DESIGN OF A HIGH ENERGY BEAM STOP FOR SPIRAL2

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Abstract

The driver accelerator of the Spiral2 facility will deliver high intensity beams. At the very end of the LINAC, the main Beam Stop will have to withstand a peak power of 200kW for deuterons.

From the beam characteristics and activation constraints, we proposed and developed a complete design for the Beam Stop. We will present this original design and the different studies and optimizations which have been done.

INTRODUCTION

The SPIRAL2 Project, located at the GANIL facility (Caen, France), will deliver intense radioactive beams [1]. A new high-power superconducting LINAC capable of accelerating 5 mA deuterons up to 40 MeV and 1 mA heavy ions up to 14.5 MeV/u is used to bombard both thick and thin targets. The production of high intensity radioactive beams of neutron-rich nuclei will be based on fission of UCx target induced by neutrons, obtained from a deuteron beam impinging on a graphite converter.

Figure 1 presents the SPIRAL2 buildings and implantation.

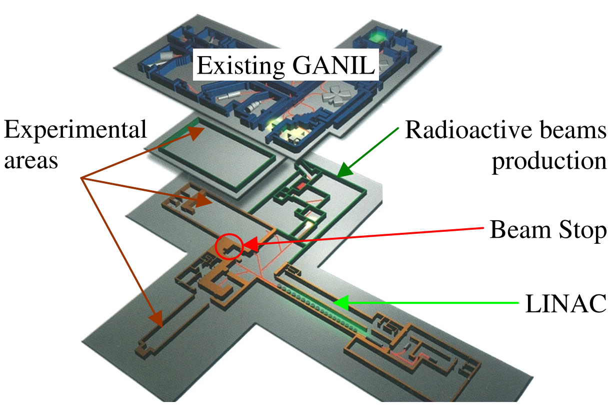

Figure 1: SPIRAL2 facilities.

The study of the Spiral2 Beam Stop led us to develop the design of a new high efficiency Beam Stop that has been nicknamed SAFARI (French acronym for Système d'Arrêt Faisceau Adapté aux Rayons Intenses –Beam Stop Device Optimized for High Intensity Beams) [2]. This paper will describe these studies on cooling & fluid optimization and thermo-mechanical dimensioning. Furthermore, we will present the functional mock-up that had been manufactured.

TECHNICAL SPECIFICATIONS

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, and is inserted into a cavity made on the backyard wall. 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: little sensitivity to geometry and beam variations.
- Steadfast: operating far from limits.
- Secure: low maintenance, small failure risks.

Beams Specifications

The last optical elements are situated far from the Beam Stop (> 6m), just behind the Beam Stop cave. Beam characteristics depend on this situation: beams can't be too divergent in order to minimize beam loss in the transfer line between the last optical element and Beam Stop.

Moreover, we have to consider a restrictive case, taking account of the largest errors on the LINAC output beam emittances growth, even if these values are largely over-estimated.

All the beam characteristics used for Beam Stop dimensioning are presented in Table 1.

Table 1: Beam parameters

Parameters	Nominal settings	Restrictive settings
Gaussian RMS	16 mm	6.6 mm
Total diameter	96 mm	39.6 mm
Total power	200 kW	200 kW
Max power density (orthogonal)	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, Spiral2 power per day will be limited to 10 kW in 1h, or equivalent (i.e. 417 W continuous or 200 kW during 3 minutes). But these reduced values are not taken into account for the Beam Stop dimensioning: we will consider a continuous 200 kW beam.

BEAM STOP DESIGN

Initial Beam Stop studies have been done with a simple geometry: 20 copper blocks of 50mm-long with conical opening, each block receiving 10 kW and was cooled by water pipes. From this geometry we improved the design to reduce the number of welding parts and water junctions.

Geometry

The SAFARI Beam Stop is composed of 10 copper parts with tapered holes.

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 (from Ø40mm to Ø112 mm).

Figure 2 presents a section of the SAFARI Beam Stop.

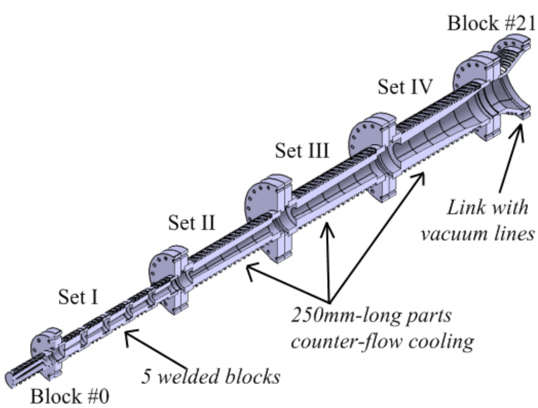

Figure 2: Beam Stop geometry.

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 counter-flow double loop for longer Sets (Fig. 3).

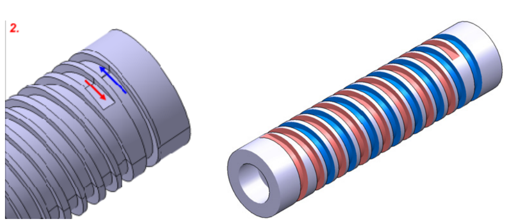

Figure 3: Counter-flow cooling system.

There are many advantages of this system:

- No contact resistance.
- No leak risk due to brazing.
- Additional security (2 pipes for 1 block).
- No possible leak toward external environment (only from one pipe to another).

