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Design and Simulation of a Water -Cooling System for a Magnetron with 2.45 GHz Frequency and 1 KW Power

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ABSTRACT

The magnetron is a microwave source. The electron efficiency of the magnetron, which defines the efficiency of converting electron flux energy into energy of high-frequency fluctuations, is very high (up to 80%). Still, almost all of the remaining part is released as heat per anode unit, which leads to its heating. This temperature increase reduces the device useful life and causes magnetron failure. One way to remove the heat generated by the magnetron is to cool it, which, depending on the type and output of the magnetron, may be cooled by air or water. Therefore, In this paper, a water-cooling system for a 1kW magnetron with a frequency of 2.45 GHz is designed and simulated by using Comsol software (version 5.6) to study the temperature changes and distributes in the magnetron under the influence of water cooling and to compare it with the state where there is no cooling. The simulation results showed that in the absence of cooling, over time (10 minutes), the magnetron temperature reaches 5680˚C, which causes the magnetron to melt. With the cooling design, we observed that the magnetron does not change temperature after 10 minutes of continuous operation in the water-cooling system and has temperature stability. This result allows the magnetron to be used for more extended periods in industrial and consumer applications such as microwave ovens.

***Keywords*:** Magnetron; Water cooling; Simulation; Comsol software.

1. Introductions

The magnetron, as an oscillator, is one of the important sources of microwave energy that uses cross-electric and magnetic fields to generate microwave signals [1]. Among other high-power microwave sources, it is the self-excited one, which means oscillations start in their own resonators without the requiring for an external signal to be amplified. In this sense, it differs from the high power microwave sources like klystrons, TWTs etc.

Today, high-power vacuum tubes, such as magnetrons, klystrons, and gyrotrons, are needed for high-energy particle accelerators and plasma heating in tokamaks [2]. In general, it can be said that magnetrons are used to generate radio frequency signals in a variety of consumer and

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industrial applications (microwave ovens, radar, plasma generators, linear accelerators, etc.) [3].

Today, high-power vacuum tubes, such as magnetrons, klystrons, and gyrotrons, are needed for high-energy particle accelerators and plasma heating in tokamaks.

In general, magnetrons are used to generate radio frequency signals in various consumer and industrial applications (microwave ovens, radar, plasma generators, linear accelerators, plasma generators, etc.). Magnetrons are used in many applications that use microwave radiation [4].

For example, the most common commercial use of a magnetron is a continuous wave in a microwave oven. An industrial application for magnetrons in the field of plasma production. In plasma generators, a magnetron can be used to generate microwave excitation energy into a plasma cavity to continue plasma production. Plasma generators using magnetrons have many applications. For example, in the manufacturing processes of semiconductor devices, such as chemical vapor deposition.

In recent years, microwave applications (such as magnetrons) for tokamak have become more significant in heating and pre-ionization. Over the years, the magnetron and its associated circuit in a microwave oven have been used in various experiments on electrodeless lamps, ion implantation, ion source development, plasma-assisted chemical vapor deposition, X-ray source development, and more. It is widely used because of its simplicity, safety, ease of availability, and economy. For example, the 2.45 GHz magnetron system has been used as a pre-ionization device in KAIST-tokamak plasma [5,6].

The electron efficiency of the magnetron, which defines the efficiency of converting electron flux energy into energy of high-frequency fluctuations, is very high (up to 80%). Still, almost all of the remaining part is released as heat per anode unit, leading to heating up. As the temperature increases, the magnetron's dimensions change. The change in dimensions results in a loss of power and a decrease in the output frequency of the device. Therefore, the magnetron cooling method is one of the most important factors for the operation of the magnetron.

Various types of magnetrons require a cooling system (especially liquid cooling) to maintain an appropriate thermal state during continuous and long-term operation. Accordingly, an air or water cooler prevents the anode temperature from rising. In general, low-energy magnetrons are cooled by air, and high-energy magnetrons are cooled by water.

