SAFARI, AN OPTIMIZED BEAM STOP DEVICE FOR HIGH INTENSITY BEAMS AT THE SPIRAL2 FACILITY

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Abstract

The final status of the 200kW Beam Stop (SAFARI) located in the high energy beam transport lines of the SPIRAL2 driver accelerator will be presented. Special focus will be done on the coupling between beam dynamic and thermo-mechanical behaviour. Optimization by various fluids studies and calculations led us to an original design of a compact copper Beam Stop with a counter-current water cooling system.

INTRODUCTION

SPIRAL2 facility at GANIL-Caen [1] will deliver high intensity rare isotope beams for fundamental research in nuclear physics, high intensity stable heavy ions beams, and high neutron flux for multidisciplinary applications. It will give access to a wide range of experiments on exotic nuclei, which have been impossible up to now. The driver accelerator will produce various accelerated beams at high intensities, especially 40 MeV deuterons up to 5mA.

This paper describes the studies performed on the high energy beam transport lines with a special focus on the line from LINAC up to the Beam Stop [2]. Then, the complete design of the new high efficiency Beam Stop nicknamed SAFARI (Système Arrêt Faisceau Adapté aux Rayons Intenses - Optimized Beam Stop Device for High Intensity Beams) will be presented [3,4]. Finally, taking into account the beam characteristics and activation constraints [5], studies and optimizations have been done on cooling and thermo-mechanical dimensioning.

BEAM DYNAMICS IN THE HEBT

The High Energy Beam Transport Lines

Since 5 years, according to the progresses of the physics requirements, a lot of parameters were taken into account: beam dynamics of various ion species at various energies, diagnostics measurements using different techniques, quadrupoles, dipoles, and correctors (steerers) sizes and locations, valves, vacuum pumps... Transport lines cost and building implantation are also crucial aspects. Finally, a major pressure on the HEBT design is the safety and radioprotection, beam losses have to be as low as possible: less than 1W/m of Deuterons beam.

At the present time, the HEBT lines (Fig. 1) are completely defined. Total length is 88.7m. 5 sub-lines compose the HEBT:

- **LHE1**: from the end of the LINAC up to the SAFARI Beam Stop;
- **LHE2**: up to the UCx target devoted to the fission fragment production;
- **LHNFS**: up to the Neutrons For Science NFS experimental area;
- **LHS3N**: up to the Super Separator Spectrometer S3 area.

Magnetic and diagnostic elements must work in a large range in energy and intensity. From safety studies and conclusions, the 200kW beam power (40MeV, 5mA of Deuterons) is the worst case in terms of dose rate for maintenance and others aspects.

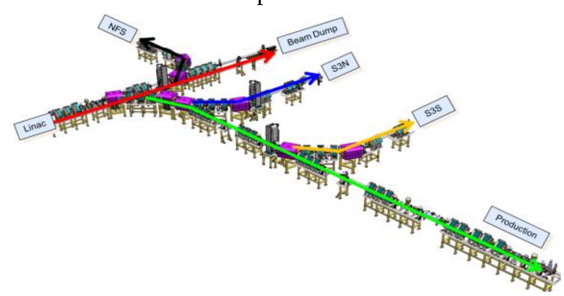

Figure 1: 3D view of the HEBT lines: LHE1 (red), LHE2 (green), LHNFS (black), LHS3N (blue).

Beam dynamics up to SAFARI

The LHE1 line is 21.3m long from LINAC exit up to SAFARI entry. According to the detailed composition of the line [4], transverse RMS beam sizes at the SAFARI entry are equal to 16mm and 3mrad for all species and energies in order to take into account to the various studies and recommendations:

- field gradients smaller than the limits,
- constraints induced by a dedicated Beam Stop room,
- no focusing lenses in the Beam Stop room,
- manageable beams in the last section,
- limited backward neutron and gamma radiation rate,
- limited vacuum volume.

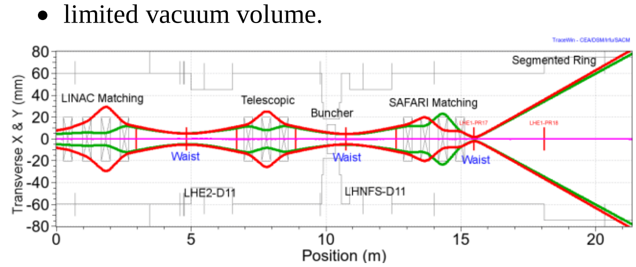

Figure 2: 5RMS deuterons beam envelops along the LHE1 using TraceWin code [6]. ϕ_{BS} entrance=154mm.

