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Works Preparatory to Long-Pulse/Steady-State Experiments in LHD

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Abstract

A steady state discharge for more than 1 hour with 3 MW heating power is a goal in the early stage of the LHD project. All the coils are superconducting, the vacuum vessel and the divertor plates are cooled by water, and a long pulse operation in heating devices (ECH, ICRF, NBI) is available. One of the concerns for this operation is an impact of residual microwave power upon rubber gaskets and windows, because the gaskets and/or the windows could be damaged by absorbing the microwave power. In order to avoid an unexpected catastrophe during the experiments due to the microwave effect, a series of tests has been carried out for several types of gate valves and windows with 84 GHz microwave incidence. The results suggest that (1) a gap in a SS flange as narrow as 0.2 mm in front of the gaskets is sufficient to prevent the power penetrating into the gasket region, (2) a fused quartz window absorbs much less power than a kovar-seal window does, (3) a mesh of 100 wires/inch is effective to reduce the power flow to the windows or the gate valves. A simplified detector for the microwave is developed in order to measure the residual power distribution outside a plasma in the vacuum vessel.

Keywords:

steady state operation, microwave absorption, safety for rubber gasket, safety for window, microwave monitor

1. Introduction

In LHD, a long-pulse steady state experiment is planned to demonstrate capability for sustaining high temperature plasmas with its configuration [1-3]. Electron cyclotron resonance heating (ECH) of 84 GHz will be one of the main heating schemes. One MW of the microwave power is planned to be injected continuously to the LHD vacuum vessel. One of the concerns is excessive heat-up and destruction of rubber gaskets and/or windows for diagnostics due to this kind of microwave power absorption. A systematic investigation has been in progress in order to avoid catastrophe with the unexpected events of the microwave absorption. Several experimental results are presented in this paper.

2. Summary of Device Arrangements for Steady-State Operation

In order to realize a steady state magnetic fields, all the main coils are superconducting [3]. The vacuum vessel has cooling channels directly welded to its inner surface [4]. Divertor striking points are covered by carbon tiles, which are bolted to cooling pipes made of stainless steel [5]. All of invessel components will be actively cooled by water, which removes 3 MW power

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in total. The vacuum chamber will be kept below 70°C during discharges. A set of heat shield panel is set between the vacuum vessel and the helical coil case and will be kept at 80 K. In a normal operation, a margin of 7 kW is expected for the refrigerator system of 80 K. Detail in the interlock condition will be under discussion. Local island divertor [6] will be installed in the early stage of experiment in order to provide particle removal function from the plasma.

A continuous microwave power of 1 MW at 84 GHz will be provided for electron cyclotron resonance heating (ECRH) [3]. Two gyrotrons and wave guide systems are now under development for this purpose. A power of 3 MW in radio frequency range will be injected in a steady state, too. Available frequency range is 25 to 90 MHz. This will be used in a scheme of ion cyclotron resonance heating (ICRH) [3]. A prototype feed-through and a launcher have been tested with an RF current equivalent to 1 MW level of the heating power. A long time operation more than 1 hour has been achieved so far [7]. A neutral beam injection (NBI) heating system is designed for 30 minutes operation and ready for commissioning soon [8].

Diagnostic systems are designed to meet the requirement for the long-pulse operation, too. Special care will be paid for windows which absorb radiated power from the plasma. An analysis was made for a required condition of the window cooling. It is reported that a peripheral cooling is effective for a window of which diameter is less than 100 mm [9]. Special arrangement is taken in the diagnostic control system in order to support continuous, real-time monitoring of major plasma parameters during the long-pulse discharge [10].

The goal of the first step is an achievement of a 3 MW, one hour discharge in the early stage of the project.

