THE DESIGN OF 1.1 MW RF DUMMY LOAD FOR THE RF SYSTEM OF 520 MeV CYCLOTRON*

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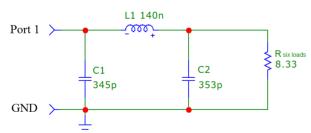
Abstract

The RF System of 520-MeV Cyclotron is operating at 23 MHz with 1 MW CW RF power. The RF dummy load is required to troubleshoot and tune the RF amplifier. The RF system is being constantly improved and the future goal is to increase cyclotron's beam current up to 400 μA, which requires increasing the RF amplifier's power. As a part of this goal, a new RF dummy load was designed.
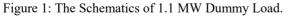
INTRODUCTION

In the past, an RF dummy load with sodium bicarbonate solution has been used for tuning and troubleshooting of the RF amplifier [1]. Operation of the RF system at different levels of RF power required readjustment of water flow as well as temperature and concentration of the sodium bicarbonate solution. The sodium bicarbonate dummy load also been the cause of equipment-damaging solution leaks in the RF room. Therefore, a decision been made to discontinue the use of that RF load and develop a new safe dummy load cooled with deionized water (which is safer in comparison with sodium bicarbonate) and able of handling over 1.1 MW CW of RF power.

SCHEMATICS

The proposed Dummy Load is based on splitting RF power over six 200 kW dummy loads. As all of these dummy loads are in parallel, the input impedance is equal to 8.33 Ω. To match impedances of 8.33 Ω to 50 Ω, the main transmission line was equipped with a pi-network consisting of two adjustable capacitors C_1, C_2 and one adjustable inductor L_1 (Figure 1).

Figure 1: The Schematics of 1.1 MW Dummy Load.

AC Analysis in Micro-Cap 11 [2] allowed to determine S-parameters in the range of 15-30 MHz, VSWR is in the Figure 2.
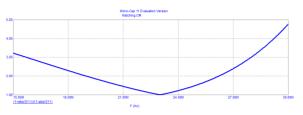
Figure 2: VSWR of the Dummy Load.

The calculation of AC current via C_1 and C_2 for input RF power equal 1.2 MW showed that $I_{C1} = 387\ A$ and $I_{C2} = 368\ A$. Maximal voltage in the dummy load is less than 11 kV. Comet adjustable capacitor CVMA-450CW/50-AAB-R1 was selected for both C_1 and C_2 as it has max current 419 A, max voltage 30 kV and is water-cooled.

THE DESIGN OF THE DUMMY LOAD

The old 600 kW sodium bicarbonate-filled dummy load consisted of a control unit (Figure 3, a)) and the dummy load itself (red rectangle in the Figure 3, b)).

The availability of free space in the RF room (see in red rectangle in Figure 3) determined the design of the new 1.1 MW Dummy Load.
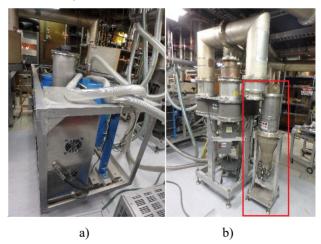

a)　　　　　　　　　　　　b)

Figure 3: The 600 kW sodium bicarbonate filled Dummy Load with in the RF Room.

The newly designed Dummy Load includes six 50 Ω of the 200 kW water-cooled RF coaxial loads arranged in series (product of Altronic Research Inc., Model 57200B). The copper-pipe inner conductors in the six-port combiner, in the inductor and in the matching circuit are water-cooled. The entry port of the combiner has an 8.33 Ω co-axial entry. Then the combiner combines three pairs of outer ports using 25 Ω transmission lines, each with a 50 Ω coaxial port. Polyurethane hoses with Swagelok fittings inserted inside inner conductors are used to feed water in through those inner conductors. The design also uses two

Comet adjustable capacitors CVMA-450CW/50-AAB-R1 that are also water-cooling. The design and the model for simulations was made using SolidWorks. Design of RF connection for these 200 kW dummy loads uses V-Band clamps (VT10835) with wedges shims [3] (Figure 4).
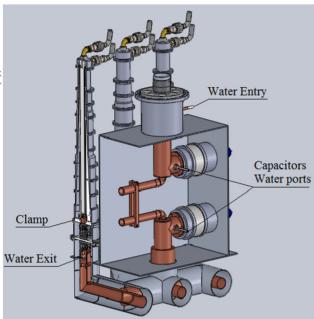

Figure 4: The Design of 1.1 MW Dummy Load.

SIMULATION OF DUMMY LOAD'S ELECTRO DYNAMIC CHARACTERISTICS IN ANSYS HFSS

The SolidWorks model was exported and adapted to simulate the field distribution and to calculate the S-parameters in ANSYS HFSS [4]. The designed capacitors consist of two coaxial cylinders, the outside diameter of the outer cylinder is equal to the diameter of selected Comet capacitor. An electrostatic simulation in COMSOL [5] allowed to calculate the capacitances of these two coaxial cylinders. The radii of these inner cylinders were the parameters of the HFSS model. Their variation helped to tune the Dummy Load and to achieve a better matching condition in the entrance port. The shorting conductor with clumps varies inductor's inductance.

