TOKAMAK DISCHARGE TEST WITH A FERRITIC FIRST WALL SIMULATING VACUUM VESSEL

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Abstract

A plasma discharge experiment, measurements and calculations of the magnetic field in the Hitachi tokamak HT-2 showed that ferritic steel is available for the vacuum vessel structural material in fusion devices, in spite of its ferromagnetism. The HT-2 has a stainless steel SS304 vacuum vessel and F82H plates were added just like a first wall, to simulate a ferritic vacuum vessel. The vacuum quality was not degraded. About 1500 discharge tries cleaned up the F82H and normal discharges was obtained. The magnetic field due to the F82H magnetization was small enough that it did not cause a problem for plasma discharge in the HT-2. Since the field due to the magnetization is expected to be smaller in large tokamaks than in the HT-2, we concluded that the ferritic steel can be used as a structural material for fusion devices.

1. INTRODUCTION

Ferritic steel is a candidate structural material for fusion reactors because of the high allowable neutron dose rate and low activation compared with the ordinary stainless steel (SS)[1,2]. Another reason is that the magnetized material can compensate for the field ripple of discrete toroidal field coils (TFCs). The Japan Atomic Energy Research Institute developed F82H (8%Cr-2%W-0.2%V-0.04%Ta-Fe) [3] ferritic steel and have a plan to test it on the JFT-2M tokamak [4].

However, ferritic steel can disturb the plasma discharge through (1) an undesirable magnetic field due to magnetization and (2) its larger outgas rate than that of SS. These disadvantages have tended dampen interest and no experiments have been done using ferritic steel ; only a vacuum test [5] and error field evaluation [4] have been made. However, we considered that it was necessary to test a discharge using the ferritic material under a condition that would have the severe effect on performance. Then, the Hitachi tokamak HT-2 [6,7] was modified with a F82H plate first wall in order to simulate the ferritic vacuum vessel and verify whether plasma discharge would be possible in the ferritic vacuum vessel. Probable influences on plasma were considered to be due to (1) the magnetic field due to the magnetization and (2) outgas impurity. We discuss these two points in this paper, using experimental results on the HT-2.

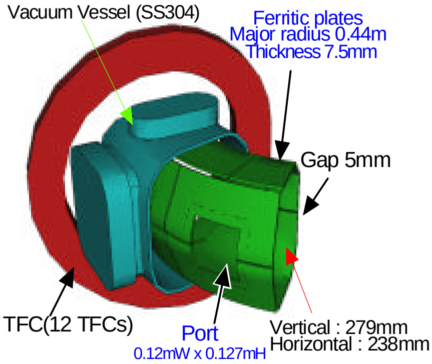

Fig.1 Placement of ferritic plates in HT-2 modification

2. HT-2 MODIFICATION AND LOCAL MAGNETIC FIELD

The HT-2 is a small tokamak with major radius 0.41m, minor radius 0.11m and plasma current I_p<50kA. Detailed descriptions of HT-2 can be found elsewhere [6,7]. Ferritic steel F82H plates are put inside of the vacuum vessel surrounding the plasma discharge area (Figs.1 and 2. The F82H first wall is divided into 4 in the poloidal direction and 12 (the number of TFCs) in the toroidal direction. Thickness of the F82H plates is 7.5mm, and gaps of the plates are 5mm. Each plates was attached on the vessel wall, considering a few hundred kg magnetic forces. Pre-baking at 350^{O}C, for 24 hours was done before installation.

The HT-2 has original 52 magnetic sensors [8], and 12 sensors are added at the plasma side of the F82H plates (Fig.2).

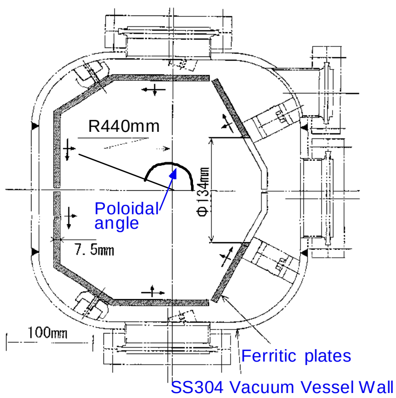

Fig. 2 Poloidal cross section of modified HT-2 vacuum vessel. Arrows denote new magnetic sensors.

