HEAT TRANSFER STUDY OF PIG ION SOURCE FOR 10MeV CYCLOTRON

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Abstract

A PIG Ion source provides H- ions for the 10 MeV cyclotron, which is designed and being manufactured by Amirkabir University of Technology. Plasma created in the anode contains the desired ions. Discharge for producing plasma consists of the both ion current from plasma towards the cathode and the secondary electron current from the cathode to the plasma. Secondary electron emission is the result of ion collision on the surface of the cathode. Heat generated by these collisions is considerably high, so a cooling system for ion source is crucial. In this paper heat transfer study of the ion source, temperature distribution and deformation of different parts simulated using ANSYS CFX. Also the thermionic emission of the electrons from cathode in the calculated temperatures by ANSYS simulated Using CST STUDIO. Results showed the maximum temperature of the cathodes are 1992 K, which is far away from the cathode melting point. The thermionic current in 1992 K of cathode simulated and the results showed an electron current of 0.00706 A at 500 V which is negligible in comparison to the discharge current of 1.10352 A. Maximum deformation were about 0.2 mm in cathode edges.

INTRODUCTION

Every system that produces heat and the working temperature is important as an operating condition of the system, needs a proper cooling and heat transfer system in order to keep the different parts of the system running on appropriate temperature. In cyclotrons different parts such as magnet, cavity and ion source need cooling system because of the heat production in different ways and temperature restrictions. Ion source also uses a cooling system in order to prevent the shape and dimensional changes in different parts and keeping them in proper working conditions. Taking into account that the power consumption in comparison to its size is very high in the ion sources, thus the design of an efficient cooling system is important.

IRANCYC-10 uses a cold cathode PIG ion source as an internal source to produce H^- ions for accelerating in acceleration chamber. The source consists of two tantalum cathodes placed at two ends of a cylindrical tungsten-cooper alloy anode and assembled together with a cooper holder in order to place inside the cooper cover assembly. The source has a height of 57 mm which is appropriate to take place in the central part of the cyclotron. Water cooling system is used to transfer the heat generated in the source in prevent it from malfunctioning the ion production.

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COOLING SYSTEM

Cooling system consists of two separate parts. One for heat transfer from the cathodes and one for the heat transfer of the anode and cover assembly. The cooling of the cathodes is done by the cathode holder which is attached to the cooling water line. The cooling line consists of two coaxial cooper tubes one for the inlet and one for the outlet of the cooling water. The heat transfer of the cathode is done by the cover assembly that uses a U shaped cooper tube to circulate the cooling water as illustrated in fig. 1. The cooling water is supplied by a chiller with an inlet temperature of 18 °C.

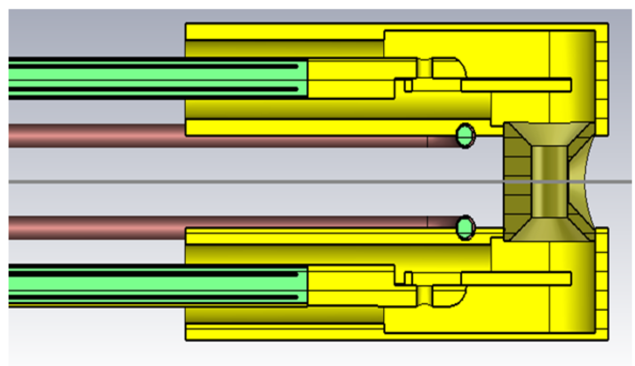

Figure 1: The cooling line of ion source.

Power Consumption Calculations

The possible energy flow in an ion source is shown in fig. 2. As it is illustrated in fig. 2 the power supplied by the power supply after passing all the possible processes changes into surface heating of the different parts of the source [1]. The power consumption in the ion source according to former simulations done by CST-PS is about 500W and the results are in good agreement with similar PIG ion source used in KIRAMS-13 cyclotrons [2].

