



VICTREX™ POLYARYL ETHER KETONES (PAEK) AND POLYETHER ETHER KETONE (PEEK) POLYMERS AND COMPOSITES FOR WIND TURBINE BRAKES, ROLLER BEARING CAGES AND SLIDING BEARINGS

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ABSTRACT

The wind turbine industry continues to seek higher power, increased torque density, improved reliability, and greater worker safety. VICTREX PAEK and PEEK polymers bring advantages of improved strength/weight ratio, wear performance, reduced size, simplification to brakes, roller bearing cages, and sliding bearings. With over 40 years of experience, Victrex can support the development of the next generation of components needed for more efficient and reliable wind turbines.

KEY WORDS

brakes, bearing cages, sliding bearings, polyether ether ketone (PEEK) and polyaryl ether ketone (PAEK) polymers

WHY CHOOSE POLYARYL ETHER KETONES (PAEK) AND POLYETHER ETHER KETONE (PEEK) POLYMERS?

Victrex has developed PEEK and PAEK polymer solutions with properties needed in high performance applications (Figure 1). Wind turbines may benefit from

- **Weight Reduction at Equivalent Stiffness:** 70-85% lower weight at equivalent stiffness compared to some metals
- **Tribological Performance:** ability to perform in hydrodynamic, mixed friction, boundary lubrication, and even dry conditions.

- **Stable Properties:** retention of properties in corrosive, contaminated, and high temperature service conditions.
- **Tunable Properties:** PAEK and PEEK polymers are thermoplastic and consequently can be formulated with additives to enable design of properties for purpose.

The following are applications that may benefit from these properties.

PEEK SLIDING BEARINGS

PEEK-based sliding bearings have been able to increase reliability and service life, decrease weight, and improve operational efficiency in multiple markets. Through collaboration with Victrex, these benefits might also be realized for wind turbine components (i.e. gearboxes).



Figure 1. Advantages of VICTREX PEEK solutions.

Lighter Weight

An automotive OEM achieved reduced cost and an 80% mass reduction for a torque converter while maintaining operating performance and efficiency. This was achieved by replacing a traditional metal roller bearing with a full PEEK bushing comprising fewer components (Figure 2). PEEK formulations have densities of about 1.3 to 1.53 g/cm³ which are up to about 70% lighter than many steels, 82% lighter than Babbitt metals, and 85% lighter than certain bronze alloys (Figure 3).^[1] Lighter weight components reduce angular momentum which could result in energy savings and potentially more compact designs. If comparable performance is achieved, turbines with greater torque density could be realized with usage of PEEK components.

