Magnetic Confinement of the Plasma Fusion by Tokamak Machine

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ABSTRACT

The thermonuclear fusion is realised by a main technique of magnetic confinement of the plasma fusion. This reaction has for object if the production of energy. After many researches, the scientists have found that the most promoter configuration is the Tokamak machine which permits this reaction of fusion in similar conditions to the one of reactions in the sun.

Keywords: thermonuclear fusion, magnetic confinement, plasma, energy, Tokamak, Lawson criterion.

1. INTRODUCTION

The thermonuclear fusion by magnetic confinement has for objective the production of energy while using some similar reactions to those that produce the energy of stars, reactions of fusion take place in a middle of 100 to 200 millions of degrees, it call plasma. A crucial objective of current research is the understanding and the modelling of mechanisms of transport of the energy and particles within plasma. To achieve the controlled thermonuclear fusion [1], it is necessary to concentrate efforts on the research of a profile that permit these reactions is the Tokamak.

2. PRINCIPLE OF THERMONUCLEAR FUSION

The nuclear fusion constitutes the mechanism to the origin of the star radiance and in particular of the Sun. Indeed, within stars, the light cores merge and produce a heavier cores [1]. During this reaction of fusion, the mass of the core produced is lower to the sum of masses of the original light cores. The difference of mass is converted to energy by the celebrate relation of Einstein [2]:

$$\Delta E = \left(m_i - m_f\right)c^2 . \qquad (1)$$

This converted energy is the origin of the heat and light that we receive. Although the energy freed by the nuclear fusion was considerable, the reactions of fusion don't produce spontaneously, of the less in conditions of temperature and pressure to which we are accustomed. Thus, the probability to observe a reaction of fusion between two cores of hydrogen on the surface of the earth is nearly hopeless. Indeed, to merge, cores, that are charged positively, first must defeat their natural tendency to repulse. It is possible when matter is in the extreme conditions as within the Sun. The main reactions of fusion are:

$$\begin{aligned} &D + T \rightarrow 4He(3.5\ MeV) + n(14.1\ MeV),\\ &D + D \rightarrow 3He(0.82\ MeV) + n(2.45\ MeV),\\ &D + D \rightarrow T(1.01\ MeV) + p(3.02\ MeV),\\ &D + 3He \rightarrow 4He(3.7\ MeV) + p(14.7\ MeV). \end{aligned}$$

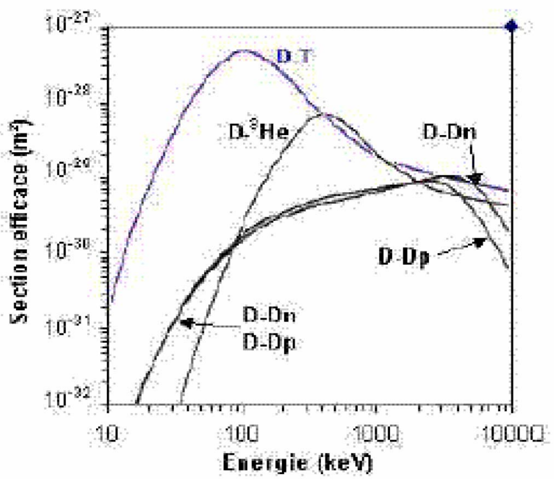

Fig. 1. Section efficient of the different reactions of fusion.

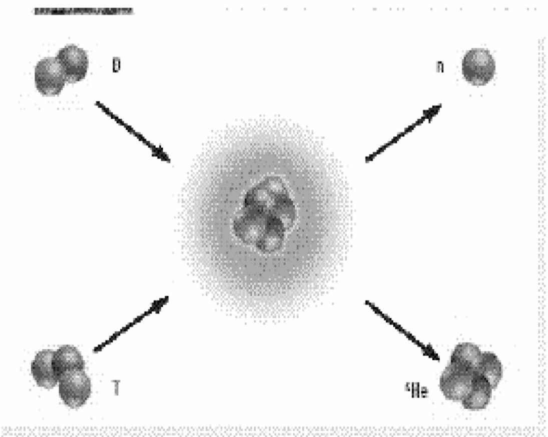

Fig. 2. The reaction of fusion thermonuclear D-T.

The figure 1 presents the efficient sections of different reactions of the fusion mentioned above [3] according to the energy of deuterium. Among these the D-T reaction (Fig. 2) appears the most attractive since it necessitate a least energy between the reagents. The mass of the helium core is lower the one of the two cores of which it is descended, deuterium and tritium. The energy required for a D-T reaction approach the 100 keV.

