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Design of focusing magnet for high power klystron*

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Abstract: An S-band 45 MW pulsed klystron is developed in Institute of High Energy Physics (IHEP). This klystron is a modified version of the existing 30 MW tube, which produces 45 MW at a 320 kV beam voltage by optimizing the focusing magnetic field. Therefore, the focusing coil needs to be re-arranged and its supporting structure is newly designed to meet 45 MW klystron demands. This paper describes the design, manufacture and operation of the focusing magnet system. The results of the magnetic field, the high power of the tube are presented. The operation status of the focusing magnet system is also included. The high power test results of the prototype tube show that the design, the manufacture and the operation of the focusing magnet system are successful.

Key words: High power; Klystron; Studies; Design; Focusing magnet

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An S-band 45 MW pulsed klystron is developed in the Institute of High Energy Physics (IHEP) for BEPCII linac[1]. This klystron is a modified version of the existing 30 MW tube, which produced 45 MW at a 320 kV beam voltage by optimizing the focusing magnetic field[2]. In order to obtain new focusing magnetic field distribution to meet the demands of the 45 MW pulsed klystron. The focusing magnet structure were redesigned and fabricated; an old focusing coil and its structures were upgraded. At first, the axial distribution of the ideal magnet field was obtained by EGUN[3] and POISSON[4] code. According to the simulation results the coils arrangement was decided and described. Then magnetic field test was done immediately, and the measured field distribution coincides with the calculation results very well. The new designed focusing system was used on a prototype, which was manufactured in 2005, and then the high power test was carried out. The test results show that this prototype tube can produce an output power of more than 45 MW at 300 kV with an efficiency of 42%. Initial tests indicate that the design, the manufacture and the operation of the focusing magnet system are successful.

1 Theoretical analysis

All practical klystrons employ magnetic confinement to control the electron beam. The aim of the focusing magnetic field is to achieve the necessary beam constraint with the minimum ripple. The analysis of this problem in the general case is very complex but some useful results can be made by making assumptions such as the existence of a uniform laminar beam[5].

For an axially symmetric beam in a constraining axial magnetic field, the electrons are subjected to three forces[6-7]. The electric field from the space-charge within the beam produces a force which tends to move the electrons radially outwards. This motion causes an interaction with the magnetic field which produces a force normal to the radius vector of the electron and the axial magnetic field. This force causes the beam to rotate. The rotation produces a further interaction with the magnetic field producing a force which is radially inwards the axis and counteracts the electrostatic repulsion. The rotation of the electrons about the axis also produces a centrifugal force on the electrons.

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In order to design the magnet system, different computer codes were used to simulate the field distributions. The structure of magnet system and ampere-turns of coils were decided by POSSION code and the beam optics of the tube was determined by EGUN code[8]. Then, adjustment and optimum were repeated, until excellent beam optics results were obtained. Fig. 1 shows the magnetic field distributions by POSSION code. Fig. 2 shows the beam optics by EGUN code under appropriate axial magnet field distributions. The green line is the axial magnet field distribution, the pink line is the beam profile and the red line is the equal-potential distributions.

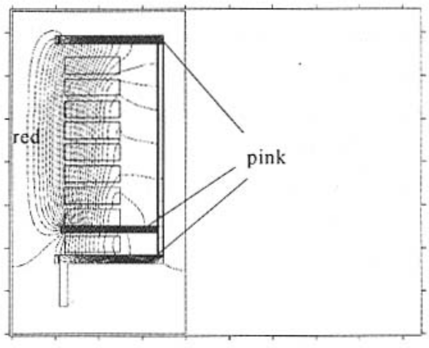

Fig. 1 Magnetic field distributions of focusing coils

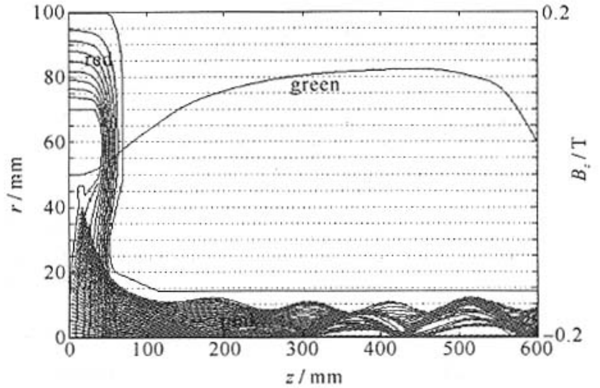

Fig. 2 Beam optics of klystron under reasonable magnetic field

2 Design descriptions

The electromagnetic system for focusing the electron beam were designed and fabricated. The flux, produced by coils consisting of many turns of copper wire wound on a framework, passes along the axis of the solenoid to the mild steel pole pieces.

