PBC Linear's Simplicity® Bearing vs. Igus's DryLin® Bearing

An Analytic Comparison of Round Shaft Plain Linear Bearings

Gregory Lyon, PE (LTB Engineering)

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Two round shaft plain bearing technologies are explored from a tribological and application standpoint. The first technology is exemplified in the PBC Linear Simplicity® bearing, which consists of a self-lubricating liner bonded to the inside of an essentially cylindrical shell. The second technology is found in the IGUS DryLin® bearing based on a self-lubricating injection molded liner affixed to the inside of a similar shell. The tribological and performance properties are considered, and then the ramifications of these properties in application are investigated. The results indicate that substantial differences in bearing life should be expected.

Introduction

There are a number of alternative technologies available in the application of linear bearings. Geometric configuration is a first level consideration, basically defining systems that can support a moment about the axis of motion, sometimes called profile rail, and those systems that are not so constrained, identified as round shaft. Round shaft bearings offer certain advantages, such as ease of application and use. Within the family of round shaft bearings, there are further classifications, including rolling element and plain. There are a number of criteria driving the selection of plain over rolling element bearings, including vibration and shock, harsh environments, prohibitions on lubricants, such criteria might be the case in food or clean room applications, etc.

Two basic families of round shaft plain bearings are delineated by the liner, the part of the bearing that makes contact with, and slides against the shaft. The first type, where the liner is formed of a material loaded with Polytetrafluoroethylene (PTFE) and bonded to the shell, is exemplified by PBC Linear's Simplicity® Bearing. A second type, where the liner is injection molded and mechanically fastened to the shell, is exemplified by the Igus DryLin® Bearing.

History

Plain bearings are the most ubiquitous of bearings. Any occurrence of sliding may be considered a plain bearing. The historical use of plain bearings is documented back to ancient Egypt, and it is reasonable to suppose that the technology has been employed since the beginning of hominid sentience. Leonardo Da Vinci was one of the first scientists to study and analyze plain bearings. His findings and those of Coulomb form important components of our understanding of friction. The modern plain bearing is the result of literally thousands of years of evolution.

Definitions

Maximum Pressure	The maximum allowable compressive stress that can be applied to the material before permanent deformation.
Maximum Speed	The limit on the relative rate of displacement between liner and shaft surfaces
PV Value	Pressure x Velocity, where Pressure is equal to the effective surface area times the applied load.
Maximum PV	The maximum dynamic performance rating of a Plain Bearing.
Coefficient of Friction	The ratio of applied to normal forces required to attain relative motion
Plain Bearing	A sliding bearing that does not contain moving parts or rolling elements, such as balls.
Plane Bearing	Common alternate spelling of "Plain" bearing most commonly found in North America. See "Plain Bearing" for definition.
Tribology	The science and engineering of interacting surfaces in relative motion, including the principles of friction, lubrication and wear.

Theory

The base technologies differ in their processing and the molecular structures that present themselves to the shaft surface. Tribological performance is at least partially attributable to the molecular differences. Some of the important operating properties for each liner are cited in table 1. Further, there are some geometric differences that affect the contact between liner and shaft. The two prospective bearings are shown in figure 1.

Table 1: Tribological properties of liners

Manufacturer	PBC Linear	Igus
Model/material	Simplicity/Frelon Gold[1]	DryLin R/Iglidur J[2]
Maximum pressure, psi	3,000	5,075
Maximum speed, ft/min, dry	300[3]	394[4]
Maximum PV, psi•ft/min	20,000	9,700
Coefficient of friction	0.125	0.06 to 0.18