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Among the new sensors, 6 are measuring tangential component and the other 6 measure the normal component on the plasma side of the F82H plates. The magnetic fitting code (SHP[8]) reconstructs the poloidal field distribution. The SHP is upgraded to take into account the F82H magnetization as modeled by surface magnetization currents, which, including eddy, coil and plasma currents, are fitted to the measured magnetic data. Then, the poloidal field distribution is reconstructed by calculating the magnetic field using the fitted current magnitudes. Limiters of 10mm height are put on the plasma side of the F82H plates to protect the sensors from the plasma. The magnetic field control system is unchanged.

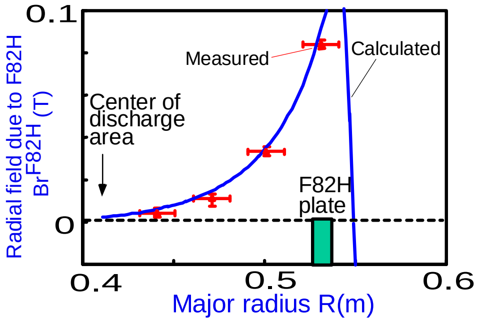

Fig.3 Local magnetic field due to magnetization and confirmation of computational accuracy

Figure 3 compares a distribution of the computationally obtained local magnetic field due to the F82H magnetization with measured data at a rectangular port. This is a radial distribution on a line which is parallel to the port axis and half way from the axis to the port edge. The calculated local field agreed well with the measured data. Next, precise calculations were carried out which showed that the local field compensated for the B_T ripple and it could be optimized by replacing a part of the port by SS[9]. Thus, the local field was considered to be no problem for tokamak plasma initiation generally, even in large tokamaks. The local field reached 0.05T at the plasma edge in the HT-2, but we calculated that this reduced the B_T ripple.

3. EXPERIMENTAL RESULTS

Experiments were done to evaluate the possibility of using the ferritic steel for the vacuum vessel of a magnetic fusion machine. The point of interests were : (1) evacuation characteristics; (2) startup and discharge characteristics; (3) magnetic field due to the ferritic field; (4) disruptive I_P decay.

3.1 Evacuation test

The F82H plate surface area in a vacuum was 5m^2, while the SS304 vessel wall area was 2.5m^2. With a 6-hour baking at 160^{O}C and a one-week evacuation, the pressure dropped to the order of 10^{-8}Torr. Main outgases were H_2 and H O. CO and CO2 were also observed at less than 1/10 the level of H_2O. The highest vacuum obtained was 2.5×10^{-8}Torr after a two-week evacuation. The outgas rate was 1.8×10^{-7} Torr*l*/(sm^2) {2.3×10^{-8} Pam^3/(sm)}, estimated by a buildup technique. This outgas rate was larger than the 250^{O}C baking case of ref.[5], but it could be cut by high temperature baking. The same kinds of outgases were observed during discharge tests, however amounts were reduced by cleaning shots. We concluded F82H could be used at 10^{-8} Torr level high vacuum in a fusion device.

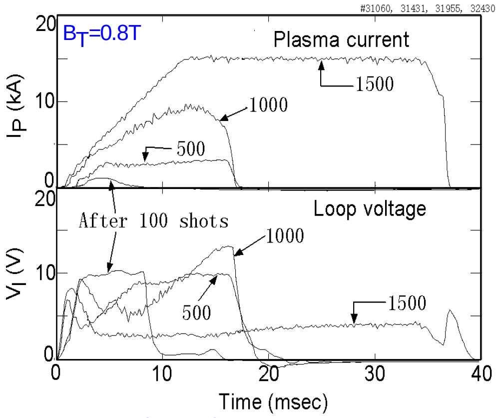

Fig.4 Waveform of plasma discharges. Discharge cleanings improved the duration.

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3.2 Startup and discharge characteristics

Discharge tests were started at the 10^{-8}Torr level vacuum. Breakdowns were easily obtained at B_T=0.6 to 2.0T, without any change in the poloidal field control system and only slight tuning of vertical and horizontal field biases, suggesting that poloidal field due to the F82H plates was weak. However, it was not easy to get, because of outgases from the new F82H first wall. For discharge cleanings, we carried successive trial of normal discharges tries at B_T=0.7 to 1.0T. This approach was the same as that used when the HT-2 was constructed for the SS304 first wall (vacuum vessel wall).

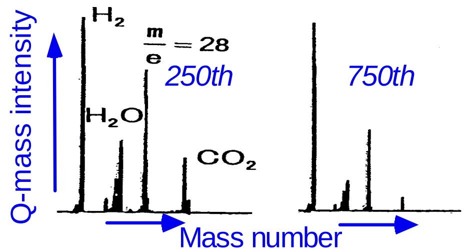

Fig.5 Residual gas just after a 250th & 750th cleaning discharge, comparing H2 gas pressure. The impurity oust gas was reduced shot by shot.

