MECHANICAL ENGINEERING AND DESIGN OF THE LHC PHASE II COLLIMATORS

A. Bertarelli, A. Dallocchio, L. Gentini, N. Mariani, R. Perret, M.A. Timmins,
CERN, Geneva, Switzerland.

Abstract

Phase II collimators will complement the existing system to improve the expected high RF impedance and limited efficiency of Phase I jaws. An international collaborative effort has been launched to identify novel advanced materials responding to the very challenging requirements of the new collimators. Complex numerical calculations simulating extreme conditions and experimental tests are in progress. In parallel, an innovative modular design concept of the jaw assembly is being developed to allow fitting in alternative materials, minimizing the thermally induced deformations, withstanding accidents and accepting high radiation doses. Phase II jaw assembly is made up of a molybdenum back-stiffener ensuring high geometrical stability and a modular jaw split in threes sectors. Each sector is equipped with a high-efficiency independent cooling circuit. Beam position monitors (BPM) are embedded in the jaws to fasten setup time and improve beam monitoring. An adjustment system will permit to fine-tune the jaw flatness just before commissioning the system. A full scale collimator prototype is being manufactured by CERN workshops to validate each feature of the new design.

INTRODUCTION

Performances of the LHC collimation system in terms of beam cleaning and machine protection strongly influences the operation of the Large Hadron Collider with particular respect to reliability and luminosity [1]. While Phase I jaws were designed to ensure maximum robustness against abnormal beam losses in operating conditions [2] [3], Phase II collimators were conceived to improve collimation efficiency and RF performances.

As previously shown [4], the development of new collimators submitted to extremely challenging requirements imposes a thorough material investigation aiming at identifying novel materials combining very diverse properties. Development, qualification and characterization of advanced materials like metal-diamond composites and SiC are addressed in collaboration with academic and industrial partners in the framework of the EuCARD research programme.

The aim of this paper is to present the design status of Phase II collimators with emphasis on engineering, thermo-mechanical analyses and tests which have driven the mechanical design and the ongoing prototyping activities.

MECHANICAL DESIGN

Research on advanced materials allowed identifying promising candidates for the new jaws [4]. However the final choice needs to be confirmed by LHC operation experience. Phase II jaw assembly relies on an innovative modular design concept which can be easily adapted to fit in different jaw materials. Phase II jaw assembly is basically made up of three main components as shown in Figure 1:

- Collimation Jaw split in three sectors.
- Brazed cooling circuits independently serving each jaw sector.
- Back-stiffener ensuring high geometrical stability and including an adjustment system to fine-tune the jaw flatness.

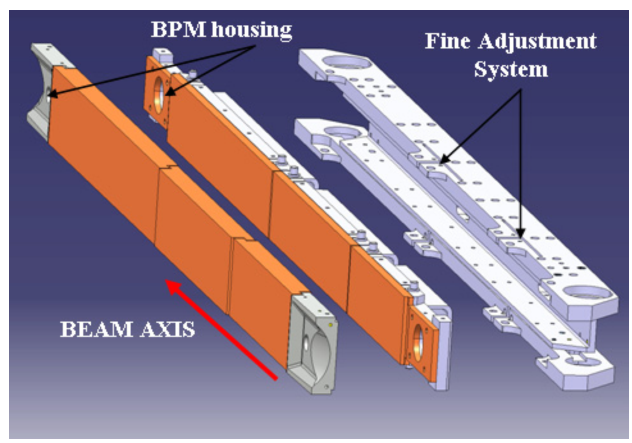

Figure 1: Phase II jaw assembly. Modular design including (from left to right) three-sector jaw, three-sector cooling circuit and back-stiffener with fine adjustment system.

Collimation Jaw

Two main options have been identified for the jaw material: metal and ceramic [4]. Metal jaw, as depicted in Figure 1, is made up of Dispersion Strengthened Copper (GliCop®); Metal-Diamond composites are a promising alternative. The ceramic solution foresees the use of SiC inserts on a conductive support as shown in Figure 2.

In all cases, the jaw is split in three sectors with independent taperings at the extremities; RF continuity is ensured via Cu-Be contact springs placed between each sector. Sectors lengths have been optimised for each material based on its interaction with the particle beam to minimise thermal deflection.