To build the focusing magnet system for China-made 45 MW klystron, the old coils on 30MW klystron was used, the supporting structure was redesigned. Another important aspect of solenoid design is the removal of the heat generated by the current passing through the coils. Cooling water, passes through the tubes, removes the heat to a heat exchanger. Considering the arrangement of the coils and cooling water, a set of focusing system is fabricated in IHEP. Fig. 3 shows the cooling water system including input and output water circulations. Fig. 4 shows the magnet coil and its supporting structure installed in test bench.

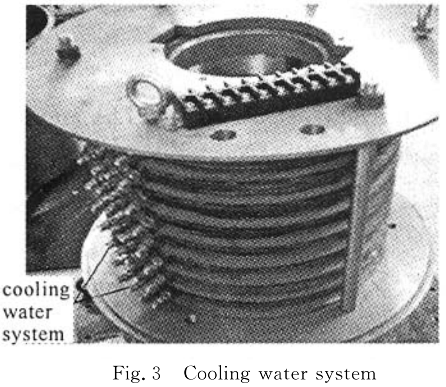

Fig. 3 Cooling water system

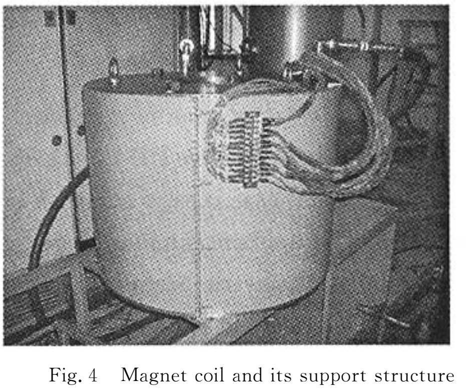

Fig. 4 Magnet coil and its support structure

There are nine magnet coils, including one bucking coil for fine tuning of the magnetic field near the cathode. The total number of power supply is six, the coil near the cathode and the two coils near the output cavity need 3 power supplies respectively. Other coils are divided into groups, each group consist of two coils in series fed by one power supply.

3 Focusing system test

According to the simulating calculation results, each supply power was given to an appropriate current value (just the simulation results). The measurement of magnetic field was done by HG-type Hall magnetic instruments. The measurement range is 0 ~ 0.2 T, resolution is 10 μT and the basic tolerance margin is ±0.8 ±0.5% by reading of the magnetometer (Gs).

To reduce the accidental tolerance, we took two measurements by using the Hall effect probe from top to bottom and from bottom to top at the center of solenoid respectively. Test results are just the average magnetic field intensity of the two measurements. Comparision between simulation and test are shown in Fig. 5.

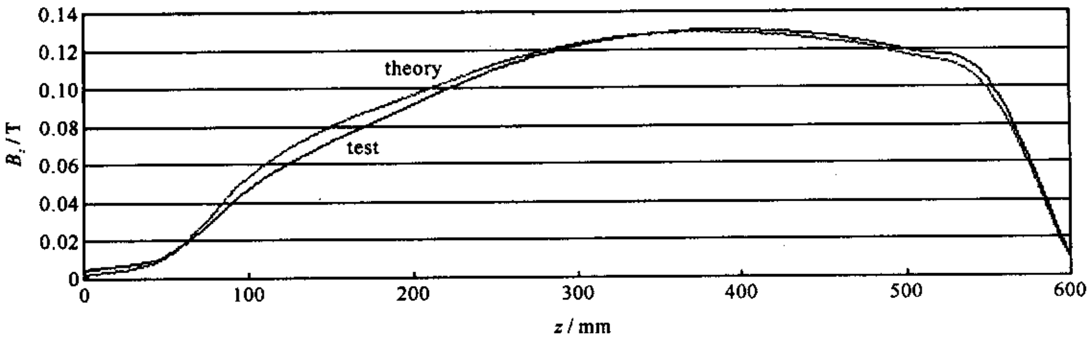

Fig. 5 Comparision between simulation results and test results of axial magnetic field

Fig. 5 shows that there is a fairly consistency between the test results and the calculation results. Namely, the simulation results by POISSON code concide with the test results very well. In general, the simulation can replace actual measurements. It also gives a good help on optimizing focusing magnet system.

