§40. Large-Scale Numerical Simulation of Direct Energy Converters for Fusion Reactors

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1. Brief Summary of Self Excitation of Travelling Wave

A conceptual design of the whole system of a D-^{3}He FRC fusion reactor has included two kinds of direct energy conversion schemes. A cusp type direct energy converter (CUSPDEC) will separate electrons and fusion proton ions, whereas the travelling wave direct energy converter (TWDEC) will convert the kinetic energy of fusion protons into a high frequency AC electric power. The basic configuration of TWDEC is a cylinder with a length of 30 m and a radius of 5 m, consisting of a modulator and decelerators, where the total energy input into the TWDEC is 272.5 MW, the frequency of travelling wave is 8.54 MHz, and the total number of grids is 32. The momentum conservation equation of fusion proton ions, Poisson's equation for the electric field including the space charge effect, and electric circuit equations of external control circuit are used in the one-dimensional approximation. The designed external circuit can yield the self-excitation of the travelling wave, showing that the maximum value of grid potential of 1.0 MV results in the maximum conversion efficiency of 70.9 %, while further optimization has yielded over 74 %.

2. Loss Mechanisms of TWDEC

2.1 Two-Dimensional Effects

Axisymmetric two-dimensional analyses are carried out, where the external electric circuits are not included and the effect of magnetic field is included. Cylindrical grids are made of five co-axial, cooling-water circular pipes of 1 cm diameter and the ratio of open space for protons is 99.2 % for each grid. The maximum efficiency of 65.5 % has been obtained with the grid voltage of 1.7 MV when the collision loss with grids is neglected. The reduction of efficiency is about 5.4 % due to the two-dimensional effect.

2.2 Collision Loss with Grids

The maximum efficiency becomes 54.7 % with the grid voltage of 1.4 MV when the collision loss is included. The optimum grid voltage decreases, simply because the higher voltage enhances the two-dimensional effect and the collision of protons with the grids. The reduction of efficiency is about 10.8 % due to the collision with grids.

2.3 Secondary Electrons

When the protons collide with the grids, the secondary electrons are produced. The copper is selected for the grids. The guiding-center approximation is used for the electrons. The averaged loss is about 1 % of the input kinetic energy of protons, and the energy is bounced between the electrons and the electric field of travelling wave. As a result, the effect of secondary electrons can be neglected.

2.4 Leakage of High Energy ^{4}He

The D-^{3}He reaction will also produce the 3.6 MeV ^{4}He's. It is assumed that the total energy of leaked 3.6 MeV ^{4}He ranges from 0.1 % and 10 % of the total kinetic energy of protons. It is shown that the reduction of produced AC power is about 60 % of kinetic energy of leaked 3.6 MeV ^{4}He. The leakage of 3.6 MeV ^{4}He should, therefore, be maintained as small as possible.

Reference

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2) Ishikawa, M., Kudo, T., Hayashi, S., Yamane, T., Tomita, Y. and Momota, H., Fusion Engineering and Design, **41**, (1998) 541-546