Made to Bear Extreme Conditions

Working below sea level, 24 hours a day, 7 days a week, subsea pumps are high-power and high-speed rotating equipment that perform under extreme conditions. Every single part of the pump has to be designed to be extremely reliable and must be tested intensively. The newly developed tilting-pad bearings offer advantages that can be used in other areas of application as well.

Certain applications, like subsea pumps or product-lubricated pumps, use low-viscosity lubricants in their bearings. For these applications, the traditional white metal bearings (babbitted bearings) are not well suited. Tilting-pad bearings made from polymer are preferable for high-power and/or high-speed pump applications. Many different tilting-pad thrust bearing designs and materials are available on the market. Depending on the pump application and design features, Sulzer as the pump manufacturer selects the bearing together with a dedicated bearing supplier.

For a subsea application with a low-viscosity fluid, the bearing manufacturer John Crane and Sulzer jointly developed a new bearing solution (Fig. 1).

1 Tilting-pad thrust bearing for extreme conditions.
Details about PEEK polymer
Polyether ether ketone (PEEK) is a colorless, organic, thermoplastic, high-performance polymer used for many engineering applications. PEEK offers excellent chemical and wear resistance and has an extremely low moisture absorption. Even at elevated temperatures, PEEK retains its superior mechanical and chemical resistance properties. PEEK melts at 343 °C and its maximum operating temperature is limited to 250 °C.

However, for this bearing application, it was decided to limit the maximum bearing temperature to 130 °C because all thermal and mechanical properties of PEEK experience a step change when they pass its glass transition temperature (143 °C).

Material selection criteria
For a high-speed and/or high-power pump with low-viscosity lubricants, Sulzer usually selects a polymer-based tilting-pad bearing. The polymer material offers many advantages over traditional bearing materials.

Advantages of polymers over metals for thrust bearings:
- Lower friction coefficient
- Higher load-leveling capability because of higher material flexibility
- Wider range of operational temperature
- Higher corrosion and chemical resistance
- Higher shock and impact resistance
- Electrical insulation.

Polymer-based tilting-pad bearings usually have either a “polymer-lined” design or a “solid polymer” design. The polymer-lined design combines the excellent tribological properties of polymers with the high structural stiffness of the steel base material. However, a polymer-lined metal pad does not provide the same load-equalizing effect offered by the higher elasticity of a solid polymer pad. A self-equalizing mechanism in a bearing is not needed when solid polyether ether ketone (PEEK) pads with a higher flexibility are used. Solid polymer tilting-pad bearings are sensitive to deformation, which is their main disadvantage. At the pad pivot, the high Hertzian contact stress might lead to a deformation or creeping of the polymer. Over time, such a deformation will result in a complete loss of the tilting-mechanism and will lead to a bearing failure.

Tilting-pad design with metal pivot
Together, John Crane and Sulzer have developed a new two-piece tilting-pad design that combines the benefits of a solid polymer design with the benefits of a polymer-lined design. The two-piece tilting-pad design, already patented by Sulzer, is illustrated in Figs. 2 and 3.

With the new solution, the contact surface between metal and PEEK is increased, thus reducing the Hertzian contact stresses in the PEEK significantly. The metal pivot, therefore, mitigates the risk of creeping at the pivot in applications with high contact stresses. At the same time, it retains the solid polymer character of the tilting pad. The pad and pivot were designed in accordance with John Crane know-how and experience from other tilting-pad bearings.

High wear resistance required
During development, the engineers tested PEEK-based material compounds for the bearing pads. The table (Fig. 4) shows that the tensile strength of virgin PEEK is...
only 14% of the tensile strength of 16MnCr5, a standard steel used to manufacture oil-lubricated, babbitted bearings. The Young’s modulus, also known as the elastic modulus, is a measure of the stiffness of a solid material. The Young’s modulus of PEEK is only 1.7% that of 16MnCr5 steel. Therefore, virgin PEEK was not suitable for this special application.

