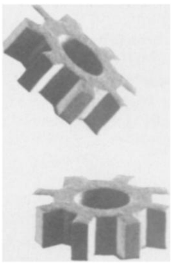
GEARING DOWN



Engineers fabricate metal parts the size of dust specks

By IVAN AMATO

How many of the world's most minuscule metal gears can fit across the head of a pin? Let's see . . . each gear measures about two hair-widths across, and a pinhead spans about 10 hairs . . . that comes out to five of the tiny gears.

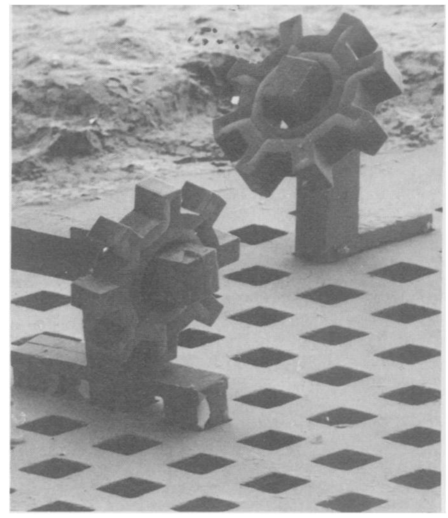
Dancing angels may still outnumber gears on the pinhead, but engineers at the University of Wisconsin-Madison seem pretty pleased with their little work. In time, these "microengineers" hope to assemble their metallic gears and other microcrafted components into miniature devices for performing delicate surgical operations, for precisely controlling subtle motion – say, in mite-sized mirrors that steer light pulses from one optical fiber into another – or for manipulating individual cells under a microscope.

But don't hold your breath. Microengineers around the world admit that they are still learning to crawl in the unfamiliar territory of microcomponents (SN: 7/1/89, p.8). "The field is still in its infancy," notes Kensall D. Wise of the University of Michigan in Ann Arbor, who is developing arrays of electrical microsensors for eavesdropping on the interactions of neurons.

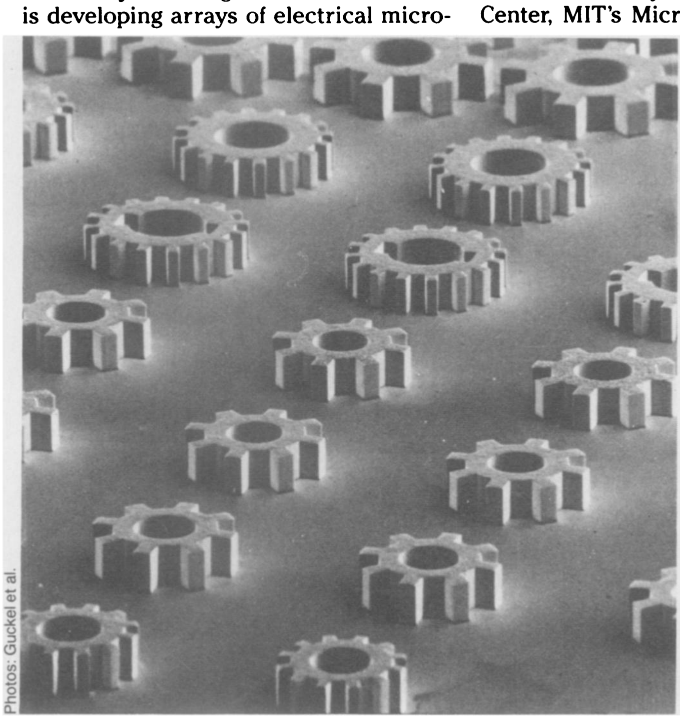
Nonetheless, microengineers see a big future for their field. "The problem we have is that there are so many different possible applications that we hope we are picking the right ones to pursue," says Henry Guckel, an electrical and computer engineer who led the Wisconsin gear-making effort.

"As far as I know, we have manufactured the smallest metal gears ever made," he says. These nickel parts, which might one day form the mechanical heart of teensy motors or minute power tools, range in width between a tenth and a fifth of a millimeter, smaller than a salt grain. The shaft hole in the smaller ones spans about 50 microns – too small for a strand of human hair to fit through. The cogs could easily fit inside the shaft of that hair.

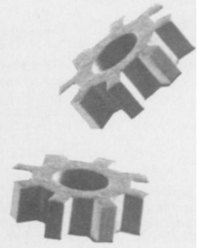
Dinky as they are, these metal gears slightly outsize their better-known and more extensively studied silicon microbrethren. The heavy focus on silicon by research teams at the University of California's Berkeley Sensor and Actuator Center, MIT's Microsystems Technology Laboratories and other microengineering labs in the United States, Japan, the Netherlands and elsewhere seems a natural extension of silicon microelectronics technology. Within the last decade, researchers have developed a versatile silicon micromachining craft that combines the lithographic techniques used by electronics engineers to pattern complex microelectronic circuitry onto fingernail-sized silicon chips, with other techniques involving chemicals that can etch precise, tiny shapes into silicon wafers.



