Design of a new generation of collimators for LEP 200

R. Jung, R. Perret, R. Valbuena
European Organization for Nuclear Research (CERN)
CH-1211 Geneva 23, Switzerland

Abstract

One hundred and twenty six movable collimator blocks have been installed for the first phase of LEP. They have proved indispensable for providing good conditions for data taking of the experiments and gave no problems for running LEP. Sixty four additional movable blocks are planned to be added for the second phase of LEP (LEP 200 project). The collimators will consist of copper blocks with tungsten inserts or of spherical tungsten blocks. Their design is adapted to maintain the original low RF loss factor of 0.06 V/pC at the nominal aperture with reduced variations over the entire useful stroke.

I. INTRODUCTION

For the first phase of LEP, one hundred and twelve movable collimator blocks have been installed around the four even intersection points housing the large LEP experimental detectors. Fourteen other collimator blocks were installed around crossing point 3 in order to define the LEP aperture. The blocks are grouped into one, two or four jaw collimators depending on their function and space available, and are designed to match cruciform, round or elliptical neighbouring vacuum chambers for minimum RF losses. Most of these collimators are installed in long straight sections where they experience only a small amount of synchrotron radiation (SR) power or in the arcs with the SR striking only the outer wall of their vacuum tank. These collimators were designed so that they could withstand the increased radiation when doubling the LEP beam energy (LEP 200 project), except two horizontal and the three vertical aperture limiting collimators which for economical reasons were made similar to the collimators used for protecting the experiments. All these collimators have been in operation since the 1989 LEP start-up. They have been very effective for providing good data taking conditions for the experiments, have given no problem to operate LEP and have proven very reliable.

Eight more collimators were quickly designed, manufactured and three installed in 1992 to protect a horizontal separator used in the pretzel scheme when SR originating in the arc dipoles was thought to be a major problem for the scheme. They have been used since then to make long term studies for preparing the operational use of the scheme. It was finally found that it was not necessary to install the five other collimators of this type at the present beam energy. The exercise proved very valuable as prototype work for the next generation of collimators.

The additional requests for the LEP 200 project are the following: sixteen two-jaw horizontal collimators for a small circular vacuum chamber (100 mm) to protect the super conducting cavities and the horizontal separators from the arc synchrotron radiation, sixteen one-jaw horizontal collimators for an elliptical chamber (131 mm x 70 mm) to protect the machine luminosity detectors from off-momentum particles, and the replacement of three vertical and two horizontal two-jaw collimators for an elliptical chamber for defining the LEP aperture. These collimators will be submitted to the full power of the SR generated in the arcs, i.e. 900W per meter of trajectory. There is a pending request for another eight horizontal two-jaw collimators with a large circular aperture (180 mm) to provide additional protection for the experiments.

II. DESIGN CONSTRAINTS FOR LOW RF LOSSES AND HIGH SYNCHROTRON RADIATION POWER DEPOSITION

As for the first generation of collimators [1], great care has been taken to minimise the RF losses in the collimators and to limit their variation over the useful stroke of the blocks. This is achieved by minimising the changes in the vacuum enclosure seen by the beam when entering and leaving the collimator. The most economical means to achieve this for the large number of items considered is to provide a rectangular shaped vacuum tank in which the blocks are moving with a maximum gap of 1 mm between tank walls and block and to have a tapered transition between the connecting vacuum chamber and the limited aperture defined by the blocks. As the blocks are movable, this taper is defined so as to minimise the disturbance over the full useful stroke. Calculations have been made with the method described in [1], the results of which were confirmed by bench measurements. The loss factor for the 100 mm circular aperture horizontal two jaw collimator is given in Figure 1.

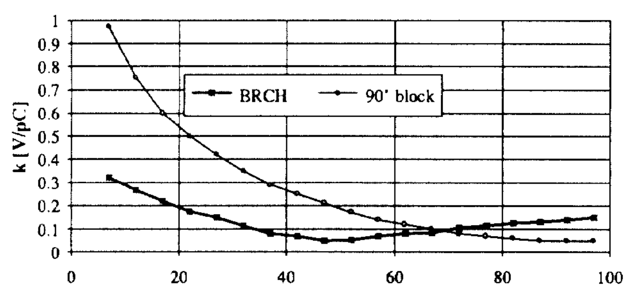

Fig. 1: Loss factor for a circular aperture two-jaw collimator, with (BRCH) and without (90^{0}) RF tapers

The second and new constraint for these collimators was the possibility to be submitted to an intense SR power deposition. The vacuum constraint imposes a maximum temperature in operation well below the bake-out temperature of 150^{0}C. For

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the vertical and inner one-jaw horizontal collimators it imposes a copper SR absorber inside the stainless steel tank to absorb the 900 W/m SR generated by a 6 mA beam at 100 GeV. For the horizontal collimators, the situation is more critical as the outer block intercepts the SR coming from a long length of beam trajectory. With the previous beam parameters, the power intercepted by the outer block can be as high as 10 kW at a half aperture of 15 mm for an elliptical vacuum chamber at the exit of the main dipoles. In order to keep a low loss factor and to distribute the SR power deposition over the largest surface, blocks with a double taper have been designed (type BRCH, see Fig.1 and 5). The power deposition coming from the RF losses is negligible compared to that from the SR. Nevertheless all surfaces exposed to the beam are cooled. Finally the collimators have to be submitted to a bake-out at 150°C and have to use stainless steel for all parts in contact with the LEP demineralized cooling water to avoid corrosion effects.

