Fabrication Methodology of Gas Foil Thrust Bearings used in High-speed Cryogenic Turboexpander

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Abstract

Cryogenic turboexpander is considered as the heart of modern gas liquefier for its high thermodynamic efficiency and high reliability. The operating speed of small-sized turboexpander is usually greater than 80,000 rpm. Such high rotational speed brings constraints in the selection of the bearings. Oil-free gas foil bearings are a novel approach to keep the process gas contamination-free and better rotor dynamic performance. The gas bearings for turboexpander are precession components of turboexpander as the permissible clearance between stator and rotor is in the range of 20 to 40 μm. So accurate fabrication methodology of these bearings is essential to preserve the performance of the turboexpander. In the current research, a pair of gas foil thrust bearings are fabricated for a vertical turboexpander used in nitrogen liquefier. The thrust bearings consist of a bearing base, bump foil, top foil and a mechanism to attach the foils to the bearing base. The bearing base is divided into four sectors and each sector is consisting of a smooth foil and a corrugated bump foil, which are mechanically attached with a bearing base using grub screws. The material of both foils are phosphorus bronze and their thickness is 100 μm. The bumps are fabricated using metal dies and die material is SS302. This paper explains in details about the fabrication of smooth foil using wire EDM, fabrication of bump foil by forming process using metal dies. The author explains the method of assembly and the necessary jigs and fixture required for the assembly.

1. Introduction:

The axial load due to the difference in pressure between the compressor and the turbine ends is supported by a pair of thrust or axial bearings. The rotor being vertically oriented, its dead weight is also taken by these bearings. To assure protection against accidental thrust reversals, a double thrust bearing is selected for the current prototype turboexpander. A pair of gas foil thrust bearing is designed for the current application, and its detailed designed data is tabulated in Table 1.

Table 1: Designed thrust bearings

Bearing parameters	Dimensions
Inner radius (R_1)	10 mm
Outer radius (R_2)	22 mm
Top Foil Thickness (t_t)	0.1 mm
Bump Foil Thickness (t_b)	0.1 mm
Bump Length ($2l_0$)	2.5 mm
Bump Pitch (s)	3.17 mm

Foil thrust bearings designed is divided into a four number of thrust pads, and each thrust pad is consist of four elements, and they are the top foil, bump foil, bearing base and an arrangement to join both foils to the bearing base.

2. Fabrication methodology

The fabrication methodology for gas foil thrust bearing is shown in Fig. 1, where the bearings block, top smooth foil and bump foils are made separately and assembled with the help of pin and screw..

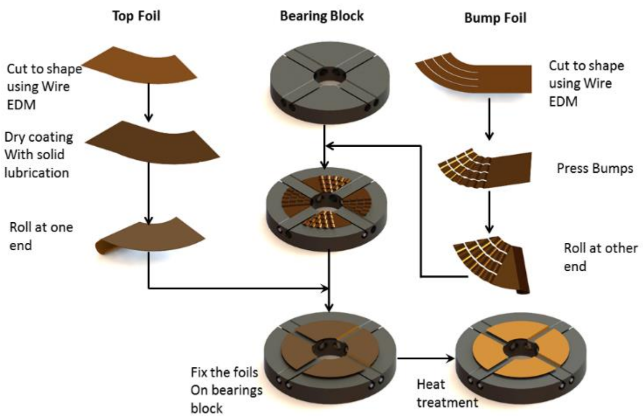


Figure 1: Fabrication methodologies of gas foil thrust bearings

The same procedure is used to fabricate both upper and lower thrust bearings with opposite leading and trailing edge of the gas foil bearings. This section explains about the fabrication of bearing base, top foils, bump forming methodology using two different sets of the dies. The FEM analysis is carried for the 2^{nd} die set, where both top and bottom are rigid dies is similar to the FEM analysis for journal bump foil forming

A bunch of thin foils were stacked together and cut to the dimensions using wire EDM same as the top smooth foil. The foil was cut to the shape with three slits as shown in Figs. 2(a) and (b). The slits are cut to ensure sufficient material flow during pressing operation of the foils.

