CATALOGUE OF LOSSES FOR THE IFMIF PROTOTYPE ACCELERATOR

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Abstract

For machine and personal protection purposes, precise knowledge of beam loss location and power are crucial, especially in a high intensity, high power accelerator like the Linear IFMIF Prototype Accelerator (LIPAc). This paper aims at discussing the protocol of appropriate studies in order to give the catalogue of beam losses in different conditions: nominal, tuning and accidental. Then first results of these studies are given.

INTRODUCTION

The IFMIF (International Fusion Materials Irradiation Facility) project will feature two accelerators accelerating 2x125 mA CW of deuteron beam to 40 MeV. Due to that very high intensity, serious challenges must be overcome [1]. That is why it has been decided to construct in a first phase a full scale prototype called LIPAc (Linear IFMIF Prototype Accelerator) accelerating deuterons only up to 9 MeV. It is presently under study and construction in Europe, to be progressively installed in Rokkasho, Japan from the end of 2012. Even at lower energy, LIPAc features already a very high beam power, reaching 1.1 MW at its end. In this situation, any loss, even tiny, can be harmful. A careful and detailed loss study is thus necessary. This paper aims at summarising the reflexions on the methodology used for these studies and at providing a "Catalogue of losses" in different operating conditions: nominal, tuning and accidental.

GENERAL DESCRIPTION

Beam power and energy are indicated along the LIPAc accelerator in Figure 1 where its general layout is given. D^+ ions are created by an ECR source, extracted by a four-electrode system at 100 keV, then transported and properly focused by a two-solenoid LEBT to be injected into a 9.8 m long RFQ, in which the beam is bunched and focused while accelerated to 5 MeV. In these low energy sections, nominal losses are substantial. In the LEBT, they consist only of non-desirable extracted species (D_2^+, D_3^+…). In the RFQ, a specific design has been made so that particles that are not properly bunched or accelerated are mostly lost in the first part where they are still at low energy. All these losses should only produce heat that have to be evacuated. The higher energy section starts with the MEBT that adjust the beam transversally and longitudinally with quadrupoles and buncher cavities to inject it into the SRF Linac. The latter consists of one cryomodule housing 8 identical solenoids and half-wave resonators that focus and accelerate the beam to its final 9 MeV energy. The beam arrives then in the HEBT whose role is to transport it through a 2.4 m diagnostic plate where various measurements on the beam are foreseen, to bend it by 20 degrees in order to reduce backward radiations and to expand it the most homogeneously possible on the beam dump. In this part, except some losses in the MEBT first part due to low energy particles not correctly accelerated in the RFQ, no other nominal loss is expected.

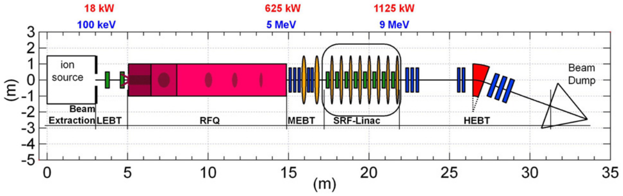

Figure 1: Beam power and energy along LIPAC.

LOSS STUDY PROTOCOL

A catalogue of losses will be useful, or even necessary in the definition of safety procedures, limitations and recommendations, aiming at protecting personnel and equipments. As a precaution, a comfortable margin (at least a factor 2 for example) should be added to the loss values given by the present studies, before any consideration at safety level.

Losses are given for the maximum beam current. Theoretically, because space charge effects decrease with intensity, losses at lower current are less than what can be inferred by a linear relation. But as a precaution, it is wise to deduce losses at lower current with a simple linear transformation.

It is foreseen that Beam Dynamics studies will be performed in order to provide a catalogue of losses along the prototype accelerator in the three following situations:

1. Nominal situations. "Nominal" means here ideal theoretical conditions, without any error. That should correspond on the real machine, to a completely satisfying situation, once the beam has been perfectly corrected and tuned. Losses in such conditions will be minimum, we cannot hope to have less. These are minimum and permanent losses we will have to withstand.

2. Tuning situations. We want to estimate losses that can occur BEFORE or DURING tuning and correction procedures, necessary for obtaining a satisfactory operation of the accelerator. These losses, larger than the nominal ones, are due to all the possible differences between the ideal, theoretical machine and the real one. These differences can be divided into two categories:

- The components do not respect exactly the theoretical specifications
- The beam behaviour is not exactly the same as what is theoretically simulated (do think to the IFMIF very high space charge regime that has never been implemented).

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These situations can be taken into account by simulating 500 machines with suitable "errors", without any corrector. The "errors" should be of two kinds:

- Mechanical, alignment and field errors, randomly distributed within the already determined tolerances.
- Tuneable parameters (gradient, field, phase, RF power, pressure…), randomly distributed within a range that can be estimated as likely on the real machine.

Concerning the tuning range, it can be for example ±10% for fields and gradients, but this range has to be examined and if necessary adjusted according to the loss level. The determination of this tuning range is also useful for setting the maximum variation allowable for each physical parameter, maximum given to the Control System which will prevent any variation beyond.

