Experimental Validation of a Thermal Model of a LOx Flooded Ball Bearing

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1. Abstract

Ball bearings of turbopumps of rocket engines are flooded into liquid oxygen or liquid hydrogen. They are also subjected to high axial forces and high rotational speed.

The cryogenic liquids do not allow the use of conventional lubricants (oil or grease). They correctly cool the bearing but, as a consequence of their low viscosity, there is no thin elastohydrodynamic film and the lubrication regime is equivalent to a dry one. The friction forces induced by the lack of conventional lubricant imply a significant heat generation at ball/race contacts.

The University of Liège reproduced the operating conditions of a cryogenic ball bearing (inner ring of 20 mm, 14000 rpm) working in liquid oxygen (105 K). A test rig [1] was manufactured and tests were performed. Several parameters were studied (loading, clearance, coating,...). The test rig permitted to measure the temperatures of both inner and outer rings. The oxygen temperatures at the inlet and the outlet of the bearing were also measured.

Without the presence of a coating on the two rings and under high loading conditions, the rings thermocouples of the test rig recorded some sudden changes in temperature. These are attributed to the phase transition of the liquid oxygen located in the vicinity of the ball/race contacts: the boiling point of the oxygen is locally exceeded. This phenomenon modified the convective heat transfer.

In this paper, a thermal model is developed to calculate the flash temperature in the contacts due to an amount of heat generated by friction. The heat flux is calculated thanks to an original ball/race contact model based on the «Strip theory» [2]. This model takes into account the deformations in the contacts (coated or not) and the dry lubricating conditions. Then, the flash temperature in the contacts is calculated by summing the bulk temperature of the rings (measured by the test rig) and the local rise in temperature (evaluated thanks to the theory of the moving heat sources [3]).

An example of flash temperature is depicted in figure 1. The blue ellipse delimits the Hertzian surface of a typical ball/inner race contact. The arrow gives the circumferential speed of the inner race relative to the contact.

Finally, it is shown that the difference between the flash and the boiling temperatures (ΔT) is correlated with the sudden increases in the measured temperatures of the ball bearing rings. When a thermal divergence is observed, ΔT (calculated by the thermal model) remains unchanged independently of the test conditions. ΔT corresponds then to a threshold value beyond which the oxygen is unable to cool the bearing.

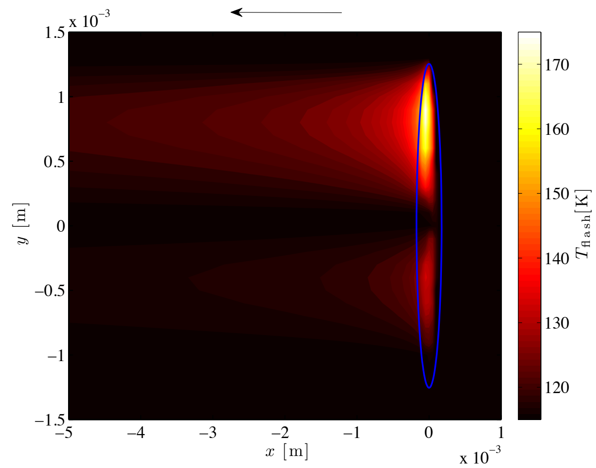

Fig.1 Flash temperature example of a typical ball/inner race contact.

2. References

[1] J.-L. Bozet, A. Germain and B. Juery. “Développement d’un boîtier d’essai dédié à l’expérimentation d’un roulement à billes noyé dans l’oxygène liquide”, Journées Roulements, 23-24 march 1994, Société Française des Mécaniciens, Paris, published in Mécanique Industrielle et Matériaux (review of GAMI), vol. 47, n°5, pp. 463–467, december 1994.

[2] D. J. Haines and E. Ollerton. “Contact stress distributions on elliptical contact surfaces subjected to radial and tangential forces”, Proceedings, Institution of Mechanical Engineers, vol. 177, pp. 95–114, 1963.

[3] H. S. Carslaw and J. C. Jaeger. “Conduction of Heat in Solids”, Oxford University Press, 2nd edition (1959), London.