# THE CONCEPTUAL DESIGN AND THERMAL ANALYSIS OF ALBA CROTCH ABSORBERS

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*Abstract*

ALBA is a 3 GeV, 268.8 m storage ring with extended Double Bend Achromat (DBA) structure under construction near Barcelona, Spain. With the design current of 400 mA, a total power of 407 kW is radiated by the circulating beam from the bending magnets. The design of the vacuum system was done by using the concept of the “crotch absorbers” which is used in many modern synchrotron light sources. These absorbers are not only going to absorb the power of the unused radiation but also will allow fast vacuum conditioning. 156 absorbers are need all around the machine in order to guarantee that no radiation will hit the chamber walls, the absorbers are grouped into three types, several design criteria have been studied in order to create our own one which is based on the number of allowed cycles before failure with the concept of the strain values. Finite element analysis (FEA) has been performed to estimate the stress, strain, maximum overall temperature and the maximum cooling temperature for all the types. The results for the critical absorber (type 3) under conservative conditions: max. overall temperature is 312.8°C, max. strain is 0.099% and max. stress is 112.3 MPa. With this strain, the absorber can withstand up to $1.10^5$ cycles of operation.

## INTRODUCTION

The main parameters of ALBA storage ring which characterize the power on the absorbers are shown in Table 1 [1].

Table 1: ALBA storage ring main parameters which characterize the power on the absorbers.

| Parameter | Unit | Value |
|---|---|---|
| Beam Energy, E | GeV | 3 |
| Nominal/Design current, $I_{nom}$. | mA | 250/400 |
| Circumference, C | m | 268.8 |
| Dipole magnetic field, B | T | 1.42 |
| Dipole magnets radius of curvature, ρ | m | 7.047 |
| Total power from bending magnets at the design current, $P_T$ | kW | 407 |

The horizontal fan of radiation from each dipole is about 200 mrad, some mrads of this radiation will be used by the beam lines and all the remaining synchrotron radiation will be absorbed by the absorbers. The power which will reach the critical absorber has a surface power density of around 246 W/mm$^2$ and a linear power density of 64.4 W/mm (with normal incidence), the max. total power on the crotch absorbers was around 5.6 kW.

The design criteria, the design of the absorbers and finite elements analysis (FEA) results are described here.

## THE LAYOUT OF THE ABSORBERS

Several absorbers have been placed after each dipole to guarantee that no radiation will hit the vacuum chamber (see Figure 1).

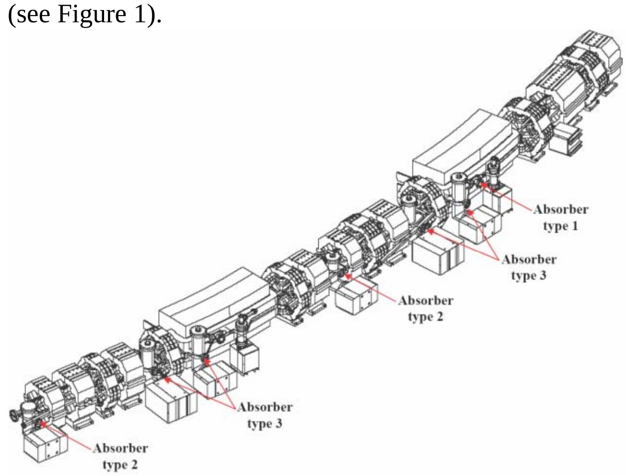


Figure 1 the distribution of the absorbers around the matching cell.

### *The Design Criteria of the Crotch Absorbers*

At the start of the design of the absorbers, a survey has been made to investigate the different design criteria being used at different accelerators. Following this, ALBA made its own design criteria which are derived from the number of cycles to fatigue based on the strain results from the FEA. To guarantee that the absorbers are safe for the life time of the machine, the material has been chosen for cycles over $1.10^5$ cycles of OFHC copper (strain less than 0.1 %) and over $1.10^5$ cycles for GlidCop® (strain less than 0.2 %).

Figure 2 shows the total strain as a function of the number of cycles to failure for OFHC copper [2]. For ALBA, the results from “curve c” have been used to determine the cycles for fatigue for the copper absorbers.

Figure 3 shows the total strain as a function of the number of cycles to failure for GlidCop® [3]. For ALBA, the results from “total strain range_400” have been used to determine the cycles for fatigue for the copper absorbers.

### *The Design of the Absorbers*

ALBA crotch absorbers follow the original design done at ANKA [4]; some modifications to the design have been implemented in order to improve the thermal and mechanical function of the absorber.



