MUON COOLING CHANNEL FOR A NEUTRINO FACTORY

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Abstract

Doubled-FOFO (DFOFO) cooling channels with engineering constraints are proposed for a neutrino factory cooling. The cooling channels are consisted of three kinds of DFOFO channel; first stage channel has 4.2T DFOFO channel; second and third channels have 4.8T DFOFO channel, but thickness of Al window are 400 micron and 300 micron, respectively. Focusing of the cooling channels is so sufficiently strong that maximum beta-function is smaller than those of FOFO and alternating cooling channels. Transverse and longitudinal emittances that are needed for the Neutrino Factory can be achieved by the using of the DFOFO channels. In the FOFO channels, particle losses in transverse direction were mainly generated in the midpoint of rf cavities in which beta-function was maximum. In order to reduce these particle losses, the FOFO lattices are reconfigurated so that period of FOFO magnetic fields are doubled. The beta-function in the DFOFO channel is designed to have minimum value in the midpoint of rf cavities. In the DFOFO channels, x-dimensional rms emittance 13000 mm mrad cools to rms 1500 mm mrad, that is, transverse cooling by a factor of 0.11 in the x phase space. Longitudinal emittance in the cooling channels increases from 13mm to 19mm. The DFOFO channels provide 6D cooing by a factor of 0.018 and show 60% particle transmission at the 180m channel.

1 INTRODUCTION

It was argued in so called PJK design parameters[1] that transverse rms emittance 1500mm-mrad and longitudinal rms emittance 30mm were needed for the neutrino factory. Accordingly, it is required to design and build up realistic cooling channels that provide these emittances.

Until now several cooling channels for a neutrino factory have been designed. In the Mucool note 50, posted by Eun-San Kim, the FOFO channel, which focuses both transverse planes simultaneously, was used for the neutrino factory cooling. Auther also designed the single and two kinds of FOFO cooling channels, Super FOFO + FOFO cooling channels, DFOFO + FOFO cooling channels and alternating solenoid channels[2]. Single and double-flip channels were designed by V. Balbekov[3]. More importantly is to simulate and design the cooling channels with engineering constraints that can provide the PJK design parameters.

In the FOFO channels, the maximum value of the beta function occurs at the midpoint of the rf cavities. The minimum value occurs at the midpoint of an absorber. The maximum and minimum values of magnetic field B_z occur at the midpoint of the rf cavities and absorber, respectively.

In this report the DFOFO channels are proposed for the neutrino factory cooling. Figure 1 shows configuration of a designed DFOFO cooling channel. In the DFOFO cooling channels, the maximum value of the beta function (and magnetic field B_z) roughly occurs at the midpoints of the first rf cavity as well as the fifth rf cavity. The minimum value of the beta function (and magnetic field B_z) roughly occurs at the midpoints of an absorber as well as the third RF. Figure 2 shows the magnetic field for four cells that exist in interface of first and second stage DFOFO channels. The simulations were performed by the using ICOOL of version 2.01.

2 CHARACTERISTICS OF THE DFOFO COOLING CHANNELS

By just increasing the total length of cooling channels, we can not make muon beam cool continuously. Bejond any critical length of total cooling channels emittance will begin to increase again. Raising magnitude of magnetic field in a cooling channel may cause betatron resonance and may result in more number of particle losses. Accordingly satisfactory cooling performences can not be achieved by just increasing total length of cooling channels and (or) by raising magnitude of magnetic field.

In the FOFO cooling channels, particle losses in transverse direction are determined by length of absorber, LH window radius and RF window radius. Smaller LH window just gives more particle losses in the initial part (about 10m) of the cooling channel. But magnitude of radius of RF window affects particle losses over relatively long cooling channel because high beta-function exist in the positions of the RF windows. As we saw in the previous FOFO cooling channels, particle losses in the transverse direction were mainly generated in midpoint of rf cavities where beta-function was maximum. This requires large radius of the rf window and results in large rf window power to reduce number of particle losses. To reduce these particle losses without increasing radius of rf window, the FOFO lattices are reconfigurated so that period of FOFO magnetic fields are doubled. The beta-function in the DFOFO channel is minimum in midpoint of rf cavities and large acceptance channels are obtained. Accordingly, with smaller number of particle losses, higher magnetic fields are available in the DFOFO cooling channels than the FOFO cooling channels. Figure 3 shows beta function β_x in one cell of the second stage DFOFO cooling channel. We note that the beta function(also the beams size) has minimum value in the midpoint of rf cavities.

