Autocatalytic Fusion-Fission Burn in the Focus of Two Magnetically Insulated Transmission Lines

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A configuration made up of two nested magnetically insulated transmission lines, the inner one carrying a high voltage lower current – and the outer one a high current lower voltage – pulse, was in a previous communication proposed for the ignition of a magnetic field assisted thermonuclear detonation wave. Unlike the fast ignition concept, it does not require the compression of the DT fusion fuel to densities in excess of the solid state. Here I show that with the same configuration, but by surrounding the DT fusion fuel with a blanket of solid U238, Th232 or B10, the ignition of a thermonuclear detonation wave is possible with densities of the DT fuel less than solid state densities, because the DT fusion neutrons can make a sufficient number of fission reactions, greatly increasing the pressure in the blanket, compressing the DT to high densities, launching a magnetic field assisted thermonuclear detonation wave. This autocatalytic fusion-fission burn has the further advantage that it can burn natural uranium, thorium and even boron.

Key words: Fusion-Fission Burn; Fast Ignition.

1. Introduction

The coupling of fission and fusion reactions with a fissile pellet surrounded by a DT blanket for the release of nuclear energy, both from fission and fusion, was proposed by the author many years ago [1, 2], as was the autocatalytic fusion-fission implosion of a DT plasma surrounded by a blanket of U238, Th232 or B10 [3]. In the latter case the coupling of the fission and fusion reactions becomes important even at temperatures less than the DT ignition temperature, because a large number of fusion neutrons are there already released at a sufficiently high rate to increase the temperature in the blanket by fast fission reactions of the 14 MeV DT fusion neutrons. For this autocatalytic fusion-fission process to work the DT has to be heated to high temperatures at densities which can be less than solid state densities. The autocatalytic fusion-fission concept also has the advantage that it can burn natural uranium, thorium, and even boron. In the case of boron 10, the fission products are the nonradioactive lithium 7 and helium.

In this communication I will show that the recently proposed novel concept for the ignition of a DT thermonuclear detonation wave in the focus of two nested magnetically insulated transmission lines [4], can also be applied to ignite an autocatalytic fusion-fission reaction. In comparison to the ignition of a DT thermonuclear detonation wave with the same configuration, less focusing of the relativistic electron beam emitted from the end of the inner transmission line is required. With the ignition of the autocatalytic fusion-fission reaction, a magnetic field assisted thermonuclear detonation wave can be launched into DT.

2. Ignition of the Autocatalytic Fusion-Fission Reaction in the Center of Two Magnetically Insulated Transmission Lines

As shown in Fig. 1, the previously proposed nested magnetically insulated transmission line configuration is here used for the ignition of an autocatalytic fusion-fission reaction, replacing the solid DT cylinder with DT gas under high pressure inside a cylinder made up from natural uranium, thorium or boron. As in the previously proposed concept, the DT is heated up by the relativistic electron beam emitted from the end of the inner transmission line. The fission reactions in the blanket by the 14 MeV DT fusion neutrons can there lead to its cylindrical implosion onto the DT, raising both the temperature and density of the latter, and with it the release of fast neutrons, further accelerating the fusion-fission reactions.

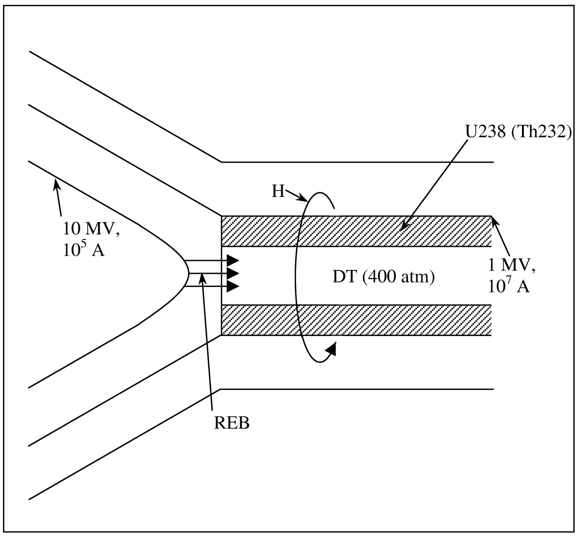

Fig. 1. Fusion-Fission Target Configuration.

Through the ignition of this autocatalytic fusion-fission reaction, a magnetic field assisted pure fusion reaction thermonuclear detonation wave can then be ignited as described in the previous communication.

