Summarized proposal of a progressive thermalization fusion reactor able to produce nuclear fusions with a mechanical gain superior or equal to 18

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Abstract: the main advantage of this fusion reactor is that the plasma after having been brought up near to the optimum conditions for D/T fusion (around 68 keV), is then maintained in this state, low energy non-thermal ions (≤15 keV) being injected as replacement ions. So the energetic cost is low and the mechanical gain (Q) is elevated (≥18), the working being continuous. Moreover, the main plasma control by the particles injectors is relatively simple. This reactor has been partly checked on a simulator.

CONTENTS Page

1. Introduction

The goal of this short presentation is to describe, with not many words and physics, a new type of colliding beam fusion reactor. It is an abstract of the published article (66 pages) available here:

Lindecker, P. (2022) Progressive Thermalization Fusion Reactor Able to Produce Nuclear Fusions at Higher Mechanical Gain. Energy and Power Engineering , 14, 35-100. https://doi.org/10.4236/epe.2022.141003

This reactor uses magnetic confinement and hosts two opposed beams of electrons and two opposed beams of ions. All these beams, initially directed axially, circulate inside a figure of “0” configuration, also called “racetrack”, as shown below.

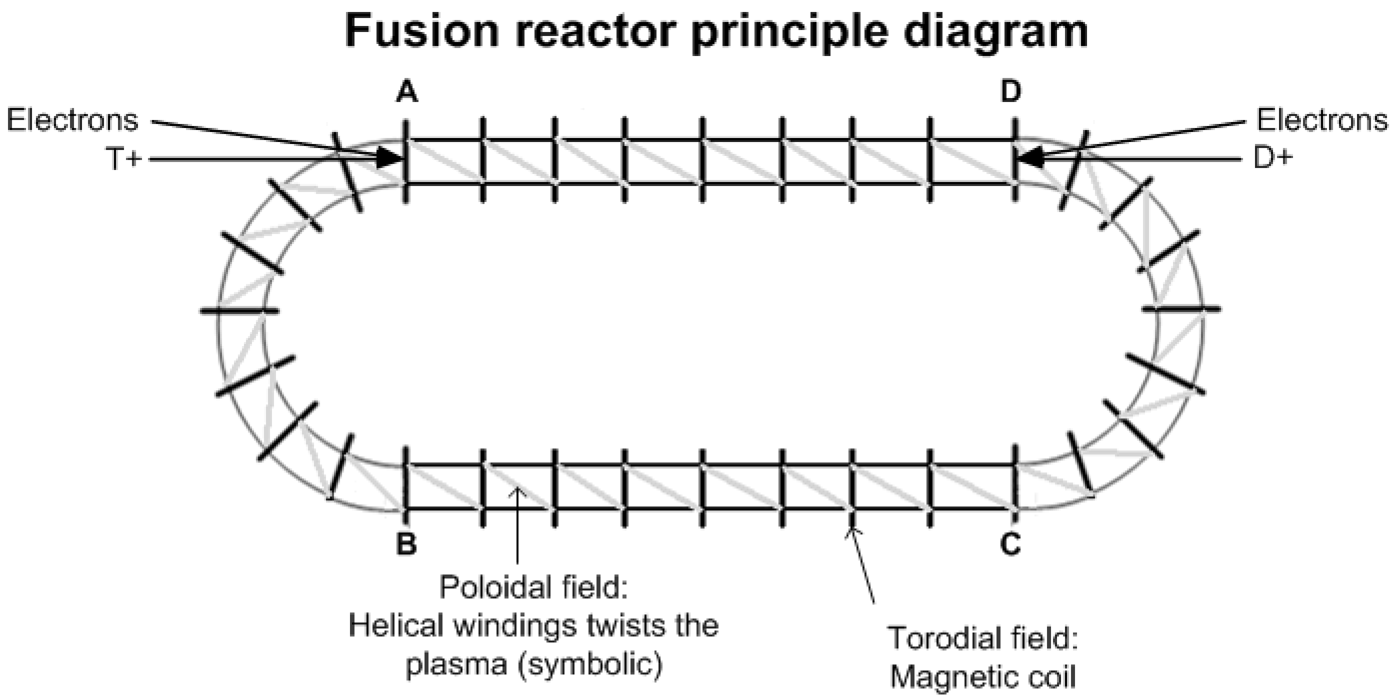

Figure 1

This reactor would produce nuclear fusions with:

- a mechanical gain, i.e. kinetic neutrons power/ mechanical injection power, superior or equal to 18,
- an electrical gain, i.e. electrical energy supplied by the alternator/ electric energy consumed (auxiliary equipment included) superior or equal to 2.6.