2. 1. The Power's Equilibrium

The fusion power of a D-T plasma per unit of volume is function of the efficient section of the reaction as well as of density of volume of each reagent. 4/5 of this power are carried by neutrons under kinetic energy shape, the remainder is carried by the particles α. As we will see it in a machine to magnetic confinement, the neutrons leave plasma while the particles α; are confined by the magnetic field [3],[4]. Then, they are going to give up their energy to the middle and so to heat plasma that receives therefore power Pa proportional to the fusion power. Losses of all origins are characterized a time of confinement of the energy τ_E the time that puts plasma to empty itself of its heat if one cuts the source of energy brutally.

$$P_{losses} = \frac{W}{\tau_E} \tag{2}$$

So if P_{add} the additional power applied from the exterior of plasma to heat it, the energetic equilibrium was positive $P_{add} + P_a \geq P_{losses}$ and if the equilibrium is null, sources are equal to losses and our plasma does not provide us of energy that we can use.

2.2. Ignition and the Lawson Criterion [4],[5]

One defines the factor of Q amplification by the equation

$$Q = \frac{P_{fusion}}{P_{add}} \tag{3}$$

If $Q < 1$, the power of the fusion reactions is inferior to the power brought by heatings (additional),
If $Q = 1$, the power of fusion reactions is equal to the power brought by heatings. This state is known under the name of the break even, it is the present goal of researches. In other terms, the heating of plasma is assured by its particles α,

If $Q > 1$, the power of fusion superior reactions to the power brought by heatings. In this case we will reach the state of ignition, the power of fusion reactions will make up for alone losses. The exterior power is not more useful and we have infinite factor Q. Plasma is “auto- kept” and we will have our nuclear fusion reactor. In these conditions and for a temperature of 10 keV the Lawson criterion verifying (2) writes :

$$n\tau_E = 10^{20}\,\text{m}^{-3}\text{s}. \tag{4}$$

3. PLASMAS DE FUSION CHARACTERISTICS

For studying characteristic of plasma fusion of D-T, we consider an electromagnetic plane monochromatic wave in plasma such as the equation of propagation of an electromagnetic ensues of Maxwell's equation and it is express by the relation:

$$\vec{k} \Lambda \vec{k} \Lambda \vec{E} + \frac{\omega^2}{c^2} \overline{\overline{\varepsilon}} \vec{E} = \vec{0}, \tag{5}$$

where $\vec{E}$ is the electric field and $\overline{\overline{\varepsilon}}$ is a dielectric tensor of plasma such as:

$$\overline{\overline{\varepsilon}} = \overline{\overline{I}} + \frac{i\overline{\overline{\sigma}}}{\varepsilon_0 \omega}. \tag{6}$$

In general the wave is propagates perpendicularly to the exterior magnetic field $\left(\vec{k} \perp \vec{B}_0\right)$ and one gets in this case the system of equations:

$$\begin{bmatrix} \varepsilon_1 & -i\varepsilon_2 & 0 \\ i\varepsilon_2 & \varepsilon_2 - N^2 & 0 \\ a_{31} & 0 & \varepsilon_3 - N^3 \end{bmatrix} \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} = 0. \tag{7}$$

The refractive index [6] is defined by $N = \frac{kc}{\omega}$ and the elements of relative dielectric permittivity $\overline{\overline{\varepsilon}}$ is giving by the expression of $\varepsilon_1 = 1 - \frac{\omega_{pe}^2}{\omega^2 - \omega_{ce}^2}$, $\varepsilon_2 = \frac{\omega_{ce}}{\omega}\frac{\omega_{pe}^2}{\omega^2 - \omega_{ce}^2}$ and $\varepsilon_3 = 1 - \frac{\omega_{pe}^2}{\omega^2}$, where $\omega_{pe} = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$ is the electronic plasma pulsation (view Fig. 3) and $\omega_{ce}\frac{eB}{m_e}$ is the electronic cyclotron pulsation.

