

Measurement of Magnetic Field Fluctuations and Plasma Rotation Speed

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Abstract An experimental investigation of effects of external resonant helical field on poloidal and radial components of magnetic field fluctuations, plasma rotation speed and plasma current in IR-T1 tokamak was presented. Eight Mirnov coils in poloidal direction and four Mirnov coils in radial direction were installed on outer surface of the IR-T1 tokamak chamber to measure poloidal and radial components of external magnetic field fluctuations. Also we inserted a Mach probe with four tips 5mm inside the IR-T1 tokamak chamber to measure plasma rotation speed. In case of absence of RHF, poloidal and radial components of external magnetic field fluctuations were measured. On the other hand, the external RHF applied to tokamak plasma and again the magnetic field fluctuations were measured. Measurement results with and without RHF ($L=2$, $L=3$, $L=2$ & 3) show that the addition of a relatively small amount of RHF could be effective for improving the quality of tokamak plasma discharge by flattening the plasma current and decreasing the magnetic field fluctuations.

Keywords Tokamak, Resonant helical field, Magnetic field fluctuations, Plasma rotation speed

1. Introduction

In magnetically confined plasmas, reducing the magnetic field fluctuations is important to confine plasmas. These magnetic field fluctuations can be measured by magnetic pick up coils such as Mirnov coils. The Plasma rotation speed can improve fusion power gain in fusion reactor. So it is important to discover parameters can affect magnetic field fluctuations and Plasma rotation speed in tokamak plasmas [1-65]. In this paper we present an experimental investigation of effects of resonant helical field on poloidal and radial components of external magnetic field fluctuations and measurement of plasma rotation speed in IR-T1 tokamak plasma which it is a small, low Beta and large aspect ratio tokamak with a circular cross section. The external RHF applied to plasma and then poloidal and radial components of external magnetic field fluctuations were measured. Measurement results with and without RHF ($L = 2$, $L = 3$, $L = 2$ & 3) show that the addition of a relatively small amount of RHF could be effective for improving the quality of tokamak plasma discharge by flattening the plasma current and decreasing the external magnetic field fluctuations. Measurement of magnetic field fluctuations will be presented in "Measurement of Magnetic Field Fluctuations with Magnetic Coils" and RHF setup on IR-T1 tokamak will be presented in "Resonant Helical Field (RHF) Setup on

IR-T1 Tokamak". Experimental results of effects of RHF on poloidal and radial components of external magnetic field fluctuations will be presented in "Experimental Results of Effects of RHF on Poloidal and Radial Components of External Magnetic Field Fluctuations". Also, experimental results of effects of RHF on plasma current will be presented in "Experimental Results of Effects of RHF on Plasma Current". Measurement of plasma rotation speed will be presented in "Measurement of Plasma Rotation Speed with Mach Probes". Summary and conclusion also will be presented in "Summary and Conclusion".

2. Measurement of Magnetic Field Fluctuations with Mirnov Coils

Mirnov coils measure induced voltage on its output V_{in} , that could be obtained theoretically from the Faraday's law [1]:

$$V_{in} = -\frac{d\phi}{dt} = -NA\frac{dB}{dt} \quad (1)$$

According to this relation, V_{in} is proportional to external magnetic field fluctuations (dB/dt). N is the number of turns in the coil of area A . So, measuring V_{in} by coils gives a measure of external magnetic field fluctuations directly. According to this approach, in the IR-T1 tokamak eight Mirnov coils were installed on outer surface of tokamak chamber to measure poloidal component of external magnetic field fluctuations as shown in Fig. 1(a) and four Mirnov coils were installed on outer surface of tokamak chamber to measure radial component of external magnetic

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field fluctuations, as shown in Fig. 1(b). Output of these coils yield V_{in} that is proportional to external magnetic field fluctuations.