It is supposed the use of a Deuterium/Tritium (D/T) fuel as it is the sole fuel able to give a good electrical gain. This D/T reactor is mainly aimed to produce electricity.

2. Principle of the fusion reactor

2.1 General state

In the standard fusion reactors, mainly Tokamaks and Stellarators, the plasma is in thermal equilibrium (i.e. the speeds follow a Maxwell Boltzmann isotropic distribution, function of the plasma energy), at a mean energy of about 15 keV. At the present time, the maximum mechanical gain obtained by these reactors is a bit below 1.

Less known are the “Colliding Beam Fusion Reactors” (CBFR), as, for example, the « Fusor » and the “Polywell”. For these reactors, the particles are initially injected radially, due to a local electrostatic field, with, ideally, a fixed sufficient magnitude. The natural evolution of the speeds distribution is a certain randomization due to collisions and space charge.
However the plasma not being neutral in these reactors, the space charge limits the maximum ions density and the mechanical gain is very low.

2.2 Proposal

The proposed reactor pertains to the CBFR category of reactors, but with a Stellarator configuration. So it is much less complex than a Tokamak.

To have an important fusion power, the beam must be necessarily neutral so as to escape from the space charge problem which drastically prevents to have a reasonable density of ions (D+/T+). So a mix of electrons and ions is proposed for neutrality.

Ions and electrons are injected with relatively elevated currents, up to the moment when the currents circulating in the figure of “0” reach their nominal values (the global current being nil). In permanent working, the electrons and D+/T+ ions are injected at a rate permitting to cover losses and fusions, so as to keep the beam neutral.

However injecting fast ions in a static electrons cloud with a sufficient energy will be useless, as most of the ions energy will be lost on electrons collisions. So the electrons must move at a sufficient speed, to reduce the stopping effect of these ones.
Moreover, if electrons are sufficiently fast, the Coulomb collisions between ions and electrons permit equilibrium of energy between all these particles.

D+/T+ ions are injected in opposition at the same speed and form a neutral beam with the injected electrons. Ions produce, at least at the beginning, frontal fusions D+ <-> T+, aside to Coulomb collisions. The beam turns in a magnetic closed loop in form of figure of “0” (see the figure 1).
After thermalization, the particles will turn on the loop in one direction or the other, randomly.

> Note 1: there is no net plasma current in this reactor because sources of current of the same magnitude are opposed (D+ with T+, and the two injections of electrons). So it will not appear disruptive instabilities, unlike Tokamaks. However, there is a bootstrap current, in the loops, which must be minimized in the same way as for Stellarators.
>
> Note 2: the reactor filling (electrons + ions) is made without any strong recommendations about the beam diameter. However, the replacement ions (for ions lost or fused) are injected at the center of the pipe, inside a 1 cm beam diameter as a first hypothesis, but in any case the most centralized possible, so to have the largest possible confinement time and a good probability of fusion.

Ions fusions (between D+ and T+) are produced:

- for a very small part, by frontal collisions, at low mean ions energy Ei (i.e. Ei around 34 keV), between injected ions not yet thermalized,
- for the rest, by central collisions, at high mean ions energy (i.e. Ei around 68 keV), between ions thermalized (completely or not).

The plasma is slowly heated by Alphas (He4) particles, up to energies (Ei ≈ 68 keV) where the central fusions are made at a condition very close to the ideal one (i.e. at a center-of-mass energy of 65 keV, about 4 times higher than in Tokamaks).
Once this state (Ei ≈ 68 keV) reached, the replacement particles can be injected at relatively low energies.

In these conditions, the fusion rate will be about 30 times better than in present Tokamaks.

2.3 About the plasma and the magnetic fields

The plasma density will be limited to 1E20 ions/m^3 so as to be compatible with the standard industrial structure materials and not to pass a Beta factor (related to the diamagnetism of particles rotating around the axial magnetic field lines) of 0.1. Therefore, the ions and electrons densities will be limited to 5E19 particles/m^3.

The toroidal magnetic field (B) must be axial relatively to the pipe, and maximum to confine particles (electrons + ions). The present industrial maximum B limit for superconducting coils is 5 T (Tesla). So this 5 T field will be supposed, as the default value.

