SCIENCE

World's smallest windmills to power cell phones

By Brian Dodson
January 13, 2014

12 Comments
3 Pictures

1.8 mm-wide windmill on a US Lincoln penny (Photo: U of Texas at Arlington)

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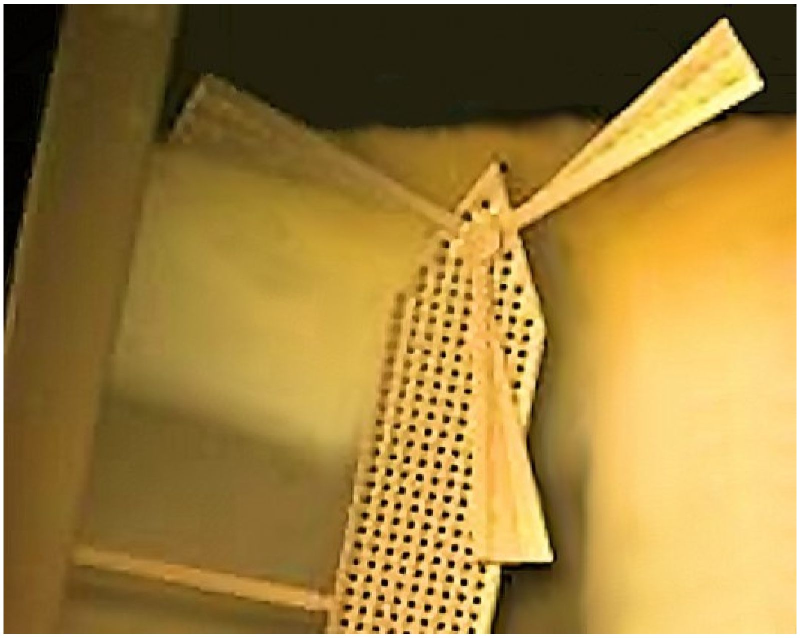
While commercial wind turbines have been trending toward larger sizes, from 300 kW capacity in 1990 to 7.5 MW in 2011, sometimes it is worth bucking the trend. Professor J.C. Chiao and his postdoc Dr. Smitha Rao of the University of Texas at Arlington have taken this contrarian philosophy to the extreme. They have developed a MEMS-based nickel alloy windmill so small that 10 could be mounted on a single grain of rice. Aimed at very-small-scale energy harvesting applications, these windmills could recharge batteries for smartphones, and directly power ultra-low-power electronic devices.

The micro-windmills (technically called horizontal axis wind turbines) have a three-bladed rotor 1.8 mm in diameter mounted on a tower about 2 mm tall.

The mount is a friction hub, but this probably becomes an air bearing when the rotor is spinning. The thickness of the windmills is about 100 microns.



Despite their size, the micro-windmills can endure strong winds, owing to being constructed of a tough nickel alloy (rather than the silicon and silicon oxide layers typical of MEMS designs) and smart aerodynamic design. “The problem most MEMS designers have is that materials are too brittle,” Rao said. “With the nickel alloy, we don’t have that same issue. They’re very, very durable.” Several thousand such windmills could be made on a single 200-mm (8-inch) silicon wafer using Rao's clever design and primarily conventional MEMS fabrication processes, resulting in very low per unit prices.

Let's get to the meat. As amazing as these devices are, can they actually be of any use? Unfortunately, detailed design information on the micro-windmills does not seem to have been published as yet, and predicting the exact performance of a horizontal-axis wind turbine is still a bit of a magic art (in the absence of serious computer modeling.) However, I have put together some rough estimates to get a feel for the potential performance levels of such micro-windmills.

The first question is how much mechanical power can a micro-windmill generate from a moving flow of air. Betz' limit tells us that the theoretical maximum conversion efficiency given an argument based on conservation principles cannot be larger than 59.3 percent of the initial kinetic energy of the airflow.

Modern turbines can achieve around 45 percent conversion, but their design includes several areas of optimization that will likely to be absent in a MEMS windmill. For example, there are limits in forming the airfoil of the turbine blades, and the level of friction and rotor chatter resulting from the standard and rather inefficient MEMS rotary bearing designs will considerably reduce the windmill's performance.

However, if the conversion efficiency is reduced to 20 percent, and later windmills are designed with more blade area (and perhaps more blades), in a 10 m/s (22 mph) airflow, a micro-windmill can deliver a significant fraction of a milliwatt. If we assume an application includes a thousand micro-windmills (and that the wind is constant), the windmill array would generate perhaps 5-10 W-hr (430-860 kJ) of mechanical power per day – about as much as is contained in a cell phone battery.