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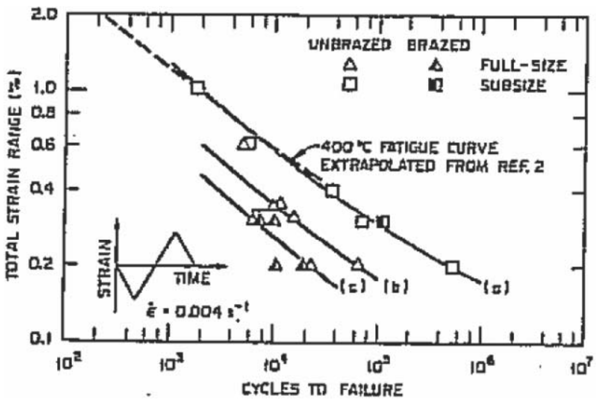


Figure 2 total strain as function of the number of cycles to failure for OFHC copper at 300 °C tested under vacuum [2].

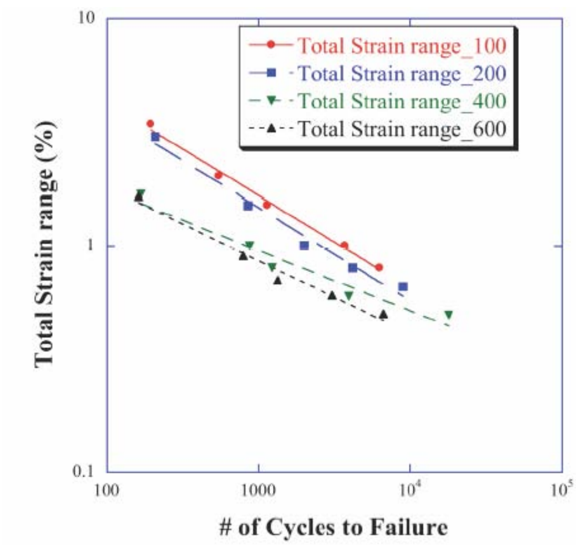


Figure 3 total strain as function of the number of cycles to failure for GlidCop® [3].

ALBA crotch absorber consists of two jaws; the total power is distributed in uniform manner on each jaw. Each jaw is cooled by a number of pinholes. The number of the pinholes depends on the type of absorber. The absorbers have been grouped into 3 types (see Figure 4): absorber type 1 and 2, receive moderate amount of power, the width of the teeth on these absorbers is 10 mm and the angle of inclination of each tooth (with respect to the plan of radiation) equals 8.8º, this reduces the power density at normal incidence by about 85 %, the absorbers of type 1 have two pin holes and type 2 have 4 pin holes. Absorber type 3 is the main (critical) absorber, this type of absorbers will take the radiation from the dipole which is installed inside it or just after it (close to the source point of the radiation) and the power there is the highest with respect to the other types. In order to reduce the total strain and to increase the number of cycles, the thickness of the teeth is 6 mm and the inclination angle of the teeth is 6.6º, 8 pin holes have been introduced to this absorber. The material type is based on the thermo–mechanical behaviour of the absorbers.

Some geometrical constrains have been implemented in order to guarantee a safe operation of the absorbers; the distance between the end of the pin holes and the edge of the absorbers is 7.5 mm, and between the edge of the teeth and the pin holes is 3.5 mm (as a minimum).

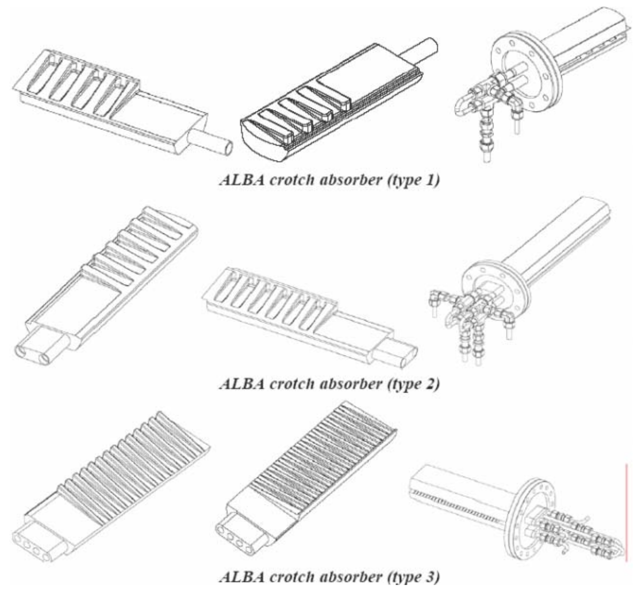


Figure 4 the two jaws and the assembly of ALBA crotch absorbers.

Few changes have been implemented in the design in order to reduce the stress and strain and to have more efficient cooling. In order to reduce the stress and strain concentration of sharp edges of the teeth, a radius (fillet) has been introduced. Also the end of the pin holes has been geometrically optimised in order to increase the efficiency of the heat transfer at that location.

