Development of Operation Scenario for Spherical Tokamak at SNU

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1. Introduction

Several concepts for nuclear fusion plant exist. In these concepts, tokamak is the most promising one to realize nuclear fusion plant. Though tokamak has leading concept, and this has world record in fusion heating power, tokamak has the critical drawback: low heating efficiency. That is the reason why we need another alternative concept which compensates tokamak's disadvantage. Spherical Torus(ST) is one of these kinds of concepts. ST is a kind of tokamak which has low aspect ratio. This feature gives ST advantages compared to conventional tokamak: high efficiency, compactness, low cost[1]. However, ST lacks central region for solenoid that is needed to start-up and sustain. Since it is the most efficient that initializing and sustaining by using solenoid, this is ST's intrinsic limitation. To overcome this, a new device which can start-up and sustain ST plasmas by means of continuous tokamak plasma injection has been designed.

2. New Concept and Possible Scenario

In this section, the new concept device for ST plasma generation is introduced. Also, from TSC (Tokamak Simulation Code [2]) simulation, possible operation scenario from the new concept will be stated.

2.1 Partial Solenoid Operation

In this study, we will try different approach for ST. Other research teams are looking for other start-up and sustaining methods instead of inductive method, in contrast, we will modify solenoid start-up to be appropriate for ST. Assuming that operation region and start-up region are separate in the chamber; we can make enough central regions for solenoid in start-up region keeping low aspect ratio for ST in operation region. This operation is named as partial solenoid operation. There are two start-up regions at both ends in partial solenoid operation. Plasmas for fusion reaction are made at both ends by using solenoids, and then two plasmas at both ends are going to be pushed by electromagnetic force from external coils. Finally, two plasmas are merged in the middle region, and ST is obtained through this merging process.

From this start-up, we do not have to give up inductive start-up method which is powerful method so far, and can use the ST’s merits; high efficiency and compactness.

2.2 AC Plasma Injection

If ST plasma in the middle is sustained during partial solenoids at both ends are charged-up, AC plasma injection from partial solenoids will be possible, which can be the efficient sustaining mean. From TSC code, ST plasma in the middle can be in equilibrium state, after partial solenoids are charged up. Figure 1 is the result of TSC code.

From this result, it is possible to use partial solenoid operation not only for start-up ST plasma, but also for sustaining and ramping-up plasma current.

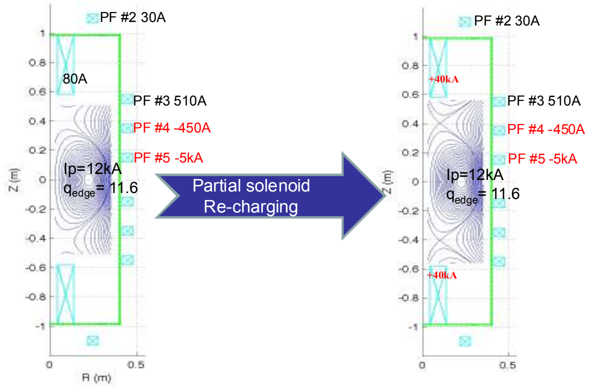

Fig. 1. Result of TSC code, the left picture shows the equilibrium state after ramping down partial solenoids, and the right one is the equilibrium state after re-charging-up partial solenoids.

2.3 Considerations for AC plasma injection

Even though, plasma can be in equilibrium after charging-up the solenoids, there are other obstacles to accomplish injecting plasma continuously.

To begin with, plasma should survive during charging-up phase of solenoids. The designing device is not big, thus the particle and energy confinement time is not long. Also, during charging-up phase, it is the negative voltage compared to plasma that is generated inductively. This negative effect will accelerate the decay of ST plasma current.

Therefore, we should consider other ways to sustain plasma during charging-up phase. Non-inductive way such as wave heating would be great way to sustain plasma. However, constructing wave heating system is another painstaking issue. The possible way for sustaining plasma is another solenoid. This solenoid should be thin and long to supply enough loop voltage to plasma as well as to avoid damaging low aspect ratio of device and plasma.

To confirm the role of thin solenoid, circuit simulation code including eddy current effect is developed. In this code, plasma is regarded as single filament which has Spitzer resistivity. From the result of this code, sustaining plasma by long solenoid is assured. Figure 2 shows the new geometry by adding long solenoid and the circuit simulation code result.

