Laser Compression and Ignition of Z-Pinch Magnetized Dense Fusion Targets

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Z. Naturforsch. **55a,** 909–911 (2000); received September 18, 2000

With thin wire multimegampere shear flow stabilized fast z-pinch discharges, magnetic fields of hundreds of megagauss can be reached in the vicinity of the discharge channel. Then, if by laser-ablation-propulsion pieces of solid DT are simultaneously shot onto the discharge channel from several sides, the DT is compressed upon impact to high densities, with the magnetic field acting as a cushion to make the compression isentropic. The highly compressed and magnetized DT target can then be ignited at one point by a pulsed laser beam launching a thermonuclear detonation wave propagating along the discharge channel. Estimates indicate thermonuclear gains large in comparison to hohlraum targets.

1. Introduction

The idea to compress and ignite by powerful laser beams a small amount of DT has been around for a long time, and so has the idea to ignite a dense DT plasma confined in a pulsed high current z-pinch discharge [1–3]. In both cases the energy for ignition is of the order ~ 10 MJ, to be deliverd in ~ 10^{-8} s. The problem for the laser ignition concept is the low (less than 1%) laser efficiency; for the z-pinch it is the magnetohydrodynamic instabilities. The z-pinch instabilities can be overcome by axial shear flow [4, 5], but this has the problem in that it leads to energy losses in the axial direction of the pinch discharge channel. However, if a thermonuclear detonation wave propagating down the pinch discharge channel shall be ignited at one point by a pulsed laser beam, a dense cool target is desired [6, 7].

In this communication we will show that by combining laser compression with the strong magnetic field of a multimegampere discharge through a thin wire one can create a dense magnetized DT target which can be ignited at one point by a pulsed high power laser. The proposed combination of laser – and electric-pulse power ignition is expected to reduce substantially the laser energy required, increasing the overall gain.

2. Launching Solid Pieces of DT on a Thin Wire Pinch Discharge

As shown in Fig. 1 several pieces of solid DT (in this example four), each with the shape of a long square cylinder, on the outside made up of an ablator, while on the inside covered with a layer of frozen DT, are simultaneously launched by laser ablation rocket propulsion onto the wire. Since with laser ablation propulsion projectile velocities of the order $v \sim 10^7$ cm/s can be reached, and assuming an ablator density of the order $\varrho \sim 1$ g/cm^3, the stagnation pressure upon impact on the wire is $p \sim \varrho v^2 \sim 10^{14}$ dyn/cm^2. Shock heating by impact is cushioned by the magnetic field H of the wire, provided that $H^2/8\pi > \varrho v^2$, or that $H > \sqrt{8\pi p} \sim 5\times 10^7$ G. In the absence of shock heating the frozen DT is compressed isentropically, with the pressure given by the Fermi equation of state

$$p \simeq 2.5\times 10^{-27}\, n^{5/3}\ [\text{dyn/cm}^2], \quad (1)$$

where n [cm^{-3}] is the particle number density.

For a pressure of $p = 10^{14}$ dyn/cm^2 one obtains $n \simeq 2.5\times 10^{24}$ cm^{-3} = 50 n_0, where $n_0 = 5\times 10^{22}$ cm^{-3} is the density of solid DT.

To launch a DT thermonuclear detonation wave propagating along a pinch discharge channel, the fusion α-particles must be confined in the channel requiring that the pinch current must be larger than $I_0 = 1.3\times 10^6$ amp [8], with a current $I \sim 10^7$ amp actually needed [9]. To reach with this current a magnetic field $H \geq 5\times 10^7$ G, the radius of the wire must be $r \leq 4\times 10^{-2}$ cm. The propagation of a thermonuclear detonation wave in a linear DT assembly further requires that

$$\varrho \ell \geq 1\ \text{g/cm}^2, \quad (2)$$

where ℓ is the length of the discharge channel. For $n = 50\, n_0$, ($\varrho \sim 5$ g/cm^3) one has $\ell > z_0 = 0.2$ cm.

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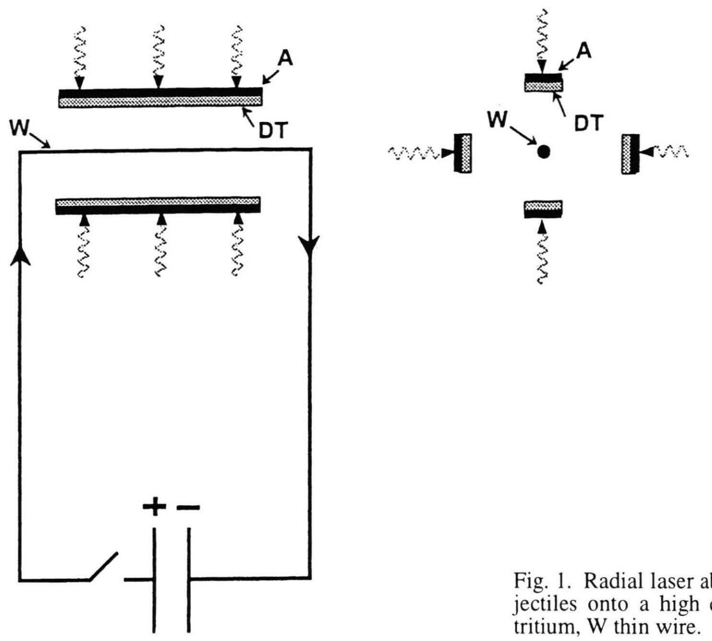

Fig. 1. Radial laser ablation propulsion of frozen deuterium-tritium projectiles onto a high current wire discharge. A ablator, DT deuterium-tritium, W thin wire.