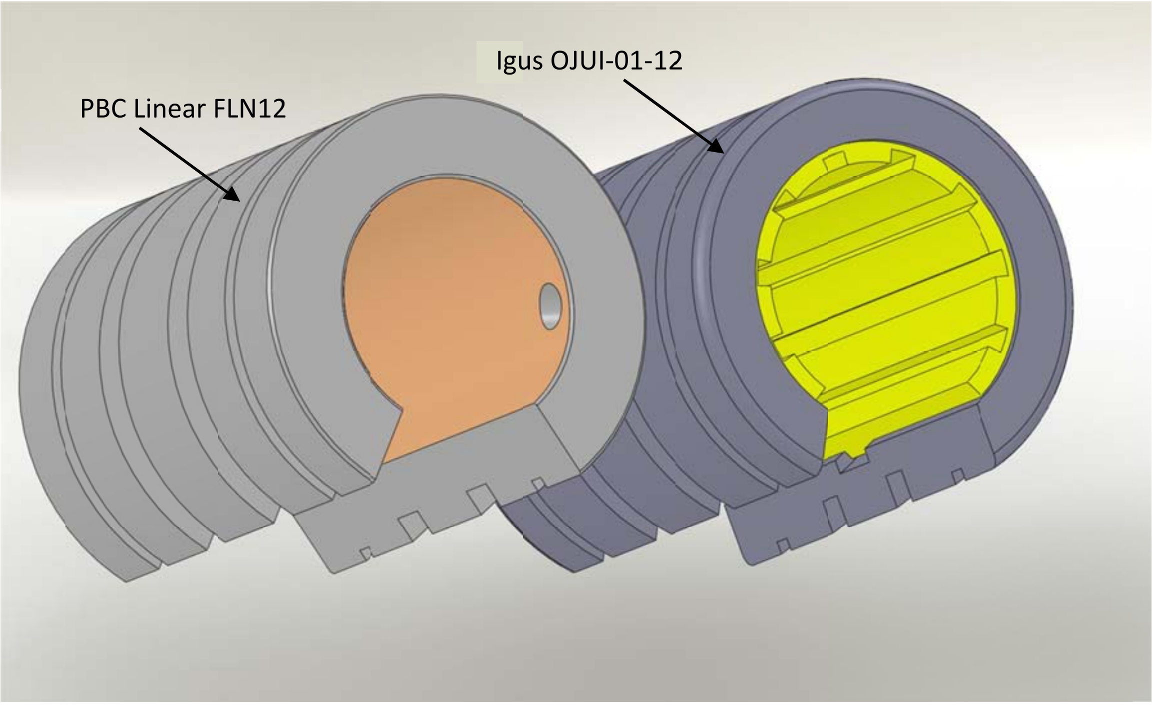


Figure 1: Geometries of selected bearings[5]

The Igus bearing features a number of axial cuts on the Inside Diameter (ID). These cuts present a somewhat reduced area of liner contacting the shaft surface while reducing a possible tangential constraint. The reduction in area results in higher contact pressures that undermine the Factor of Safety as related to the material Pressure Velocity limit. The Factor of Safety and Pressure Velocity limits will be discussed further.

Case Study

In application, the tribological and geometric properties have ramifications on expected performance. Figure 2 graphically presents an application example. Table 2 defines the parameters for this application example, which is based loosely on a food processing axis. External lubricants are prohibited.