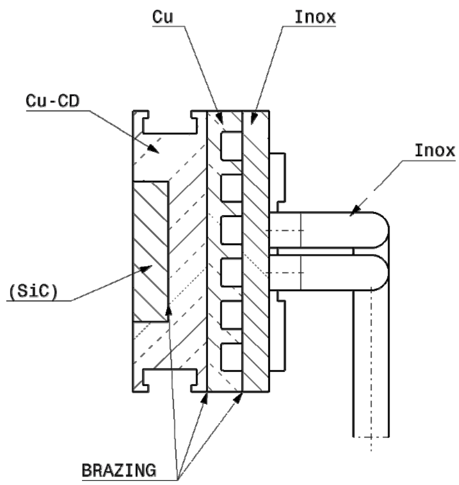

Figure 2: Phase II equipped jaw. The cooling system is brazed to the jaw. Two possible solutions: Cu-CD jaw and Cu-CD jaw with SiC inserts (both conductive and non-conductive options can be implemented).

Jaw tapering has been specially designed to integrate BPM sensors (Figure 1, Figure 3a and Figure 4) allowing rapid alignment of collimator jaws. Jaw tapering is made up of Aluminium in order to limit the energy deposition in this region and to avoid potential damage to the BPMs.

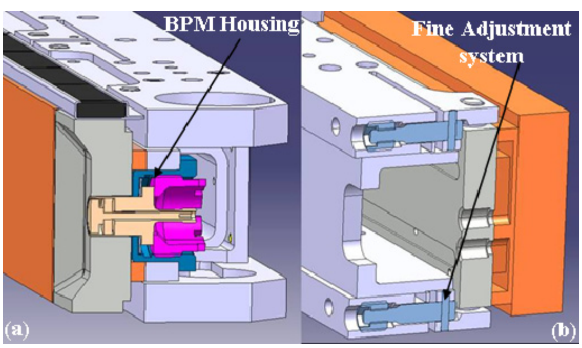

Figure 3: Cross-section of jaw tapering with housing and fine positioning system for BPM.

Cooling System

The use of high-Z materials for jaws, such as Copper, implies very high thermal loads. Improved cooling efficiency was obtained using independent coolers for each jaw sector. Each cooling circuit is directly machined from a solid bloc with a brazed cover. OFE-Cu and Stainless Steel (see Figure 4) are used to ensure high reliability of the brazed joint and to avoid any UHV tightness problem. A dedicated testing procedure has been established qualify each single cooler for series production.

A U-shaped stiffener is brazed to the stainless steel cover (Figure 4) to enhance the inertia of the cross-section thus limiting thermal deflection.

Particular attention is paid to the brazing procedure that must be optimized for each jaw material. Several brazing tests and FEM simulations were performed in order to overcome problems due to CTE mismatch: brazing between Cu and SiC is critical, while promising results have been obtained between Mo and SiC.

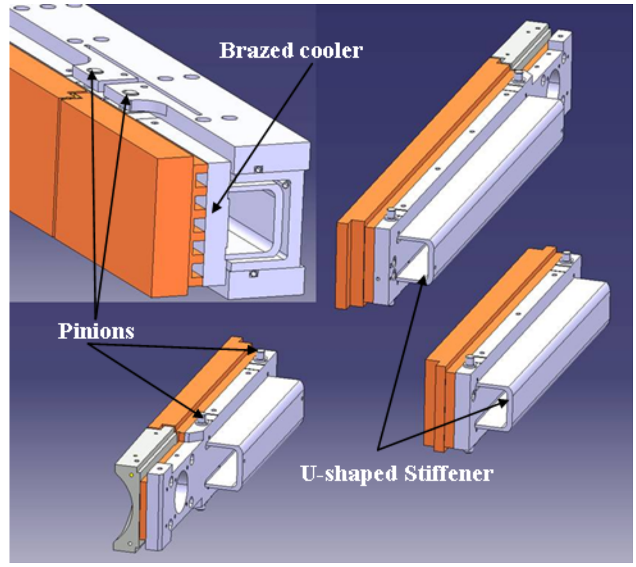

Figure 4: Equipped jaw sectors made up of jaw sector, cooling circuit with brazed cover and U-shaped stiffener..

Back-Stiffener

The main function of the back-stiffener (Figure 1), made up of Molybdenum, is to ensure geometrical stability for the active part of the jaw assembly. The back-stiffener is relatively far away from the particle beam axis (so limiting deposited thermal load); a dedicated beam pipe is devoted to its thermal stabilisation. We can hence assume that, it is only affected by very limited thermal deformation in normal working condition.

Each equipped jaw sector is simply supported, via two pivots placed at its extremities, on the back-stiffener, as shown in Figure 1 and Figure 4. An adjustment system made up of push-pull screws acting on the supporting pivots (Figure 3b) permits to fine-tune the jaw flatness just before commissioning the system.

