FE-03

Multiwatt Microscale Permanent-Magnet Generators Operating at High Temperatures.

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Recently there has been much work in the development of microscale mechanical-to-electrical generators as an essential component of heat-engine-driven electrical power sources for portable electronics. Although a number of small form-factor generator systems have been presented [1-4], less attention has been paid to their high temperature performance. We report microscale permanent-magnet generators delivering 8W of DC power to an external load at room temperature, dropping to 4W at an operating temperature of 200°C, demonstrating that permanent magnet microgenerators are a feasible approach to microscale heat-engine-driven mechanical-to-electrical power converters.

GENERATOR DESIGN

The generators are three-phase, eight-pole, synchronous machines, each consisting of copper stator windings with epoxy interlayer dielectric and a multi-poled permanent magnet rotor, operating at speeds of up to 300 krpm and powered by an external air-driven turbine. Ferromagnetic NiFeMo and FeCoV serve as back iron materials in the stator and rotor, respectively. As shown in Fig.1, high-speed rotors [1] and optimized stator winding geometry [2] were used for high-temperature experiments.

HIGH-TEMPERATURE TESING

In this application, operation temperature issues are exacerbated by the compact nature of these microsystems and the difficulties involved in maintaining large internal thermal gradients. SmCo and NdFeB rotors were tested. Although SmCo has a lower room temperature remanence, it possesses a much higher Curie temperature (Tc~800°C) and maximum operating temperature (Tmax~300°C) than NdFeB (Tc~300°C, Tmax~100°C). Remanence temperature dependence of rotor magnets in the size scales of interest were experimentally determined using a vibrating sample magnetometer. NdFeB cannot be used above approximately 100°C due to nearly complete remanence loss, while SmCo retains approximately 90% of its remanence up to 250°C. Winding resistances were also assessed as a function of temperature using a four-point measurement system. In first approximation, experimental data exhibit a linear dependence of copper winding resistance with temperature, approximately doubling between room temperature and 250°C.

POWER GENERATION

To test generators in operation, a custom 15 mm inner diameter 'oven' (300°C max) consisting of a coil inside a ceramic furnace tube was employed to selectively heat the stator and the rotor. Fig. 3 presents DC output power to an external load for a SmCo device as a function of speed and parameterized by operating temperature, showing an approximately 50% drop at 200°C (4 Watts of DC power capability across resistive load). Fig. 4 shows calculated DC output power to an external load at 300 krpm as a function of temperature for both SmCo and NdFeB rotors. SmCo appears the appropriate choice for multi-watt microgenerators tightly integrated with heat engines.

CONCLUSION

MEMS-based microgenerators capable of multi-watt power output over a wide range of temperature are feasible. Higher temperature testing and understanding of thermomechanical issues are underway.

ACKNOWLEDGEMENT

This project is supported in part by the Army Research Laboratory Collaborative Technology Alliance. The authors would like to thank Prof. J. Lang and Dr. S. Das of MIT for valuable technical discussion.
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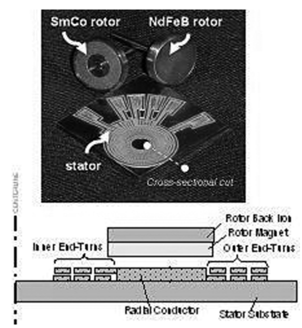
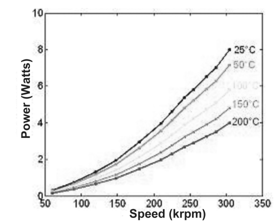
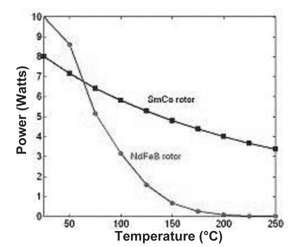


(a) Optimized winding geometry stator and rotors (b) Cross-sectional schematics.



Output DC power delivered to external load as a function of speed parameterized by temperature for a SmCo rotor



Output DC power as a function of temperature at 300 krpm