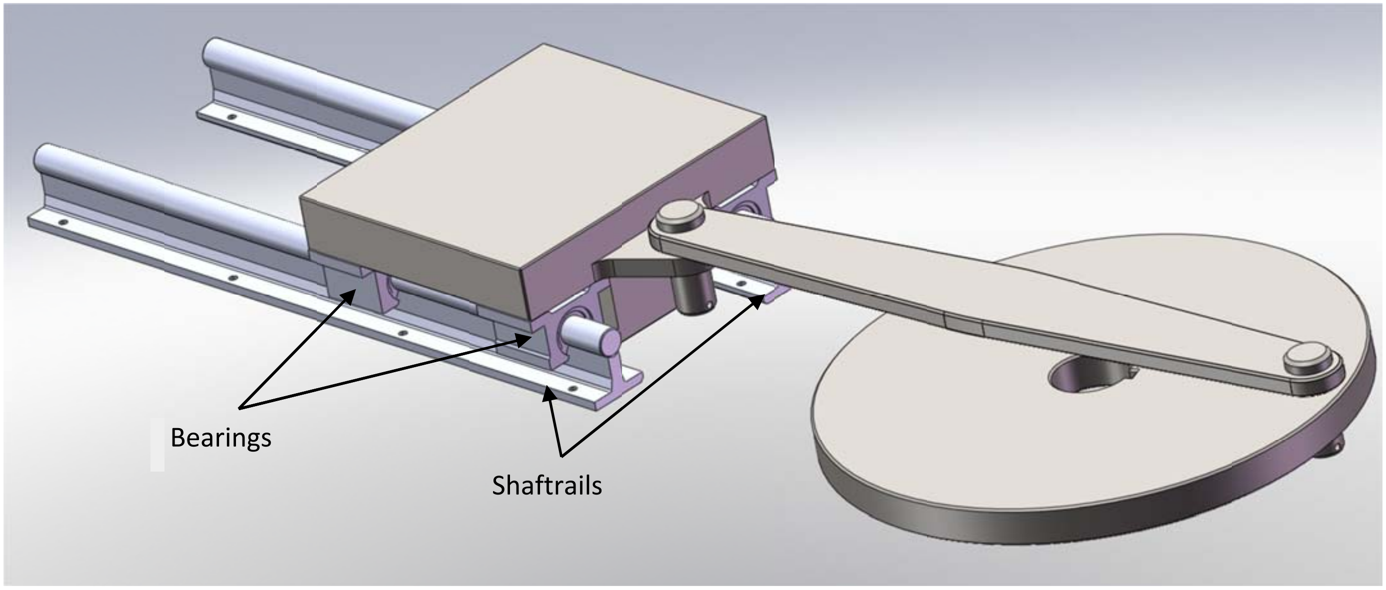


Figure 2: Application

Table 2: Application parameters

Axis orientation	Horizontal	Drive type	crank
Number of shafts	2	Stroke length, in	12
Shaft diameter, inch	0.75	Period, s	2.5
Distance between shafts on center, inch	6	Duty cycle, %	100
Bearings per shaft	2	Shut down per year, weeks	2
Distance between bearing centers, inch	6	Temperature	ambient
Total load, lbf	53	Washdown	none
Moments, in•lbf	negligible	Other chemicals	none

The failure criteria for this application are two-fold. First, the wear criterion of 0.0075 in. must not be exceeded. Wear in excess of this figure will cause unacceptable positioning error of the axis. Second, the PV limit cannot be exceeded. Exceeding the PV limit can cause overheating of the liner material, high wear and possible lock-up. A factor of safety can reasonably be applied to the PV limit to reduce the probability of catastrophic failure.

In most applications it is desirable to design for a bearing life of at least one year. This provides some flexibility for Preventive Maintenance (PM), so that bearing replacement can be scheduled for the yearly shut-down.

Further it reduces the likelihood that production time will be lost due to shut down to replace worn or failed bearings. Accordingly the yearly travel for the conditions cited is:

$$T = (2S/P)t_{PM} \tag{1}$$

Where:

T = travel
S = stroke
P = period
t_{PM} = time to scheduled PM bearing replacement

In this example the total travel in one year is $3.00(10^8)$ or 300 million inches. This then is the target travel against which the predicted lives will be evaluated.

Since this is a crank application the position of the system at any time about the center plane can be estimated as:

$$x = S \sin(2\pi t/P) \tag{2}$$

Where:

x = position of carriage about center plane
t = time

The maximum velocity can be found by differentiation:

$$v_{max} = 2\pi S/P \tag{3}$$

Where:

v_{max} = Maximum velocity

In this application the maximum velocity is 30.16 in/s. Differentiating again yields the maximum acceleration:

$$a_{max} = S(2\pi/P)^2 \tag{4}$$

Where:

a_{max} = maximum acceleration

In this application the maximum acceleration is 75.80 in/s^2.

As a starting point, a ¾ inch diameter nominal shaft system was selected. From the PBC Linear General Catalog, page 52, and from the Igus online expert system, DryLin Expert 2.0 by Igus (UK) Ltd., http://www.igus.co.uk/DryLinexpert/default.aspx, the expected wear in this application may be estimated. In the case of PBC, the wear rate was interpolated and rounded up from the graph provided, and the travel at the wear limit calculated. The wear rate by this method was estimated as 2.5 (10^{-5}) or 25 millionths inch of wear per million inches of travel. For the Igus product, the travel at the wear limit was obtained by iterating the running distance, i.e. travel to attain the wear limit. An exemplar page from the expert system is shown below.

