Precision Tooling for Manufacturing of an Underspring for a Generation II Gas Foil Bearing

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Abstract

Gas foil bearings (GFBs) have enabled commercially successful microturbomachinery for distributed power generation. With rotor spinning, the compliant surface of a GFB retracts to generate a gas film that supports the rotor load with nearly friction free operation. The bearing elastic structure or underspring is composed of a metal foil strip with preformed bumps, whose stiffness determines the overall bearing resilience. Inaccurate manufacturing methods create great variations in bumps' stiffnesses which ultimately affect GFB performance. This project aims to design and construct a tooling set for manufacturing of corrugated bump strip layers for use as undersprings in GFBs. A manufacturing process detailed in the open literature is retaken. Upper and lower bump forming dies are wire EDM (Electrical Discharge machining) with a maximum tolerance < 20 μm. A CNC machine precisely builds upper and lower die beds. With alignment pins, the die beds holding the bump forming dies ensure accurate alignment when press forming bump strip layers. A simple static load – deflection test aids to estimate the stiffness of the manufactured bump strip layer. Test data compare favorably with single bump predictions based on simple elasticity formulas .

Introduction

The performance of Gas Foil Bearings (GFBs) depends mainly on their elastic structure or underspring comprised of a metal foil strip with preformed bumps: See Fig. 1. Designed tool sets, precisely manufactured, are used to build bump strip layers whose stiffness depends on geometry and material properties. Presently, the project develops a tooling set to build bump strip layers following a published design [1,2] and within strict manufacturing tolerances. Table 1 shows dimensions of the Wire EDM bump forming dies (upper and lower).

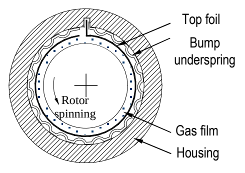

Fig 1. Schematic view of bump type gas foil bearing

Table 1. Dimensions of machined bump forming dies

Bump pitch, mm	3.5 +/- 0.01
Bump half length, mm	1.5 +/- 0.01
Bump height, mm	0.4 +/- 0.01
Forming die length, mm	100 +/- 0.1
Forming die height, mm	12 +/- 0.1
Forming die width, mm	28 +/- 0.1
Bump arc length, rad.	1.56

Bump foil nominal dimensions

Table 2 lists the measured dimensions of the formed bump strip layers with foil thicknesses of 76.2 μm, 101.6 μm, and 127 μm. All measurements are taken at the middle center plane of the layers using a microscope with an uncertainty of 0.1 μm. Fig. 6 illustrates dimensional parameters of a single bump.

Table 2. Measurements of bump strip layer nominal dimensions

Bump strip layer No.	#1	#2	#3
Foil thickness (t_b), μm	76.2	101.6	127
Bump pitch (s_o), mm	3.499	3.507	3.504
Bump height (h_b), mm	0.387	0.416	0.411
Bump half length (l_o), mm	1.553	1.582	1.518
Bump arc angle (α), rad	1.464	1.541	1.585

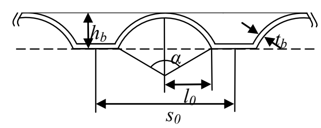

Fig. 6. Geometry of a single bump

Tool Manufacturing

Ten locking screws affix an upper (lower) bump forming die to an upper (lower) die bed, each fabricated from SAE A-2 tool steel and cut by wire EDM. Both dies were commercially procured.

The bump foil strip forming tool consists of the upper and lower dies, facing each other, secured by two alignment pins that restrict unwanted motions. A 28 mm (width) x 100 mm (length) stainless steel foil sheet is placed atop the lower die, and the upper die is fastened on top.

The die beds are made of 1020 steel for machineability. A ~12" piece of bar stock is cut with a horizontal band saw into two 5.2" segments, which are then faced with a manually operated Bridgeport knee mill down to the specified dimensions (2.576" x 5.118" x 0.984" +/- 0.005"). The forming piece pockets and alignment holes are cut with a CNC mil (Haas VF1B vertical machining center with 0.002 mm repeatability) programmed using FeatureCAM (ver. 14.0.1.62, 2007). The locking screw holes are drilled using the quill feed on a Bridgeport mill and hand tapped.

