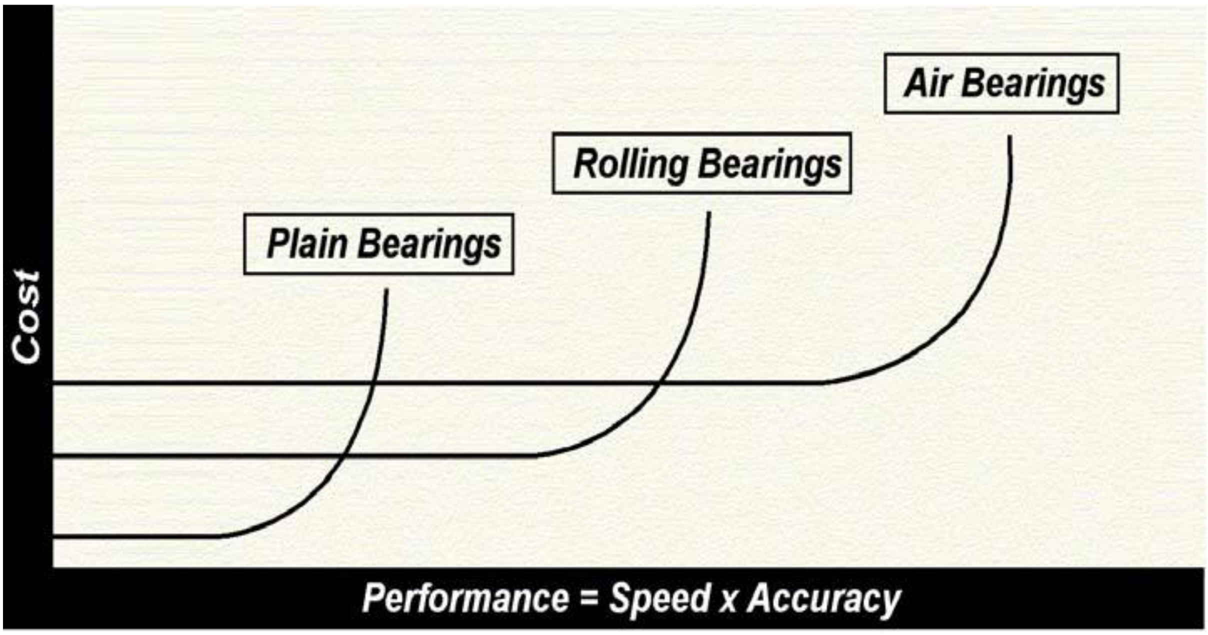

Figure 1 Bearing Performance vs Cost

The purpose of this guide is to answer the common questions that designers have when first considering air bearings, as well as to provide detailed information that will help ensure the success of your advanced application. This is believed to be the first such collection of information regarding the selection, mounting, and application of commercially available air bearing products.

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1.2 What is an Air Bearing?

Unlike contact roller bearings, air bearings utilize a thin film of pressurized air to provide a 'zero friction' load bearing interface between surfaces that would otherwise be in contact with each other (Figure 2).

Being non-contact, air bearings avoid the traditional bearing-related problems of friction, wear, and lubricant handling, and offer distinct advantages in precision positioning and high-speed applications. The fluid film of the bearing is achieved by supplying a flow of air through the bearing face and into the bearing gap. This is typically accomplished through an orifice or a porous media that restricts or meters the flow of air into the gap, referred to in Figure 2 as R1. The restriction is designed such that, although the air is constantly escaping from the bearing gap, the flow of pressurized air through the restriction is sufficient to match the flow through the gap. It is the restriction through the gap, R2 that maintains the pressure under the bearing and supports the working load. If air pressure were introduced to the gap without restriction (R1), the flying height would be higher, the air consumption higher, and the stiffness would be lower than could be achieved with proper restriction. This restriction is referred to as air bearing compensation. It is used to optimize the bearing with respect to lift, load, and stiffness for particular applications and will be discussed later in more detail.

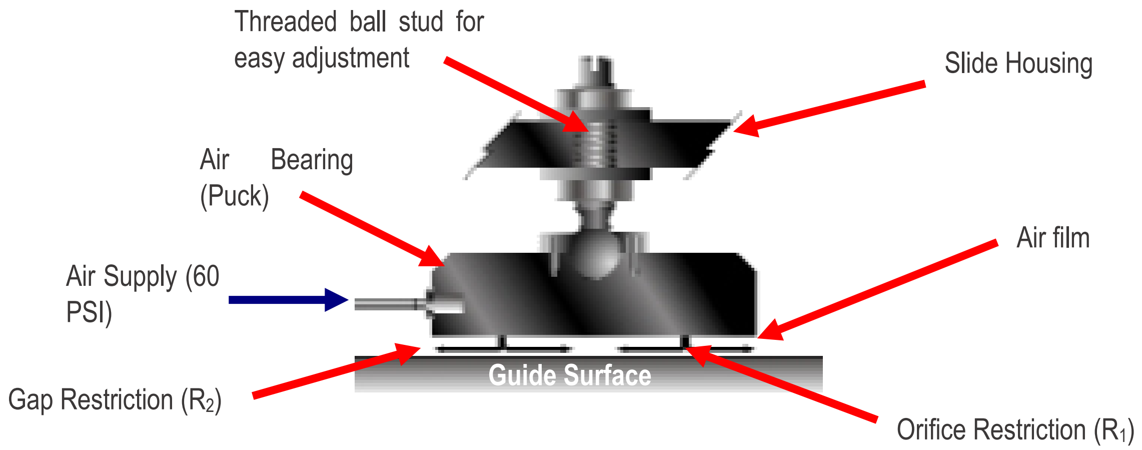

Figure 2 Flat Air Bearing

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1.3 Why use air bearings?

Because of their advantages over rolling element bearings, air bearings are a natural choice for applications such as Coordinate Measuring Machines, precision machine tools, semiconductor wafer processing machines, and other clean room, high speed, and precision positioning environments. The main advantages of air bearings are listed below. Some of the specific concerns of the design engineer (friction, wear, stiffness, and load capacity) are then discussed in more detail.

Table 1 Why use air bearings?

ZERO FRICTION....
Because of zero static friction, infinite resolution and very high repeatability are possible.
ZERO WEAR....
Non-contact means virtually zero wear resulting in consistent machine performance and low particle generation.
STRAIGHTER MOTION....
Rolling element bearings are directly influenced by surface finish and irregularities on the guide. Being non-contact air bearings average these errors.
SILENT AND SMOOTH OPERATION....
Recirculating rollers or balls create noise and vibration as hard elements become loaded and unloaded and change direction in return tubes. This is especially noticeable in the resolution of scanners.
HIGHER DAMPING....
Being fluid film bearings, air bearings have a squeeze film damping effect resulting in higher dynamic stiffness and better controllability.
ELIMINATES OIL....
Air bearings do not use oil lubrication, eliminating the problems associated with oil. In dusty environments (dry machining) ways are dry and bearings are self-cleaning because positive air pressure pushes dust away. In contrast, oil lubrication becomes a lapping slurry.
HIGH SPEEDS....
High speeds - high acceleration. No balls or rollers to slip at high acceleration.

1.3.1 Friction

Variances in friction have always been at the heart of precision positioning problems, particularly when attempting to initiate or stop motion precisely. This is because especially in plain bearings, but also in rolling bearings, the static coefficient of friction is higher than the dynamic coefficient of friction. In other words, it takes more force to initiate motion than it does to maintain motion. So, when a motor turns a screw to push a slide, the screw winds up and stores some of the energy because of the high static friction. When the slide starts to move, the friction falls and the screw unwinds, pushing the slide past its desired position. This phenomenon is known as 'stick-slip' and is most pronounced in plain way systems. However, it can also cause positioning or bandwidth issues even in machines with rolling element bearings and closed loop feedback.

Today heavy machine tool slides can be positioned within .0001" using rolling element bearings because the difference between the static and dynamic coefficients of friction is reduced by an order of magnitude compared to plain bearings. But even rolling element bearings are reaching their limits. For instance, in some areas of the electronics capital equipment industry, positioning to even .00001" is considered too course. Rolling element bearing manufacturers have started to reduce their preloading (compromising stiffness) in what has become known as a 'California Fit' in an effort to meet these requirements, but there are limits to how effective this can be.

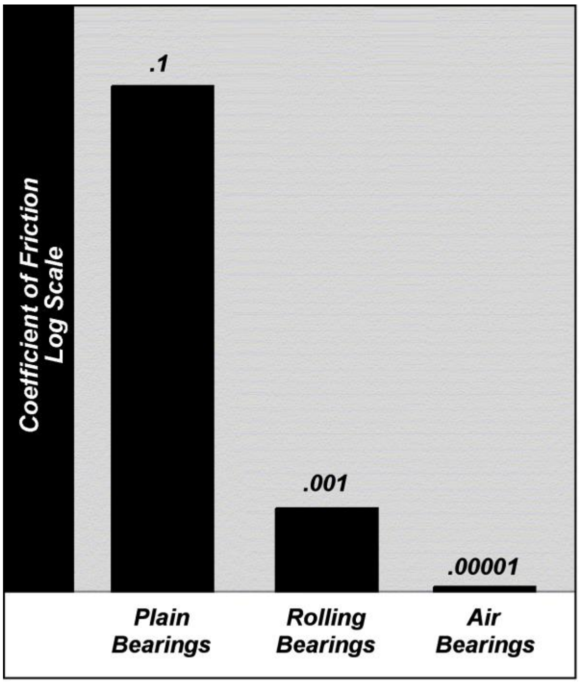

Figure 3 Coefficients of Friction

In air bearings there is no difference between static and dynamic coefficients of friction so the stick-slip issue is completely eliminated. Friction in air bearings is a function of air shear from motion, so at zero velocity there would be zero friction making infinite motion resolution theoretically possible.

Friction has a direct effect on efficiency. In fact, one of the first air bearing patents applied for was by Westinghouse for use in vertical steam driven generating turbines. Westinghouse knew that because the viscosity of air is several hundred times lower than that of oil, he could reduce the energy loss due to oil shear. Unfortunately for Westinghouse, at that time (1890) it was exceedingly difficult to manufacture the large bearing surfaces to the high precision required for air bearings to work. Today large turbines still use oil based hydrodynamic bearings, but many of the new micro turbines on the market are employing aerodynamic bearing systems to improve efficiency. Friction also has an effect on precision. Remember the old saying, what are the three main sources of error in a precision machine? Heat, heat, and heat! Friction creates heat, which is a precision engineer's worst enemy. For instance, when a spindle heats up it grows axially. As the heat conducts into the headstock it will expand and the center of rotation will grow away from the base. In most cases air bearings will create significantly less heat in a given application than a rolling element or plain bearing. This is not to say that air bearings cannot create heat, as they can but relative speeds need to exceed 100 feet per second before significant heat can be measured.

1.3.2 Wear

Mechanical wear is another thorn in the side of the design engineer. Advanced machines are requiring faster speeds and higher reliability. In fact, there are machines currently on the market that make a billion moves per year. It is impractical to perform accelerated testing on such a machine so at best the engineer must employ speed, acceleration, and loading calculations in order to estimate the life of the bearing. This problem is avoided with air bearings due to their non-contact nature. Speed, acceleration, and loading are not wear factors and they have no influence on the life of the air bearing.

The mode of wear in an air bearing is erosion, so the cleanliness of the air has the greatest effect. Air bearings are immune to conventional notions of wear and will perform exactly the same in the 10th year of operation as they did in the first, even after a billion cycles per year. This is a big advantage when it comes to machine reliability. Equipment builders that can say to their customers that wear has been eliminated, as a variable that could affect their statistical process control will have a distinct competitive advantage. The lack of debris from wear and no need for oil lubrication due to the non-contact nature of air bearings also means that they are ideally suited for use in clean room, medical, pharmaceutical, and food processing environments. Air bearings also excel in dry dusty environments such as salt or sugar factories, which can be highly corrosive. In these environments any oil lubrication quickly becomes a lapping slurry. Air bearings have a self-purging effect with constant air exiting the bearing blowing away light dry dust.

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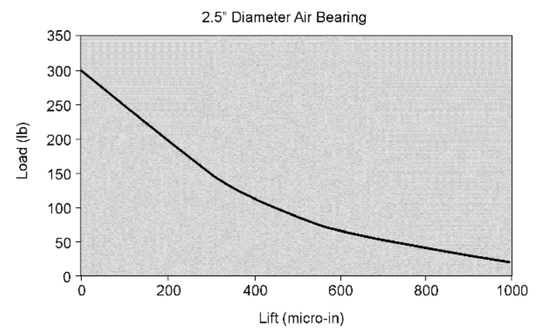
1.3.3 Stiffness

A common misconception about air bearings is that they do not have the required stiffness for precision applications. However, a 6" diameter bearing running at 60psi actually has a stiffness greater than 2,000,000 lb./in. with a load of 1,000 lbs. Put another way, that's less than one half of a millionth of an inch deflection per pound of additional force. By testing a bearing through a range of loads and measuring the change in air gap, a stiffness plot can be created like the one shown in Figure 4. Notice that the slope is not linear and as the film gets thinner the stiffness gets higher. Pressure and surface area both affect stiffness proportionately, but the most significant factor in air bearing stiffness is the idea and use of compensation.

Compensation is a way of controlling the flow of air into the air gap and is the true key to air bearing stiffness. The object of compensation is to create a restriction of the airflow into the gap before the restriction of the gap itself. The air gap must be a restriction otherwise the pressure would not remain under the bearing and it would instead equalize with the ambient pressure. But how can the pressure reserve created by a restriction of airflow into the air gap provide stiffness? Consider the case where the flow through the orifice at 60psi is equal to the flow through the gap with a 150-pound load on a bearing flying at 300 micro inches. A 2.5-inch dia. bearing has nearly 5 square inches of surface area so the average pressure under the face of the bearing will be 30 psi. Now imagine that the load increases to 200 pounds. This increases the average pressure under the air bearing to 40psi and compresses the air gap to 200 micro inches. The reduced gap creates increased restriction and reduces the flow. The reserve pressure that had been held back by the orifice now allows for increased pressure in the gap, creating a restoring force that gives the air bearing stiffness.



Lift load curves are useful for sizing air bearing. Notice also that the slope of the curve is representative of bearing stiffness. A vertical line would represent infinite stiffness and a horizontal line would represent zero stiffness.

$$\text{Stiffness} = \frac{\Delta\ \text{Load}}{\Delta\ \text{Lift}}$$

Load (lbs)	Lift (micro-in)	Δ Load	Δ Lift	Stiffness (lbs/in)	Compliance (micro-in/lbs)
100	450				
		25	90	277,778	3.6
125	360				
		25	60	416,667	2.4
150	300				
		25	50	500,000	2.0
175	250				
		25	50	500,000	2.0
200	200				

The stiffness between any two points on the curve in figure 2 can be calculated as shown. Stiffness is typically expressed in pounds per inch units, but it is more intuitively obvious when described in micro inch per pound terms. So rather than saying a bearing has 500,000 lbs/in stiffness we may say it will displace two micro inches for each pound load.

Figure 4 Air bearing stiffness

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1.3.4 Load capacity

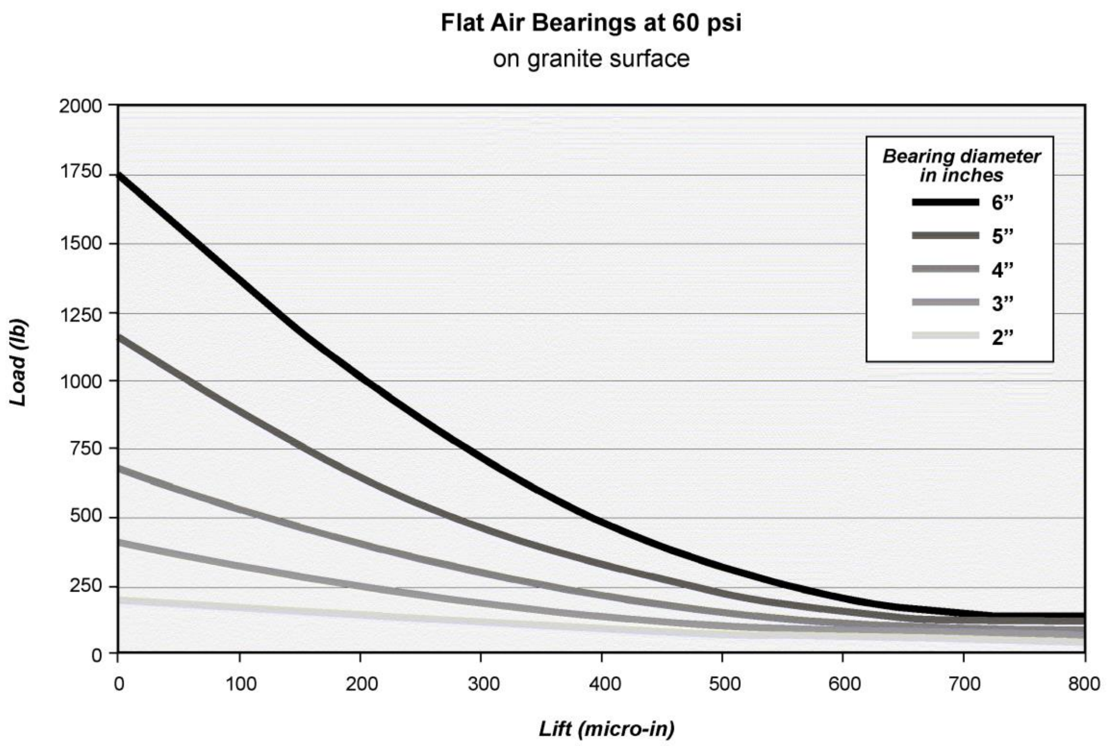

Figure 5 Lift-load curves

It can be seen from the above that compensation compromises load capacity for the benefit of stiffness and stability. Evan without compensation the maximum theoretical load capacity of the bearing could not be described as surface area times input pressure. A load equal to this value would ground the bearing.

The air bearings will not actually carry the full theoretical load because there is leakage around the edges of the bearing that prevents the pressure from being equal across the whole face. As the air issues from the orifice it expands through the gap, traveling away from the orifice and giving rise to pressure gradients in the gap that can be mapped as pressure profiles (figure 6). These pressure profiles are influenced by the amount and location of orifices and grooves, and especially by the type of compensation used, with porous compensation giving the most consistent pressure distribution under the bearing.

When compensation is used to increase bearing stiffness, the average pressure under the bearing is usually about 50 percent of the input supply pressure. Air bearings can therefore generally be considered to be 50 percent efficient with regard to input pressure. This rule of thumb is modified by the shape and size of the bearing. Bearings that have a high percentage of their area near the edge of the bearing like small or narrow bearings will have lower efficiency, while larger bearings will have higher efficiencies. This is one of the reasons that it can be more challenging to make smaller rather than larger bearings.

Although the load capacity of air bearings is limited compared to rolling element bearings, they carry the same load per unit area as traditional plain bearings for machine tools. This is usually more than sufficient for today's high-speed, lightweight machine applications.

