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Power deposition in the vacuum chambers of the MQW magnets of IR3 and IR7

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Abstract

Motivated by several changes made to the collimation system, we calculated the power deposited in the vacuum chambers of the MQW modules of IR3 with graphite collimator jaws for the former V6.2 version. Using the minimum lifetime recently specified for the nominal stored intensity, we conclude that the power deposition in the vacuum chamber of some MQW modules is too large in the presence of bake-out system. Either a cooling system must be envisaged or the specification of the minimum lifetime must be raised from one to three hours. These results might have to be evaluated again if the final insertion differs substantially from the one used in the present simulation.

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1 Introduction

In former cascading studies related to the collimation insertions [2, 3], the power deposition in the vacuum chambers of the warm magnets was found small enough to not generate a problem. But in the meantime, many changes occurred, justifying a closer look at this issue:

1. Initially, the copper chamber was electrically insulated with a thin kapton foil (or similar) and clamped into the magnets when the two upper and lower halves were closed together. The chamber was therefore partly in contact with the yoke. The thin kapton foil was not a strong thermal barrier, providing a quite good contact with the yoke. The latter is cooled by contact with the coils. In addition, in the warm MQW quadrupoles, which are most exposed to power deposition, there is much space around the vacuum chamber allowing for convective thermal exchange with the yoke. In the meantime, it was discovered that the vacuum chamber must be baked-out at $\sim 250^\circ$ [1]. The chamber must therefore be thermally insulated, limiting the heat exchange with its surrounding.
2. Because of a limited mechanical stability of the magnet, the vacuum chamber is now inserted into the magnet after it is fully assembled. Its size was therefore reduced and it thus catches more particles produced at the collimators, and therefore more power.
3. The collimator material was changed to materials with lower Z (graphite, Z=6), in order to survive erratic dump events [4]. With low-Z jaws, the cascade is made wider, thus diluting the power deposition inside the jaws. Because the integrated power deposition in the jaw is smaller, the deposition elsewhere is increased, in particular in the narrow vacuum chambers which are located downstream of them.
4. The specification of the beam conditions were modified [5]. The collimation insertions must now allow for a low steady beam lifetime $\tau_{\min} = 1$ hour (Table 1 of [5]).

We therefore revisited the case of the power deposition in the vacuum chamber of the MQW magnets. The method used and the results are discussed in Section 2. Some conclusions are drawn in Section 3. We presently lack cascade data for IR7 with graphite jaws, where we expect to observe sometimes poor lifetime. We therefore used IR3 data, with IR7 bad lifetimes. But, the topology of the insertion is quite similar with respect to the issue studied here. Protons interact on the primary jaws, secondary particles impact on the first and second secondary ones, and finally the cascade fully develops in the magnets located downstream. The conclusions drawn for IR3 apply therefore as well for IR7 with reasonably high confidence.

2 Method and results

At present, the final layout and hardware of the insertions is still under work. We thus used the layout V6.2, were the former Aluminum and Copper jaws are replaced by double density graphite. This work is presently done only for the momentum cleaning insertion in IR3. The MQW vacuum chamber is sufficiently distant from the jaws to not be very sensitive to the approximation made by using half length / double density graphite. A detailed description of the insertion and of its modellisation made for running K2 and MARS cascade codes can be found in [3]. The power deposition in the vacuum chamber is integrated in three longitudinal segments along the MQW, namely two short 15 cm long sections at the extremities and a 311 cm long central segment. A transverse section of the MQW magnet is shown in Fig. 1. In the simulation, the vacuum chamber has a section delimited by two radii, namely an inner radius of $r_{in} = 2.2$ cm and an outer radius of $r_{out} = 2.4$ cm. The power density is averaged azimuthally. We did not look at the MBW data, for which the vacuum chamber section is still under discussion and which catches less power. The results are shown for the chamber of each MQW module of the two most exposed sets of quadrupoles, namely Q5L and Q4R in Fig. 2 and 3. The same plots are given in Fig 4 and 5 for the most exposed module of each assembly. The result are given for Beam 1. The contribution

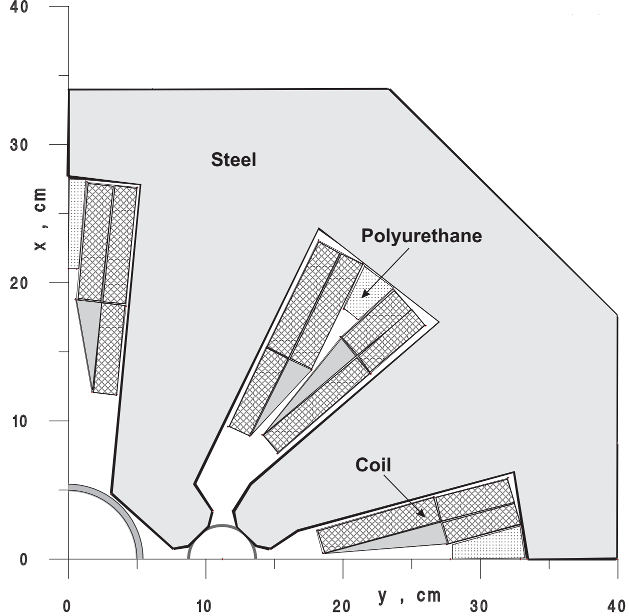

Figure 1: The cross-section of the MQW magnet as defined for the MARS cascade calculation

