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New antenna spreads good vibrations in fusion plasma

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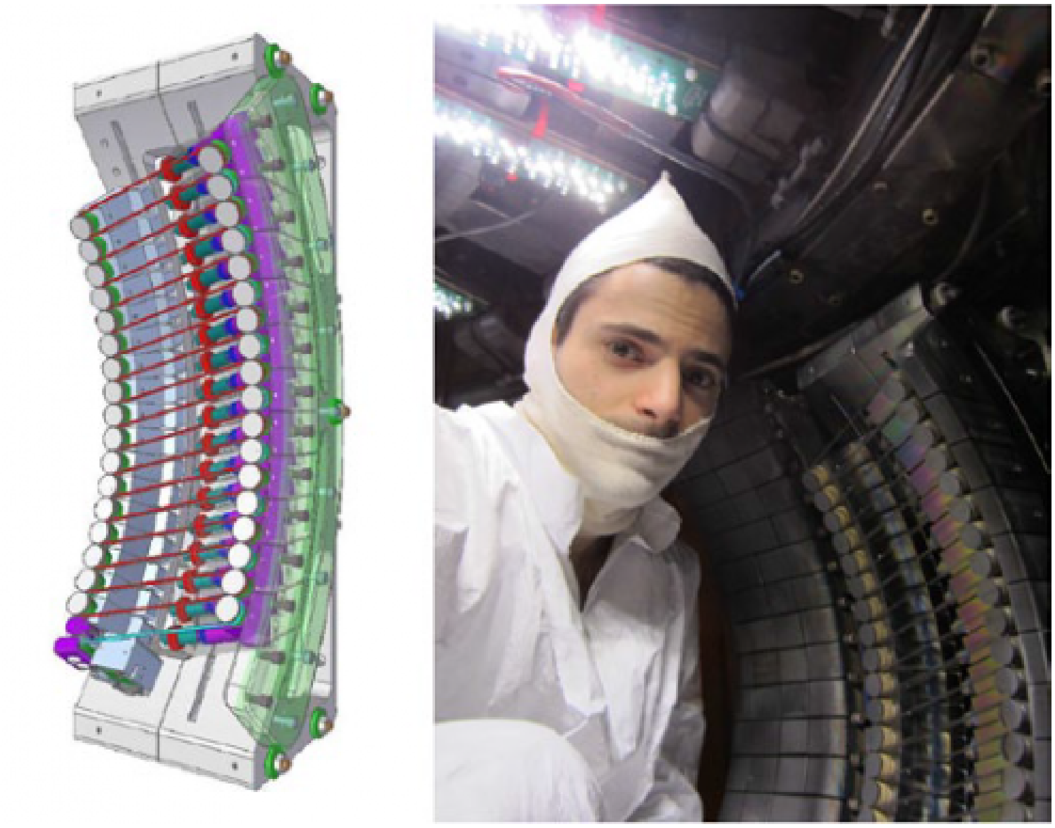

The Shoelace Antenna is a novel structure developed at MIT's Alcator C-Mod tokamak to drive short-wavelength fluctuations at the plasma boundary. The antenna gets its name from the crisscross pattern traversed by its single winding of molybdenum-wire, shown in red in the model. Electrical current flows at radio frequencies through the crisscrossing wire pattern to induce fluctuations in the plasma. (Right) Antenna mounted inside the Alcator C-Mod vacuum vessel. One of the authors sits alongside, wearing special clothing to keep the machine interior clean. Credit: T. Golfinopoulos

If you want to catch a firefly, any old glass jar will do. But when you're trying to bottle a star—the goal of fusion energy research—the bottle needs to be very special. A tokamak is one type of fusion bottle, capable of holding extremely hot plasma (10 times hotter than the sun) and keeping it stable while harvesting the prodigious amounts of energy produced in the fusion process. Of course, the trick is to keep the hot stuff in. And this is a complicated task.

Turbulence at the edge of a tokamak largely sets how permeable the plasma boundary is to heat and particles. In turn, the amount of heat and particles leaking out of the plasma edge determines the performance and design of the machine. Too little confinement and the plasma can't get hot enough to reach fusion temperatures without the construction of an enormous and costly machine. Too much confinement, and impurities—usually metal or carbon atoms from the wall—build up inside the hydrogen plasma, making steady state operation impossible. A great deal of research in fusion physics is devoted to tuning the controls to strike a balance between these extremes.

Tuning the controls globally inevitably involves sacrifices in the form of reduced performance or extreme heat loading on internal components. So, what we would really like are local valves to regulate heat and particle flows. And it turns out that controlled shaking of the plasma edge provides just such a possibility. Under the right conditions, special resonant vibrations appear naturally at the plasma edge. They take over from the turbulence, and often fix outflows at more favorable levels while suppressing violent bursts of heat and plasma. At present, the standard way to call up these edge fluctuations is to tune the control parameters of the tokamak until they turn on spontaneously.

But at MIT's Plasma Science and Fusion Center, we have been able to excite edge fluctuations directly for the first time. This is done with a novel device, the "Shoelace Antenna," developed for the Alcator C-Mod tokamak. The Shoelace Antenna gets its name from the crisscross pattern traversed by its single winding of molybdenum-wire.

The antenna is specially designed to match the wavelength of the target oscillations, while a custom power system covers the broad frequency range of the fluctuations. The operating principle is not so different from a violin string vibrating just right so as to build up an acoustic wave inside the sound box. The broadband power system lets us play all the notes in the scale.

The antenna sits extremely close to the plasma boundary, only one half centimeter (0.2 inches) away from the plasma that is 44 centimeters across. This close operation requires robust engineering to avoid melting the antenna. The plasma-facing materials must withstand temperatures that can exceed 1000ºC, the winding posts must accommodate thermal expansion of the wire, and the antenna must have protective plasma limiters at either side. These constraints add to already tough standards for the harsh in-vessel environment. But the additional effort is needed to maximize the antenna's ability to shake the plasma edge and induce the desired fluctuations.

Exciting initial experiments have shown that the robust engineering has been worth it: the antenna successfully induces fluctuations in the plasma that are similar to the naturally occurring modes that first inspired the study. In some situations, the antenna-driven vibrations are the dominant feature in the relevant part of the frequency spectrum. All this has been achieved using only 2 kW of input power - about a factor of one thousand smaller than power levels used for plasma heating, and only one fifth of the way to the antenna design limit.

While this early work has already taught us a great deal about the physics of the plasma edge, from a technological perspective, the ultimate hope is that an antenna such as this one may actively stimulate and control edge oscillations, giving fusion scientists and engineers that local valve to control heat and particle transport across the plasma boundary. Future experiments have already been planned to explore this very question, to learn whether these kinds of antennas will be control knobs to optimize the performance of the entire machine, and bring us a step closer to bottling a star.

More information: Abstracts: YI2.00005 External Excitation of a Drift-Alfven Wave Response in the Alcator C-Mod Edge Plasma and its Relationship to the Quasi-Coherent Mode
Session YI2: Edge and Pedestal 9:30 AM:30 PM, Friday, November 15, 2013 Room: Plaza E

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