DESIGN AND CONSTRUCTION OF LEP COLLIMATORS

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Abstract

Movable collimators will be installed in LEP to protect the experiments and the electrostatic separators from synchrotron radiation and off-momentum electrons and positrons. The collimators consist of copper blocks with tungsten inserts moving in 500 mm long parallelepipedic vacuum tanks. They will place at least 30 radiation lengths of matter across the obstructed aperture. Great importance has been given to minimize higher order mode losses and construction costs. The copper blocks have been designed with a shape for matching circular, elliptical and cruciform vacuum chambers. The collimator blocks are water cooled and will be moved with stepping motors under microprocessor control with a resolution of 5 μm and an absolute setting accuracy better than 100 μm.

1. Introduction

A large number of collimator blocks (114) will be installed in LEP. Most (108) are copper blocks with tungsten inserts whereas 6 are aluminium blocks. The latter will also be used for dumping the stored beams.

These blocks are part of 41 two-jaw collimators and 8 four-jaw collimators. The collimators are installed in sections with circular, elliptical and cruciform vacuum chambers. Forty collimators are positioned in straight sections around the four experimental points to control essentially the photon background in the experimental detectors, but also to protect the electrostatic separators, whereas the remaining nine are installed in a non-experimental crossing point (three) and in an arc (six) to control the LEP aperture. Only the first category will be considered here in detail.

The various functions and operating principles of these collimators are described in [1,2,3]. The blocks have to be controlled in position individually and must be able to cover half the aperture at least in order to give the best background conditions for the experiments.

Due to the large number of blocks, it is important to reduce the higher order mode losses while keeping a design compatible with an economical manufacturing process.

2. Conceptual design of the collimators

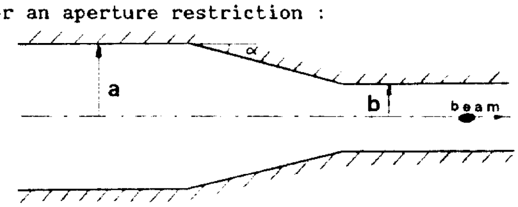
For housing the 2-jaw collimators 500 mm are available. After considering several solutions, the following design was arrived at.

The vacuum tank is a parallelepipedic vessel of the same width (height) as the vacuum chamber in the case of vertical (horizontal) collimators. Moving in this vessel, are two blocks. The clearance between block and tank has been kept to a minimum, less than 1 mm, in order to minimize the RF losses. There are no sliding contacts between the blocks and the vacuum vessel's walls.

Once the tank is fitted with two flanges, the available length for the blocks is 380 mm. To guarantee the 30 radiation lengths of absorbing material, the central part has to be made of tungsten with a length of 120 mm. On the basis of the predicted nominal positions [1] of the blocks, the block ends are machined to assure a smooth transition between the vacuum tube and the restricted central volume defined by the collimator block. For economical reasons, the transition will be milled with one single tool inclined at a given angle. It is therefore the intersection of an inclined cylinder witn the block.

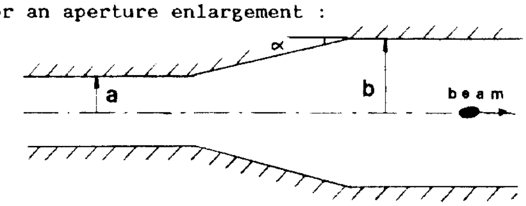
The milling diameter and angle have been chosen in order to minimize the RF loss factor k. This was done with a program running interactively on a personal computer using the following empirical formulae [4] for cylindrical systems. If the longitudinal standard deviation σ of the beam bunch is expressed in millimeters, then :

- for an aperture restriction :



$$k = \frac{5}{\sigma}\sin(\alpha)\,\log\frac{a}{b} \qquad [\mathrm{V/pC}]$$

- for an aperture enlargement :



$$k = \frac{5}{\sigma}\log\left[\frac{a}{b} + \left(1 - \frac{a}{b}\right)\frac{\alpha}{\sin\alpha}\right] \qquad [\mathrm{V/pC}]$$

For the considered geometries, the aperture cross-section has been divided into sectors in each of which the real geometry has been approximated by a cylindrical one. The loss factor of the resulting obstacle is the sum of the fractions of the individual loss factors. A partition into 32 sectors gives sufficient accuracy. The resulting shape for a horizontal block in an elliptical vacuum chamber sector is given below.