The table on the left outlines your system configuration and gives you the option of making corrections. The table on the right shows the results of the functional check and the service life calculation. Critical values are highlighted in red. Click on the "Optimization" button to show which properties can be changed to improve the system configuration.

Range

Property	Value
System	2 x SWA-12,610 4 x OJUI-01-12
Shaft material	Cf53 steel, hardened, smoothed, tolerance h6
Distance shafts (b)	152.4 mm
Distance bearings (wx)	152.4 mm
Installation type	horizontal
Drive	Single drive with fixed/floating bearing
Drive coordinate (ay)	0 mm
Drive coordinate (az)	76.2 mm
Centre of mass coordinate (sx)	0 mm
Centre of mass coordinate (sy)	0 mm
Centre of mass coordinate (sz)	76.2 mm
Weight force (Fs)	235.8 N
acceleration (a)	1.9 m/s²
Running distance	3218.7 km
Shafts length	609.6 mm

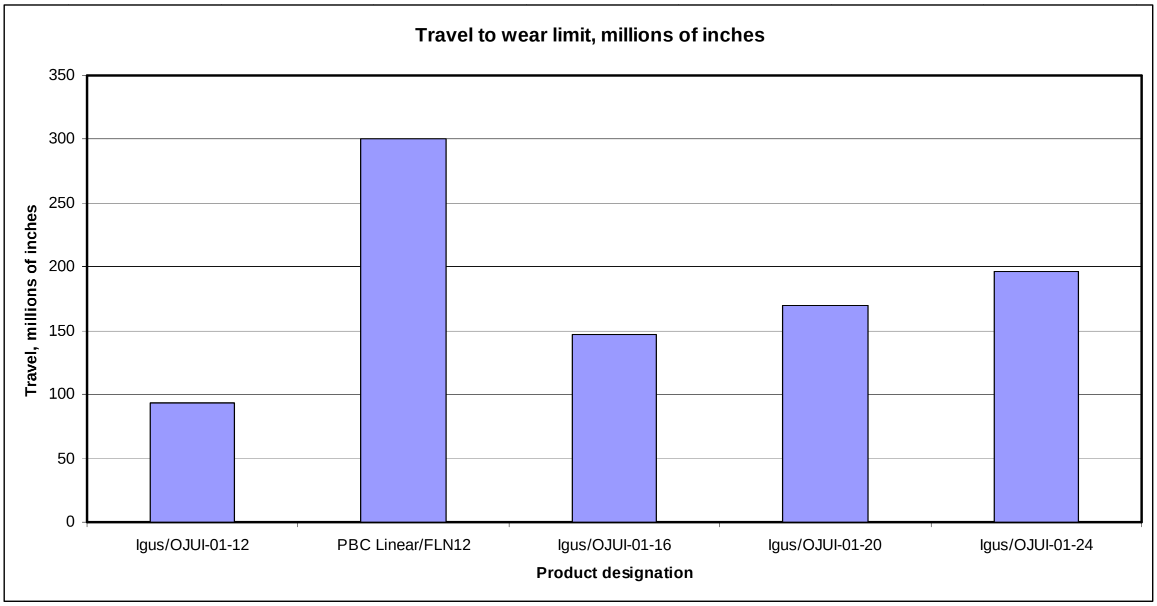
Result

Property	Value
Running characteristics	OK
load	OK
Wear	OK
Wear y-direction	0.26 mm
Wear z-direction	0.17 mm
max. permitted long-term speed	0.7 m/s
required min. drive force	105 N
permitted storage temperature	90 °C
max. load y-direction	59 N
Safety factor y-direction	33.09
max. load z-direction	29 N
Safety factor z-direction	45.3
Clearance at centre of mass (new status)	0.1 mm
Clearance at centre of mass (end of operation)	0.4 mm

Figure 3: Exemplar page from Igus DryLin Expert System 2.0 by Igus (UK) Ltd.

Results, Life and Cost

Graph 1, and table 3 present the estimated travel of the bearing systems to attain the wear limit. Additional sizes of the Igus product are displayed for comparison to the application requirements, since the initial size 12 did not provide sufficient life. Refer to figure 4 for a representation of the relative bearing sizes.



