Pint-Sized Engine Packs a Bundle of Energy
Carlos Fernandez-Pello’s tiny engine uses computer chip technology to generate power.
Two years ago, when Berkeley mechanical engineering professor Carlos Fernandez-Pello first suggested building an internal combustion engine smaller than a millimeter in size, his colleagues said it could not be done. Now, as Fernandez-Pello tests a working engine the size of a penny—an intermediate step toward the even smaller micro-engine he envisions—his colleagues have admitted how wrong they were. These days, even his critics talk about how best to use a micro-engine in everything from remote sensors to minirovers. And they have begun to realize just how much the tiny engines could change the way they think about power, engines, and batteries.

This potential revolution began brewing after a lecture by Berkeley mechanical engineering/electrical and computer sciences professor Albert Pisano, then on leave from Berkeley to work as a program manager at DARPA (Defense Advanced Research Projects Agency). Pisano’s lecture on the importance of MEMS (microelectromechanical systems) research inspired Fernandez-Pello to begin thinking about using the miniaturized computer chip-making technology to generate power. As electronic and mechanical systems have diminished in size, their energy requirements have been similarly reduced. Batteries meet those power needs, but they tend to be big and bulky. Could micro-engines actually replace batteries and provide the milliwatts of power needed by MEMS-style minirovers and sensors?

“Micro-engines are not for packing a lot of energy in a small volume,” says Pisano, whose area of expertise on this project is the design and fabrication of the engines, down to the micro-scale. “Their liquid hydrocarbon fuels, like butane, kerosene, or propane, pack at least 10 times more energy, pound for pound, than batteries do, even after taking into account how inefficiently an engine burns fuel,” he says. That means, according to Pisano, that an engine could be 10 times smaller than a battery and still deliver the same amount of energy. Or, he adds, it could be the same size as a battery and last 10 times longer.

The micro-engine Fernandez-Pello decided to build was a Wankel engine, a tiny version of the rotary engine Mazda once trumpeted in its cars. At the heart of the Wankel engine is a triangular rotor that both spins and precesses—the point about which it spins also moves in a circle. As the rotor turns, its three corners stay in constant contact with the walls of the strangely shaped combustion chamber. This causes the pocket between each side of the rotor and the chamber walls to change in volume as the rotor turns, compressing and expanding an air-fuel mixture in the pocket like pistons in a regular piston engine.

“It’s very simple,” Fernandez-Pello notes, “because it has only one hole in and one hole out—the intake and outtake ports.” The Wankel engine has no valves that open or close, and no moving parts beyond the rotor. The revolving rotor acts like both a valve and piston, controlling the pocket’s intake, compression, expansion, and exhaust. The Wankel engine is also relatively flat, crucial because MEMS technology is essentially planar. Everything fits on a chip.

But would a micro-Wankel engine work? About two years ago when Fernandez-Pello came up with the notion to give it a try, the smallest internal combustion engines were those used in model airplanes, no more than two inches across. Conventional wisdom held that combustion could not be sustained in anything smaller. The reaction, it was widely believed, would be quickly quenched or put out as the burning gas touched the cool walls of the combustion chamber. Since the ratio of surface area to volume increases as devices shrink, there is proportionately more wall surface to cool the burning gas in smaller engines, and any combustion would therefore be quickly extinguished. Fernandez-Pello, the project’s principal investigator in charge of all aspects of combustion on a micro-scale, argued that if you could somehow warm the walls, quenching would no longer be a problem. “Pello’s a brave guy,” Pisano says. “He put his neck on the line.” Fernandez-Pello was able to show experimentally that there were several ways to warm the walls by tracking engines so they heat each other, or by recycling exhaust. He proved that sustained combustion was possible on scales 10 to 20 times smaller than the experts had thought.

Teaming up with Pisano (who now holds the prestigious FANUC Chair of Mechanical Systems and is director of the Electronics Research Laboratory), and Berkeley bioengineering/mechanical engineering professor and micro-fluidics expert Dorian Liepmann, the team set out to build a prototype micro-engine.

They decided to split the three-year, DARPA-funded project into two phases. They would begin by building a micro-engine no bigger than a penny. This intermediate step would allow them to learn about and solve the problems sure to arise in shrinking a Wankel engine. Then, later, when they knew what better they were dealing with, they would reduce the size of the engine even more. Their eventual goal was to build a micro-engine smaller than a millimeter square.

