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Abstract

The design of the poloidal field (PF) system includes the ohmic heating field system and the equilibrium (EQ) field system, and is the basis for the design of a magnetic confinement fusion device. A coupling between the poloidal and plasma currents, especially the eddy current in the stabilizing shell, yields design difficulties. The effects of the eddy current in the stabilizing shell on the poloidal magnetic field also cannot be ignored. A new PF system design is thus proposed. By using a low-$\mu$ material ($\mu = 0.001, \varepsilon = 1$) instead of a conductive shell, an electromagnetic model is established that can provide a continuous eddy current distribution on the conductive shell. In this model, a 3D time-domain problem with shells translates into a 2D magnetostatic problem, and the accuracy of the calculation is improved. Based on these current distributions, we design the PF system and analyze how the EQ coils and conductive shell affect the plasma EQ when the plasma ramps up. To meet the mainframe design requirements and achieve an efficient power-supply design, the position and connection of the poloidal coils are optimized further.

Keywords: RFP, KTX, poloidal field system, electromagnetic design

(Some figures may appear in colour only in the online journal)

1. Introduction

The reversed field pinch (RFP) is one of the three main types of toroidal magnetic field confinement configurations [1]. Unlike the tokamak, which has a much larger magnetic field in the toroidal direction than in the poloidal direction, the RFP has comparable field strength in both directions. The RFP device produces most of its magnetic field by currents that flow inside the plasma; external coils provide only a small-edge toroidal field (TF), with its sign reversed with respect to the central one.

The RFP configuration has three main advantages. Because of the lower overall fields, an RFP device may not require superconducting magnets. The RFP can, in principle, achieve ignition solely with ohmic heating (OH) current. The RFP tends to be more susceptible to non-linear effects and turbulence. There are many non-linear plasma physical phenomena, such as magnetic self-organization, that have favorable implications for global confinement [2–5].

The largest RFP device in operation is the RFX-mod ($R/a = 2/0.46$) in Padua, Italy [6, 7]. Other RFP devices include the MST ($R/a = 1.5/0.5$) in the United States [8], EXTRAP T2R ($R/a = 1.24/0.18$) in Sweden [9], TPE-RX ($R/a = 1.72/0.45$) in Japan [10] and KTX ($R/a = 1.4/0.4$) in China [11].

A new method for designing the poloidal field (PF) of an RFP device and the PF system of the KTX device is proposed in this paper. The design problem of coupling the PF in an
RFP device, which ensures the feasibility of advanced control technology in engineering, has been solved in KTX by using a concept similar to that proposed for the RFX experiment. The PF designed using this method achieves an efficient driving of the plasma current and adaptive maintenance of the plasma equilibrium (EQ).

The design of a PF system that includes an OH field system and an EQ field system is the basis for the design of a magnetic confinement fusion device [7, 8, 12]. Whether in the tokamak or in the RFP configuration, the coupling of poloidal coils is difficult to design, especially with the existence of a stabilizing shell [13]. A large eddy current exists on the stabilizing shell when the plasma current ramps up [14]. The eddy current is non-uniformly distributed along the poloidal direction and exhibits a synchronous increase with the OH current. This uncertainty caused by the spatial and temporal evolution makes the RFP design difficult.

Because the PF system design must meet the engineering design requirements and must account for the mechanical support and the various port and flange arrangements, the number of constraint conditions increases.

The KTX PF system is composed of an OH system and an EQ system [11]. The KTX PF system generates a flux swing, drives the plasma current and controls the EQ. The OH windings should provide a large flux swing of 5 Wb in some tens of milliseconds; however, the stray field in the plasma region should be less than 30 Gauss. The EQ windings should provide a suitable EQ to control the plasma, limit the error field at gaps and holes and reduce the flux swing requirement.

In this paper, a design method for the PF system and KTX device is presented and used to design them.

2. KTX electromagnetic model

2.1. Overview of the KTX electromagnetic model

The PF system has two main functions. The OH coils produce and drive plasma current, while ensuring that the stray field in the plasma region is less than 30 Gauss. The EQ coils maintain the plasma EQ. The OH current, EQ current, eddy current in the stabilizing shell and plasma current are coupled. These four types of currents must be integrated and unified in design.

To calculate these four types of current distribution, a new model is established in the KTX PF system design. The preliminary magnetic field configuration is determined according to the size and radius of the device. The continuous distributions of the OH and EQ current are given by the electromagnetic model. The plasma current is substituted by filament current, and a low-μ material (μ = 0.001, ε = 1) is used instead of a conductor shell.