Graph 1: Estimated travel lives to wear limit [6,7]

Table 3: Estimated travel and comparison to application requirements [6,7]

Product designation	Nominal shaft diameter, in	Travel to wear limit, millions of inches	Travel target / Travel to wear limit	Bearing replacements
PBC Linear/FLN12	0.75	300	1.0	0
igus/OJUI-01-12	0.75	93.48	3.1	3
Igus/OJUI-01-16	1.00	146.9	2.0	2
Igus/OJUI-01-20	1.25	169.7	1.7	1
Igus/OJUI-01-24	1.50	196.5	1.5	1

The third column defines the ratio between the target travel and the estimated travel to wear limit. When this ratio exceeds unity, the implication is a requirement to replace the bearings. The last column is an estimate of the number of times the bearings need replacement within the time between scheduled PM service, in this case one year, during which time the application is out of service. Note that in the case of the Igus/OJUI-01-16, two bearing lives are just short of making the required travel, but the ratio of travel target to travel to wear limit is rounded to assume sufficient bearing life.

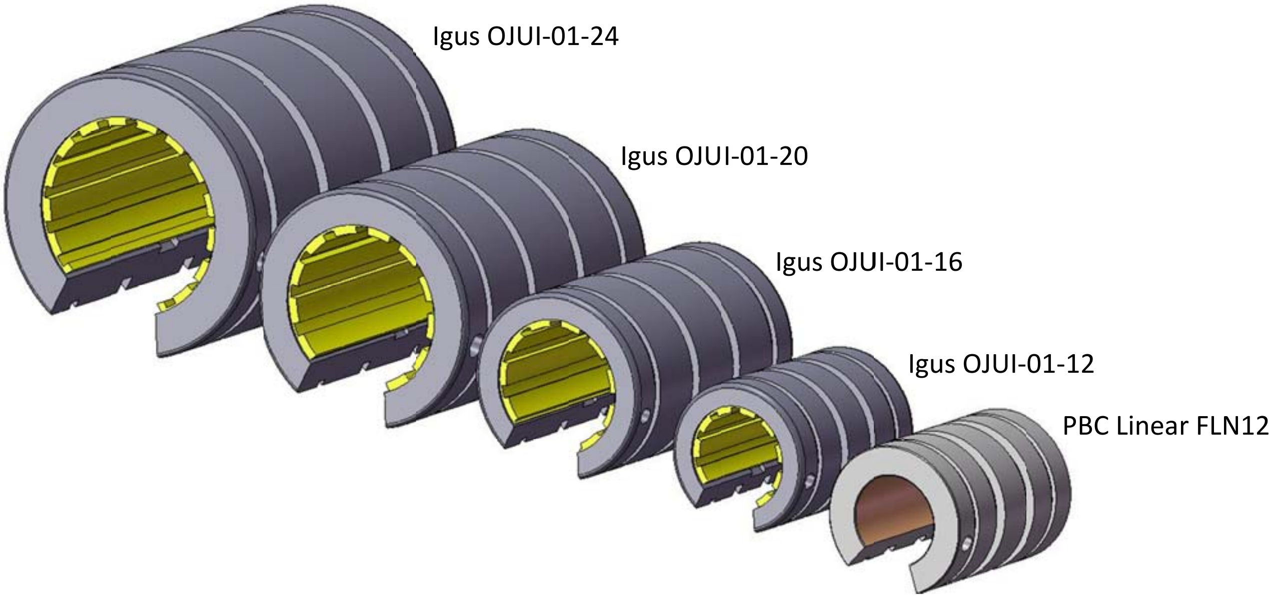


Figure 4: Relative sizes of bearings

From a budgetary standpoint, both the number of bearing changes, as well as an increase in system size represent cost risers. An estimate of the cost of the initial installation is offered in table 4.