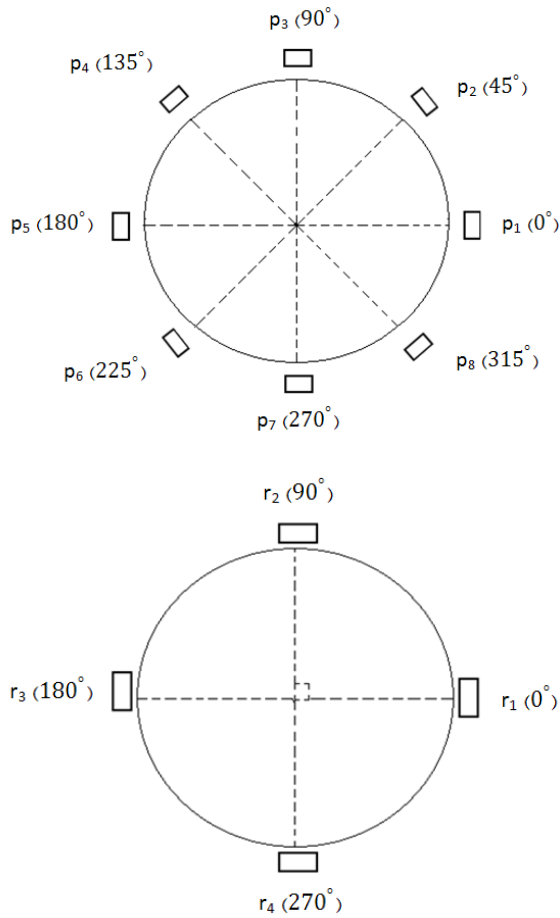


Figure 1. Arrangement of (a) poloidal (b) radial Mirnov coils on the outer surface of IR-T1 tokamak chamber

3. Resonant Helical Field (RHF) Setup on IR-T1 Tokamak

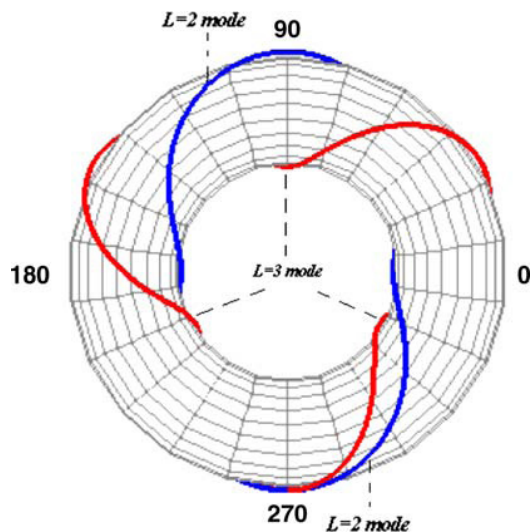


Figure 2. Positions of the RHF coils ($L = 2$ & $L = 3$ modes) on outer surface of the IR-T1 tokamak chamber

The RHF is an external helical magnetic field which can improve the tokamak plasma confinement. In the IR-T1, this field is produced by two winding with optimized geometry conductors wound externally around the tokamak chamber with a given helicity. The minor radius of these helical windings are 21 cm ($L = 2$, $n = 1$) and 22 cm ($L = 3$, $n = 1$) and also major radius is 50 cm (see Fig. 2). In this experiment, the current through the helical windings was between 200 and 300 A, which is very low compared with the plasma current (32 kA).

4. Experimental Results of Effects of RHF on Poloidal and Radial Components of External Magnetic Field Fluctuations

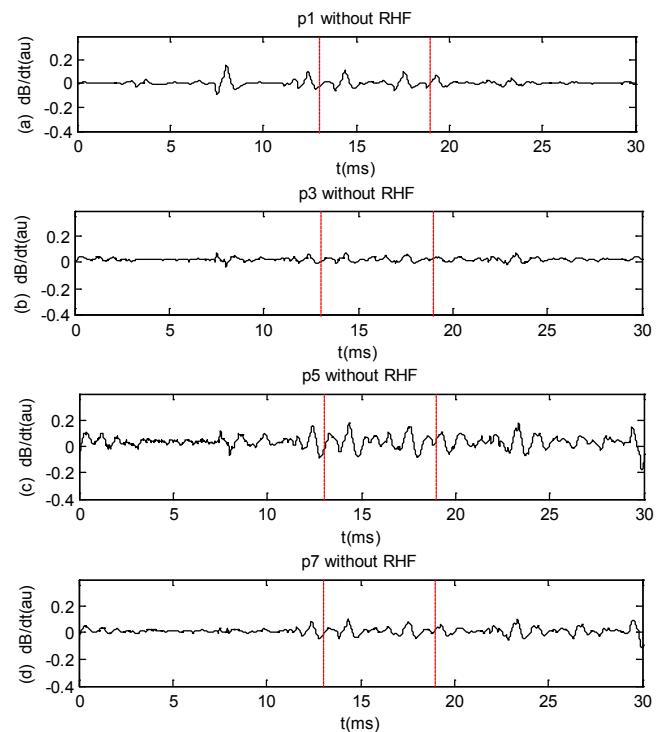


Figure 3. Poloidal component of external magnetic field fluctuations was measured by coils (a) p1, (b) p3, (c) p5, and (d) p7, without RHF