3. Microwave Absorption by Gaskets

One of the concerns in the long pulse operation is damages due to microwave absorption by rubber gaskets, which are set in the gate valves distributed in the torus. In the high power experiments, at least one MW microwave power is injected to the LHD vacuum vessel. Even if 90% of an injected power is absorbed by the plasma, the residual power is as large as 100 kW, with which precaution is needed for a danger of burning in rubber gaskets because some kinds of rubber could be a good absorber of the microwave power. Relative absorption rate was investigated for 5 types of rubber gaskets at frequencies of 2.45 GHz and 84 GHz. There was a hope that some gaskets other than viton could have a smaller absorption rate for the microwave power. Figure 1 shows results for these gaskets with a microwave power of 500 W at 2.45 GHz. The vertical axis indicates the temperature rise with one minutes irradiation, which corresponds to the relative absorption rate. Difference in the temperature can be seen among different kinds of the rubber materials. The silicon rubber absorbs much less power than the viton rubber does. Figure 2 shows results at 84 GHz with a time averaged power of 500 W and 250 W. No significant difference can be seen in the absorption rate among viton, silicon and crystal rubbers. Thus it has been concluded that no merit is expected with the rubbers other than viton at around 84 GHz range of frequency.

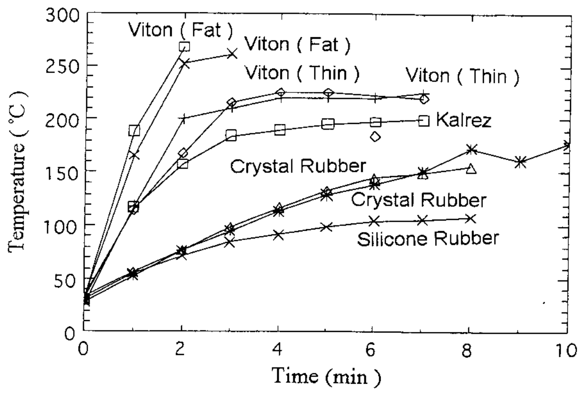

Fig. 1 Temperature rise of gaskets with irradiation of a microwave power of 400 W at 2.45 GHz.

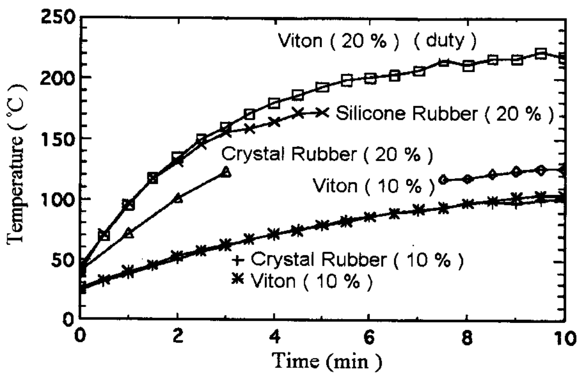

Fig. 2 Temperature rise of gaskets with irradiation of a microwave at 84 GHz. Duty cycle of 20% corresponds to ~ 500 W, and 10% ~ 250W.

Two types of gate valves have been tested at 84 GHz. The power was guided to a test chamber and the valves were irradiated in a similar condition which was expected in the steady state experiments of LHD. If we assume that 10% of 1 MW power is distributed inside a volume of 20 m^3, a bit smaller of the plasma volume in LHD, average volume density of the power is 5 kW/m^3. In this experiment, a microwave with a peak power of around 200 kW was injected to a test chamber of – 0.5 m^3 in volume. Duty cycle was between 1 and 6%. The valves were set on a port hole of 150 mm in diameter. Average port-through power level was checked with a water load and found to be between 200 and 700 W depending on the duty cycle. Figure 3 shows relative temperature rise of the gasket on the two types valves. The valve was closed during the power injection as is seen in the top of the figure. The type A valve has 3 mm gap in front of the gasket while the type B has 0.2 mm. Temperature rise was much smaller in the type B valve than in type A. With the largest power in Fig. 3 for 20 seconds, damages were found on the viton gasket of the type A valve. It was checked that this power level was the threshold of these damages. The damages are distributed on the inner side of the gasket, which indicates that power penetrated through the gap was dominantly absorbed from the inner side. This means that the gap is responsible for the damages. On the other hand, no damage has been observed in the type B after exposure to the largest power for 60 seconds. From these comparison, it has been concluded that the type B valve, which has a 0.2 mm opening in front of the gasket, is much safer than type A with a 3 mm opening. The wavelength of the 84 GHz microwave is 3.6 mm. The gap of 3.0 mm is not small enough to avoid penetration of the power. Critical gap width is not yet clear and is planned to be investigated.