Resembling wagon wheels in a repair shop, these nickel microgears rest on minuscule shaft structures plugged into a grid of holes.



A good sneeze could scatter these metal microgears – the world's smallest – into oblivion. The tiniest of the nickel gears (shown here greatly enlarged) span 100 microns or so, with shaft holes that even a hair couldn't poke through.



How the metal microgears differ from their silicon counterparts is what Guckel and his colleagues find so exciting. And expanding the list of materials and methods available to the world's micromachine shops rates as one of the most pressing challenges for microengineers, says Noel C. MacDonald of the National Nanofabrication Laboratory at Cornell University, who is developing ways of working tungsten into microstructures.

One of the most promising material properties of the nickel gears is simply their width, Guckel notes. The Wisconsin engineers have made them 100 microns thick, tens of times thicker than their silicon cousins.

With thickness comes stiffness. Superthin silicon microstructures often curl up like potato chips due to residual, internal stresses left over from the fabrication processes. The metal components' added thickness apparently quenches this problem.

Their brawn stokes Guckel's optimism that micromachines might indeed be capable of doing real-world work, such as powering a microknife for clearing obstructed arteries.

The flat and flimsy silicon microcomponents seem unlikely candidates for micromachines that move, lift or push things, he says. They have shown their mettle in commercial sensors, however. Pressure sensors – which consist of silicon membranes etched so thin that changes in external pressure result in changes in the membranes' easily monitored electrical resistance – now keep track of blood pressure in human patients and manifold pressure in millions of cars. Still, microengineers say their field has reached a point at which they need to demonstrate more commercially viable applications for their small wares.

In addition to focusing on metal rather than silicon, the Wisconsin team employs a rarely used fabrication technique to make microgears, shafts, gear stands and other tiny objects. The process, pioneered by scientists at the Karlsruh (Germany) Nuclear Research Center, goes by the name LIGA.

This acronym derives from the German words for its three main steps:

• LI for *lithographie*, in this case using powerful synchrotron X-rays shining through a stencil-like mask for etching deep patterns of parts, such as gears, into a layer of a light-sensitive polymer called a photoresist, which has been deposited onto a metal plate. The X-ray-exposed areas of the layer are chemically weakened enough for solvents to clear away the polymer there, leaving behind tiny molds.

• G for *galvanoformung*, in which an electric field drives or draws a metal such as nickel or chromium into the etched mold created by the lithography step.

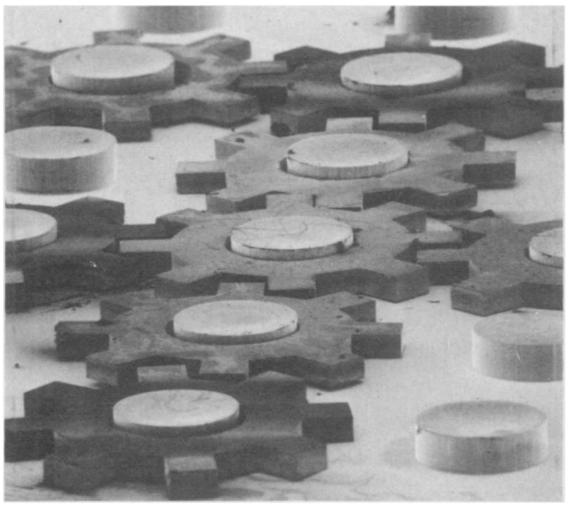
• And finally A for *abformung*, in which the resulting metallic structures serve as micromolds for shaping another material into the desired parts.

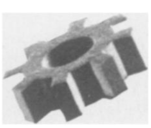
Since the Wisconsin researchers wanted metal gears, they only needed to use the LI and G steps. But to get free-moving parts, they had to do one more thing. Between the metal base and the thick polymer photoresist, they sandwiched a thin "sacrificial layer" of another polymer. After forming the tiny metal components and dissolving away the rest of the photoresist polymer, they then freed the components from the base by dissolving the sacrificial layer.

Using charged metal pins, they could pick up the microcomponents, move them around, put them on shafts and arrange them into rudimentary assemblies. The team has even meshed tiny gears into a minuscule gear train, notes mechanical engineer Edward G. Lovell, who works with Guckel on the project.

Teensy gears provide a cute way of demonstrating engineering know-how. But "success in the end will depend on commercializing these tiny things," Guckel says. The nearest-term possibilities, according to Lovell, fall in the sensor category – perhaps motion and pressure sensors – with microknives and other, more mechanical devices requiring more development time.

"We hope people in the medical arena hear about this ," says Lovell, "and give us some guidance about what they would want to see." □





By placing nickel microgears on nearby shafts, engineers have assembled what may be the smallest metallic gear train ever made.