from Beam 2 to Beam 1 chambers was checked and found to marginally modify the picture. All the data in the figures are normalized to an integrated proton loss of $\dot{n} = 10^9$ protons/s, with a corresponding beam lifetime $\tau = N_{\rm coast}/\dot{n} = 3.3\times10^{14}/10^9 = 3.23\times10^5\,s = 90$ hours. The most exposed chamber is located in the last module of Q5L, see Fig 4. The average value is $w = 0.03\ \mathrm{W/cm}^{-3}$. The power deposition does not much differ at the extremities and in the long central segment, ensuring a not too strong variation inside the latter one. The volume of the chamber is $V = \pi(r_{out}^2 - r_{in}^2)L = 985\,\mathrm{cm}^3$, with $L = 341\,\mathrm{cm}$. The total power is therefore $W = wV = 29.6\,\mathrm{W}$. For a minimum beam lifetime $\tau_{\rm min} = 1$ h, the maximum steady power deposition is

$$\hat{W} = W\frac{\tau}{\tau_{\rm min}} = 2.7\,\mathrm{kW}\ . \qquad (1)$$

This must be compared to the thermal leakage through the chamber insulation. This was measured by C. Rathjen [6]. In order to reach the steady bake-out temperature of 250° ($\Delta T_{\rm bake-out} = 150^\circ$), a power of $W_{\rm bake-out} = 2.04\,\mathrm{kW}$ must be injected. In order to avoid excessive out-gassing during operation at the minimum steady beam lifetime, the temperature excursion of the chamber should be less than $\Delta T_{\rm steady} \approx 75^\circ$. It can therefore be concluded that the power deposition shall not exceed

$$W_{\rm min} = W_{\rm bake-out}\frac{\Delta T_{\rm steady}}{\Delta T_{\rm bake-out}} = 1\ \mathrm{kW}\ . \qquad (2)$$

Otherwise some changes must be envisaged. Two options can be considered.

1. Embed a water cooling capillary to the vacuum chamber, packed inside the bake-out jacket
2. Revise the value $\tau_{\rm min}$. According to the above quoted data, this value should be raised up to

$$\tau'_{\rm min} = \frac{\hat{W}}{W_{\rm min}}\tau_{\rm min} = 2.7\ \mathrm{hour}\ , \qquad (3)$$

indicating that the current specification of the minimum steady lifetime is below the acceptable one within the present baseline design.

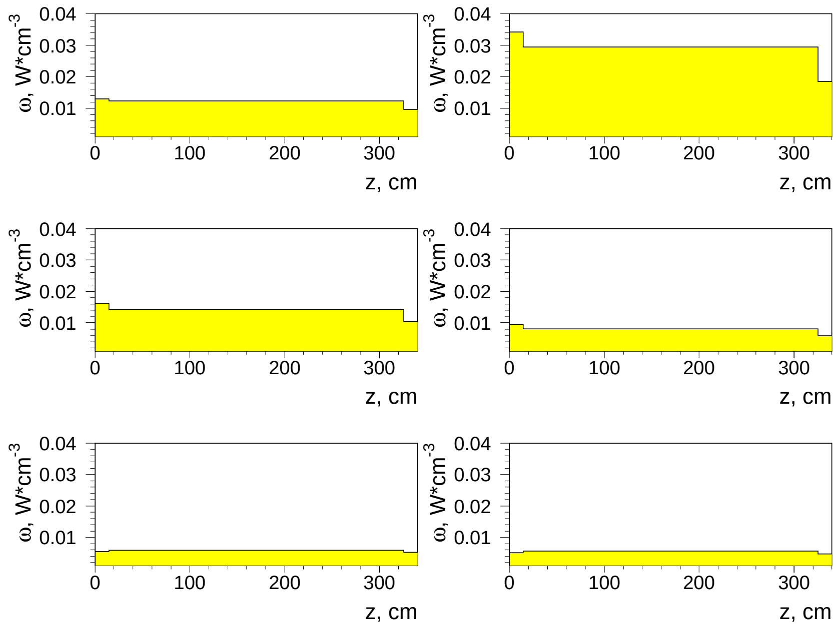

Figure 2: The power density deposition in the vacuum chamber of each module of the quadrupole assembly Q5L, see text. The sequence of the modules reads left to right, then next row.

