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THE LHC COLLIMATORS

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Abstract

In the framework of the LHC Collimator project, TS department has been assigned the task to design the series collimators and to manufacture prototypes to be tested in summer 2004. Their concept must comply with a very demanding specification, entailing a temperature on the collimating jaws not exceeding 50 ºC in steady conditions and an unparalleled overall geometrical stability of 25 µm on a 1200 mm span, meeting, at the same time, the challenging deadlines required by the project schedule.
To respond to these tough and sometimes conflicting constraints, the chosen design appeals to a mixture of traditional and innovative technologies, largely drawing from LEP collimator experience. The specification imposes a low-Z material for the collimator jaws, directing the design towards graphite or such novel materials as 2-D and 3-D Carbon/Carbon composites. An accurate mechanical design has allowed to considerably reduce the mechanical play and to optimize the geometrical stability. The mechanical lay-out and a summary of the in-depth thermo-mechanical calculations concerning cooling efficiency, temperature distribution, mechanical strength and deformations are presented.

1 INTRODUCTION

In the early operation period of the LHC (phase 1), the collimation system baseline will be formed by a 3-stage system including Primary (TCP), Secondary (TCS) and Tertiary (TCT) collimators; for each collimator type several geometrical configurations are foreseen (horizontal, vertical, skew). Additionally, other special collimators must be installed, including Injection Protectors, Beam Scrapers, etc. The design of these components has been assigned to TS department and must comply with the very demanding functional specification entailed by the highly energetic beam handled in the LHC rings. These requirements represent a major challenge for the mechanical design, since, among other, they impose [1]:

- High absorbed heat loads,
- Very accurate geometric precision and dimensional stability (25 μm on 1200 mm),
- Limited maximum temperature (temperatures in excess of 50º C are accepted only on limited portions of the jaw),
- High robustness in nominal and accident scenarios.

At the same time, the design phase must meet the tough deadlines required by the general time schedule (the first TCS prototypes are to be manufactured by May 2004). On top of this, LHC collimators will be amongst the most radioactive elements of the machine. This will most certainly enforce appropriate shielding, having an impact on the design of some components and on the arrangement of the limited space reserved for the collimators. In addressing these severe constraints, it was decided to give the highest priority to the Secondary Collimators (TCS) given that they are the most critical from the mechanical point of view [2].

2 THE DESIGN CONCEPT

The present design (**Figure 1**) is the result of the analysis of a wide spectrum of options and alternatives; the guiding principle has been the use and optimization of proven technologies, mainly based on LEP collimator experience [3]. However, due to the very demanding specification, it was also necessary to consider innovative technologies and novel materials, such as Carbon/Carbon composites. The main technical features of the LHC secondary collimator design are:

- An internal alignment system allowing both lateral displacement and angular adjustment (tilt).
- A jaw clamping system to ensure good thermal conductance and free thermal expansion.
- An efficient cooling system.

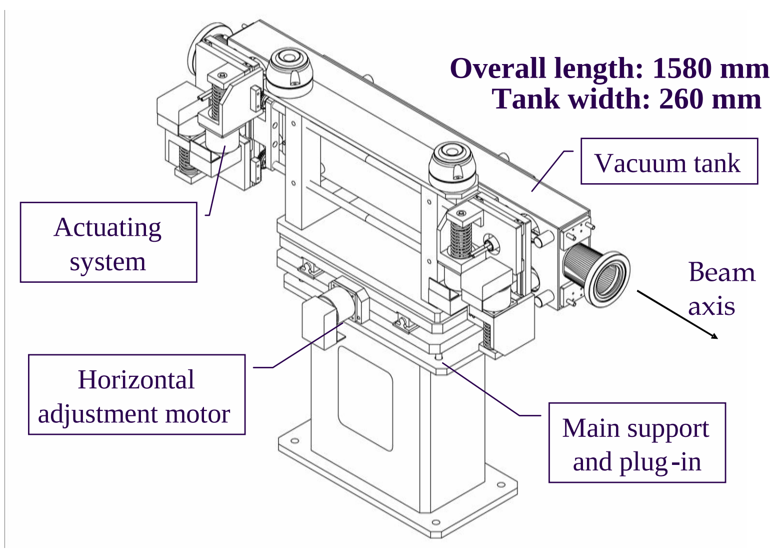


Figure 1: General lay-out and dimensions of the LHC secondary collimator (vertical configuration)

- A precise actuation system including a semi-automatic mechanical return and a misalignment prevention device.
- A plug-in external alignment system, allowing a quick and simple positioning of the collimator assembly in the machine.
- A motorization and a control set.

2.1 The jaw assembly design

As required by the functional specification, the collimating jaws must evacuate a high thermal power, maintaining low temperature and, at the same time, ensure mechanical robustness and keep deformations under an extremely low limit. On top of that, the collimator induced impedance must be kept to a minimum. To meet the impedance requirement and ensure a sufficient mechanical robustness, only low-Z materials like graphite or carbon-carbon composites (C/C) could be used for the jaws.