The compression energy, supplied by the lasers driving the ablative propulsion of the solid DT is of the order

$$E \sim pV, \tag{3}$$

where V is the volume of the compressed DT. If it tightly surrounds the wire one may put $V \sim r^2 \ell$. For $\ell \simeq 3$ cm, $r \sim 10^{-2}$ cm, one has $V \sim 3\times10^{-4}$ cm^3, and $E \sim 3\times10^{10}$ erg = 3 kJ. Assuming a 10% laser ablation propulsion efficiency, a laser energy of 30 kJ would be sufficient.

The magnetic energy stored in the discharge channel is of the order

$$E_m \sim (H^2/8\pi)\, V \cdot \log (R/r), \tag{4}$$

where R is radius of the outer return current conductor. for $R \sim 3$ cm, $r \sim 10^{-2}$ cm, $V \sim 3\times10^{-4}$ cm^3, $H \sim 5\times10^7$ G, one has $E_M \sim 10^{11}$ erg ~ 10 kJ.

The laser energy needed to launch a thermonuclear detonation wave is of the order

$$E_{ign} \sim 3\, nkT \cdot z_0\, r^2, \tag{5}$$

and one finds with $kT \sim 10^{-8}$ erg that $E_{ign} \sim 3\times10^{12}$ erg ~ 300 kJ. This energy has to be delivered in the time $\tau \sim r/v_{th} \sim 10^{-10}$ s, where $v_{th} \sim 10^8$ cm/s is thermal particle velocity. With $E_{ign} \sim 300$ kJ, the required laser power is $P \sim 3\times10^{15}$ Watt, comparable to the power for the fast ignitor concept [10].

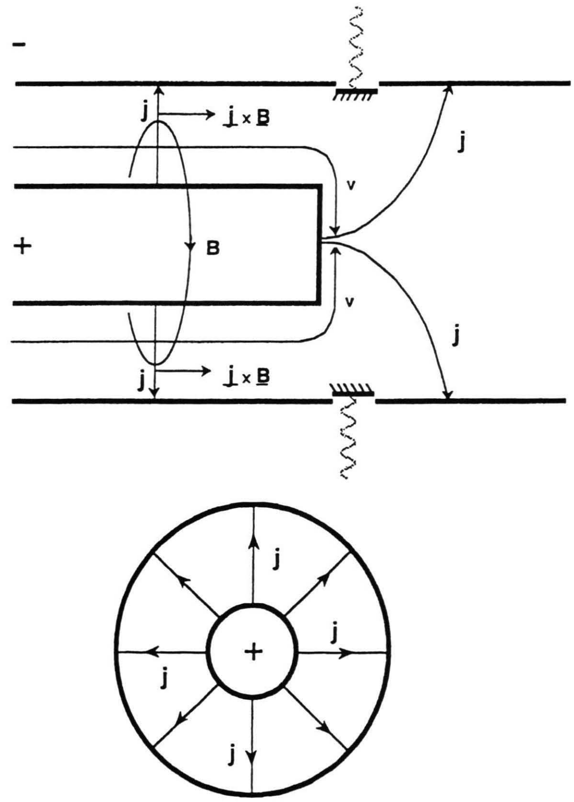

Fig. 2. Plasma focus high current discharge made with wires and with deuterium-tritium projectiles, shot onto the discharge channel as in Figure 1.

The thermonuclear energy released is of the order (18 MeV $\simeq 3\times10^{-5}$ erg per fusion reaction):

$$E_f \sim 3\times10^{-5} n \cdot V \approx 2\times10^{16}\ \text{erg} = 2\times10^{3}\ \text{MJ}. \quad (6)$$

This gain compares well with hohlraum radiation implosion targets. The reason for the high gain is the utilization of the large, ($H \sim 10^8$ G), magnetic field of the high-current discharge through the thin wire.

The compression of the DT must be done within the same time as the duration of the high current discharge, the latter taking place in ~ 10^{-7} s. The projectile acceleration with a final velocity of ~ 10^7 cm/s over a length of ~ 1 cm takes the same time.

3. Shear Flow Stabilization

The stabilization by axial shear flow can be done in a variety of ways, as those previously suggested [4, 5, 7]. The very good stability of the plasma focus which most likely results from axial shear flow occurring in this configuration, suggests to combine the plasma focus concept with the wire pinch discharge, as shown in Figure 2. In this concept the plasma is replaced with several thin wires. There one should obtain a shear flow stabilized high Z dense z-pinch along the axis, onto which the DT pieces would have to be shot.

[1] J. Nuckolls, L. Wood, A. Thiessen, and G. Zimmerman, Nature, London **239,** 139 (1972).
[2] K. A. Brueckner, IEE Trans. Plasma Sci. PS-1, 13 (1973).
[3] W. Bennett, Phys. Rev. **45,** 890 (1934).
[4] F. Winterberg, Beitr. Plasmaphys. **25,** 117 (1985).
[5] T. D. Arber and D. F. Howell, Phys. Plasmas **3,** 554 (1996).
[6] F. Winterberg, Z. Naturforsch. **53a,** 933 (1998).
[7] F. Winterberg, Z. Naturforsch. **54a,** 459 (1999).
[8] F. Winterberg, Atomkernenergie-Kerntechnik **39,** 181, 265 (1981).
[9] J. G. Linhart, Il Nuovo Cim. A **106,** 1949 (1993).
[10] M. Tabak et al., Physics of Plasmas **1,** 1626 (1994).