ISS AMMONIA PUMP FAILURE NUMERICAL ASSESSMENT

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Abstract: *The objective of this study is to provide insights into the failure of the ammonia pump on the external active thermal control system of the International Space Station in 2010. The pump rotor was supported with hydrodynamic bearings lubricated by the process fluid and operated in conditions of instability. The study also deals with specifics of the use of tilting pad journal bearings used in zero-gravity conditions.*

1. Model and instability

The pump failure was in detail described in [1]. The pump rotor was supported in hydrodynamic bearings lubricated by the process fluid (ammonia) with a corresponding dynamic viscosity of 1.68×10^{-4} Pa.s (2.62 MPa, 275 K). Journal bearings with 18 mm and 9 mm diameter, with four axial grooves, had a radial clearance of 0.0468 and 0.0234 mm respectively (relative clearance 2.6×10^{-3}). Journal bearings working with low-viscosity fluids are prone to instability, especially in zero-gravity conditions, even if axial grooves break the sliding surface.

However, with zero load corresponding to zero-gravity conditions, cylindrical bearing, i.e., bearing without preload, is inherently unstable because no force returns the journal into the central position. To prove this fact by calculation an approximate rotor model of the ISS pump was developed according to Fig. 7 of [1].

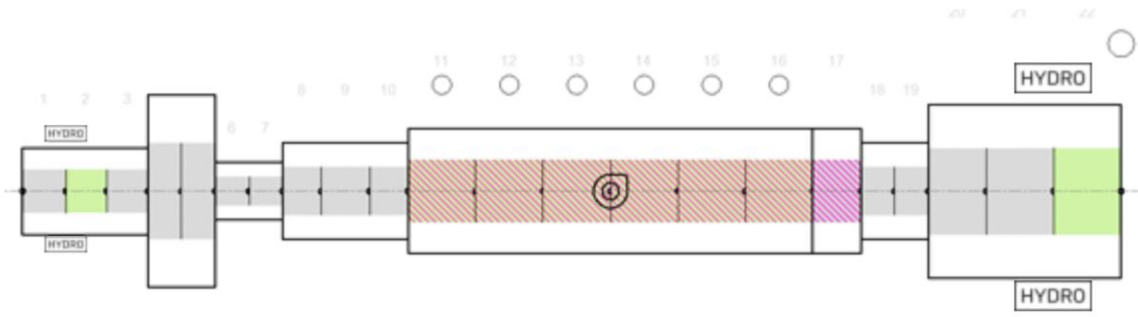

Fig. 1 Rotor model according to [1]

Such a rotor model cannot be accurate except for the known bearing span of 144 mm. However, for the purpose of determining rotor stability, such inaccuracy is not too significant. Bearing geometry is in this respect critical, and it was described sufficiently in [1]: diameter 18 mm and 9 mm with relative clearance of 0.26 % with four axial grooves around the periphery. Rotor dynamic analysis of such rotor has shown **bearing instability starting at the speed of 5 000 rpm**. The extreme bearing wear encountered after the ammonia pump failure was not caused by **unspecified forces** but certainly **by rotor running in conditions of instability**, when rotor vibration amplitudes reach the entire bearing clearance.

2. Comparison to different bearing designs

When cylindrical bearings with axial grooves (Fig. 2) were replaced in a dynamic model with four-lobed bearings with sufficient preload (Fig. 3) the rotor become stable even in zero-gravity conditions.

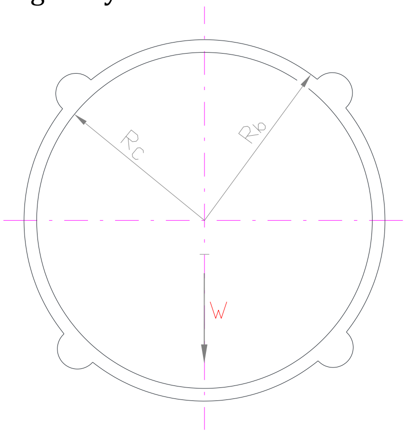

Fig. 2 Cylindrical four-groove bearing

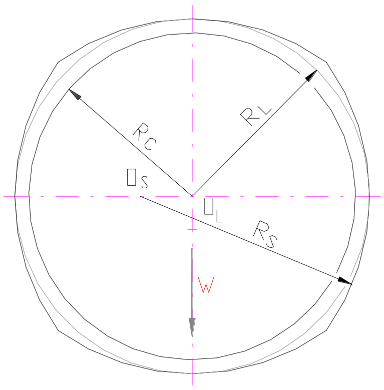

Fig. 3 Four-lobed bearing

The difference between the two bearings is the radius R_S, which in the cylindrical bearing is the same as bearing radius R_L, while in four-lobed bearing $R_s > R_L$. Thus, even with the journal in the central position, each bearing pad generates force acting in the direction of the bearing center, forcing the journal to the bearing center. With adequately designed four-lobed bearings of the same size, instability starts at the speed of 66 000 rpm.

Regarding rotor stability, the best stability properties provide tilting pad bearings due to their very small cross-coupling stiffness terms Kxy, Kyx, which promotes journal motion around the bearing center, thus destabilizing the rotor. Fig. 4 shows the difference between cross-coupling terms of cylindrical bearings with four axial grooves and tilting pad bearing (TPJB).

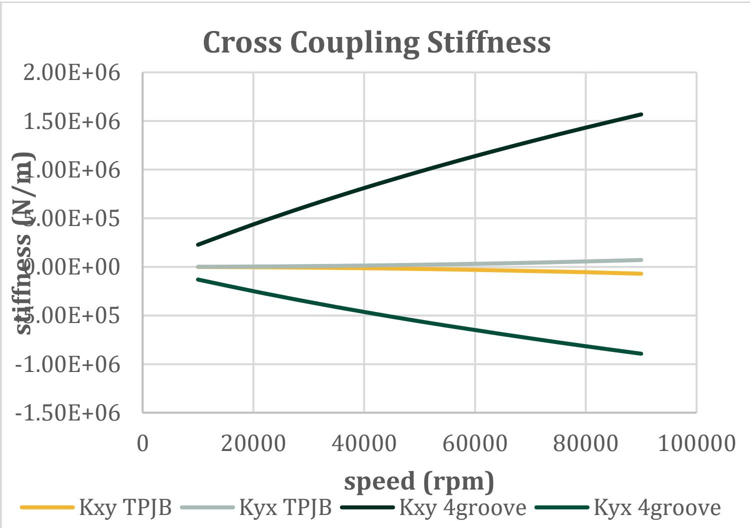

Fig. 4 Cross-coupling stiffness terms of cylindrical four-groove bearing and TPJB

It is evident that cross-coupling stiffness terms of four-groove bearing are of the order 10^5 to 10^6 N/m, while maximum TBJB cross-coupling stiffness is of the order 10^4 N/m, i.e., two orders lower. **Using the TBJB of the same size, no stability limit was found.**

References:

[1] Bruckner. R. J. – Manco, R. A.: ISS Ammonia Pump Recovery, and Lesson Learned – A Hydrodynamic Bearing Perspective. Proceedings of the 42nd Aerospace Mechanism Symposium, NASA Goddard Space Flight Center, 2014

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