3 PARAMETERS OF THE DFOFO COOLING CHANNELS

Designed cooling channels have three different DFOFO lattices. First stage cooling channel has 35 cells with 4.2 T magnetic field Bz. Second stage cooling channel has 25 cells with 4.8 T magnetic field Bz. Third stage cooling channel has 40 cells with 4.8 T magnetic field B_z that has different thickness of Al window with the second stage channel. A cell length of all cooling channels have the same as 1.8m. These cooling channels also satisfy enginnering constraints.

3.1 LH Absorber and LH window (Al)

The thicknesses and radii of the LH absorber and the LH window affect particle losses in transverse direction. Thicker LH absorber and LH window show more particle losses and require larger rf gradient. As the beam sizes are smaller by cooling, we can use smaller radii of the LH absorber in the second and third stages channela than the first stage channel.

3.2 Gap

About 12cm gap between the LH window and rf cavity is considered for rf fabrication and assembly.

3.3 Rf cavity

Rf cavities of pillbox type with 5-cell structure are used. Rf cell length and raidus are 26.09cm and 45.45cm, respectively. Rf frequency (f_{rf}) is 250 MHz and rf gradient is 15 MV/m. Smaller rf gradients may be used in the case that larger rf phase angles are set. But large rf phase angles increase nonlinear behaviors of the beam and result in more number of particle losses.

3.4 Rf window (Be)

Power for rf window is proportional to the r^4 , where r is radius of rf window. Radius and thickness of rf window also affect the number of the particle losses.

3.5 Sheets

Sheets are used to generate magnetic fields. Note that polarity of DFOFO channels are different from the FOFO channels. 40cm interval between sheets is considered for power supply from klystron. Engineering feasilibity is a complicated function that depends on such parameters as field, current density, and stress on the conductor. A conservative rule of thumb for solenoids built from NB_3Sn superconductor is [4] $BJR < 310MP_a$, where B is the field at the coil, J the area current density, and R the radius. For the 4.8T DFOFO the relevant values are $B = 4.8T$, $J = 32.1A/mm^2$, $R = 0.625m$, giving $BJR = 180.5MP_a$.

The parameters of DFOFO cooling channels are summarized in Table-1.

Table 1: DOFO cooling channel parameters

Number of stage	**First**	**Second**	**Third**
RF frequency(MHz)	250	250	250
Magnetic field(Bz)(T)	4.2	4.8	4.8
Rf gradients (MV/m)	15	15	15
Channel length(m)/cell	1.8	1.8	1.8
Number of Channel	35	25	40
Minimum β-function(cm)	40	30	30
Maximum β-function(cm)	70	65	65
LH length(cm)/cell	21.4	24	25.6
LH window thickness(μm)	650	400	300
LH window radius(cm)	20	16	7.5
Be window thickness(μm)	125	125	125
Be window radius(cm)	19	15	13

Table 2: DOFO cooling channel parameters

	units	**Initial**	**Final**
Particles tracked		1000	600
Transverse emit.(x)	mm-mrad	13000	1500
Longitudinal emit.(z)	mm	13	19
6D emittance($\times 10^{-12}$)	$(m - rad)^3$	570000	29883
rms bunch length(σ_z)	cm	9.3	10
rms beam size(σ_x)	cm	5.0	1.28
rms dPz/Pz	%	13.7	23.7

Table 3: PJK cooling parameters for a Neutrino Factory

	units	**Initial**	**Final**
Transverse emit.(x)	mm-mrad	9000	1500
Longitudinal emit.(z)	mm	15	30
rms bunch length(σ_z)	cm	9	12
rms dPz/Pz	%	8	12

4 SIMULATION RESULTS

The initial beam distribution is generated by a random Gaussian with 13000 mm-mrad transvese and 13 mm longitudinal emittances. A beam with a longitudinal momemtum of Pz=195 MeV/c with rms momemtum spread of 13.7% is used.

