
Micro Electric Machines for Micro Turbomachinery

Personnel

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Sponsorship

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This project is part of the MIT Micro Gas Turbine Engine Project. The MIT Micro Gas Turbine Engine Project has the goal of using MEMS fabrication technologies to construct compact electric power generation systems from a gas turbine generator comprising a compressor, combustor, turbine and electric generator. Another system under development is a stand-alone turbine/generator. The MIT Micro Gas Turbine Engine Project is highly interdisciplinary, involving students, staff and faculty from several academic departments and laboratories.

This project seeks to develop the motors and generators employed in the micro turbomachines mentioned above, and to develop their power and control electronics. Following the analysis of several candidate machine types, the electric induction machine was selected for these applications. This electric machine is a disk-shaped axial-field machine, and is shown in edge view in Figure 22. On one side of its air gap, platinum stator electrodes are supported by a thick silicon-dioxide insulator buried in a substrate. The electrodes are connected to form one or more phases, and are excited so as to impose a potential wave which travels around the stator. On the other side of the air gap is the rotor, which rotates as a disk. The rotor consists of a conducting polysilicon film supported by a silicon-dioxide insulator buried in a substrate. Photographs of an actual stator and rotor are shown in Figure 23.

During motoring operation, the power electronics excite the stator electrodes to produce a potential wave which travels around the stator with a speed exceeding that of the rotor. This wave, and the corresponding charges which reside on the stator electrodes, induce image charges on the rotor surface across the air gap. Since the speed of the traveling potential wave exceeds the mechanical speed of the rotor, convection alone cannot synchronize the rotor charges with the traveling wave, as must happen in steady state. Thus, the rotor charges must conduct through the rotor film to maintain synchronism.

The conduction process must in turn be driven by a tangential electric field, and so the rotor charges lag behind the potential wave to produce that field, as shown in Figure A. Finally, the tangential electric field acts on the rotor charges to impart a tangential surface stress on the rotor, which in turn results in a motoring torque. During generating operation, the rotor speed exceeds that of the traveling potential wave, and the torque is reversed.

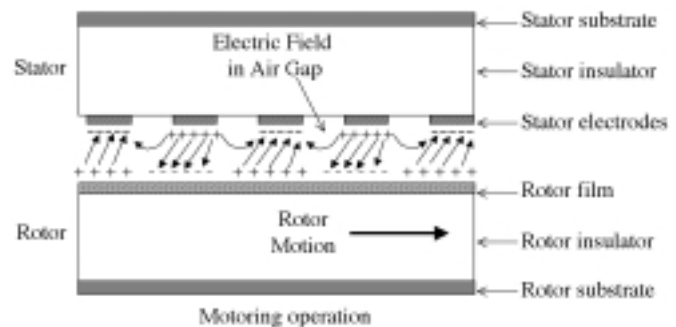


Fig. 22: An expanded view of a tethered micro magnetic induction motor showing the rotor above and the stator below.

Detailed models of the electric induction machine have been developed and used to design an optimized 6-phase machine having a 4-mm diameter. As a motor, this machine is expected to produce a 3-W mechanical output at 2.4 Mrpm when its phases are excited with 300-V 3-MHz sinusoids. Operated as a generator, this machine is expected to output 0.5 W at 300 V and 1.5 MHz. An initial set of motor/generator devices have been built; these machines incorporate electrical elements on one face of the spinning rotor disk and micro machined turbine blades on the other side. Because these devices are intended to operate as both motors and generators, it is critical to design the device structure and fabrication flow to minimize electrical losses in operation. To minimize electrical losses, the stator's interconnected electrode structure must be fabricated of a low resistivity metal. Because the stator must survive high temperatures during both fabrication and operation, it employs a two-level platinum structure with deposited oxides for the interlayer dielectric.