In recent years, many efforts have been made to improve magnetron cooling due to the expansion of the use of magnetrons in industry and heating to increase its performance at higher power levels. The need for a magnetron cooler becomes apparent when the magnetron cathode heats up and reaches operating temperature within seconds of turning it on. Even if the magnetron is very efficient, several hundred watts of power must be transmitted by aluminum cooling blades (air coolers).

One technology for modifying home and industrial microwave oven magnetrons to work at higher power levels is to use water cooling instead of air [7,8]. Also, in recent years, the temperature and frequency distribution method and performance analysis of the magnetic anode unit liquid cooling system with different output capacities, as well as estimating the water heat transfer coefficient and examining its changes in terms of temperature, using simulation Various, have been examined.

For example, in [9], a water cooling system is designed for a magnetron with a power of 30 kW and a frequency of 2.45 GHz. In [10], the aim is to analyze the performance of the liquid cooling system of the magnetron anode unit with an output power of 1.0 kW.

The purpose of this article is to design and simulate a water cooler for a magnetron with a frequency of 2.45 GHz and a power of 1 kW. In this paper, the effect of water cooling on magnetron performance is investigated by using Comsol software.

The full description of the results is given in the discussion and the results and design and simulation sections.

2. Design and Simulation

In this study, in order to investigate the changes in magnetron temperature under constant pressure and fluid velocity over time, two modules, Pipe Flow and Heat Transfer in solids of Comsol software (version 5.6) have been used. The pipe Flow module is one of the modules of COMSOL Multiphysics software that is designed to model and simulate fluid flow in pipes and ducts. This module can also be used to design and optimize cooling systems. This module contains several physical interfaces, one of which is the Nonisothermal Pipe Flow interface, which we used in this article (as shown in Figure 1). The Nonisothermal Pipe Flow interface resolves pressure and temperature simultaneously and completely. The following constant momentum and continuity equations describe the static flow inside the pipe system and are solved by the Nonisothermal Pipe Flow interface:

$$0 = -\nabla p - f_D \frac{\rho}{2d_h} u|u| + F \tag{1}$$

$$\nabla \cdot (A\rho u) = 0 \tag{2}$$

Above, A is the cross-section of the pipe (m^2), ρ density (kg / m^3), u (m / s) the velocity of the fluid in the tangential direction of the curved section of the pipe, and p (N / m^2) the pressure. F (N / m^3) is a volumetric force, like gravity [11].

The Heat Transfer in the solids module has been used to investigate the heat load created on the wall of the magnetron anode cavity under the influence of the circulating fluid (water) in the cooling system (as shown in Figures 2 and 4). This module has been used to define the thermal-structural formula of the problem by considering the following boundary conditions and equation: [12]

1. Temperature: to design a thermally stable state, the outer boundaries of the magnetron are cooled by liquid cooling systems. The temperature of these external boundaries is equal to the temperature of the coolant.
2. Heat Source: when electrons collide with the cavity wall, they transfer their energy to the cavity and consequently increase its temperature.

$$\rho c_p \bar{u} \cdot \Delta T = \nabla \cdot (k\Delta T) + Q \tag{3}$$

3. Results and Discussion

The main function of the magnetron starts with the emission of electrons when the magnetron is turned on. It continues with the formation of an electron cloud around the cathode under electric and magnetic fields. Finally, energy transfer occurs between electrons and fields in the holes, and the oscillations reach a saturation power. These oscillations continue until the magnetron is turned off. Since electrons reach the anode unit with a limited speed in the magnetron, their kinetic energy is converted into heat. This heat represents the main efficiency drop in the magnetron.