Figure 5 shows the results of HFSS simulation for the electrical component of the RF field's middle plane, for the case of $1\,W$ of entry power, when VSWR better than 1.04 was reached.
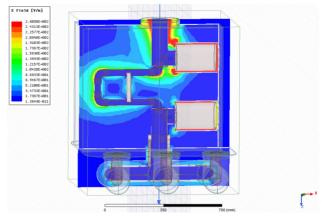

Figure 5: The distribution of the electric field in RF field's the middle plane (result of simulation in HFSS)

The tuning of $VSWR = 1.01$ with ± 0.01 required adjustments to only C_2 and L_1. After perfect matching, C_1 and C_2 were recalculated (using the new geometry from HFSS) in COMSOL using the electrostatic solver. As the result of that simulation, C_1 kept the same dimensions and value, only the value of C_2 was adjusted to $C_2 = 360\,pF$.

SIMULATION OF STEADY-STATE THERMAL CHARACTERISTICS IN ANSYS ANSYS WORKBENCH

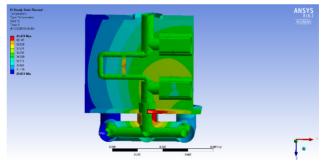The steady-state thermal simulation in ANSYS Workbench shows that temperature distribution (Figure 6).

Figure 6: Temperature distribution calculated by ANSYS Workbench.

The maximum temperature was below 42℃. The simulation also showed that only 1 kW of RF Power dissipated inside the Dummy Load body and the inner conductors. The rest of RF power (about 1.1 MW) dissipated in six 200 kW dummy loads [6]. To remove all heat flow from the designed Dummy Load required a water flow of 127 Gal/min. Table 1 shows water flow distribution between different parts of the Dummy Load.

Table 1: Cooling Water Flows in the Dummy Load

Part of the dummy load	Water flow, gal/min
200 kW dummy loads	120
Capacitors	6.4
Inner conductor and the inductor	0.6
All parts of 1.1 MW Dummy Load	127

SIMULATION OF WATER FEEDING

The design of the Dummy Load has its own water-cooling system independent from the water-cooling systems of 200 kW dummy loads and capacitors. The water inlet is located in the entrance port (port 1). The water outlets are located in the ports of the 200 kW dummy loads. The plastic hoses that feed the water through the outside conductor of the 9-inch coaxial line in the entrance port and in the outlet ports, pass through the space between outer and inner conductor (Figures 7, 8). The plastic hoses are subject to being burned in this type of an arrangement [7]. To avoid this problem, the diameter of the entry hole inside the inner conductor was increased. The metal fittings were also moved deeper inside the inner conductor. This allowed to reduce the level of the electric field near surface of the plastic hose. To prevent any possible water leak, reliable Swagelok fittings were used [8].

Figure 7: Water Feedthrough at the Entrance of the 1.1 MW Dummy Load.

Figure 8: Water bullets used in the 9-inch transmission line for water feeding.

Water feed through the conductor creates high electric field near edge of the water-feed through hole. The level of RF field near the edge of hole depends on the diameter of this hole. This high field could burn plastic hose used for the water supply [3]. The simulation of the water feedthrough transmission line in ANSYS HFSS shows the presented design can keep the level of field below the maximum level in the 9-inch transmission line (Figure 9).

Figure 9: The simulation of water feedthrough.

If one of the dummy load resistor is burned, the VSWR in the entrance of 1.1 MW dummy load will be below 1.2. In this case, reflected power will be less 9 kW that could be consumed in the combiner dummy load without any problem. The future goal is to interlock the main RF system when a resistor burns. Another goal is to install the voltage pickups in every 200 kW Dummy Load ports to compare the signals of these pickups. The pickup control box will generate interlocks.

Figure 10 shows the layout RF room, where the 1.1 MW dummy load (pos. 5) is in green and the control unit of dummy load based on sodium bicarbonate solution (pos. 2) is in red.
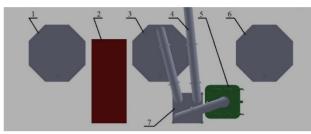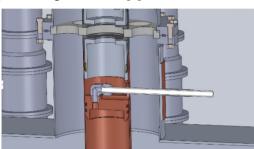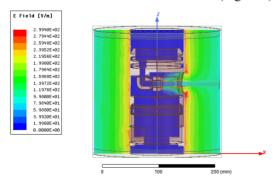

Figure 10: The layout RF room with the 1.1 MW dummy load.

The RF combiner is in pos. 1, 3 and 6; RF switch is in pos. 7, the output transmission line is in pos. 4. The new dummy load not only makes the layout of the RF room safer, but also allows more room for maintenance of the RF equipment in the RF room.

CONCLUSION

The design of the 1.1 MW Dummy Load for the RF System of 520-MeV Cyclotron is now complete. Electromagnetic and thermal analysis was accomplished through ANSYS simulations. Six standard 200 kW RF loads with matching pi-network are employed in the design. The water flow required for cooling is about 127 Gal/min. We are planning to fabricate the Dummy Load in the near future.

REFERENCES

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