Finite Element Analysis of Bump Forming Process on Thin Phosphorus Bronze Foils Used in Complaint Gas Foil Bearings

Suraj K Behera*, Debabrata Mohapatra, Ranjit Kumar Sahoo

National Institute of Technology, Rourkela, Sundergarh, Odisha, India-769008.
*Corresponding e-mail: beherask@nitrkl.ac.in

Keywords: Gas Foil Bearings; Turboexpander; Finite Element Method; Forming;

Abstract

Gas bearings are used in high-speed turbomachines such as turboexpander to avoid contamination of process gas. The low viscosity of gases uses as a lubricant in gas bearings lowers the rotor dynamic properties such as bearing stiffness and damping. Use of compliant gas foil bearing is a solution to overcome above issue by use of thin spring-like corrugated bump shaped foils in the gas bearings. These compliant gas foil bearings are considered as precision components of high-speed turbomachinery as the radial clearance of these bearings are within 20 to 40 μm. So precise fabrications of the corrugated thin bump foil are an essential part in the manufacturing stage of gas foil bearings. The thin bump foils are nearly 100 μm thick and with a bump height of 500 μm. The bumps are fabricated by forming operation using metal dies. The major problem encountered during the fabrication of thin bump foils using a forming process is the spring back and damage. The spring-back of the thin foils during forming operation destroys the preciseness of the bearings as it affects overall bearing clearance. Current work explains the simulation of forming process using finite element methods to predict the stress distribution, total deformation, damage and spring back. The foil material uses in the investigation is phosphor bronze and metal dies are SS302. The simulation is performed for conditions such as by varying top die loading and unloading speed. The parameter which guides the deformation process and controls the spring back majorly is the stroke speed of top die. The accurate speed for the forming operation is found to be 4.8 mm/s for the current application. The forming process above this speed results lesser spring-back but possibility of increasing damage and thinning of foils. The current work also proposes suitable conditions to design metal dies, where the spring back effect can be minimized.

1. Introduction

The major issues faced by a flexible top die can be overcome by use of a top rigid die. With both the dies being the rigid, application of heat during bump forming operation is possible to reduce springback effect and maintain uniformity in the bump height [1]. The decision to go for rigid top die in 2nd phase also makes the die design process relaxed by the use of commercial software such as ANSYS LS-DYNA, DEFORM 3D, etc. These software packages help to predict the forming load needed for bump formation, stress distribution over bump foil and damage to bump foils for various forming parameters. The schematic of the bottom and top die with the workpiece is shown in Fig. 1.

2. FEM Analysis of Forming

The FEM analyses for bump formation is carried using DEFORM 3D. The 3D models for foil, top, and bottom dies are created using SolidWorks (Fig 1). The profile of bumps on the bottom die is kept same as bump dimension. However, the profile of bumps on the top die is reduced to minimize the springback effect. Table 1 shows the input parameters for simulation of bump foil formation and these parameters were used to simulate the load prediction on the top die, deformation, effective stress and damage on the workpiece or bump foil. Fig 2 shows the predicted load during forming operation is 40.7 kN for phosphor bronze. The simulated results such as deformation, effective stress and damage of the forming are shown from Figs 3 to 5 for workpiece material of phosphor bronze. The effective stress is found to be higher than the yield stress of phosphor bronze, and the bumps are formed as per prerequisite with no damage at the bump area.

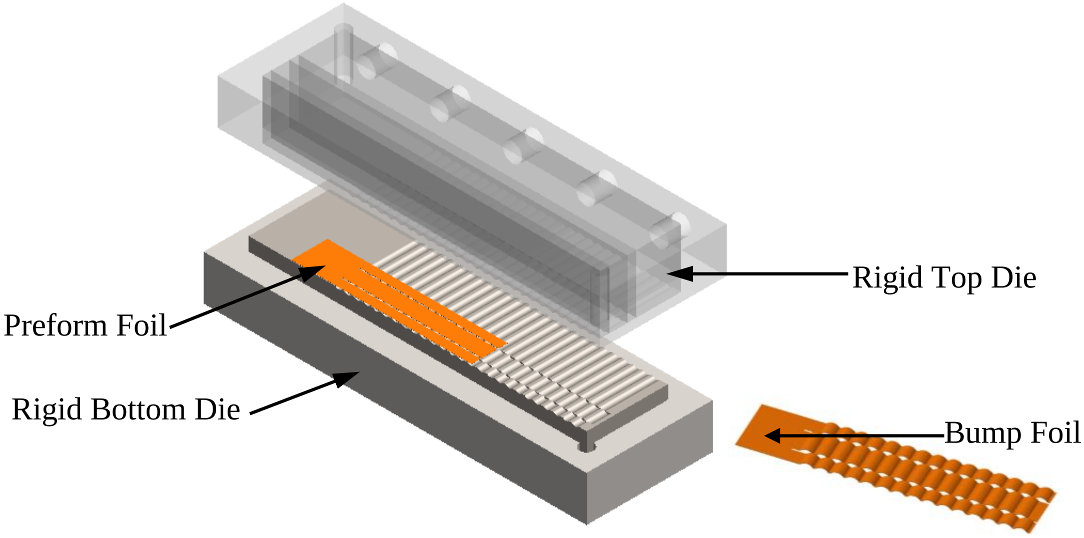


Figure 1: Tooling for fabrication of jour bump foil with rigid top and bottom dies