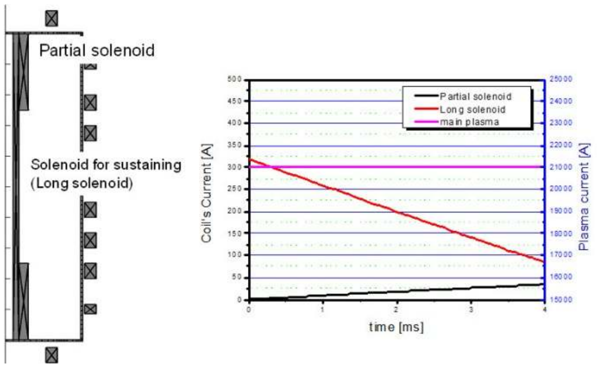

Fig. 2. New geometry including long solenoid (left) and circuit simulation result when plasma current is 21kA (right).

2.4 Outline of Operation Scenario

Based on partial solenoid operation and the above considerations, outline of operation scenario is developed. Figure 3 shows the specific waveforms of solenoid and plasma during operation. Solenoid design is performed considering breakdown condition[3] and volt-second consumption[4], and then waveforms are obtained from circuit simulation.

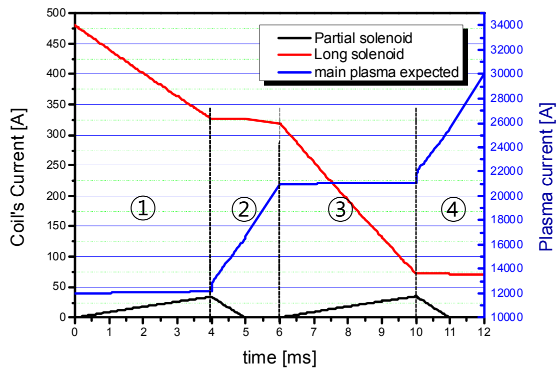

Fig. 3. Specific waveforms of operation scenario (12kA plasma generation is assumed.)

In figure 3, the scenario has four phases except for start-up phase. The assumption in this scenario is that 12kA plasma is generated by merging from partial solenoid operation. The first phase is solenoid charging-up phase. In this phase, loop voltage to sustain plasma should be supplied. Partial solenoid is charged up to enough volt-second to ramp up 4.5kA plasma. The second phase is plasma current ramp-up by merging phase. Charged partial solenoids are ramped down, which results 4.5kA plasma near the both ends of chamber. From merging process of these two small plasmas and 12kA plasma, plasma current will increase up to 21kA from 12kA. The third and last phase is same as the first and second phase. Through these phases, plasma current would increase up to 30kA. This scenario would be the initial scenario of our device, and by complementing power supplies for solenoids and heating system, the target plasma current will increase than initial value.

To confirm the feasibility of scenario, equilibrium state is obtained from TSC code. From the result of simulation, position of plasma should be moved at each phase due to stray field of long solenoid. Figure 4 shows the result of equilibrium analysis.

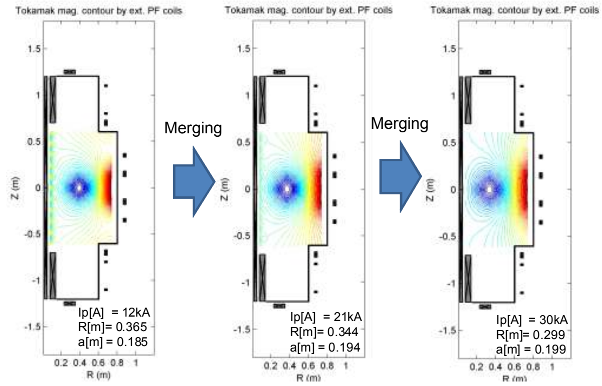

Fig. 4. Equilibrium analysis results from TSC code

3. Conclusions

The new concept for start-up ST plasma and the scenario in the new concept device are developed by using two different codes. From simulation results, it is concluded that AC plasma injection scenario in partial solenoid operation is possible. Experimental verification of the operation will be demonstrated in near future.

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