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Spheromak charts new beam potential

by Charles B. Stevens

Researchers at the Princeton Plasma Physics Laboratory in New Jersey report that they have achieved the initial goals set for their S-1 spheromak experiment. Despite some initial mechanical problems, the S-1 has now reached true plasma operation with temperatures above 1 million degrees Celsius (100 electron Volts) and energy confinement times of ca. one-thousandth of a second. These results further confirm the scientific principles of the spheromak which were first demonstrated on the Los Alamos CTX spheromak. The spheromak is the most promising advanced concept for economic and compact magnetic-fusion reactors. In the nearer term, spheromaks have numerous potential applications to the development of pulsed power and directed-energy-beam technology.

The S-1 success is particularly significant because it proves that an entirely different kind of spheromak than that of the Los Alamos CTX works.

Self-organized magnetic plasmas

To achieve fusion, hydrogen gas must be heated to 100 million degrees Celsius while being contained and thermally insulated to maintain the gas energy flux density. At these high temperatures, ordinary matter becomes "electrified"—ionized—and is called plasma. Ionized plasmas interact strongly with magnetic fields such that the plasma can be stably confined and insulated within a properly designed configuration of magnetic fields—a "magnetic bottle."

The most successful magnetic confinement designs have used copper coils which generate the magnetic bottle as electric current is passed through them. In the tokamak, the magnets are placed around a donut-shaped vacuum chamber into which the hydrogen fuel is injected.

The spheromak, and, more generally, the compact torus (CT), improves on this type of approach by having the confining magnetic fields generated by electric currents within the plasma itself. By eliminating external copper coils, the plasma donut can be made much smaller and efficient. In particular, because plasmas can be held together by electric currents, they can sustain much higher current levels than conductors made out of ordinary materials. As a result, the spheromak offers an efficient and economical means to achieve the high energy flux densities which are essential for both fusion and directed-energy beams.

Because the spheromak is a self-organized magnetic plasma, it can be physically removed from the formation chamber and moved about. In fact, because the spheromak actually contains a very small amount of mass (a few millionths of a pound) confined within an intense magnetic field, it can be easily accelerated to hypervelocities in excess of 10,000 kilometers per second.

Such "translation" experiments have been carried out on the FRC compact torus at Los Alamos and other spheromak translation experiments are being pursued at Lawrence Livermore National Lab in California. For power reactors, the ability to transport the fusion plasma around can dramatically decrease both engineering problems and capital costs.

In terms of directed-energy beams, the hypervelocity spheromak is extremely potent. Because the spheromak has only a small mass and contains most of its energy within its confining magnetic field, it offers one of the best means of readily achieving energy densification. The plasmoid can be easily compressed and/or accelerated to high velocities near the speed of light with just a few yards of a simple, metal electrode shaped in the form of a funnel. The spheromak enters one end and is accelerated and compressed by an electric current which is passed through the conical (funnel) electrode. As a result, the plasmoid is compressed.

The plasmoid self-confining magnetic field plays two important roles in this energy-compression process. First, it insulates the metal electrode from the heat of the plasmoid. Second, most of the energy amplification is taken up by the "compressed" magnetic field. The magnetization of the compressed energy provides many versatile methods of its later conversion to useful electrical energy such as the acceleration of charged particle beams.

Traveling at a significant fraction of the speed of light, the plasmoid could deliver a power flux on target in excess of 10,000 trillion watts per cm^2. Alternatively, a highly compressed or accelerated spheromak represents a versatile technology for power amplification for driving other types of particle beams, lasers, and microwave generators. Livermore is currently pursuing concepts for compression of electromagnetic waves with high velocity spheromaks to produce trillion-watt microwave bursts.

The S-1 represents a qualitatively different approach to spheromaks than the Los Alamos CTX. The CTX is dynamically created by a plasma gun. The S-1 is statically generated by a complex magnet core system. Success with both systems represents a substantial rate of progress in the science of compact tori. In the near future, Princeton researchers will be attempting to decrease the size of the S-1 so that higher plasma electric current densities can be achieved. They will also be exploring the use of the dynamo effect found on the CTX, which could permit the spheromak to be sustained in a steady-state mode of operation.