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Design of the power system for dynamic resonant magnetic perturbation coils on the J-TEXT tokamak

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HIGHLIGHTS

- We introduce the dynamic resonant magnetic perturbation coils system on J-TEXT.
- Details of the design of the power supply system have been presented.
- At DC mode, two antiparallel 6-pulse phase thyristor rectifiers were chosen.
- An AC–DC–AC converter including a series resonant inverter was adopted for AC mode.
- Some engineering testing result was given in this paper.

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ABSTRACT

A set of in-vessel saddle coils has been installed on J-TEXT tokamak. They are proposed for further researches on controlling tearing modes and driving plasma rotation by static and dynamic resonant magnetic perturbations (RMPs). The saddle coils will be energized by DC with the amplitude up to 10 kA, or AC with maximum amplitude up to 5 kA within the frequency range of 1–5 kHz. At DC mode two antiparallel 6-pulse phase thyristor rectifiers are chosen to obtain bidirectional current, while at AC mode an AC–DC–AC converter including a series resonant inverter can generate current of various amplitudes and frequencies. The paper presents the design of the power supply system, based on the definition of the power supply requirements and the feasibility of implementation of the topology and control strategy. Some simulation and experimental results are given in the end.

1. Introduction

The control of plasma instabilities is a very important issue in Tokamak experiments. Among today's solutions, active control with in-vessel saddle coils is regarded as one of the most effective approaches to study the tearing modes, error field penetration, mitigation of edge localized modes and so on [1,2].

A set of active coils has already been mounted on the outside of the vacuum vessel of J-TEXT [3], which can generate static magnetic perturbation, only. In order to enhance experiments on the interaction between applied RMPs and plasma, it is planned to install groups of in-vessel saddle coils. This upgrade scheme consists of the design, fabrication and installation of the coils and the relevant power supply (PS) system.

Based on considerations on the vessel geometry and electromagnetic features of the coils, four groups of saddle coils are designed and distributed symmetrically on the inside of the J-TEXT vessel [4]. The layout of the dynamic resonant magnetic perturbation (DRMP) coils is shown in Fig. 1. The coil sets are divided into two parts consisting of two groups of coils which are spatially 180° phase shifted to each other in toroidal direction (Fig. 2). Each part will be energized independently by DC or AC, using a real-time control system. In this paper, the requirements for the DRMP coils system are introduced first. Afterwards, a detailed description of the PS system design and some testing results are presented.

2. PS requirements and design

2.1. PS requirements

In literature [4], the magnetic field design of the DRMP coils system has been described deeply. In order to generate strong enough $m/n = 2/1$ (m, n: poloidal and toroidal mode numbers respectively) perturbation field in both DC and AC operation mode, the PS should have the electrical features shown in Table 1. The impedance of

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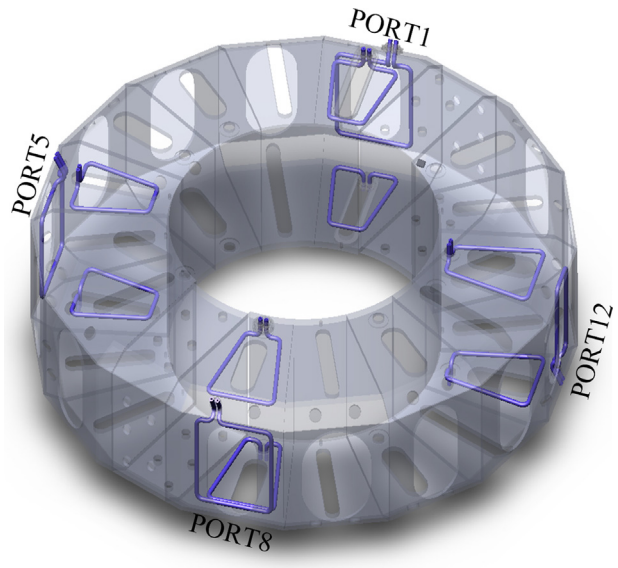

Fig. 1. Layout of the DRMP coils on J-TEXT.

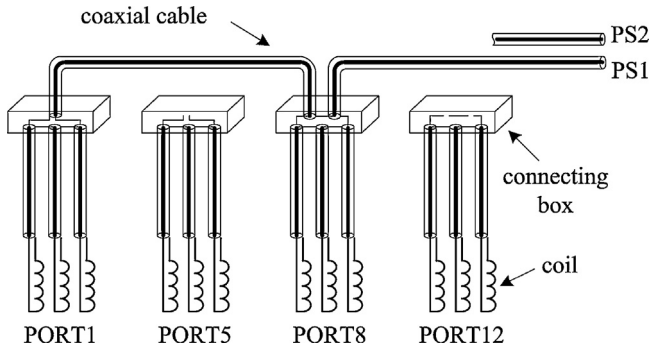

Fig. 2. Series connection of the coils.

the coil load has been calculated earlier, and it is in agreement with the results of the measurements reported in Table 2. To meet all requirements with suitable design margin, the output power should be 2500 kW and 1200 kW for the DC and AC PS respectively.