This model aims to calculate the magnetic field and flux by using the finite-element method. These current distributions and the flux along different outlines can be used to design the PF and optimize the PF power-supply system.

As shown in figure 1, two different outlines exist on the conductive components. The red line (solid) shows the OH winding outline and is the location of the preliminary version of the OH coils. The blue line (dashed) shows the EQ winding outline, which is an ‘oval runway’ shape and is compatible with the ‘Double-C’ structure, as explained in section 3.1; it is also the location of the preliminary version of the EQ coils. The EQ winding is also intended to be a ‘Double-C’ structure.

2.2. Advantages of the KTX electromagnetic model

In general, the ohmic current, EQ current with the existence of a stabilizing shell and the eddy current in the stabilizing shell should be calculated using a 3D time-domain simulation. Because of the presence of a vertical gap in the stabilizing shell that prevents the circulation of a net current in the toroidal direction, the eddy current is in a bipolar distribution in the poloidal direction far from the gap. Under this circumstance, the eddy current distributions calculated in 2D and 3D are almost the same. Figure 2(a) compares two methods for calculating the EQ currents. With the KTX electromagnetic model, the 3D time-domain model is converted into a 2D static magnetic model, thus greatly improving the simulation efficiency.

In a single computation, three different currents can be calculated efficiently. These currents can be calculated by integrating the magnetic field along different outlines. As shown in figure 2(b), the OH current, EQ current and eddy current can be calculated in the same computation. These different currents can be used to design the PF system and analyze the eddy current on the shell when the plasma ramps up.

During the PF system design, the interaction between the stabilizing shell and the PF system is considered. The distribution of the eddy current on the conductive shell with the existence of EQ coils can also be calculated easily by using the electromagnetic model. In the electromagnetic model, the OH current, EQ current, eddy current on the shell and the plasma current are coupled. The eddy current on the stabilizing shell depends on the EQ and plasma currents. Figure 3(a) shows the eddy current on the stabilizing shell.
with/without an EQ current, with the OH and plasma currents remaining unchanged. We arrive at the conclusion that when the plasma ramps up, the eddy current on the shell controls the plasma. The EQ coils reduce the eddy current on the shell. The eddy current, together with the EQ coils, maintains the plasma EQ. To eliminate the error field at the gaps and around the ports, the plasma and EQ currents must ramp up synchronously. Figure 3(b) shows that the magnetic flux of the OH coils can be reduced significantly with the existence of EQ coils. In other words, the OH efficiency can be improved by using an integrated design of the PF-stabilizing shell system. The poloidal system can be optimized through the OH current, EQ current and eddy current. Therefore, the KTX PF system is adaptive and efficient.

In this model, the current distribution is only relevant to the shape of the different outlines. To design a ‘Double-C’ structure, the ‘Double-C’ EQ outlines must be set. Through this model, the KTX PF system can be designed under any geometric shapes.

Figure 4 shows the KTX PF system design with the KTX electromagnetic model. The design has three main steps.

3. The KTX PF system

3.1. Overview of the KTX PF system

The inductance of the circular cross-section of the plasma current loop is related to the geometric size of the KTX and the plasma self-inductance.

\[
L_p = \mu_0 R \left( \frac{8R}{a} - 2 + \frac{l_0}{2} \right).
\]

The plasma self-inductance is determined by the current distribution profile. For most of the actual current distribution, \(l_i = 2L_{eq}/\mu_0 R = 1.0\). Thus, the estimated self-inductance of the plasma is \(\sim 3.2 \mu H\).

The poloidal flux and the corresponding magnetic energy that are required for plasma discharge are provided mainly by the OH coils. The first part of the poloidal flux is used to break down the gas and ramp up the plasma current. The second part of the poloidal flux is used for OH consumption. The ohmic field, EQ field and plasma in the KTX are coupled during operation. When the plasma ramps up, a reverse current is produced in which the total ampere-turns are equal to...
the plasma current in the EQ coils. With this shielding effect, the poloidal flux and corresponding magnetic energy can be optimized efficiently.