4 Operation status

After physical analysis, computer simulation, mechanical design and fabrication, the prototype tube including the new focusing magnet system were tested on the test bench. The test results show that this protype tube can produce an output power of more than 45 MW at 300 kV with an efficiency of 42%. Initial tests indicate the design of the focusing system meets its demands. Fig. 6 shows the output power *vs* high voltage for the test.

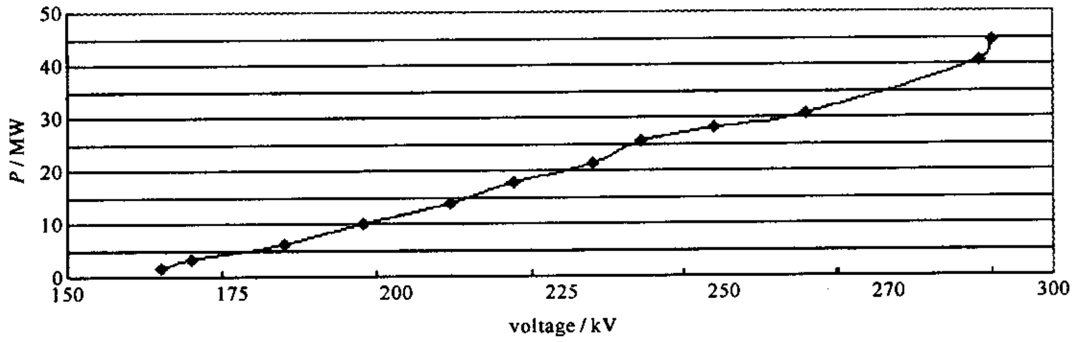

Fig. 6 Output power *vs* pulse voltage

According to high power test process, we obtain the operation value of the focusing coil. Table 1 shows the compareision between calculation results and operation status. From Table 1 we can see that there is a slight different between the operation value and the calculation results. The main reason is that the influence of the iron flange to the magnet field near the output cavity is not considered. From the high power test results of the prototype tube, we can see that the design, manufacture and operation of the focusing magnet

Table 1 Comparision between calculation and operation status

supply power series No.	1	2	3	4	5	6
calculation results/A	5.6	11.7	6.8	7.9	5.2	2.6
operation status/A	4.2	8.2	6.3	5.2	7.7	4.4

system are successful.

5 Conclusion

The design of focusing magnet system for 45 MW tube includes many aspects, such as physical design, mechanical design, cooling water design, magnet test and high power test of the tube. The magnet system will operate with 6 powers including a bucking coil power. EGUN and POISSON codes are used to simulate the beam optics and magnetic field distribution. From the high power test results, the prototype tube can produce an output power of more than 45 MW at 300 kV with an efficiency of 42%.

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高功率速调管聚焦磁场设计研究

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摘 要： 国产45 MW速调管是在原国产30 MW HK-1型速调管的基础上改进和发展起来的，其聚焦磁场设计也是参照30 MW速调管聚焦磁场设计并在其基础上加工改造完成。为此必须对旧聚焦系统进行改造，设计出符合需要的磁场分布，以满足45 MW速调管工作的需要。首先从理论上找出速调管工作时的理想磁场值，根据该磁场分布设计出相应的线圈结构；其次根据45 MW速调管的结构尺寸，对30 MW速调管的线圈支架进行改造，利用旧线圈和新支架组成新的聚焦系统；最后，根据理论模拟和测试结果，调整和优化各组线圈的电流值，给出速调管工作时的各组聚焦电源运行参考值。叙述了新聚焦线圈的理论设计和测试分析，包括新线圈支架的设计、水冷系统与线圈的结构安排和整体的测试结果，最后根据速调管高功率测试运行状态给出速调管工作时的聚焦线圈电流的参考值。

关键词： 高功率； 速调管； 分析； 测试； 聚焦磁场