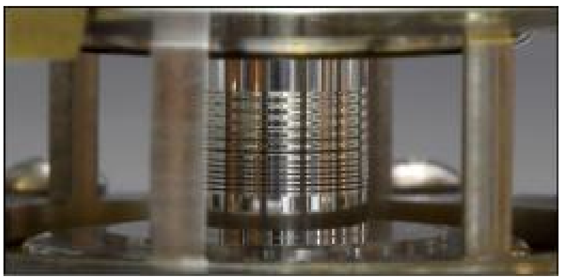
Scientists image the sea monster of nuclear fusion: the Rayleigh-Taylor instability

November 12 2010



This is an optical photograph of an aluminum z-pinch target tube installed in the Z machine.

(PhysOrg.com) -- A new X-ray imaging capability has taken pictures of a critical instability at the heart of Sandia's huge Z accelerator. The effort may help remove a major impediment in the worldwide, multidecade, multibillion dollar effort to harness nuclear fusion to generate electrical power from sea water.

"These are the first controlled measurements of the growth of magneto-Rayleigh-Taylor [MRT] instabilities" in fast Z-pinches, said project lead Daniel Sinars.

MRT instabilities are spoilers that arise wherever electromagnetic forces are used to contract (pinch) a plasma, which is essentially a cloud of ions. The pinch method is the basis of the operation of Z, a dark-horse contender in the fusion race.

A pinch contracts plasma so suddenly and tightly that hydrogen isotopes available from sea water, placed in a capsule within the plasma, should fuse.

That's the intent. Instead, the instability rapidly crimps the cylindrically contracting plasma until it resembles a string of sausages, or shreds the plasma into more fantastic, equally useless shapes. This damaged contraction loses the perfect symmetry of forces necessary to fuse the material.

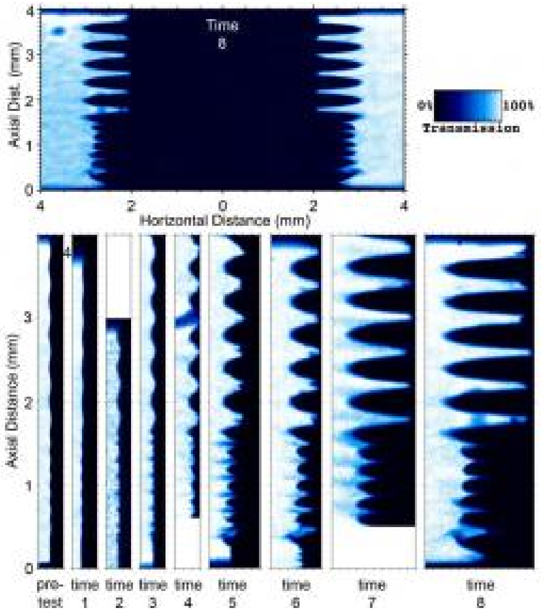
Fast pinches at Z, which take place in less than 100 nanoseconds, already have produced some neutrons, a proof of fusion. But a major reason not enough neutrons have been produced to provide a source of peacetime electrical power is the MRT instability.

Sinars led seven experimental shots to map the disturbance. The experiments were motivated by a concept proposed last year by Sandia researcher Steve Slutz.

Traditionally, scientists would use an array of spidery wires to create a compressed, X-ray-generating ion cloud. The X-rays were then used to compress fusion fuel.

Slutz suggested that the magnetic pinching forces could be used to directly fuse fuel by compressing a solid aluminum liner around fusion material preheated by a laser.

Because the new concept would not produce X-rays as a heating tool but instead relied on directly compressing the fuel with magnetic pressure, the MRT instability was the primary threat to the concept.



The top image is an X-ray (6.151 keV) photograph of the same target (see photo above) compressed by electromagnetic forces. The sequence of images below is cropped to show both outside edges of a cylinder from a camera's point of view as they distort over time in the grip of the MRT instability. Some of the jet-like features are approximately 50 microns, smaller in diameter than a human hair.

“Once we started looking at solid liners it was easy to conceive of doing a controlled experiment to study the growth of the instability,” Sinars said.

This is because experimenters could etch the solid tubes, creating instabilities to whatever degree they desired. Accurate etching is not an option with fragile wire arrays.

The MRT problem occurs because even minute dips in a current-carrying surface — imperfections merely 10 nanometers in amplitude — can grow exponentially in amplitude to millimeter scales. In the experiments by Sinars and others, the tubes were scored with a sinusoidal perturbation to intentionally start this process.

“The series of pictures over a time scale of 100 nanoseconds brought the life of the MRT into focus,” Sinars said.

Previously, competing computer simulation programs had given conflicting predictions as to the extent of the threat posed by the MRT instability, leaving researchers in the position, says Sinars, of “a man with two watches: he never really knows what time it is.”

The more accurate simulations will enable researchers to better tweak the conditions of future Z firings, more effectively combating the effect of the instability.

Researchers believe that with thick liners and control of the MRT, the Z machine could achieve an output of 100 kilojoules to match the 100 kilojoules input to the fuel to start the fusion reaction. “That would be scientific breakeven,” Sinars said. “No one has achieved that.”

That day, he says, may be just two to three years away.

The work is reported in a paper in the Oct. 29 issue of *Physical Review Letters.*

Provided by Sandia National Laboratories