While the amount of power available may not be enormous, it is

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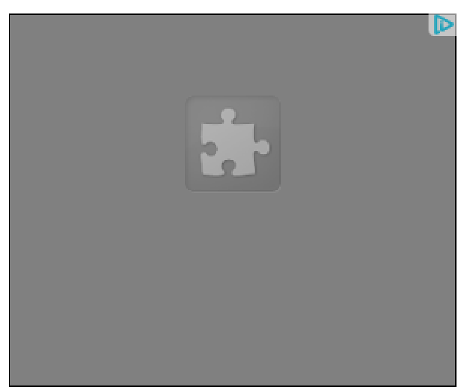


encouraging that it is sufficient for a host of operations, even if cell phone charging may be at the upper end of such applications. Consider bridge sensors. The sensor assemblies under development work at sub-microwatt levels most of the time, slowly accumulating data and awaiting a trigger signal to dump their information in a short burst of transmission. An average input of a few microwatts is all such a sensor requires. Many applications exist for energy harvesting, particularly in situations where revisiting sensors in place is impractical.

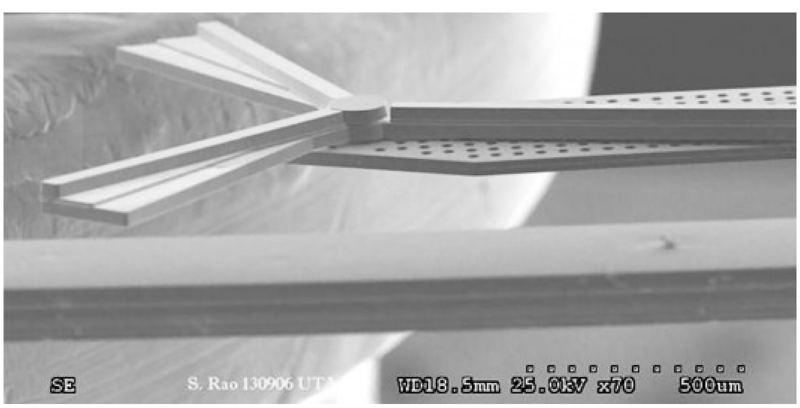
There is a potential problem that a suspicious observer would spot. Not the issue of how to convert this small amount of mechanical power into electricity; we'll look at that in a moment. The potential problem involves the boundary layer of air flowing by a surface.

A principle of modern aerodynamics is that when air flows past a surface, the air immediately next to the surface does not move relative to that surface; that is, there is a no-slip condition between the two substances. As we know that away from the surface the airflow remains largely unaffected (assuming the airflow is directed along the surface), there must be some characteristic distance away from the surface where the airflow attains its original value. This slowed layer is called the boundary layer, and the distance at which the airflow is moving relative to the surface at 99 percent of its full velocity is called the boundary layer thickness.

Here's the potential problem: if the micro-windmill is small compared to the boundary layer thickness, the air flow will be dramatically slowed. As the mechanical power of the windmill varies as the cube of the airflow speed, windmills buried in the boundary layer would be emasculated.

Fortunately, all works out well for the micro-windmills. At reasonable wind speeds, the boundary layer thickness likely to be encountered is smaller than a millimeter, or about one-third the total height of the windmill (I suspect that Chiao and Rao had done this calculation before making the windmill!).

The remaining engineering challenge is to convert a fraction of a milliwatt of mechanical energy efficiently into electrical energy. Not surprisingly, this won't be done by making a rotary electromagnetic generator half a millimeter in diameter with direct drive to the windmill's rotor. On this size scale, electrostatic forces are, on average, far stronger than are electromagnetic forces. Nor will a thousand windmills be coupled together using gears and transmissions; the mechanisms are simply not sufficiently efficient for such tiny devices.



The most likely electric generator would be an electrostatic generator in which the windmill itself is the generator. If the rotor is electrically isolated from the tower, the two form a capacitor whose value changes by a factor of (very roughly) 100 as the blades spin. If the capacitor is charged to one volt when one of the blades is over the tower (maximum capacitance), after which the charge on the windmill is isolated, the stored electrostatic energy will become 100 times larger when the rotor is turned 60 degrees by the wind to an inverted Y orientation. This extra energy comes from the torque of the rotor turning the rotor by 60 degrees.

At this point, the capacitor is discharged into a storage supercapacitor or battery, and the generator is ready for the next cycle. With a coating of a high-k dielectric on the tower, perhaps 10 microwatts of electric power will be generated by a single windmill, depending on wind velocity. Note that my estimate is based on a crude model; better designs will increase the conversion efficiency considerably.

In addition to the unusual development of the micro-windmill, Chiao's lab has produced a range of MEMS devices and components that should help the development of medical micro-robotics. UT-Arlington has entered into a collaborative agreement with WinMEMS Technology of Taiwan for commercial development of these MEMS innovations.

“The company was quite surprised with the micro-windmill idea when we showed the demo video of working devices,” Rao said. “It was something completely out of the blue for them and their investors.” For us as well.

Source: University of Texas at Arlington manliness.

About the Author

From an early age Brian wanted to become a scientist. He did, earning a Ph.D. in physics and embarking on an R&D career which has recently broken the 40th anniversary. What he didn't expect was that along the way he would become a patent agent, a rocket scientist, a gourmet cook, a biotech entrepreneur, an opera tenor and a science writer. All articles by Brian Dodson

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12 Comments

um.