Table 1
Electrical requirements of the DRMP coils on J-TEXT.

	DC power	AC power
Number of units	2	2
Frequency	0	1–5 kHz
Output current	±10 kA	5 kA(peak)@5 kHz
Output voltage	±250 V	<1000 V(peak)
Ripple of current	<5%	–
THD of current	–	<5%
Duty cycle	1 s/300 s	1 s/300 s

Table 2
Parameters of the coils.[a]

Frequency	Port1+Port8	Port5+Port12
0	4.6 mΩ	4.4 mΩ
1000 Hz	15.91 mΩ/6.86 μH	15.94 mΩ/6.77 μH
2000 Hz	22.54 mΩ/6.38 μH	22.17 mΩ/6.31 μH
3000 Hz	28.63 mΩ/6.12 μH	27.94 mΩ/6.04 μH
4000 Hz	34.74 mΩ/5.91 μH	34.19 mΩ/5.87 μH
5000 Hz	40.47 mΩ/5.78 μH	40.01 mΩ/5.74 μH

[a] Measure results using Precision Magnetics Analyzer 3260B (Wayne Kerr electronics).

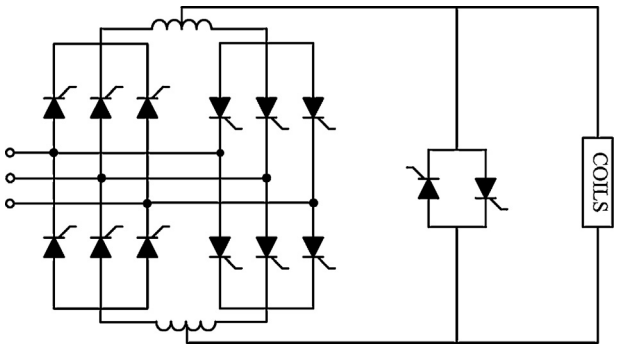

Fig. 3. Selected topology for DC PS.

This kind of PS features fairly unique electrical parameters and characteristics, for example, fast dynamic response, high quality of output waveform and wide tuning range. Even so, many Tokamak experiment devices have completed the design of PS for active coils based on their own requirements [2]. Any of these designs is a result of comprehensive consideration of the feasibility, difficulty, cost, size, etc. For J-TEXT, DC and AC PS system for the DRMP coils are designed separately. So, two DC PSs and two AC PSs are needed for the coils system.

2.2. DC PS design

The DC PS should provide controllable DC with a maximum value of 10 kA. A phase-controlled thyristor rectifier could be the best choice, which is a cost-effective and highly developed technology. A detailed comparison of 12-pulse with 6-pulse rectifier has been done before adoption of 6-pulse rectifier topology, in terms of ripple, cost and size. In order to meet requirements of different operation scenarios, the DC PS must have the capacity for generating various current waveforms. The waveforms could be unipolar or bipolar, symmetrical or asymmetrical, which is quite helpful for plenty experiments. As shown in Fig. 3, two antiparallel 6-pulse phase-controlled thyristor rectifiers have been chosen.

Safety and reliability are both very important for the PS system. A bidirectional bypass branch that can offer a path for the load current when a fault occurs is added to the output of the rectifier. The branch is comprised of several thyristors that are in parallel. The smoothing reactor with three terminals combines the two antiparallel three-phase bridge rectifiers, which guarantees that the PS can be operated safely in four-quadrant operation mode. Moreover, the reactor also plays the role of a filter, making the output current wave smoother.

2.3. AC PS design

A broad variety of topologies has been used in the design of AC PS that can supply thousands of amperes current with bandwidth up to thousands of hertz in the research of plasma instabilities control [2,5]. The difficulty in finding an appropriate technical solution is to choose the DC/AC converter implemented by fully controllable semiconductor switches. For semiconductors, the maximum of switching frequency decreases when rating power increases. The best choice for the semiconductor switch is the insulated gate bipolar transistor (IGBT) in the given range of power and frequency defined in Table 1.

The next step is to select an appropriate topology that can not only satisfy the output requirements, but also reduce the switching frequency as much as possible. Among the possible considerations, cascaded H-bridges multilevel inverter, using carrier-phase-shifted