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Requirements for the Control of DEMO Reactor and its System Research and Development
核融合原型炉に求められる制御要件とシステム開発

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The mission of the DEMO reactor is to demonstrate electricity production in a power plant level. The key issue for the control of the power plant is how to maintain a constant fusion power output. However, the diagnostic measurements would provide poor information due to a heavy DEMO neutron and gamma radiation environment. For compensation, the control system has to be supported by the intelligent simulation codes that predict plasma behavior. A long range program for the codes development has to be established as one of the most critical R&D for the DEMO reactor. It is also required for the fusion researchers to make research plans with a clear recognition of code validation toward the DEMO.

1. Introduction

There are several critical issues toward DEMO fusion reactors. These issues were discussed more extensively in a published text book on fusion reactors [1]. However, because of the urgent issues for on-going programs or for ITER issues, it has not been discussed for quite a long time on how we can control the fusion power plant in a steady state. It does not mean that the issue is the tokamak current drive. We assume that any problem on the current sustainment facing today can be solved by the time of DEMO stage. Yet we have to recognize the importance of the control of power plants for electricity generation.

2. General Requirements

As decided by the report of the Japan Atomic Energy Committee, the mission of the fusion DEMO reactor is to demonstrate electricity generation in a plant scale [2]. It is also understood that the DEMO is the last integrated R&D machine before commercial reactors [3]. This requirement imposes an additional mission to the DEMO reactor, namely, "an appropriate level of economical perspective leading to commercialization". The DEMO plant will have control knobs such as coil currents, heating/current drive system power, neutral gas input, etc. How can we keep the constant fusion output by controlling these knobs? To do so, the control system has to know the response, an explicit form of the function in terms of variants of actuators . The feedback or feed forward control signal should be continuously sent to keep P_f $(A_1,A_2,A_3,\ \ldots.)$ = const. The machine operating reference point will be chosen on the multi-dimensional curved surface of the function P_f. Thus, by the time of the start of operation of DEMO reactor, a functional form for the plasma control has to be known and defined clearly.

This simple consideration will lead to more pragmatic requirements.

1) The multi-dimensional surface should be as simple as possible. This means that the number of actuators should be minimized and control logic must be simple to avoid conflicts among actuators.

2) The operational limit has to be known in advance on this multi-dimensional surface to protect the machine from abnormal event such as disruption, sudden termination of the plasma. With the help of such information, the operation point will be chosen at a reasonable distance apart from

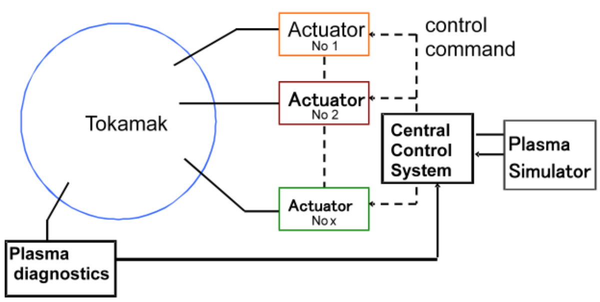

Fig. 1 Control system for DEMO with intelligent plasma simulator

the operational limit.

3. The Environment for the DEMO Reactor

In order to satisfy the requirement "appropriate level of economical perspective" for DEMO, following consideration has to be incorporated into the DEMO design.

1) The tritium should be self supplied. This requires a high tritium breeding ratio, in a range of 1.05 overall.

2) The machine should be operated at a higher plasma pressure than ITER in a steady state mode.

One may note that the DEMO reactor is the first integrated machine of all the components needed for the commercial reactors, but it is also the first integrated machine to be operated in steady state and truly burning state at high Q value (The ITER will be operated only at Q~5 in steady state mode.). Therefore, the neutron environment is much harder, higher than ITER 5 times by flux, and 100 times in order by fluence.

Such an environment will allow the diagnostic system to a restricted space and location. In particular, the position of the magnetic diagnostic system such as magnetic probes or loop coils to control the position of the plasma would be of a great concern.

If information by the diagnostic system is much poorer than we could expect in ITER, in more straightforwardly, if the magnetic measurements can be done only at an insensitive location to the plasma behavior, how can we operate the power plant in steady state with confidence? What can compensate the lack of diagnostic information against DEMO plasma ?

4. Control System of the DEMO Reactor

The Fig.1 shows a possible simple structure of the DEMO control system. The central control system can control all the actuators based on the information measured by the diagnostic system. It may be inevitable for the simulation code system plays an essential role of the DEMO control system to compensate information and predict plasma behavior in real time.

Nowadays a variety of simulation codes have been developed and are under development to analyze and understand toroidal plasma, but the codes required for the DEMO control have to provide what is going on inside the plasma on the basis of insufficient data and also predict precisely the behavior of the plasma. Such codes should be highly reliable, accurate and fast response which can cover every behavior of the plasma. In other words, every plasma behavior must be fully studied and expressed by these codes by that time.

So the issue is how to develop such a huge codes system and how to validate these codes before the actual use in the DEMO operation. Because this is not the issue of choice nor issue of efficiency, the nation that wants to have a DEMO machine must develop such codes as essential element of the machine, just as R&D on the superconducting magnet or tritium breeding blanket. Any existing machine or future machines such as ITER or satellite tokamaks should be used for code validation.

5. Impact on the DEMO Staged Operation

Even with a sufficient development and validation of the codes before the completion of the DEMO reactor, one may encounter a contradictory question whether the developed codes can accurately express the DEMO plasma without validation by the DEMO machine itself. The DEMO construction and operation plan has to take into account of this issue at an early stage..

6. Proposed Study on the Issues

Those issues discussed above are based on the foreseen difficulty of diagnostics of the DEMO reactor. Therefore, primary efforts have to be focused to study a radiation environment a little more precisely. Therefore, the proposal is

1) To study and develop a DEMO radiation map and find possible access of the essential diagnostics, assess their technical feasibility and potentials and identify necessary R&D.

2) For the development of the codes, try to develop a long range development program, and propose sharing and collaboration to the international society, since a level of resources needed would be much bigger than those envisaged until now.

Acknowledgments

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References

[1] "Text Fusion Reactors" JPFR **87** Supplement 2011..

[2] "The 3rd Phase Basic Program on Fusion Research and Development" Atomic energy Commission, 1992.

[3] "C&R of the 3rd Basic Program of Fusion Research and Development" Atomic Energy Commission, Nov. 2005.