Bearing this in mind, the chosen design of the jaw assembly was based on the *clamping concept*: the graphite or C/C jaw is pressed against the copper-made heat exchanger by a Dispersion Strengthened Copper (Glidcop®) bar on which a series of steel springs is acting. The jaw assembly is held together by Glidcop® plates (**Figure 2**).

Since the thermal expansion coefficient of copper is about three times larger than that of graphite, a fixed joint between the jaw and the copper plate is not possible; the contact must allow for relative slipping between the two surfaces. At the same time, to ensure proper heat conduction at the contact interface, a certain pressure has to be applied between these surfaces. The pressure was estimated through a semi-analytical model and set to 5 bars. To validate the concept, an experimental campaign has been set up: preliminary results [4] show very good agreement with analytical and numerical calculations.

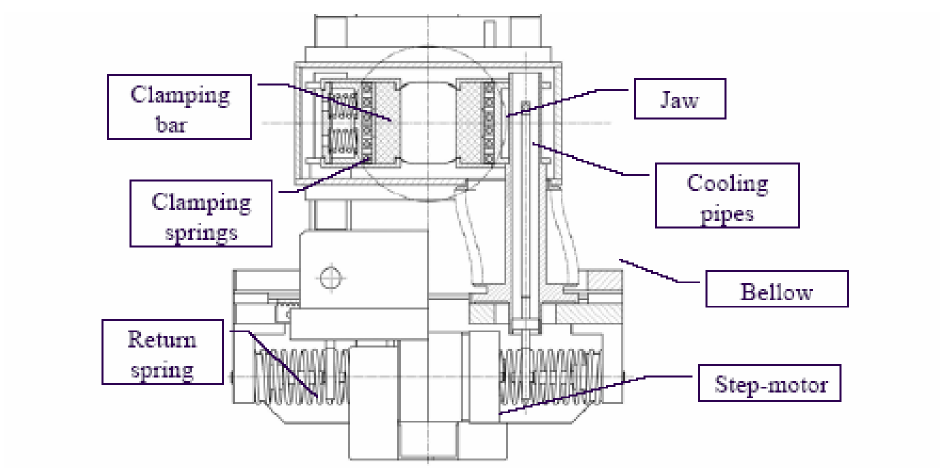


Figure 2: Secondary collimator mechanical assembly (cross-section of a horizontal TCS)

2.2 The jaw cooling system

Each jaw is cooled by the water of the general cooling circuit of sectors 3 and 7. The heat exchanger is constituted by two OFE-copper pipes per jaw brazed on one side to a copper plate and on the other to the Glidcop® bar. Each pipe has three turns to increase the heat exchange capability. To ease the brazing and avoid harmful air traps, the pipe section is squared. The inner diameter of the pipes is 6 mm. The water flow rate is 5 l/min per pipe, leading to a flow velocity of ~3 m/s: indeed, this value is rather high and might lead to erosion-corrosion problems on the soft copper pipe bends; however it is necessary to ensure the evacuation of the high heat loads while minimizing the temperature gradients. Inlet water temperature is 27 ºC. This system has also been conceived to limit thermal-induced deformations; the heat sink is sandwiched between the jaw and the bar, having opposed temperature gradients: this is exploited to mutually compensate the natural thermal deformations of the bar and the jaw and so to restrain the overall deflection. A simplified model to predict thermally induced deflections has been developed.

2.3 The motorization

Each jaw is independently actuated by two stepper-motors (**Figure 3**). This allows both lateral displacement and angular adjustment. Excessive tilt of the jaw is prevented by a rack and pinion system which avoids relative deviation larger than *2 mm* (i.e. *2 mrad*) between the two axles. Vacuum tightness is guaranteed by four bellows which can be bent sideways. The system is preloaded by a return spring to make it play-free. The return spring also ensures a semi-automatic back-driving of the jaw in case of motor failure. The position control is guaranteed by the motor encoder and by four linear position sensors. Stops and anti-collision devices for jaw motion are also foreseen.

