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THE DESIGN AND USE OF FARADAY CAGE IN LINAC TEMPORARY LINE OF CSNS

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Abstract

In the end of linac temporary line in CSNS, we need a faraday cage to absorb the beam. in the experiment it will be mounted and used twice. according to the beam energy and current of CSNS, we choose water-cooled pipe structure with tilted panel after simulation with Ansys. the main principle of the faraday cage is to simplify the structure and reduce the radiation activation of it, to do this, we also do the simulation of radiation. to make sure the faraday cage is safe in beam experiment, we also plug in a pt100 Platinum resistance to monitor the temperature. after faraday cage is built and mounted on the line, it works well and sustain the beam bombardment.

INTRODUCTION

China spallation neutron source (CSNS) is the first spallation neutron source in developing countries. In linac, there are a 50 keV H- iron source, a 3 MeV Radio Frequency Quadrupole(RFQ), and a 80 MeV Drift Tube Linac(DTL). In the first stage of beam experiment, when the H- come to the end of Medium Energy Beam Transport(MEBT) with 3 MeV energy and the end of DTL1 with energy 26.7 MeV, we need a temporary line with some beam measuring equipment like BPM, wire scanner to check the parameter of beam is right. And at the end of temporary line, we need to design a faraday cage to absorb the beam safely.

MACHINE DESIGN OF FARADAY CAGE

Plan Selection

In the 973 foundation project, we use “V” type beam stop as in Fig. 1, it is built with Oxygen free copper covered with aluminium using water cooling, and contain vacuum structure, the angle between the center line and surface is 8°. This beam stop is designed for 3.5 MeV proton, 20 mA beam current and 15% duty cycle, inside it , we use quadrate tunnel structure to improve cooling efficiency.

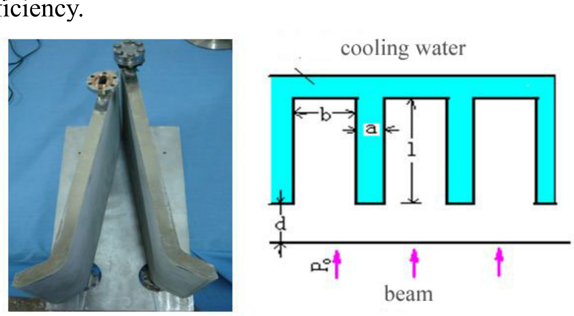

Figure 1: External shape and quadrate tunnel.

In the CSNS temporary line, because the “V” type cooling system is too complex that the welds leaks sometime, to simplify the design and machining, we decide to use just one tilted board and set the welds of water cooling pipe out of the vacuum structure. The faraday cage should be able to absorb beam as in Table 1.

Table 1: Parameter of Beam in Temporary Line

Energy	26.7 MeV	3 MeV
Peak current	15 mA	15 mA
Beam frequency	5 Hz	5 Hz
width	500 μs	500 μs

Physical Design

To start the simulation, first we should get the peak heat flux from Eq. (1), in it we set up the beam sigma size to 2.5 mm temporarily,

$$A\cdot\int_0^{0.025}\int_0^{0.025} e^{-\frac{x^2+y^2}{2\times0.0025^2}}dx\cdot dy = 400\mathrm{kW} \cdot \qquad (1)$$

then we should get the heat exchange coefficient h as in Eq. (2), which is the thermal conductivity of cooling water, d is the equivalent diameter of cooling pipe, 4 times of cross-sectional area divide by perimeter, Nu is the Nusselt number as in Eq. (3),

$$h = \frac{\lambda\bullet Nu}{d} \cdot \qquad (2)$$

for forced convection heat transfer of turbulent flow in the tube, the Dietus-Belt formula is widely used to get Nusselt number, for cooling water n=0.3, Pr is Prandtl number, and Re Critical Reynolds number.

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{n} \,. \qquad (3)$$

After all this is done, we build model and set the cooling water pipe to different size, while the interval between pipe is fixed to 4mm as in Fig. 2, and in the calculation before we find that if the faraday cage is vertical to beam we can’t get temperature under melting point, so we set up a slope between faraday cage and central axis to 10° ,and the beam size σ to 2.5 mm, with the slope of faraday board, the actual area of beam will become bigger to make the heat flux less.