So you get to blow on your cellphone all day? Or put it outside in the wind all day to charge it?

I think it's cool they can make these things, but I don't see how they can be particularly useful. The cross-section area of the turbine is so small it simply doesn't have much access to any wind energy.

Adrien

13th January, 2014 @ 01:09 pm PST

What an amazing miniturisation idea!

I had an idea - make a lot of little tiles designed to electrically link together into larger sections and cover the wind-facing side(s) of a house!

At worst they could power the exterior lighting needs by each little tile or larger section feeding a LED bulb or two.

At best, with a low energy eco-house, they could help keep the whole thing running!

The Skud

13th January, 2014 @ 05:47 pm PST

I think this is an excellent development if modified to the right application. At lot of a car's energy is lost through air drag. Maybe you can use that drag for a bit extra electrical power. You will never get a complete aerodynamic car but you might increase the efficiency.

Bobbert

13th January, 2014 @ 10:20 pm PST

@ Bobbert

I think you might be on to something. You might like to develop it into a perpetual motion machine, it has all the necessary features.

Mel Tisdale

14th January, 2014 @ 05:59 am PST

Why is it that wind engine idiots cannot get beyond 3 blades?

Clearly one of the worst configurations for maximum extraction of wind power.

Bill

Lewis M. Dickens III

14th January, 2014 @ 08:22 am PST

April first?

F.Gogoni

14th January, 2014 @ 08:29 am PST

It saddens me to see bright researchers frittering their lives away on such meaningless "problems." We have an energy problem but it's unrelated to cell phone charging. I am sure there will be new and useful applications for MEMS technologies. While these cute little windmills are a nice demonstration of what can be done, I suggest Professor Chiao find a more compelling use.

CliffG

14th January, 2014 @ 08:42 am PST

I like this idea but what if it rains or is dusty outside?

Maybe place it next to an aircon outlet to charge your phone? A lot of companies have banned phone/computer charging because of soaring electricity prices. Could be good for a well ventilated office.

Magnetron

14th January, 2014 @ 12:27 pm PST

Perhaps marginally feasible if an array of these are used. I did a quick calculation using P=A*1/2*pV^3.

A = approximate area of iphone 5 ~ .0075m^2

p = air density at sea level ~ 1.225 kg/m^3

V = 15 mph ~ 6.7 m/s a reasonable wind, about the speed of the average city bike commuter. This is just as a starting point.

In a theoretical world, assuming you are 100% efficient and your micro wind turbine array has an effective area of the size of an iPhone5, you only get about 1.4 watts. But in the real world, I'd be impressed if you got 25% energy conversion efficiency out of it as alignment, obstructions, turbulance, and nearby surface can all drastically decrease efficiency. Add to hat, packing efficiency. Then there is the roughly 0.9 packing limit of circular shapes. Factor in support structures and wiring, I'd venture to guess that you have a 0.8 packing efficiency, So, say you can achieve 25% conversion efficiency and 0.8 packing efficiency, you end up with about 20%. In other words, you could generate only about 0.28 Watts. Divide by 5V, you get 56 mA of current to device being charged. For the example iPhone5, with it's 1440mAh battery, it would need over 25 hours to fully charge.

In other words, useless except during storms which no one in their right mind would leave their expensive smart phone out.

sk8dad

14th January, 2014 @ 02:18 pm PST

@ Lewis M. Dickens,

"Clearly" one of the worst configurations for maximum extraction of wind power? Are you the commenter who used to call himself "Island Architect" and always touted Bill Allison's 1970s vintage eight-bladed turbine as "clearly" superior, so superior that nobody has used the design in any way, shape or form even though the patents have expired? As a character in an old movie once said, "I do not think that word means what you think it means."

A better design would be a competitive advantage, and "clearly" no wind energy company would continue to use an inferior design if such a better one existed, unless you believe in tinfoil hat conspiracy theories.

Gadgeteer

14th January, 2014 @ 06:59 pm PST

Um...

Now _there_ is a solution looking for a problem, if I ever saw one.

ljaques

14th January, 2014 @ 08:51 pm PST

It's hard enough to hold a cell phone without inadvertantly turning down the volume. How could you hold a cell phone without destrying these teeny windmills? This truly reads like a National Lampoon parody of a 1950s Popular Science issue.

Satweavers

15th January, 2014 @ 11:07 am PST

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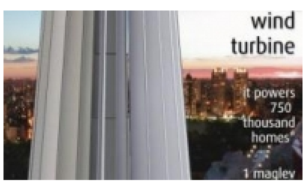

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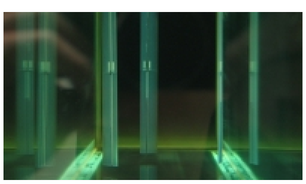

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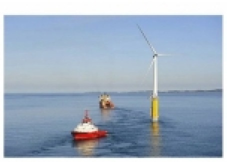

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