Table 4: Costs associated with initial bearing installation [8,9]

Product designation	Cost, 4 bearings	Cost, 2 shaft-rails	Initial cost	Percentage of lowest cost
Igus/OJUI-01-12	$61.56	$612.82	**$674.38**	**100%**
PBC Linear/FLN12	$74.36	$612.82	$687.18	**102%**
Igus/OJUI-01-16	$105.32	$730.24	$835.56	**124%**
Igus/OJUI-01-20	$173.72	$878.56	$1,052.28	**156%**
Igus/OJUI-01-24	$202.52	$989.74	$1,192.26	**177%**

The lowest cost in column 4 is printed in bold, in this case the Igus/OJUI-01-12. Table 5 recites the required bearing replacements as presented in table 3. Again, the lowest cost is printed in bold in column 3, this time the PBC Linear/FLN12.

Table 5: Costs to Preventive Maintenance (PM)

Product designation	Bearing replacements	Total cost	Percentage of lowest cost
PBC Linear/FLN12	0	**$687.18**	**100%**
Igus/OJUI-01-12	3	$859.06	**125%**
Igus/OJUI-01-16	1	$940.88	**137%**
Igus/OJUI-01-20	1	$1,226.00	**178%**
Igus/OJUI-01-24	1	$1,394.78	**203%**

The shaft rails are steel and will likely not need replacement. The lowest initial cost is achieved by the Igus/OJUI-01-12. The Pacific/FLN12 costs $12.80, or 2% more. Within the time period to the first scheduled PM, however, the bearings will require replacement in order to avoid a wear failure. In the case that the equipment is built by an Original Equipment Manufacturer (OEM), then the end user should expect to incur more than $180 in replacement bearings; 3 replacements of 4 bearings at $61.56 equals $184.68. In the case that the OEM operates the equipment for its own purposes then the Igus/OJUI-01-12 results in an increase in cost of $171.88, or 25% more than the PBC Linear/FLN12. The cost to scheduled PM is then the yearly cost, to be incurred every year that the system is in service. Further, the initial cost, as well as any replacement cost, rises with an increase in equipment size.

Additional replacement expenses will be realized through shipping, administrative and installation costs, and downtime incurred as a result of replacing bearings. These costs can vary wildly, so Table 6 is a very rough attempt to make estimates. A row is left to the reader to add additional cost components not recited here, and a column is left for different values of cost components. The second column, indicating 0 replacements, includes the other costs for a one time installation.

Table 6: Other costs associated with bearing replacements

Cost component	Number of Replacements				
	0	1	2	3	x
Maintenance	$50.00	$100.00	$150.00	$200.00	$ -
Administration	$25.00	$50.00	$75.00	$100.00	$ -
Shipping	$15.00	$30.00	$45.00	$60.00	$ -
Lost production	$150.00	$300.00	$450.00	$600.00	$ -
User specific 1	$ -	$ -	$ -	$ -	$ -
User specific 2	$ -	$ -	$ -	$ -	$ -
Total "Other" Costs	**$240.00**	**$480.00**	**$720.00**	**$960.00**	$ -

Results, PV and cost

In evaluation of the second performance criterion, based on PV, the effective areas of each bearing need be defined to determine the pressure. The accepted method of determining pressure in this class of bearing is to divide the load by the projected area of the bearing in the plane of loading. In the case of a simple bore, such as the PBC Linear product, the projected area is the product of the inner diameter and the length. In the case of the Igus product, however, the area is the sum of the projected areas of the discrete pads in the plane of loading (refer to figure 5).