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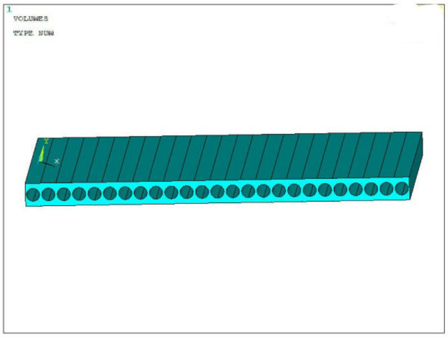

Figure 2: Model of beam stop with cooling pipe.

Then after simulation we get peak temperature distributed as follow in Fig. 3, from this we can check that 8 mm size of cooling pipe is most suitable.

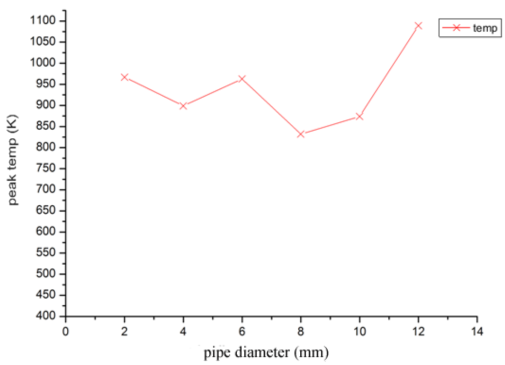

Figure 3: Temperature in different diameter of pipe.

To determine the distance between pipe, we use pipe diameter 8 mm as we got from last step, and change the distance until we get Fig. 4 below, we can find that 12 mm of pipe distance should be used to minimize temperature and suitable for machining.

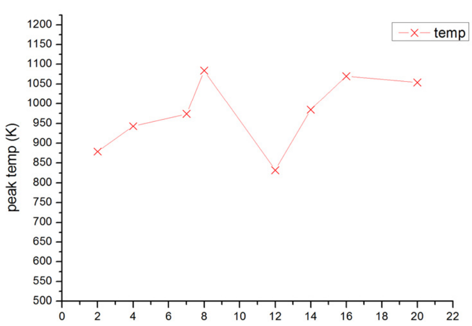

Figure 4: Temperature in different distance of pipe.

At last we should find out the minimum beam σ can be used for faraday cage. We build model with 8 mm pipe diameter and 12 mm distance, slope angle to 10°, change beam size and get Fig. 5, so if we want to make sure faraday cage is safe, the σ size at 3 MeV should be bigger than 0.7 mm, while at 26.7 MeV the minimum size is 2 mm.

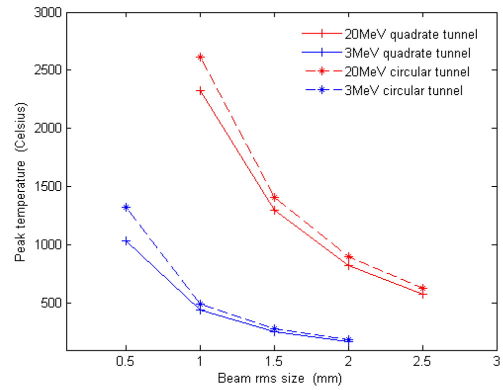

Figure 5: Temperature in different beam size.

The activation energy of Cu in proton particle is about 2.7 MeV, while the activation energy of C is 32 MeV, to reduce the activation probability of Cu, we plate one layer of graphite on the copper board. According to 26.7 MeV proton, the continuous-slowing-down approximation range [1] in graphite should be about 2 mm [2], so we set the thickness of graphite to 2.5mm. Because graphite has different thermal conductivity [3], we compare graphite with conductivity of 129 W/m.K and 1500 W/m.K, and find from Fig. 6 that higher conductivity is better and decide to use it.

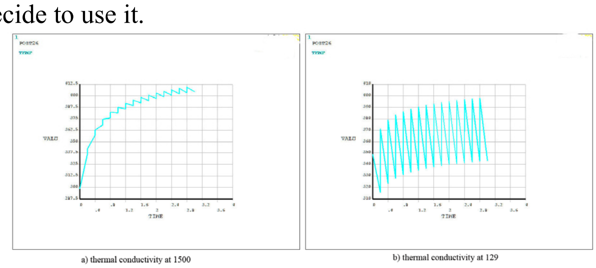

Figure 6: Peak temperature in different conductivity.

