

# An Integrated Multiwatt Permanent Magnet Turbine Generator

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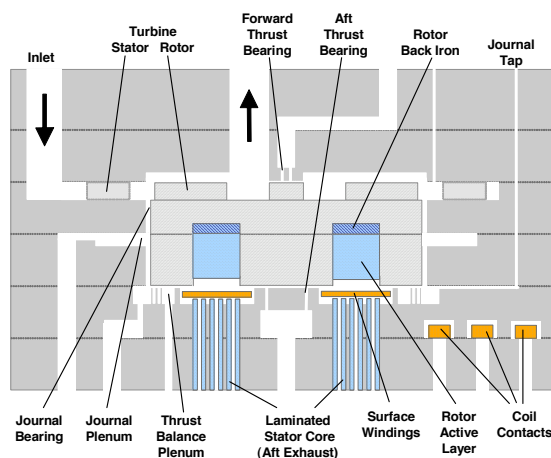
Sponsorship: ARL Collaborative Technology Alliance

There is a need for compact, high-performance power sources that can outperform the energy density of modern batteries for use in portable electronics, autonomous sensors, robotics, and other applications. Previous research efforts on a micro-scale, axial-flux, permanent-magnet turbine generator [1-2] culminated in a spinning rotor test stand that delivered 8 W DC output power through a diode bridge rectifier with an overall generator system efficiency of 26.6%. In these experiments, the generator rotor was mounted via a steel shaft to an air-driven, ball-bearing supported spindle and spun to the desired operational speed.

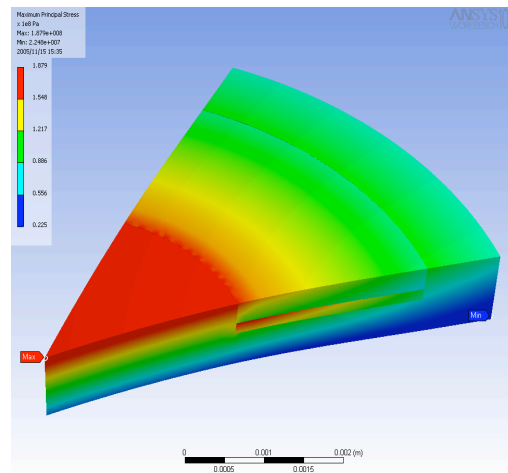
Current research efforts aim to fully integrate the permanent-magnet (PM) generator design into the silicon micro-turbine engine fabrication process and create devices that can deliver 10 W DC output power when driven by compressed air. The integrated generator will couple energy from the compressed air to the rotor through microfabricated turbine blades attached to the backside of the rotor. One important

challenge in this integration process is the structural integrity of the magnetic rotor spinning at a tip speed near 300 m/s, or equivalently 450 krpm.

Based on power requirements, a 300- $\mu\text{m}$  thick circular NdFeB PM with an inner radius of 2.5 mm and an outer radius of 5 mm must be embedded into the silicon rotor on top of a 150  $\mu\text{m}$  FeCoV back iron. FEA analysis shows that the maximum principle stress at 450 krpm in the silicon rotor, 900- $\mu\text{m}$  thick and 12 mm in diameter, with bonded annular PM and back iron pieces, will be approximately 180 MPa through the entire structure. This stress is well below the tensile strength of silicon and FeCoV. However, because the PM is brittle and has a typical tensile strength around 83 MPa, it is unclear whether the material will fracture. Tests are currently underway to characterize the reference strength and Weibull modulus of the PM, and from these results, a working rotor design will be proposed.



▲ Figure 1: Conceptual schematic of the fully integrated surface-wound permanent magnet turbine generator. The bottom two wafers constitute the stator and coil winding of the generator while wafers 3, 4, and 5 form the magnetic rotor. A center-fed journal-bearing design is shown in the schematic, but an axial-fed design is also possible.



▲ Figure 2: An FEA simulation for the magnetic rotor structure spinning at 450 krpm. Because of the fully-bonded boundary conditions, most of the load is carried by the silicon hub. The maximum principal stresses in the silicon, PM, and back iron are 176.7 MPa, 188.0 MPa, and 184.5 MPa, respectively.

## REFERENCES

- [1] D.P. Arnold, et al., "High-speed characterization and mechanical modeling of micro-scale, axial-flux, permanent-magnet generators," in *Digest Tech. Papers Transducers '05 Conference*, Seoul, South Korea, June 10-14, 2005, pp. 284-287.
- [2] S. Das, "Magnetic machines and power electronics for power MEMS applications," Ph.D. thesis, Massachusetts Institute of Technology, Cambridge, MA, 2005.