At first, the loop voltage V_l was high (12V: voltage limit due to power supply capacity), I was small (2kA) and discharge duration (τ_d=3ms) was short due to the impurity gas from the F82H. Cleaning improved the discharge. Normal discharge of I_p=15kA and τ = 40ms with B =0.7-2.0T was obtained after about 1500 cleaning discharges. Figure 4 shows the improvement, from the 100th to the 1500th discharge. The 1500th one was a normal 35ms, 15kA discharge obtained with the F82H plates. Just after construction of the HT-2, about 1500 cleaning discharges improved the discharge characteristics with the SS304 first wall. Figure 5 shows quadrupole mass analyzer signals 2 seconds after discharges of about 250th and 700th cleaning shots. The outgases during discharges were H_2O(18), CO(28) and CO_2(44). Their amounts were reduced by the cleanings. Then we concluded that the outgas release from F82H was not a severe problem in the HT-2 and that F82H was as suitable as SS304 for the first wall.

3.3 Magnetic field due to F82H plates

The magnetic fields due to F82H plates have two components : (1) a local field around the ports and (2) a toroidally uniform poloidal field. The former error field was discussed in section 2, and we recognized that the local field could be compensated for by adequate ferritic material placement. The poloidal field due to the F82H was evaluated experimentally as follows.

Figure 6 plots I_p and three magnetic sensor signals. They were measured on positions on the plasma side of the F82H, between the F82H and vessel wall, and on the atomospheric side. Magnitudes of each signal differed mainly due to distances from the plasma. However, the two vacuum side signals (2nd & 3rd plots) were quite similar in spite of the F82H plates between them, meaning that the fully magnetized F82H plates did not create a strong poloidal field. On the other hand, the atmospheric side plot was quiet different waveform, because of eddy current on the SS304 vessel wall. Consequently, the influence of the F82H magnetization was less than the eddy current on the vessel wall.

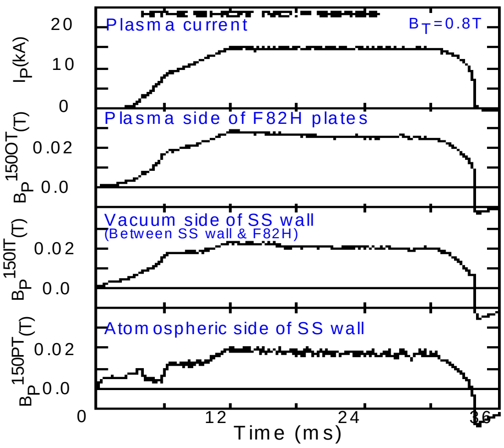

Fig.6 Typical waveforms of Bp signal. Plasma current and three poloidal fields at poloidal angle of 150 degrees are plotted.

In order to discuss the magnetic field due to the magnetization quantitatively, the poloidal magnetic field was reconstructed from experimentally obtained magnetic data, using SHP[8]. Figure 7 shows the reconstructed poloidal fields for two discharges. Left hand contour plots are total poloidal field and right hand ones are the field due to the F82H plates only. The large R side F82H plates had a large poloidal flux, which leaked into the plasma area and created a poloidal field B_V^M to reduce the B_V^{EQ}. The B^M was, 1×10^{-3}T in the top case and 2×10^{-3}T in the bottom case.. The equilibrium vertical field B_V^{EQ} were -1.2×10^{-2}T and -1.5×10^{-2} T, respectively, and we concluded that B_V^M was roughly 10% of the B_V^{EQ} in the HT-2 at B =0.8T. Comparing the two reconstructed magnetic field, we saw that the field due to the F82H plates depended on the plasma position and had a tendency to destabilize it. However, we concluded that ferromagnetism had no significant effect on the plasma equilibrium control properties, except when the plasma position was very close to the F82H plates.