In order to measurement of poloidal and radial components of external magnetic field fluctuations, eight Mirnov coils were installed in poloidal direction and four Mirnov coils were installed in radial direction on the outer surface of the IR-T1 tokamak chamber as shown in Fig. 1. First of all, we measured poloidal and radial components of external magnetic field fluctuations without RHF and then we measured them with RHF in $L = 2$, $L = 3$ and $L = 2$ & $L = 3$ modes separately. After data analyzing and programming, we obtained 48 figures, for each coil we plotted four figures in four states: without RHF and with RHF in $L = 2$, $L = 3$ and $L = 2$ & $L = 3$ modes separately. We have shown some results in Figs. 3, 4, 5, ..., 10. Measurement results with and without RHF ($L = 2$, $L = 3$, $L = 2$ & $L = 3$) show that the addition of a relatively small amount of RHF, specially $L = 2$ mode, could

be effective for decreasing the poloidal and radial components of external magnetic field fluctuations.

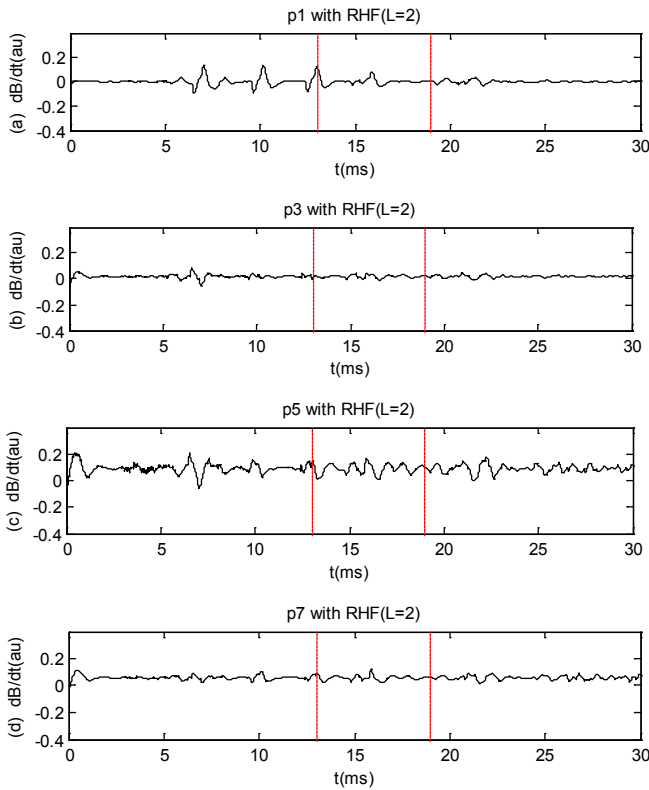


Figure 4. Poloidal component of external magnetic field fluctuations was measured by coils (a) p1, (b) p3, (c) p5, and (d) p7, with RHF (L=2 mode) at 13-19 ms