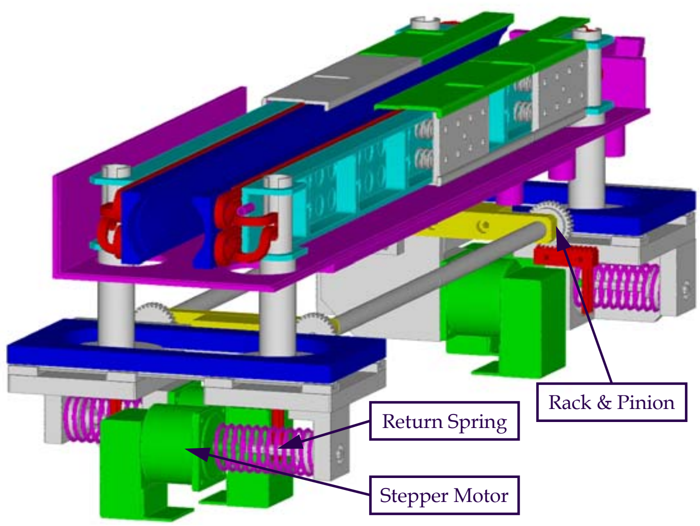


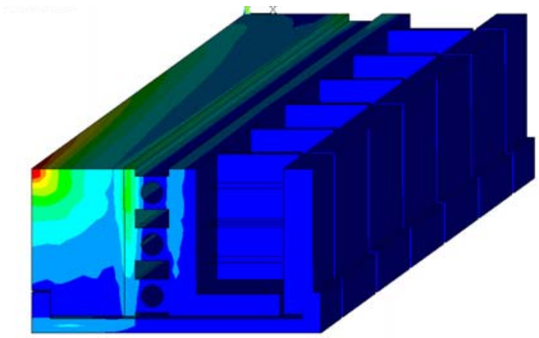
Figure 3: Secondary collimator components including motorisation and actuation system

3 THERMO-MECHANICAL CALCULATIONS

The thermal and mechanical calculations of the collimators were mainly carried out through Finite Element analyses, using the ANSYS® code. Several FE models were studied (2-D, partial 3-D and full-scale 3-D), with various materials for jaws, heat exchanger and support bar (C/C, graphite, steel, OFE-copper, Glidcop®), considering temperature-dependent material properties. Input thermal loads were directly drawn from physical simulations (FLUKA code) for several scenarios: nominal operating conditions, peak beam loss and the accident cases, as defined in the beam load specification [1].

The definition of boundary conditions took into account both the contact interface between the jaw and the heat exchanger as well as the heat convection on the wet surface of the pipes. The thermal conductance at the contact interface was introduced in the FE model as a function of the local contact pressure. The convection (film) coefficient was analytically calculated as a function of the friction coefficient (surface roughness 0.001 mm) and of water temperature, leading, with a water flow of 5 l/min at 27 ºC, to a film coefficient of 12360 W/m^{2}K on each pipe.

Only a brief summary of numerical results is given here (see ref. [5] for details): as a general rule, thermal calculations show that, in nominal conditions, maximum jaw temperature exceeds 50 ºC on a very limited area (**Figure 4**) and only for some materials, while temperatures up to 76 ºC are reached during the 10 s peak loss transient. Required geometrical stability is very difficult to attain under the given heat loads: anyhow results obtained from the FE full-scale model indicate that the



25 μm requirement might be met in nominal conditions for the "softer" materials (i.e. Graphite and 2-D C/C) but not by the "stiffer" 3-D C/C. Finally, stress analysis shows that quasi-static stresses do not pose a serious problem, while dynamic stresses excited by the accident-case thermal shock might reach quite high values though not exceeding the material allowable strength. More detailed analyses are necessary on this specific issue.

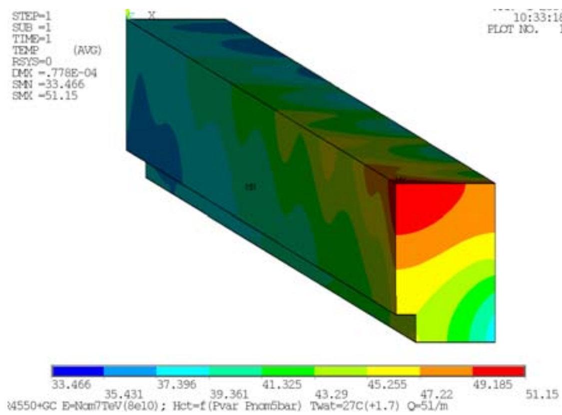


Figure 4: FE 3-D model showing thermal load and resulting temperature distribution over a graphite jaw

4 CONCLUSIONS

The LHC collimator functional specification poses a serious challenge to the mechanical design of these components. The main features and characteristics of the technical concept addressing these requirements were presented, along with an outline of the thermo-mechanical calculations which led to the present layout.

Though the design is mainly "traditional" and based on previous experiences, a thorough optimisation activity has been performed to maximise performances and dimensional stability. When known technologies and traditional materials were not suitable, new solutions have been explored (clamping technology for the joint between the jaw and the heat exchanger and Carbon/Carbon composites for the jaw).

As a whole, at the present stage of development, calculation results and first preliminary tests show that the Functional Specification might be met for the given heat loads provided the "right" materials are chosen. Of course, these preliminary conclusions will have to be confirmed in the near future by more accurate analyses of the definitive design and by the results of the ongoing tests.

5 ACKNOWLEDGEMENT

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6 REFERENCES

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