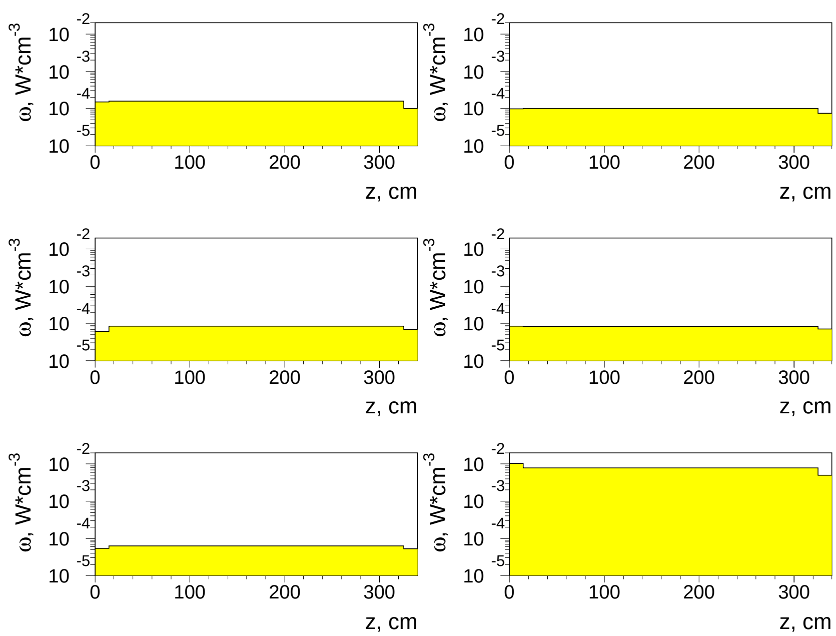

Figure 3: The power density deposition in the vacuum chamber of each module of the quadrupole assembly Q4R, see text.

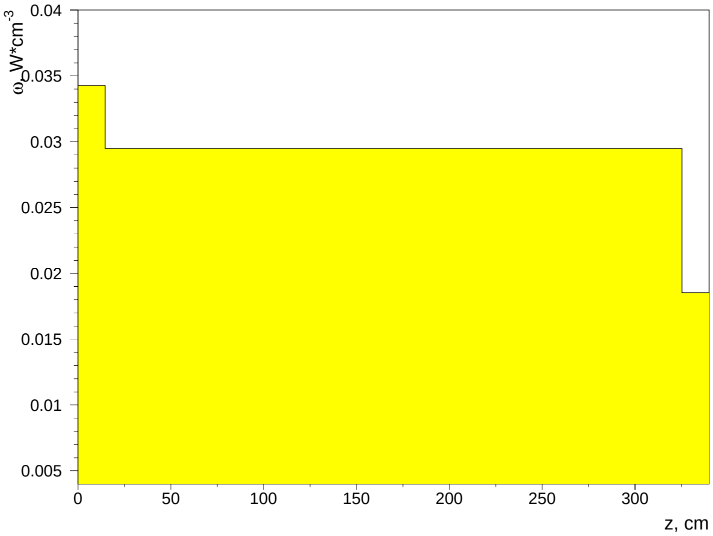

Figure 4: The power density deposition in the vacuum chamber of the most exposed module of the quadrupole assembly Q5L, see text.

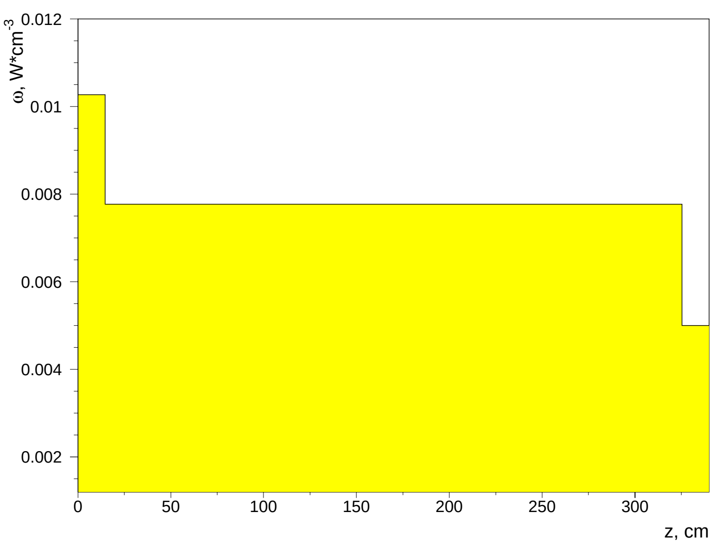

Figure 5: The power density deposition in the vacuum chamber of the most exposed module of the quadrupole assembly Q4R, see text.

3 Conclusions

We calculated the power deposited in the vacuum chambers of the MQW modules of IR3 with graphite collimator jaws. Using the minimum lifetime recently specified for the nominal stored intensity, we conclude that the power deposition in the vacuum chamber of some MQW modules is too large in the presence of a bake-out system. Either a cooling system must be envisaged or the specification of the minimum lifetime must be raised from one to three hours. These results might have to be evaluated again if the final insertion differs substantially from the one used in the present simulation.

References

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[6] C. Rathjen, Private communication, October 2003.