Surface area x input pressure = grounding force

Surface area x input pressure x efficiency = load capacity

1.4 Types of Air bearing technology

There are two basic types of precision air bearings: aerodynamic bearings and aerostatic bearings:

Aerodynamic bearings

Aerodynamic bearings depend on relative motion between the bearing surfaces and usually some type of spiral grooves to draw the air between the bearing lands. This bearing action is very similar to hydroplaning in your automobile on a puddle of water at high speed. At a lower speed your tire would cut through the water to the road. In just this way, aerodynamic bearings require relative motion between the surfaces, when there is no motion or when the motion is not fast enough to generate the air film the bearing surfaces will come into contact. Aerodynamic bearings are often referred to as foil bearings or self-acting bearings. Examples of this type of bearing include the read-write head flying over a spinning disk, crankshaft journals, camshaft journals, and thrust bearings for electrical generator turbines.

Aerostatic bearings

Aerostatic bearings require an external pressurized air source. This air pressure is introduced between the bearing surfaces by precision holes, grooves, steps or porous compensation techniques. Because aerostatic bearings have a pressurized air source they can maintain an air gap in the absence of relative motion between the bearing surfaces.

Orifice and Porous Media Technology

Air bearings are typically classed as ‘orifice’ or ‘porous media’ bearings. In orifice bearings the pressurized air is supplied to the bearing surface through a small number of precisely sized holes. The concept is similar to the air hockey table amusement game, but with the holes in the puck rather than the table. Porous media air bearings are quite different in that the air is supplied through the entire surface of the bearing (Figure 6). The porous material controls the airflow in the same way an orifice bearing would do if it had millions of miniature holes across its surface.

Broadly speaking there are two techniques for achieving the compensating effect in air bearings. Orifice compensation is traditionally the most widely used method, but porous surface compensation is rapidly emerging as the method of choice due to its many advantages and increasing availability.

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In traditional orifice compensation the precisely sized orifices are strategically placed on the bearing and are often combined with grooves to distribute the pressurized air evenly across the bearing face. However, if the bearing face becomes scratched across a groove or near an orifice, the volume of air that escapes may be more than the orifice can supply, causing the bearing to crash even with normal air supply pressure. Rather than the small number of orifices of conventional air bearings, porous air bearings control the airflow across the entire bearing surface through millions of holes in the porous material. Because of this they are harder to clog and will still fly even after being severely scratched.

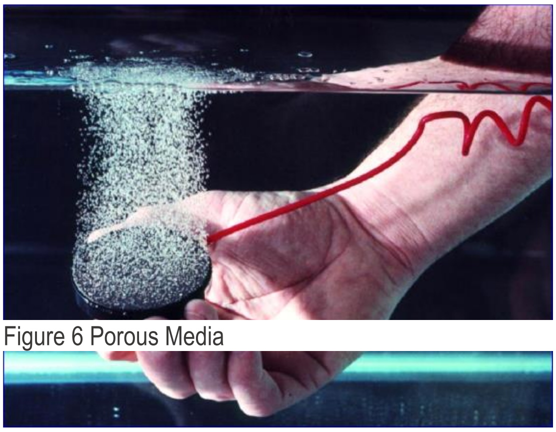

Figure 6 Porous Media

Even under normal operations, the air in an orifice air bearing loses pressure and creates pressure gradients in the air gap as it expands away from the orifice or groove. This is not an issue for porous air bearings where the air pressure remains almost uniform across the entire surface (see Figure 7).

Porous carbon has been found to be one of the best materials for this purpose, producing an ideal supply of uniform air pressure across the face of the bearing while automatically restricting and damping the air flow at the same time. The carbon surface also provides greater bearing protection if there is an air supply failure, and allows the bearings to be moved during air failure without damaging the support surface.

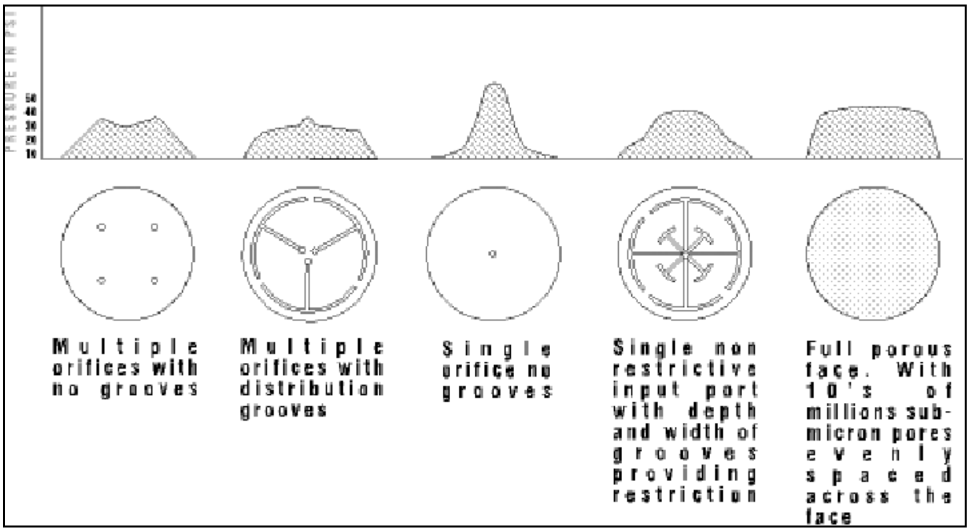

Figure 7 Air bearing pressure profiles

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Lift off and collapse

When grounded, a flat orifice bearing only has the area of the orifice (and air distribution grooves) available to establish initial lift force. This limits the ability to preload orifice type air bearings. Porous media air bearings supply air pressure across the entire face, even when grounded.

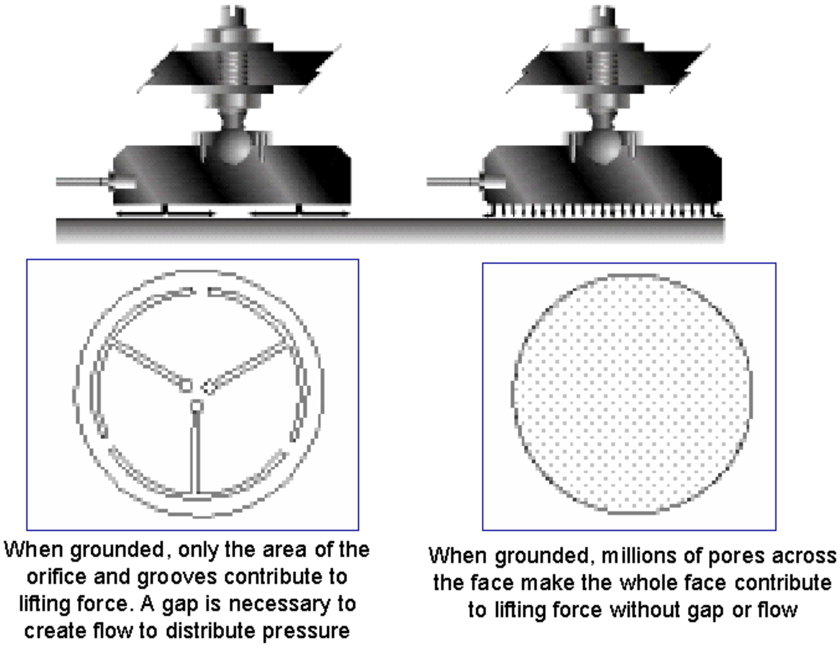

Figure 8 Orifice vs. Porous Media

Pitch moment stiffness

Is interesting to note how this effect distinguishes porous and orifice air bearing types when comparing pitch moments stiffness of an individual bearing. As orifice bearings are dependent on flow across the face of the bearing an angular change in the gap e.g.; when one side of the gap gets large and the other side gets small an unstable situation will be created where the available flow will rapidly lose its pressure following the path of least resistance (the large gap) and away from the area that needs it most (the small gap). The porous bearing in contrast still has pressure issuing from the small gap area. This gives the porous bearing higher tilt moment capacity and stiffness.

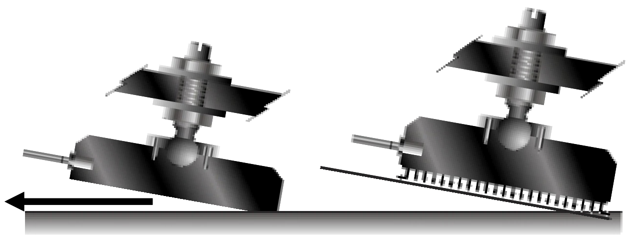

Figure 9 Pitch Moment Stifness

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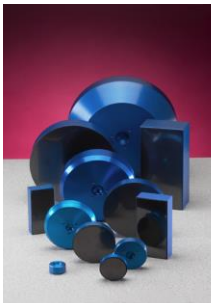
1.5 Air Bearing Products

Air bearings are typically available in one of five types of product: Complete details on each type of air bearing product, including selection, mounting, configurations, and handling are covered in the later sections of this application guide.

1.5.1 Flat Bearings (Pucks)

Flat Bearings may be round or rectangular, and are typically mounted using a threaded ball screw. They can also be bonded in place using a patented vacuum replication process.



Flat Air Bearings

1.5.2 Air Bushings

Air bushings offer the least expensive method of utilizing air bearing technology. They are designed to fit standard shaft sizes, and can often be used as direct replacement of existing bushings.

Air bushings

1.5.3 Vacuum Preloaded Air Bearings (VPL's)

Vacuum Preloaded Bearings (VPLs) are similar to flat air bearings but they utilize vacuum to provide preloading of the bearing against the guide surface.

Vacuum Preloaded Air Bearings

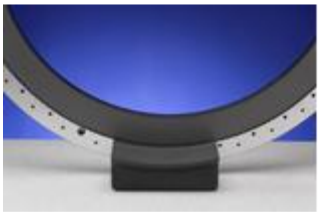
1.5.4 Air Bearing Slides

Air Bearing Slides are complete slide assemblies that use flat pad air bearing technology integrated into a compact air bearing slide package.

Air Bearing Slides

1.5.5 Radial Bearings

Radial bearings are ideal for very large rotary bearing applications and give you all the benefits of air bearings: no friction, no wear, no lubrication, and no noise.



Radial Bearings

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1.6 Air Bearing Applications

New Way® Air Bearings are used in a variety of applications including: Coordinate Measuring Machines, Precision Machine Tools, Semiconductor Wafer Processing, Medical Machines, Optical Lens Production Equipment, Digital Printers, Lithography, Precision Gauging, Diamond Turning Machines, Materials Testing Machines, Crystal Pulling, Rotary Tables, Spindles, and Friction Testing.

New Way® air bearings offer distinct advantages for different industries and markets as outlined below.

1.6.1 Machines for the Image Setting Industry

This includes machines for computer to plate (CTP) and high-resolution scanning in the prepress industry. These machines employ high speed spinning optics traveling down the center on an internal drum. Laser beam is reflected off the optic and directed to the internal diameter of the drum. Air bearings are important for axis of rotation and translate the spindle down the center of the guide. Pitch and yaw errors are magnified by the distance from the optic to the internal drum surface by the Abbe principle. Air bearings are used in order to minimize these pitch and yaw errors. Air bearings are used in order to minimize these pitch and yaw errors which result in banding artifacts in the image.

1.6.2 Coordinate Measuring Machines

Most coordinate measuring machines (CMMs) are built with air bearings because they allow for infinite resolution. Because air bearings actually float on a pressurized film of air there is no physical contact. This means only the shear of the molecules contributes to friction. The static and dynamic coefficients of friction at startup are identical and there is no stick-slip effect. This minimizes lost motion and reversal errors around the triggering of the probe. And because air bearings are more repeatable and smoother than rolling element bearings error correction is more effective. Mechanically, this allows for infinite motion resolution (putting the controls engineer back on the hot seat.

1.6.3 Testing Equipment

Many tensile and friction testing machines can be influenced be the friction in rolling element bearings. Wear in the bearings can also result in inconsistencies with testing processes. For this reason, many of the most accurate friction testing machines use air bearings to eliminate mechanical contact friction. Many testing machines require very accurate force control. The elimination of friction dramatically increases resolution of the instrument. Fatigue testing (another oscillating type test equipment) will often cause 'fretting' in rolling element bearings. Being non-contact, air bearings are insensitive to high frequency short travel applications.

1.6.4 High Speed Equipment

Machines are being designed today that have moving elements that may cycle as many times as one billion cycles per year. It is simply not reasonable to try to do accelerated life testing on such machines. Another alternative is to switch the mode of wear by changing the bearing technology from roller bearings to air bearings. In air bearings the speed or distance the bearing travels does not affect wear. The mode of wear in air bearings is erosion, so the amount of particulates in the incoming air is the determining factor in how long a bearing will last. Even assuming relatively dirty is used, the calculated life of an air bearing is measured in centuries regardless of whether it is moving at one billion cycles a year or remaining stationary. The dynamic coefficient of friction increases with speed and will only contribute heat problems at over 20 meters per second and then only in confined rotating applications.

Ultra accurate machine tools

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Many of the most accurate machine tools in the world employ air bearing technology. The zero static coefficient of friction allows for unmatched performance during stage reversal in contouring applications. Very accurate velocity control and elimination of perturbations in the stage movement allow for the turning of optical quality surface finishes that are measured on the angstrom level. Errors in geometries on manufactured parts are often on the order of several millionths of an inch.

1.6.5 Linear Stages

The benefits of air bearings, and porous media air bearing technology in particular, are often incorporated into high performance linear stages. New Way® modular air bearings allow ultra-precision, frictionless stages to be designed and built with standard off the shelf components that are inexpensive and easy to use.

1.6.6 OEM

Air bearings are found throughout OEM precision machine applications. OEMs can either incorporate complete linear stages into their machines, or they can integrate their own stages using modular air bearing products.

1.6.7 Custom Projects and Test Rigs

If you thought that air bearing technology was beyond the scope of your one-time, custom project, then think again. New Way is the only company to offer standard, modular air bearing products that can be easily integrated into your custom machine, test rig, or custom gaging application. With a wide selection of flat air bearings, air bushings, vacuum preloaded bearings, and air bearing slides in stock, the benefits of porous media air bearing technology are available to those with even the smallest of projects. The frictionless properties of air bearings provide for finer resolution of motion and allow significantly lower forces than can be achieved with rolling element bearings.

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2 Part II: CHOOSE AN AIR BEARINGS

2.1 Selecting the right air bearing product for your application

The charts on the following two pages can be used to select which air bearing product is best suited for your application, and what effect the operating environment may have on air bearing performance.

Table 2 AIR BEARING PRODUCT SELECTION CHART

	FLAT PADS	BUSHINGS	VPLs	STAGES
COST	This is the most common type of air bearing stage in use. Pads are inexpensive. Stage structures are inexpensive. Guide ways are the more expensive component. The number of bearings can add up in a large or complicated application.	This is the least expensive air bearing system. Round shafting is readily available. Only 3 bushings are required to constrain a stage to a single axis of motion.	Using VPLs on a single plane can provide X and Y motion, saving costs. However, VPLs are more expensive then flat pads as they are more complicated and larger. VPLs are often flexure-mounted which can also add to costs. VPLs may be bonded into place with a patented process to reduce mounting costs.	Air stages have air bearings integrated into them and fit to a guide way. This minimizes assembly, inventory, and purchase part lists for the customer, but will most often be the most expensive.
ASSEMBLY	Easiest assembly. Low cost mounting components. Flexibility in alignments from threaded studs.	Easy assembly. “O” rings provide self-alignment. Mounting components are easy sourced by the customer or can be purchased from New Way.	VPL systems require more assembly care. Most flexure designs are somewhat fragile. Patented vacuum replication process can be employed (with license agreement) for robust and inexpensive mounting.	No customer assembly required.
PRECISION	The straightness of motion will be dependent on the accuracy of the guide ways used. When pre-loaded by an opposing pad the stage will be over-constrained. In some cases, errors in the guide may be averaged.	Round way stages can achieve high accuracies especially when strokes are limited to less then 6”. Most bushing stages are employed where smoothness, speed, or low friction are required.	Because VPLs can be arranged kinematically correct, the highest precision is possible. Of course, other precision engineering principals will also need to be adhered to in order to achieve this high precision.	Because stages can often have more air bearing surface area and shorter distances between pay load and guide, they will have higher stiffness and less angular errors caused by off drive axis masses.
STIFFNESS	Preloaded flat pads have high stiffness. In most cases bending or diaphragm effects of the structure result in lower structure stiffness then in air films.	Since bushings guide on end supported shafts, bending of the shaft is usually the limiting factor in system stiffness. The “O” ring mounting can also limit stiffness. A simple potting procedure can hard fix this compliance. Stiff stages can be constructed with short strokes. See bushing section for more detail on how gaps affect performance.	VPLs have variable stiffness. System stiffness is often limited by the mounting flexure. Our standard VPLs are best used in lightly loaded, low acceleration, ultra high precision applications where their exact constraint is used to advantage. More robust systems with higher load capacities and stiffness can be constructed using large custom VPLs and our replication process.	New Way air stages built with our patented replication process offer the highest stiffness for a given space.
LOAD CAPACITY	Flat bearings have the highest load capacity. Custom bearings can carry over 10,000 lbs each.	Air bushings have limited load capacity. Being “O” ring mounted it is possible to gang them together to increase load capacity.	Flexure mounted modular VPLs have very limited load capacity. Larger, bonded VPLs can have much higher load capacities.	Stages can have high load capacity.
PLUMBING	Plumbing is simple. One air line goes to a manifold on each axis, with bearings from that axis fed from the manifold.	As air bushing stages can be made with fewer bearings, plumbing often is simpler.	Second air tube required for vacuum. Vacuum air tube should be larger diameter for good conductance.	Air Stages are the simplest to plumb. They require only one air pressure line.

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Table 3 EFFECT OF ENVIRONMENT ON AIR BEARING PERFORMANCE

ENVIRONMENT	EFFECT ON AIR BEARING PERFORMANCE
Dust	Very resistant to dry dust. Will clear a path on dusty surface. Care should be taken not to let dust build up at ends of travel or it will tend to pack clearance areas full. Consider angled surfaces to reduce this effect.
Oil	Oil dripping on the guide is to be avoided! Oil will fill the air gap and create drag. Disassembly, cleaning and possible replacement of bearings may be required (see cleaning issues).
Water	Water dripping on guide is to be avoided! Water will fill the air gap and create drag. Drying the guide way and supplying clean, dry air to the bearings will restore original performance. Be wary of corrosion or caustic reactions of the guides to the water.
Temperature	Stock Air bearings are designed to operate at room temperature. A variance of +/-30°F is acceptable in almost all applications. Larger bearings will be affected more by temperature differences. Pay close attention to thermal effects on your structures.

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3 PART III: DESIGNING WITH AIR BEARINGS

3.1 Air Bearing Guides

Air bearings can be run on different types of guide material. Common guide surfaces include granite, hard-coated aluminum, ceramics, glass, stainless steel, and chromed steel.

