

Superconducting bearings for a LHe transfer pump

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Abstract. Superconducting bearings are used in a number of applications for high speed, low loss suspension. Most of these applications suspend a warm shaft and thus require continuous cooling, which leads to additional power consumption. Therefore, it seems advantageous to use these bearings in systems that are inherently cold. One respective application is a submerged pump for the transfer of liquid helium into mobile dewars. Centrifugal pumps require tight sealing clearances, especially for low viscosity fluids and small sizes. This paper covers the design and qualification of superconducting YBCO bearings for a laboratory sized liquid helium transfer pump. Emphasis is given to the axial positioning, which strongly influences the achievable volumetric efficiency.

1. Introduction

Presently, most of the decanting stations of laboratory sized helium liquefiers use single-flow transfer lines and pressurized storage dewars for the filling of mobile dewars. In these systems, the flash gas is heated to ambient temperature and fed into the recovery system, subsequently to be purified and re-liquefied again. This causes a loss of potential refrigeration capacity. The associated evaporation losses are up to 30%. To overcome this, a submersible liquid helium (LHe) pump was designed thirty years ago at the Walther-Meissner-Institute for Low Temperature Research (WMI) in Garching, Germany [1, 2].

This pump reportedly allows reduction of the transfer losses to 2% by recirculating the gaseous helium displaced in the receiving dewar through a double-flow transfer line. It applies passive permanent magnetic radial bearings and an active magnetic axial bearing. The latter causes a static heat inleak through its current leads and a dynamic heat inleak during operation. Superconducting bearings can overcome these shortcomings. They operate frictionless and do not need external electronics. The storage dewars of laboratory liquefiers usually remain cold for the lifetime of the liquefier, which is in the order of 20 to 30 years. Therefore it seems advantageous to apply superconducting bearings, which are positioned once and remain levitating until the decommissioning of the storage dewar. Based on the principle design of the WMI pump (small outer diameter, concentric flow path) we are developing a new pump. In this paper, the achievable positioning accuracy, which determines the gap loss, is investigated.



2. General design of the pump

A general sketch of the pump design is shown in figure 1. It is designed to fill a 100l mobile dewar in about 5 mins. The pressure drop of the transfer line was estimated to 350 mbar. To fulfill the requirements, a centrifugal type pump with an impeller diameter of 32 mm, rotating at 15 000 rpm was designed. It features a guide wheel rather than a spiral to limit the outer diameter.

For low viscosity fluids, such as helium, it is crucial to limit the recirculation over the shroud disc by efficient sealing. To avoid wear, a non-contact gap seal was designed between the shroud and the casing. Figure 2 shows the volumetric efficiency with respect to the sealing gap, computed following the rough calculation given by Sigloch [3]. It can be stated that the clearance has to be below 0.1 mm to achieve volumetric efficiencies above 70 %. An axial gap rather than a radial gap has been chosen for the following reasons: The axial stiffness of the cylindrical bearings is about twice the radial stiffness, so that positioning is more accurate. Additionally, an axial gap can be adjusted by moving the shaft along its axis (in warm state, by the positioning mechanism), while for a radial adjustment a relatively complex iris or similar would have to be applied.