So far we can give the model of faraday cage according to the angel, pipe diameter, pipe distance, parameter of graphite board, as in Fig. 7.

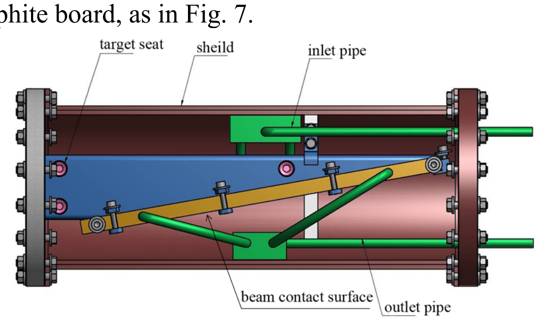

Figure 7: Model of faraday cage.

Radioprotection

Considering that faraday cage will work long time under 26.7 MeV proton at 15 mA current, it is necessary to consider the radioprotection around it. In calculation we set beam width to 500 us, frequency 25 Hz, run continuously 100 day, and after stop 4 hours, the radiation dose near the surface of faraday cage can be 60 mSv/h, as in Fig. 8.

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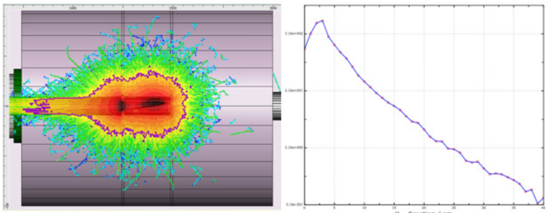

Figure 8: Residual radiation dose in horizontal mSv/h.

So it is necessary to add additional shielding facility, we use 5 cm thick lead plate to build box to cover faraday cage, and make residual radiation as equal as beam loss at 1 W/m. because the leap is very soft, we use concrete to support lead plate. After beam experiment is over, faraday cage will be totally activated and should be dealt as highly radioactive waste. About the cooling water of faraday cage, only low concentration and low life N-16 can be found, we need not to consider about it because its half life is only 7.13 s.

To make sure faraday cage is safe, we also add one PT100 thermal resistance on the faraday cage next to the water pipe, pt100 signals transformed by transmitter can be transported to work area to monitor the temperature during beam experiment.

MACHINING INSTALLATION AND EXPERIMENT

After machining and necessary test like vacuum and water pressure is done, the installation is finished at the end of Medium Energy Beam Transport (MEBT) of CSNS, as in Fig. 9, here the energy is only 3 MeV and current is 5 mA, so the radiation and temperature is very low.

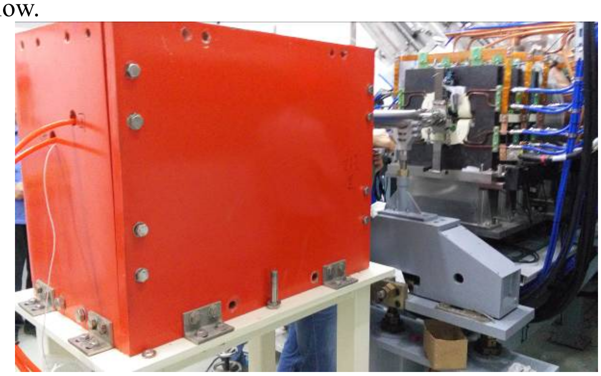

Figure 9: Installation at the end of MEBT.

Then it is moved to the end of the first quarter of Drift Tube Linac (DTL), in this place the final beam energy is 21.67 MeV, beam current 10 mA, pulse width is 400 us, repetition frequency is 5 Hz, the beam parameter is smaller than design to make sure safety of faraday cage.and in experiment the highest temperature from PT100 is under 30° .

CONCLUSION

The faraday cage is designed to absorb beam of MEBT and first quarter of DTL in linac temporary line of CSNS, it should not be damaged at the energy of 26.7 MeV and current 15 mA, also the radioprotection should be considered. After all the beam experiment is done successfully, the faraday cage works well and residual radiation around it is safe, so we can conclude that this single sloping plate structure with cooling pipe meets the demands as expected.

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