These simulations can be made for the whole machine, from start to end. Losses for each location along z are collected for all the simulated cases, from which curves of RMS and maximum losses can then be deduced.

3. Accidental situations. These situations are not the same for all the sections. Reflexions and analysis should be carried out to detect what is the worst case, what is the main affected location or equipment, when one tuneable parameter (gradient, field, phase, RF power, pressure…), or a given combination of them, are suddenly switched off. We have also to consider the situations where correctors fail, resulting in sending the beam into the beam pipe wall. But attention will also be paid to detect if there is an intermediate case which can induce more losses, for example in the transition from the nominal value to zero for specific field or gradient.

RESULTS AND DISCUSSIONS

Start-to-end simulations with 10^6 macroparticles have been thoroughly carried out with the TraceWin code [2]. For the sake of realism, the used input beam results from calculations of the ECR source extraction system with the AXCEL code [3], and most of the elements of the accelerators are represented by their field map calculated by finite element methods.

Losses in the nominal case are given in Figure 2. As stated above, losses occur in the first part of the RFQ (some tens of W), in the MEBT where scrapers have been installed to collect them (3 W) and in the bending magnet (1 W). They all come from particles not correctly bunched and accelerated by the accelerating structures which are the RFQ and the SRF-Linac.

Losses in one type of tuning situation are shown in Figure 3, where mechanical, alignment and field errors randomly distributed within tolerances [4] are considered. The power lost is reported for different percentages of error cases for a total of 500 error cases. In the worst case, losses in the RFQ are only about 20% more than in no-error case, and are everywhere else less than 2 watts. Except near the very end, at the location of the fixed scraper destined to protect the beam dump surroundings, where losses go up to 400 W in 1 case over 500.

Studies are currently done for the second type of tuning situations simulated by the means of tuneable parameter errors up to 10% of nominal values. A careful examination of the RFQ transmission is being undertaken in order to provide meaningful results.

Losses in accidental situations encounter some difficulties in the low energy part to modelise errors so that the complex space charge compensation in the LEBT can be correctly taken into account [5]. For the high energy part [6] ($E > 5$ MeV), from the MEBT to the Beam Dump, losses are shown in Figures 4 and 5. Sudden breakdowns of all magnetic and electric elements such as quadrupoles, solenoids, accelerating cavities, bunchers have been studied. Two cases of failure have been thoroughly studied: failure of each element separately while all other ones stay at their nominal setting and global failure of all the elements corresponding to a general electric breakdown for example. Intermediate situations have also been simulated for field strengths at 0, 25, 50, 75, 80, 85, 90, 95, 110, and 115 % of their nominal value, which is referred as 100 %.

We can observe that losses induced by individual element breakdowns are generally higher by a factor of two compared to a global breakdown of all elements. Failures around 90 – 110 % imply losses of the order of hundreds W, while higher failures imply losses up to hundreds of kW. Emergency beam stop systems should be designed accordingly in order to efficiently protect accelerator elements.

The hot points can also be easily identified. They are different for the cases of global or individual failure. In case of global failure, the last HEBT drift is the most exposed for small field trips, while the MEBT last part and the SRF Linac first part is the most exposed for high field trips. In case of individual failure, the hottest regions are the second scraper, the fourth quadrupole in the MEBT, the 6th solenoid in the SRF Linac, the diagnostic plate, the last triplet and the scraper in the HEBT.

It is worth mentioning that even in case where no loss occurs, these field trips can induce important beam size variations that cannot be withstand by the Beam Dump. These variations have also been carefully studied in Figures 6 and 7. If a variation of ± 10 mm around the nominal beam size can be tolerated (to be confirmed by more detailed studies), then only beam trips less than 95 – 105 % can be tolerated. Once more, emergency beam stop systems should be designed accordingly.

CONCLUSION

For a high power accelerator as IFMIF, a detailed catalogue of losses is necessary for defining safety procedures such as the rapidity of the emergency stop system, or for deciding the maximum authorised for beam intensity and field variation ranges during tuning. A protocol has been discussed aiming at establishing the beam dynamics simulations allowing to provide beam losses in nominal, tuning and accidental situations. Some first results are shown in this paper, which remain to be consolidated and completed.

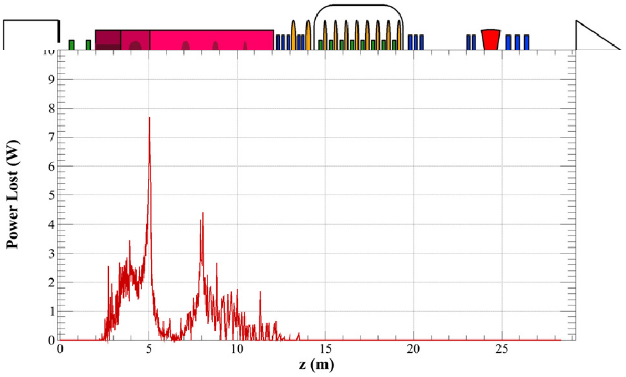

Figure 2: Power lost in nominal situation.