3.1.1 Guide Surface Considerations

Surface finish, local flatness issues and possibly even holes in the counter surface need to be taken into consideration.

3.1.2 Surface finish

We recommend a 16rms finish or better. Rougher surfaces may be used. The down side here is that the surface roughness must be considered as part of the gap so this influence is greater when designing for small gaps. Also damage is more likely to occur on the bearing face during a touch down while in motion.

3.1.3 Local flatness

The local flatness, which is the flatness under the bearing at any one time, should be less than 50% of the design air gap. This is a worst-case scenario and in reality, it is relatively easy to keep this number less than 10% of the air gap.

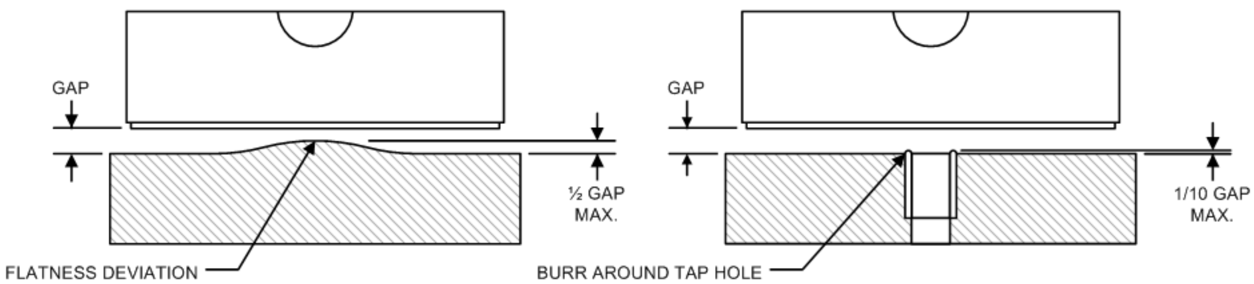

Figure 10 Surface Flatness

3.1.4 Holes in the guide

With respect to holes in the guide surface it should be remembered that orifice bearings simply do not work flying over holes, it is very convenient that porous bearings work well flying over perforated surfaces. We do pay a price though in that a lower lift for a given load must be accepted. How much lower? By example a 80mm bearing flying over an optical table with ¼ 20 threaded holes on one inch centers will have about 50% of its normal load capacity at 10 microns. The higher the air pressure in the gap the higher the efficiency losses from the holes.

3.1.5 Seams in the guide way

Seams in the guide ways should be avoided. With an air gap of 5 microns a step in a seam of 10 microns would be like the bearing hitting a wall.

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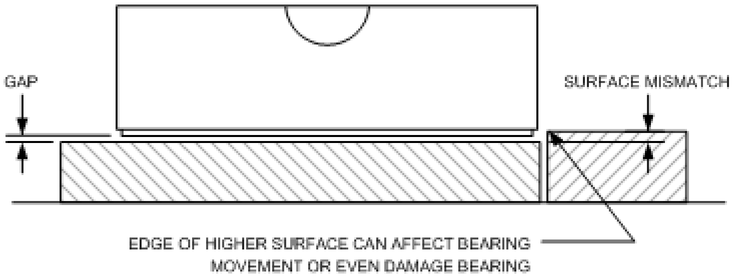

Figure 11 Seams in the guide way

3.2 Stiffness and Preload

Stiffness is an important factor when designing any precision motion system, with bearing stiffness being a significant factor in overall performance. The higher the stiffness, the less compliance there will be when loads are applied. Preloading is a method of increasing bearing stiffness that is used for all types of bearings.

Preloading in roller bearings follows the rules of Hertz Ian contact stresses. Basically, as a ball bearing is pressed against its race, the point or line of contact becomes larger as the load becomes heavier. The larger contact area leads to higher stiffness. In roller bearings this desire to increase stiffness must be weighed against higher friction and wear from the preloading.

Preloading in air bearings follows the rules of fluid dynamics. As air bearings are loaded, the air gap gets smaller and the pressure in the air film rises. Because air is a compressible fluid it has a spring rate or stiffness. Higher pressures are essentially a preload on that air spring. If you think of the air gap as a column with a uniform spring rate it is evident that the shorter the column, the higher its stiffness will be. The factors that determine stiffness in air bearings are the pressure in air gap, the thickness of the air gap, and the projected surface area of the bearing.

Intuitively it may be difficult to comprehend how an air bearing could ever have stiffness as high as a roller bearing, which is in physical contact. It should be remembered though that a point or even a line of contact has theoretically no area. Such minimal contact area creates very high local stresses and so requires very hard materials to avoid deformation. In air bearings the load is transmitted through an air gap that is projected over an area several orders of magnitude larger than roller bearings. This wide air gap is also an important function in squeeze film damping, which can be very advantageous in precision systems.

Air bearings can be preloaded using added mass, magnets, vacuum, or by mounting 2 air bearings on opposite sides of a guide rail. Adding mass often runs counter to the requirements for high acceleration and fast settling time. Magnetic preloading requires that the guide surface be metal under each axis, so metal strips would need to be inserted on a granite base, adding to the complexity and cost of the structure. Air bearings are most frequently preloaded by configuring air bearings opposite each other as shown in **Error! Reference source not found.**). This r equires a significant amount of space, requires two parallel surfaces, and doubles the total mass of the bearing

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components. Vacuum preloading offers an elegant solution that minimizes bearing mass and height, and can be utilized on granite as well as metallic guide surfaces.

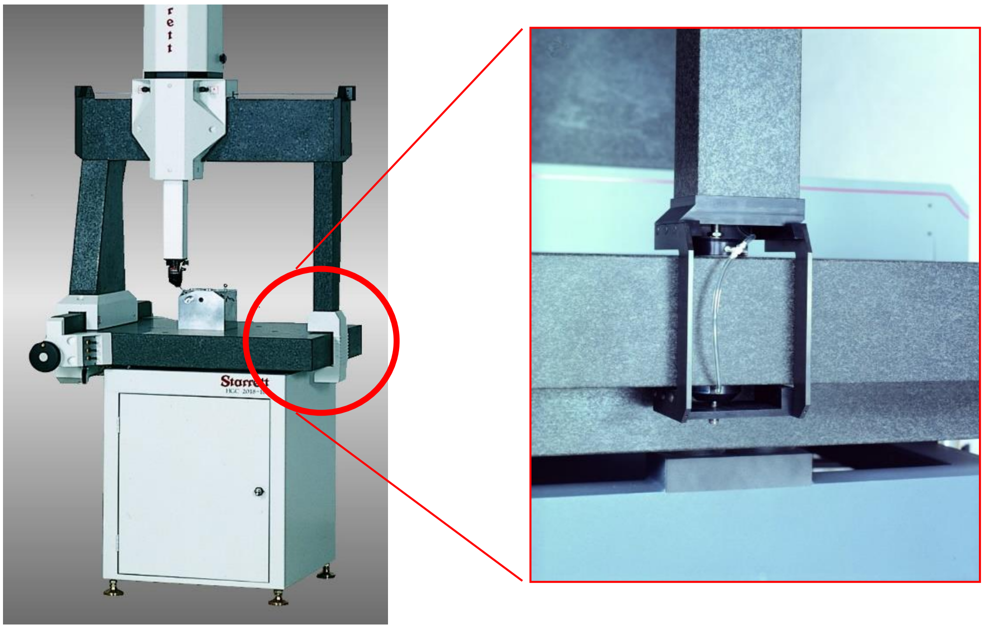

Figure 12 New Way® Air Bearings on a Coordinate Measuring Machine

3.2.1 Now on to ways of preloading air bearings:

1. Air bearings can be loaded with mass. An example of this might be moving a large object about on the surface of a precision granite surface plate or optical table. This is usually best on three bearings as three points describe a plane. When a known mass is to be supported, the bearings should be sized so the load that each bearing carries drives the air Gap to the desired area of the lift load curves or stiffness. Sometimes stiffness is not issue, for instance there may not be a change in load. Or their might be a desire to fly the bearings on surfaces that are less than flat. For instance in the case of an aluminum optical table with quarter 20 holes on 1 inch centers you'll often find raised high spots. Here, selecting an oversize bearing would be wise as a will result in the higher flying height and withstand more abuse.

2. Air bearings can be preloaded with vacuum. Air bearing lands or inactive surfaces that are finished at the same plane as the bearing face can be used as a vacuum seal. It is counter intuitive that an air gap which is being pressurized with air can be a seal for the vacuum, but it works quite nicely. When you consider that a vacuum preloaded bearing may consume less than 5 cubic feet of air per hour and that only half of that will find its way into the vacuum chamber it is easier to see. Ambient pressure groves between active air bearing areas combined with seal lands dramatically reduce even that small flow into the vacuum. The vacuum load is created in the center area where vacuum is drawn. By drawling vacuum in this area, outside atmosphere actually presses down on the Bering creating a pre load force equal to the projected area of the vacuum pocket times the pressure differential. This pressure differential can easily be two-thirds of a perfect vacuum, which is 20 in. of mercury or negative 10 PSI. The advantage of vacuum preloading is that it creates a Preloading force on the bearings without adding mass. Also preloading is possible over a plain in X and Y without having the guide surface be metal as would be required with magnetic preload. Large monolithic vacuum preloaded bearings say for instance 12in. square can create over

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800 pounds of preload force of the and stiffness well over 2 million pounds per inch, with only a single pound of payload. This technique is used to advantage when high acceleration stages need fast settling times. By guiding in X and Y off of a precision plane the Abby errors and tolerance buildups from stacked linear axis are eliminated providing for exceptional flatness of motion.

3. Magnets, like vacuum can create a preload without adding much mass. Metal strips parallel to the guide surfaces can be used for preloading linear axis. But in order to preload in X and Y the whole guide surface must be metal. Magnets are often used between two air bearings, mounted in some sort of a threaded holder which allows adjustment of the magnets to the metal strip. By adjusting the Clarence the preload force can be optimized.

4. Air bearings are most frequently preloaded by another air bearing. In this case it is possible to double the stiffness of the assembly as the stiffness of the two bearings are additive. It is usually best to try to preload bearings directly opposite one another to avoid structural distortions.

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3.3 Loads Acting on Air Bearing Systems

3.3.1 Gravity Loading

Structural Considerations and Kinematics

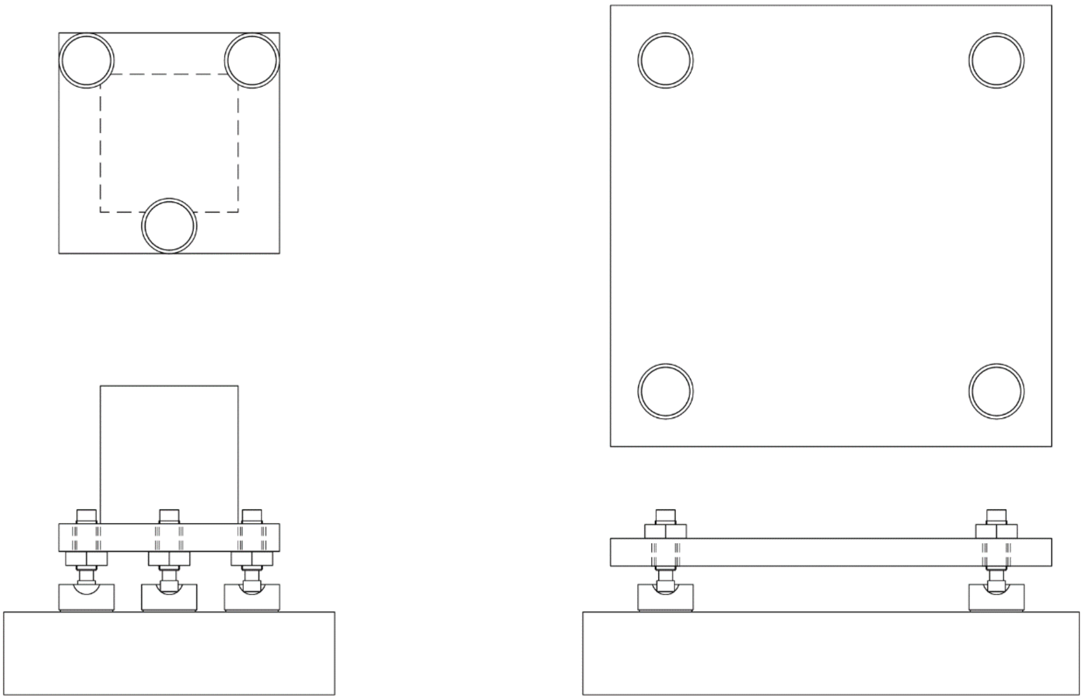

Figure 13 Supporting a load on a flat plate

When supporting a simple load on a flat surface it is often best to use three bearings for a three-point stance. This avoids the rocking problem of four-legged chairs. (See the section on kinematics). This three-legged stance is especially important if the structure being supported it is very stiff (having a tall cross-section) or if the surface supporting it is not very flat. If the structure being supported is not very stiff (say a plate with widely spaced bearings) than a four-legged stance may be more stable by virtue of a wider footprint. The plate would be considered elastic rather than a rigid body.

3.3.2 Payload distribution and mobility

Now consider if the load will be evenly distributed across the bearings. Will there be a change in payload? Will the load change position as another axis stacked on top would? Size the bearings so that the maximum load the bearing will see will not result in an air gap that is less than you are comfortable with, (a good rule of thumb is 3 to 5 microns). Consult the lift load charts for the individual bearings to determine this value. Please note that larger bearings running at a lower pressure can reduce airflow requirements, increase damping and stiffness and provide a much higher safety factor than a bearing that it is sized at its margin of capability at a relatively high pressure.

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3.3.3 Preloading with other air bearings

When preloading with other air bearings the preload force needs to be considered when sizing the bearings. Preloading with other air bearings is usually employed to provide a bi-directional load capacity or to increase the air film stiffness. When the preload forces are high relative to any anticipated change in load, stiffness will be high. In other words larger bearings preloaded against each other will result in higher stiffness. In fact the stiffness of two opposed bearings are additive. So preloading two bearings against each other, each with 500,000 pounds per inch stiffness will result in one million pounds per inch stiffness. The preload force though needs to be subtracted from the capacity of the bearings

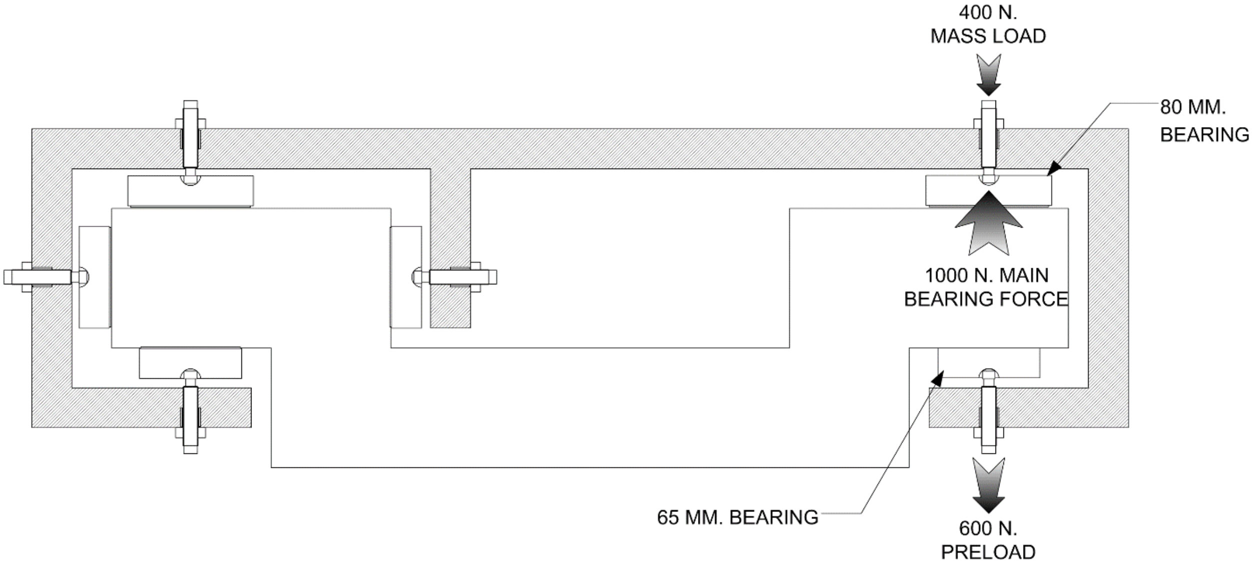

Figure 14 Preloading with other air bearings

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3.3.4 Dynamic Loading

When designing a high-performance stage (high acceleration, fast settling time) it is critical to drive the stage on the center of mass! Often, because of other design considerations, this is not possible. Any mass off the drive axis will result in a moment force that needs to be resisted by the air bearings during acceleration and deceleration. So these dynamic loads need to be considered when sizing the air bearings

This model presumes no change in the air film stiffness and infinite stiffness of all structures.

