Hybrid Absorber for the RFOFO Ring Cooler

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Abstract

Special absorber for the RFOFO ring cooler is proposed. It presents a flat cryogenic vessel with liquid hydrogen and inserted lithium hydride wedge. Its advantages over a liquid hydrogen wedge absorber are a simpler design and thiner aluminum windows. Cooling simulation shows that the RFOFO cooler with this absorber has higher performances in comparison with earlier considered versions.

1 Introduction

One of problems of the RFOFO ring cooler is a complicated liquid hydrogen wedge absorber schematically shown in Fig.1, left [1-3]. The cryogenic vessel of triangular shape with angle $100^\circ - 125^\circ$ requires rather thick aluminum wall which will give a considerable contribution to multiple scattering. Therefore, a reasonable approach this shape by a smooth cylindrical surface was considered in Ref. [1], causing considerable degradation of the cooler performances also.

A solution proposed in this note is shown schematically in the right Fig.1. It is an usual LH_2 absorber with (almost) flat walls and LiH wedge absorber inside which overlaps a half of the beam pipe. Generally, replacement of H_2 absorber on LiH one should cause an increase of equilibrium transverse emittance by factor about 2. However, at considered wedge-shaped insertion, the cooling and scattering occurs mostly in hydrogen, especially at the end of cooling when the beam radius is small. Therefore, expected increase of transverse emittance due to the usage of LiH should be not so much – maybe 10-20%. Probably, this deterioration can be compensated or even exceeded owing to thiner Al walls of the flat vessel which moreover are placed perpendicularly the beam, in contrast with the triangular vessel. It is believed also that a manufacture of this absorber is a less challenging problem.

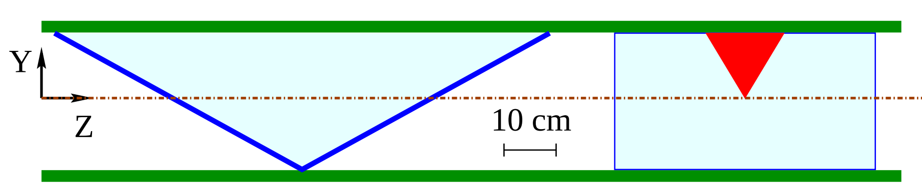

Figure 1: Schematic of absorbers: left – usual, right – proposed hybrid. Blue – liquid hydrogen, red – lithium hydride, dark blue – aluminum walls, green – beam pipe, brown dashed line – beam axis.

We will apply this absorber to the cooler described in detail in Ref. [2]. Very similar design was considered in Ref. [3] differing mostly by parameters of the absorber what are just the subject of our investigation. Injected beam is the same as in Ref. [4] where cooling of a 'compressed' bunch was considered as a part of a front-end simulation for a $\mu^+\mu^-$collider. 16000 incident muons are used for all the simulations.

2 Basic Absorbers

A comparison of the absorbers without Al windows taken into account is performed in this section. Parameters of the LH_2 triangular absorber are taken from Ref. [4] and listed in Table 1. Parameters of the hybrid absorber used below are listed in Table 2. As before, they are optimized to provide maximal 6D merit factor after 10 turns cooling. Note that the merit factor is determined like Ref. [4] simply as a density in 6D phase space without normalization on initial value, but with normalization on number of incident protons:

$$MF = \frac{\mu/p}{\varepsilon_6}$$

Evolution of the beam parameters is presented in Fig.2 and their magnitudes in the beginning and after 10 turns are compared in Table 3 for both absorbers. At first glance it looks strange that the final transverse emittance is almost the same in both cases (vertical emittance is even less with hybrid absorber), but the longitudinal emittance increases in return. The point is that the hybrid absorber provides less emittance exchange. Indeed, it is seen from Tables 1 and 2 that gradient of energy loss is more by factor 1.65 in LiH absorber then in LH_2 one. However, LiH absorber covers only a half of the aperture so that its real strength is about 20% less then strength of LH_2 absorber which fully covers the aperture. Because of this, the decrement of transverse cooling increases what probably compensates more scattering in LiH. At the same reason longitudinal decrement now is about 0.8 of the initial quantity. According to Fig.2, old longitudinal cooling factor was about 10. Therefore its new value should be $10^{0.8} \simeq 6.3$, i.e. new longitudinal emittance of the cooled beam should be approximately 1.6 times more of the old one what is in a good agreement with Table 3: $0.541/0.324 \simeq 1.67$.