> Note 1: if it appears that the Beta limit for this reactor could be raised up to a value higher than 0.1, it would be possible to consider a lower magnetic field. For example, for Beta max=0.82, it could be envisaged to work with a field of 1.4 T, i.e. with the maximum B field of permanent magnets.

Note 2: the consumed cryogenic power for superconductive coils (and thermal shield) will probably be the biggest source of auxiliary power. Now as, roughly, the cryogenic electric power for superconductive coils depends on the pipe radius (Rp) and the power supplied by the reactor depends on Rp^2, it will be advantageous to make big units.

At fusion densities, a poloidal field is indispensable to limit the particles shift inside loops (see the figure 1).

2.4 Simplified working and energy balance

The working is continuous, the fusion reaction being: D+ + T+ ->He4+ (+3.5 MeV) + n (+14.1 MeV)

A part of the Alpha particles (He4) kinetic energy is used:

- to heat the plasma cooled by radiations (Bremsstrahlung) and particles losses and consequently,
- to bring the plasma to an equilibrium state and then to maintain this one, in this state.

Once the equilibrium state (near Ei=68 keV) reached, replacement particles (ions in fact for the very big majority) are injected at relatively low energies. For example, D+ ions could be injected axially at 12 keV, T+ ions at 18 keV but in the opposed direction and electrons at 14.4 keV, in both directions.

The rest of the fusion power is shared into 2 parts:

- the rest of the Alpha particles (unused) lost in the pipe wall or in the Divertor,
- the neutrons kinetic energy transformed in heat inside the Lithium blanket, this heat being used by the water/steam circuit (mainly boiler, steam generators and turbine), to finally supply electricity thanks to the alternator.

The following figure summarizes the reactor energy balance, from which the mechanical gain is calculated.

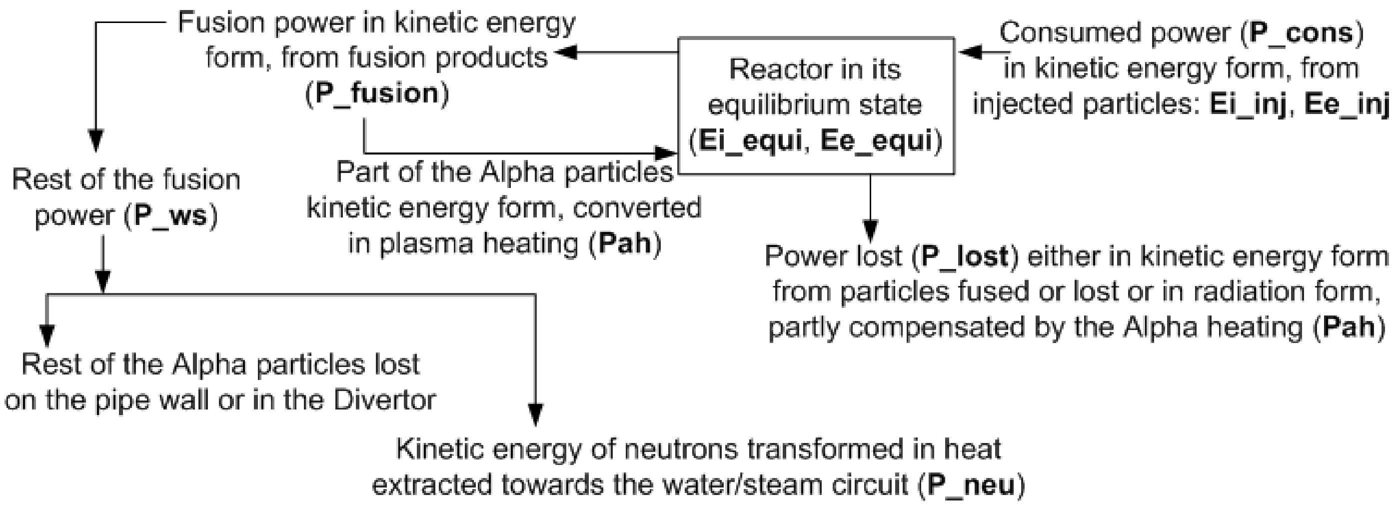

Figure 2

3 Conclusion

This type of reactor, synthesis of a Stellarator and a CBFR reactor, could, perhaps, be a solution for massive electricity production.