Plasma Focus Fusion (PFF) - Power Generation Project (PGP)

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INTRODUZIONE

Si ringrazia il Prof. Valerio Benzi, che ci ha sostenuto nel presentare a codesto convegno il lavoro fin qui svolto dall'ing. Lerner relativo allo stesso Suo ambito di ricerca.
Si auspica che questa possa essere la giusta sede al fine di individuare potenziali enti interessati a promuovere un programma di studio sulla fattibilità tecnico-scientifica del PFF per la realizzazione di un primo PGP da effettuarsi in Italia.

L'obbiettivo di questa presentazione è individuare partners per la pianificazione del progetto da farsi per conto di un Ente pubblico locale, quale potrebbe essere la Regione Emilia Romagna, in collaborazione alle Università regionali interessate a sviluppare questo tipo di tecnologia, in modo da ottenere il co-finanziamento da parte della CEE.

Il progetto mira alla produzione di un mini impianto PFF in grado di produrre energia elettrica, con le seguenti caratteristiche:

- pulita, senza uso di prodotti radioattivi e residui inquinanti,
- pratica, possibilità di produrre piccoli impianti di generazione, (un impianto da 20 MW occupa uno spazio di un TIR)
- ecologica, zero emissioni di CO2
- economica, produrrebbe energia elettrica più di quella che consuma, anche per produrre l'idrogeno necessario al suo funzionamento,
- sostenibile, il combustibile di fusione oltre all'idrogeno, prevede una minima quantità di boro, (circa 1 Kg/anno in un impianto da 20 MW).

Summary

Lawrenceville Plasma Physics is planning to set up a new experimental facility that can test the feasibility of an environmentally safe, cheap and unlimited energy source from hydrogen-boron fusion using the Plasma Focus Technology.

Hydrogen-boron fusion with the plasma focus (focus fusion) can potentially supply energy without generating radioactive materials and at far less cost than any existing energy source. Experiments performed by Lawrenceville Plasma Physics (LPP) and collaborators at Texas A&M University have already demonstrated that the billion-degree-plus temperature needed for hydrogen-boron fusion has been achieved with this device. In addition, these experiments and earlier ones performed by LPP and University of Illinois have confirmed major aspects of the theory of the plasma focus developed by LPP President Eric J. Lerner. This theory predicts that net energy production is possible with focus fusion at extremely low costs.

The new facility, will allow carrying out experimental tests to optimize the efficiency of the focus device, to test new theoretical predictions, and to carry out initial experiments with hydrogen-boron (decaborane) fuel. LPP will provide a team of researcher with years of experience in plasma focus research.

Main goal of experiments is to achieve a hydrogen-boron fusion energy yield that is a substantial fraction of the energy input to the plasma. This will be the first step of a business plan project aiming to reach the break-even within three-years.

Potential Advantages of Focus Fusion

Fusion reactors using hydrogen-boron fuel and the plasma focus device, "focus fusion" reactors, would have several great advantages over existing energy sources:

1. Focus fusion reactors are safe and environmentally sound: No long-term radioactive by-products or pollutants are produced. The end-product is harmless helium gas. Focus fusion reactors would be free of radioactivity and the small number of low-energy neutrons emitted (less than 1/500th of total energy) could be easily absorbed in several inches of shielding.

2. Focus fusion reactors are cheap. Almost all of the energy (99.8%) is released in the motion of charged particles that can be converted to electricity directly, eliminating the need for generating steam to drive turbines, which account for most of the cost of electricity today. Focus fusion costs will be less than one fifth of present energy costs.

3. Focus fusion reactors are small and decentralized. Focus fusion reactors can fit into a garage and can be made as small as 2 MW, sufficient for a small community.

4. Focus fusion energy is essentially unlimited. The raw materials for hydrogen-boron fuel are exceedingly common. Hydrogen comes from ordinary water and boron from either abundant deposits or from sea-salt. Supplies of boron would be sufficient to maintain overall power consumption ten times the present global level for a billion years.