3. Scaling Laws of the Autocatalytic Fusion-Fission Reaction

The DT filled cylinder shall have the length l, the radius r, and is surrounded by a blanket of thickness δ, consisting of U238, Th232 or B10. The DT fusion reaction rate in the DT cylinder per unit volume is given by

$$\frac{\partial n}{\partial t} = \frac{n^2}{4}\langle\sigma v\rangle \tag{1}$$

where n is the DT number density and $\langle\sigma v\rangle$ the fusion reaction cross section velocity product averaged over a Maxwellian.

From (1) one obtains for the neutron flux at the surface of the cylinder of radius r

$$\phi = \frac{1}{2\pi r}\int_0^r \frac{n^2}{4}\langle\sigma v\rangle 2\pi r'\mathrm{d}r' = \frac{r}{8}\langle\sigma v\rangle n^2 \tag{2}$$

The fission reaction mean free path of the DT fusion neutrons in the blanket is Σ_f^{-1}, where $\Sigma_\mathrm{f} = n_\mathrm{f}\sigma_\mathrm{f}$ is the macroscopic fast fission cross section of the blanket, with n_f the atomic number density of the blanket and σ_f the fast fission cross section. For solid uranium $n_\mathrm{f} = 4\times10^{22}$ cm^{-3} and $\sigma_\mathrm{f} \cong 2\times10^{-24}$ cm^2, whereby $\Sigma_\mathrm{f}^{-1} \sim 10$ cm. We assume that $\delta \ll \Sigma_\mathrm{f}^{-1}$, making ϕ nearly constant throughout the blanket. In such a thin blanket, the energy released per unit volume and in the time τ is

$$\varepsilon = \Sigma_\mathrm{f}\phi(\varepsilon_\mathrm{f}+\varepsilon_0)\tau \tag{3}$$

where ε_f the fission energy and ε_0 the kinetic energy of the DT fusion neutrons. The time τ is the inertial confinement time of the blanket, which is of the order

$$\tau \sim \frac{\delta}{a}, \tag{4}$$

where $a \cong \sqrt{p/\rho}$ is the velocity of sound in the hot blanket of density ρ.

The justification of (3) can perhaps be better seen by writing it with the help of (4) as follows:

$$\varepsilon = \phi\,(\varepsilon_\mathrm{f}+\varepsilon_0)\left(\frac{\delta}{L}\right)\frac{1}{a} \tag{3a}$$

where $L = 1/\Sigma_\mathrm{f}$ is the fusion reaction length in the blanket, with the fraction (δ/L) of neutrons passing through the blanket making a fission. Without the division by the velocity of sound a, (3a) would be the energy flux density in the blanket.

Since by order of magnitude $p \approx \varepsilon$, one has

$$\tau = \delta\sqrt{\rho/\varepsilon} \tag{5}$$

and one obtains from (3)

$$\varepsilon = \left[\Sigma_\mathrm{f}\phi\,(\varepsilon_\mathrm{f}+\varepsilon_0)\,\delta\right]^{2/3}\rho^{1/3}. \tag{6}$$

By inserting ϕ from (2) this becomes

$$\varepsilon = (1/4)\left[\Sigma_\mathrm{f}\,(\varepsilon_\mathrm{f}+\varepsilon_0)\,\langle\sigma v\rangle n^2 r\delta\right]^{2/3}\rho^{1/3} \tag{7}$$

If $\varepsilon > 2nkT$, where $2nkT$ is the DT plasma pressure, the blanket begins to implode the DT plasma, accelerating the coupled fusion-fission reaction.

With the help of (7) the condition that $\varepsilon > 2nkT$ can be written as

$$n(r\delta)^2 > \frac{(kT)^3}{\langle\sigma v\rangle^2}\frac{5/2}{\left[\Sigma_\mathrm{f}\,(\varepsilon_\mathrm{f}+\varepsilon_0)\right]^2\rho} \tag{8}$$

The smallest possible density of the DT plasma to satisfy this inequality is given by the minimum of $(kT)^3/\langle\sigma v\rangle^2$ which is at $T \cong 15$ keV, where $(kT)^3/\langle\sigma v\rangle^2 \cong 2\times10^8$ erg^{3}s^2/cm^6. We therefore have for the minimum

$$n(r\delta)^2\,|_{\min} \approx 10^{11}\,[\Sigma_\mathrm{f}\,(\varepsilon_\mathrm{f}+\varepsilon_0)]^{-2}\,\rho^{-1}[\text{ cm}]. \quad (9)$$