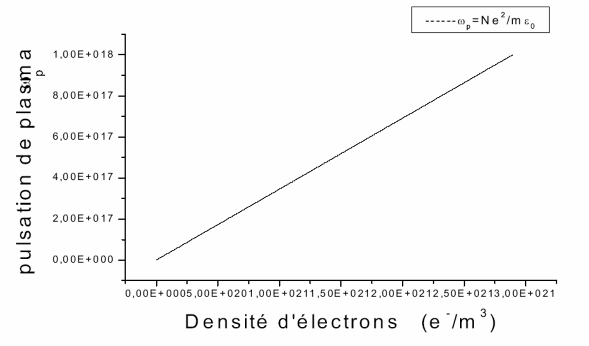

Fig. 3. The electronic plasma pulsation.

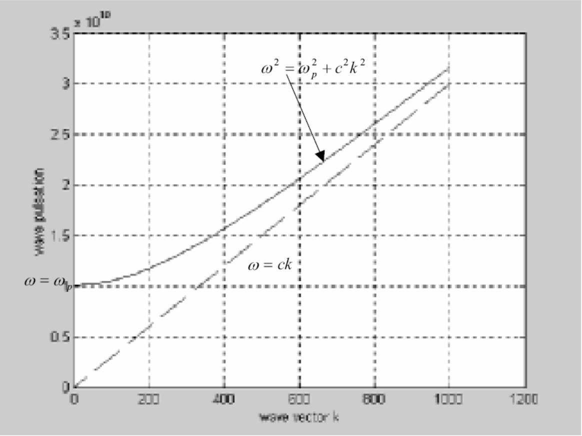

Fig. 4. Dispersion curve for a plasma.

In Fig. 4 it is shown that for $\omega > \omega_{pe}$, we have propagation and for $\omega < \omega_{pe}$, we have an evanescent wave.

The system of equation (7) presents no trivial solutions if its determinant is nul. One gets so the general scattering relation [7]:

$$\left(\varepsilon_3 - N^2\right)\left(\varepsilon_1 - N^2\varepsilon_1 - \varepsilon_2^2\right) = 0 \tag{8}$$

This equation admits two solutions corresponding to two modes of polarization: ordinary mode and extraordinary mode. For ordinary mode, the solution of equation (8) is $\varepsilon_2 = N^2$, therefore

$$N_0^2 = 1 - \frac{\omega_{pe}^2}{\omega^2}. \tag{9}$$

In ordinary mode, the propagation of the wave depends only of the density of plasma. The extraordinary mode is defined by $\varepsilon_1^2 - N^2\varepsilon_1 - \varepsilon_2^2 = 0$, where

$$N_x^2 = 1 - \frac{\omega_{pe}^2}{\omega^2}\frac{\left(\omega^2 - \omega_{pe}^2\right)}{\left(\omega^2 - \omega_{pe}^2 - \omega_{ce}^2\right)}. \tag{10}$$

The index of refraction is depending of electronic plasma pulsation and electronic cyclotron pulsation that depend at its tower of the exterior

4. THE MAGNETIC CONFINEMENT

Plasma is a fluid electrically conductor, but neuter globally, and in which ions and electrons nearly move independently the some of others. Dived in a magnetic field, they are going to follow trajectories in shape of indications that roll up around lines of field and remain there trapped. It is the principle of the magnetic confinement [4].

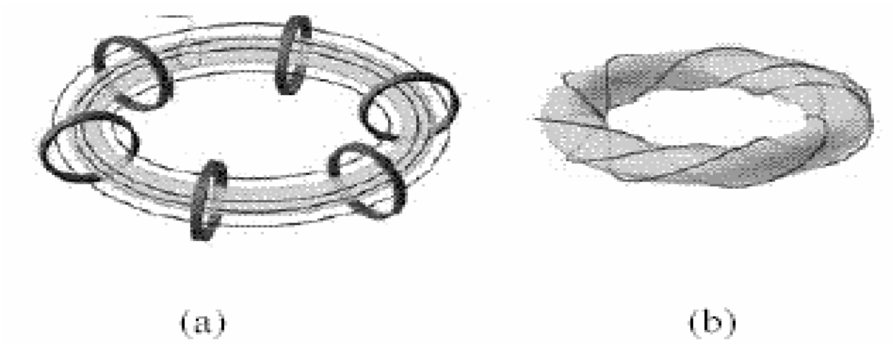

Fig. 5. Magnetic confinement principle.

The hot and dense plasma to the breast of which takes place reactions of fusion must be isolated of the surrounding wall that containing it in order to avoid foulness that can cool it. Therefore figure 5 present the method employee to trap particles of plasma thanks to an adapted magnetic profile. Knowing that the loaded particles roll up around the field lines therefore transversely to the magnetic field, these particles are enlivened of a cyclotronic movement of frequency sketched in Fig. 5.