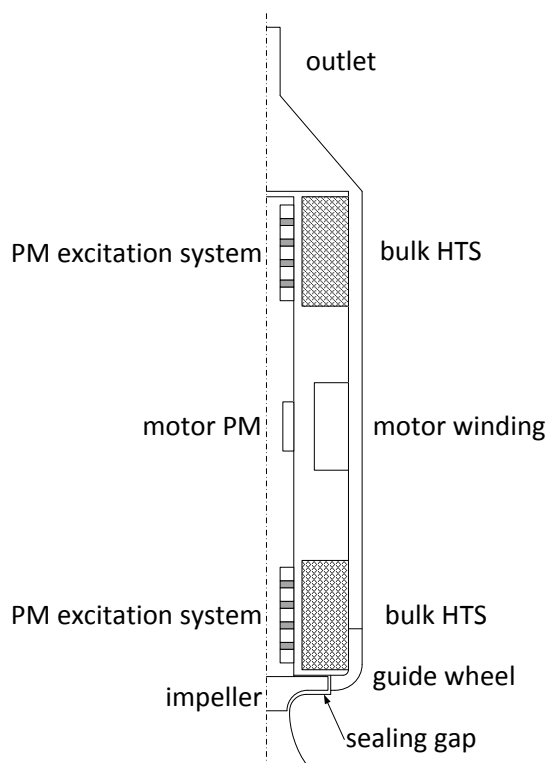


Figure 1. General design of the pump

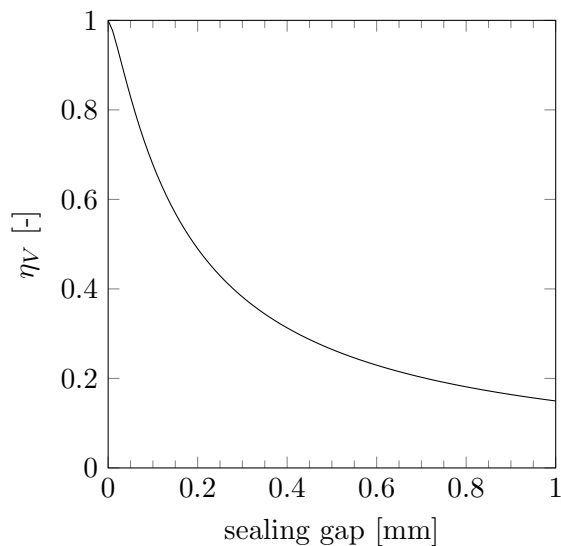


Figure 2. Volumetric efficiency over sealing gap

Two bearings are arranged in a distance of ca. 100 mm. In principle, a single bearing would be sufficient to restrict five degrees of freedom, but due to the lower radial stiffness, the angular stiffness is comparably low. Therefore precession can be avoided by adding a second bearing with a respecting lever. With this configuration a tilt of the shaft, which would result in a considerable reduction of the radial clearance of the impeller, can be minimized.

The motor is positioned between the bearings to avoid drag by the non-axisymmetric field of its permanent magnet.

3. Superconducting magnetic bearings

The bulk superconductors are made of melt-textured $Y_{1.55}Ba_2Cu_3O_x$. The rings are 20 mm high with an outer diameter of 38.6 mm and a 20.8 mm bore (see figure 3). Six seed crystals were used to achieve alignment of the a-b planes within the cylinder wall. Two of these rings are glued into a copper tube to form a bearing. For the excitation system, the NdFeB magnets and flux guiding rings are arranged as shown in figure 3. The magnetization directions are symbolized by arrows.

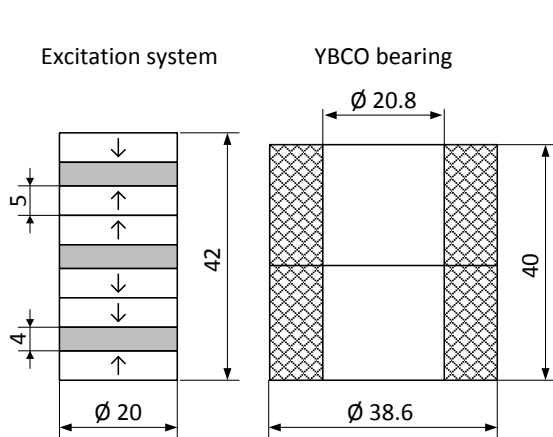


Figure 3. Design of the bearing system

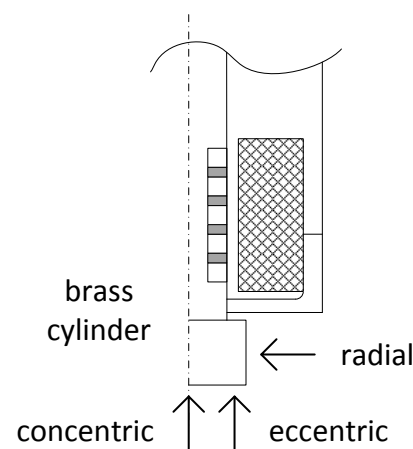


Figure 4. Measurement positions

4. Preliminary Measurements

Tests of the bearings were conducted in liquid nitrogen for simplicity. For these, a prototype of the pump was constructed with a brass cylinder instead of the impeller which was used as a reference for the eddy current distance sensors. These were calibrated against the reference in liquid nitrogen by the manufacturer, to a linearity of $2.5 \mu\text{m}$. The distances were measured on three positions against the cylinder at the lower end of the shaft: axial concentric, axial eccentric and radial (refer to figure 4). During the cool down, the rotor was suspended by a mechanical positioning mechanism, which was released as the entire prototype had cooled down to liquid nitrogen temperature. A closing of the axial clearance of approximately 0.025 mm was observed.

Subsequently, the pump shaft was accelerated to 20 000 rpm with 100 rpm s^{-1} . The axial measurement with the concentrically mounted sensor showed a variation of only $\pm 0.002 \text{ mm}$ at 15 000 rpm. Note that this value is in the order of the linearity of the sensor. Additional tests were performed with eccentric mounting of the sensor with a distance of 7 mm to the axis of rotation. The results are shown in figure 5. The values at low speed show the deviation caused by manufacturing and alignment tolerances of $\pm 0.013 \text{ mm}$. Subtracting this value from the variation at 15 000 rpm of $\pm 0.017 \text{ mm}$ leads to only $\pm 0.004 \text{ mm}$ which can be attributed to the dynamic movement of the shaft. This means that the rotor shows only a very small precession at the design speed. At higher speeds, the amplitudes are higher since the excitations due to unbalance become larger than the damping of the bearings. This can also be seen in the radial measurements in figure 6.