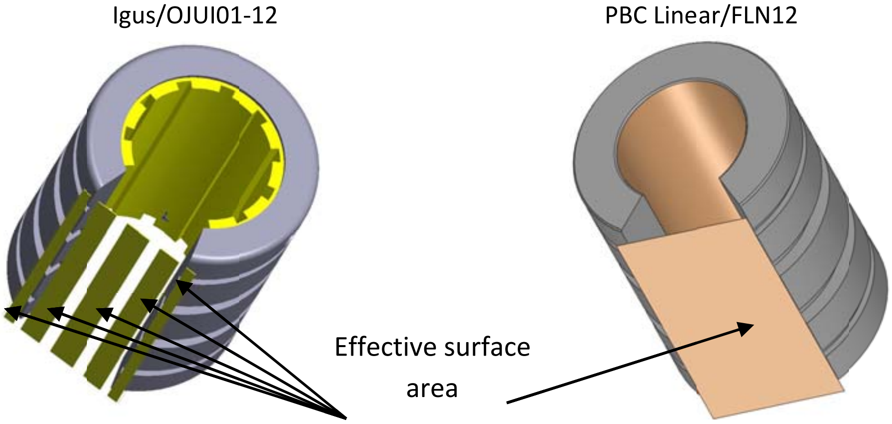


Figure 5: Projected areas

Table 7, top of next page, presents the effective bearing areas, the resultant operating pressures, PV's and comparison to PV limits. The Factor of Safety (FOS) is calculated by dividing the PV limit, column 5, by the application PV in column 4. The last column is analogous to a 'cost of reliability', where the cost of the bearing is divided by the Factor of Safety.

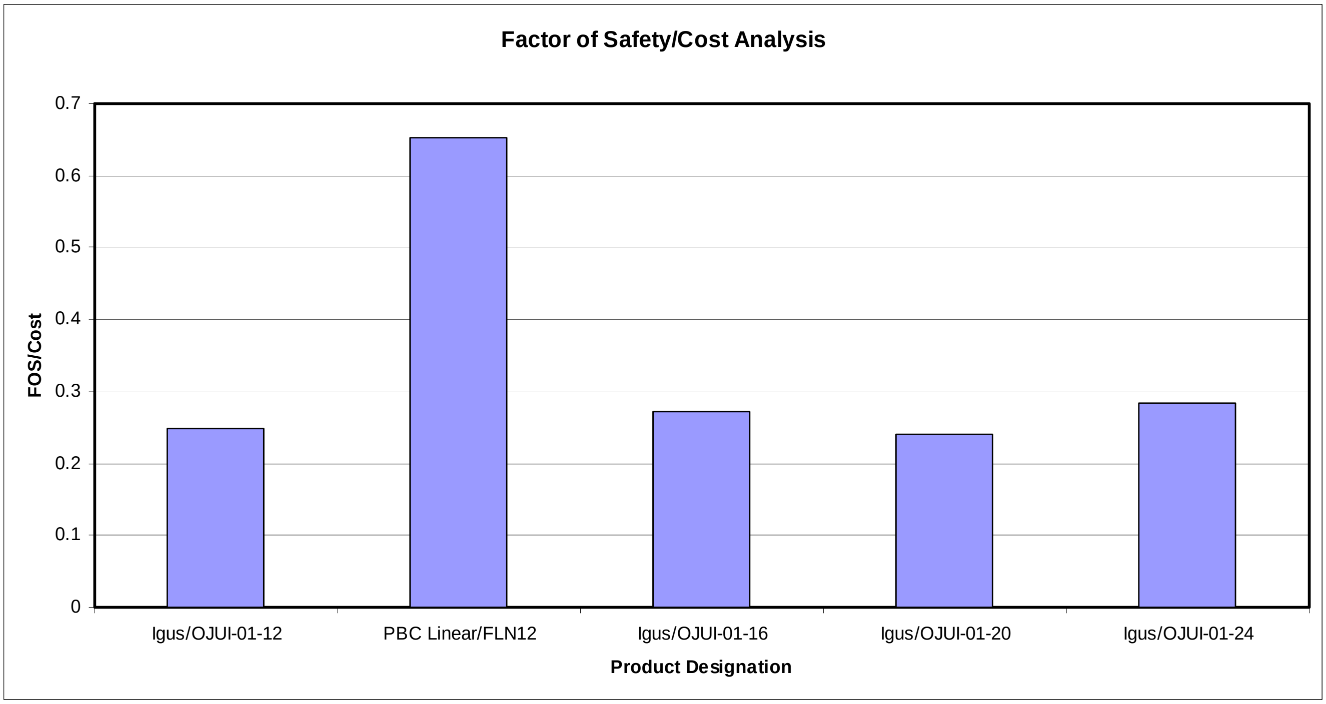
Table 7: PV values and limits

Product designation	Area, in2	Pressure, PSI	PV, PSI x ft/min	PV limit, PSI x ft/min	Factor of Safety	Bearing cost	$/FOS point
Igus/OJUI-01-12	0.787	16.84	2539	9,700	3.8	$15.39	$4.05
Igus/OJUI-01-16	1.481	8.95	1349	9,700	7.2	$26.33	$3.66
Igus/OJUI-01-20	2.147	6.17	931	9,700	10.4	$43.43	$4.18
PBC Linear/FLN12	1.213	10.92	1647	20,000	**12.1**	**$18.59**	**$1.53**
Igus/OJUI-01-24	2.952	4.49	677	9,700	14.3	$50.63	$3.54