A preliminary test has been carried out for the valves with valve-opened condition. No serious temperature rise has been observed on the gasket so far even with the highest power.

4. Microwave Absorption by Window Materials

The power absorption was investigated for two kinds of window material. The port-through power is around 300 W. Figure 4 shows comparison between a kovar glass window and quartz window. The kovar glass window, which is widely used as a view port, has much larger absorption rate for the microwave power than the quartz window has. It has been observed that

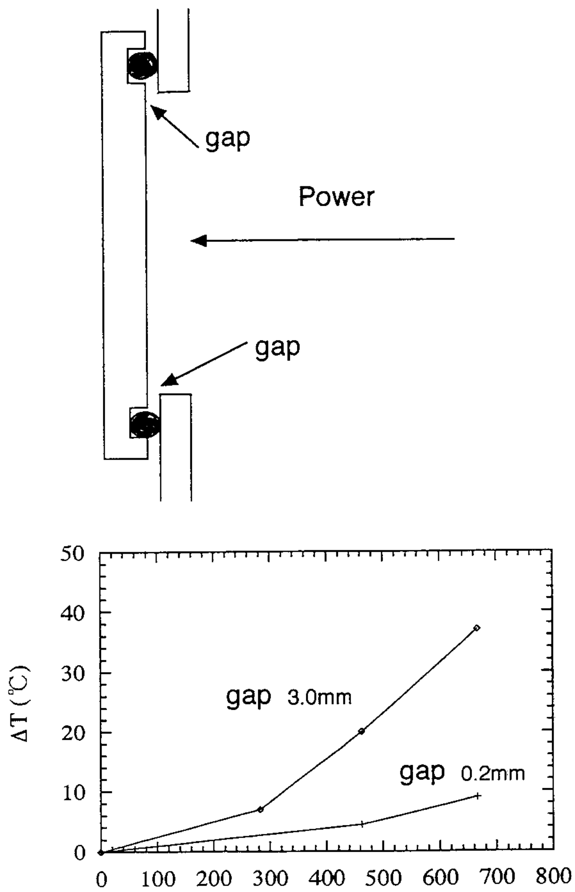

Fig. 3 top: Schematic drawing of geometrical condition in valve-closed mode.
bottom: Relative temperature rise of gaskets in two types of gate valve after 30 seconds irradiation of 84 GHz microwave.
A:width of the gap is 3 mm, B: 0.2 mm

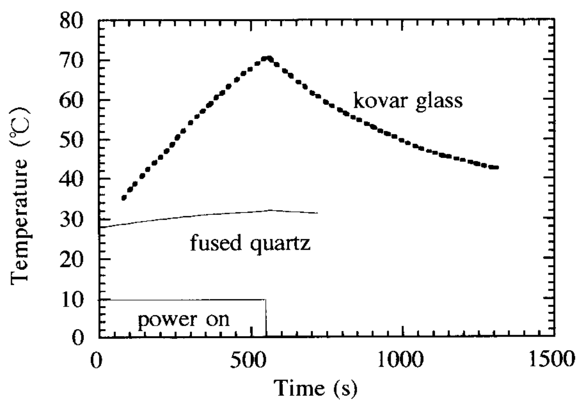

Fig. 4 Temperature behavior with time on two windows. The port-through power is 300 W.

the kovar glass window is easily cracked at irradiation of the microwave power of several hundreds watts. Thus quartz windows are recommendable for all the view ports in LHD.