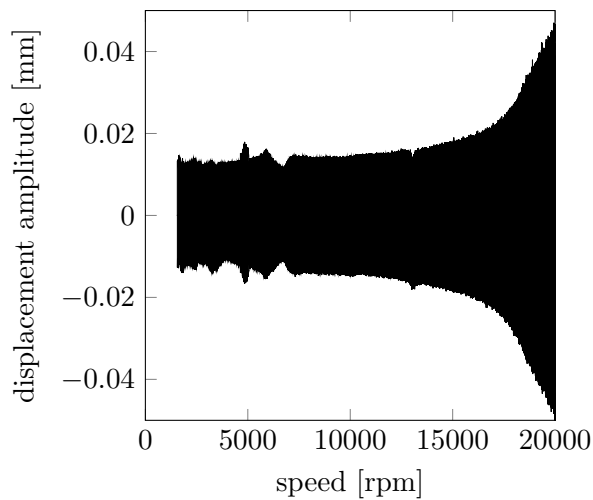


Figure 5. Displacement over speed, eccentric measurement

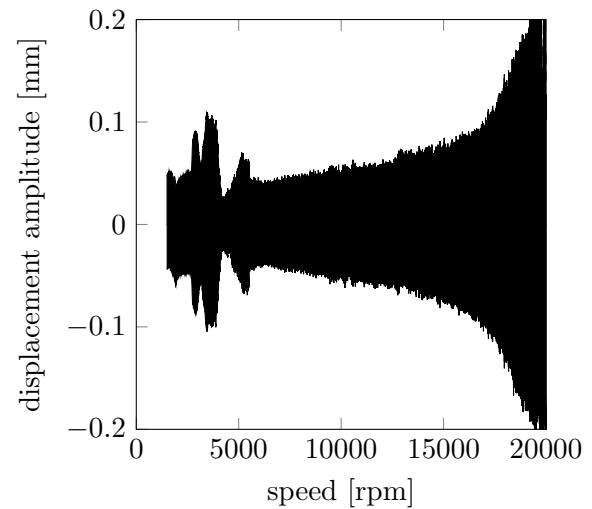


Figure 6. Displacement over speed, radial measurement

In order to measure the stiffness of the bearing, additional measurements were performed with a platform attached at the upper end of the shaft. This platform was above the LN₂ level and was loaded with measurement weights to apply an axial load on the bearings. The resulting axial movement is shown in figure 7. Derived from that, the axial stiffness is 265 N mm^{-1} .

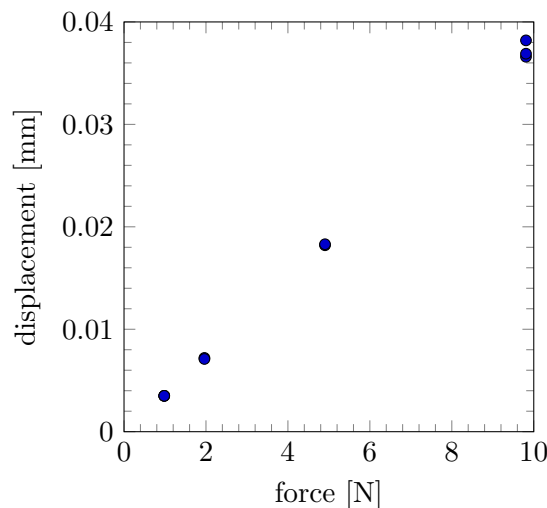


Figure 7. Displacement over force

5. Axial clearances during operation in LHe

When operating in LHe, the axial sealing gap has to be kept as low as possible to achieve high efficiencies while operating without contact. The pump has not been operated in LHe as of yet. Following Krabbes [4] about a doubling of the stiffness at 4.2 K compared to the value at 77 K can be expected. Therefore the closings of the clearance and the dynamic movement will also only be half the value measured in LN₂, except for the closing caused by the thermal contraction of the system.

The pressure forces acting on back of the hub disc are 28 N, resulting in a downward movement of the shaft of 0.054 mm. Assuming that the manufacturing tolerances will scale linearly with the diameter, a variation of ± 0.03 mm can be expected at the rim.

When setting the warm clearance to 0.14 mm, a working point of 0.05 mm can be achieved in LHe. Thus a high volumetric efficiency without contact of the rotor and stator seems possible.

6. Outlook

During the tests of the prototype without the wheel, quite high losses were found. These will be addressed in a future publication. Furthermore, the prototype will be upgraded to a complete pump and tested in liquid nitrogen and liquid helium, before it is installed in the stationary dewar and used for the daily filling operations.

References

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