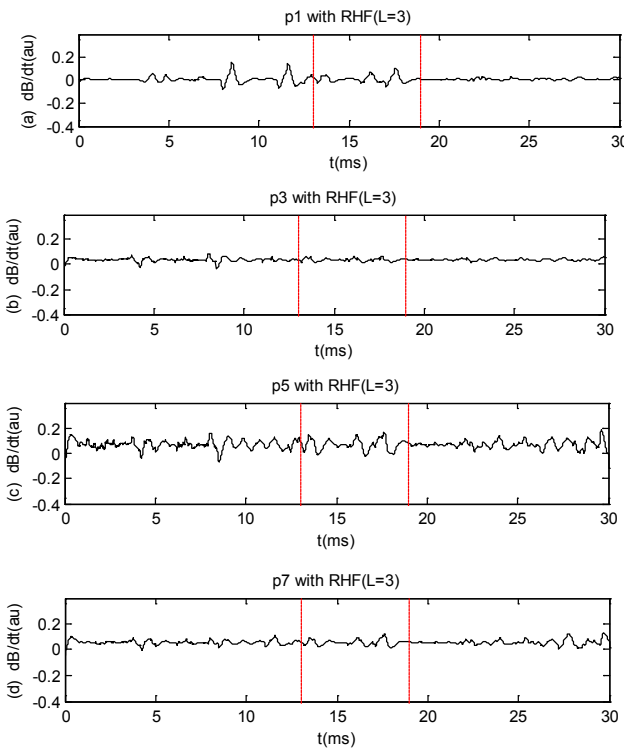


Figure 5. Poloidal component of external magnetic field fluctuations was measured by coils (a) p1, (b) p3, (c) p5, and (d) p7, with RHF (L=3 mode) at 13-19 ms

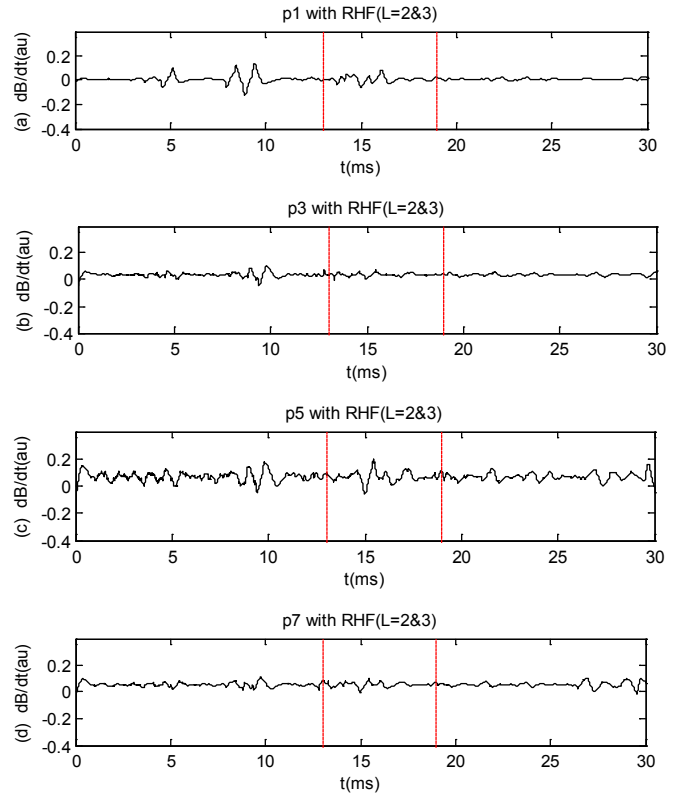


Figure 6. Poloidal component of external magnetic field fluctuations was measured by coils (a) p1, (b) p3, (c) p5, and (d) p7, with RHF (L=2&3 mode) at 13-19 ms

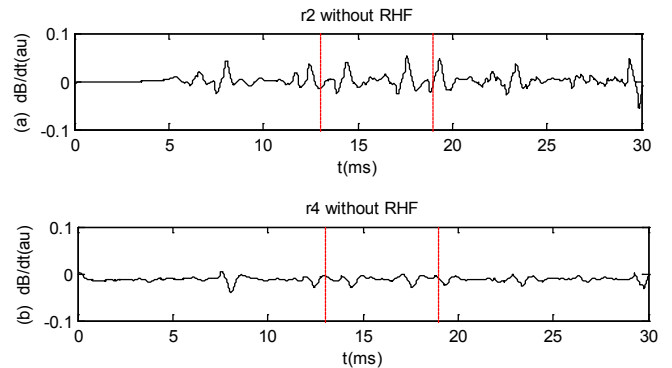


Figure 7. Radial component of external magnetic field fluctuations was measured by coils (a) r2, (b) r4, without RHF