How the Plasma Focus Works

In operation, a pulse of electricity from the input capacitor bank (an energy storage device) is discharged into the plasma focus, which is inside a small vacuum chamber (Figure 1).

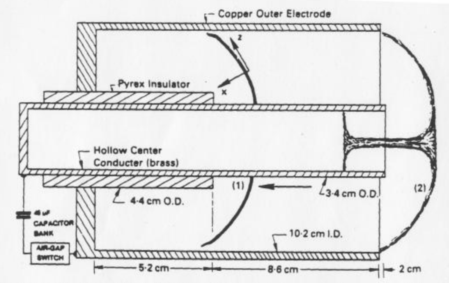

FIGURE 1. Cross section of typical plasma-focus device. Plasma sheath is shown while moving down electrodes and at time when plasmoids are produced.

The chamber is filled with a dilute gas, decaborane, fed from the fuel chamber. (A kilogram of fuel will be sufficient for a year's operation.) The plasma focus consist of two copper electrodes nested inside each other with the outer one consisting of a circular array of rods and inner one is a single hollow copper rod.

(Figure 2)

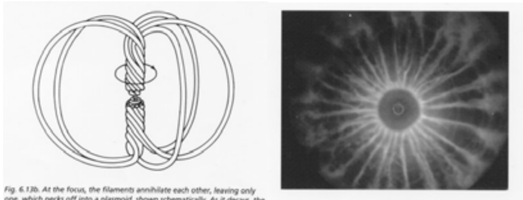

Fig. 6.13b. At the focus, the filaments annihilate each other, leaving only one, which necks off into a plasmoid, shown schematically. As it decays, the plasmoid emits two beams, each made up of tiny filaments organized into a helical pattern.

Fig. 6.13a. As the sheath carrying the inward-moving current forms, pairs of vortex filaments are generated.

For a few millionths of a second, an intense current flows from the outer to the inner electrode through the gas. Guided by the current's own magnetic field, the current forms itself into a thin sheath of tiny filaments--little whirlwinds of hot, electrically-conducting gas or plasma. The sheath travels to the end of the inner electrode, where the magnetic fields produced by the currents, without external magnets, pinch and twist the plasma into a tiny, dense ball or plasmoid only a few thousandths of an inch across. Within this plasmoid intense electrical fields are generated, causing it to emit a beam of electrons in one direction and a beam of ions, or positively charged nuclei, in the other. In the process the plasmoid heats itself to very high temperatures (over a billion degrees K) and fusion reactions take place, before it decays in a few hundred-millionths of a second.

Electric energy from the pulsed ion beam is coupled through coils into an electrical circuit. Fast switches direct the energy into the output capacitor bank. Part of the energy is then be recycled back to drive the next pulse, while the excess, the net energy, is fed into a power grid. A 2 MW prototype would pulse about 500 times a second.

Helium from the spent ion beam is exhausted to a storage vessel. Excess heat is carried away by a cooling system surrounding the vacuum chamber.

Feasibility of Focus Fusion

Hydrogen-boron fusion is considered technically difficult because of the high temperatures required and because x-rays radiated by the electrons in the plasma tend to cool it. However LPP has developed a detailed theory of functioning of the plasma focus that shows how these challenges can be overcome, and this theory has received substantial experimental confirmation.

Since August, 2001, a team of physicists led by Eric J. Lerner of Lawrenceville Plasma Physics for the first time demonstrated the achievement of temperatures above one billion degrees in a plasma focus device – high enough for hydrogen-boron reactions. This breakthrough, reported in May, 2002 at the International Conference on Plasma Science (Banff, Alberta, Canada), took place at Texas A & M University and was funded by NASA's Jet Propulsion Laboratory.

Earlier experiments at the University of Illinois had confirmed many of the detailed predictions of the theory, and the new Texas experiments also showed excellent agreement with the theoretical predictions of such important quantities as the density, temperature and magnetic field within the plasma.