THERMO-MECHANICAL ANALYSIS

An in-depth thermo-mechanical analysis was crucial to design development and validation. Particular care was devoted to the CFD analysis of the coolers to optimize their cooling efficiency. A detailed thermo-structural FEM model was implemented to evaluate the behaviour of the jaw assembly in nominal working conditions. FLUKA team provided detailed energy distributions maps used as input for these calculations [5]. In case of GlidCop® jaws, Phase II collimators are submitted to very high thermal loads, up to 25kW in steady-state conditions. Thermal deflection obtained via FEM analysis is around 30÷40µm (Figure 5). These promising results support the validity of the proposed design in terms of geometrical stability and cooling efficiency.

Optimization of brazing procedures for different materials is presently ongoing. Experimental tests have been numerically simulated by FEM in order to validate numerical models thus improving the design of brazed interfaces.

Finally, accident scenarios including direct beam impact on phase II jaws have been considered. Relying on FLUKA results, structural damages provoked by particle beam impact have been preliminarily assessed both for metal and ceramic jaws. Detailed evaluation of a beam impact with its structural damages requires complex studies including phase change of the material and shock waves propagation. An innovative numerical method based on hydrodynamic approach is under development in the framework of the EuCARD collaboration.

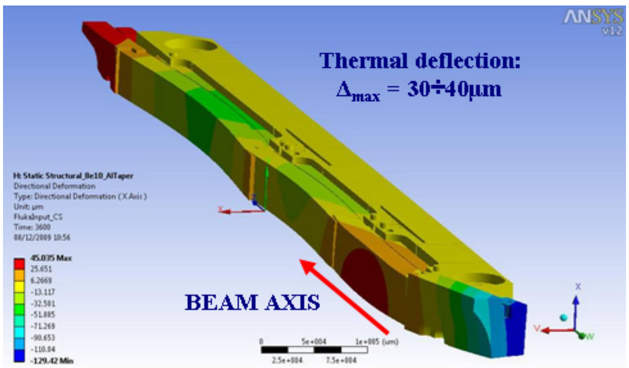

Figure 5: Thermo-mechanical analysis performed via FEM method. Jaw thermal deflection is about 30÷40μm.

PROTOTYPING

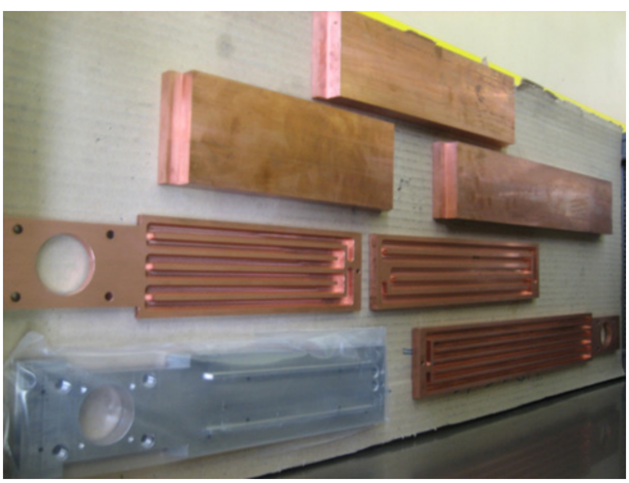

Figure 6: Main components of equipped jaw sectors. First Phase II prototype with GlidCop Jaws.

Design of the cooling system for Phase II collimators has been preliminarily validated by the production of two cooler demonstrators on which a dedicated testing procedure has been developed in order to qualify the design. A crucial point of the Phase II design is the integration of beam diagnostic sensors BPMs on the movable jaws. Particular attention has been paid to the development of a functional prototype equipped with several BPMs to validate the principle of fast alignment based on beam diagnostic sensors. BPM functional prototype has been successfully tested in the laboratory and then installed in the SPS tunnel at CERN; first indications are very positives while in-depth beam tests are foreseen for the coming months.

Finally, a full scale prototype of Phase II collimator with GliCop® jaws (see Figure 6) is being manufactured by CERN workshops to validate each feature of the new design. Production of further prototypes has been planned in order to test ceramic jaws and to experimentally assess collimator robustness in the HiRadMat facility [6].

CONCLUSIONS

To overcome intrinsic limitations of Phase I collimation system, new Phase II collimators are being developed. Given the extremely challenging and conflicting requirements, research of new advanced materials is complemented by an innovative design of the jaw assembly. A modular concept, allowing using different jaw materials with a common supporting structure, is described in detail. Main achievements obtained by thermo-mechanical analyses are presented as well as status of prototype manufacturing.

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