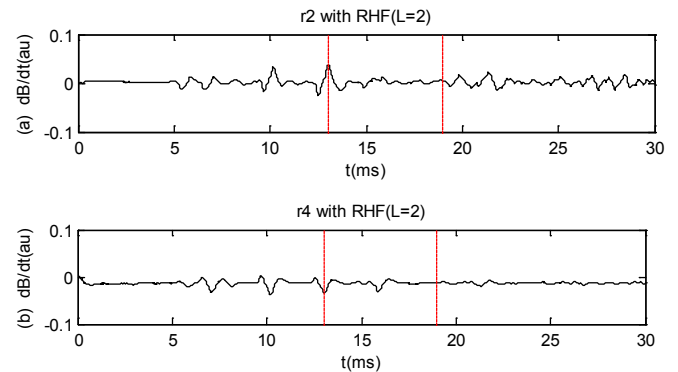


Figure 8. Radial component of external magnetic field fluctuations was measured by coils (a) r2, (b) r4, with RHF (L=2) at 13-19 ms

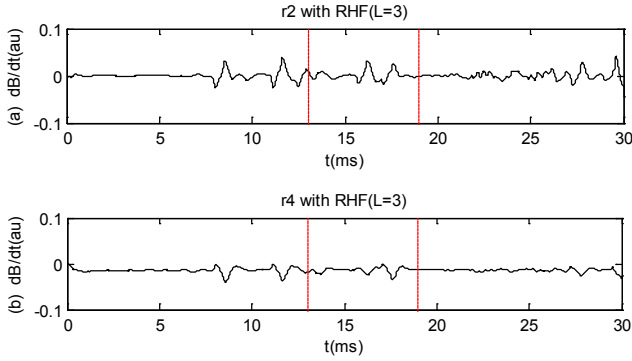


Figure 9. Radial component of external magnetic field fluctuations was measured by coils (a) r2, (b) r4, with RHF (L=3) at 13-19 ms

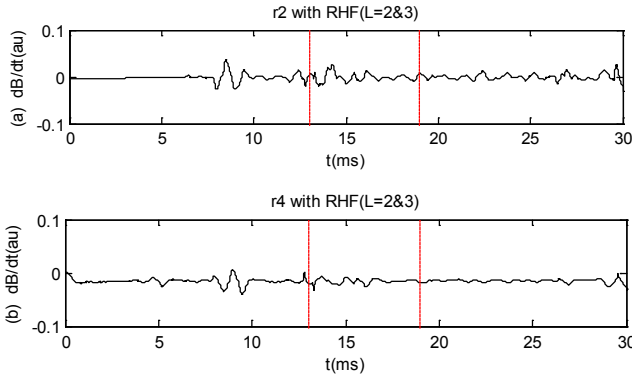


Figure 10. Radial component of external magnetic field fluctuations was measured by coils (a) r2, (b) r4, with RHF (L=2&3) at 13-19 ms

5. Measurement of Plasma Rotation Speed with Mach Probe

Mach probes measure saturation voltage V_s that is proportional to saturation current I_s . We used the Mach probe with four tips, two tips measure saturation voltage in poloidal direction and two tips measure saturation voltage in toroidal direction as shown in Fig. 11. All of the theories express the ratio of the Mach probe upstream and downstream currents as follows [2]:

$$\frac{j_a}{j_b} = e^{KM}, \quad (2)$$

or, rearranging,

$$M = \frac{1}{K} \ln \frac{j_a}{j_b}. \quad (3)$$

M is the Mach number and K is a calibration constant.

In this work, we used the Hutchinson model with $K=1.7$ for $T_i/T_e=0.2$. Then, plasma rotation velocity obtains from [3]:

$$M = \frac{v_p}{c_s}, \quad (4)$$

V_p is plasma rotation speed and C_s is ion acoustic velocity that can obtain from [4]:

$$c_s = \sqrt{\frac{k(T_e + T_i)}{M_i}}. \quad (5)$$

That, $M_i=1.673 \times 10^{-27}$ kg, is ion mass. In this experiment $KT_e=200$ eV.

6. Experimental Results of Measurement of Plasma Rotation Speed

According to this approach, we inserted a Mach probe with four tips inside the IR-T1 tokamak chamber and 50cm inside the plasma. Firstly we measured saturation voltages in poloidal direction and calculated the Mach number in poloidal direction by eq.3, and then we calculated plasma rotation speed by eq.4 and eq.5. Result has been shown in Fig. 12.