The beam size is a compromise between all these aspects. In nominal mode, 40W beam losses occur on the segmented ring located 1m before SAFARI. This element will be a control of size and beam position.

Errors studies

Intense errors studies have been done in order to evaluate clearly the different contributions associated to the beam matching, alignments and losses in the line, on the segmented collimators and SAFARI induced constraints.

By taking into account all errors (input beam, quadrupoles and diagnostics [4]) we have determined that the beam alignment is known along the line and at the SARAFI entrance at 4mm with a confidence level to 99.7%. The beam size fluctuation around 16mm is less than 1mm at 3σ. No beam losses occur along the line except on the segmented ring with an average of 40W with 30W RMS.

If we increase the errors on the beam, quadrupoles and diagnostics, we clearly see that the beam matching and alignment is less satisfied. The contribution of the beam coming from the LINAC is dominated, we observe that the matching is difficult to obtain by changing the LINAC beam exit matching by -80% to 200%. However the beam size increases largely along the line and the beam interlock will be done by the 3 loss rings located along the line. Therefore, no strong impact will occur on SAFARI.

During the first part of the safety study in 2008, we have given a very large constraint for the beam size at the Beam Stop entrance with size $RMS_{x,y}$=6.6mm. This beam size is theoretically feasible but the last 4^{th} quadrupoles fields to the last subsection have to be modified by a large factor (up to ±30%) in order to have a $RMS_{x,y}$=6.6mm.

INPUT PARAMETERS FOR SAFARI

General Specifications

The Beam Stop receives 200 kW of Deuterons and the high level of activation requires protective specifications. The Beam Stop is located in a dedicated room, with concrete walls. It is inserted into a cavity. Moreover, access to this area is restricted so maintenance and handling must be reduced to a minimum.

Therefore the Beam Stop system should respect these characteristics:

- Stable: low sensitivity to geometry and beam.
- Steadfast: operating far from limits.
- Safe: low maintenance, small failure risks.

Beams Specifications

All the beam characteristics used for SAFARI dimensioning are given in Table 1.

Table 1: SAFARI input beam parameters

Parameters	Nominal settings	Restrictive settings
Gaussian RMS	16 mm	6.6 mm
Total power	200 kW	200 kW
Max power density	12400 W/cm²	73000 W/cm²
Max power density (2° face projected)	435 W/cm²	2550 W/cm²

In fact, due to high level of activation, power per day on SAFARI will be limited to 10 kW during 1h, or equivalent (i.e. 417W continuous or 200kW during 3min). But these reduced values are not taken into account for dimensioning: we consider a steady-state 200kW beam.

Beam Stop Design

From initial geometry studies, various design improvements were achieved in order to reduce the number of welding parts and water junctions.

The SAFARI device is composed of 10 copper parts with progressive tapered holes. Total length is 1600mm. The Beam Stop is divided into 4 Sets and 2 smaller Blocks (#0 & #21). Stopping face of Block #0 (on the beam axis) is a tilted plate instead of a tapered hole. For machining matters, the first Set is divided into 5 parts while Sets II, III and IV are one united piece. Inner shape marries to the beam characteristics in order to smooth for the best power density and improve thermo-mechanical behaviour. Opening half angle varies from 1.4° (near beam axis) to 11° and more for Block #21. External radiuses are adjusted to minimize mechanical stress without losing the cooling efficiency.

Cooling system

The cooling system is made of helical rectangular channels directly machined into the material and located at the outer face of the blocks. Tightness is guaranteed by an adjusted (and welded) copper ring at the outside.

Two different kinds of water cooling are used: single loop and double loop with counter-flow for longer Sets. There are many advantages of this system: no contact resistance, no leak risk due to brazing, additional security (2 pipes for 1 block) and no possible contamination toward external environment.

Beam power deposit in SAFARI

From the point of view of the particle penetration inside the copper structure, it has been clearly showed that the power deposit is on the outer face of the Beam Stop. 40MeV Deuterons beam diffusion on Copper represents 5.4% of the incident power [7]. Figure 3 presents the beam losses using different techniques.

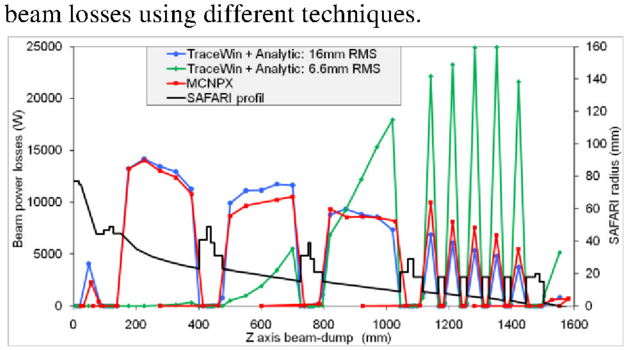

Figure 3: 40MeV-5mA deuterons beam power losses along SAFARI axis for a TraceWin/analytic calculation with $RMS_{x,y}$=16mm (blue), $RMS_{x,y}$=6.6mm (green) and MCNPX calculation (red).