Table 1: Basic liquid hydrogen absorber (no Al windows)

Maximal length	96.4 cm
Length along central orbit	48.2 cm
Distance from the center to edge	12.5 cm
Angle at the edge	125°
Energy loss on central line at E = 220 MeV	15.1 MeV
Gradient of the energy loss dE/dY	1.21 MeV/cm

Table 2: Basic liquid hybrid (no Al windows)

Length of the absorber	48.2 cm
Maximal length of LiH insertion	14.4 cm
Angle at the edge	60°
Energy loss on central line at E = 220 MeV	15.1 MeV
Gradient of the energy loss in LiH absorber	2.00 MeV/cm

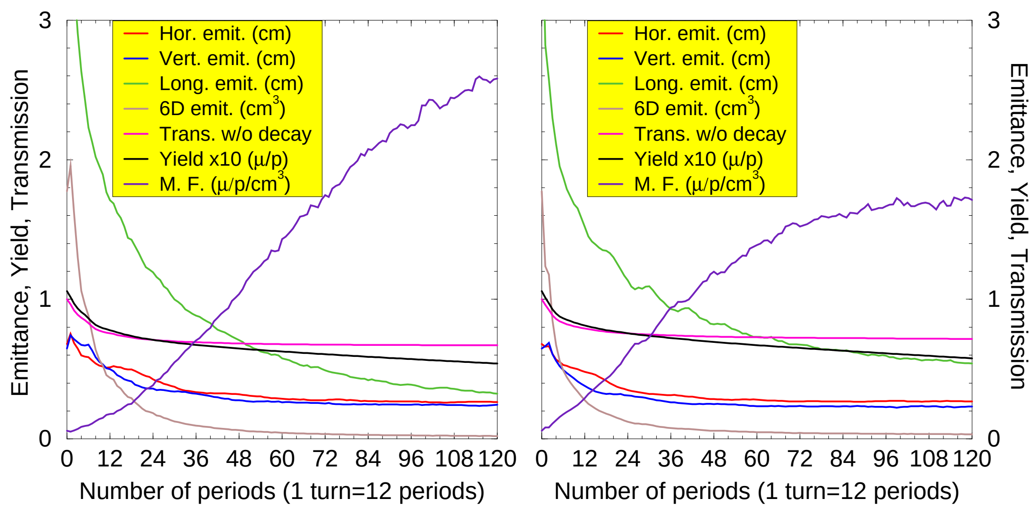

Figure 2: Evolution of the beam parameters at the cooling. Left – LH_2 absorber, right – hybrid absorber (no windows).

Table 3: Beam parameters in the beginning and after 10 turns

Parameter	Beginning*	LH_2 absorber	Hybrid absorber
Horizontal emittance (cm)	.633	.265	.270
Vertical emittance (cm)	.613	.244	.232
Longitudinal emittance (cm)	2.50	.324	.541
6D emittance (cm^3)	.968	.0209	.0337
Transmission w/o decay	1	.671	.716
Yield (muon/proton)	.107	.0540	.0578
6D merit factor (cm^{-3})	.105	2.58	1.71

(*) window -25 cm $< ct <$ 50 cm

3 Effect of Aluminum Windows

A beam pipe of radius 10 cm is fit for the beam with characteristics as in Table 3. Flat aluminum alloy windows for the hybrid absorber can be as thin as 0.1 mm at this radius. However, for safety we will consider windows of thickness 0.22 mm also [5]. The situation with the triangular LH_2 absorber is less distinct because an engineering design of similar absorber is not performed yet. Following Ref. [3] we will consider Al windows of thickness 0.25–0.5 mm.