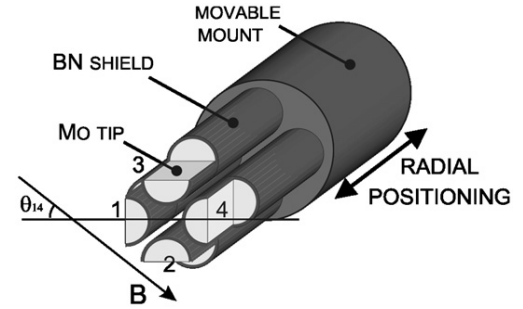


Figure 11. Mach probe with four tips

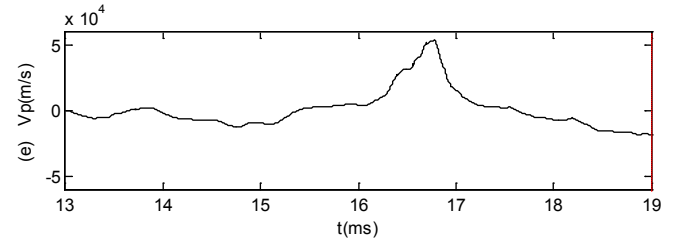


Figure 12. Measurement of poloidal component of plasma rotation speed

7. Experimental Result of Effect of RHF on Plasma Current

For measurement of plasma current I_p a Rogowski coil was installed on the outer surface of the IR-T1 tokamak chamber. We measured plasma current without RHF and with RHF in L = 2, L = 3 and L = 2 & 3 modes separately. Results show that the addition of a relatively small amount of RHF, specially L = 3 mode, could be effective for improving the quality of tokamak plasma discharge by flattening the plasma current as shown in Fig. 13.

8. Summary and Discussion

In this paper we present an experimental investigation of effects of resonant helical field on poloidal and radial components of external magnetic field fluctuations, and

plasma current in the IR-T1 tokamak plasma, also we measure plasma rotation speed. Eight Mirnov coils in poloidal direction and four Mirnov coils in radial direction were installed on outer surface of the IR-T1 tokamak chamber to measure the poloidal and radial components of external magnetic field fluctuations as showed in Fig. 1, also we inserted a Mach probe with four tips inside the IR-T1 tokamak chamber and 50 cm inside the plasma to measure the plasma rotation speed in the IR-T1 tokamak. On the other hand, the external RHF applied to tokamak plasma and again the external magnetic field fluctuations were measured. Measurements with and without RHF ($L = 2$, $L = 3$, $L = 2 \& 3$) show that the addition of a relatively small amount of RHF could be effective for improving the quality of tokamak plasma discharge by flattening the plasma current and reducing the external magnetic field fluctuations.

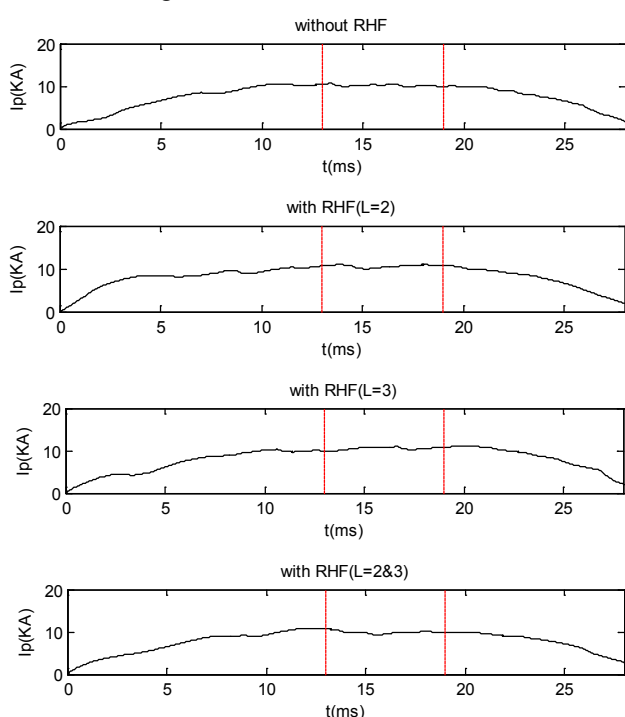


Figure 13. Measurement of plasma current (a) without RHF, (b) with RHF($L=2$ mode), (c) with RHF($L=3$ mode), (d) with RHF($L=2\&3$ mode)

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