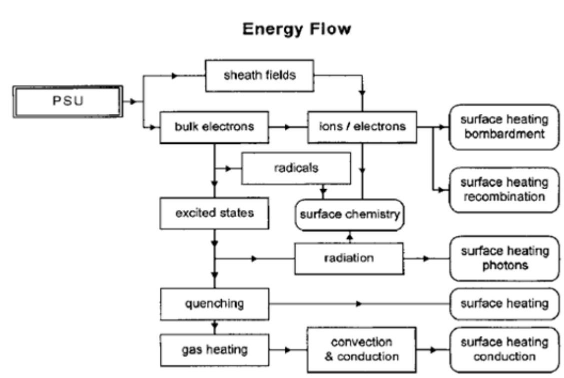

Figure 2: The energy flow in ion source.

CFD Simulations

CFD simulations has been done in order to have the temperature distribution of the different parts of ion source using ANSYS CFX. The geometry of the source for CFD simulations in ANSYS is shown in fig. 3.

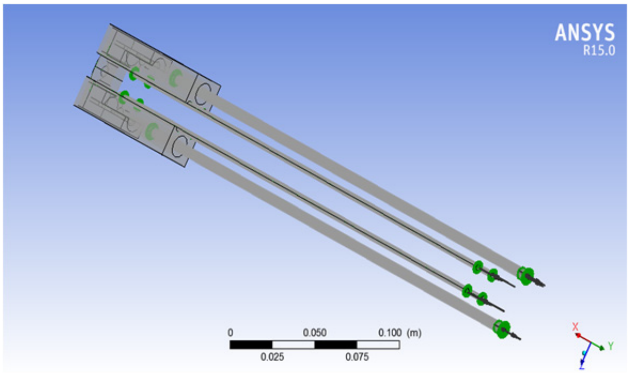

Figure 3: The geometry of the PIG ion source.

The Tetra-Hedrons patch-conforming meshing method has been used. With the use of inflation technique for the higher accuracy of the calculations the desired mesh has done. The meshing statistics is shown in table 1.

Table 1: CFD Mesh Statistics

ANSYS CFX (CFD)	
Total Nodes	4711455
Total elements	12948819
Average Skewness	0.20753

The power consumed in the source imported as surface heating and the temperature distribution simulated with different inlet velocities of the cooling water from 1 m/s corresponding 0.007 kg/s of flow rate to 5m/s corresponding 0.04 kg/s of flow rate.

Temperature Distribution Results

Simulation for different flow rates of the cooling water has been done and the temperature distribution of different parts extracted as it is shown in fig. 4.

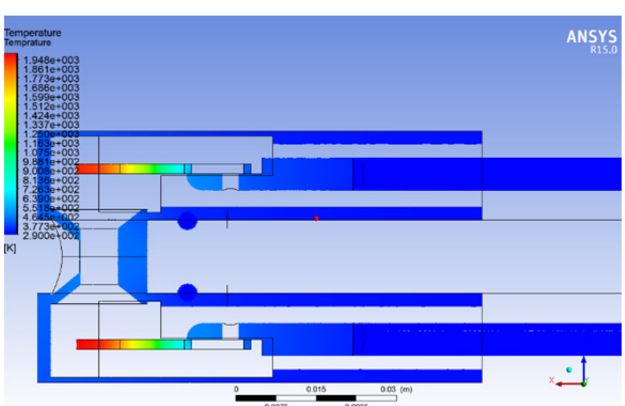

Figure 4: Temperature distribution of different parts.

Figure 5 shows the streamline of the cooling water circulating in the cooling line and transfers heat from the source.