In the world of electronics, heat can drastically shorten the life of a device. Therefore, it is necessary to remove the heat from the vital components in order to maintain optimal performance without shortening the lifespan. Most of the heat produced in a tube is in the collector of a linear beam tube or gyrotron or the anode of a magnetron. The tube body and the magnetron anode are heated by the impact of electrons and RF losses in the interaction structure. The anode of the magnetron may be deformed and melted due to high heat, and the life of the tube will decrease. Therefore, adequate cooling of a high-power vacuum tube such as a magnetron is very important. Inadequate cooling causes significant pipe failure or serious reduction in system power. In order to remove the heat generated by the magnetron, sufficient cooling is necessary. Depending on the type and outlet, the anode block may be air or water cooled. Low-power magnetrons are generally cooled with air, and high-energy magnetrons are cooled with water. According to Figure 5, it can be seen that if there is no cooling, after 5 minutes of turning on the magnetron, the temperature of the device reaches 2800 degrees Celsius, and this increase in temperature leads to the malfunctioning of the device. And magnetron failure. With the design of the water cooler, we see temperature stability so that after continuous work for up to 5 minutes, we will not have temperature changes. This shows the efficiency of the simulated cooling device and the good ability of this device It is heat removal. In the Pipe Flow module, we set the pressure value to 1 Pa and the velocity value to 0.02 m/s to check the temperature changes in the system under this pressure and velocity. Figure (1) shows the temperature distribution for the fluid in the cooling system. As can be seen from the Figure, water enters the cooling system at 2°C and exits at 16.2°C. In a liquid cooling system, the greater the difference between the inlet and outlet temperatures of the water, the higher its ability to dissipate heat. In the system designed in this paper, we see a temperature difference of 14.2 °C.

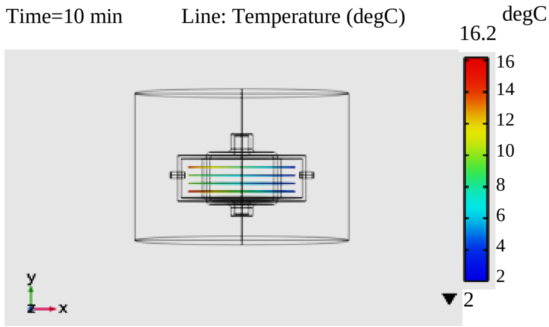

Fig. 1. Fluid temperature changes in the cooling device over time.

In other words, the temperature distribution for the cooling fluid in this system was such that under a constant pressure of 1Pa and a constant speed of 0.02 m/s, it had an excellent ability to remove excess heat generated in the device. We want to see how the temperature changes over time in the presence of a cooling fluid. Figure (2) shows how the temperature changes over 10 minutes in the presence of coolant. Figure (3) shows the trend of temperature changes over time in the presence of water cooling.

Figure (4) Shows the magnetron temperature rise over time without any cooling system, and Figure (5) shows a comparison of temperature changes in terms of magnetron time without cooling and with the presence of water cooling (the results of this Figure are based on simulations performed in 10 minutes). According to Figure (5), it is observed that in the absence of cooling, after 10 minutes of turning on the magnetron, the temperature of the device reaches 5680°C, and this increase in temperature leads to malfunction of the device and failure of the magnetron. By designing the water cooler, we observed that the magnetron did not change temperature after continuous operation for up to 10 minutes, and we see temperature stability, which indicates the efficiency of the simulated cooling device and its good ability to remove heat.

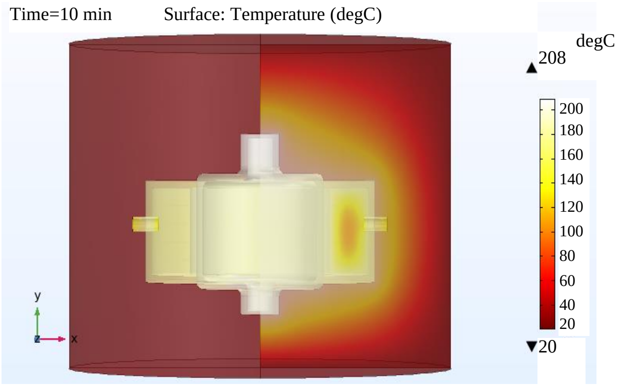

Fig. 2. Temperature changes over a period of 10 minutes in the presence of coolant.