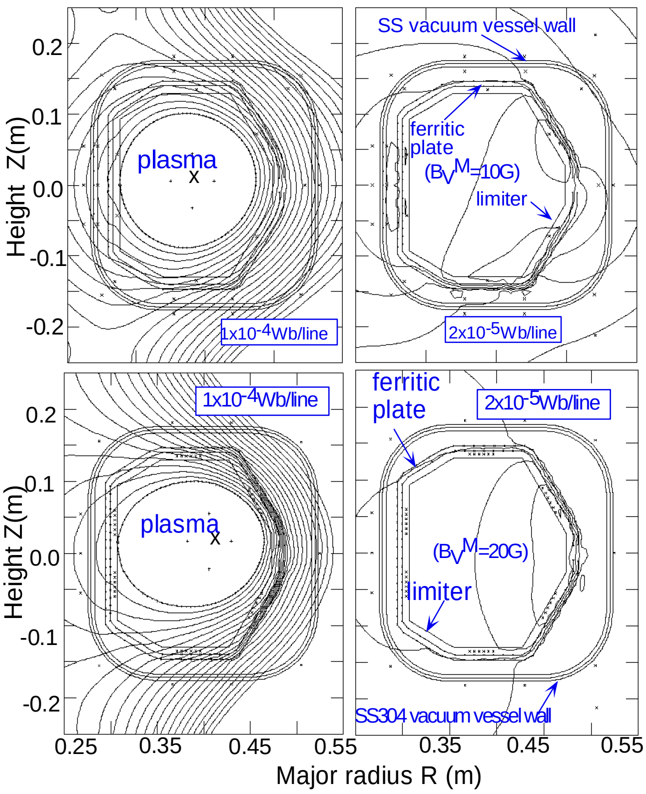

Fig.7 Reconstructed poloidal magnetic field of I_P=15kA discharge. Top two are a discharge with the magnetix axis at the vessel center. Bottom two are with a shifted magnetic axis and larger vertical field B_V^M due to F82H plates.

3.4 Disruptive I_P decay rate

During the disruptive I_P decay, plasma movement is toward the vessel wall [10], and plasma current is located very close to the wall, i.e. F82H plates. This situation may destabilize the plasma current position and accelerate the I_P decay. A disruptive I_P decay waveform is plotted in Fig.8, in which I_P, H   line radiation, plasma vertical position Z_P and V are plotted. The I decayed in 1.5ms with a slow vertical displacement event (VDE). The decay rate dI_P/dt during VDE has been discussed for the original HT-2 and the dI_P/dt for slow VDE was I_P/(1.5ms) [10], which was almost same as that in Fig.8. We concluded that the F82H plates did not accelerate the disruptive I_P decay.

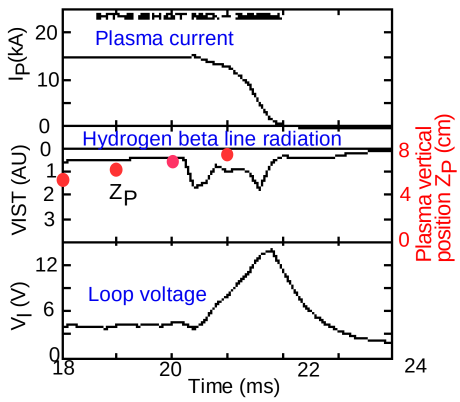

Fig.8 Disruptive plasma cuurrent decay with ferritic plates

3.5 Extrapolation to larger fusion device

The results obtained were positive for use of ferritic steel for the vacuum vessel, but we insist that confinement degradation in high performance plasma of larger fusion devices due to the local field and the out gas, should be tested. However, we consider the following points will be seen.

The magnetic field due to ferritic steel is roughly proportional to $t_{F82H}/(B_T a_V)$, where t_{F82H} is thickness of the plates, a_V is minor radius of the torus-shaped ferritic steel and a   is a parameter of distance between the plasma area and the plates (vessel wall). In larger tokamaks like a reactor, B_T is more than 5 times larger than typical HT-2 experiments of B_T=0.8T. The t   /(a) should be the same or smaller than for the HT-2. Then, we consider that in larger tokamaks the magnetic field in the plasma area due to the magnetization is small or roughly 1/10 of the HT-2 case. The out gas release rate is slightly larger than for the SS wall [5], but the rate is still small enough to obtain 10^{-8}Torr (10^{-6}Pa) level high vacuum. These discussion seems to confirm use of ferritic steel in fusion devices to utilize its advantage of B_T ripple reduction.

4. SUMMARY

Work to date has shown that ferritic steel can be used for structural material of the vacuum vessel. The ferritic steel was tested in HT-2, putting F82H plates as the first wall for ferritic vacuum vessel simulation. A high vacuum was obtained and the poloidal field due to the magnetization of ferritic plates, did not disturb the plasma discharge. Little change of characteristics was observed in the plasma initiation and disruptive I_P decay. However, the effects on the plasma confinement including improvement due to reduction of the B_T ripple should be examined experimentally in medium and then large tokamaks.

Acknowledgments

The authors thank to JFT-2M group of Japan Atomic Energy Research Institute, for their fruitful comments on this experiment.

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