BEAM STOP BEHAVIOUR

Cooling optimization

The fluid flow through a curved passage is peculiar because of the secondary flows generated as a result of the centrifugal force. It creates vortexes, called Dean Vortexes, which mix water and enhance heat transfer [3].

For the main parts of the Beam Stop, we use counter-flow cooling pipes. The major benefits of this system are:

- Increase cooling efficiency, and thus reduce water outlet temperature.
- Homogenize material temperature, and thus reduce mechanical stress.

Table 2 presents the different fluid temperatures and Figure 4 details the water flow on a counter-flow system (Set IV), calculated with FloEFD.

Table 2: Water outlet temperature

Device	Cooling system	Water outlet temperature
Block #0	Single loop	32 °C
Set I	Single loop	42 °C
Set II	Counter-flow	57 °C
Set III	Counter-flow	64 °C
Set IV	Counter-flow	74°C
Block #21	Single loop	52 °C

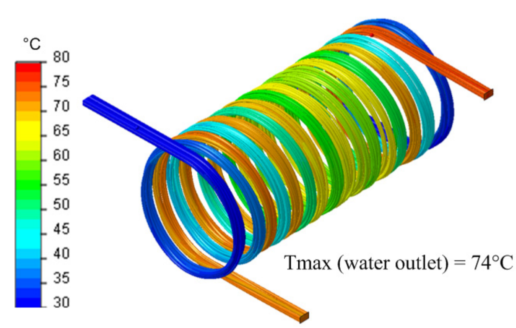

Figure 4: Fluid temperatures in Set IV.

Thermo-mechanical Behaviour

The optimized design of the SAFARI Beam Stop and its cooling system enable it to withstand 200 kW particle beams 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 of the SAFARI device is reached on the inner faces. This is also on theses faces that the mechanical stress is the highest (due to thermal expansion). Calculated temperature with Ansys software along Beam Stop abscissa is shown on Figure 5.

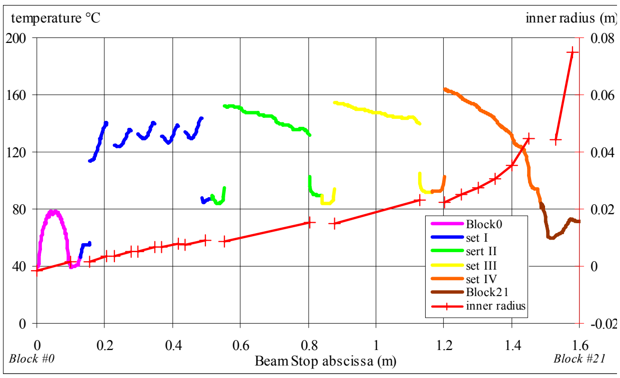

Figure 5: Temperature on the Beam Stop's inner face.

Restrictive Beams

SAFARI Beam Stop 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. Operating mode is then with pulsed beams:

- 10 %: 2ms of full power every 20 ms.
- 1%: 2ms of full power every 200 ms.

In these cases, Beam Stop performances are limited by mechanical behaviour (stress ~ σmax) due to differential thermal expansion but temperature remains largely within its nominal range.

SAFARI PROTOTYPE

In order to validate functional behaviour and manufacturing process, the manufacturing of a partial mock-up has been decided:

- Block #0 because of its original design and location on the beam axis (easier for beam tests).
- Set II because of its counter-flow cooling system.

Prototype has been realized through the European Collaboration SPIRAL2 PP with **CIEMAT Madrid**. It has been manufactured by *TRINOS Vacuum Projects* in Valencia (Figure 6).

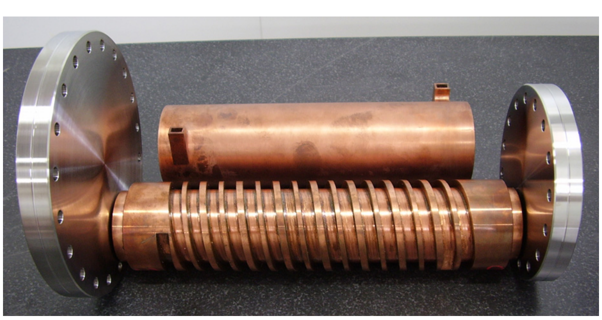

Figure 6: SAFARI parts before assembling.

Some parts of the SAFARI device require special and non conventional machining. Inner tapered holes, due to their length and their thinness are machined by *Wire Electrical Discharge Machining*, respecting dimensional tolerances and surface finish.

Concerning assembling, *Electron Beam Welding* is preferred to vacuum brazing. Advantages are various: no re-crystallization during welding (T<650°C), a thin weld fillet and a process cheaper and repairable.

CONCLUSION

The original design of the SAFARI Beam Stop and its cooling system fulfils all the technical requirements initially imposed, even with the largely over-estimated beam parameters.

The SAFARI prototype, currently under flow and thermal tests, should confirm the different analytical studies and numerical calculations that have been done.

Manufacturing of the final Beam Stop is scheduled for next year.

ACKNOWLEGMENTS

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[3] Tilak T. Chandratilleke & Nursubyakto, "Numerical prediction of secondary flow and convective heat transfer in externally heated curved rectangular ducts", *International Journal of Thermal Sciences 42* (2003) 187-198.