First of all we will carry out some analytical estimations. Note that transverse emittance of the beam in considered cooler actually reaches equilibrium value. It is easy to show in linear approximation that in a cooler with combined absorber it is:

$$\varepsilon_{H+A} = \varepsilon_H \left[1 + \left(\frac{\varepsilon_A}{\varepsilon_H} - 1\right)\frac{\Delta E_A}{\Delta E_A + \Delta E_H}\right]$$

where symbols A and H mark different materials, ε_A and ε_H are equilibrium emittances of the same cooler with corresponding uniform absorbers, ΔE_A and ΔE_H are energy loss in the parts of combined absorber. In our case total energy loss in the absorber $\Delta E_A + \Delta E_H = 15.1$ MeV at the energy 220 MeV. If A and H mean aluminum and hydrogen, then with good accuracy $\varepsilon_A/\varepsilon_H \simeq 7$, and $\Delta E_A(\mathrm{MeV}) \simeq 0.5\, h(\mathrm{mm})/\cos\alpha$ where h is thickness of Al window and α is the angle of its inclination. For our LH_2 absorber $\alpha = 62.5^\circ$, and previous formula gives the following expression for relative increase of transverse emittance due to 2 aluminum windows:

$$\Delta\varepsilon/\varepsilon \simeq 0.86\, h\ (\mathrm{mm})$$

what gives $22-43\%$ at $h = 0.25-0.5$ mm. Because emittance without windows is about 0.25 cm, expected emittance is $0.3-0.35$ cm. For the flat hybrid absorber the same formula gives an estimation: $\Delta\varepsilon/\varepsilon \simeq 0.4\, h$ (mm) i.e. $4-8\%$ at $h = 0.1-0.2$ mm. Note that the lower quantity is rather close to the statistical error at 16000 incident muons.

Results of the simulation are presented in Fig.3 and Table 4. It is seen first of all that LH_2 absorber of thickness 0.25 mm and hybrid one of 0.1 mm provide almost identical 6D cooling. The main difference is distribution of the cooling factors: hybrid absorber provides more transverse and less longitudinal cooling. An explanation of this effect is given in previous section. However, a

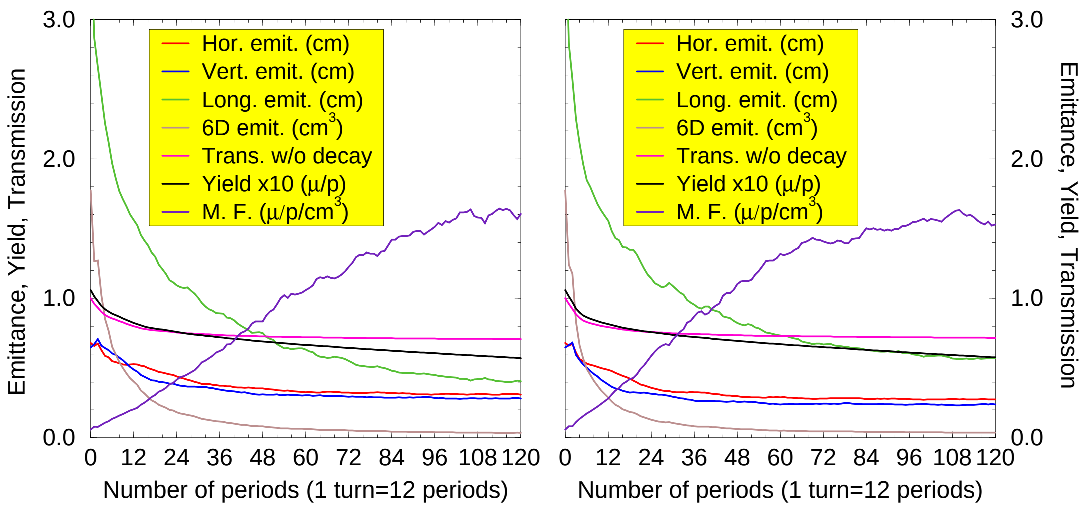

Figure 3: Evolution of the beam parameters at the cooling. Left – LH_2 absorber with 0.25 mm Al window, right – hybrid absorber with 0.1 mm Al window.

