NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NO. NAS 7−918

TECHNICAL SUPPORT PACKAGE

On

MINIATURE GAS−TURBINE POWER GENERATOR

for 01/01/2003

NASA TECH BRIEF Vol. 27, No. 1

from

JPL NEW TECHNOLOGY REPORT NPO− 20933

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pp. i, 1−2

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01/01/2003

Miniature Gas-Turbine Power Generator

Energy density would greatly exceed that of a typical battery system.

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A proposed microelectromechanical system (MEMS) containing a closed-Brayton-cycle turbine would serve as a prototype of electric-power generators for special applications in which high energy densities are required and in which, heretofore, batteries have been used. The system would have a volume of about 6 cm^3 and would operate with a thermal efficiency >30 percent, generating up to 50 W of electrical power. The energy density of the proposed system would be about 10 times that of the best battery-based systems now available, and, as such, would be comparable to that of a fuel cell.

The working gas for the turbine would be Xe containing small quantities of CO_2, O_2, and H_2O as gaseous lubricants. The gas would be contained in an enclosed circulation system, within which the pressure would typically range between 5 and 50 atm (between 0.5 and 5 MPa). The heat for the Brayton cycle could be supplied by any of a number of sources, including a solar concentrator or a combustor burning a hydrocarbon or other fuel. The system would include novel heat-transfer and heat-management components. The turbine would be connected to an electric power generator/starter motor.

The system would include a main rotor shaft with gas bearings; the bearing surfaces would be made of a ceramic material coated with nanocrystalline diamond. The shaft could withstand speed of 400,000 rpm or perhaps more, with bearing-wear rates less than $10^{-4}\times$ those of silicon bearings and 0.05 to 0.1× those of SiC bearings, and with a coefficient of friction about 0.1× that of Si or SiC bearings. The components of the system would be fabricated by a combination of (1) three-dimensional x-ray lithography and (2) highly precise injection molding of diamond-compatible metals and ceramic materials. The materials and fabrication techniques would be suitable for mass production.

The disadvantages of the proposed system are that unlike a battery-based system, it could generate a perceptible amount of sound, and, if it were to burn fuel, then it would also generate exhaust, similarly to other combustion-based power sources.

This work was done by Dean Wiberg, Stephen Vargo, Victor White, and Kirill Shcheglov of Caltech and Philip Muntz of the University of Southern California for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Machinery/Automation category.*

NPO-20933

PLEASE BE AS CLEAR AND SPECIFIC AS POSSIBLE, AS THIS REPORT MAY BE MADE AVAILABLE THROUGH TECH BRIEFS

Sections 1 (Novelty), 2A (Problem), and 2B (Solution) must be completed fully. Your published paper may be attached to satisfy Section 2C (Description and Explanation).

1. Novelty - Describe what is new and different about your work and its improvements over the prior art.
The device is a wide temperature range microelectromechanical system (MEMS) power source capable of generating up to 50 W of electrical power with a thermal efficiency of greater than 30% and a volume of about 6 cubic centimeters. The main innovations of this device include: Utilization of a unique, closed Brayton cycle gas turbine system energized by any of a number of suitable heat sources including solar; the system operates in an isolated environment at an elevated ambient pressure level of typically 5-50 atm. The working gas is Xe containing small quantities of CO_2, O_2 and H_2O as added gaseous lubricants. The proposed system includes a brushless electric power generator/starter motor and will have a thermal efficiency greater than 30%. · Incorporation of a main rotor shaft with Argonne nanocrystalline diamond (ANCD) coated gas bearings capable of operating up to at least 400,000 RPM, with wear rates 10,000 times lower than that of Si and 20-100 times lower than that of SiC, and with a coefficient of friction ten times lower than that of Si and SiC. · Deployment of novel thermal management and heat transfer elements in a MEMS scale system, to enable operation of a high specific energy MEMS device requiring a wide temperature range without significant thermal interference with co-located MEMS components. · Fabrication using 3-D LIGA and injection molding techniques to produce optimized turbines, compressors and other flow components via high precision molds filled with diamond-compatible metals and ceramic materials suitable for mass production.
2. Technical Disclosure

   A. Problem - Motivation that led to development or problem that was solved.
   The problem is to develop a miniaturized electric power generator system capable of high energy density in a very small volume. Such a device should have substantially better energy density than conventional storage batteries.

   B. Solution
   A small turbine engine capable of generating electrical or shaft energy was identified as the solution. Combustion of hydrocarbon fuels provides for an energy density approximately 10 times greater than can be achieved with electrochemical storage devices. Sizing of the fuel tanks or replenishment of fuel in smaller tanks allow satisfaction of long duration requirements.

   C. Detailed Description and Explanation
   See section 1 above and figure 1 for description and explanation

   Figure 1. MEMS based turbine design with heat recuperation (cross-section through axis of rotation)
   (Figure 1 on attached page)

The figure shows a radial inflow turbine 4 mm across made from silicon, using deep reactive ion etching [HN5], a relatively new fabrication method. With minor changes in the airfoil shapes, the same device will function as a centrifugal compressor. Calculations show that such a turbine driving an electrostatic induction generator of similar size will supply tens of watts of continuous electric power. When made of refractory material, like silicon carbide, and combined with the compressor and combustor, a complete gas-turbine generator of under 1 cm^3 can be realized delivering as much as 50 W of electric power, or 0.2 N of thrust. The energy density of hydrocarbon fuels is so high that an equivalent mass in this technology can deliver 10 to 30 times the energy of even the most advanced battery materials.

Figure 1

1 **The little engine that could.** Electron micrograph of a 4-mm-diameter silicon microturbine. [C. C. Lin and M. A. Schmidt]

There is also a remarkable benefit that derives from the cube-square law: If the power per unit airflow remains constant, then, because the airflow scales with the square of a linear dimension whereas the mass scales with the cube, the power-to-weight ratio would increase linearly as the size is reduced. Detailed calculations indicate that the scaling is not quite this dramatic, but a millimeter-size engine would have a thrust-to-weight ratio of about 100:1, compared to 10:1 for the best modern aircraft engines. This level of performance may have profound implications for flight vehicles. Of course, unless large arrays of such microdevices are used, vehicle masses would have to be constrained to a few tens of grams. This is a little small for most passengers, but there is now serious interest in sensor-laden microairplanes (11) [HN6]. And, as an astute child of one of the authors recently noted, 1400 of them working in parallel could levitate his skateboard.

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“The work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.”