After considering the mutual inductance of the EQ coils, when the plasma current is 1 MA, the equivalent inductance of the plasma is 2.0 μH, as described in section 3.4. The flux required to generate a plasma current loop is 2 Wb. The second part of the poloidal flux is determined by the plasma loop resistance and the duration of the plasma flat-top phase. In this paper, we selected the following design targets: a loop resistance and the duration of the plasma is 2.0 μH when the plasma current is 1 MA, the equivalent inductance of the plasma is 10 μH, as described in section 3.4. The flux required to generate a plasma current loop is 2 Wb. The second part of the poloidal flux is determined by the plasma loop resistance and the duration of the plasma flat-top phase. In this paper, we selected the following design targets: a loop resistance and the duration of the plasma flat-top phase.

To design the PF system, OH and EQ coils must be designed independently. By optimizing the diagnostic ports and power-supply system, the OH and EQ coils were adjusted to achieve a better design.

In the current RFP device, it is very difficult to enter the shell or vacuum chamber. This makes it difficult to maintain and update the vacuum chamber, and the cost of doing so is extremely high. To solve the above problems and provide the necessary experimental conditions for installing the advanced lithium wall, the vacuum chamber and stabilizing shell of the KTX are conceived as retractable structures. The ‘Double-C’ retractable design led to a ‘Double-C’ section of the PF system that differs from a traditional circular section configuration.

When the plasma ramps up, the eddy current in the EQ coils and the stabilizing shell produce a magnetic field that tends to maintain the plasma in EQ. The adaptive eddy current in the EQ coils can significantly decrease the eddy current distribution on the stabilizing shell and reduce the error field during the plasma ramp-up. The EQ coils of the KTX devices must be prioritized in the design.

Although there are many auxiliary heating methods in the tokamak, the OH efficiency is lower than that in the RFP device. In addition to the OH, it is necessary to add various wave heating methods to the device. The scenario is different in the KTX device; the OH efficiency is sufficiently high to achieve the target plasma temperature solely by OH. Therefore, it is important to improve the OH efficiency through the design of the PF system.

The plasma discharge time in a typical tokamak device is longer than that in the KTX device. Therefore, the eddy current in the EQ coil of the KTX device is smaller than that in a tokamak device. The plasma current changes rapidly during ramp-up. The interactions between the eddy current in the stabilizing shell, the non-circular cross-sectional EQ current and the plasma current complicate the design of the poloidal system of the KTX device. A method for realizing the adaptive function of the PF system is especially important.

### 3.2. OH field system

The main function of the OH field in the KTX is to provide volt seconds, which breaks down the gas, starts the plasma and maintains the flat-top plasma. During the initiating breakdown and start-up phase, the rise time of the currents is ~10 ms, which is very short, and the required loop voltage $V_{\text{loop}}$ can reach 200 V. During the maintenance phase of the flat-top plasma, the discharge time is longer than the initiating breakdown and start-up phase and can reach 100 ms. The loop voltage is as low as 10–20 V. To allow a more rapid plasma breakdown, a large zero-field region is required in the KTX.

During the design of the OH field coil, the following conditions should be satisfied:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>the OH coils should provide a large flux swing of 5 Wb in some tens of milliseconds;</td>
<td></td>
</tr>
<tr>
<td>the stray field in the plasma region should not be greater than 30 Gauss when the flux is 5 Wb;</td>
<td></td>
</tr>
<tr>
<td>the design should meet the requirement of optimizing the power-supply system:</td>
<td></td>
</tr>
<tr>
<td>(1) all OH coils use a single power supply. The current per turn should be the same in each coil. The voltage should be less than 250 V per turn and the current density should be less than $1 \times 10^8$ A m$^{-2}$;</td>
<td></td>
</tr>
</tbody>
</table>
all OH coils are split into sectors to decouple the power-supply system. Each sector should have the same turns and the same self-inductance.

The design should meet the requirement of optimizing the mainframe system:

1. the arrangement of OH coils should meet the requirement of the 'Double-C' structure;
2. the arrangement of OH coils should meet the requirements of the diagnostic ports and support structure.

The KTX uses an air-core coil design. The OH winding consists of 200 turns that are wound in 26 coils. The detailed composition is shown in figure 5 (red parts). The geometric parameters of the upper half plan of the coil are shown in table 1. By taking the mid-plane of the KTX as the plane of symmetry, the thirteen upper and lower coils from OH1 to OH13 lie symmetrically from the inside out, and the 18 coils from OH1 to OH9, with a total of 182 turns, provide most of the volt seconds required by the KTX. The eight coils from OH10 to OH13, with a total of 14 turns, decrease the stray field of the plasma region. This arrangement of OH coils

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**Figure 5.** Cross-sectional view of the PF system of KTX.