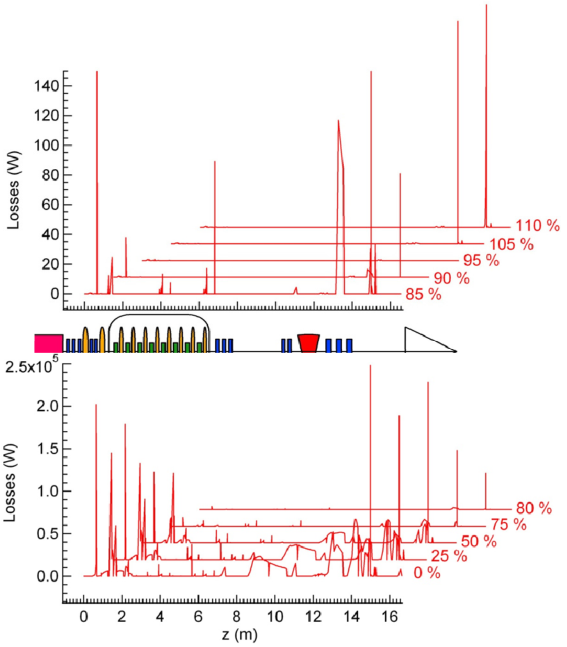

Figure 4: Power lost in case of individual element failures.

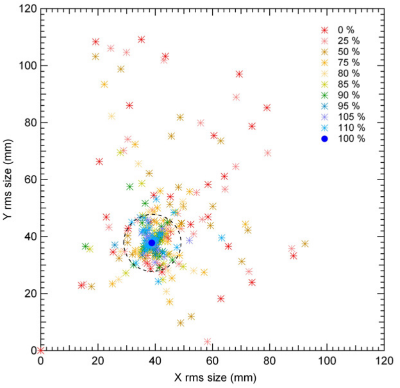

Figure 6: RMS Beam size at the Beam Dump entrance in case of individual element failures. The circle indicates the tolerated zone (to be confirmed).

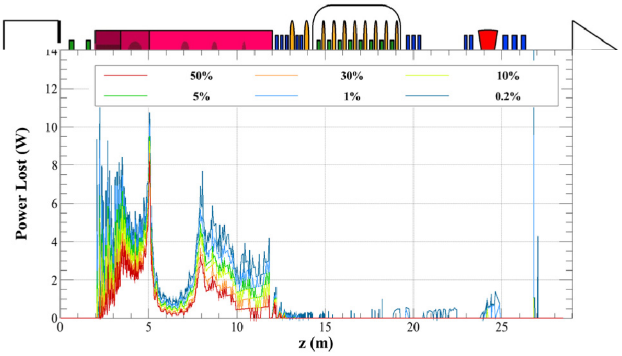

Figure 3: Power lost for different percentages of 500 error cases (mechanical, alignment and field errors).

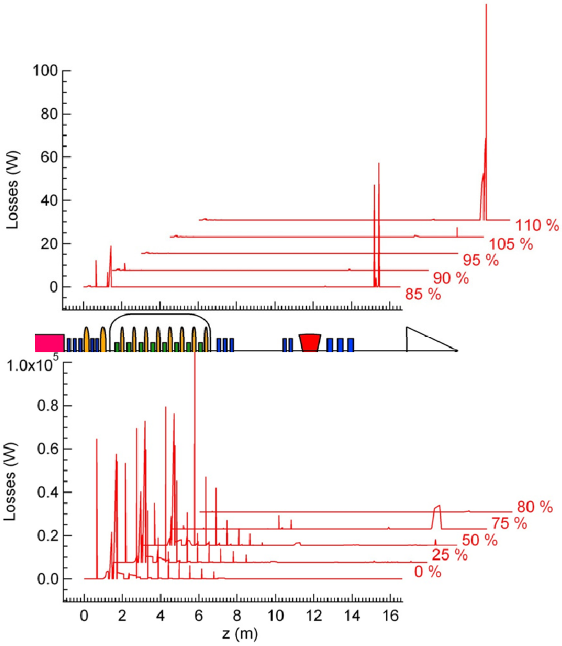

Figure 5: Power lost in case of global element failures.

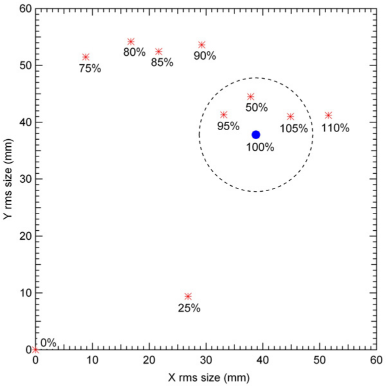

Figure 7: RMS Beam size at the Beam Dump entrance in case of individual element failures. The circle indicates the tolerated zone (to be confirmed).

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