We can clearly observe a particularly good agreement between the different techniques. In addition, a $RMS_{x,y}$=6.6mm over-focused beam induces a growth of the power deposition by a factor 5 in the last 400mm which is a large constraints on the stress of SAFARI.

BEAM STOP BEHAVIOUR

Cooling optimization

Fluid flow and cooling received particular attention to improve performance and operating safety. The major benefits of the counter-flow system, used for the main parts, are to increase cooling efficiency (thus reduce water outlet temperature) and to homogenize material temperature (thus reduce mechanical stress). The fluid flow through the curved pipes generates secondary flows due to the centrifugal force and it creates Dean Vortexes, which mix water and enhance heat transfer [8]. We also adjusted precisely each flow parameter like velocity (increase convection without damage pipes) and pressure drop for a balanced flow. Thus, this system enables an efficient cooling without an excessive water warming: maximum water temperature rising is 44°C for set IV.

Thermo-mechanical behaviour

The optimized design of SAFARI and its cooling system enable it to withstand 200 kW beam power and fulfil all thermal and mechanical requirements previously defined:

- Maximum copper temperature < 200°C.
- Maximum water temperature < 75°C.
- Maximum Von Mises stress < 180 MPa.

The maximum temperature on each block is reached on the inner faces, this is also where the mechanical stress is the highest due to thermal expansion, see figure 4.

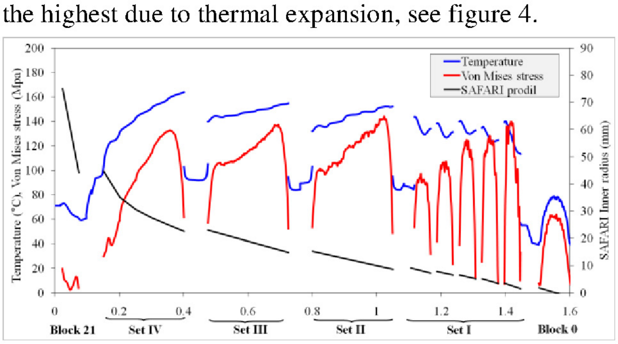

Figure 4: Temperature and Von Mises stress on SAFARI inner face using Ansys calculation.

Restrictive beams

SAFARI is also dimensioned to resist to highly over-focused beams. Therefore, maximum heat flux on Block #0 and Set I inner faces increases beyond 2500 W/cm² with a pulsed operating mode (2ms pulses at 1% or 10%).

In these cases, Beam Stop performances are limited by mechanical behaviour (stress ~ σmax) due to differential thermal expansion but not by temperature (T<140°C).

SAFARI PROTOTYPE

In order to validate functional behaviour and manufacturing process, a partial prototype has been realized through the European Collaboration SPIRAL2PP with **CIEMAT Madrid**. It has required non conventional machining and special assembling, as *Electrical Discharge Machining* and Cu/SS *Electron Beam Welding*.

This first prototype has been delivered and is currently undergoing flow and thermal tests (see figure 5).

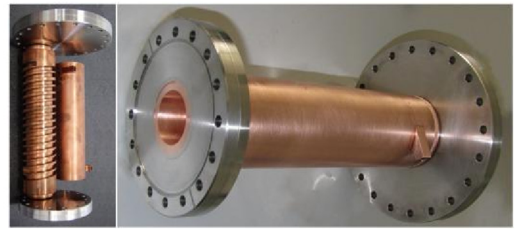

Figure 5: SAFARI set II before/after assembling.

New improvements are also under studies before the final design, as current measurement on the last blocks of the Beam Stop in order to monitor incoming beams.

CONCLUSION

We have presented the beam specifications along the HEBT lines from LINAC exit up to SAFARI. Precise calculations have been performed like errors calculations and power deposit contribution. A special accent has been put on interaction aspects such as coupling between beam properties, safety and thermo-mechanical behaviour.

It led us to an original design for SAFARI and its cooling system that fulfils all the technical requirements, even with the largely over-estimated beam parameters.

The SAFARI prototype should confirm analytical studies and numerical calculations and manufacturing of the final Beam Stop is scheduled for the end of the year.

ACKNOWLEGMENTS

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