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 taken. 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.

### 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 are 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 22 mm (width) × 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 machinability. A 12.5" piece of bar stock is cut out with a horizontal band saw into 5.2" segments, which are then faced with a manually operated Bridgeport knee mill for a consistent thickness. The forming piece pockets and align alignment holes are cut with a CNC mill (Haas VF-15 vertical machining center with 0.002 mm repeatability) programmed using FeatureCAM (ver. 14.0.1.02, 2007). The locking screw holes are drilled using the quill feed on a Bridgeport mill and hand tapped.

### 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.

### Bump foil nominal dimensions

<table>
<thead>
<tr>
<th>Table 2. Measurements of bump strip layer nominal dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bump strip layer No. 1</td>
</tr>
<tr>
<td>Foil thickness (t), µm</td>
</tr>
<tr>
<td>Bump pitch (s), mm</td>
</tr>
<tr>
<td>Bump half-length (l), mm</td>
</tr>
<tr>
<td>Bump half-length (h), mm</td>
</tr>
<tr>
<td>Bump arc length (s0), rad</td>
</tr>
</tbody>
</table>

### Tooling set manufacturing

Photographs of upper and lower dies of bump foil strip forming tool are shown in Fig. 2. Photographs of wire EDM forming dies are shown in Fig. 3. Photographs of upper and lower dies are shown in Fig. 4. Bump forming tools installed on hydraulic press machine are shown in Fig. 5. Bump stiffness measurements and comparison to predictions

### 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). Test data compared to model predictions using a dry-friction coefficient of 0.15.

### 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 providing a middle plane with adequate pressure.

### Table 1. Dimensions of formed bump

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bump pitch</td>
<td>3.5 +/- 0.01</td>
<td>±0.01</td>
</tr>
<tr>
<td>Bump half-length</td>
<td>1.5 +/- 0.01</td>
<td>±0.01</td>
</tr>
<tr>
<td>Bump height</td>
<td>0.4 +/- 0.01</td>
<td>±0.01</td>
</tr>
<tr>
<td>Forming die length</td>
<td>100 +/- 0.1</td>
<td>±0.1</td>
</tr>
<tr>
<td>Forming die height</td>
<td>12 +/- 0.1</td>
<td>±0.1</td>
</tr>
<tr>
<td>Forming die width</td>
<td>28 +/- 0.1</td>
<td>±0.1</td>
</tr>
<tr>
<td>Bump arc-length, rad</td>
<td>1.56</td>
<td></td>
</tr>
</tbody>
</table>

### References


Acknowledgement

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