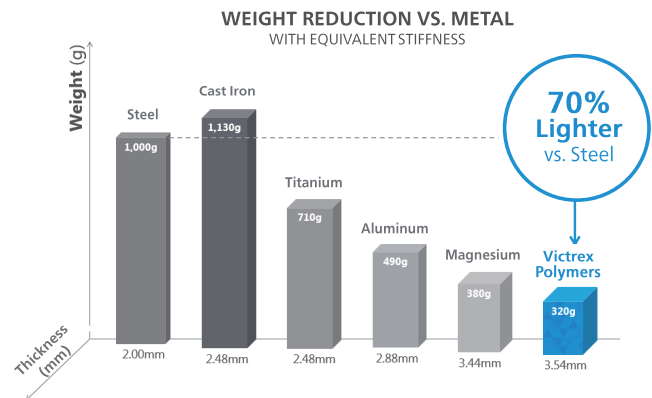
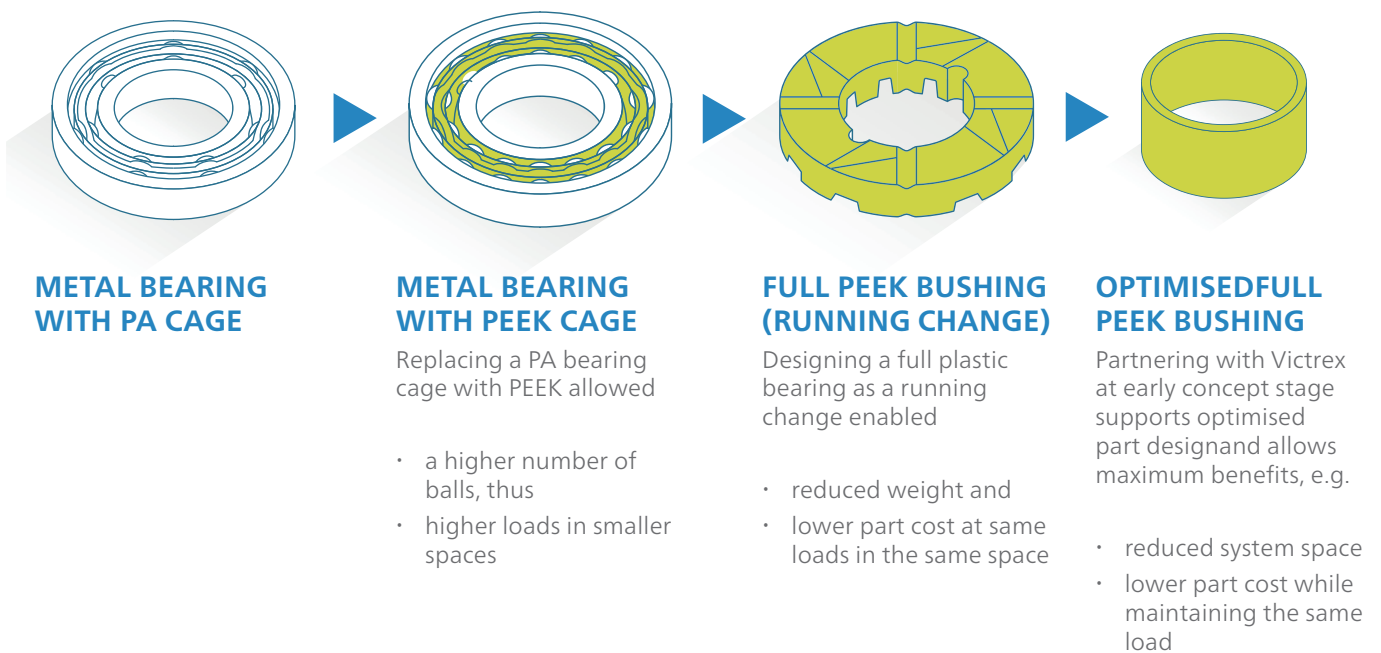


Figure 3. Improved energy efficiency through weight reduction.

Working together from concept stage to product launch, we can go beyond small measures and truly create solutions that will give our customers real competitive advantage.



We understand the characteristics and behaviours of PEEK right through the manufacturing process - help our customers achieve new ways of solving complex challenges - true innovation.

Figure 2. Transition from roller to journal bearings with VICTREX PEEK technologies.

Tribological Performance

Bearings systems in wind turbines can experience a broad range of operating pressures and velocities. At sufficient and steady velocity, hydrodynamic lubrication can provide sufficient lift to separate opposing bearing surfaces, however that is not always present. Mixed lubrication can occur at lower velocities and during changing wind direction resulting in wear due to contact of asperities on opposing surfaces. [2] Startup and shutdown can result in direct contact of bearings surfaces described as boundary lubrication which can result in severe wear. [3]

VICTREX PAEK formulations have been developed for strength, coefficient of friction, and wear performance in dry conditions. Figure 4 shows the operating regime of three grades as defined by limiting pressure-velocity (PV). Higher limiting PV indicates the ability to reduce friction in absence of liquid lubricants without melting or other mechanism leading to more rapid wear.

In 2015, Waukesha Bearings® Jie Zhou found a PEEK system to perform at approximately 50% higher

maximum pressure at 11000 rpm compared to a Babbitt metal for a thrust bearing (Figure 5). At 9.6 MPa, the Babbitt bearing exhibited distress in the form of creep and lubricant coking on the trailing edge. In contrast, the PEEK system was able to perform to 14.5 MPa at 11000 rpm with limited deformation. [4] If used in a wind turbine sliding bearing, benefits could include reduced wear, extended service life, and reduced maintenance. This in turn may reduce costs (such as operational expense, OPEX) to the developer.

