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Numerical Exploration into Feasibility of Current Drive by Synchrotron Radiation in Tokamaks

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Tokamak, one of the leading concepts for theremonuclear fusion, requires plasma current to maintain burning plasma condition. At plasma start-up phase, the plasma current is driven inductively as varying magnetic flux created by a center solenoid coil. A challenge in tokamaks is that the inductive current drive is not available for long pulse operations. Therefore, great efforts have been made for improving non-inductve current drive techniques, e.g., electron cyclotron current drive (ECCD) and neutral beam current drive (NBCD) systems. The power required for the current drive in demo reactors can be as high as 100 MW [1], being a major concern for the feasibility of tokamak type fusion reactors. This study is motivated to improve current drive efficiency by using synchrotron radiation (SR).

In demo reactors, unlike conventional tokamaks, a large amount of stored energy will be emitted by SR. Waves emitted from the plasma are reflected at the first wall and subsequently re-enter the plasma, where they are absorbed via the same mechanism as ECCD; this process is referred to as SRCD. Utilizing SR may help reduce the power needed for current drive. This idea has been investigated in the early 80s [2].

However, the absorption of high-order harmonics contained in SR has only been partially evaluated. Therefore, the objective of this study is to assess the feasibility of SRCD through numerical analyses of high-order harmonic absorption and current drive performance, targeting the JA DEMO plasma.

In this study, the radiation transport code CYTRAN [3] was used to calculate SR. CYTRAN allows for the consideration of plasma spatial distribution using magnetic surface-averaged values. Based on equilibrium data from JA DEMO, relevant parameters were set for the calculation.

Figure 1 shows the SR spectrum calculated by CYTRAN. Strong emissions can be confirmed up to 1000–1500 GHz, with a total radiated power of 72 MW. Then, we analyzed propagation and absorption using the TRAVIS code [4], with the assumption that the electromagnetic wave corresponding to this power spectrum is launched from the first wall. TRAVIS takes into account plasma geometry and parameter profiles.

The analysis is conducted under conditions that maximize the utilization of SR power—specifically, assuming that all SR is reflected from the region on the low-field side equatorial plane (Fig. 2). Wave absorption depends on altitude and azimuth angles. In this study, the azimuth angle was varied from 0 to 65 degrees while the altitude angle was kept at 0 degrees.

Figure 3 shows the driven current as a function of the incident angle of the SR. The calculation indicated that a maximum driven current of 0.5 MA is achieved when the incident angle is set to 33 degrees. These results suggest the potential effectiveness of SRCD.

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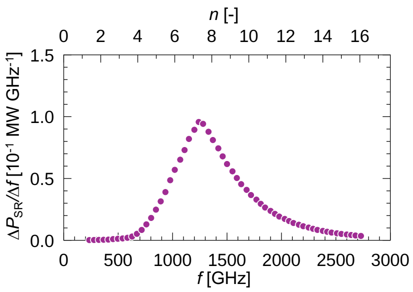

Fig. 1 SR spectrum. f represents frequency, n is the harmonic number ($n = f/f_c$), and P_{SR} denotes the radiated power.

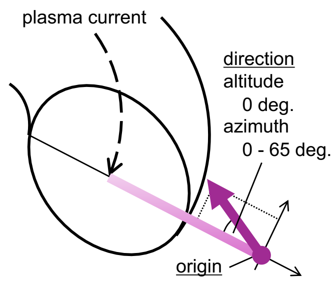

Fig. 2 SR incident conditions. Toroidal symmetry allows limiting incident azimuth angles to the range of 0 to 65 degrees.

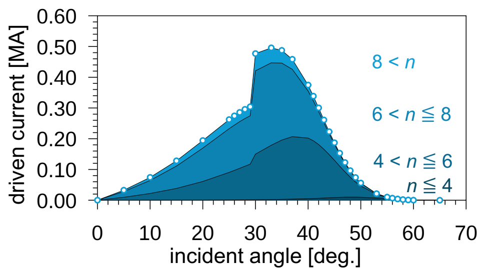

Fig. 3 Driven current as a function of the SR incident angle. Each colored region indicates the contribution from the corresponding frequency range (e.g., $n \leq 4, 4 < n \leq 6$, ...).

References
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