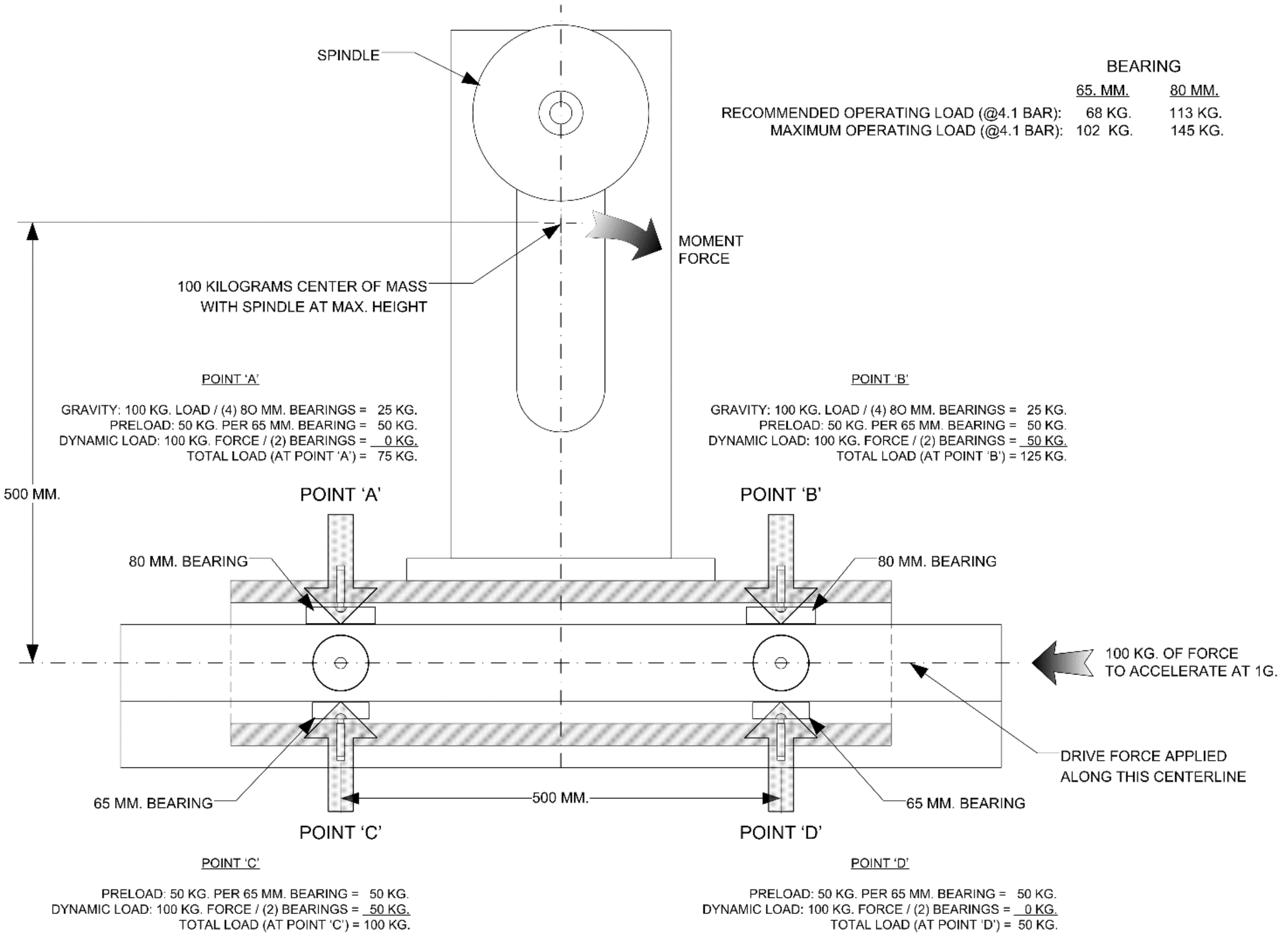

Figure 15 Dynamic Loading

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4 PART IV: SETTING UP AND USING AIR BEARINGS

4.1.1 Flat Air Bearings

Mounting and Adjusting

Why use ball studs to mount flat pad air bearings? When mounting air bearings it is critical that the face of the bearing be parallel with the guide surface on which it runs. Even a few microns of out of parallelism across a 75-millimeter air bearing would significantly degrade the bearings performance. For this reason it is quite difficult to bolt bearings rigidly in place. A spherical socket and a ball stud work much better and cost much less than the precision match machining that would be required to bolt the bearings in-place. Additionally the threaded ball studs make alignments and preloading of the bearings easy, speeding machine assembly. Their modularity makes them easy to change or replace.



Figure 16 - Ball stud options for flat air bearings

New Way offers two types of ball studs:

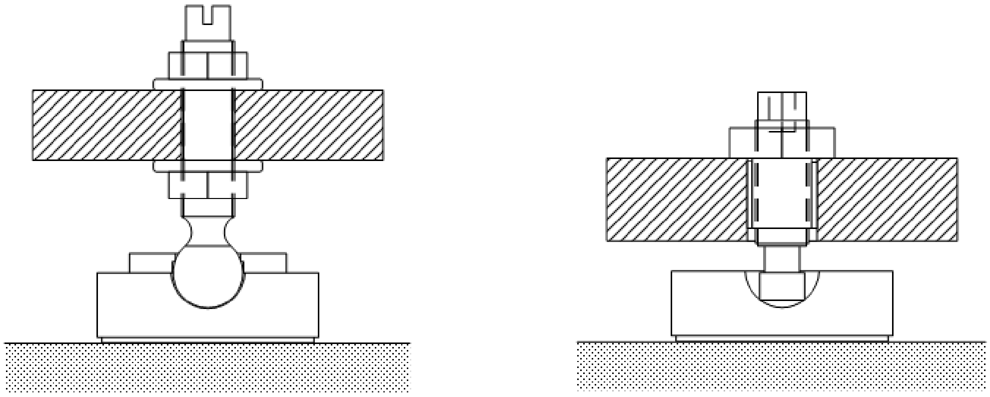

Figure 17 - Old and New Ball Stud Designs

New Way metric bearings provide three threaded holes for a retaining clip that keeps the bearing on the ball stud. The ball studs are available with medium or fine pitch thread. The studs come with two nuts and washers so it may not be necessary to tap your structure. New Way provides complete drill, reamer and tap information on our web site and the recommend tapping of the structure for easiest adjustment of the bearings. The retainer studs are handy when the supported structure may be picked up and moved, say to another test stand or if the bearings mount to face up and some type of removable flat platen is set on top of them. Or when the bearings are guiding a vertical ram and it is desired to have the bearings in place when the ram is inserted. This stud and retainer can be cumbersome during assembly or disassembly. The ball diameter is larger than the thread diameter is so it screws in from one side only. Also, once the ball stud is in place it is not convenient or impossible to screw the retainer clip on or off. So, the clip and bearing but must be assembled on the ball stud prior to the ball stud installation into the structure. This style ball stud is available for both metric and imperial bearings but threaded holes for the retainer clip are available on the metric bearings only. Complete drawings of our studs, retainer clips and our bearings are available on our web site. The use of this stud also requires more clearance between the back of the bearing and the mounting structure.

New Way insert spherical studs are very convenient to use. A brass insert with a coarse thread on its outside dia. threads into the structure. The insert has fine threads for preload and adjustment. The stainless steel stud has a spherical end that is smaller than the thread diameter, making it possible to remove the stud from either side. Wrench flats just above the spherical end allow adjustments from bearing side also. The bronze insert has a setscrew to lock the stud into adjustment. Minimal clearance is required between the structure and back of the bearing conserving space. If needed bearings are readily swapped out or replaced by backing off the ball studs and slipping the bearing out. This style ball stud is available for metric and imperial bearings. Complete drawings are available on our Web site.

It is not necessary to buy your mounting hardware from New Way. You may use our drawings to manufacture our design on your own. Or design and manufacture your own completely. Many of our customers have modified screws or bolts. Glued balls into screws or glued balls into the bearings and captured them with modified bolts.

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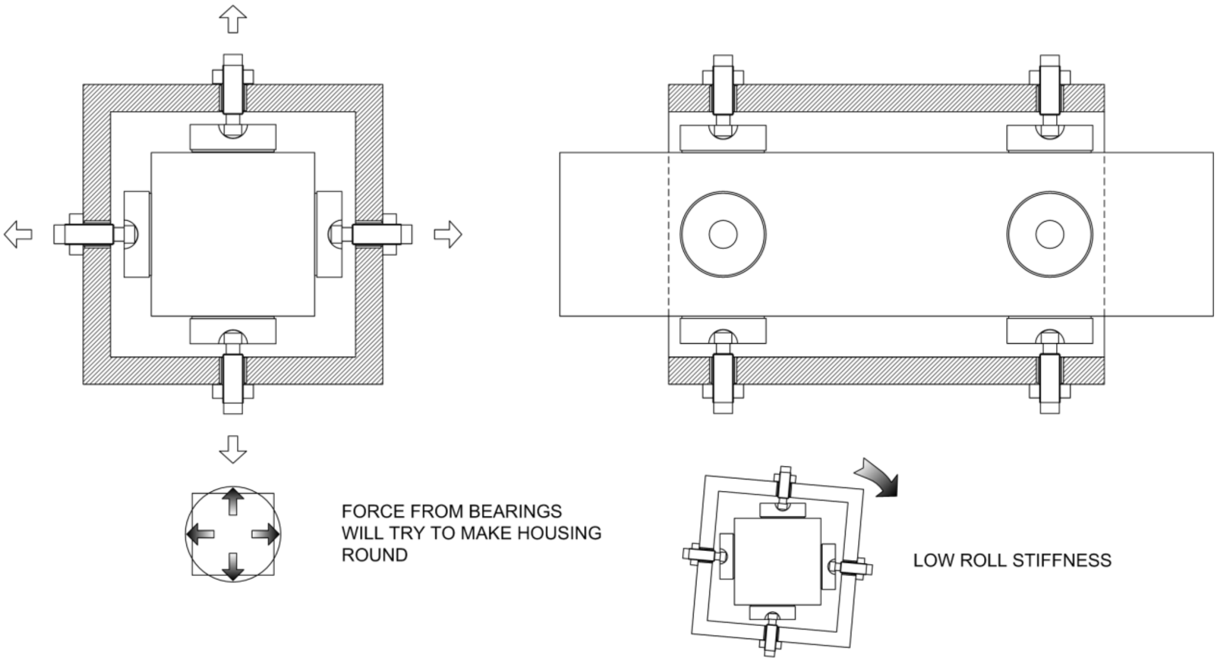
4.2 Typical Configurations

The following pages show typical configurations of flat air bearings with brief descriptions of benefits and/or drawbacks.



This design suffers from low roll stiffness although it makes for easy alignments and setup.

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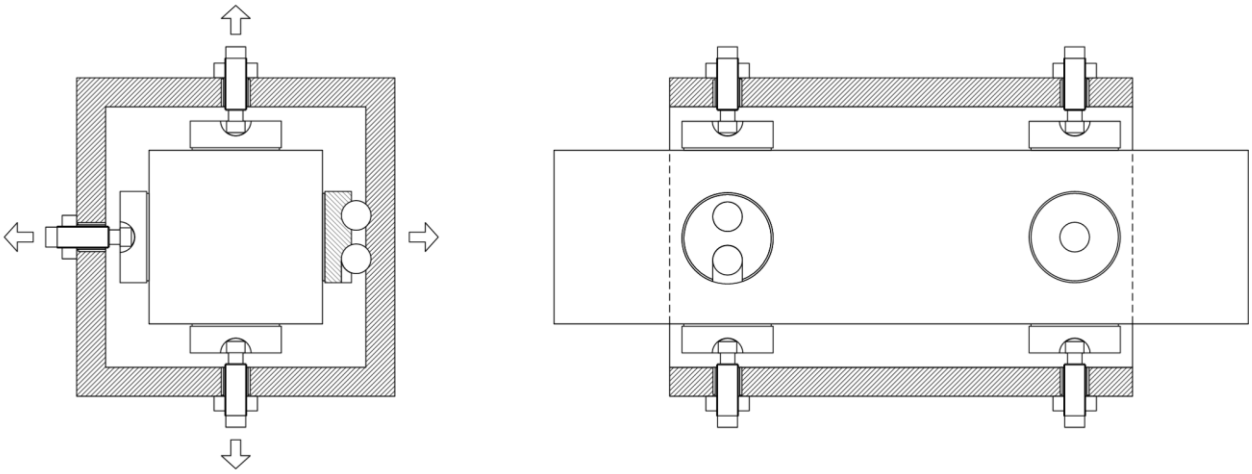
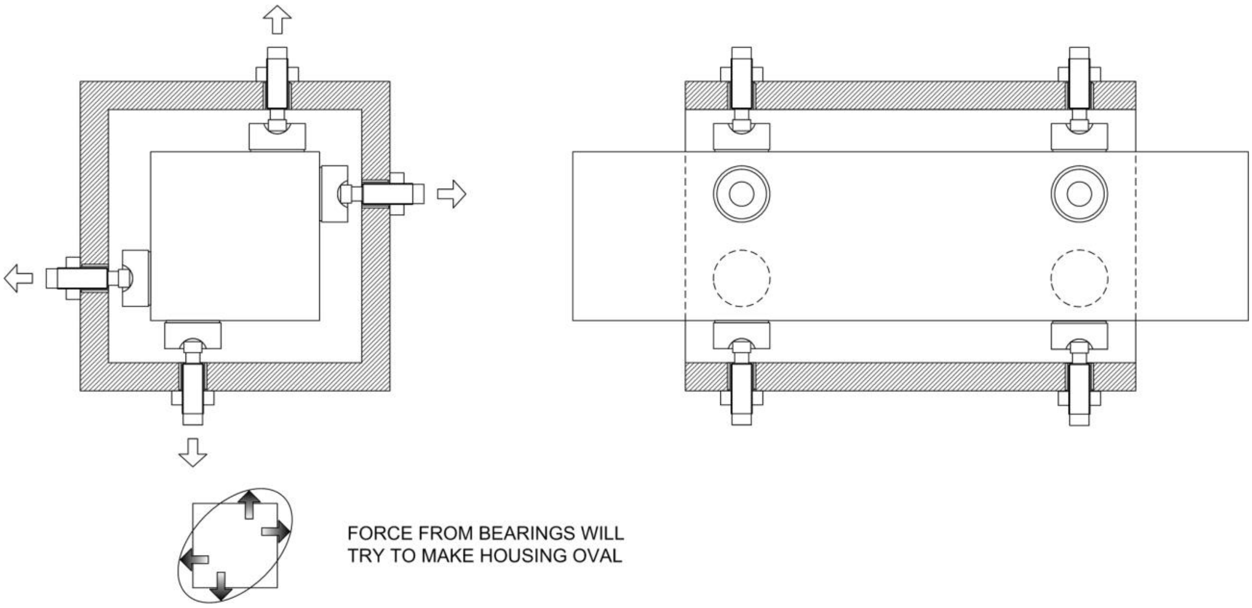
Using a second ball in a locating slot on one of the bearings constrains the roll about the axis. Stiffness and roll capacity is still limited to the pitch stiffness and roll capacity of a single bearing.



This design has higher roll stiffness. As the bearings are not directly across from each other it can be difficult to separate angular adjustments from roll adjustments.



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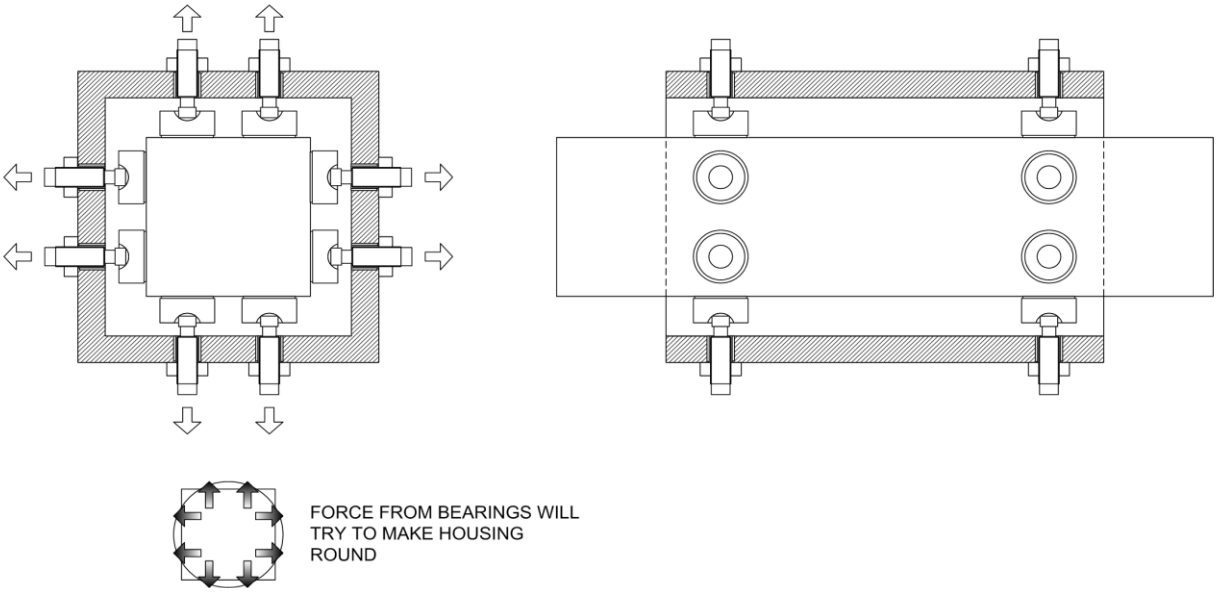
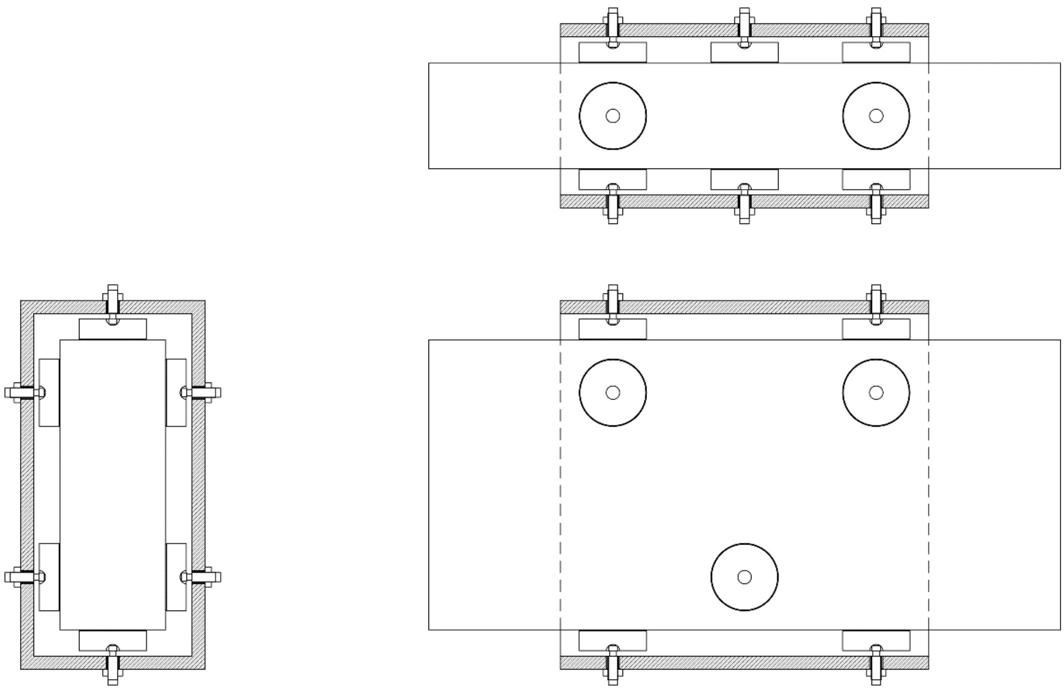
This design has 2x the roll and pitch stiffness and twice the load capacity. The setup and adjustment will be more difficult especially if the housing is relatively stiff. If the housing is not stiff it is more likely to elastically deform.



Bearings preloading directly across from each other. 3 sets establishing a plane. 2 sets establishing a line. 10 bearings are used in this layout.



More deterministic in its preload on the 3 bearings establishing a plane and the 2 establishing a line. Very easy alignments, uses less bearings, has lower stiffness. 7 bearings used in this layout.