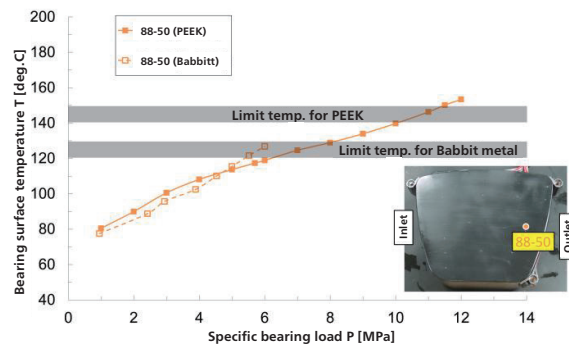


Figure 5. Thrust bearing surface temperature (PEEK vs Babbitt) as a function of specific bearing load. [5]

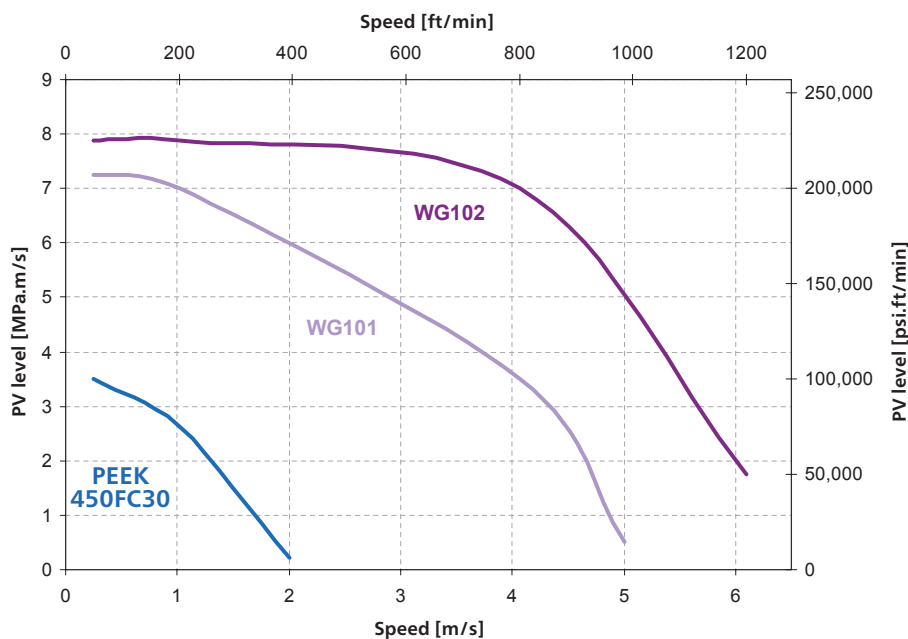


Figure 4. Limiting PV for PAEK wear grades (ASTM D3702 thrust washer test).

Bearing Cages

The performance and reliability of the rolling-element bearings and bearings cages are dependent of the bearing component materials. VICTREX PEEK polymer can replace metal to reduce system cost and save weight, as well as substitute standard polymers which cannot meet increasing temperature and chemical resistance performance requirements.

Bearing cages are mechanically stressed by friction, tension and inertia forces and are exposed to external influences due to lubricants, lubricant additives and their decomposition products which can be corrosive, as well as organic solvents and coolants. The extent of these factors depends on such parameters as temperature, impact resistance, vibrations or a combination of these and other unknown factors. Bearing cages made from PEEK polymer are characterized by their balanced combination of strength and elasticity. The low coefficient of friction of the polymer on a steel surface produces minimal friction between the cage surface and the balls so that there is very little heat and wear inside the bearing. Moreover, the low density of the material reduces the weight which, in turn, reduces the moment of inertia force and gives greater angular velocity to the bearing. Tribologically optimized compounds allow the bearings to run dry for a brief period without the danger of friction wear or damage. This suggests that the amount of applied grease could be reduced to an absolute minimum, thereby making a favorable environmental contribution.

Silver/Copper plating replaced by VICOTE™ coatings in needle roller bearings are widely used in crankshaft and connecting rod mechanisms in engines. Their purpose is to reduce the friction between two rotating surfaces. As a result, they are subject to extreme wear especially on the outer surface. Current solutions may be more expensive and might not provide adequate wear relative to the demands of the application. When tested at 9,000 rpm for 100 hours, VICOTE Coatings, with a 50% lower thickness, outperformed traditional silver/copper plating, which wears away under the same test conditions causing damage to the cage and premature failure of the bearing.