5. Transmission Test for Meshes

Insertion of mesh in the plasma side of windows or gate valves is one of the ways to avoid power penetration to the region where these objects are located. Transmission of the microwave power has been tested for two types of mesh. The type A copper mesh has 70 wires/inch, and its geometrical transparency is 90%. The other type B of nickel mesh has 100 wires/inch and its geometrical transparency is 70%. Transmission rate of the microwave power was 20% for type A. Transmission power was not detectable for the type B mesh. The power absorption by the meshes themselves is not significant. Thermal conductivity of the mesh does not pray a significant role for transmission/reflection. From this result, the type B mesh is recommended for the application in LHD at the moment.

6. Development of a Simplified Sensor for Power Monitor

It is important to monitor the residual microwave power distribution in the actual LHD experiment. It might be desirable to set water-load type of sensor in order to get absolute power level. However, more compact, simplified sensor could be convenient if a number of sensors are required to be distributed along the torus. From this reason, a microwave sensor is now under development. This consists of a sensor head and a thermocouple. The head is a small chip of a material which absorbs the microwave power. Preliminary test has been carried out for 3 head materials, that is, graphite, alumina and stainless steel. Linearity in the sensitivity of the sensor has confirmed with this test. The sensitivity will be calibrated absolutely against a water-load type power meter. Damage threshold for the gate valves and windows will be measured in the test stand before the real experiment in LHD, with which the experiments in LHD could proceed without an unexpected catastrophe on these objects.

7. Summary

Coil systems, a vacuum vessel, divertor plates, and all invessel components are designed to meet 3 MW steady state operation, Heating systems of ECRH, ICRH, NBI are designed for long time continuous operation. The goal of the steady state experiment is a 3 MW, one hour operation. All the hardware systems are designed and developed for achieving this target.

Various kinds of rubber gasket have been tested against the microwave power absorption. While a difference was observed for absorption rate at 2.45 GHz among the rubber gasket materials, no significant difference could be seen at 84 GHz. Two types of real gate valves have been tested under microwave power conditions similar to LHD. Damages were found on a viton gasket of one of the valves, in which a gap in front of the gasket was 3 mm in valve-closed mode. No serious damage has been found on the gasket in valve-open mode so far.

A kovar window strongly absorbed the microwave, which resulted in crack generation on the window. No significant power absorption has been seen for a fused quartz window. A mesh of 100 wires/inch is found to reduce effectively the penetration of microwave power.

A simplified sensor is under development to monitor the residual microwave power in LHD.

References

[1] A. Iiyoshi *et al.*, Fusion Technology **17**, 169 (1990).

[2] O. Motojima *et al.*, *Plasma Physics and Controlled Fusion Research*, 1990 (*Proc. 13th IAEA Conference on Plasma Physics and Controlled Nuclear Fusion Research*, 1990, Washington), Vol. 3, p. 513.

[3] M. Fujiwara, K. Yamazaki *et al.*, J. Fusion Energy **15**, 7 (1996).

[4] A. Komori *et al.*, *private communication.*

[5] Y. Kubota, N. Noda *et al.*, HTD-Vol. 317, *Proc. ASME Heat Transfer Division*, ed. R. J. Cochran *et al.*, American Physical Society, New York, p. 159 (1995).

[6] N. Ohyabu *et al.*, J. Nucl. Mater. **220-222** (1995) 298.

[7] Kumazawa *et al.*, *19th SOFT*, 1996, Lisbon.

[8] Y. Takeiri *et al.*, *private communication.*

[9] A. Ejiri, NIFS-MEMO-17, Nov. 1996.

[10] H. Nakanishi and LABCOM Group, in these Proceedings, p.409 (1998).