Sandia researcher shares European physics prize for work; observations transformed Z-pinch field

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Work led to major increase in power output and hastened first fusion success

Albuquerque, N.M. _ Some physicists believe that the pulses of power formed in a technique called a Z-pinch may one day be a more efficient source of fusion power than magnetic confinement used by Tokamak reactors, the current leading contender for controlled nuclear fusion.

A major reason for this belief began in January 1995 when Sandia researcher Tom Sanford saw strange behavior in the wires forming a Z-pinch as he sat in his office examining technical photographs from a new camera.

A Z-pinch is a plasma formed from wires hung vertically and then ionized by a large electric current. The magnetic field accompanying any electric current "pinches" the plasma, which emits energy as its component ions run out of traveling room and are forced to brake to a sudden stop.

Sanford's observation, explained below, led him to follow-up work that, by increasing the number of wires in a pinch, significantly increased the output radiation pulse by nearly a factor of three, from 15 to 40 terawatts. The result put Z-pinches on the road to far higher outputs and improved them from a tool of somewhat abstract investigation into a possible source of power from controlled nuclear fusion.

For this work and further experiments, Sanford shared the European Physical Society's Hannes Alfven Prize "for the remarkable achievements of the multi-filament Z-pinch development in the recent years" with Malcolm Haines, former director of London's Imperial College Plasma Physics Dept., and Valentin Smirnov, director of the Institute of Nuclear Fusion at the Kurchatov Institute in Moscow.

The three shared a prize of 5,000 Euros, awarded on June 27 at this year's annual meeting of the Society in Tarragona, Spain.

Both Smirnov and Haines, in separate interviews, described the considerable depth and longevity of their own contributions to Z-pinch development but graciously gave credit to Sanford and Sandia for his observation and the Labs' subsequent validating tests by a number of personnel.

"[Sanford's] technical observation was correct, but he had to be stubbornly persuasive to get resources transferred to this [multifilament] area," observed Haines.

Said Smirnov, "The greatest achievement [in Z-pinch work] was made by Sandia in increasing the radiating material of the wires and in reconstructing PBFA II to Z."

Sanford's key experiment, which used nearly 200 wires -- something that had never been done -- led to a furious burst of work by Sandia technical staff on experiments that produced nearly 80 terawatts of X-ray power from tungsten wire arrays on an accelerator called Saturn. The increase in X-ray output increased the excitement about the ongoing project to convert a more powerful pulsed power facility called PBFA-II into a high-current driver for Z-pinch implosions.

Completed in September 1996 and soon dubbed Z, this accelerator soon produced more than 200 TW of X-rays for nuclear stockpile and fusion energy purposes.

What Sanford saw

It had been known for more than a century that a large current passing through thin wires would vaporize them, like an electrical short-circuit does fuses. Since the 1950s, it had been observed that thin wires, if strung in the shape of a cylinder, would form a plasma compressed by the magnetic field that accompanies the flow of electrical current. This was known as a Z-pinch. (Z is the direction of the axis of a cylinder in mathematics.)

It was believed each wire's ions -- the ghosts of the wires, if you will --essentially gave up their individuality, metaphorically held hands to become a kind of cylindrical gaseous cloud or shell compressed toward the center of the now-vaporized cylinder. Based on this belief, experimentalists around the world saw no reason to hang more than a few wires to form the pinch. Hanging the few-micron-thick wires was a tedious, time-consuming task; they were almost too thin to see and could break in an instant. Adding more wires in earlier experiments did not significantly increase Z-pinch outputs.

But Sanford had seen something else.

A pinhole camera newly installed at Sandia had electronics that allowed a nanosecond exposure and had no lens to shatter from the force of an explosion. The object of its attention merely needed to be placed at its focal length. Aided by protective devices, it could be placed close to the wire array and take pictures of unequalled clarity.

What its film showed was that individual plasma cylinders formed around each wire in a 24-wire array. Each wire, in effect, was selfpinching. And each lurched inward, inharmoniously with its neighbors, in the grip of the overall magnetic field.

While the effect of each wire forming its own plasma cylinder had been observed by others in experiments that used 12 wires, it was unexpected to see the same phenomenon with 24 wires.

"If they're still clumping like this," thought Sanford, "[using only] a few wires seems like a bad idea."

Installing many more wires in the array, he thought, might create the magnetic shell mistakenly thought to be already in place.

If the radiated power already achieved were merely the result of individual wire shells in effect staggering inward, how much more power could be obtained from an implosion involving many more wires that created a true shell that compressed coherently toward the center of the pinch?

The power created might exceed the simple addition of individual wire plasmas added to other wire plasmas.

Experiments with a large number of wires had never been tried because of the complexity of building the arrays. Sanford, with aid from other Sandians, proceeded to find out.

He had been trained by two high-energy physics Nobel laureates -- Leon Lederman and Sam Ting -- not to settle for inconclusive solutions.

In the tenacity of his experiments, says his manager Ray Leeper simply, "Tom's a bulldog."

Sanford set up a series of experiments, using different radii of wires with spacing adjusted to keep the total wire mass constant, to determine whether wire size and spacing had any appreciable effect as his team painstakingly measured X-ray output produced by arrays ranging from a very small number to nearly 200 wires. The results were clear. A larger number of thinner wires with smaller spacing between them sent the output of Saturn, and later the machine that became known as Z, skyrocketing, and eventually caused a change in the world scientific view of the Z-pinch process.

"Where it ends up, we don't know yet," Sanford says. "But it's regenerated a worldwide effort on Z pinches."

Sanford, who has been "riding the tsunami of papers" generated by his discovery, has since then been "swimming in the ocean of Z-pinch physics," (as he phrases these things), turning out more than 20 papers in the last 10 years on the phenomenon, and his work is ongoing.

Sandia's Z Machine, looked down at from the ceiling of the building that houses it, resembles a 120-foot-diameter wagon wheel. Its rim is formed by a series of large electrical capacitors. With the throw of a firing switch, these transfer 20 million amps to 36 "spokes" -- large metal conduits -- that link the capacitors to the vacuum chamber at the hub of the machine. Inside the hub sits the almost invisibly thin wires whose destruction will form the Z pinch. The wires form a cylinder only about as big as a spool of thread. It is on this machine that the most powerful Z-pinch experiments have been achieved.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration. With main facilities in Albuquerque, N.M., and Livermore, Calif., Sandia has major R&D responsibilities in national security, energy and environmental technologies, and economic competitiveness.

Source: DOE/Sandia National Laboratories

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