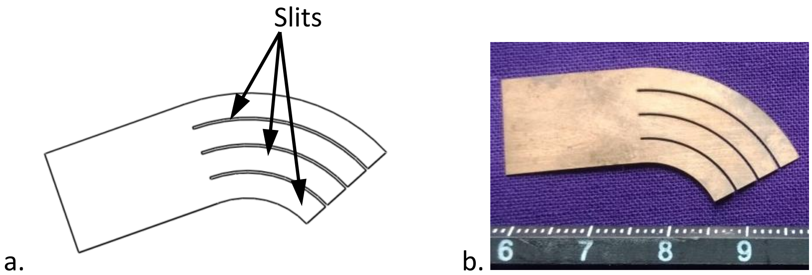
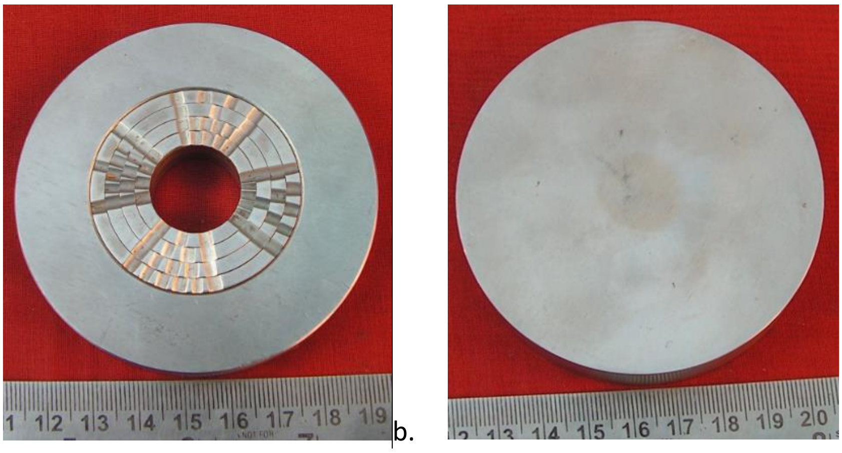


Figure 2: Smooth foil with slit before bump formation a. 2D geometry b. Fabricated

3. Thrust bump foil using flexible top die

The die set consists of a rigid bottom die, a flexible rubber sheet and a rigid plate. This arrangement reduces the tooling cost, so an attempt is made to fabricate thrust bump foil using flexible rubber sheet as a top die. The rigid die is with corrugated bump shape consisting of multiple circular bump strips to fabricate generation II thrust bump foil. The thin foil is placed in between the rigid bottom die and a flexible rubber sheet [2]. On the top of the rubber sheet, a smooth circular metal plate is placed to ensure uniform pressure to the rubber sheet during forming operation. The flexible rubber sheet applies a hydrostatic pressure on thin, smooth foil, and the smooth foil takes the shape of bumps on the rigid bottom die. The amount of forming load to be applied is done experimentally to ensure the least spring back and equal bump heights.

The bottom die consists of set of circular bump strip, placed inside a tooling frame. The circular bump strips are designed to fabricate bump foil of various pitches. Figs. 3 shows the tooling developed for the fabrication of generation II thrust bump foils. For current application, the bump die set was fabricated using SS 304. The flexible rubber sheet is a 2 mm thick silicon rubber sheet. Load-displacement curve during forming operation is shown in Fig. 4. Experimental studies show forming loads above 120 kN results bump foil with crack and below 110 kN consequences moderate deformation. So all the bump foils are formed with forming load between 110-120 kN for forming bumps of preferred dimensions. The fabricated thrust bump foils with complete deformation are shown in Figs. 5.



a. b.

Figure 3: Tooling for fabrication of generation II bump journal foil

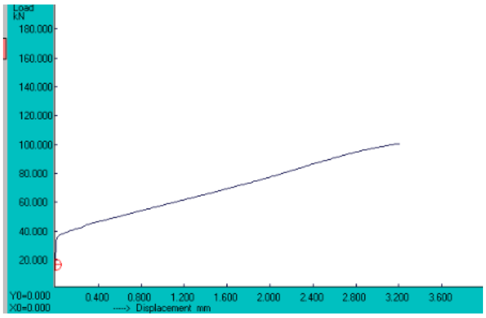


Figure 4: Load-displacement curve during journal bump formation

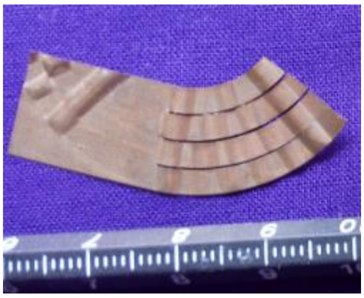


Figure 5: Fabricated thrust bump foils

Figure 6: Assembled bump foil with the bearing base

Figure 7: Assembled lower and upper gas foil thrust bearing with layer of MoS_2 coating on top foil

The fabricated bump foil is fixed with the grub screw as shown in Fig 6. The top foil with a coating of MOS_2 is mechanically fitted with the bearing base as shown in Fig 7.

Conclusions

A detailed fabrication methodology for fabrication of gas foil thrust bearings is presented in current paper. The fabricated foil bear is used in a cryogenic turboexpander rotating at 80000 rpm with an axial load of nearly 80N.

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