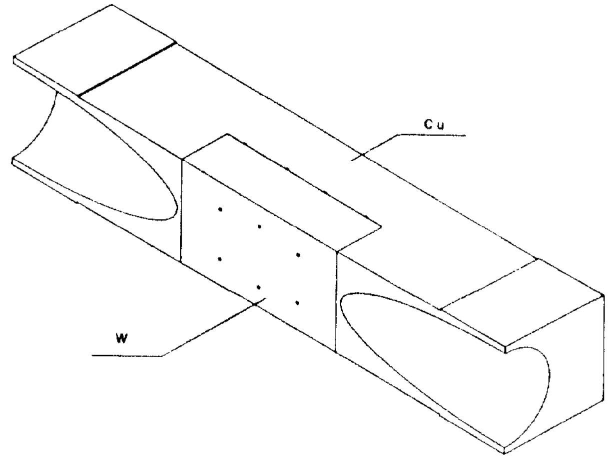


Fig. 1 Horizontal collimator block for an elliptical vacuum chamber sector

The predicted loss factors together with the ones measured on the set-up described in [5] are given next as a function of the collimator aperture, for blocks with and without transitions.

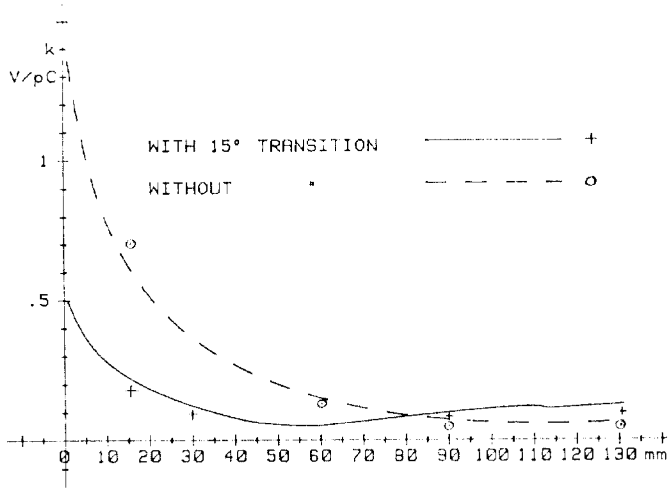


Fig. 2 Calculated variation of the RF loss factor k of a horizontal two-jaw collimator as a function of the collimator aperture, for blocks with and without matching transitions. Given also are the values measured on a full-scale model.

The agreement between the prediction and the measurement is good.

With the considered shape, it is possible to machine most of the collimator block from copper and to use only a central tungsten insert to cover the volume of the matching transitions.

The same procedure has been followed for all collimator blocks, resulting in four shapes : horizontal and vertical blocks for elliptical chambers (131 mm X 70 mm), blocks for circular chambers (158 mm diameter) and blocks for cruciform quadrupole chambers (158 mm envelope). In the latter case, only 600 mm were available for four blocks, horizontal and vertical pairs, the horizontal blocks embedding also an 80 mm long calorimeter for background and relative luminosity measurements. It was observed that the loss factor of the four blocks with abrupt transitions between the horizontal and vertical block pairs is the same as that for a single pair of blocks having the same transitions on both ends, in the domain of aperture restrictions of interest.

The variations of the loss factor k with respect to the ratio of the collimator aperture to the beam pipe aperture is given below for the various LEP collimators.

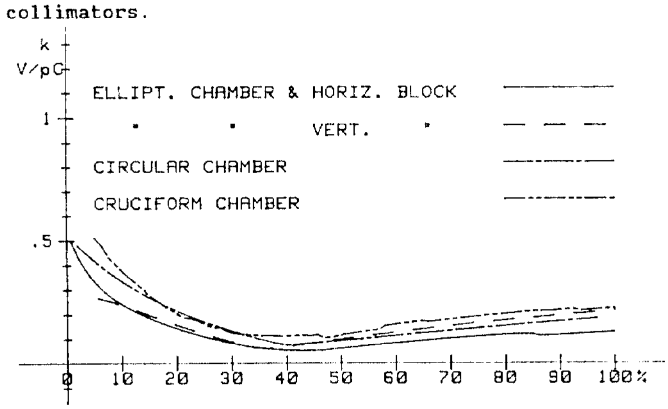


Fig. 3 Calculated variation of the RF loss factor k for the LEP two-jaw collimators as a function of the relative collimator aperture for the various optimized blocks.