## THE RESULTS OF THE FEA

The stress, strain and temperature distribution based on linear elastic analysis have been calculated using the FEA program ANSYS. Two fluid conditions have been considered in the analysis:

Assumption 1 (conservative approach): Average water temperature = average from the fluid analysis, convective heat transfer coefficient = $10^4$ W/m$^2$.C. Assumption 2 (realistic approach): average water temperature = 23 ºC, Convective heat transfer coefficient = 1.5.$10^4$ W/m$^2$.C. Table 2 shows the results of the FEA for the maximum overall temperature on the absorber ($T_{ov,max}$ (ºC)) the maximum cooling water temperature ($T_{c,max}$ (ºC)), the maximum stress (MPa) and the maximum total strain (%) on the different types of the crotch absorbers.

Some safety factors were considered: the power input on the absorbers was based on the design parameters of the machine, rectangular approximation for the power in the absorbers (i.e. considering the power as a rectangle which has the same surface area under the Gaussian power profile and having the maximum angular power density), the material properties as a function of temperature of the GlidCop® absorbers were considered.

Based on the FEA results, the material for each type of the crotch absorbers has been chosen: in order to have more than $1.10^5$ cycles for the crotch absorbers, absorbers type 1 and 2 will be manufactured using OFHC copper, and to guarantee the same number of cycles for type 3, GlidCop® will be used.

Table 2 summary of the results of the FEA for all the absorbers for assumption 1 and 2.

| | Assumption 1 | | | |
|---|---|---|---|---|
| **Abs.** # | **$T_{ov, max}$** (°C) | **$T_{c, max}$** (°C) | **Stress** (MPa) | **Strain** (%) |
| 1 | 91 | 62 | 21.8 | 0.019 |
| 2 | 128 | 66 | 46 | 0.044 |
| 3 | 313 | 91 | 112 | 0.10 |
| | Assumption 2 | | | |
| **Abs.** # | **$T_{ov, max}$** (°C) | **$T_{c, max}$** (°C) | **Stress** (MPa) | **Strain** (%) |
| 1 | 79 | 51 | 20 | 0.018 |
| 2 | 109 | 50 | 46 | 0.04 |
| 3 | 290 | 70 | 112 | 0.098 |

Figure 5 shows the FEA results for the strain for crotch absorber type 3.

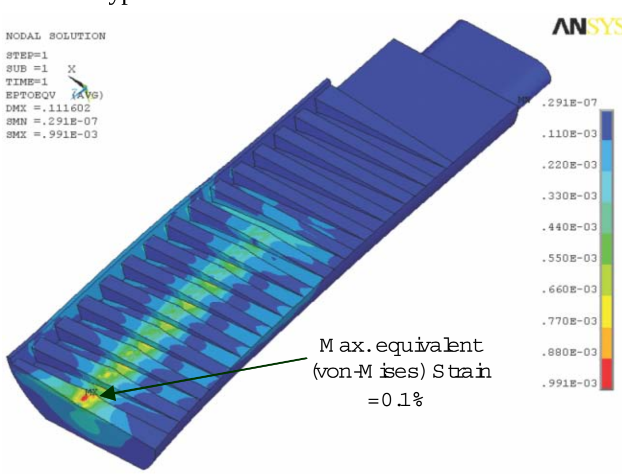


Figure 5 the equivalent von-Mises strain for the critical absorber (type 3, cooling assumption 1).

The real behaviour of copper is elasto-plastic, i.e. considering the stress-strain curve for the material (in case the material reached the yield value then the plastic behaviour of the material will be considered in obtaining the stress and the strain values). Elasto-plastic analysis have been performed for absorber type 2 (OFHC copper), to estimate the real stress and strain on the absorber and to guarantee that it is safe to use copper for this type. The max. stress and strain from these analysis was 36 MPa and 0.05 %, respectively, the results are within ALBA design criteria.

## CONCLUSION

For ALBA, the cycles for fatigue based on the strain values for copper OFHC and GlidCop® is the design criteria being followed, and to guarantee that the absorbers are safe for the life time of the machine, the material have been chosen for cycles over $1.10^5$ cycles of OFHC copper (strain = 0.1%) and over $1.10^5$ cycles for GlidCop® (strain = 0.2%).

The absorbers have been grouped in three types, depends in their location in the machine, the amount of power they will receive. The material has been chosen for these absorbers depend on the FEA.

FEA has been performed with two fluid conditions using linear elastic analysis, the FEA with elasto-plastic assumptions has been performed for type 2 absorbers.

Based on the results of the FEA and the design criteria, type 1 and 2 will be manufactured from OFHC copper and type 3 from GlidCop®.

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