**Table 1.** Geometric parameters of the OH coils of KTX.

<table>
<thead>
<tr>
<th>OH</th>
<th>$Z_{low}$ (m)</th>
<th>$Z_{high}$ (m)</th>
<th>$R_{in}$ (m)</th>
<th>$R_{out}$ (m)</th>
<th>Turn</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH1</td>
<td>0.016</td>
<td>0.144</td>
<td>0.433</td>
<td>0.661</td>
<td>14</td>
<td>A</td>
</tr>
<tr>
<td>OH2</td>
<td>0.176</td>
<td>0.304</td>
<td>0.433</td>
<td>0.661</td>
<td>14</td>
<td>B</td>
</tr>
<tr>
<td>OH3</td>
<td>0.336</td>
<td>0.464</td>
<td>0.433</td>
<td>0.661</td>
<td>14</td>
<td>C</td>
</tr>
<tr>
<td>OH4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.499</td>
<td>0.741</td>
<td>11</td>
<td>B</td>
</tr>
<tr>
<td>OH5</td>
<td>0.64</td>
<td>0.74</td>
<td>0.551</td>
<td>0.793</td>
<td>11</td>
<td>A</td>
</tr>
<tr>
<td>OH6</td>
<td>0.844</td>
<td>0.887</td>
<td>0.659</td>
<td>0.901</td>
<td>11</td>
<td>C</td>
</tr>
<tr>
<td>OH7</td>
<td>0.957</td>
<td>1.023</td>
<td>0.883</td>
<td>0.937</td>
<td>6</td>
<td>B</td>
</tr>
<tr>
<td>OH8</td>
<td>1.141</td>
<td>1.301</td>
<td>1.073</td>
<td>1.127</td>
<td>6</td>
<td>A</td>
</tr>
<tr>
<td>OH9</td>
<td>1.432</td>
<td>1.538</td>
<td>1.275</td>
<td>1.329</td>
<td>4</td>
<td>C</td>
</tr>
<tr>
<td>OH10</td>
<td>1.48</td>
<td>1.52</td>
<td>1.809</td>
<td>1.891</td>
<td>3</td>
<td>C</td>
</tr>
<tr>
<td>OH11</td>
<td>1.48</td>
<td>1.52</td>
<td>2.116</td>
<td>2.17</td>
<td>2</td>
<td>B</td>
</tr>
<tr>
<td>OH12</td>
<td>1.48</td>
<td>1.52</td>
<td>2.571</td>
<td>2.599</td>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>OH13</td>
<td>1.469</td>
<td>1.531</td>
<td>3.421</td>
<td>3.519</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
saves space for diagnostic ports and a ‘Double-C’ structure. The arrangement is also compatible with the blue EQ coils and green TF coils.

When the current in the OH coil is 50 kA (maximum nominal current), the total ampere-turns is 10 MA × turns, and the flux can achieve a maximum value of 5 Wb, as designed. In this case, the stray field in the plasma region is shown in figure 6, where the maximum stray field in the plasma region is less than 30 Gauss (black circle is the outline of the vacuum chamber). The loop voltage is set to 200 V. The voltage of the OH field coil cannot exceed 50 kV. Therefore, the OH of the KTX can use a single power supply.

The OH coils, EQ coils, plasma current and copper shell will produce tens of thousands of kilo-ampere, or even mega-ampere, toroidal currents during the operation of the KTX device. These large toroidal currents change rapidly in milliseconds. Therefore, a decoupling between the OH coils, EQ coils, plasma current and copper shell is critical when designing the KTX device. By designing the OH coils individually and by connecting to the circuit of the EQ coils, the OH coils meet the decoupling requirements. The specific strategy is as follows. To optimize the power-supply system, the OH coils are split into three sectors. All OH coils are connected in series and use a single power supply. The self-inductance of each sector and the mutual inductance with the other sector must be equal.

The basic picture should be as follows. When the three sectors of the OH coils are connected in series, they have the same current and approximately the same terminal voltage.

Table 2 lists the grouping strategy of the KTX OH coils and the mutual inductance, in which the 13th coil is used to adjust the coefficient of inductance from each group. The three turn coils are taken into the A, B and C sectors (each sector has one turn) individually.