Regardless of format, VICTREX PEEK polymer as a bearing cage material provides the following benefits ^[6]:

- ▲ Accommodates high continuous temperatures and very high speeds
- ▲ Reduces heat generated by the bearing
- ▲ Reduces energy consumption
- ▲ Accommodates shock forces and high centrifugal forces
- ▲ Enables bearing to survive longer under poor lubrication conditions
- ▲ Extends bearing service life



Figure 6. PEEK bearing cage for roller bearing.

Brakes

Brakes serve and/or enable multiple functions in wind turbines from electricity generation to emergency stoppage. Yaw brakes and motors position the nacelle and blades upwind to drive the rotors. Several studies have identified failure of yaw systems have been a significant cause of overall downtime. ^{[7], [8]} Often used as a drag brake, yaw brakes have been reported to apply about 50-500 kN to counteract torque. For a nacelle with 4-8 brakes this corresponds to about 20 MPa pressure. Operating temperatures are typically -40 to 80°C.

PAEK polymers have mechanical performance and wear characteristics that can translate to robust brake performance at these service conditions. The base material provides stable modulus up to about the onset of about the glass transition temperature (T_g). ^[9]

For example, a gear rim with a diameter of 2 m which is yawing at 5°/s, has an effective linear velocity of 0.085 m/s.^[10] For a pressure of 20 MPa the corresponding PV would be 1.7 MPa·m/s. This value is well below the limiting PV of the previous PEEK examples (Figure 4). If implemented in a yaw brake, a PAEK-based brake could have the ability to impart higher braking pressures with less slippage. Reduced yaw error with PEEK and PAEK brakes could increase energy production, help to prevent shut downs, and potentially avoid structural damage in more extreme situations.^[10]

Additional Benefits

In addition, VICTREX PEEK exhibits a broad spectrum of characteristics that may benefit multiple applications. Several properties below could increase operational efficiency by extending service life, reducing maintenance, improving safety, health, and environment (Figure 1).

High Temperature and Pressure Performance

VICTREX PEEK solutions have provided stable performance in temperatures ranging from -196°C (-321°F) up to 260°C (500°F) with the capability of withstanding differential pressures up to 207 MPa

(30,000 psi). These properties may enable bearings to survive the high loads present in transitional states of operation in bearings for wind turbines.

Corrosion Resistance

VICTREX PEEK-based solutions also provide durability even when operating in corrosive elements such as hydrocarbon lubricants and corrosive environments. Offshore installations where salts and other chemicals typically corrode metals may benefit from replacement with PEEK. Aging experiments show stability of tensile strength at elevated temperatures when submerged in water and seawater environments.^[11]

Ease of Manufacture and Prototyping

Because VICTREX PEEK is a thermoplastic, it can be manufactured into parts with existing melt processing technologies such as injection molding, compression molding, and machining. These processes are well-established, scalable, and cost effective. Also, PEEK is compatible with emerging additive manufacturing technologies (“3D printing”). As a result, bearings engineers may enjoy design freedom and rapid prototyping to potentially realize faster product development cycles.

Comparison of PEEK to other Bearing Cage Materials			
Solid PEEK vs standard polymer cage (PA66)	Solid PEEK vs brass cage	Solid PEEK vs steel cage	VICOTE vs metal coated with Silver & Copper
Solid PEEK solution	Solid PEEK solution	Solid PEEK solution	VICOTE coated solution
Benefits: <ul style="list-style-type: none"> Suitability for higher temps Thermal ageing PEEK stiffness at 140 °C PA66: 120 °C in “non-aggressive” media and 100 °C in EP oils Chemical ageing High chemical resistance Higher wear resistance No absorption of humidity, thus no change of physical properties Longer lifetime 	Benefits: <ul style="list-style-type: none"> Weight reduction Higher flexibility Lower friction Emergency properties, no sudden blocking of bearing More space for grease reservoir or oil flow 	Benefits: <ul style="list-style-type: none"> Better tribological properties Lower friction Higher flexibility Emergency properties, no sudden blocking of bearing Weight reduction Lower lubricant consumption Thermal ageing Longer lifetime Efficient assembling process 	Benefits: <ul style="list-style-type: none"> Excellent wear properties compared to copper/silver coated solution Increased abrasion resistance In addition the Cu/Ag coating application technique can cause hydrogen embrittlement of the cage leading to premature failure of the bearing so VICOTE is an exciting new solution for the coating of bearings
Typical applications: <ul style="list-style-type: none"> PEEK cages in high speed centrifugal compressors, lubricated with refrigerant 	Typical applications: <ul style="list-style-type: none"> Ball bearing in a helicopter gearbox PEEK cages in construction equipment 	Typical applications: <ul style="list-style-type: none"> Alternator Truck transmission 	Typical applications: <ul style="list-style-type: none"> Needle Roller Bearing for motorcycle engines