None of the bearing systems would be expected to fail by PV, but the Factor of Safety provides a relative assessment of the robustness of the application. The Igus product, because of the discontinuous bore has a relatively smaller area, resulting in higher operating pressures. A further detriment to the resultant FOS for the Igus product is the lower PV limit. The size 20 Igus bearing approaches the FOS afforded by the PBC Linear bearing. It has, however, an initial cost of over $360 more than the PBC Linear product, and will require replacements within the PM cycle. The first Igus product to provide a better FOS to the PBC Linear is the size 24, with an attendant yearly cost increase of $707.60, or 103%, refer to table 5.

Graph 2 depicts the ratios of the Factor of Safety (FOS) to the cost for the same products; essentially a performance to cost ratio. The PBC Linear/FLN12 demonstrates a significantly higher performance to cost ratio.

Graph 2: PV FOS vs cost



Conclusion

Two bearing technologies are explored from a tribological and application standpoint. The base technologies consist of differences in the bearing material; PBC Linear Simplicity offers a self-lubricating liner bonded to the inside of an essentially cylindrical shell, Igus DryLin offers a self-lubricating injection molded liner affixed to the inside of a similar shell. There are further differences in geometry, the ramifications of which are explored. The tribological and performance properties are contrasted, and then the ramifications of the properties in a typical application are investigated. The results indicate that substantial differences in bearing life should be expected. The two criteria for comparison in application are total wear and operating PV as a function of PV limit. In both criteria, The PBC Linear product outperforms the Igus product. In order to match the performance of the PBC Linear product, the Igus product needs either multiple replacements or larger size product. Both approaches result in the incurrence of substantial cost increases. It is concluded that for this application, the PBC Linear Simplicity with Frelon Gold is the superior candidate.

The methodology employed in this paper is suitable for other applications. Care should be taken however to allow for other factors, should they exist, such as thermal excursions, chemical exposure, etc.

About the Author

Greg Lyon is the principal at LTB Engineering, an engineering research and development firm located in New York. He has extensive experience in the field of linear bearings including a twelve year tenure at Thomson Industries where he served as Director of Research & Development, with responsibility for new product & technology development. Thomson is a manufacturer of linear bearings and systems, including plain bearings. Mr. Lyon is the inventor on twelve patents related to linear bearings, and is published. He served as the US delegate to the ISO working group on linear bearings.

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Footnotes:

1. Pacific Bearing Linear Motion Systems Catalog, p. 51
2. Igus website
3. Pacific Bearing Linear Motion Systems Catalog, p. 51, running dry
4. Igus website, estimated from graph, running dry on steel
5. CAD models downloaded from Pacific and Igus websites
6. Simplicity wear calculated by linear interpolation from catalog data
7. Igus wear calculated by iteration in DryLin Expert 2.0
8. Pacific costs from quote
9. Igus costs from Igus website
10. MSC Industrial catalog, 2010/2011p. 3801

Further Information

If you're still having difficulties, contact a PBC Linear Application Engineer to discuss your application. You can contact an engineer directly by calling 1.800.962.8979 (from within the USA) or +1.815.389.5600 (from outside the USA). If you prefer e-mail, e-mail an engineer at: appeng@pbclinear.com

Version

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Updates

n/a

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Worldwide Headquarters

PBC Linear, A Pacific Bearing Co.
6402 E. Rockton Road
Roscoe, IL 61073
USA

Toll-Free: +1.800.962.8979
Office: +1.815.389.5600
Fax: +1.815.389.5790
sales@pbclinear.com
www.pbclinear.com

European Branch

PBC Lineartechnik GmbH, A Pacific Bearing Co.
Niermannsweg 11-15
D-40699 Erkrath
Germany

Office: +49.211.416073.10
Fax: +49.211.416073.11
sales_gmbh@pbclinear.de
www.pbclinear.de