Reinforcing with carbon fibers
Embedding carbon fibers into a polymer increases the tensile strength. The engineers calculated the necessary amount of carbon to be used with the help of a finite element analysis. A carbon fiber reinforced PEEK compound with 30% of short, but randomly oriented carbon fibers is not able to cope with the stresses and would show unacceptably high deflections.

Only a PEEK composite with a carbon fiber content of 50% has enough strength to handle the stresses. The tilting-pads have been compression molded out of PEEK-impregnated fabric. With this material, the deflections are reduced, making it suitable for this application. The higher compressibility of the PEEK composite offers the advantage of better load equalization — especially for thrust bearings — and allows higher specific loads. The compression-molded material is anisotropic, showing different material properties in different directions. The carbon fibers of the composite are oriented in the X/Y plane (plane of pad width/length). Therefore, the mechanical and thermal properties (tensile strength, thermal expansion, etc.) are dominated in this plane by the carbon fibers. In the direction of the pad height (Z-plane), perpendicular to the fibers, these properties are dominated by the PEEK matrix.

Additionally, for good wear resistance and to prevent wire wooling at the bearing, a tungsten carbide coating was applied to the thrust collar. This coating is a Sulzer proprietary coating, called SumePump™ SA coating, and is applied with the high-velocity-oxygen-fuel (HVOF) method.

Successful thrust bearing qualification
The newly developed tilting-pad thrust bearing has been tested under realistic operating conditions typical for low-viscous applications, e.g., application in a subsea

![Table with comparison of the mechanical and thermal properties of different bearing materials.](image)

4 Table with comparison of the mechanical and thermal properties of different bearing materials.

“We developed this bearing in cooperation with Sulzer, mainly to be used in subsea pumps. Our combined knowledge of bearing technology, tribological material expertise, and design know-how led to an innovative solution. The FEA calculation method helped us to select the right material quite fast. Reliability is extremely important for subsea pumps, which operate up to 3 000 m below the sea level. The bearing fulfilled all requirements during the intensive test procedure. We are proud of this result, and we hope that this kind of bearing will be used in other industries as well, e.g., for topside applications.”

Dr. Dieter Henssler, Engineering Manager, John Crane Bearing Technology GmbH, Germany

Sky-High to Deep-Sea
pump motor unit. These qualification tests were conducted on a dedicated test loop on Sulzer’s development test-bed in Winterthur, Switzerland. The fully instrumented test installation allows Sulzer engineers to record power losses, thrust load, lubricant flow rate, and temperatures at various locations (Fig. 5).

To verify the long-term bearing performance, the thrust bearing was operated at maximum load with a lubricant inlet temperature of 50 °C simulating realistic operating conditions. The thrust bearing was tested using a water-based lubricant with a viscosity grade equivalent to ISO VG 5. The lubricant inlet temperature was varied between 20 °C and 50 °C, and a specific pad load up to 3.8 MPa was applied. The testing speed ranged from 1 500 to 6 000 rpm. The bearing tests included two test series with safety factors of loads higher than the design load: 1.5 times higher and 2 times higher load respectively.

After 250 consecutive loaded start-stops, the bearing was inspected. No signs of wear were observed on the pads or on the thrust collar itself. Pad roughness measurements taken before and after the tests are comparable, proving that a sufficient fluid film thickness was maintained during the whole test. A measurement of the pad thickness performed before and after the tests showed no deviations. This proves a good hydrodynamic lubrication of the tilting-pad thrust bearing.

**Control of the pad temperature**

The calculated temperature distribution at 4 000 rpm at a specific load of 2.09 MPa and a lubricant inlet temperature of 30 °C can be seen in Fig. 6. The bearing temperature measured at the probe location for this operating condition was 66 °C. The calculated temperature is between 64 ° and 66 °C. This shows an excellent correlation between simulation and measurement.

**Wide application range expected**

The newly developed tilting-pad thrust bearing is now available to the market — primarily for pump applications with low-viscous lubricants. Similar bearings can be used as a potential direct replacement for babbitt bearings to achieve extended operating limits.

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