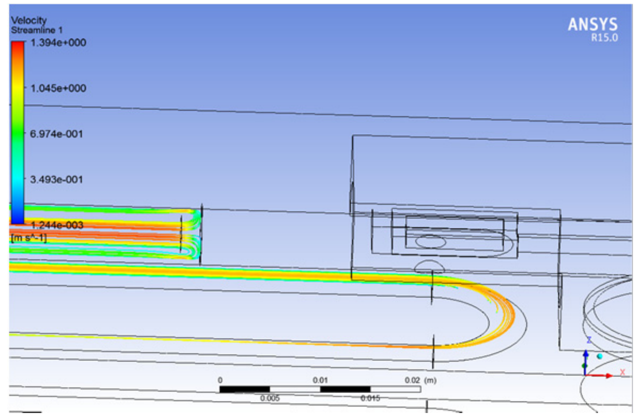

Figure 5: Streamline of cooling water in cooling line.

The maximum and minimum temperature of the cathode with different flow rates of the cooling water is shown in fig. 6. As it is illustrated the maximum temperature of the cathode in the worst case (minimum flow rate) is 1992 K and is in head part of the cathode which is under the bombardment of the ions.

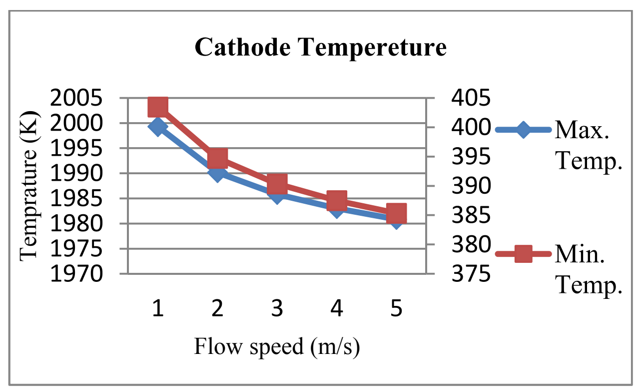

Figure 6: Max and min temperature of cathode with flow.

The temperature distribution of the anode with different flow rates of water is shown in fig. 7. The maximum temperature in worst case is 472 K and it occurs near the exit slit of the chimney.

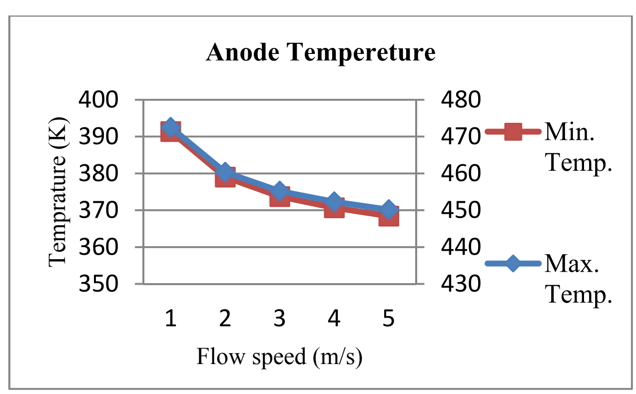

Figure 7: Max and min temperature of anode with flow.

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The temperature distribution in the cooling water also illustrated in fig. 8. As it is shown in the fig. 8 the maximum temperature of the water is 345K which is far away from the vaporization point of the water. Thus the single phase assumption for the calculations is completely satisfied.

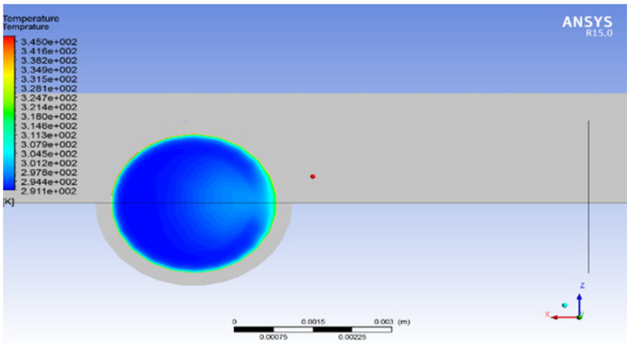

Figure 8: Temperature distribution in cooling water.