Table 1. Comparison of PEEK with other materials for bearing cage applications.^[14]

Nontoxic

VICTREX PEEK polymers are high in purity and nontoxic. Used in dental and healthcare industries, minimal extractables and leachables support human health in medical devices including implants. Workers contact with new or worn PEEK parts should have less risk compared to some white metals which can contain lead, antimony, and other potentially toxic substances. ^{[12], [13]}

CONCLUSIONS

VICTREX PAEK and PEEK materials have the potential to increase strength, wear performance, and corrosion resistance of sliding bearings, bearing cages, and brakes. Potential outcomes could include the following:

- **Greater Reliability at Similar Specifications:** Weight reduction, more compact designs, wear resistance, and corrosion resistance could reduce damage to components and supporting structures over time. Their combined effect could result in longer intervals between repair/maintenance and ultimately extended service life before eventual replacement.
- **Increased Power Generation:** Turbine components that can support higher torque density which could enable greater power generation.

In these and other ways, VICTREX PAEK and PEEK polymers may enable greater competitiveness along the value chain from suppliers to OEMs to wind asset developers and operators. Immediate opportunities for improvement include brakes, roller bearing cages, and sliding bearings. With over 40 years of experience, Victrex can support the development of the next generation of components needed for more efficient and reliable wind turbines.

REFERENCES

1. https://www.engineersedge.com/materials/densities_of_metals_and_elements_table_13976.htm
2. https://www.victrex.com/~media/literature/en/2017-11_auto_powertrain_solutions_en_a4.pdf
3. Lubrication Regimes Explained by Noria Corporation
4. Jie Zhou, Waukesha Bearings® "Temperature Monitoring of PEEK Bearings", Society of Tribologists and Lubrication Engineers Conference, Las Vegas, May 15-19, 2016.
5. Sumi Yuki, et al. "Development of thrust bearings with high specific load." ASME Turbo Expo 2014: Turbine Technical Conference and Exposition, America
6. https://victrexplc.sharepoint.com/sites/technicaldatabase/tdb_MAIN/Global%20Tech%20Services/Technical%20Service%20Curriculum/3.0%20Technical%20Knowledge/3.02%20Application%20Training/Bearings%20Flyer%2010_4.pdf
7. S Pfaffel, S Faulstich, K Rohrig "Performance and Reliability of Wind Turbines: A Review", Energies 2017, 10, 1904.
8. Wilkinson M and Hendriks B 2009 "Reliawind Reliability Focused Research on Optimizing Wind Energy Systems Design, Operations and Maintenance: Tools, Proof of Concepts, Guidelines & Methodologies for a New Generation: Tech. Rep. 212966
9. Victrex technical data sheets for 450G, HT G45, ST G45.
10. "Yawing characteristics during slippage of the nacelle of a multi MW wind turbine" <https://iopscience.iop.org/article/10.1088/1742-6596/753/6/062010/pdf>
11. Pushing Boundaries towards Future Performance – PEEK Polymer Solutions for the Energy Industry https://www.victrex.com/~media/literature/en/energy_market_brochure_2015.pdf
12. "Improved Bearing Alloy – A Contribution Toward Environmental Protection" by Rolf Koring Proceedings of the 32nd Turbomachinery Symposium (2003) 85-90.
13. http://edge.rit.edu/edge/P14453/public/Research/2-LEADER_Understanding_Journal_Bearings.pdf
14. https://victrexplc.sharepoint.com/:w:/r/sites/technicaldatabase/tdb_MAIN/shared_space/_layouts/15/Doc.aspx?sourcedoc=%7B827671DC-9E16-4E70-864A-418CDBD8C1ED%7D&file=Bearing%20CagesComparativeProsCons2007.doc&action=default&mobileredirect=true&DefaultItemOpen=1



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