III. THERMAL AND MECHANICAL STRESS CALCULATION RESULTS

An intensive use of Finite Element Modelization (FEM) programs has been made in order to evaluate the steady temperature field in the collimator blocks when heated by SR. The amount of energy deposition depends on the position of the horizontal outer block w.r.t. the beam orbit and of the material traversed, i.e. copper and tungsten. The calculations were made for the separator and superconducting cavity protection collimators BRCH which are the most critical case.

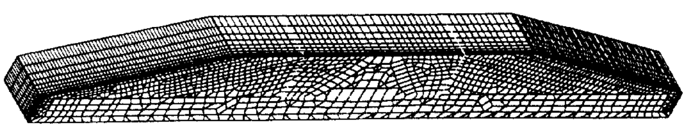

Fig. 2: FEM modelization of half of a collimator jaw of type BRCH

Only one half of the jaw was considered for the FEM because of the symmetry plane on which appropriate boundary conditions of zero flux were applied. In order to simulate as accurately as possible the non-uniformity of the power deposition, a mesh of seven thousand 8-node cubes or 6-node prisms was generated: Fig. 2.

The heat source was defined for each volume by taking into account the SR deposition calculated from the convolution of the energy deposition as a function of depth and material with the beam size. The total power deposited in the jaw is equal to 5 kW. This heat has to be removed by water cooling for which only the rear surface of the block is available. As the surfaces in contact with the cooling water have to be made of stainless steel, the whole rear surface had to be taken as exchange surface, so as to compensate for the bad heat conduction properties of the stainless steel. The cooling circuit is machined into two stainless steel plates brazed onto the copper block. As the available water pressure drop is of six bars, and taking into account the cooling duct shape, the average water cooling flow was predicted to be equal to 20 l/min in each circuit. The convective heat transfer coefficient can be computed using the Colburn formula and is found to be equal to $L=0.02\ W \times mm^{-2} \times {}^{o}C^{-1}$. The calculated isothermal lines are presented in Fig. 3. The highest temperature is found in the median plane of the block with a maximum temperature of 108°C. There is also a hot spot of 95°C in the tungsten block. The copper part had to be extended before the tungsten in order to decrease this temperature. The average block temperature is equal to 70° C.

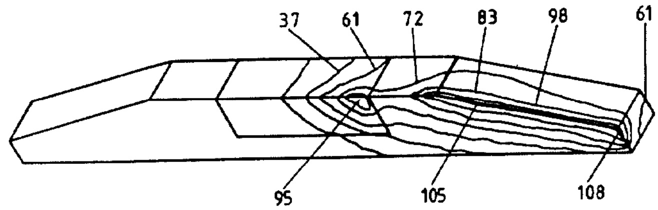

Fig. 3: Isothermal lines of the BRCH block

It is well known that parallelepipedic tanks are not adapted to vacuum vessel design. It was necessary to check that the wall deformations under vacuum will remain within acceptable limits. The FEM structure analysis code CASTEM was used to compute the tank stresses and deformations. Because of the three symmetry planes of the tank, only one eighth of the tank was modelled. The mesh was made of one thousand 20-node cubic elements.

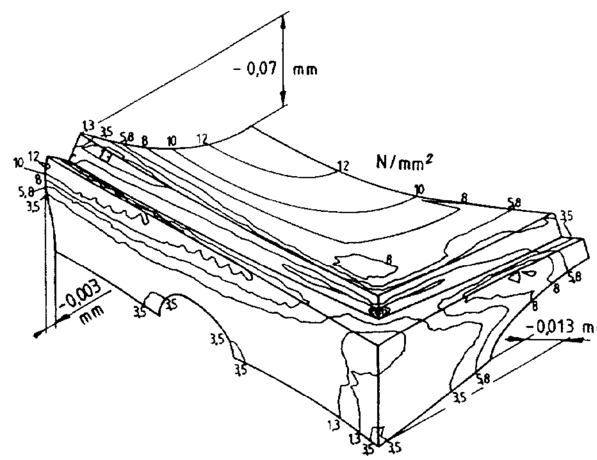

Fig. 4: Tank deformation (x1000) and isostress lines

The result of the deformation calculation is presented in Fig. 4, where the deformations are magnified a thousand times. The maximum deformation of 70 µm occurs as expected at the centre of the largest face of the tank. The maximum equivalent von Mises stress is equal to 18 N/mm^2, which is acceptable.

