DESIGN STUDY OF MAGNETIC CHANNEL AT NIRS-AVF930

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Abstract

In the NIRS-AVF930 cyclotron, a current magnetic channel has been used for ten years, and the flow of cooling water gradually decreases. Therefore, the high energy operation such as 70 MeV proton became recently difficult. As the design specification of this magnetic channel is very severe, the flow velocity of cooling water is very fast as 5.4 m/sec. The condition of the current magnetic channel and the design consideration of a new one will be presented.

INTRODUCTION

The NIRS (National Institute of Radiological Sciences) -AVF930 cyclotron is used mainly for RI production [1]. The other utilizations are the studies on radiation dosimeters and radiation damage tests, where height energy proton beam such as 70 MeV was frequently used. The proton energy of 70 MeV is almost maximum in NIRS-AVF930 operation. However, that high energy operation became difficult recently, and the source of this problem is decreases in cooling water of the magnetic channel. The magnetic channel is composed of eight coil units made with hollow conductor, and two coil units among them are cooled with a chiller system in the high energy operation. Those two coils are longest coil in the magnetic channel. Therefore, low power consumption and low temperature at the outlet of cooling water is needed for of high energy operation in the new design magnetic channel.

PRESENT STATE CONDITION OF THE MAGNETIC CHANNEL

In the current magnetic channel, the maximum design current is 1300 A, and the current density is 56.5 A/cm^2. This magnetic channel is composed of a hollow conductor type that size is 6×6 mm^2 and diameter of cooling water hole is 4 mmϕ. The A2 coil(see Figure 1) is the longest coil in a magnetic channel, and has the problem that is rises of the temperature at the outlet cooling water. In Figure 2, measured temperatures of the cooling water at outlet of the A2 coil were plotted against the current of the magnetic channel. The water temperature at the outlet was increased up to 70 degrees at 1000 A, where interlock of water temperature will work.

There are two causes of the temperature rise in the present magnetic channel. One of the causes is decreases in flow of cooling water. At the beginning, flow of cooling water in A2 coil was 3.0 L/min with pressure drop of 1.2 MPa, but that is 2.14 L/min at present with same pressure drop. Another cause is increase in resistance of magnetic channel. At beginning, resistance of magnetic channel was 48.9 mΩ, but now that value is 54.2 mΩ. Therefore, power consumption increased with this higher resistance.

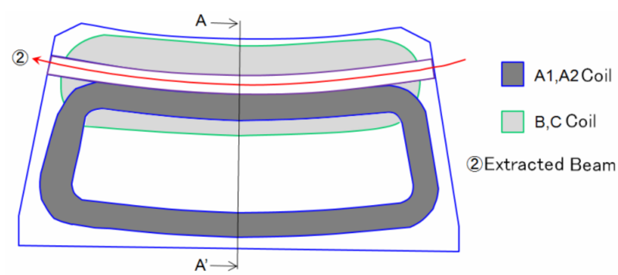

Figure 1a: The horizontal sectional view at median plane.

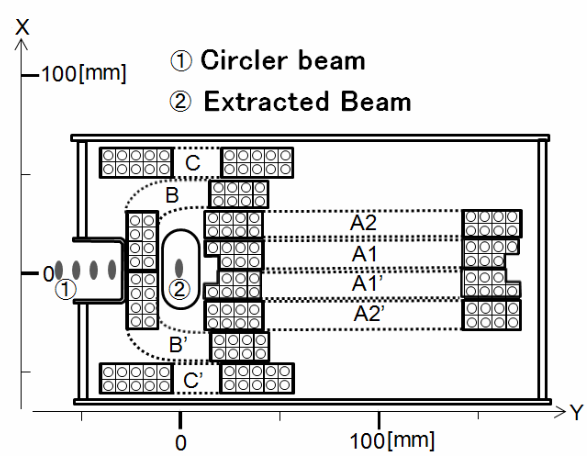

Figure 1b: The vertical sectionals view at a plane A-A'.

STRUCTURE OF THE MAGNETIC CHANNEL AND NEW DESIGN

Figure 1b shows the cross section of the current magnetic channel, which is composed from the eight coils with four types. Those eight coils are made of the hollow conductor that has cross section of 6×6 mm^2 with hole of 4 mmϕ in diameter.

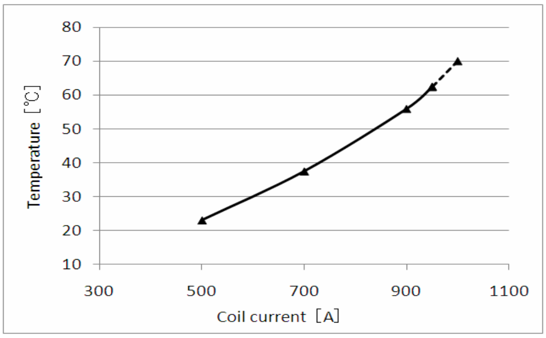

Figure 2: Temperatures of the cooling water at outlet of the A2 coil. Inlet 10 Deg, Flow rate 2.14 L/min

The temperature rise of cooling water is maximum at the A2 coil in those eight coils. The A2 coil was wound outside of the extracted beam orbit. The vertical space for the magnetic channel is limited at 140 mm with magnetic pole of the NIRS-AVF930.