3.3. Design of EQ coil

The EQ coil of the KTX has two main functions. One is to produce the vertical field required by the EQ plasma to inhibit the plasma’s outward expansion. In the KTX design, the plasma is located in the inner part of the vacuum chamber, which is wrapped in a copper shell. The penetration time of the copper shell is approximately 20 ms. When the plasma ramps up, the plasma EQ is maintained mostly by the copper shell and the EQ coil. The shell and EQ coils work together to control the plasma. If a well-designed EQ current ramps up with the plasma current synchronously, then the eddy current on the shell is reduced to zero. Thus, the error field on the gaps or ports will be reduced. Nonetheless, in the flat-top phase, the EQ is more dependent on the EQ coil.

The other function is to optimize the poloidal flux. When the EQ coil’s total ampere-turns are equal to the plasma current and the coil’s current direction is the opposite of the plasma current, the coils can shield the poloidal flux generated by the plasma within the space that is around the coils, thus reducing the poloidal flux and corresponding magnetic energy required by the discharge.

The EQ coil design should satisfy the following conditions:

- the EQ coils can provide a sufficient vertical field to maintain 1 MA of plasma current;
- the flux surface should fit the copper shell closely to ensure that the eddy current on the shell is sufficiently small. Such a design could reduce the error field at the gaps;
- optimize the poloidal flux. The total current in the EQ coils is equal to the plasma current but is opposite in direction.

The EQ coil design should meet the requirements of the optimized power-supply system:

1. EQ sectors should be connected to OH sectors in parallel to allow a decoupling with OH coils;
2. each pair of EQ coils, which are placed in a symmetrical position with respect to the equatorial plane, uses one additional power supply. The EQ coils should be well designed to minimize the voltage of these power supplies.

The design should meet the requirement of optimizing a mainframe system:

1. the arrangement of the EQ coils should meet the requirement of the ‘Double-C’ structure;
2. the arrangement of the EQ coils should meet the requirements of the diagnostic ports and support structure.

The EQ winding of the KTX device is composed of 12 coils. The detailed composition is shown in figure 5 (blue part). The geometric parameters of the upper half plan of the coil are shown in table 3. In those 12 coils, the symmetry to
the mid-plane of the KTX is divided into the upper and lower sides. Two symmetrical coils are connected in series. Figure 5 shows that the EQ coils reserve the space for diagnostic ports and are compatible with the red OH coils and green TF coil. The arrangement also meets the requirements of a ‘Double-C’ structure. The outermost coil is located at a height of 0.412 m. In this design, \(\sim 700 \times 800 \text{ mm}^2\) area exists for the vacuum chamber to be pulled apart horizontally.

When the plasma current is 1 MA, the current in each EQ coil is shown in Table 3. Six pairs of EQ coils are divided into three sectors. Each EQ sector is connected to one OH sector in parallel. The circuit is shown in figure 9. To minimize the requirement of an additional power supply, each EQ sector has the same total current: \(I_1 + I_6 = I_2 + I_5 = I_3 + I_4 = 8.0 \text{ kA}\).

The EQ results are checked by using the electromagnetic model and the KTX-FIT. As shown in figures 7(a) and (b), the KTX design meets the requirements of the plasma EQ and can provide a suitable EQ to control the plasma.

### 3.4. Optimization of the PF system

In the above examples of plasma EQ, the outermost two EQ coils must be located far apart, and the total ampere-turns are slightly larger than the plasma current. The total ampere-turns of the EQ coil are approximately –1 MA. Under the synergistic effect of the EQ and plasma currents, the poloidal magnetic field produced by the plasma is shielded in the space surrounded by the EQ coil. The equivalent plasma self-inductance decreases from 3.2 \(\mu\text{H}\) to an equivalent inductance of 2.0 \(\mu\text{H}\), which significantly optimizes the poloidal magnetic flux and energy required.

In the KTX device, the OH coil, EQ coil, plasma current and eddy current in the copper shell are coupled. During the start-up and extinguishing of the plasma phase, millions of ampere-turns of toroidal current in the OH coil change rapidly within milliseconds. Thousands of volts of pulsed high voltage can be induced in the EQ coil, which can lead to significant technical difficulties in the EQ coil design. To avoid a large pulsed voltage in the coils, the OH and EQ coils in the KTX device are divided into sectors and connected in a bespoke manner. When the plasma ramps up, the well-designed position of each EQ coil results in no requirement for additional power supplies for the EQ coils. However, two main limiting factors exist in the KTX, so a new decoupling method is required.