For LEP with 5 mA beams, these loss factors will result in power losses of up to 400 W per collimator. This implies that water cooling has to be foreseen for the blocks and the vacuum tanks. The power deposited by synchrotron radiation is negligeable.

From previous experience [6], the reliability and precision obtained with stepping motors and resolvers was excellent. Therefore these components have been chosen to control and to measure the position of the blocks. The resolution of the position control will be 5 µm with a 1 mm pitch driving screw and a standard 200 steps per turn stepping motor.

3. Detailed mechanical design

The vacuum box is made from stainless steel. As mentionned previously, a maximum gap of 1 mm is requested between sliding blocks and vacuum box walls. This results in strict machining tolerances on the inner box faces (0.05 mm flatness), stiffening by ribs of the larger box sides to reduce deflections caused by the atmospheric pressure, and careful welding assembly. Electron beam welding is used, resulting in assembly precisions within 0.1 mm.

Vacuum considerations affect the design of the collimators as they must operate at an ultra high vacuum of 10^{-10} Torr. This implies strict acceptance conditions on materials (inclusion counts and grain size), fine machining (surface roughness better than N7), strict procedures for chemical cleaning and handling, and a final firing operation in a clean vacuum of 10^{-6} Torr. Exits for ion pumps are included for an efficient pumping of the rear volume of the blocks. A further constraint is given by the possibility of baking the installed instrument at up to 300°C to achieve the requested pressure.

Finally the maximum tolerated operating temperature is limited to 60°C. This implies the use of a cooling fluid, which was chosen to be the demineralized water available in the LEP ring. To avoid the problem of galvanic corrosion between different metals, only aluminium and stainless steel elements are acceptable for the cooling circuits. The chosen solution for the copper blocks is a cooling spiral machined in a stainless steel disk, the latter being brazed to the copper and having two covers avoiding direct vacuum-water joints.

The vacuum connection between the moving blocks and the vacuum box is assured by diaphragm stainless steel welded bellows of 0.13 mm thickness having a high stroke to length ratio for long lifetime.

The employed materials are oxygen free copper for the blocks for its suitability to brazing, sintered tungsten blocks with a 95 % tungsten content and acceptable vacuum characteristics, and AISI 304L stainless steel with specific vacuum characteristics. The collimators are fitted with positioning and levelling devices.The blocks are driven through screw-nut mechanisms with stepping motors and the positions are checked with resolvers and end switches.

Extensive use of modern engineering and drawing techniques has been made in the design of the collimators. Several finite elements codes have been employed for structural and thermal calculations in order to optimize the final design. All drawings have been made using Computer Aided Design. This technique found an excellent application in the study of the collimators, where the limited allocated space was often a constraining factor.

The double collimators present additional design constraints, the major one arising from the extremely limited space available.

The collimator box results from the combination of a horizontal and a vertical box. An ingenious transition piece maintains a 1 mm gap between sliding horizontal and vertical blocks and between blocks and box walls.

A further constraint is given by the fitting of a calorimeter in the horizontal blocks. In order to guarantee a uniform material thickness in front of the 40 x 40 mm^2 silicon detectors, the massive copper transition is replaced over that area by a 0.1 mm copper skin obtained by electro-deposition. The calorimeter itself slides inside a stainless steel piece which has 1 mm thin walls in front of the calorimeter and towards the beam. This piece carries also the cooling circuits for the collimator block in the form of grooves machined by electro-erosion, which limits the number of welds and hence the possible sources of leaks. It is brazed to the copper block.

The following figure shows an open view of a vertical collimator for an elliptical vacuum chamber sector.