In addition, new theoretical work by LPP has demonstrated that the extremely high magnetic fields within the plasmoids of the plasma focus will drastically reduce x-ray cooling of the plasmas. Such fields decrease the flow of energy from the reacting nuclei or ions to the electrons, thus reducing the electrons' temperature and therefore the x-ray power they emit. LPP's Lerner presented these new theoretical results at the annual meeting of the American Physical Society in April 2003 (Philadelphia) and at the Fifth Symposium on Current Trends in International Fusion Research in March, 2003(Washington, D.C.). The Symposium brings together the leading researchers in the fusion field and is sponsored by the International Atomic Energy Agency (IAEA) and the Global Foundation, Inc. The new results, which were received with great interest by the Symposium participants, will be published in the Proceedings of the Symposium. Details of the magnetic effect are presented in the Appendix.

Project Objectives

Lawrenceville Plasma Physics is now preparing for the next set of experiments, jointly run together with a team of experimental physicists who have years of experience with the plasma focus device.

These experiments, which will take about a year once the equipment is ready, are aimed at achieving a number of goals essential to moving toward a focus fusion reactor. First they are aimed at optimizing the efficiency of energy transfer into the tiny plasmoids. These are magnetically self-confined knots of dense, extremely hot plasma where the fusion reactions take place. Second, the experiments will test the ability of the plasma focus to generate magnetic fields in excess of a billion gauss (over a billion times the magnetic field of the earth.) Such giga-gauss fields (megatesla) will reduce the amount of energy lost when hot electrons emit x-rays. This in turn will allow the plasma to stay hotter and produce more fusion energy. Third, the experiments will produce significant amounts of fusion energy from hydrogen-boron fuel. These experiments should directly pave the way for a future set aimed at achieving break-even energy production--as much fusion energy out as is fed into the plasma.

The new plasma focus device that will be used for these experiments is physically small, and will, together with its power supply, fit in a small room. However it will be capable of producing 1.5 million amps of current in a short pulse, which will make it one of the most powerful plasma focus devices in the world, comparable with the other two large plasma focus devices in North America. In addition, it will be designed for small electrode size and high magnetic fields beyond those that can be achieved at other facilities. The facility will be designed to produce data that can be used for a variety of purposes in addition to the priory one of fusion power. It will also be capable of simulating astrophysical phenomena, such as quasars and neutron stars, and of investigations aimed at near-term industrial applications of the plasma focus, such as the production of intense microwave radiation.

The facility will be equipped with the most sophisticated set of diagnostic instruments in the focus community. Data from the instruments will enable researchers to fully characterize the plasma's size, temperature, and density and to test the theory of plasma focus operation.

Project Tasks

Task 1. Purchase of equipment**.**
This task involves the purchase of the capacitor bank by FFS and the purchase of the switching circuits and necessary diagnostic instruments.

Task 2. Theoretical calculations and design of electrodes and experiment.
Lawrenceville Plasma Physics will carry out extensive theoretical calculations, especially on the new magnetic field effect, which will determine the range of operating conditions for the experiments and the design of the electrodes.

Task 3. Assembly of Facility.
Once all equipment is on hand the facility will be assembled, including fabrication of the electrodes, assembly of the capacitors into the bank, integration of the switching circuits, and assembly and positioning of the diagnostic instruments.

Task 4. Planning and Preparation for future experiments
While the facility is being assembled, LPP will be planning and making preparations for the next set of experiments, so that there will be no break in work following completion of the first experimental tests. These plans will of course be refined on the basis of the initial experimental results.

Task 5. Testing of facility and calibration of instruments
Once the facility is fully assembled, LPP will carry out a series of preliminary tests using deuterium and helium fill gases to shake down the facility and to calibrate all the instruments.