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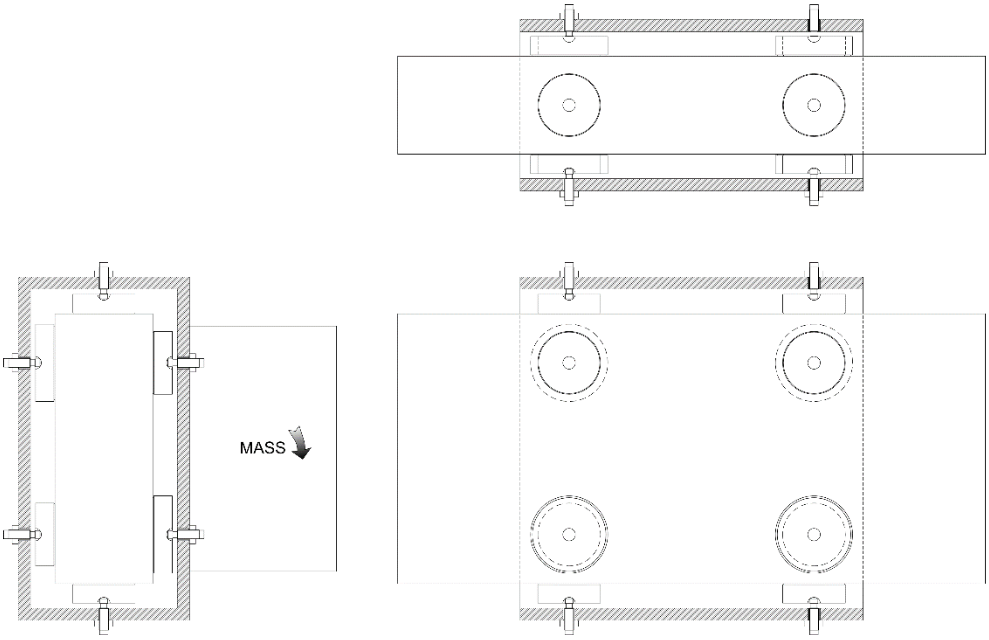
If a large off axis mass is found in the design. You may consider using larger or more bearings in the locations where the weight will bear. Note that if the mass is big enough to require a large difference in bearings or sizes, the slide may not operate without the mass.



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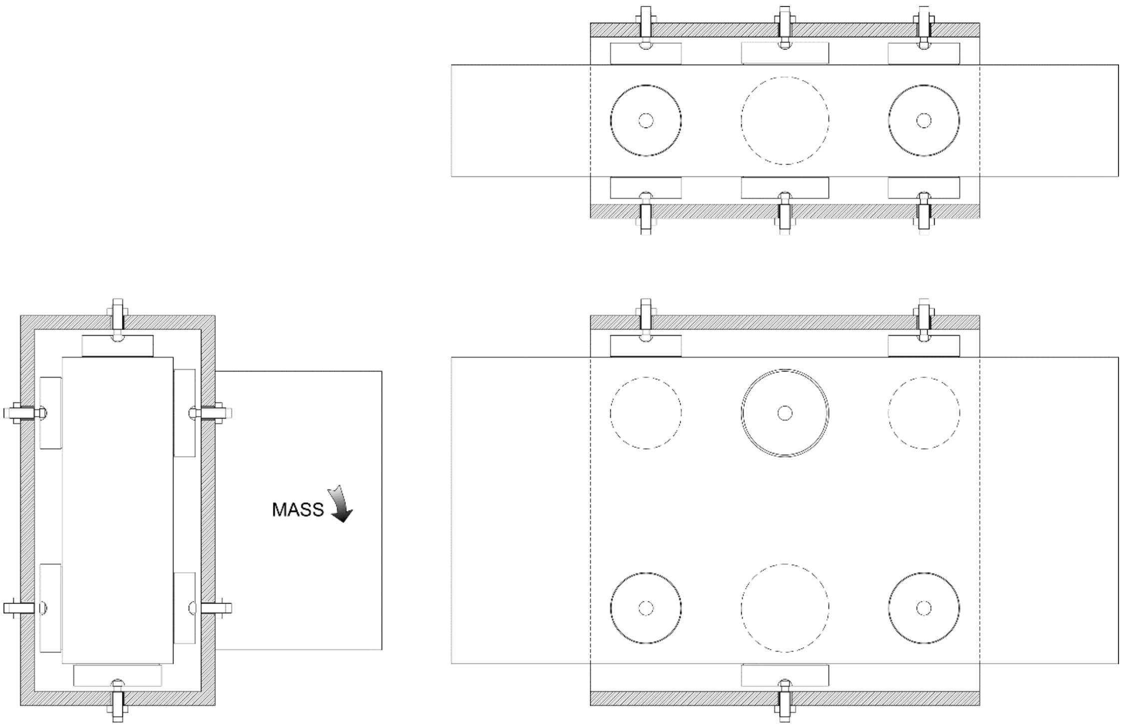
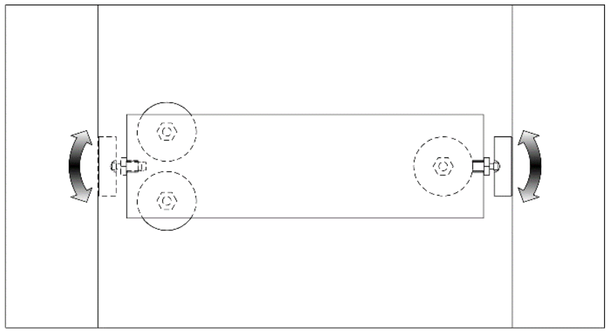
Directly opposed bearings with size bias to counteract load. 12 bearings used

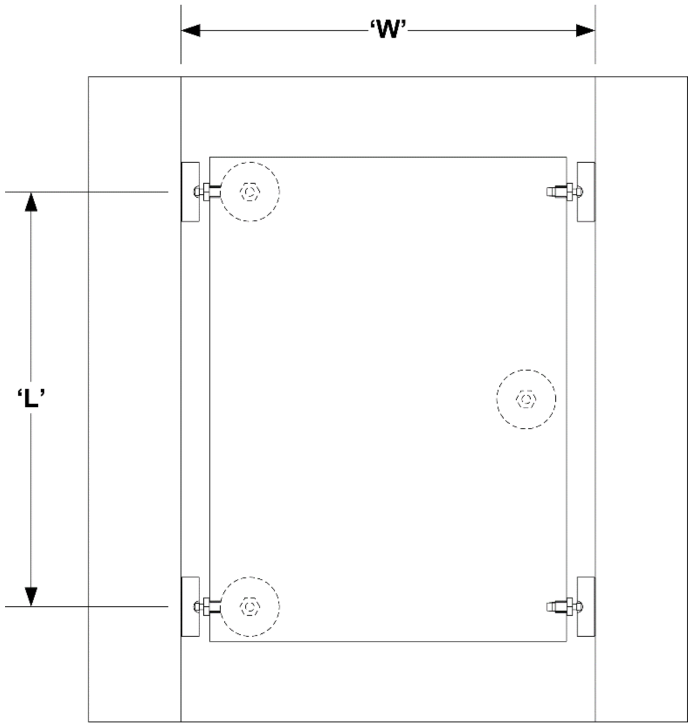


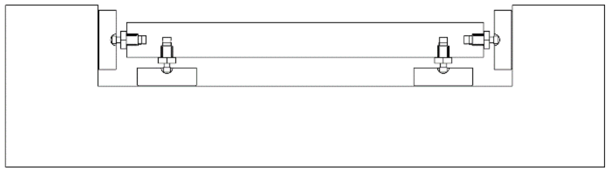
Staggered bearing locations with quantity bias to counteract load. 9 bearings used.

This is a very unstable design. Any lead or lag error between the two sides will result in a yaw force. The higher the preload force the higher the yaw force. A good controls engineer may be able to deal with this using linear motors and encoders on both sides. This arrangement though is not recommended.



When four bearings are used the situation is much improved, but until L equals or exceeds W the system will be relatively unstable.





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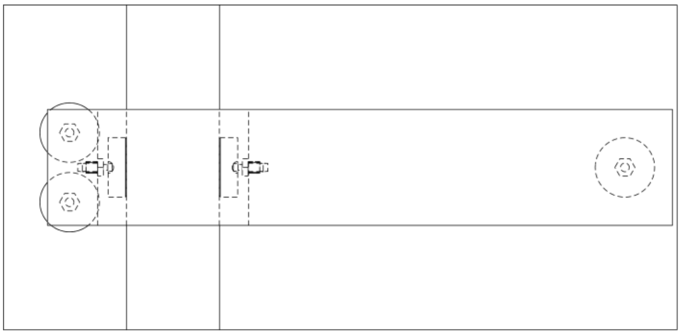
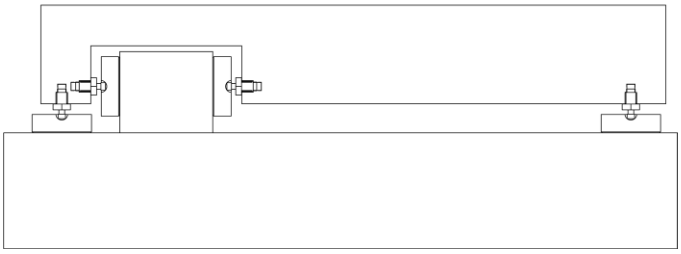
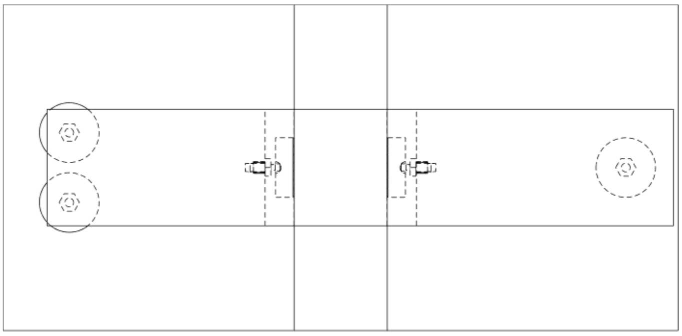
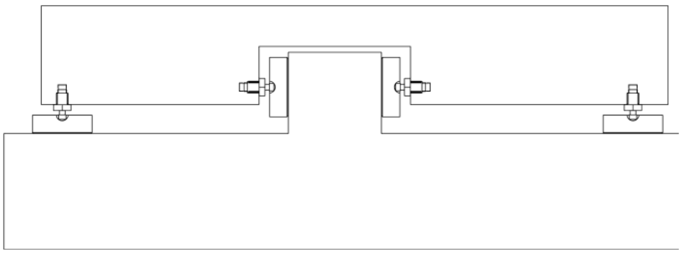
This guidance system is inherently stable, the two bearings will always be trying to find the shortest distance across the guide way. The higher the preload force the higher the squaring force will be.









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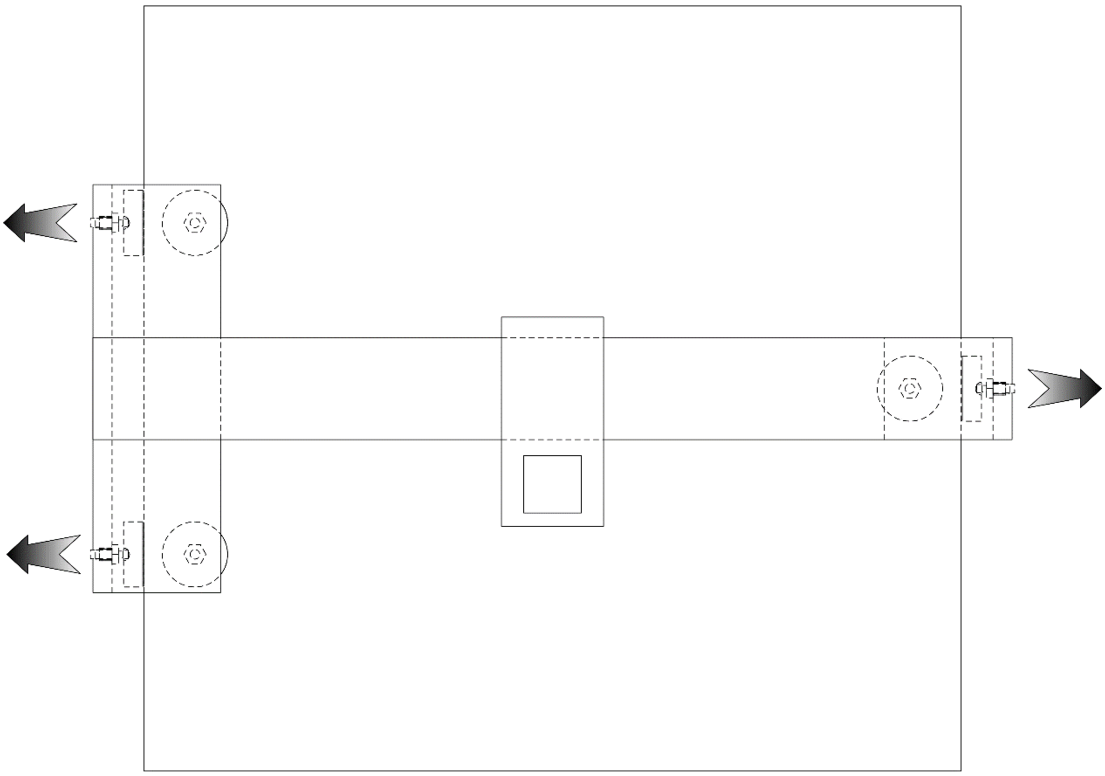
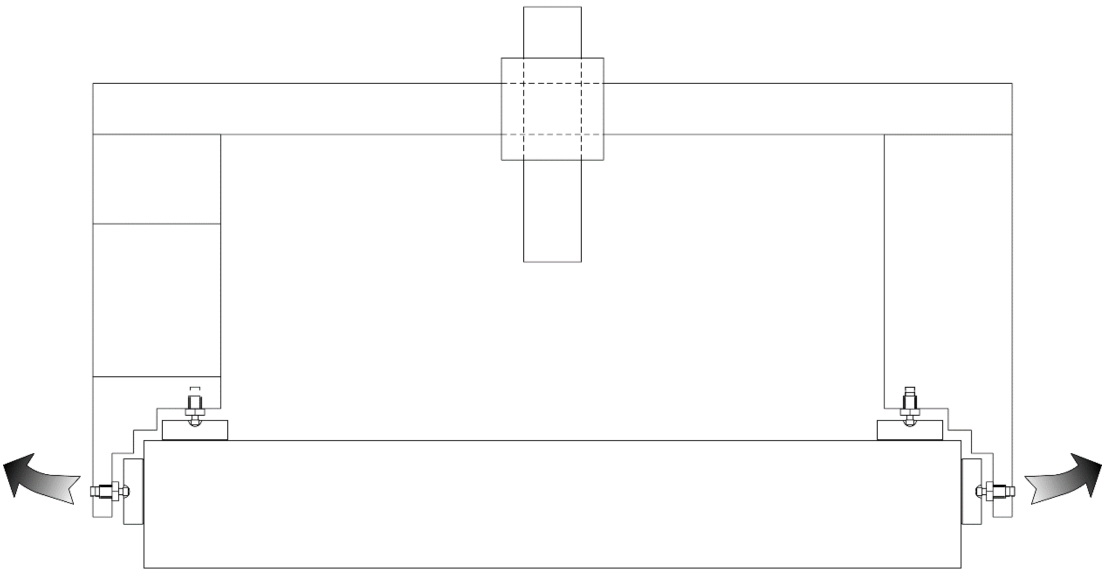
This design suffers from gantry splay.





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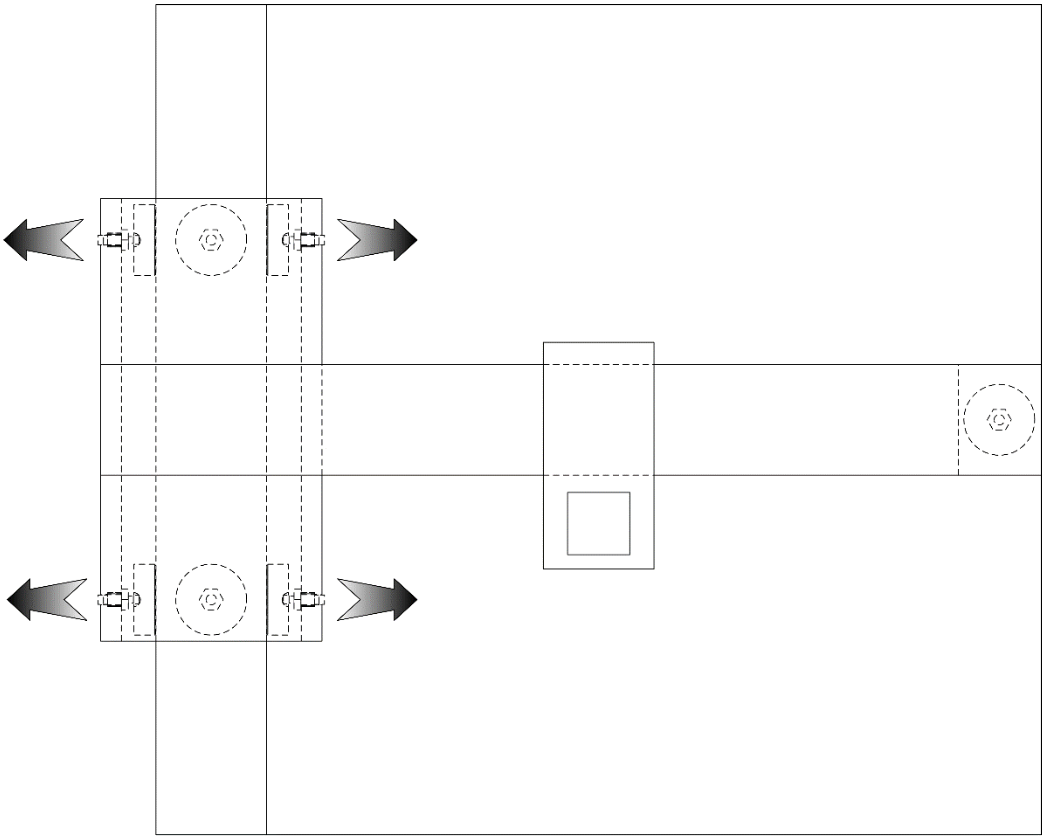
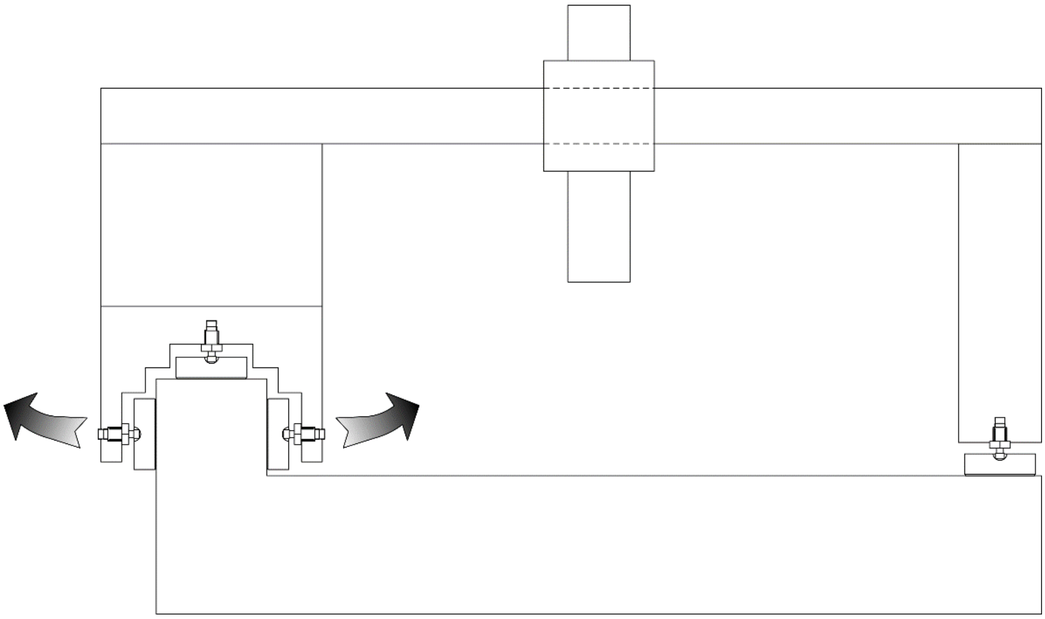
This design has significantly less gantry splay.