Their movement the long of field lines remains free and they can run away therefore by extremities of the profile for it as closing again the magnetic limps to form a tore (a) while applying a toroidal field . However that is not sufficient in such a configuration particles are enlivened of a vertical drift speed that lets escape plasma. For it one adds a magnetic field said perpendicular poloidal to field toroidal so that lines of field must be helical so that the drift is compensated during the movement (b).

5. MACHINE OF MAGNETIC CONFINEMENT:TOKAMAK

The Tokamak is a thermonuclear fusion instrument developed first in USSR. Big Tokamaks were constructed and functioned in several countries (France, Japan, Big Brittany) and several new machines are in progress of construction. In a Tokamak [8], as the shows the figure 6 [4, 3]the loaded particles that constitute the hot plasma are confined inside by a magnetic field of a tore. The magnetic strengths acting on particles in displacement of plasma prevent the plasma to touch wall of the room. The current that generates the magnetic field is misled in plasma himself and is heated it at the same time. However, an auto-kept thermonuclear reaction doesn't have been able to again be get (reaction that doesn't produce more energy than it consumes some). From the figure 5, the field magnetic poloidal is creates by a current circulating toroidal in plasma himself, that becomes the secondary of a transformator.

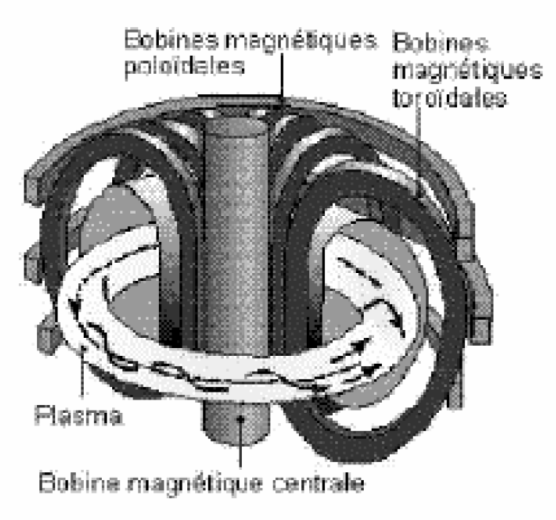

Fig. 6. Tokamak configuration.

6. CONCLUSION

In the present article, one concludes that the fusion is conditioned by the Lawson criterion that requires a product density - minimal confinement time, it presents the Tokamak in so much that device to magnetic confinement the more promoter. On time where the energetic needs of an worldwide population don't stop increasing, the research of alternative energy sources imposes more and more to satisfy the demand. It is in this setting that the controlled thermonuclear fusion appears as being a solution extremely viable to long term for the electric energy production. This project « ITER » consists to construct a « Tokamak » machine in France, that should constitute the biggest scientific yard of this century.

But, although the reaction of fusion produces in herself no radioactive loss, neutrons products during the reaction of fusion, make that the structure interns of the power station herself becomes radioactive while it functions, at the end of the length of life of a fusion power station, these parts of the reactor must be disassembled and must be stocked during about hundred years.

REFERENCES

[1] F.D. Escande, “Thermonuclear plasma magnetically confined “, Laboratory P2IM, CNRS. Marseille (2004).
[2] G. Bonhomme, “Heating by waves in Tokamaks “, presented at Conference, 6th days of the Network Cold Plasmas, Bonascre, 2-5 Oct. 2007.
[3] Address web http://fused.ppl.gov/cpec/chart.html, "Fusion", CPEC- Fusion-USA 1997.

[4] M. Chatelier, P .Magand, "The fusion by magnetic confinement", Magazine CLEPS CEA-N° 49, spring 2004.

[5] G. Tresset, "*Characterization, Modelling and Control Advanced Script in the JET Tokamak*", Ph.D. Thesis, Marseille 2002.

[6] R. Dumont, "Waves in the plasma of Tokamak, interaction wave-plasma, maser radiation, plasma and astrophysics", Association Euratom-CEA, pp. 15-20, 25 Feb. 2005.

[7] V. Laure, "*Measure of Magnetohydro-Dynamic Activity and the Micro-Turbulence by Reflectometry*", Ph.D. Thesis, University of Henri Poicare, Nancy, 13 April 2005.

[8] S. Kehtari, "Nuclear Fusion & Tokamak", PPT presentation, 2003.