Task 6 First experimental set
The first set of experiments will test the theory that higher efficiency of energy transfer into the plasmoid or hot spot can be achieved with higher run-down velocities and a larger ratio of cathode/anode diameter, up to 5. Testing of tapered electrodes to minimize inductance. Test with D, He or He-D mixtures, using 5 cm diameter cathodes. As many as 10 anodes of different lengths, diameters, tapers and insulator lengths will be tested, with the same cathode.

Task 7 Second experimental set
The second experiment will test of predictions that PF can achieve giga-gauss magnetic field in hot spots and that these fields can inhibit heating of electrons by ions. Some data relevant to this test should be obtained in the first set of experiments. A second set would aim at achieving the highest possible magnetic fields by reducing the diameters of the cathode and anode, down to a 2.5 cm cathode diameter, maintaining the aspect ratio optimized in task 5.

Task 8 Third experimental set
The third experiment will test using mixtures of He or H and $p^{11}B$ (decaborane) to achieve pinches with this mixture and to

observe secondary neutrons indicating $p^{11}B$ fusion. The goal would be to add $p^{11}B$ to an optimally function He or H gas, and the gradually increase the $p^{11}B$ while seeking new optimal conditions.

Task 9 Fourth experimental set
The fourth experiment will be tests with pure decaborane, based on optimized conditions derived with mixtures.

Task 10 Preparation of papers for publication.

Historical time line for the development of the Dense Plasma Focus (DPF)

1964 -The Plasma Focus is invented simultaneously in the US and the USSR by Mather and Fillipov, experiments were also made in Italy by Nardi since the early 60's.

Late 60's to early 70's - Winston Bostick and Victorio Nardi at Stevens Institute of Technology, Hoboken, NJ, develop the basic theory of the plasma focus, showing that energy is concentrated into tiny hot-spots or plasmoids, contained by enormous magnetic fields. Their discoveries become highly controversial, as other researchers insist that the energy is far more diffuse and ignore mounting experimental evidence from Stevens and other groups. During this same period US fusion efforts become concentrated almost exclusively on the tokomak. However, the number of groups around the world doing focus work grows to a few dozen. Funding for each group remains very limited. Work is also hampered by lack of quantitative version of Bostick-Nardi theory.

1986-- Eric Lerner of Lawrenceville Plasma Physics publishes first quantitative theory of DPF and plasmoid, using theory to successfully model quasars. The theory is based on Bostick-Nardi model, and was developed with advice from Nardi. In the next few years this theory is extended to predict plasma focus performance for various fuels, showing that improved performance is expected with hydrogen-boron fuels.

Late 80's to early 90's-- End of Cold war and decrease in general funding of physical science leads to drastic cuts in focus fusion, with about half of the groups ceasing to function and many others redirecting research to x-ray lithographic applications. Fusion funding is cut and concentrated ever more narrowly on Tokomaks.

1994--Experiments performed at University of Illinois on small plasma focus confirm predictions of Lerner's theory, including five-fold enhancement of output with smaller electrodes.

2001--Experiments at Texas A &M university confirm predictions from Lerner theory that energies above 100keV(equivalent to 1.1 billion degrees) can be achieved with plasma focus.

2002--New theoretical calculations indicate that strong magnetic field in DPF can suppress heating of electrons and thus x-ray cooling of plasma. This makes achieving net energy easier and implies that very compact electrodes are desirable.

Appendix: Magnetic Field Effects

One of the key problems on the way to a functioning focus fusion reactor is the way that x-rays can cool a proton-boron plasma. When hot, high-velocity electrons collide with boron nuclei, the electrons are accelerated. All accelerated charges emit radiation, and the electrons emit x-ray radiation that can leave the tiny plasmoid, robbing it of energy and cooling it. Previous calculations indicated that fusion reactors would heat the plasma only about two or three times as fast as the x-rays cooled it, a relatively narrow margin.

