Gyroid lattice for 3D printed pad of Tilting Pad Journal Bearings

Ludovico DASSI, Steven CHATTERTON and Paolo PENNACCHI

Hydrodynamic journal bearings are essential power transmission elements for industrial rotating machineries. Continuously growing of specific power allows more compact and efficient machines, to be obtained by reducing the environmental footprint of production plants. The aim of the work is to design an innovative pad for Tilting Pad Journal Bearings with an embedded cooling circuit to limit the oil-film temperature. Heat exchange has been relevantly increased using bioinspired gyroid lattice. The complete thermo-mechanical study is performed with numerical and experimental analysis. Such a complicated geometry has been manufactured by Bound metal deposition, an innovative Metal 3D printing technology.

Keywords: *tilting-pad journal bearings, Gyroid structure, 3D Bound metal deposition*

1. Introduction

Fluid film bearings are standard equipment for supporting large shaft lines of industrial machineries. This technology relies on hydrodynamic lubrication principle which guarantees low friction and higher stability with respect to other solutions.

The behavior of the lubricant film is strongly influenced by local temperature field. Frictional heat is generated by shear stress in the oil film and this reduces lubricant density and viscosity with detrimental effects on bearing performances. Moreover, coating materials, like Babbitt metal, generally have a limited melting point, so the temperature field has to be carefully controlled to avoid damages.

Generally, cooling is performed by injection of cold oil at pad leading edge but a more efficient solution consist in the internal cooling of pads [1].

The aim of this paper is to develop an improved layout of internal circuit, taking the advantages of pioneering gyroid lattice structures that have high mechanical resistance and increased heat exchange properties.

The proposed cooling circuit is characterized by a suitable path that covers uniformly the sliding surface; the lattice geometry allows to increase the surface/volume ratio enhancing the heat convection term.

Gyroid lattice is a very complex 3D shape and standard machining techniques are not able to produce it. Metal 3D printing technology is a convenient solution for manufacturing of the pad and, in particular, Bound Metal deposition simplifies the task. Basically, the production is performed in three steps. The first one is a filament extrusion printing of metal powder bonded with polymer and wax (binder). Then, the chemical debinding is performed in a solvent bath and finally thermal debinding and sintering is done in a furnace.

2. Gyroid structures

Gyroid lattice is a bioinspired geometry in the nanoscale, studied the first time by Alan Schoen in 1970s. The structure is noticed in C.Rubi butterfly’s wings and it guarantees lightness and good mechanical performances [2]. From the mathematical point of view, gyroid belongs to the Triple Period Minimal Surface (TPMS), family of curves which minimize the surface energy for a given boundary. As a result lattice is characterized by smoothness with no edges or corners. The mathematical expression is reported as follows:

$$\varphi(x,y,z) = \cos(x)\sin(y) + \cos(y)\sin(z) + \cos(z)\sin(x) = 0 \qquad (1)$$

$$\varphi(x,y,z) = \cos(x)\sin(y) + \cos(y)\sin(z) + \cos(z)\sin(x) = 0$$

Once the minimal surface is defined, there are two possible ways to create gyroid structures, as shown in Fig. 1.

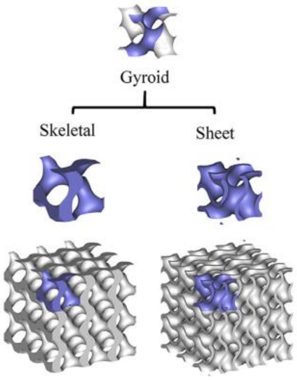

Fig. 1 Gyroid structures

The first one relies on the surface thickening and brings to *sheet based* TPMS structures. The surfaces facing towards the individual domains are offset in two directions perpendicular to the surface, creating a solid surface wall with a homogeneous thickness. The second way is obtained by solidifying one of the two volumes defined by the minimal surface, yielding to a *skeletal based* TPMS structure.

Relevant parameters to fully define gyroid shape are: lattice type (sheet or skeletal), unit cell length (edge of

---

L.Dassi, S.Chatterton and P.Pennacchi are with Dept. of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milan, ITALY, ludovico.dassi@polimi.it, steven.chatterton@polimi.it, paolo.pennacchi@polimi.it

the minimum repeatable cell), relative density (percentage of solid volume in an elementary cube) and external lattice dimensions (obtained by repetition in space of minimum cell).