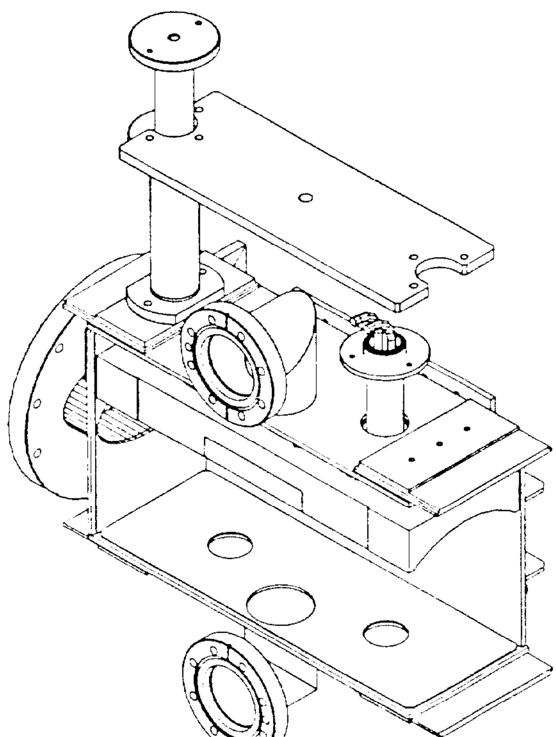


Fig. 4 Open view of a vertical collimator for an elliptical vacuum chamber sector.

4. Construction of a prototype collimator

A prototype of a vertical collimator for an elliptical vacuum chamber sector has been built at CERN. The finished collimator has been successfully tested for leak tightness and baked out to 300°C, establishing its limit vacuum to be better than 2×10^{-10} Torr.

The stepping motor control was tested yielding satisfactory results. The blocks were repeatedly cycled with movement under vacuum.

The effectiveness of the cooling circuit was tested by simulating the heating of the blocks and the box surfaces normally exposed to the beam. Measured temperatures were in good accordance with the predicted values. The maximum temperature in the box is kept at 55°C, with a total deposited power of 1800 W, by using water at 25°C with a flow of 10 l/min.

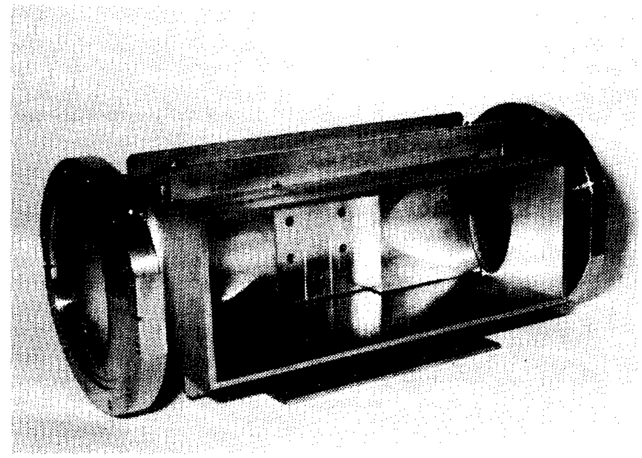


Fig. 5 Prototype vertical collimator prior to final assembly : the lower copper block without its tungsten insert is shown in its predicted position.

5. Status of the project

A series of 32 collimators and 3 spares consisting of 8 vertical and 8 horizontal collimators for elliptical vacuum chambers and 16 collimators for circular chambers is currently being built in industry . The 8 double collimators plus spare for cruciform chambers are under construction at CERN.

Six aperture collimators will be obtained by a slight modification to the described elliptical ones. The other three will need a new design of the blocks which will be made of aluminium and incorporate the cooling circuit. They will have the same type of transitions as described, but the cooling circuit will be such as to guarantee a material density of 2 radiation lengths over the whole block volume. All these blocks will have a cylindrical surface towards the beam, with radii of 10 and 15 m. The cylindrical surface of the aluminium blocks will be gold-plated (10 μm) [1,2].

6. Aknowledgements

Acknowledgements are due to A. Maurer for his numerous contributions to the design of these collimators, to G. Foffano who did the detailed design using CAD, to P. Morel who built the prototype and to the members of LEP and ST divisions who contributed to the project.

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