Study of oscillating flows inside a reticular regenerator: impact of internal scale on the operating frequency

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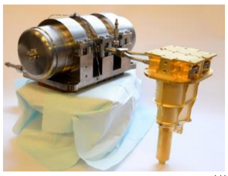
Context

- Cryogenic cooling for space IR sensors
- Low vibrations and high lifetime device

} **Pulse tube cryocooler (PTC)**



PTC 15K by Air Liquide(1)

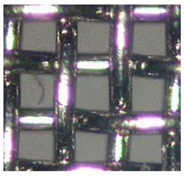
Cryogenic cooling:
⇒ Helium gas compression/expansion cycles
⇒ Oscillating flow

Objective: miniaturization
⇒ Smaller device and same performances

Miniaturization of the regenerator

Regenerator

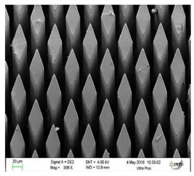
Thermal sponge ⇒ heart of the PTC



Metal grid(2)

- Commonly used
- Disadvantage: miniaturization limits

➡ New geometry



Diamond-shaped pillars(3)

- Control of porosity
- Ordered structure
- Silicium (Si) etching: DRIE

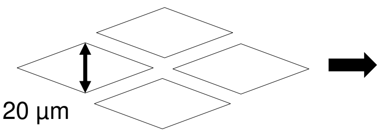
⬅ **Oscillating flow study**

Making of reticular microregenerators

Properties

- Length: 20 mm
- Width: 4 mm
- Height: ~300 µm
- Pillar's width: 20 µm

- Staggered diamond-shaped pillars
  ⇒ Better compromise between pressure drop and heat transfers



Microfabrication steps

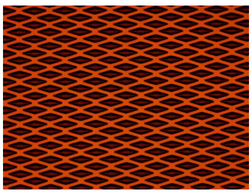
1: Resin spreading on Si

2: Insolation UV rays

3: Chemical developpement of insolated resin

4: Silicium etching with DRIE technique

5: Si-Pyrex sealing



Lithography pattern with a 33° angle and 40% of porosity

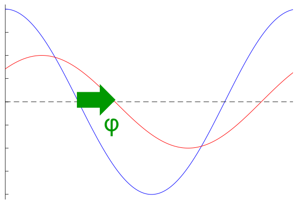
Hydrodynamic performances for an oscillating flow

Definition of oscillating flow

Pressure drop ΔP and mean velocity u:
⇒ Sinusoidal signals

$$\Delta P(t) = \Delta\tilde{P}.\cos(\omega t)$$

$$u(t) = \tilde{u}.\cos(\omega t - \varphi)$$



φ: phase lag between pressure drop and velocity

Dimensionless numbers

- Maximum Reynolds number Re_{max}:

$$Re_{max} = \frac{\tilde{u}.D_h}{\nu}$$

- Valensi number Va:

$$Va = \frac{\omega.{D_h}^2}{\nu}$$

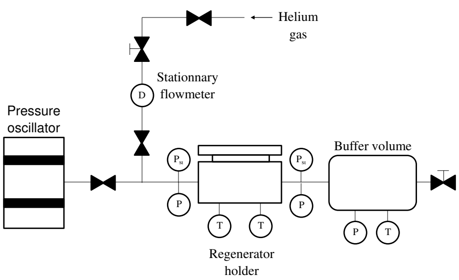
- Darcy's friction factor f:

$$f = \frac{D_h}{L} \times \frac{\Delta\tilde{P}}{\frac{1}{2}\rho.\tilde{u}^2} \times \cos(\varphi)$$

***f* is a function of Re_{max} and Va**

Oscillating flow test bench

Pressure drop test bench



- Stationnary/oscillating flow test bench
- Friction factor: Measurement of pressure drop and flowrate

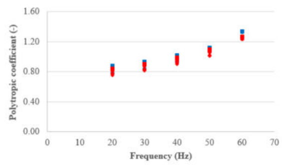
⇒ **No commercial flowmeter for oscillating flows**

Flowmeter test bench

Picture of flowmeter test bench

- Use of buffer volume
- Compression/expansion cycles
  ⇒ Determination of polytropic coefficient ξ

$$\xi = \frac{\ln\left(1 + \frac{\tilde{P}}{P_0}\right)}{\ln\left(\frac{V_0}{V_0 - \tilde{V}}\right)}$$



Conclusion

- Si etching : good method for miniaturization
- New definition of friction factor:
  ⇒ One more dimensionless number than stationnary flow: Valensi number

Future work

- Use of pressure drop test bench for friction factor measurement
- CFD simulation with OpenFOAM

References

(1) : https://www.d-sbt.fr/Pages/LCCS/Tubes-a-gaz-pulse.aspx
(2) : Choi, S.; Nam, K.; Jeong, S. Investigation on the pressure drop characteristics of cryocooler regenerators under oscillating flow and pulsating pressure conditions. *Cryogenics* **2004**, *44* (3), 203–210. https://doi.org/10.1016/j.cryogenics.2003.11.006.
(3) : Sochinskii, Arkadii. 2018. « *Premier pas vers la miniaturisation des cryoréfrigérateurs spatiaux* ».