

## Multi-Watt Electric Power from a Microfabricated Permanent-Magnet Generator

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Presented here are the design, fabrication, and characterization of three-phase permanent magnet (PM) machines that convert 2.3 W of mechanical power and deliver 1.1 W of DC electrical power to a resistive load at a rotational speed of 120,000 rpm. Such microgenerators are an important system-level component of compact MEMS-based power sources, such as combustion-driven or air-driven microengines [1].

The generators are three-phase, eight-pole, synchronous machines, each consisting of a surface-wound stator (Figure 1) and a multi-poled PM rotor (Figure 2(a)). The stator uses three Cu windings that are dielectrically isolated from a 1-mm thick NiFeMo (Supermalloy) substrate by a 3  $\mu\text{m}$  spin-on-glass layer and/or 5  $\mu\text{m}$  polyimide layer. The coils were fabricated using a two-layer electroplating process [2]. They were measured to be 80-120  $\mu\text{m}$  thick and 50-550  $\mu\text{m}$  in width. The microfabricated coils, with their small inter-conductor gaps and variable width geometry, are the key for enabling high power output. The rotor contains an annular SmCo PM and a ferromagnetic FeCoV (Hiperco50) backiron, each 9.525

mm OD, 3.175 mm ID, and 500  $\mu\text{m}$  thick. The SmCo PM and FeCoV backirons were, then, assembled and glued into a pre-formed PMMA cup, which was fit onto a 1.6 mm shaft (Figure 2(b)).

For characterization, a high-speed spinning rotor test stand, incorporating an air-turbine driven spindle, was constructed. The stator was positioned under the rotor using an xyz-micropositioner, which permitted precise ( $\pm 5 \mu\text{m}$ ) adjustment of the air gap. A three-phase step-up transformer (1:6 turn ratio) and Schottky diode bridge were used to rectify the output voltage for DC power generation across a load resistor. The power data for the 2-turn/pole machine shows a quadratic dependence on speed for a fixed load (Figure 2(c)) and typical power transfer dependence for varying loads (Figure 2(d)), with a maximum demonstrated power of 1.1 W (2.9 MW/m<sup>3</sup> power density).

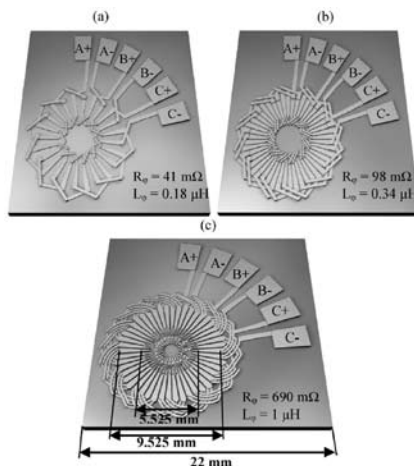


Figure 1: Conceptual drawings of (a) 1-turn/pole, (b) 2-turn/pole, and (c) 4-turn/pole surface wound stators. The measured phase resistance and inductance are indicated for each type.

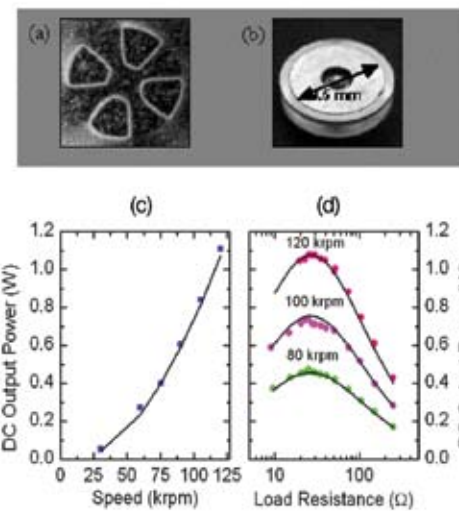


Figure 2: (a) Magnetic pole pattern using magnetic viewing paper and (b) 500  $\mu\text{m}$  thick PM rotor and backiron mounted onto shaft. DC output power across load resistor for 2-turn stator at 100  $\mu\text{m}$  air gap vs. (c) rotational speed for 30  $\Omega$  load and (d) load resistance at 80, 100, and 120 krpm.

### REFERENCES:

- [1] Jacobson, S.A., A.H. Epstein, "An Informal Survey of Power MEMS," *ISMME*, 2003.
- [2] Park, J.W., M.G. Allen, "Ultralow-Profile Micromachined Power Inductors with Highly Laminated Ni/Fe Cores: Application to Low-Megahertz DC-DC Converter," *IEEE Trans. Mag.*, vol. 39, pp. 3184-3186, 2003.