For natural uranium (and thorium), one has $\Sigma_\mathrm{f} \cong 0.8\times10^{-1}$ cm, $\varepsilon_\mathrm{f}+\varepsilon_0 \cong 3\times10^{-4}$ erg, and $\rho = 18$ g/cm^3. For these numbers one finds that $n(r\delta)^2\,|_{\min} \approx 10^{-19}$ cm. With $n = 10^{22}$ cm^{-3}, realized for DT gas at room temperature compressed to 400 atm, one has $(r\delta)^2 = 10^{-3}$ cm^4. Choosing $\delta = 2r$ (equal thickness of blanket and core), one finds that $r = 0.13$ cm. These numbers also apply for thorium.

For boron (B10), $\varepsilon_\mathrm{f}+\varepsilon_0 \cong 3\times10^{-5}$ erg, i. e. about 10 times smaller than for uranium. There one has $n(r\delta)^2\,|_{\min} \sim 10^{-21}$ cm^{-1}. For solid DT (instead of DT at 400 atm) with $n = 5\times10^{22}$ cm^{-3} one finds $(r\delta)^2 = 2\times10^{-2}$ cm^4, and for $\delta = 2r$, that $r = 0.27$ cm.

Also instructive is the magnitude of the pressure the blanket exerts on the DT plasma core. In the case where the DT plasma pressure is balanced by the pressure of the blanket, the pressure is $p = 2nkT$ at $T = 15$ keV $= 2.4\times10^{-8}$ erg. With $n(r\delta)^2 = 10^{19}$ cm^{-1} for an uranium blanket, and $n(r\delta)^2 = 10^{21}$ cm^{-1} for a boron blanket, one finds that

$$p = 5\times10^{11}(r\delta)^{-2}\left[\mathrm{dyn/cm^2}\right], \quad \text{uranium},$$

$$p = 5\times10^{13}(r\delta)^{-2}\left[\mathrm{dyn/cm^2}\right], \quad \text{boron}.$$

For uranium we had $(r\delta)^2 = 10^{-3}$ cm^4, hence $p = 5\times10^{14}$ dyn/cm^2, and for boron $(r\delta)^2 = 2\times10^{-2}$ cm^4, $p = 2.5\times10^{15}$ dyn/cm^2.

In the outer transmission line a current of the order $I \sim 10^7$ A is required to confine the charged fusion products, a necessary condition for thermonuclear burn. To reach at a radius $r = 0.13$ cm a magnetic pressure equal to the pressure in the uranium blanket, would require a much larger current of $I \sim 3\times10^8$ A. To let the magnetic field diffuse through the blanket and to confine the charged fusion products to within the DT cylinder requires a semi- or non-conducting blanket. This could be done by doping a non-conducting medium with metallic uranium or thorium.

4. Ignition and Burn

As in the previous communication, the heating is done by a relativistic electron beam through the combined action of the electrostatic two-stream instability and the strong magnetic field, with the relativistic electron beam coming from the inner transmission line and the magnetic field from the current flowing through the outer line. For the ignition (of the magnetic field assisted thermonuclear detonation wave) a volume of the order $\pi r^2\times 2r$ has to be heated to 15 keV. For the example of a dense DT plasma with a number density of 10^{22} cm^{-3} surrounded by a uranium blanket, this energy is about 10^6 J. With the radiation loss time for 15 keV and a number density of 10^{22} cm^{-3} of the order 10^{-7} s, this energy could be supplied by a 30 MV, 300 kA relativistic electron beam. For a boron blanket the ignition energy would be about 50 times larger.

Because part of the neutrons, released behind the detonation front react with the uranium in the blanket ahead of the front, the pressure there created will implode the DT, accelerating the reaction rate of this autocatalytic detonation wave burn.

[1] F. Winterberg, Nature London **241**, 449 (1973).
[2] F. Winterberg, in "Laser Interaction and Related Plasma Phenomena," Vol. 3B, p. 519ff. Plenum Press, New York 1974.
[3] F. Winterberg, Atomkernenergie – Kerntechnik **44**, 145 (1984).
[4] F. Winterberg, Z. F. Naturforsch. **58a**, 197 (2003).