Figure 4 shows the decrease in transverse (x) normalized emittance as a function of distance along the channels. The system provides cooling by a factor of 8.6 in both the x and y (not shown) transverse phase spaces. It shows that transverse emittance cools to 1500 mm-mrad which is needed

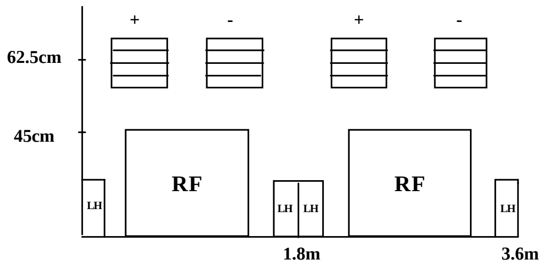

Figure 1: Configuration of the DFOFO cooling channel which has 1.8m cell long. Rf cavities of pillbox type with 5-cell structure are used. Al windoe is used to sustain the liquid hydrogen. Sheets with 50 cm long and 15cm height are used to generate realistic magnetic fields.

for the neutrino factory. The cooling channels shows the increase by a factor of 1.46 in longitudinal normalized emittance in the channels (not shown). The small increase in longitudinal emittance is caused by the particle losses. 6-D normalized emittance shows decrease by a factor of 0.018, i.e. a factor of 55. Figure 5 shows the decrease in the rms beam size as a function of distance along the channels.

Table 2 also reports the initial and final beam parameters of rms beam size σ_x, rms bunch length σ_z and rms longitudinal momentum deviation. PJK cooling paramters for a neutrino factory are shown in Table-3.

5 CONCLUSION

DFOFO cooling channels which satisfy enginnering constraints are proposed. It is shown that the cooling parameters for the neutrino factory can be achieved by the using of the DFOFO cooling channels. The particle transmission in DFOFO channel is higher than the FOFO channel and alternating solenoid channel by 10%-20%. Further investigations are being performed to use lower current density and shorter total length of the DFOFO cooling channels.

REFERENCES

[1] R. Palmer, Mucool notes 46, 1999.

[2] Eun-San Kim, Mucool notes 128, 1999.

[3] V. Balbekov, Mucool notes 98 and 118, 2000.

[4] Fermi Feasibility Study Report, Fermi Lab., 2000

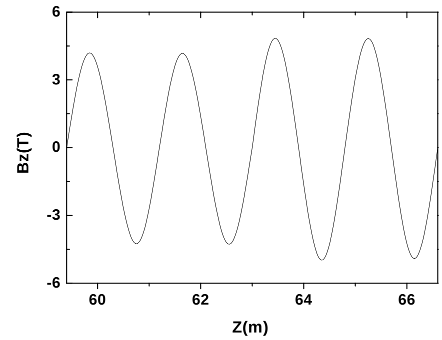

Figure 2: Magnetic field (Bz) $vs.$ Z(m) in interface of first and second DFOFO cooling channels. The magnetic field has minimum values in the midpoint of rf cavities.

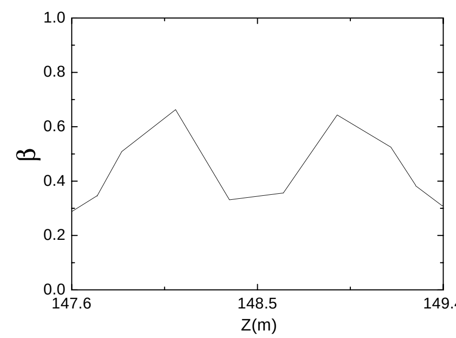

Figure 3: Beta function $(\beta_x) vs.$ Z(m) in one cell of second stage DFOFO cooling channel..

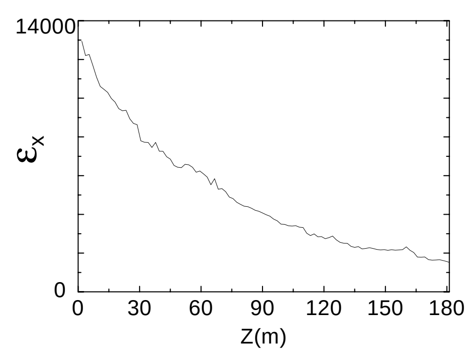

Figure 4: X-dimensional emittance $(mm-mrad)$ $vs.$ Z(m) in the DFOFO cooling channels

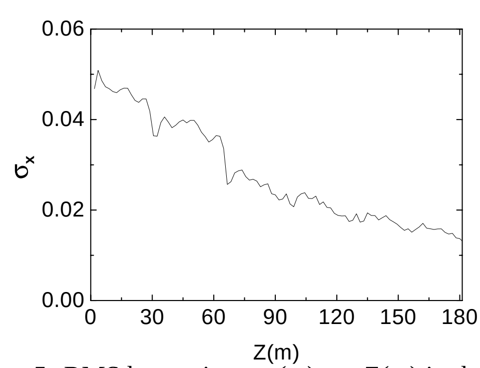

Figure 5: RMS beam size σ_x (m) $vs.$ Z(m) in the DFOFO cooling channels