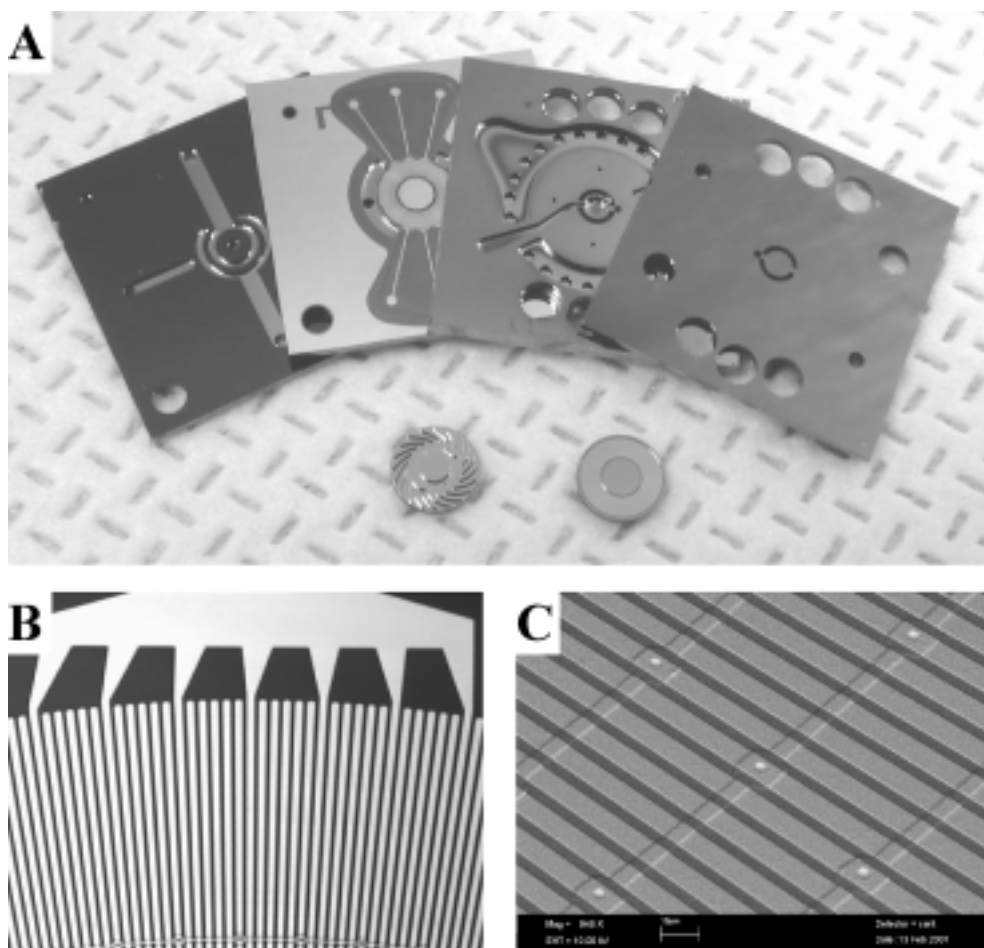


Fig. 23: A) Photograph of die levels from the motor/generator. The outer levels are for fluid handling. The second level from the left is the electrical stator. The second level from the right houses the spinning rotor. The rotor's electrical elements and etched turbine blades are shown below. B) Close-up photograph of the electrical stator, showing how an electrical lead connects to every sixth electrode to create a six phase machine. C) SEM micrograph of the electrical stator, showing the electrodes and interconnection rings that group every sixth electrode together.

To date, our micro electric induction machines have been tested as torque metrology devices and as spinning micromotors at partial stator excitation voltage. Figure 24 shows the motor's power and torque measured as a function of stator excitation frequency at a fixed stator excitation voltage of 45 V peak. Figure 25 shows the motor power and torque measured as a function of stator excitation voltage at a constant excitation

frequency of 200 kHz. The data show good agreement with the model, suggesting that the devices will achieve the target power levels at full voltage and frequency. Our work now focuses on the fabrication and demonstration of microgenerators to be mounted on the compressor shroud of the micro gas turbine engine; demonstration is expected this year.