First, because the major radius of the KTX torus is only 1.4 m, a much smaller space exists for the arrangement of the EQ coils. The narrow space in the EQ coil region makes decoupling the power supply more difficult. The conflict with diagnostic ports or other wires should be considered in the design process.

Second, to achieve the design of a ‘Double-C’ structure, the EQ coils should not be too close to the TF coils. The inhomogeneity of the spatial position of the EQ coils complicates the decoupling conditions. Figure 8 shows that for EQ1–EQ4, each EQ coil is relatively symmetrical compared with the plasma position; their responses to the change in plasma current are similar, for the most part. However, the EQ5 and EQ6 coils are located farther from the plasma current than from the other EQ coils. When the plasma ramps up, if the EQ5 and EQ6 coils have the same number of turns as the other EQ coils, the induced currents in the EQ5 and EQ6...
coils are smaller than those in the other coils. The additional power supply will require a higher voltage; otherwise, the eddy current on the shell will be much larger. The result of this spatial inhomogeneity is that the above design requires a further change from the original decoupling.

In the final design, an easier method to decouple the PF coils, plasma current and copper shell is used. The circuit shown in figure 9 is used to fulfill the decoupling of the power-supply system. Two conditions are required, as discussed below.

First, each sector of the PF coil should have the same flux. The flux of each sector is shown in table 4. The physical meaning of these fluxes is that, according to the inhomogeneity of the spatial position of the EQ coils, the original decoupling coefficients must add the coupling from the plasma current and copper shell to the PF coil. In this case, the original decoupling coefficient becomes complicated. We must consider the interaction between the plasma current, copper shell and PF coil. Where three currents exist simultaneously, the total flux of each sector is calculated. If the position and total ampere-turns of each PF coil are kept unchanged, then the EQ condition will remain unchanged. To ensure that each sector has the same flux, the turns and current of each EQ coil can be adjusted. The same total flux per sector can guarantee the same magnetic field change response and yield the same induced voltage in each group of coils. This will result in a reduction in the requirement for an additional power supply and eddy current on the shell.

Second, the total current of each sector of the EQ coil (1, 6), (2, 5) and (3, 4) must be the same. The circuit in figure 9 shows that the three sectors of the OH coil have the same current and that the circuit is compatible with the OH field design. To fulfill the above design, the physical design ideas are as follows: the total current in each group of EQ coils is the same, and the three sectors of OH coils that are connected in parallel should have the same current and voltage.

### Table 4. Total flux of each sector of OH and EQ coils.

<table>
<thead>
<tr>
<th>Coil No.</th>
<th>Total Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector A</td>
<td>125</td>
</tr>
<tr>
<td>Sector B</td>
<td>128</td>
</tr>
<tr>
<td>Sector C</td>
<td>131</td>
</tr>
<tr>
<td>EQ1</td>
<td>127</td>
</tr>
<tr>
<td>EQ2</td>
<td>127</td>
</tr>
<tr>
<td>EQ3</td>
<td>131</td>
</tr>
<tr>
<td>EQ4</td>
<td>128</td>
</tr>
<tr>
<td>EQ5</td>
<td>130</td>
</tr>
<tr>
<td>EQ6</td>
<td>131</td>
</tr>
</tbody>
</table>

4. Conclusion

A new design for a PF system for RFP devices has been presented. The design contains fewer coils and sections, which allows a more convenient arrangement of the support structures and diagnostic ports. The ‘Double-C’ structure allows the chamber to be separated to provide direct access to the interior of the chamber. When the plasma ramps up, the EQ current, which is synchronized with the plasma current, is used to save some magnetic flux and improve the utilization efficiency of the OH coils. When designing the PF system, the stabilizing shell and the effects of the eddy current in the stabilizing shell are fully considered. Considering the OH coil, EQ coils, plasma currents and stabilizing shell, a new optimization idea is proposed, and the final PF design is optimized using this method. The PF windings are located strategically to minimize the power-supply requirements. The design of the PF system can maintain the plasma current, provide an adaptive optimization design of the plasma EQ, enhance the OH efficiency and provide the important advantages of OH to the RFP configuration.

Figure 8. Spatial inhomogeneity of EQ coil (Wb).

Figure 9. PF circuit diagram (U and D represent the upper and lower coil pairs).
Acknowledgments

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