Table 4: Beam parameters in the beginning and after 10 turns

Absorber Al window thickness (mm)	LH_2 0	LH_2 0.25	LH_2 0.5	Hybrid 0	Hybrid 0.1	Hybrid 0.22
Horizontal emittance (cm)	.265	.310	.356	.270	.276	.286
Vertical emittance (cm)	.244	.282	.324	.232	.239	.247
Longitudinal emittance	.324	.407	.516	.541	.573	.585
6D emittance (cm^3)	.0209	.0356	.0595	.0337	.0377	.0413
Transmission w/o decay	.671	.708	.688	.716	.717	.712
Yield (muon/proton)	.0540	.0572	.0555	.0578	.0576	.0574
6D merit factor (cm^{-3})	2.58	1.61	.934	1.71	1.53	1.39

thickening of the windows effects stronger on the LH_2 absorber, and at the thickness of 0.5 mm it is certainly worse then the hybrid absorber with windows of 0.22 mm. Probably, the flat hybrid absorber is preferable from engineering point of view also.

Note that the dependence of transverse emittance on the thickness of Al windows is in a satisfactory agreement with the analytical estimation. However, rather strong effect of the windows on longitudinal emittance is observed also. It could not be explained by straggling, because relative statistical fluctuations of the energy loss almost do not depend on material. Probably, the reason is a very known fact that energy of a particle correlates with amplitude of betatron oscillations. It is illustrated by Fig.4 where the correlation is shown at LH_2 absorber without (left) and with (right) 0.5 mm windows (see also Ref. [4]). The amplitude is defined by the formula:

$$A = \sqrt{x^2 + y^2 + (p_x^2 + p_y^2)(c/eB_{ef})^2}$$

where effective axial field $B_{ef} = 3.5$ T is applied [4]. The correlation arises both from nonlinear dependence of revolution frequency and energy loss in the absorber on the betatron amplitude. First effect shifts the synchronous energy of a particle, second – synchronous phase. One can believe also that at such conditions scattering provides some additional longitudinal heating like straggling, what explains why the energy spread is more on the right plot at the some amplitude.

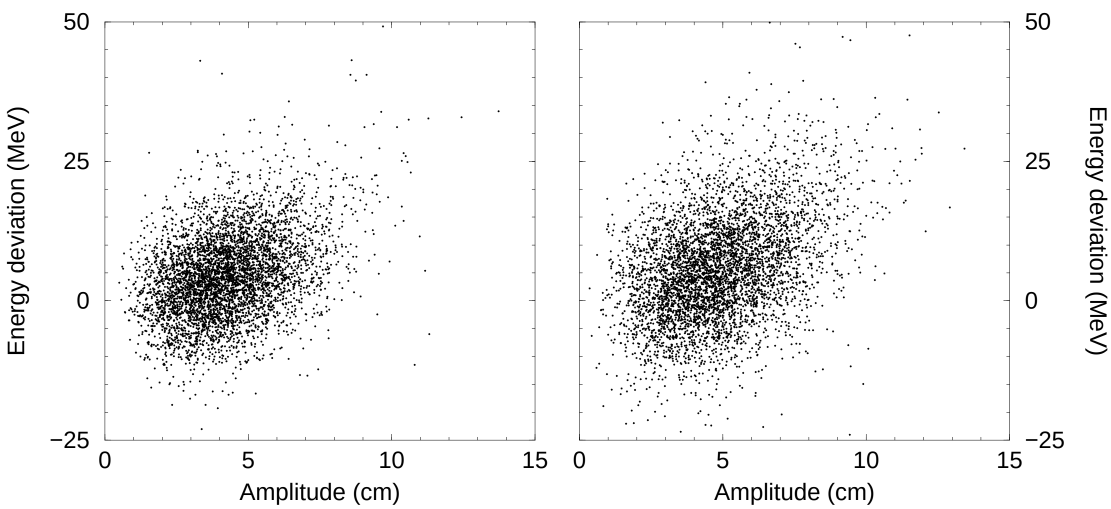

Figure 4: Phase space: amplitude of transverse oscillations - energy at LH_2 absorber. Left – no windows, right – Al windows of thickness 0.5 mm.

4 Conclusion

Thus, the hybrid absorber with flat Al windows of thickness 0.1 mm provides approximately the same performances of the RFOFO ring cooler as triangular $LH-2$ absorber with 0.25 mm windows. A thickening of the windows effects considerably stronger on the $LH-2$ absorber. Probably, an engineering design is required to complete the problem.

5 Acknowledgments

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References

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