STRUCTURAL ANALYSIS

In order to have the deformation of the parts the temperature distribution calculated in CFD simulations imported in ANSYS STATIC STRUCTURAL and the deformation of the parts have been simulated in the worst scenario which is the temperature with minimum flow rate of the cooling water.

The proper mesh for the structural analysis has been used and the meshing statistics is shown in table 2.

Table 1: Structural Mesh Statistics

ANSYS Static Structure	
Total Nodes	529947
Total elements	352999
Average Skewness	0.232996

The results from the structural analysis are shown in fig. 9. The maximum deformation of the cathode is 0.2mm where it has the maximum temperature of 1992K.

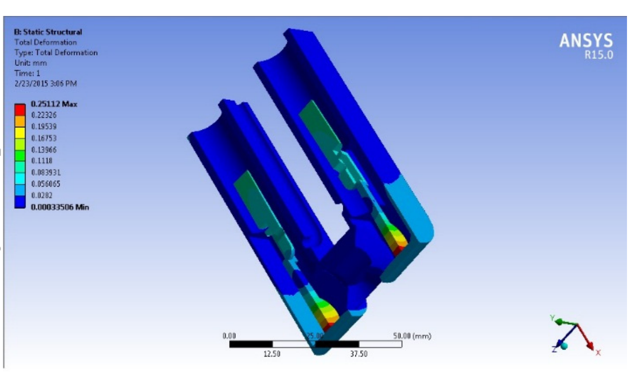

Figure 9: Deformation of different parts of ion source.

THERMAL CURRENT OF ELECTRONS

Temperature rise in the metals results in emission of electrons which consists a current called thermal electron current. In this area also the temperature rise of the cathodes lead to thermionic emission of electrons. For studying this phenomenon analysis has been done in CST-PS by importing the temperature distribution results from the CFD analysis. Electric field strength also effects the work function and thus the emission of the electrons according to equation 1 [3]:

$$j_e = A(1-\bar{R})\,T^2\,exp\left\{-\frac{e}{kT}\left(\varphi-\sqrt{\frac{eE}{4\pi\varepsilon_0}}\right)\right\} \tag{1}$$

The maximum temperature (worst case) has been imported from ANSYS to CST-PS and the thermal current from the cathode in the presence of 1.8 tesla magnetic field (center of the cyclotron) with varying electric field (cathode voltage) simulated. The results showed a thermal electron current of 0.00706A which is 0.6% of the total current (1.10352A) on the cathode. Thus it can be ignored with no important effect on the calculations.

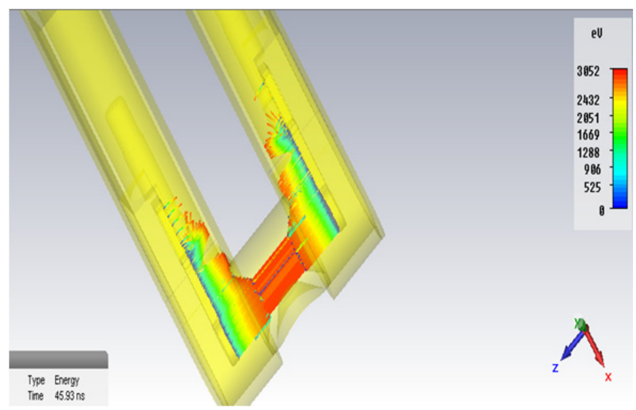

Figure 10: Thermionic emission of cathode in CST-PS.

CONCLUSION

Heat transfer of the PIG ion source has been studied using ANSYS CFX. Results showed the maximum temperature of the cathodes are 1992 K, which is far away from the cathode melting point. The thermionic current in 1992 K of cathode simulated and the results showed an electron current of 0.00706 A at 500 V which is negligible in comparison to the discharge current of 1.10352 A. Maximum deformation were about 0.2 mm in cathode edges.

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