Challenges of Cryogenic Turbopump Bearing Engineering

Technological advances in a growing market

The increase of investments of space nations, the growing number of missions, the trend towards re-use, increased efforts to reduce carbon footprint, and the development of space tourism are all factors driving the the launch vehicle engines and spacecraft market.

Although growth in this market will continue to be strong in the coming years, the challenge facing the engine industry will remain considerable, namely to reduce development costs and increase performance, while ensuring the reliability of future engines.

Technological advances are, of course, key here. These technological advances include the use of alternative fluids that make easier the fuel handling and the improvement of production processes through additive manufacturing. Innovation has thus opened up new opportunities, translated in terms of cost optimization, although trade-offs still need to be considered in terms of performance.

Reliability of turbopumps

But innovation must also be expressed in maintaining and improving reliability. Reliability, and by corollary safety when it comes to manned flights, cannot be compromised.

While many successful R&D programs have been conducted in this direction, it is no exaggeration to say that little significant progress has been made with regard to ball bearings used in turbopumps. These remain a major element of cryogenic engines, and it is clear that many problems encountered in recent decades have not yet been able to find a satisfactory answer. Launchers have experienced extremely damaging failures, in particular due to thermal instabilities within the bearings of the turbopumps, cage instability or even *ball speed variation phenomena*. A sudden increase in temperature in a cryogenic bearing when the level of friction becomes too high, is a major problem that can lead to the destruction of the bearing. Temperature increase must be taken into account.

However, given the size of the stakes in financial, technical and even political terms, associated with the development of new engines, it is essential to provide new solutions at the turbopump bearings level, which will guarantee their reliability.

Limitations of the « catalog » approach and innovative ball bearing engineering

If innovation in the field of turbopump ball bearings has been very limited or non-existent so far, let us first remain realistic: it will not result in new mechanical concepts that will replace the bearing. But even if it is a relatively simple mechanical element, the phenomena that govern its operation in the extreme conditions encountered in turbopumps are still largely unknown.

Innovation therefore comes from the understanding of the physical phenomena that govern the operation of bearings. At the heart of these. Because deep understanding leads to appropriate solutions.

Indeed, the “off-the-shelf approach”, which consists of selecting a bearing from a catalog based on the sizing on the one hand, and the loads on the other, clearly has its limits. The selection of the bearing in this case is indeed essentially focused on fatigue in connection with the lifespan of the bearing. However, fatigue and lifespan are not the determining factors in the choice of a cryo-bearing for a turbopump. The « catalog » approach also does not provide information on the behavior of the bearing itself. This is reflected in particular by the absence of data concerning its internal geometry. However, this internal geometry plays a decisive role in the good performance of cryogenic bearings.

Where the "catalog" approach has shown its limits, an innovative characterization method based on a power criterion to achieve bearing equilibrium opens new perspectives. It leads directly to innovative bearing designs that provide concrete answers to the most critical applications. And turbopumps are a perfect example of this.

Classical modeling based on Newtonian dynamics does not allow accurate bearing equilibrium to be achieved. The one based on the power criterion definitely can. In particular, it makes it possible to understand the basics of sudden temperature rises in cryo-bearings, and to take into account the age instability or *Ball Speed Variation* phenomena, that can lead to the rupture of the bearing. And that’s a major step forward.

Concretely

The way forward is therefore to be able, via modeling, to have a precise idea of what is happening at the heart of the bearing of a turbopump with regard to potential bad behavior: thermal instability, cage instability, ball speed variation, power dissipation by friction…

Based on an analysis of data relating to operating conditions, lifespan, sizing and loads, the engineering process must ultimately lead to a new design of the elements making up the bearing, to ensure its increased reliability; being understood that the good behavior of the bearing is not limited to the resistance to fatigue.

The engineering process will vary depending on the input data. If the problem is specific, in other words, if the problem has already been highlighted on a bearing that has already been selected, the engineering will first consist in modeling its behavior via characterization tools that are based on the power criterion. An optimized design will be deduced from this, which can be experimentally validated before implementation in operational conditions.

If the problem to be addressed is broader, i.e. when defining a turbopump bearing « from scratch », the engineering process will be iterative. The new design will be achieved through an approach that will first rely on a good understanding of the bearing environment and its operating conditions. On this basis, a first modeling exercise will be carried out to lead to a first selection of bearings. Tests will be then carried out on a dedicated bench and optimization will follow at different levels (e.g. towards cage instability or thermal instability). The optimization will again be subject to experimental validation.

In both cases, the aim will be to identify the operating limits of the bearings, particularly according to the loads, and to determine the elements of design that will ensure their proper performance.

In both cases, effective and open collaboration between the motor designer, the partner in charge of bearing engineering, the possible bearing manufacturer, and the person responsible for the test infrastructure, will remain essential.

Conclusion

In the aerospace industry, preventing problems will always be more effective and less expensive than solving them. And turbopump bearings are no exception.

The bad news is that a deep understanding of what goes on inside the bearings of turbopumps cannot be dispensed with in new engine development programs. The good news is that when it is carried out in an innovative, precise and rigorous way, it directly contributes to ensuring the success of these programs, and to sustaining the related investments. And certainly also, to ensure a decisive competitive advantage for the actors who will engage in the process.

What is your next step now?

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