In this design study, size of the A2 coil is 6×9 mm2 to decrease temperature of cooling water. The cross sectional area of conductor is expanded by a factor of 1.6 compared with the existing magnetic channel. The resistance at the A2 coil will be reduced by 40% and we can reduce its power consumption.

In addition, the cross sectional area of water flow is expanded by a factor of 1.4 compared with the existing magnetic channel, thereby the temperature rise is suppressed almost 50% at the outlet of cooling water in the A2 coil.

However, expansion of the conductor make problem that is influence to the magnetic field. Therefore, using POISSON/SUPERFISH programs from LAACG[2], the magnetic field is estimated for the updating design of the magnetic channel.

The polarity of leakage magnetic flax at orbit of circulating beam in the cyclotron is same a as cyclotron main magnetic flax. The leakage flax is very important because circulating beam passes several times on the line “P” in figure 4.

As the first step, the cross sectional area of A2 coil conductor was expanded, which is Figure 4(2), and calculated magnetic fields on the line “P” are plotted in Figure 5(2). This leakage magnetic field is high compared with the present magnetic channel, so that adjustment is necessary such as change of the B-coil position. In the new design, the B-coil position is moved to inside at the cyclotron, and turn radius in the B-coil conductor is smaller than the present design, it shown to the Figure 4(3). This result of calculated leakage magnetic field at new design is plotted in Figure 5(3).

The calculated leakage magnetic field with the new design is similar to the leakage field of the present magnetic channel.

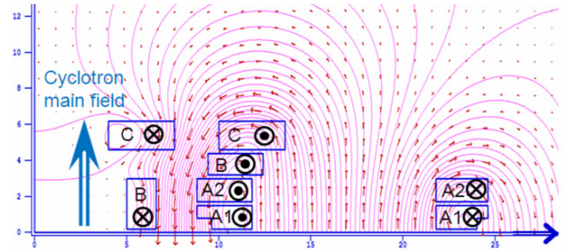

Figure 3: The magnetic field 2D-simulation by POISSON/SUPERFISH.

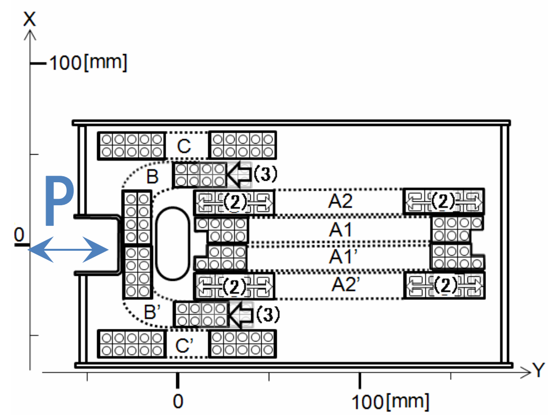

Figure 4: Conductor layout plan of magnetic channel.

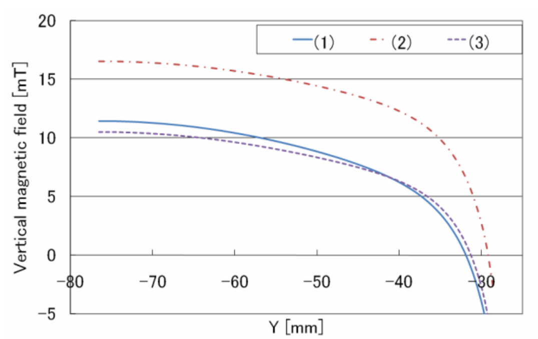

Figure 5: Vertical magnetic field at Line “P”.

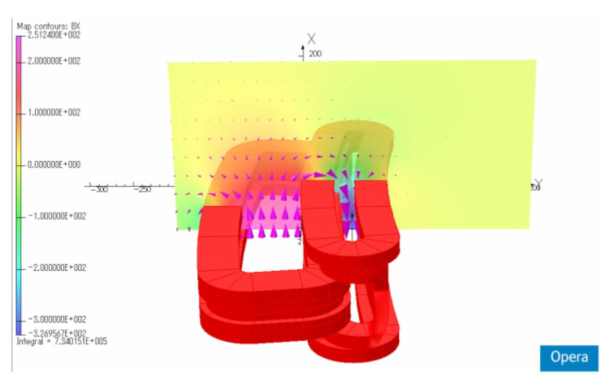

Figure 6: The magnetic field 3D-simulation by Opera-3D/TOSCA.