In building the mini-engine, the team found that they had to design not only the engine, but all the peripheral equipment, from small-scale dynamometers, clutches, and ignition systems, to test machines. “On the one hand, all this has created more problems that we have to solve,” Fernandez-Pello notes. “On the other hand, we are developing a new field.”

The penny-sized mini-engine, fabricated out of metal in the mechanical engineering department’s machine shop, now runs under its own power. “We’re getting some energy out,” Pisano says. “And we’re working on improving the engine efficiency.” Initially, the team used a hydrogen and oxygen fuel mixture because it was easier to ignite. Now they are switching to hydrocarbon fuels, which are easier to handle. And they are tinkering with the ignition timing and rotor sealing, among other things, trying to optimize the workings of the mini-engine.

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By Sally Stephens

Tiny engine could revolutionize today’s notion of power, engines, and batteries

B y B a r b a r a S t e f a n o s

This tiny engine could revolutionize today’s notion of power, engines, and batteries.
Imagine a world where every light bulb has its own micro-engine as a power source, making power cords a thing of the past. "If you're talking about power per pound of fuel," says Pisano, "fuel inefficiently burned still whomps the daylights out of batteries." Because of this, micro-engines should prove particularly effective anywhere you need small, long-lasting power sources, such as in satellites, or for remote or autonomous systems or sensors.

In addition to their miniature size and large energy potential, micro-engines should be relatively inexpensive. "MEMS is based on the fabrication techniques of the computer chip industry," Fernandez-Pello explains. "The idea is to have a sensor, engine, and a controlling microprocessor manufactured simultaneously on the same chip," he says. If micro-engines could be mass-produced like computer chips, their costs should remain relatively low, according to Fernandez-Pello. And that, in turn, could influence the way micro-engines are used. The military already has an eye on using micro-engines to power mini-sensors able to sniff out biological weapons in battle zones. If the micro-engine-powered mini-sensors are relatively cheap, the military could drop large numbers onto an area before troops arrive. The sheer numbers of sensors dropped would ensure that enough survive to send back useful, and potentially life-saving, information.

Other applications involve using the torque generated by the micro-engine's moving rotor to turn the wheels or engine blades of micro-rovers or mini-airplanes. Perhaps one day, says Fernandez-Pello, every soldier will carry a small personal reconnaissance device (a mini-rover or mini-airplane), packed with sensors and powered by micro-engines.

Beyond a wide range of military applications are those that would affect most anyone's daily life. Pisano imagines a day when micro-engines could replace batteries in devices like laptop computers or cellular phones. "If my laptop runs out of battery power, I could recharge only every 45 days," he says. "The long life of hydrocarbon-fueled micro-engines makes that a possibility. Plus a micro-engine power pack would probably be much cheaper and lighter than today's batteries. This game is all about price and power-per-pound," says Pisano. "And that's the micro-Wankel game."

Ultimately, says Pisano, micro-engines could affect how we think about power. Today, an enormous electrical infrastructure is already in place, able to power household appliances from lamps to thermostats. At the same time, ongoing advances in electronics mean these devices require less and less energy. "Much of the cost of these appliances goes into the heavy-duty infrastructure required to bring energy to them. But as their energy consumption comes down, that infrastructure becomes unnecessarily expensive," Pisano notes. "That's where a portable, self-contained energy source suddenly makes financial sense." That is just the kind of low-power energy source micro-engines could provide. Pisano envisions a world where every light bulb has its own micro-engine as a power source, making power cords a thing of the past. "If I want lights in my backyard," says Pisano, "I'll just stick a few light bulbs on stakes wherever I need them and turn them on." Cheap, micro-engine-powered thermostats could be taped to the wall, communicating via radio with the furnace. "When their fuel runs low, the entire thermostat could be replaced," says Pisano. "These are the sorts of changes you'll start seeing if micro power sources are there."

But the first order of business is to get a micro-engine up and running, an accomplishment the team thinks could happen within the next five years. "Even then," says Liepmann, "a huge amount of research and development remains to be done before the micro-engine is ready to go to market." One remaining concern is the exhaust. The by-products of combustion are water and carbon dioxide. "But our engine is so small," says Fernandez-Pello. "And there is so little burning that very little comes out, even less carbon dioxide than we exhale."

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