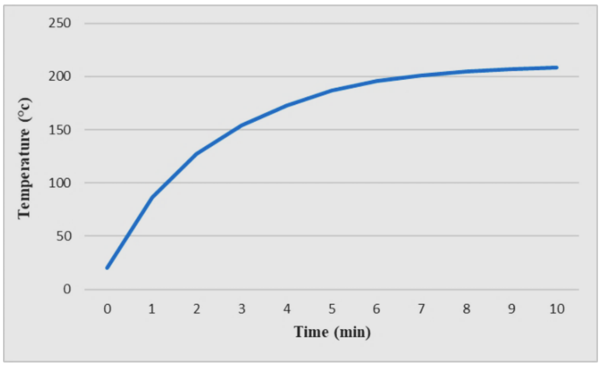

Fig. 3. The trend of temperature change over time in the presence of coolant.

According to Figure (3), it can be said that from the sixth minute onwards, we see temperature stability, and the temperature remains constant at 208°C after 10 minutes. That is, the magnetron temperature does not exceed 208°C after 10 minutes of continuous operation in the presence of water cooling.

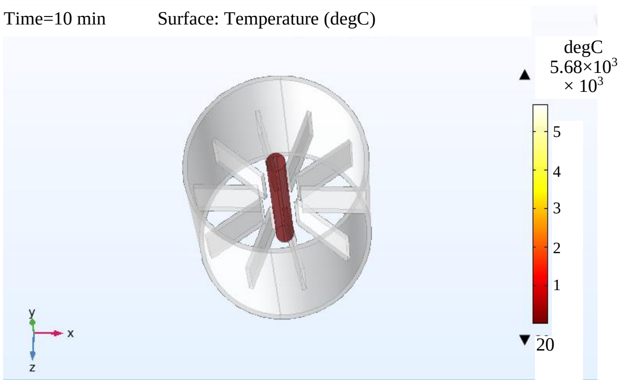

Fig. 4. Magnetron temperature rise over time without cooler.

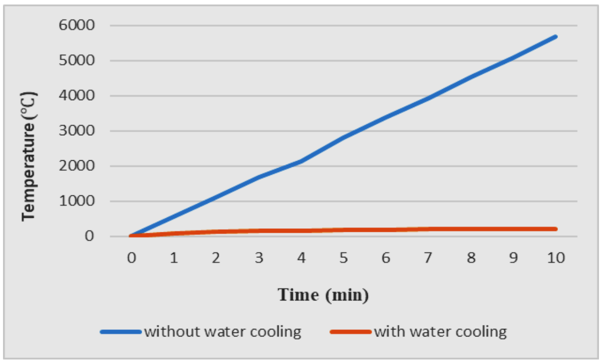

Fig. 5. The process of changing the temperature of the magnetron over 10 minutes. Red diagram: in the presence of a water cooler, blue diagram: without the presence of a cooler.

4. Conclusions

Since pulsed magnetrons typically scatter significant amounts of power at the anode (typically half the average input power), most have some form of auxiliary cooling, depending on the type and output of the anode. Whether they need water or air cooling to reduce power loss.

Adequate cooling is necessary to prevent the magnetron temperature from rising and subsequent failure of the device. Therefore, this paper designed and simulated a water cooler for a 1kW magnetron. Initially, we examined the rate of increase of the magnetron temperature without the presence of cooling and observed that after 10 minutes, the magnetron temperature reaches 5680°C, which this increase in temperature caused the magnetron to damage and even melt. Using the Heat Transfer in Solids and Pipe Flow modules of comsol software, we designed a water cooling system to observe how the temperature is distributed in the magnetron in the presence of the cooling fluid.

We observed that after 10 minutes from the start of operation of the magnetron, its temperature did not rise above 208°C, and we will not have temperature changes, which indicates the efficiency of the simulated cooling device and its good ability to remove heat.

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