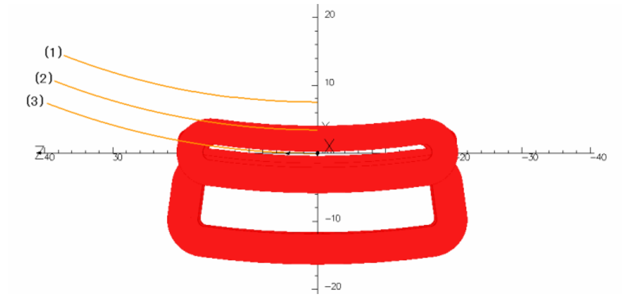

Figure 7: Arc orbit for comparing to magnetic field in OPERA-3D/TOSCA. (1) Radius 90cm from centre of cyclotron. (2) Radius 94cm from centre of cyclotron. (3) Radius 97.5cm from centre of cyclotron. (extracted beam orbit)

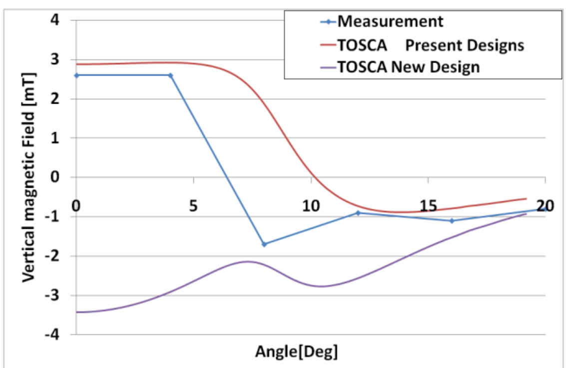

Figure 8: Magnetic field at arc orbit of radius 90 cm.

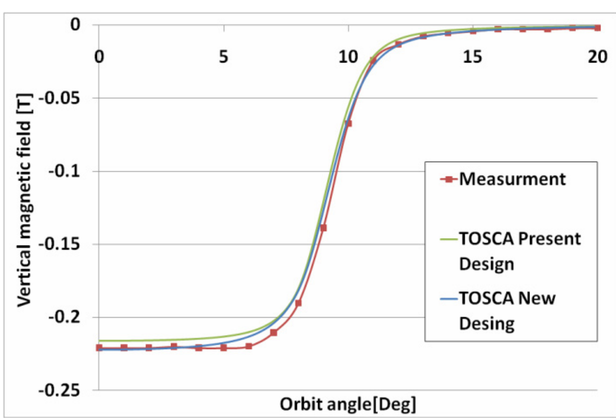

Figure 9: Magnetic field at extracted beam orbit of radius 97.5 cm.

In addition, using Opera-3D/Tosca programs from Vector Fields [3], the 3D magnetic field calculation was performed for updating the design of the magnetic channel. The calculated results of magnetic fields were compared between the present magnetic channel and the updated one.

In the magnetic field have two important points at the magnetic channel.

One is enough the magnetic fields for extracted beam at extraction orbit that has radius of 97.5 mm. The other important point is reducing the leakage field at orbit of

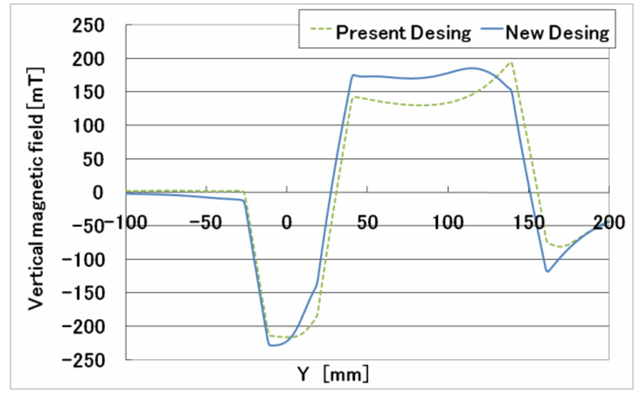

Figure 10: Magnetic field at centre of magnetic channel

circulating beam in the cyclotron. Therefore, the leakage field is compared in the orbit, where orbital radius is 90cm. These calculated magnetic fields with the both designs are plotted in figures 8, 9 and 10. Additionally, the measured leakage magnetic fields of the present magnetic channel are plotted in Figure 8.

At the circulating orbit, calculated magnetic field will agreed with measured magnetic field in the present magnetic channel. In contrast to this agreement, polarity of calculated magnetic field with the new design is inverse, and maximum value of new design is 3.4 mT and angular distribution of leakage magnetic field is broad.

At the extracted beam orbit, the calculated magnetic field in new design is enough for beam extraction.

Moreover, the magnetic fields at extracted beam position (Y=0) have a gradient with the new design, which is shown in Figure 10.

For this reason, the optimization of conductor arrangement is further required in order to low leakage magnetic field and smaller radial gradient in extracted beam position.

CONCLUSIONS

The magnetic field calculation is performed for the updating design of the magnetic channel, where the A2 coil was expanded the cross section area of conductor and cooling water hole. Calculating with Opera-3D/Tosca programs from Vector Fields, the radial distributions of the magnetic fields have a radial gradient at extracted beam area. Therefore, the further optimization of arrangement at conductor is necessary.

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[2] POISSON/SUPERFISH Group of Codes, Available at the Los Alamos National Laboratory, LA-UR-87-126 (1987). http://laacg1.lanl.gov/laacg.

[3] TOSCA, Vector Fields Ltd., www.vectorfields.com, Software for electromagnetic design, Oxford, UK.