But calculations performed by Eric Lerner of Lawrenceville Plasma Physics indicate that the strong magnetic fields in a plasmoid can make that situation far better for fusion. The magnetic field makes it harder for the ions to heat the electrons, allowing the electrons to be far cooler than the ions. Cooler electrons radiate less x-ray energy, so that fusion power may be about ten times as large as x-ray losses, rather than just two or three times. In addition, the new calculations seem to indicate that more compact focus devices with higher magnetic fields are more desirable.

To understand how the magnetic effect works, it's important to note first how ions heat electron in the plasma. For fundamental mechanical reasons, a particle can only impart energy to particles that are traveling slower than it is. A simple way of seeing this is to imagine two runners, one fat (the ion) and one skinny (the electron). If the electron is running faster it can catch up to the ion and give it a shove, increasing the ion's energy. But if the ion is running faster, it can give the electron a shove, increasing the skinny runner's energy. In either case the faster particle gives up energy to a the slower particle. This is the case even if the slower particle has far more energy to gin with due to its greater mass. Since ions have at least 1836 items as much mass as electrons, slower moving ions often have far more energy than electrons, but if the electrons move faster, the ions gain still more energy at the electrons' expense.

In a plasma without a strong magnetic field, however, the are always a few electrons that are randomly moving more slowly that the ions. The ions give up energy to those electrons, which then mix in with the rest. So in a "normal plasma" energy does get equalized and the ions and electrons end up at the same temperature, with the average ion moving far slower than the average electron, but faster than some electrons.

A powerful magnetic field, more than several billion gauss (several billion times the magnetic field of the Earth) changes this situation. The magnetic field imposes a lower speed limit on the electrons – ALL electrons have to travel faster than this critical velocity. This is a quantum-mechanical effect. In any magnetic field, an electron moves in a helical orbit around the direction of the magnet field, the magnetic field line. The size of the orbit, the gyro radius, gets smaller for lower electron velocities and for HIGHER magnetic fields. But quantum mechanics dictates that associated with each electron is a wave, which gets longer as the electron velocity goes down. An electron can only be located with one wavelength, not within a smaller volume.

At a certain point, the gyro radius shrinks down to the same size as the electrons wavelength. It can't shrink any further. So far a given magnetic field, there is a minimum velocity that an electron can have – a smaller velocity would makes its gyro radius smaller than its wavelength, an impossibility.

This means that for very powerful magnetic fields, ions moving slower that the slowest possible electrons will not be able to heat the electrons at all. They will have NO electrons moving slower than they are. But if the ions have to move faster than the electrons to heat them, they must have far greater energy – at least 1836 items as much energy, or 1836 times' higher temperature. So instead of ions and electrons having the same temperature, the electrons are far cooler than the ions. This in turn leads to far less x-ray cooling.

The effects of magnetic fields on ion-electron collisions has been studied for some time. It was first pointed out in the 1970's by Oak Ridge researcher J. Rand McNally, and more recently astronomers studying neutron stars, which have powerful magnetic fields, noted the same effect. However, Lerner was the first to point out that this effect would have a large impact on the plasma focus, where such strong magnetic fields are possible. Experiments have already demonstrated 0.4 giga-gauss fields, and smaller DPF, with stronger initial magnetic fields can reach as high as 20 giga-gauss.

Feb 2004: Simulation Results Confirm Focus Fusion Can Produce Net Energy

The holy grail of fusion research is net energy production, more energy out than in. Recent simulations of the focus fusion device show that net energy production may be achievable with our next set of experiments at the University of Ferrara. Additionally, power generating reactors must achieve net electricity production which takes into account the inefficiency of converting fusion energy output (high energy particles and x-rays) to electricity. For conventional Deuterium-Tritium reactor designs that produce heat to run a steam generator this is a big problem because of the low efficiency of the steam generator. However, focus fusion will generate electricity directly from its charged particle beam and x-rays at high efficiency. So for focus fusion reactors net electricity production is not far beyond net energy production. For more details see the latest newsletter and simulation plots.

More at: http://www.focusfusion.org