Table 1: Input parameter for FEM analysis

Sl No	Input Parameter	Values
1	Workpiece materials	Phosphor bronze
2	Top die/Primary die	Rigid
3	Bottom die	Rigid
4	Movement of the workpiece	Vertically downward
5	Movement of top die	Vertically downward
6	Movement of bottom die	Fixed
7	Stroke speed of the top die	0.06 mm/s
8	No of steps	100
9	Stop conditions	Release the forming load after traveling 0.61 mm

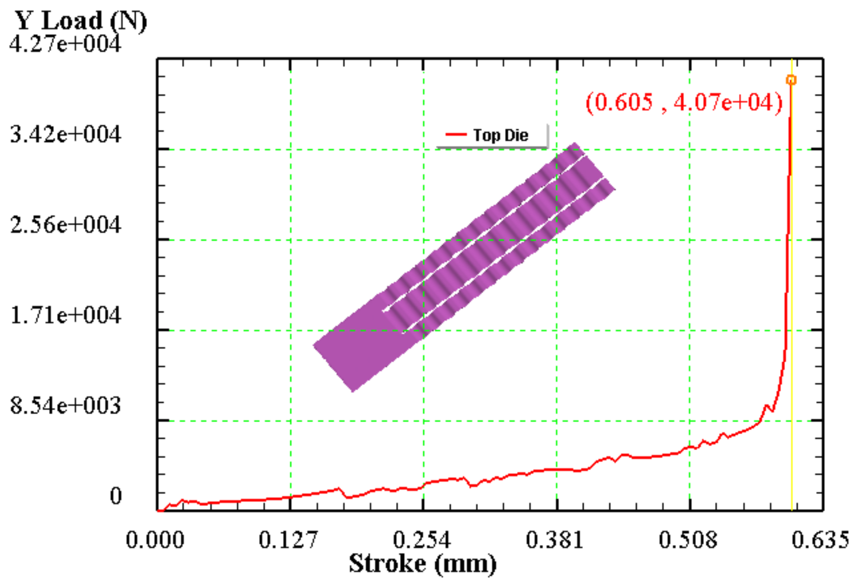


Figure 2: Load prediction curves for the top die during bump forming simulation over phosphor bronze

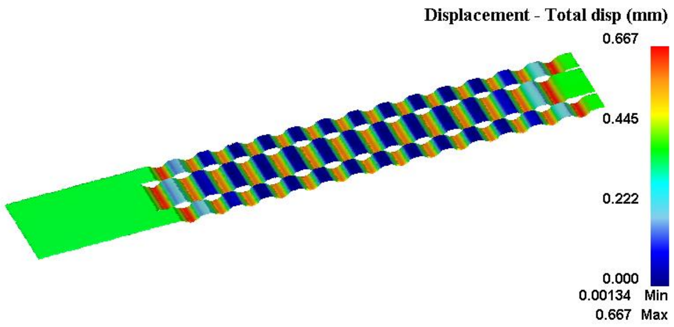


Figure 3: Displacement for phosphor bronze bump foil

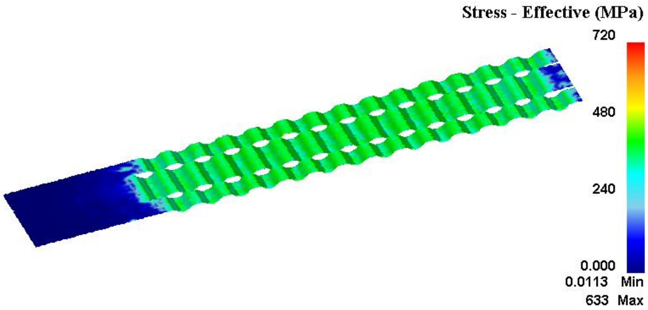


Figure 4: Stress distribution for phosphor bronze bump foil

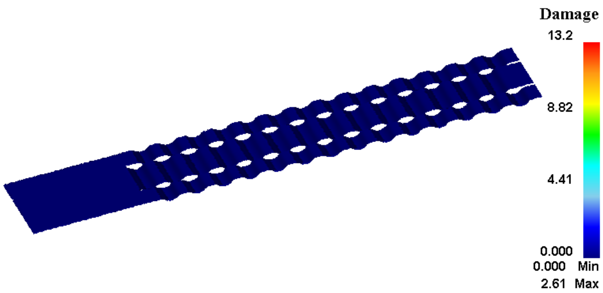
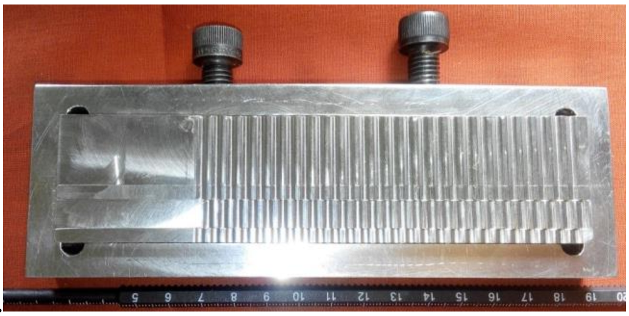


Figure 5: Damage for phosphor bronze bump foil

a. 