IV. MECHANICAL DESIGN AND PROJECT STATUS

There are three main subassemblies in a collimator:

-the mobile blocks for defining the aperture
-the vacuum vessel
-the auxiliary elements, e.g., the block guiding system, the water cooling circuits, the support.

The collimator blocks are of three types: tungsten blocks with a spherical surface polished to optical quality, copper blocks with tungsten inserts, either flat or spherical, and copper blocks only when the SR power deposition is too high and when copper alone is acceptable as an absorber. Tungsten lengths of 100 and 175 mm are used for best photon and electron absorption, and spherical surfaces have been asked for on some collimators in order to have always the block surface tangent to the particle trajectory whatever errors occur in beam orbit and collimator alignment. Copper blocks are used in the horizontal aperture limiting secondary collimators which are submitted to the full SR power of the arcs and where the particle absorption is less critical. The tungsten used is a sintered alloy containing 95% of tungsten and 5% of copper. OFHC copper is used for its better brazing properties. As mentioned earlier, the constraints on the BRCH blocks were the most stringent ones and request a more complex construction: Fig. 5.

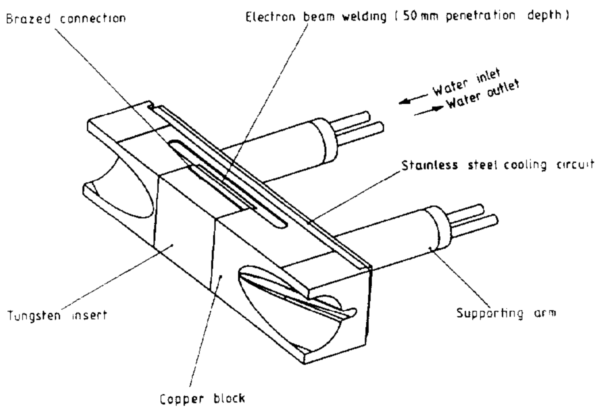

Fig. 5: BRCH collimator block with double input taper, tungsten insert and at the rear, the supporting tubes

The main absorber is a 100 mm long tungsten block. This block is brazed onto a 13 mm thick OFHC copper plate in order to provide the best thermal contact. On the other hand, there is a 450 mm long base OFHC copper block which provides the RF matching transitions to the 100 mm diameter circular vacuum chamber, has a stainless steel machined cooling circuit brazed to its rear surface and absorbs the less energetic SR before the final absorption in tungsten. The two blocks are joined together through a final operation consisting of a full depth electron beam welding in order to guarantee minimum deformation of the finished block.

The dimensions of the vacuum vessel depend on the surrounding vacuum chamber and on the block length. They do not exceed 460 x 300 x 120 mm^3. The tank is an e-beam welded stainless steel structure made of 6 mm thick plates. It is rigidified in order to minimise the deformations when under vacuum by brazing to the largest walls a 12 mm thick plate. The water cooling circuit is machined in it. All stainless steel parts in contact with vacuum have been fired up to 900°C to remove any hydrogen and well defined cleaning procedures have been used before final assembly to reach the operating pressure of 10^{-8} Pa.

The blocks are connected to the tank with welded disk bellows and fixed to a support fitted with precision bearings sliding on circular shafts for best precision. Each block is driven by a stepping motor with a 2.5 μm resolution and its position is checked independently with a resolver geared to the motor. The main support is made of aluminium and includes on its upper part alignment references for precise positioning in the tunnel. Spring compensators are fitted to most of the blocks to compensate the weight and the atmospheric pressure due to the bellows in order to reduce the load of the stepping motors.

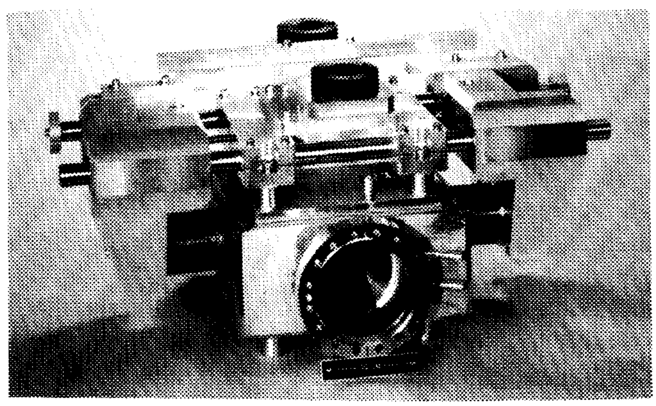

Fig. 6: Horizontal two-jaw collimator ready for installation

A series of seventeen one-jaw spherical tungsten collimators have been built in industry, and five vertical and three horizontal two-jaw collimators for aperture limitation have been built at CERN. Nine of these collimators have been installed during the 1992/93 winter stop. The order for the complex seventeen separator protection collimators BRCH has been placed with industry and the preseries collimator is expected for May 1993. The design for the additional horizontal experiments protection collimators is finished and ready to go out for production, depending on the final go-ahead.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1] F. Bertinelli, R. Jung: Design and construction of LEP collimators, Proc. 1987 Accelerator Conf., Washington DC