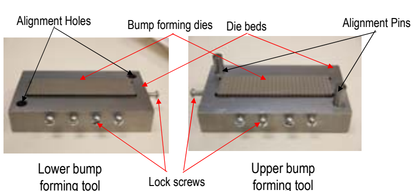

Fig. 2. Photographs of upper and lower dies of bump foil strip forming tool

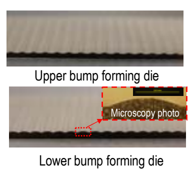

Fig. 3. Photographs of wire EDM upper and lower forming dies

Bump stiffness measurements and comparison to predictions

Fig.7 shows a test setup to measure an imposed displacement (deflection) on a bump strip layer secured in between two solid metal block fixtures and the reaction force with a dynamometer contacting the upper block. Two eddy current sensors measure the upper block displacement. Only 11 bumps from the foil strip are in contact with the metal blocks. A preload of 67 N makes all bumps contact both the upper and lower blocks. Measurements are conducted for five static loading / unloading cycle. Fig. 8 shows the static load versus deflection test data for three bump strip layers (foil thickness: 76.2 μm, 101.6 μm, 127 μm).

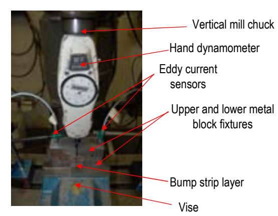

Fig. 7. Test rig for determining static stiffness of sample bump foils.

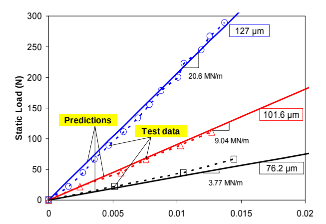

Fig. 8. Static force versus deflection for three bump strip layers with foil thickness 76.2 μm (3 mil), 101.6 μm (4 mil), and 127 μm (5 mil). Test data compared to model predictions using a dry-friction coefficient of 0.15

Fig. 8 shows the test data – average of five measurements - during static loading tests and predictions from a single free-free ends bump stiffness model [3] which takes a constant bump pitch (s_o), half-length (l_o). and height (h_b). The recorded static load increases linearly with deflection and is proportional to the thickness[3] of the bump strip layer, i.e. $W \sim t_b^3$. In general, test data are in good agreement with predictions, thus validating the simple bump stiffness model [3] widely used in the open literature.

Production of bump strip layers

A hydraulic hand press machine (Fig. 4) imposes compression forces on the bump forming tool which holds a precut 301 stainless steel foil, as shown in Fig. 5. The applied compression force varies from 5 tons to 10 tons depending on the foil thicknesses: 76.2 μm, 101.6 μm and 127 μm.

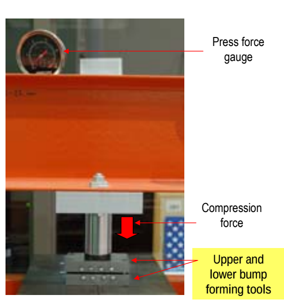

Fig. 4. Bump forming tools installed on hydraulic press machine

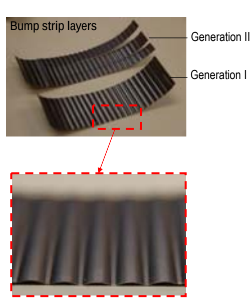

Fig. 5. Productions of generation I and II bump strip layers

Conclusions

A tooling set for manufacturing bump foil strip layers was constructed. With a hydraulic press the tool was used to make strip layers with foil thickness of 76.2 μm, 101.6 μm, and 127 μm. Examination with a microscope shows the relevant dimensions of the bumps with 0.1 um uncertainty. Static load versus bump strip layer deformation aid to determine the bump layer stiffness with excellent correlation to predictions based on elasticity formulas.

Close inspection reveals that the middle plane and central regions of the bump strip layers are better formed than those at the edge regions. The acting pressure is not uniformly distributed over the contact area since the press ram-forming tool surface is smaller than the contact pressure area . Hence, a middle insert section with one side fitting the hydraulic arm and the other enclosing the tool size is recommended to transmit a uniform pressure, thus ensuring all bumps are formed evenly.

Acknowledgement

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