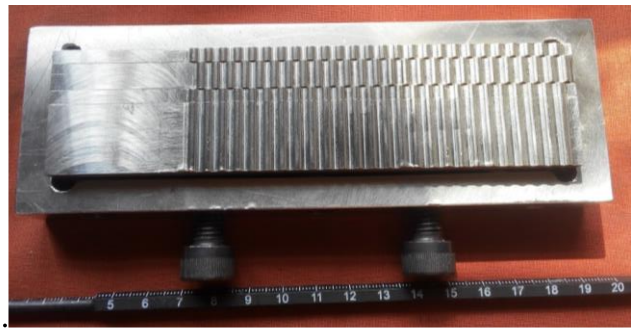
b. 

Figure 6: Fabricated rigid dies for the generation I and II bump foil a. Top b. Bottom

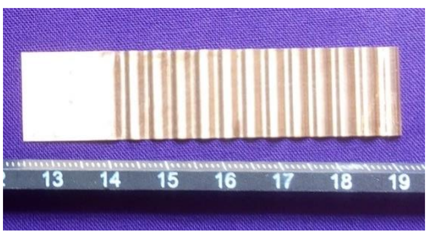
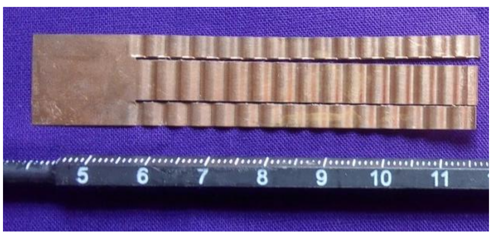
a.  b. 

Figure 7: Fabricated generation I(a.) and II (b.) bump foil with 2nd die set

The die set is designed for forming both generation bump foils, and the fabricated dies for bump formation are shown in Fig 6. The fabricated bump foils(both generation I and II) are shown in Fig 7. For the recent application, generation II bump foils are used for its higher load carrying capacity compared with generation I[1].

The fabricated bumps confirm uniformity in bump height, which is an essential part of bump forming. Further application of heat during bump formation is possible with rigid bump dies, which increases the flowability of the material and decrease the spring back.

3. Assembly of gas foil journal bearings

The assembly step comes after fabrication of all parts such as bearings base, top foil, bump foils, pins, and screws. Both top and bump foil on the bearings base can be fixed either by welding or by using pins and screws. Spot-welding is a procedure frequently used in the manufacture of gas foils bearings. However, welding alters the structure and metallurgy of thin foils and these welds, if not heat treated, can be an initiation site for degradation such as fatigue cracks [1]. So heat treatment is done after the assembly foils. In current approach pins and screw are used for assembly, where the ends of the bump and smooth foils are rolled to fit into the axial hole (4 mmϕ) on the bearing. In this axial hole, a semi-circular pin is inserted, and two grub screws are fastened in the transverse direction to hold the foils and bearing base together. The assembled journal foil bearing is shown in Fig. 8.

Figure 8: Assembly of bump and smooth foil on a single axial hole

During the forming operation sof copper alloys by cold working, strength and hardness increase as a result of plastic strain [2]. This is because elastic strain accompanies the plastic strain, and residual stresses remain in the product and can result in stress corrosion and cracking of material in service. So, heat treatments for the foils are necessary to relieve the internal stress. A temperature commonly used for annealing cold-worked copper alloys is 350^{o}C. To prevent oxidation during heat treatment, inert gas or vacuum heat treatment is preferable, but for lightly loaded bearings operating at relatively low temperatures as in current applications are found to be cost effective with air heat treatment [3].

4. Conclusions

The FEM analysis of the bump foil forming helped to design appropriate metal dies for the forming operation of the bump foil. Forming analysis is providing load required for complete forming operation. The radial bearings fabricated is used in a cryogenic turboexpander rotating at 80000 rpm.

Reference

[1] Bulat, M. P., and Bulat, P. V., 2013, "The history of the gas bearings theory development," World Applied Sciences Journal, 27(7), pp. 893-897.

[2] Christopher DellaCorte , Kevin C. Radil , Robert J. Bruckner & S. Adam Howard (2008). “Design, Fabrication, and Performance of Open Source Generation I and II Compliant Hydrodynamic Gas Foil Bearings”. Tribology Transactions, 51:3, 254-264

[3] Xiong.L.-Y, Wu.G, Liu.L.-Q, Ling.M.-F, and Chen.C.-Z, 1997, “Development of Aerodynamic Foil Journal Bearings for a High Speed Cryogenic TurboExpander,” Cryogenics, 37(4), pp. 221–230.