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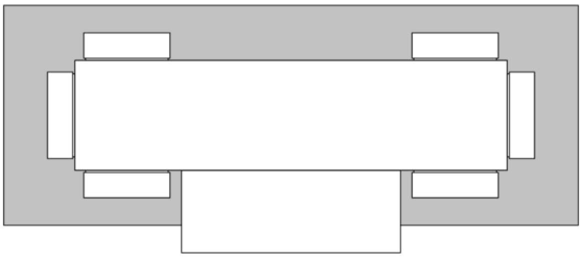
Single Rail

Continuously Supported

Pro: Easy to Manufacture and Align.

Con: Straightness Guidance bearings relatively far apart.

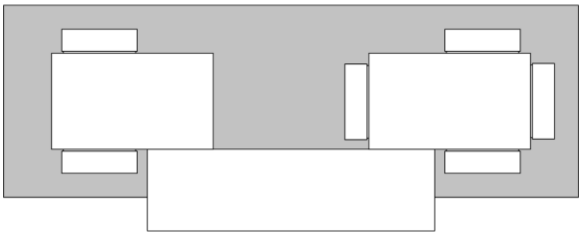


Double Rails

Continuously Supported - Single Rail Guidance

Pro: Straightness guidance bearings are relatively near each other.

Con: More difficult alignment for flatness.

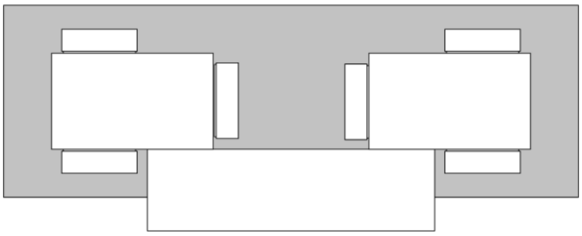


Double Rails

Inside Edge Guidance

Pro: Center of guidance is center of mass.

Con: Difficult to align 2 rails parallel.



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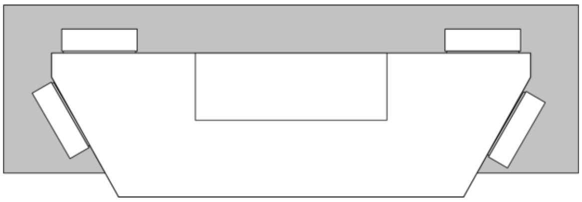
Dovetail

Continuously Supported

Pro: Fewer bearings required.

Con: Lower bearings must be larger to achieve same pre-load. Metrology of the guide bar can be difficult.

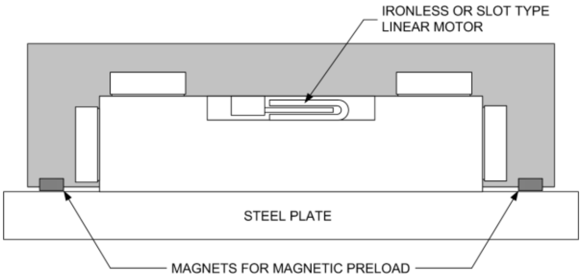


Magnetic Preload

Single Guide

Pro: Does not need to be mounted on surface plate

Con: Guide assembly often from 2 materials

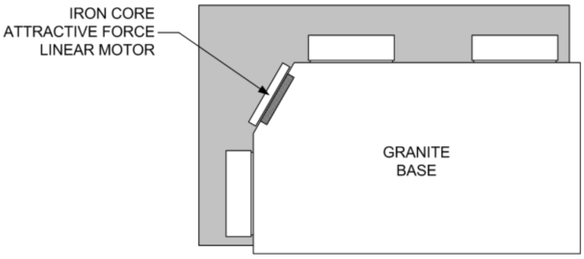


Magnetic Preload

Axtrusion Guide

Pro: Only 2 precision surfaces. Attractive force from 1 linear motor preloads flatness and straightness bearings.

Con: User license required

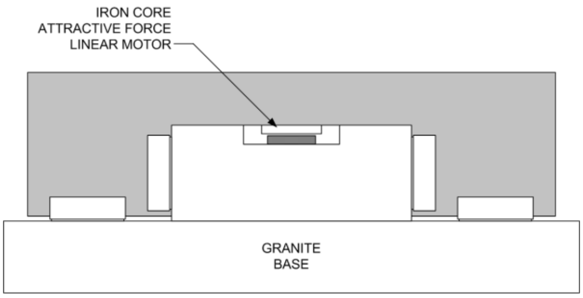


Magnetic Preload

Single Guide

Pro: Widely spaced load carrying bearings. Does not require magnetic strips.

Con: Requires mounting on granite base. Use of iron core motor for pre-load may result in cogging.



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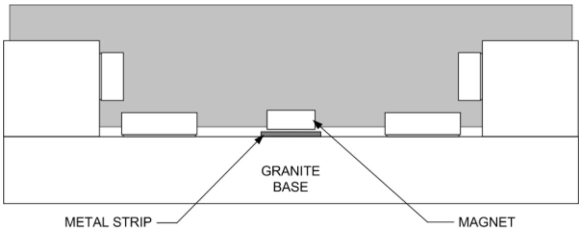
Magnetic Preload

Inside Guide

Pro: Widely spaced load carrying bearings

Con: Difficult alignment of vertical guides. Straightness guidance bearings far apart.

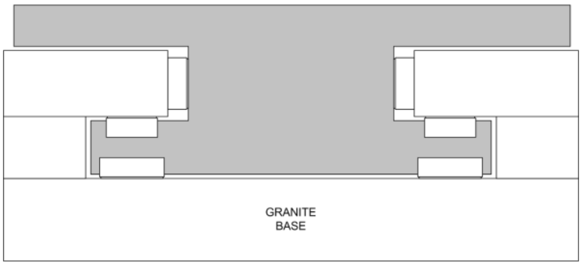


Double Rail Keeper

Inside Guide

Pro: Flatness guidance from base granite.

Con: Difficult alignment of straightness guide rails. More deflection of keeper.

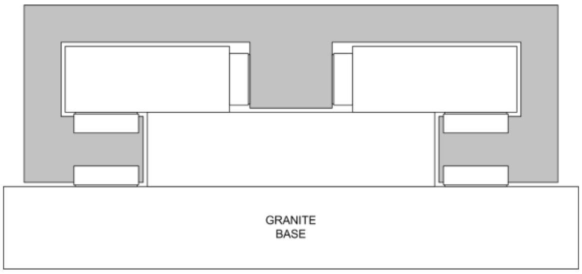


Double Rail Keeper

Outside Guide

Pro: Flatness guidance from base granite. Less deflection of keeper.

Con: Difficult alignment of straightness guide rails.

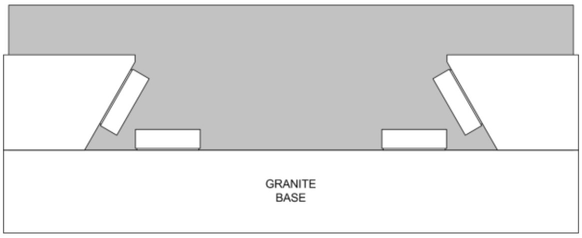


Double Rail Keeper

Inside Dovetail Guide

Pro: Less precision surfaces. Suitable for wide stages.

Con: Doubly difficult alignment! Minimal pre-load capability.



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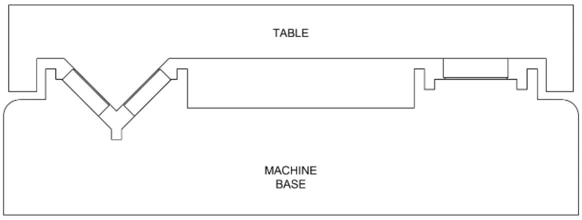
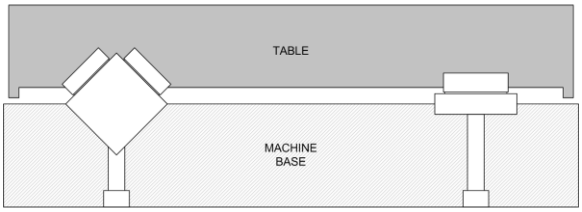
Female V and Flat



Pro: Quasi Kinematic Design.

Con: Requires gravity pre-load. Guide ways integral with base.

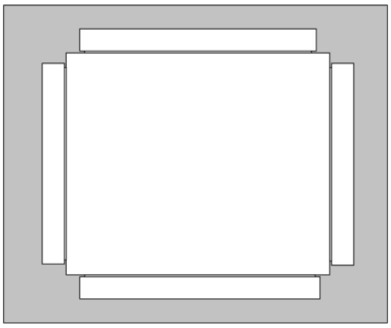
Male V and Flat



Pro: Quasi Kinematic Design. Removable guide surfaces.

Con: Requires gravity pre-load.

Square Guide

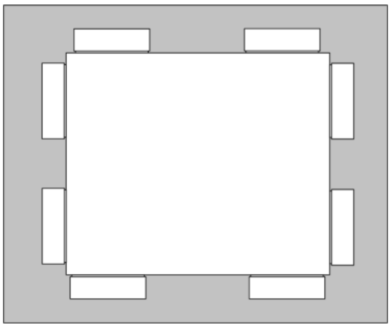


Full Bearing

Pro: High Load Capacity

Con: Housing Distortion

Square Guide



Split Bearing

Pro: High roll capacity

Con: Requires more bearings

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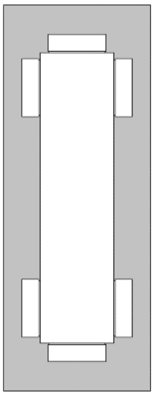
Rectangular Guide

Pro: Less beam deflection.

Con: Requires more vertical space.

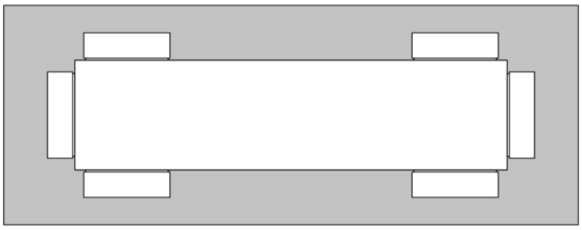


Single Rail

End Supported

Pro: Easy to Manufacture and Align.

Con: Straightness Guidance bearings relatively far apart.



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4.3 VPL's

4.3.1 Vacuum Preloaded Air Bearing Technology

Vacuum preloading is a technique where the fundamental principle is to create a vacuum under the bearing structure to effectively preload the bearing against the guide surface while simultaneously supplying pressurized air to the bearing surface to prevent the bearing from making physical contact. The trick is to realize that air bearing lands, or any inactive surfaces that are on the same plane as the bearing face, can be used as a vacuum seal. It is counter-intuitive that an air gap which is being pressurized with air can be a seal for the vacuum, but it actually works very effectively. When you consider that a VPL may consume less than 5 cubic feet of air per hour, and that only half of that will find its way into the vacuum, it is easier to understand. In addition, the small flow into the vacuum can be dramatically reduced when ambient pressure grooves between active air bearing areas are combined with the seal lands. The preload force is created in the center area where vacuum is drawn. The outside atmosphere effectively presses down on the bearing creating a preload force equal to the projected area of the vacuum pocket multiplied by the pressure differential. It is relatively easy to create a vacuum of 20 inches of mercury (negative 10 psi), almost two-thirds of a perfect vacuum. A large monolithic VPL, for example 12 inches square, can create over 800 pounds of preload force and a stiffness of well over 2 million pounds per inch, with only a single pound of payload. The advantage of vacuum preloading is that it creates a preloading force on the bearings without adding mass. This technique is used to advantage when high acceleration stages need fast settling times. By guiding X and Y axes off a precision plane the Abby errors and tolerance buildups from stacked linear axis are eliminated thus providing for exceptional flatness of motion. Finally, VPLs allow simultaneous preloading over a plane on both X and Y axes without having the entire guide surface be metal as would be required with magnetic preloading.

A common design of vacuum preloaded air bearing has the air bearing land in the center and the vacuum around the perimeter. A drawback of this configuration is that it draws air (and debris) in from the environment surrounding the bearing, acting somewhat like a vacuum cleaner. A better VPL design has the air bearing land around the entire perimeter of the bearing, creating the seal to contain the vacuum in the center of the bearing (see **Error! Reference s ource not found.**). An additional benefit of having the air bearing land on the perimeter is that the continual positive flow of air to ambient from the air bearing actively keeps dust and contaminants away from the bearing surface.

Vacuum preloaded bearings can be designed using either orifice or porous media technology. However, porous media bearings have the significant advantage over their orifice counterparts in that they will not damage the guide surface should there be an inadvertent loss of air. The porous media material will itself act as a plain bearing surface. For this reason, porous media VPLs are easier to use and are more robust than orifice designs.

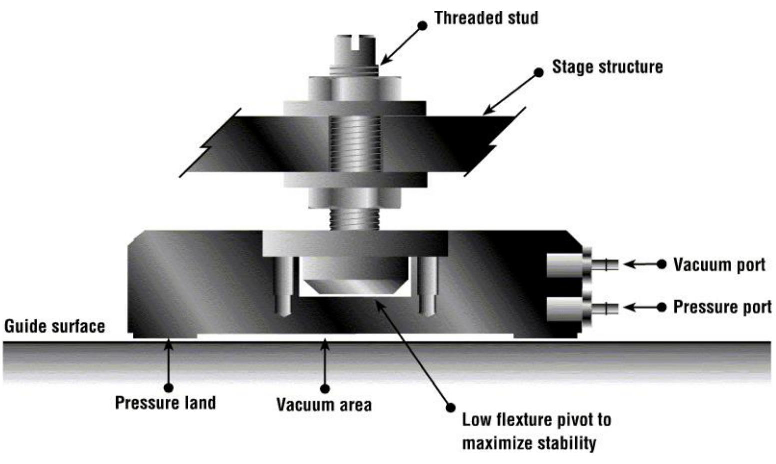

Figure 18 Vacuum Preloaded Air Bearing

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Porous Media VPLs are available as off the shelf modular products, or as custom components that can be manufactured integral to other structural components (under a Z stage for example). Modular VPLs are mounted with flexures that provide self-alignment of the bearing faces and height adjustment without friction or hysteresis. Custom VPLs can also be bonded in place using a process patented by New Way that produces a precision stage, without expensive precision machining. This technique is used to great effect in the X and Y stages of the Electroglas 300mm Wafer Prober (see **Error! Reference source not found.**). A large, square VPL is also employed under the Z stage to allow it to float over the granite base. By adjusting the vacuum and air pressure, flying height and stiffness can be exactly optimized. Adjustability of air film thickness can be used in wafer processing for focusing, squaring, and sub-micron vertical positioning over a range of 20 microns.

Figure 19 Custom VPLs used on Electroglas' 300mm Wafer Prober

4.3.2 Kinematics and Elastic Averaging

A kinematic design employs the theory of exact constraint. That is: three points define a plane, two points define a line, and one point describes a position on the axis of motion defined by the plane and line. One of the big advantages is that by knowing the stiffness and location of the support points in a kinematically supported structure, closed-ended mathematical equations can be used to predict the characteristics of the system, thus making the system 'deterministic'. Modular vacuum preloaded air bearings mounted on flexures are easily utilized to support structures kinematically.

In contrast, the common practice of preloading bearings against each other on opposite sides of a beam is an example of 'elastic averaging'. In this case 4 bearings or points describe a line. But because the two sides of the beam are not likely to be perfectly parallel it is more difficult to predict or define error motions. Furthermore, changes in size between the bearing structure and the beam due to thermal differences highlight the issue of 'over constraint". A large, monolithic VPL mounted on a plane is another example of elastic averaging.

Three, small VPLs flexure-mounted to a piece of aluminum tooling plate would create an inexpensive, kinematically correct stage. The threaded flexures would provide for adjustment of total height and for squaring the plate to some other reference. No precision machining would be required to build such a stage, and manufacturing and assembly would be straightforward. Distortions from the pressure and vacuum forces are isolated to the bearing itself and are not transmitted through the flexure into the structure.

Conversely, a large monolithic VPL would have much higher stiffness and load capacity. However, it would be a much larger surface to make flat, would require more craftsmanship in manufacture and assembly, and its structure would to have to be stiff enough to withstand the distortions from the vacuum and pressure loads. Also, its integration with other stage components may be more complicated. And last but not least the motion of the plane would not be as deterministic, but it would tend to average out errors in the guide plane.

So which is the best design principal to follow? That depends on your application and where you stand in the classic debate between instrument builders who complain about machines not being deterministic, and machine builders who complain about instruments that are not robust.

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Kinematic:

- Deterministic
- Does not require precision machining
- Easier manufacturing
- Stiffness and capacity limited

Elastic averaging:

- Non-deterministic
- Requires precision machining
- More difficult to manufacture
- High stiffness and capacity

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4.4 Air Bushings

4.4.1 Air Bushing Installation

Inspect the ID of the pillow block for any burrs or sharp edges. Be sure the ‘O’ rings are seated properly in their grooves on the air bushing housing. Wet the ‘O’ rings and the bore with alcohol just prior to inserting the bushing into the bore.

Supply clean dry compressed air between 40 and 100 P.S.I. into the pillow block. With a clean cloth or towel and alcohol wipe the pin and shaft to be inserted into the bushing. Carefully insert the shaft into the bushing with the air pressure on.

