Turbopump Ball Bearing Engineering

Risks and Opportunities

Image: J2 motor Saturn V Rocket (credit techno-science.net)

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Risks and Opportunities

Turbopump bearings are exceptionally critical components and are often the primary cause of pump failure. These bearings can encounter various issues, such as overheating, cage instability, or other anomalies.

This is why the engineering approach to defining these bearings must focus on minimizing risks and creating the conditions for success.

On the catalog approach

The common, intuitive method for defining a turbopump bearing often relies on an off-the-shelf (COTS) approach. This is the solution most frequently requested by new-space players.

However, turbopump bearings are vital components and are often the leading factor in pump misbehavior. These bearings can experience various issues, such as overheating, cage instability, or other anomalies. While the COTS option may appear advantageous in terms of cost, it may pose significant risks for turbopump applications. This “off-the-shelf approach” typically involves selecting a bearing from a catalog based on sizing and load specifications. However, this method focuses primarily on fatigue to determine the lifespan, which may not be the most critical factor when selecting bearings for a turbopump.

Moreover, catalog solutions fail to provide insights into the bearing’s internal geometry, which plays a decisive role in ensuring the performance of bearings. Without this crucial information, it is impossible to fully understand the bearing's behavior.

A better approach involves detailed modeling to understand what happens within the bearing during operation. This includes assessing potential issues such as thermal instability, cage instability, variations in ball speed, and friction-related power dissipation.

For these reasons, APO-GEE exclusively follows a custom-engineered approach for turbopump bearings. We do not supply COTS bearings for turbopumps, nor do we maintain a catalog or provide related datasheets.

On the custom engineering approach

APO-GEE's approach to turbopump bearings is therefore exclusively based on a thorough analysis of operating conditions, lifespan, sizing, and loads. The goal of the engineering process is to develop a new bearing design that ensures improved reliability. Importantly, bearing performance is not limited to fatigue resistance alone.

The engineering process varies depending on the specificities of the problem:

1. Addressing a specific Issue. If the issue is well-defined (e.g., an existing bearing has demonstrated specific problems), the process begins with detailed modeling of the bearing's behavior. This involves using advanced characterization tools to identify the root cause of the problem. From there, an optimized design is created, which undergoes experimental validation before implementation in operational conditions.

2. Designing a bearing from scratch. For broader challenges, where a bearing must be designed entirely from scratch, the engineering process is iterative. This begins with a detailed understanding of the bearing's operating environment and conditions. Initial modeling is conducted to develop a preliminary design, followed by testing on specialized benches. Optimization is then carried out at various levels, addressing issues like cage instability or thermal instability. Each iteration is validated experimentally to refine the design.

In both cases, the objective is to identify the operating limits of the bearing under specific loads and define design elements that ensure optimal performance.

Collaboration is crucial throughout this process, involving all stakeholders: the motor designer, APO-GEE, and the bearing manufacturer (if applicable), and the test infrastructure team.

On the engineering process requirements

For the engineering phase, the following information is required:

- Operating temperatures and environmental details.
- Bearing speed and loads.
- A description of the assembly.
- Detailed information about the current bearing's parameters (dimensions, internal geometry and materials).
- An explanation of why the currently selected bearing did not meet requirements or a description of encountered issues (if applicable).

All shared information are of course be protected under an NDA.

On timeline and cost Estimation

The engineering process for a turbopump bearing is inherently iterative and typically spans several months. Providing an accurate cost estimate at an early stage is sometimes not possible, as it depends on the availability and quality of the input data. A time-based approach can therefore be recommended at the first phases, transitioning to fixed development costs as the process progresses and becomes more defined.

On modeling, testing, and validation

APO-GEE uses proprietary tools to model and compute the behavior of bearings. As previously mentioned however, real-world testing, whether conducted at your facilities or third-party sites is essential. These tests provide critical data, which can be used to refine the bearing specifications if necessary.

Our experience with analyzing turbopump bearing behavior highlighted the necessity of this testing phase. It is indispensable for ensuring performance and reliability.

Conclusion

The engineering of turbopump bearings for rocket engines presents both significant risks and exceptional opportunities for innovation. While off-the-shelf (COTS) solutions may initially seem attractive, they fall short in addressing the complex demands of environment and high-performance requirements.

APO-GEE's custom-engineered approach prioritizes reliability, performance, and tailored solutions through detailed modeling, iterative design, and rigorous testing. By collaborating closely with all stakeholders and leveraging advanced tools, we ensure that each bearing is optimized for its unique operational context.

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