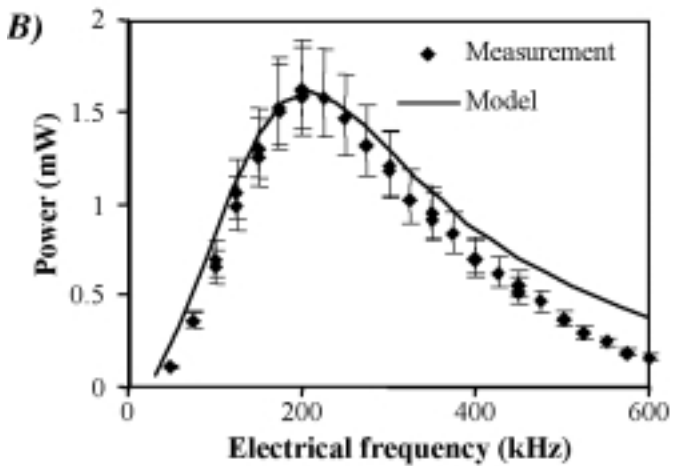
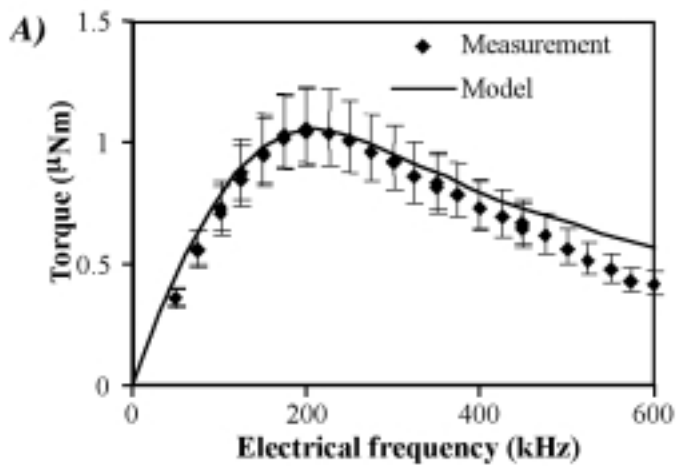


Fig. 24: A) Measured motor torque and B) measured motor power as a function of electrical excitation frequency at a fixed stator excitation voltage of 45 V.

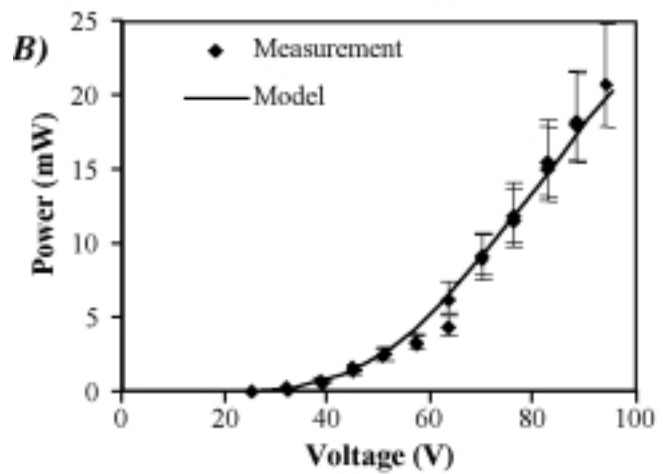
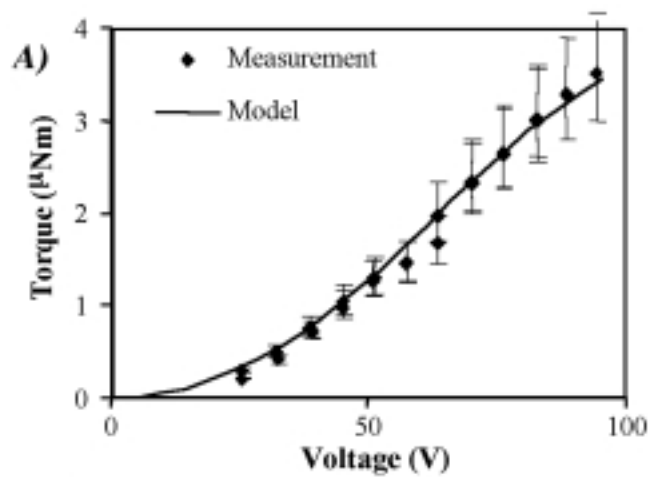


Fig. 25: A) Measured motor torque and B) measured motor power as a function of stator excitation voltage at a fixed stator excitation frequency of 200 kHz.