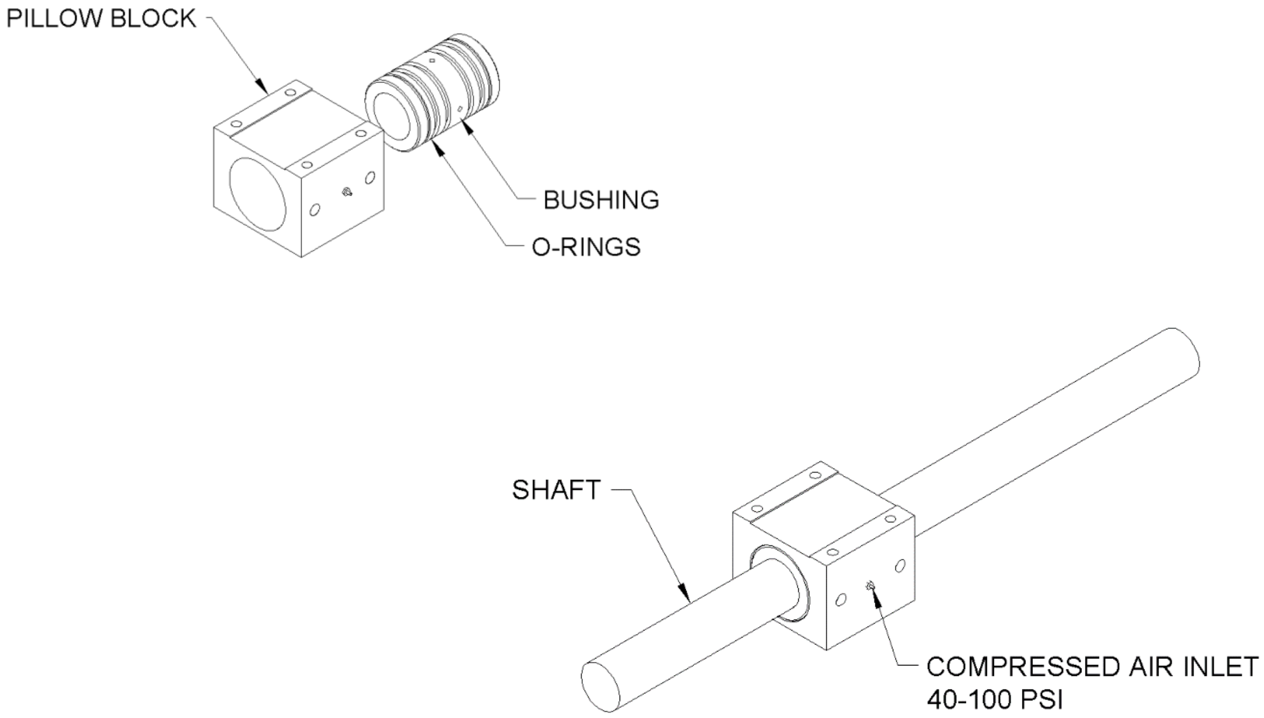

Figure 20 Mounting Air Bushings

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4.4.2 Assembling an Air Bushing Slide

Attach end mounts to the shafts while the bushings are on the shafts with light screw pressure. Using gauge blocks between the shafts tighten the end mounts to the base: this will establish parallelism of the shafts. Tighten the end mounts on the shafts and recheck parallelism of the shafts. It may be necessary to loosen and retighten the End mounts to the base.

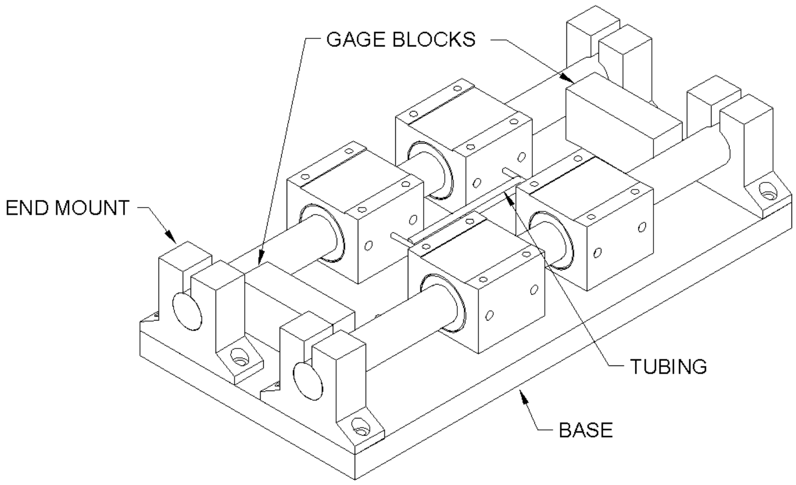

Figure 21 Using Gage Blocks to establish parallelism

With air pressure applied align and bolt the top plate to the pillow blocks. Check to be sure that the stage floats freely over its entire travel. The 'O' rings should provide enough compliance to compensate for parallelism errors in the shafts or out of flatness of the top plate. Please note that this is only an example of an assembly procedure there are certainly other legitimate assembly sequences.

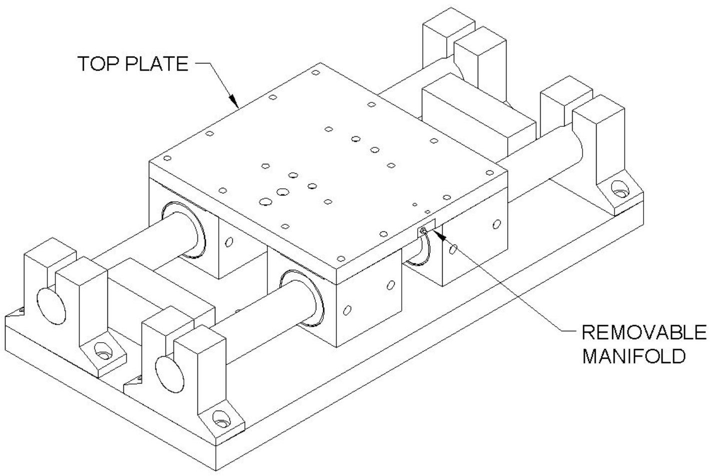

Figure 22 Top Plate Attached

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It is possible to eliminate compliance of the 'O' rings by potting the bushings into the pillow block housings but not required. The pillow block housings have holes 180 degrees apart that align axially with the centers of the two 'O' ring sets. With the air pressure on, the epoxy is injected in one side until it comes out the opposite side. Tape is then used to seal the injection ports and vents and the epoxy is allowed to cure with air pressure on. This procedure is useful where high stiffness is required and the alignment of the rails can be done with high precision.

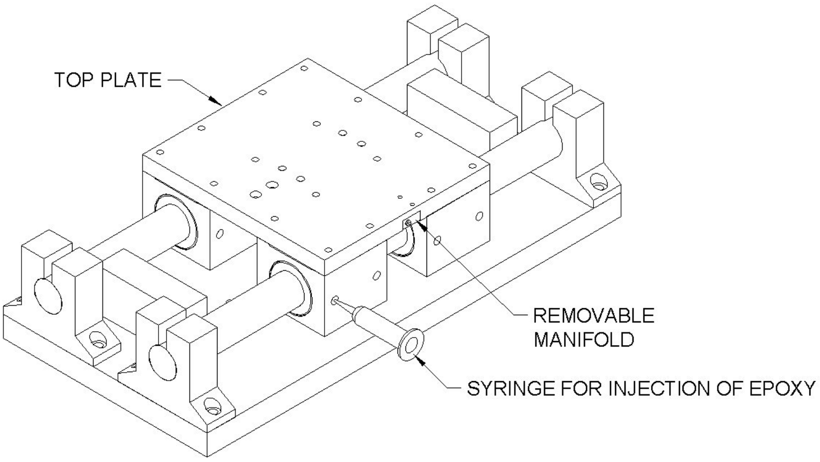

Figure 23 Bonding the air bushings in place

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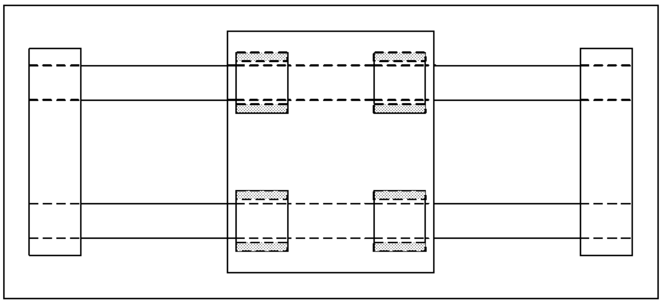
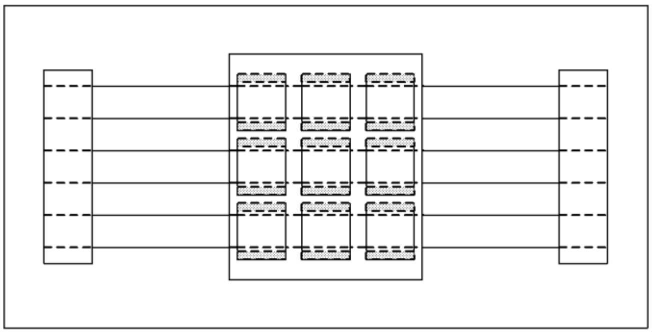
4.4.3 Typical configurations

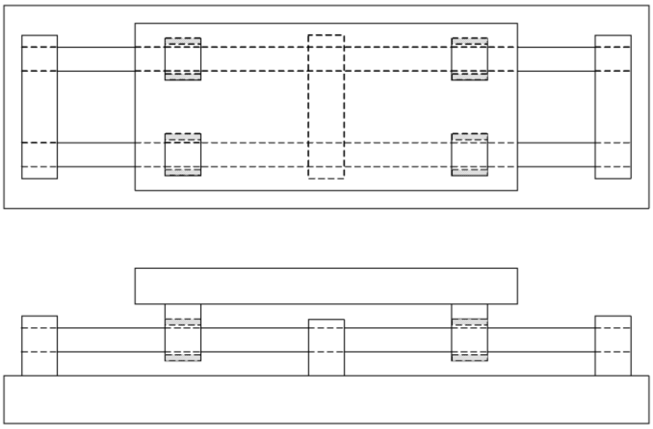
Three air bushings are all that is required to constrain five axis of motion.



Four air bushings is the most typical configuration for creating a linear slide from air bushings.



In cases were higher load capacity is required extra bushings can be added and or extra shafts can be used.



As the deflection of the end supported shafts tends to be the major source of compliance, especially in longer stages, center supports significantly increase stiffness (if the application allows).

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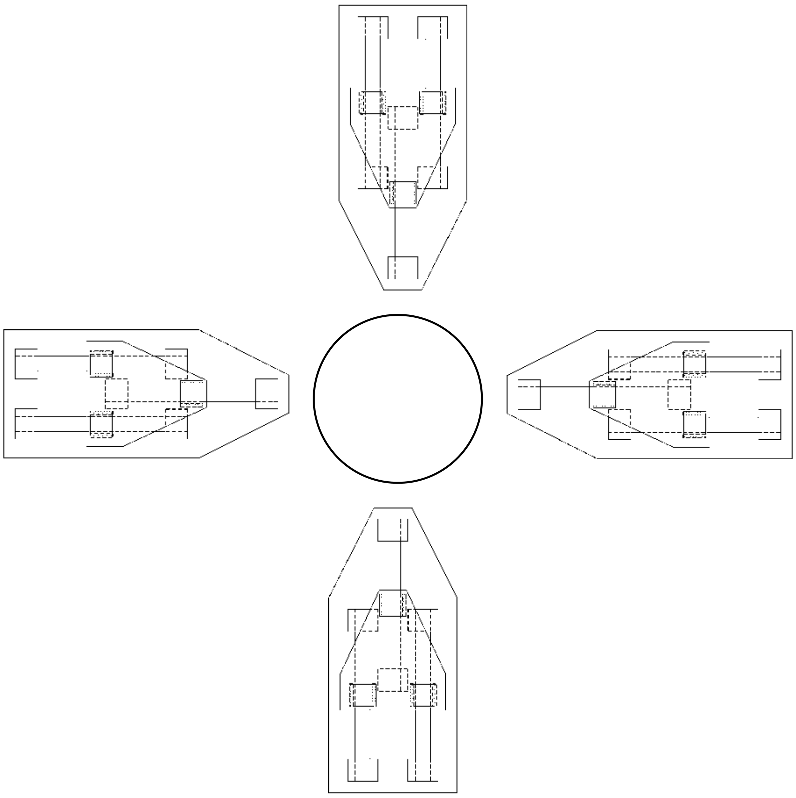
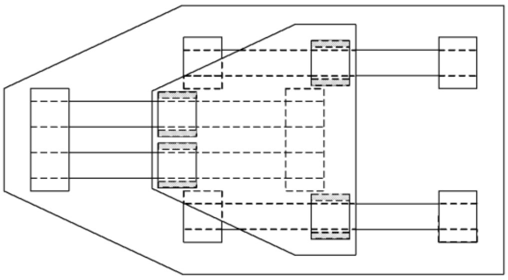
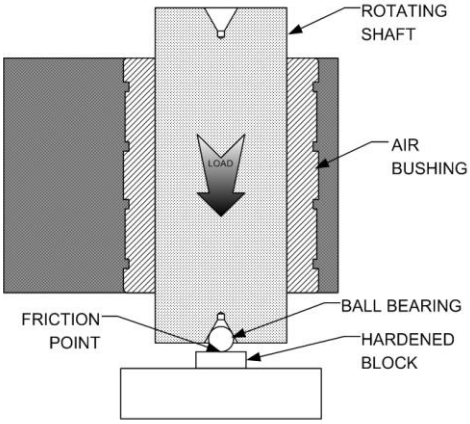


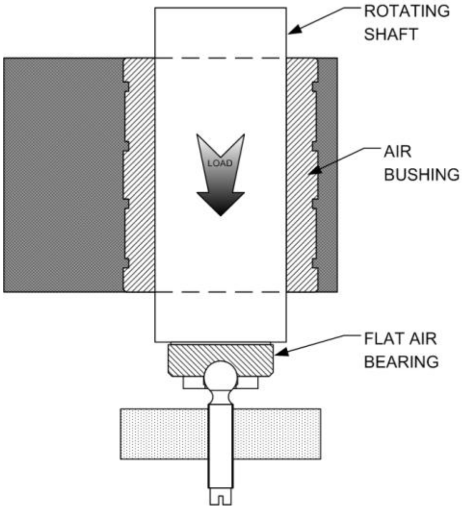
Air bushings stages lend themselves to arraying themselves around a Rotary table



Very high stiffness low-profile stages can be constructed using bushings. Multiple bearing sets and shafts can make for difficult assembly operations. Replication techniques can be employed that greatly minimize this problem.

In cases were the rotating shaft has been ground on a OD grinding machine the shaft will likely have an accurate conical center in it. A ball bearing can be glued into this conical seat and then run against a hard end surface such as a micrometer anvil. This does result in some coulomb friction but the amount of friction is amazingly small.





In other cases it may be preferable to finish the end of the shaft flat and support it with a stationary air bearing.

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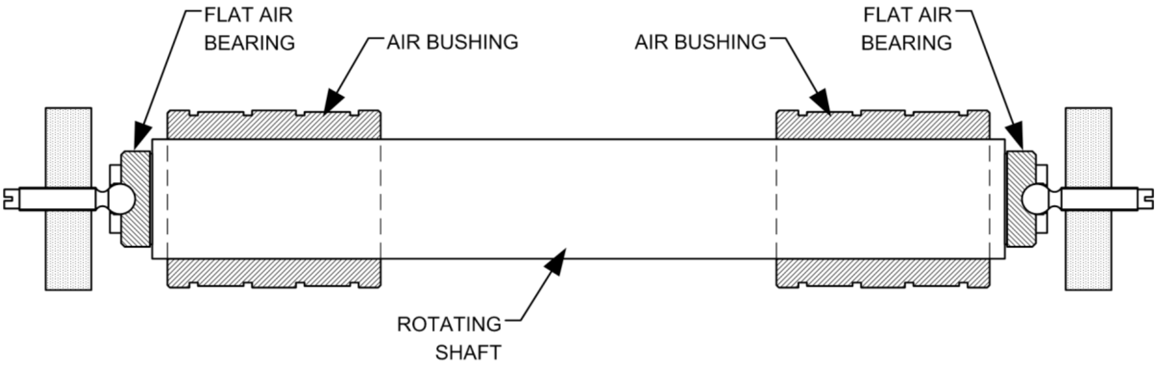

Common application for creating zero friction pulleys for counter balances or Web handling

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4.5 Rotary Tables

The spinning or spindle artifact is the most critical component when trying for lowest possible error motions. Ultra-precision machining techniques are recommended. Fortunately, conventional precision turning and grinding can achieve excellent results because the two critical surfaces (radial and thrust) can be finished in one chucking. Care must be taken not to distort the spindle from chucking forces. New Way will supply ultra-precision diamond turned artifacts for our air bearing customers.

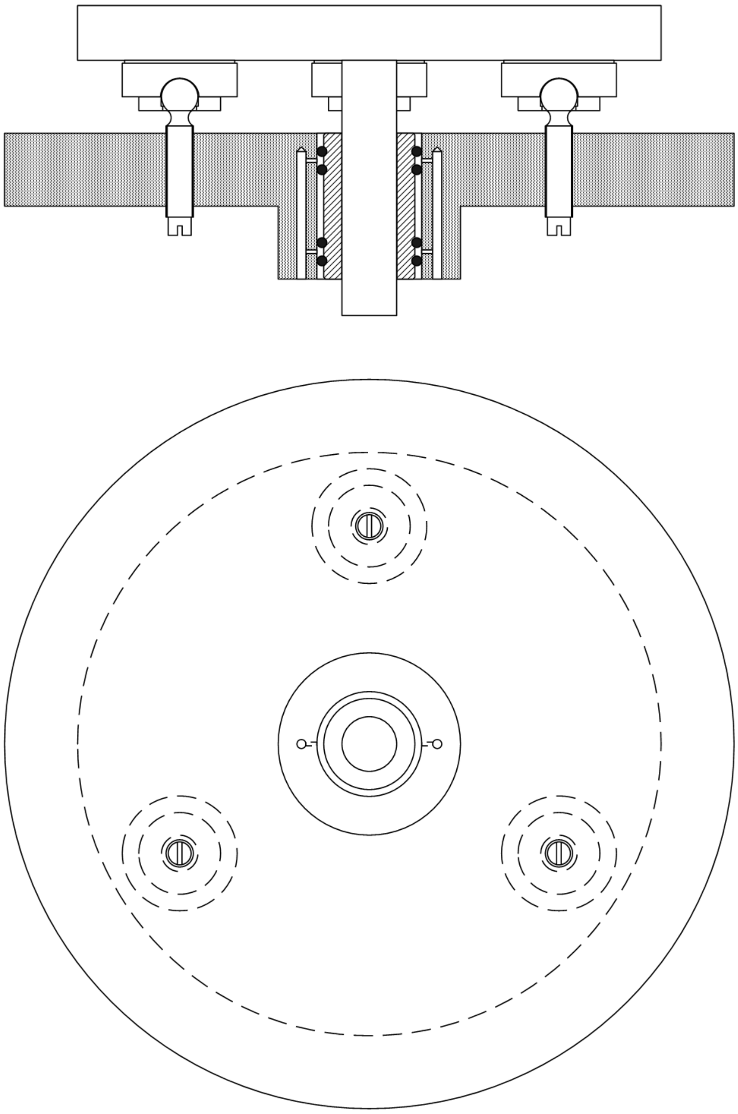

Figure 24 Rotary Table

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Ball Studs can be used to adjust total height and the angle of the axis of rotation. Once set, the bushing can be potted to increase radial stiffness. The ‘o’-rings allow the bushing to align itself with the spindle axis. Three conical seats in the plate will describe a plane and elevation that may not need adjusting.