3. Pad design

The fluid dynamics performances of the lattice are investigated, carrying out both numerical and experimental tests. Some cylindrical samples are considered to simplify the problem and a complete thermo-fluid dynamics analysis is performed to find the best trade off on performances (pressure drop and heat exchange) for pad application. A parametrical study is performed to directly match different lattice geometries and to study the effects of parameters settings (cell length, relative density, working fluid, flow rate and solid material).

Cell length is fixed to 8mm for printability limits, both solid and sheet types are considered, relative density is ranged between 15-45%, ISOVG68 oil and water are considered as working fluid, for the solid part steel or copper have been investigated.

The lattice type more suitable for the application is Sheet RD35% because it guarantees the highest heat exchange keeping the same pressure drop. The proposed cooling circuit is characterized by a suitable path that covers uniformly the sliding surface (M-shape serpentine), whereas the lattice geometry allows to increase the surface/volume ratio enhancing the heat convection term

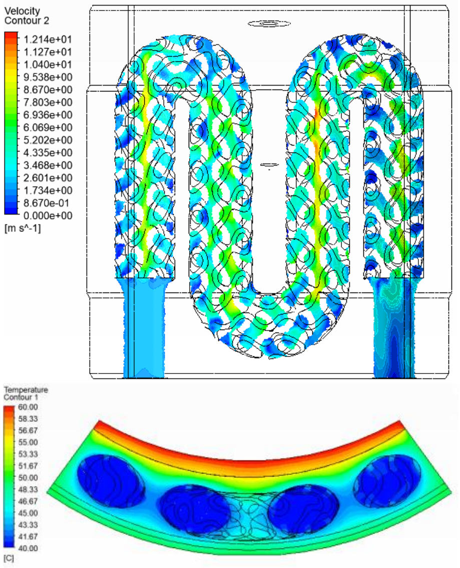

Fig. 2 Cross sections of sheet35 lattice

4. Results

Generally speaking, gyroid lattice is confirmed to be an effective solution to create compact heat exchangers. The numerical results show great opportunities but production process variability has to be taken in consideration. For pad application, main goal is to significantly increase the heat exchange while counter pressure is a soft constrain and it is chosen lower than 5 bars for technical simplicity. In the case of oil as cooling fluid, sheet lattice have better exchange than solid ones, Sheet 45 has excessively high pressure drops while Sheet 35 at 4L/min seems to be a good trade-off for the application (*Q: +65%, Δp :+705%* with respect to baseline, 6 channels with oil). Sheet 35 lattice is chosen and SS316L as material. Concerning the static mechanical analysis, the proposed solution guarantees at least the same stiffness of baseline layout and no stress intensification is visible inside lattice domain. The deformation field computed by numerical FEM analysis is shown in Fig. 3. The maximum deformation in micrometers of pad structure, under nominal load, are listed in Table 1.

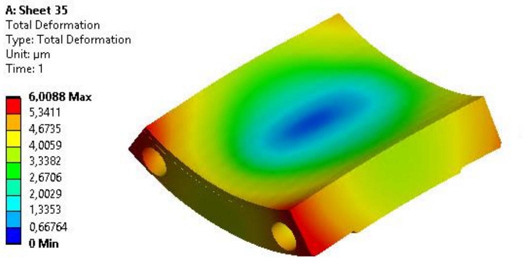

Fig. 3 Pad deformation

Table 1 Pad deformation

Internal Layout	Max deformation [µm]	[%]
6 Channels	6.77	-
Elliptical void	8.84	+30.6%
Sheet 35	6.00	-12.8%
Sheet 45	4.11	-68.5%
Solid 15	7.70	+13.7%
Solid 25	6.85	+1.2%
Solid 35	6.21	-3.5%
Solid 45	4.31	-71.8%

References

[1] P. Pennacchi, Introduction of advanced technologies for steam turbine bearings.

[2] W. Li, G. Yu and Z. Yu, "Bioinspired heat exchangers based on triply periodic minimal surfaces for supercritical Co2 cycles," Applied Thermal Engineering, 2020.

[3] Al-Ketan, R. Rezgui and R. Rowshan, "Microarchitected Stretching-Dominated mechanical metamaterials with Minimal Surface Topologies," Advanced Engineering Materials, 2018.

[4] O. Kwon, M. Choi and Y. Choi, "Heat transfer and pressure drop characteristics in zigzag channel angles of printed circuit heat exchangers," Korean J. Air Cond. Refrig. Eng., pp. 475-482, 2009.