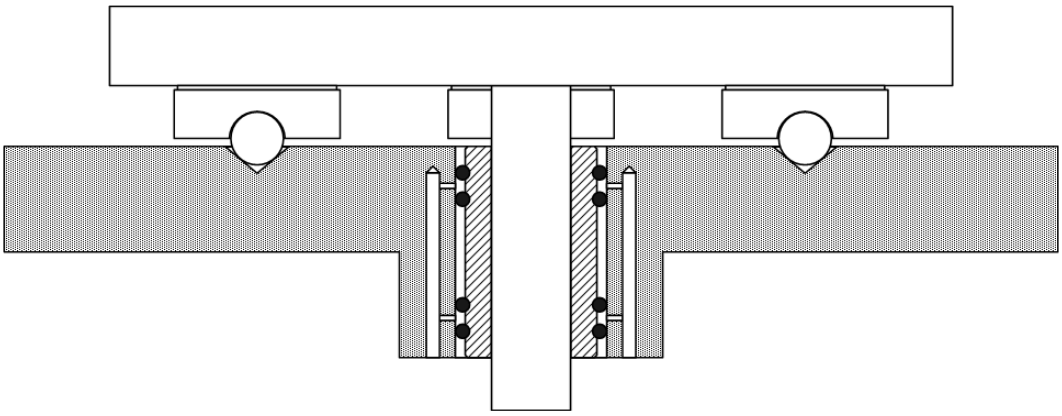

Figure 25 - Rotary Table Air Bearings

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5 PART V: ADDITIONAL INFORMATION

5.1 Air Supply

Air bearings are considered to be air lubricated which makes the atmosphere a convenient tank for recirculation. Unless they are operating a vacuum or in an ultra-clean environment. Here differentially pumped grooves or scavenge grooves can completely eliminate leakage of air or particulates into the vacuum or clean environments.

Air bearing should be supplied with air that is relatively free of particulates water and oil. Please reference the table of ISO air quality classes for what constitutes relatively clean. New Way recommends a quality class of four or the lower.

	QUALITY CLASS	DIRT (Particle size in micron)	WATER Pressure Dew point > F (ppm. vol.) at 100psi g	OIL (including vapor mg/m3)
	1	0.1	-94 (0.3)	0.01
	2	1	-40 (16)	0.1
RECOMMENDED	3	5	-4 (128)	1.0
MINIMUM SPECS	4	15	+37.4 (940)	5
	5	40	+44.6 (1240)	25
	6	-	+50 (1500)	-

Please note that different types of air bearings are sensitive to different types of contamination. For example, porous bearings are not sensitive to particulates like bits of Teflon tape, sealant or liners shedding from the inside of fatiguing air tubes. In fact you could porous sand directly into a porous bearing airport with no derogatory effects. This would be catastrophic for an orifice or step compensated bearing. Oil contamination though is more easily cleaned out of an orifice bearing than a porous bearing. Water contamination can usually be corrected by the introduction of clean dry air to the system providing the components are not subject to oxidation.

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5.2 Measuring flow

Air is a compressible fluid. If one cubic foot of air at atmospheric pressure is compressed to 60psi, about four times atmospheric pressure, it will occupy less than one-half of a cubic foot of volume. This nonlinear relationship requires a correction factor based on pressure to be applied to flow measurements of pressurized air when using venturi (Visi-float) based flow meters, they may say SCFH right on the face but this referrers only when the exit side of the flow meter is at ambient pressure. Mass flow meters are an exception and do not require correction as they actually count molecules but are nearly 10 times the cost of conventional flow meters. Mass flow meters may take some time to settle to a correct reading.

Figure 27 Mass Flow Meter

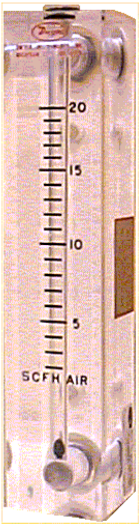

Figure 26 Mass Flow Meter

Note that the century flow meter clearly states standard cubic feet per hour SCFH on the gauge. Please be advised that this is only the case if the exit side of the flow meter is to atmospheric pressure. In air bearing applications flow meters are employed in the supply line to the bearing so the exit pressure from the gage is likely to be four to six times atmospheric pressure. In this case the flow measured is in cubic feet per hour gauge CFHG. When CFHG units are used there should always be a pressure associated with it. It is only standard cubic feet per hour that is presumed to be at atmospheric pressure.

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5.3 Flow

Q2 = Q1 * SQRT (P2/P1)

Q1 = Observed flow meter reading (CFHG)

Q2 = Actual flow corrected for pressure (SCFH)

P1 = Standard atmospheric pressure, 14.7 PSI

P2 = Actual pressure, 14.7 PSI + pressure in PSI inside flow meter.

CFHG = Cubic Feet per Hour Gage

SCFH = Standard Cubic Feet per Hour

SCFM = Standard Cubic Feet per Minute

@60 PSI multiply CFHG by 2.25 to get SCFH

@80 PSI multiply CFHG by 2.53 to get SCFH

@120 PSI multiply CFHG by 3.027 to get SCFH

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5.4 Plumbing

Plumbing air to multiple air bearings is relatively simple. The supply lines may be run in series or individually. It is most common to have manifolds on each axis that are plumbed in series with individual bearings on that axis that are plumbed in series or individually. The larger tubing is used to feed the manifolds while smaller tubing is used for branching off to individual bearings.

New Way provides tubing and assorted fitting types as a convenience to our customers. Please visit our website at www.newwayprecision.com for information. If you are an OEM and will be building multiple machines it will be less expensive for you to source these items directly. Links to potential suppliers are provided for your convenience. Quality tubing and fittings can save money and lost time dealing with possible leaks and compatibility issues.

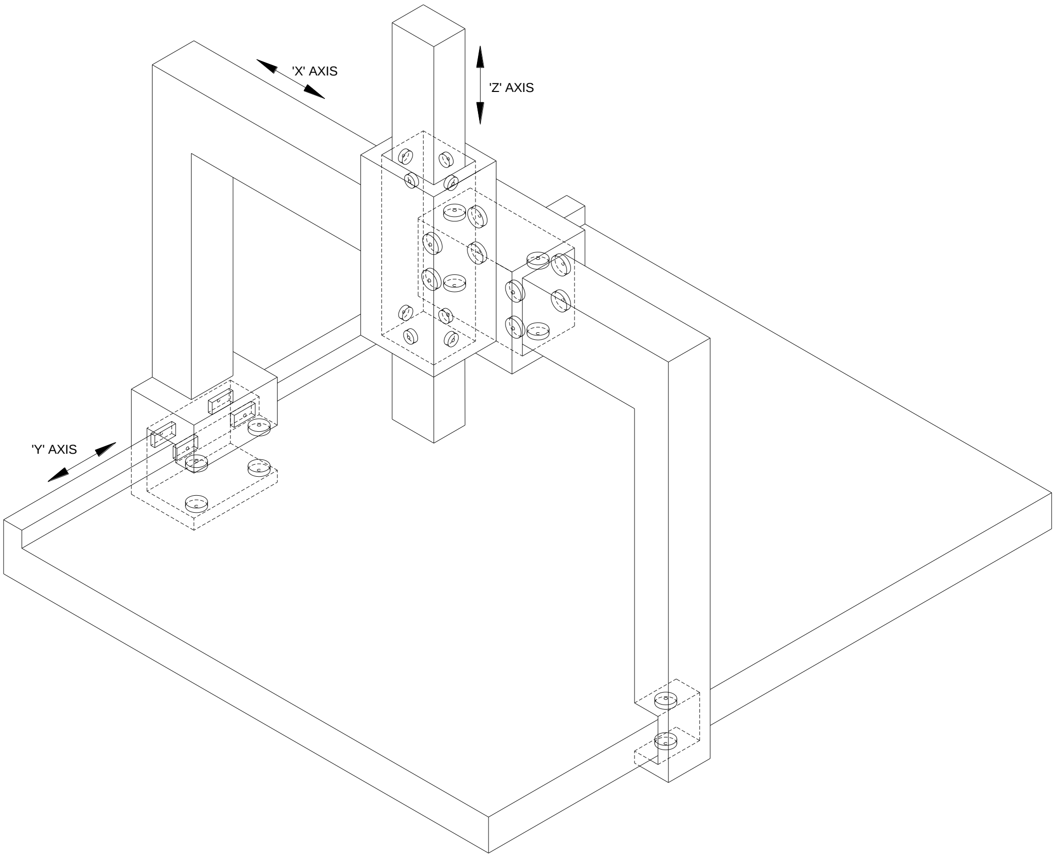

Figure 28 Typical bearing layout for a CMM

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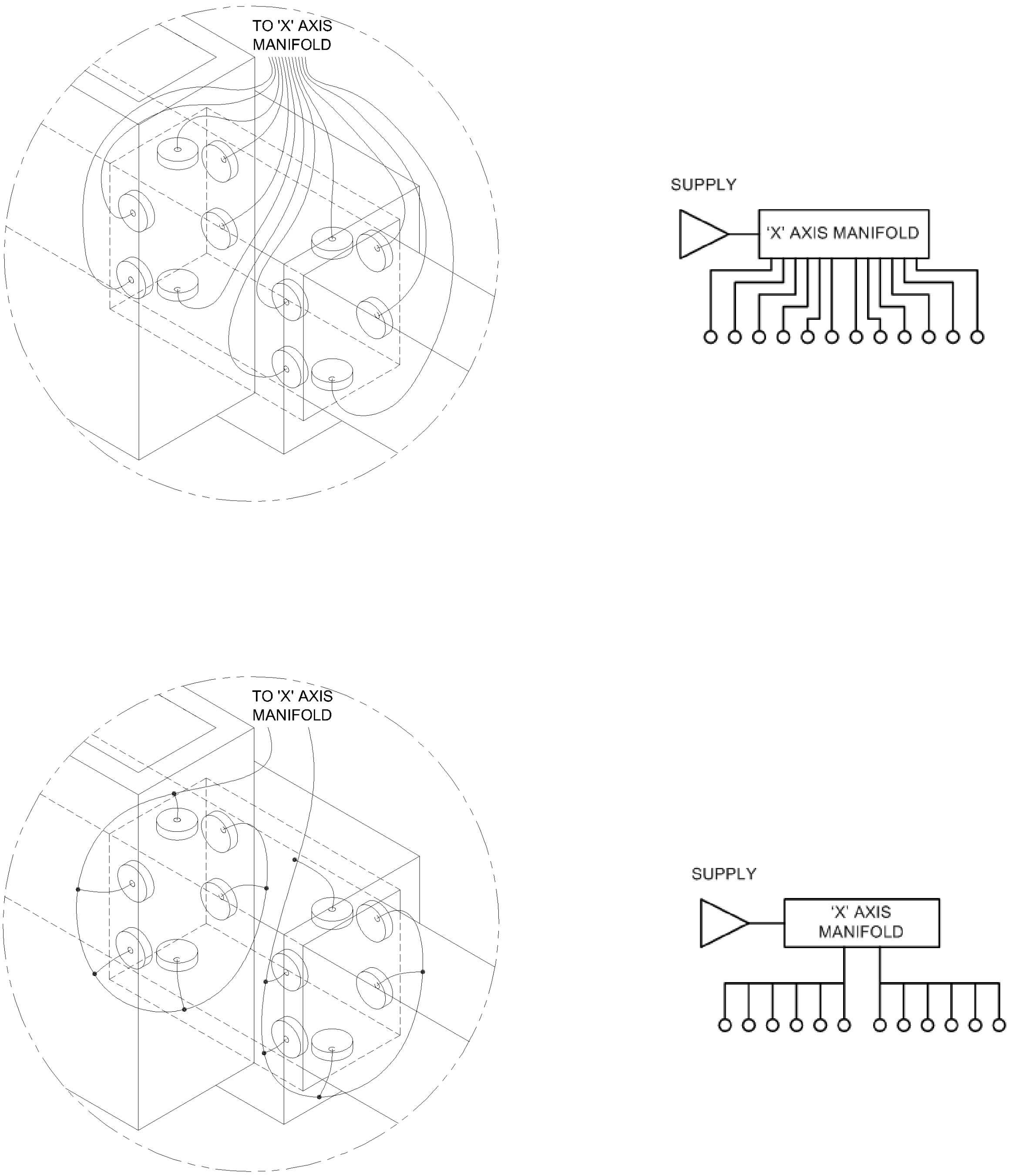

Figure 29 - Options for connecting air supply to air bearings

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5.5 Air flow through the bearing gap

Airflow through a bearing gap is quite sensitive to the gap; in fact it is a cube function of the gap. As an example of two inch diameter bearing with 75 pounds of load would consume 4 standard cubic feet per hour at 200 micro inches of lift. For this bearing to carry the same load at 400 micro inches of lift 64 standard cubic feet per hour of air would be required. It can easily be seen that small gaps keep restriction high and hence reduce flow and power requirements. Less airflow means less air needs to be compressed cleaned and dried reducing cost of ownership issues.

Is interesting to note how this effect distinguishes porous and orifice air bearing types when comparing pitch moments stiffness of an individual bearing. As orifice bearings are dependent on flow across the face of the bearing an angular change in the gap e.g.; when one side of the gap gets large and the other side gets small an unstable situation will be created where the available flow will rapidly lose its pressure following the path of least resistance (the large gap) and away from the area that needs it most (the small gap). The porous bearing in contrast still has pressure issuing from the small gap area. This gives the porous bearing higher tilt moment capacity and stiffness.

This same effect is why uncompensated journal bearings do not work. At first you may think that by pressurizing an annular groove that the air pressure would equalize and support the shaft. In fact the shaft will press against one side closing the gap on that side completely as the now two times larger gap on the other side creates less restriction than an even the way around.

5.6 Air Supply Requirements

5.6.1 Air Quality

Compressed air used to supply an air bearing must be properly cleaned and dried. Air bearing performance and useful lifetime greatly depends on the quality of the compressed air. An efficient system ensures minimum pressure loss, removal of contaminants such us water, oil, dirt, rust, and other foreign materials. Particles will not affect the performance or life of New Way® Porous Air Bearings, but oil and water will. In order to ensure the specified performance and useful lifetime of the bearings, it is recommended that the following minimum criteria be met:

ISO 8573.1 Quality Classes				
	QUALITY CLASS	DIRT (Particle size in micron)	WATER Pressure Dew Point °F @ 100 PSIG	OIL (including vapor mg/m³)
	1	0.1	-94	0.01
	2	1	-40	0.1
RECOMMENDED >	3	5	-4	1.0
MINIMUM SPECS>	4	15	+37	5
	5	40	+45	25
	6	-	+50	-

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5.6.2 Filtering and drying compressed air for air bearings

General-purpose filters are used to remove the bulk of particles before it gets downstream and damages the coalescing filter. The Coalescing filter is used to remove oil and liquid water, including all the particles that passed through the general-purpose filter. The desiccant dryer is used to remove the water vapor before it condenses.

Component	Dirt Particle Size in Microns	Water Vapor Dew Point °F @ 100 PSIG	Oil & Liquid Water mg/m
General Purpose Filter	25	N/A	N/A
Coalescing Filter	0.1	N/A	0.5
Desiccant Dryer	N/A	-40	N/A

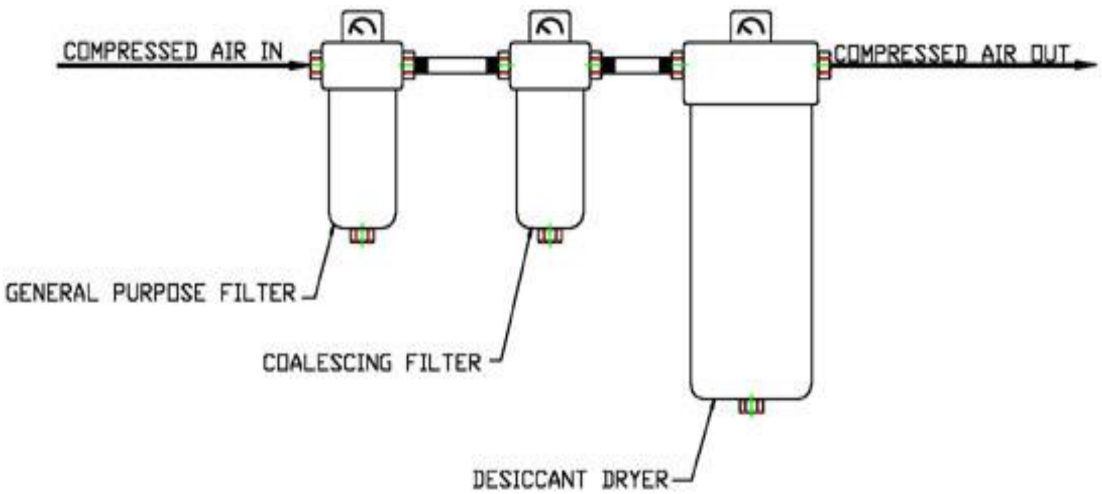

Figure 30 Filtering and Drying Compressed Air

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5.6.3 Flow Equivalents

1 Cu. Ft. / Hr.		**1 Cu. Ft. / Min.**	
.0166	Cu. Ft. / Min.	60	Cu Ft. / Hr.
.4719	LPM	28.316	LPM
28.316	LPH	1699	LPH
471.947	CC / Min.	28317	CC / Min.
28317	CC / Hr.	1,699,011	CC / Hr.
.1247	Gal. / Min.C	7.481	Gal. / Min.
7.481	Gal. / Hr.	448.831	Gal./ Hr.
1 CC / Min.		**1 CC / Hr.**	
60	CC / Hr.	.0167	CC / Min.
.000035	Cu. Ft. / Min.	.0000005	Cu. Ft. / Min.
.0021	Cu. Ft. / Hr.	.00003	Cu. Ft. / Hr.
.001	LPM	.000017	LPM
.06	LPH	.001	LPH
.00026	Gal. / Min	.000004	Gal. / Min.
.0159	Gal. / Hr.	.00026	Gal. / Hr.
1 LPM.		**1 LPH**	
60	LPH	.0166	LPM
.035	Cu. Ft. / Min.	.00059	Cu. Ft. / Min.
2.1189	Cu. Ft. / Hr.	.035	Cu. Ft. / Hr.
1000	CC / Min.	16.667	CC / Min.
60,002	CC / Hr.	1000	CC / Hr.
.264	Gal. / Min.	.004	Gal. / Min.
15.851	Gal. / Hr.	.264	Gal. / Hr.
1 Gal. / Min.		**1 Gal. / Hr.**	
0	Gal. / Hr.	.0167	Gal. / Min.
.1337	Cu. Ft. / Min.	.002	Cu. Ft./Min.
8.021	Cu. Ft. / Hr.	.1337	Cu. Ft. / Hr.
3.785	LPM	.063	LPM
227.118	LPH	3.785	LPH
3,785.415	CC / Min.	63.069	CC / Min.
227,125	CC / Hr.	3785	CC / Hr.