COLLIMATORS FOR THE RF SEPARATED BEAM

by

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1. Introduction

The first Radiofrequency Separated beam line (1) is one of the most complex ever built at CERN. Apart from the RF cavities and beam stopper of the Separator itself, it included seven bending magnets, sixteen quadrupoles and ten collimators. Six of these collimators have apertures adjustable in the vertical direction and four in the horizontal. This complexity and the consequent difficulties foreseen in the setting up and operation of the beam, led us to decide that a particular effort should be made to assure a simple and precise remote operation of all components. Such operation had already been achieved for the control of the currents in the beam magnets, but the state of the art in proportional remote control of component position was not so good.

This report describes the work of an interdivisional collaboration of CERN technical groups each specialised in their contribution to a collimator design incorporating several novel features: remote control and direct digital indication of jaw position to a precision of ± 0.1 mm; independent jaw movement allowing eccentric beam setting; monitoring of beam position by means of scintillator counters attached to the jaws; automatic closure (for use of the collimator as a beam blocker by the PS accelerator control group); and specially designed microswitches of negligible degassing rate for use as limit switches inside the collimator vacuum box.

2. Geometry and Material

In this section are described the considerations determining the geometrical specification, both orthogonal to the beam direction (lateral geometry) and along the beam direction (length).

2.1. Lateral geometry

A collimator is a device which ideally presents to the particle beam a perfectly opaque shield round a well-defined aperture of adjustable shape. Rectangular aperture collimators, operating on
the principle of a (simplified) camera iris have been designed in which it is possible to alter simultaneously and continuously both aperture dimensions — but for beam particle energies in the region of 10 GeV, such a design becomes impracticable. Fortunately, the design of the RF Separator beam gives momentum selection in the horizontal plane and mass selection in the vertical plane, allowing us to make horizontal and vertical collimation at different points along the beam. We can thus make separate collimators of simpler design: for collimating with a rectangular aperture variable in the horizontal dimension (we shall refer to this as a "horizontal" collimator, although it is actually a vertical slit) and for collimating with a variable vertical dimension (a "vertical" collimator).

The basic aperture definition is identical for both types (figure 1). The section is shown for a horizontal collimator, and represents a vertical collimator section when rotated through 90°. The lateral geometrical specifications in the design are:

1) The positions of the two blocks should be remotely and independently controllable and be capable of remote indication with a precision of ± 0.1 mm.

2) The range of movement of the blocks should permit the maximum beam section ø 180 mm to be cleared and also permit eccentric slit positioning up to a maximum of 50 mm off centre (at zero slit width).

3) The clearance between the moving blocks and the fixed blocks should not exceed 0.5 mm.

4) For alignment in the beam line, the collimator body should be fully orientable over a range of ± 15 mm, with a positioning sensitivity of 0.1 mm.

5) When the moving blocks are touching, the distance between their adjacent faces should not exceed 0.1 - 0.2 mm.

6) In view of the premium on space in the experimental halls, especially in the horizontal directions, the design should aim at as small an overall width as possible.
2.2. Length

Apart from the minimisation of overall plan surface just mentioned, the dimension of the collimator blocks in the beam direction is determined by the requirement that that part of the beam which does not pass freely through the collimator aperture must be eliminated from the beam. This elimination is made possible by the momentum loss of the unwanted part of the beam as it traverses the collimator block material, allowing this part to be physically removed from the beam by subsequent momentum analysing magnets - or, if it reaches the bubble chamber, to be distinguished by the deviation of its direction, curvature and ionisation from the means of those of the beam particles.

The amount of momentum loss to be specified is somewhat arbitrary, since the amount required depends on the location of the collimator along the length of the beam and on the momentum bite of the beam: collimators well upstream have more subsequent momentum analysis and in principle therefore require less momentum loss. We have decided to standardise the collimators to one length and that unwanted particles should lose at least 600 MeV/c momentum in traversing this length. This loss corresponds to $6^\circ/\circ$ of the design momentum 10 GeV/c of the RF separated beam. The momentum bite of the final analysing section of this beam is about $4^\circ/\circ$, so that all particles suffering a $6^\circ/\circ$ loss before reaching this section are eliminated by it.

The principal modes of momentum loss are by nuclear interactions, in which the interacting particles lose a large fraction of their momentum, and by ionisation or excitation loss in which the particles lose momentum gradually in a large number of atomic electron collisions. The determining factor in choosing the length is the ionisation or excitation loss since all singly charged particles at these energies undergo it to the same degree - with very little straggling. Momentum loss by nuclear interaction, on the other hand,
is a mechanism efficient only for the rejection of strongly interacting particles, and even then the leakage factor is considerable (see later). The ionisation or excitation loss of singly-charged particles of momentum 10 GeV/c is in the region of the minimum on the loss v. momentum curve i.e. about 1.5 Mev/gm cm$^{-2}$. To lose 600 Mev, then, $\omega 400$ gm cm$^{-2}$ length of material is required. The length in cm is obtained after consideration of the best material to use for the collimator blocks (next section).

2.3. Material

Ideally we require that the unwanted particles should not be deflected out of the block material while in the process of losing the required amount of momentum. In other words we require a material which combines a high stopping power with low scattering. In addition, the requirement to minimize the block length imposes a lower limit to the density. The three requirements: short nuclear interactions mean free path $\lambda$, long scattering length $X_0$ and maximum density $\rho$, can be combined to form a quality factor $\lambda/X_0\rho$, to guide the choice of material. This factor is given in Table 1 as a function of atomic number $Z$.

On this argument, the optimum material is seen to be in the region of iron or copper. Copper being slightly superior, we have decided to face all the collimator blocks with a 2 cm thickness of it. For reasons of superior machinability, mechanical strength and economy, the main body of the blocks we have made of iron, copperplated to minimise contamination of the vacuum. An exception to this is the pair of collimators adjacent to the $E_3$ ring, which we have made non-magnetic (brass) to avoid distortion of the ring magnetic field.

The block length has therefore been chosen as 50 cm, i.e. $\omega 400$ gm cm$^{-2}$ at the density of iron/brass. This corresponds to about 3 nuclear interaction lengths and therefore attenuates strongly-interacting particles by a factor of about 20.
Table 1. Choice of Block Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Z</th>
<th>A</th>
<th>$X_0$</th>
<th>$\lambda$</th>
<th>$\rho$</th>
<th>$\lambda/\rho X_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>13</td>
<td>27</td>
<td>24</td>
<td>113</td>
<td>2.7</td>
<td>1.75</td>
</tr>
<tr>
<td>Iron</td>
<td>26</td>
<td>55.8</td>
<td>13.8</td>
<td>136</td>
<td>2.9</td>
<td>1.25</td>
</tr>
<tr>
<td>Copper</td>
<td>29</td>
<td>63.6</td>
<td>12.8</td>
<td>140</td>
<td>9.0</td>
<td>1.22</td>
</tr>
<tr>
<td>Zinc</td>
<td>30</td>
<td>65.4</td>
<td>12.4</td>
<td>142</td>
<td>7.14</td>
<td>1.60</td>
</tr>
<tr>
<td>Lead</td>
<td>83</td>
<td>207.2</td>
<td>5.8</td>
<td>190</td>
<td>11.4</td>
<td>2.88</td>
</tr>
<tr>
<td>Platinum</td>
<td>78</td>
<td>195</td>
<td>6.0</td>
<td>168</td>
<td>21.5</td>
<td>1.51</td>
</tr>
<tr>
<td>Gold</td>
<td>79</td>
<td>197</td>
<td>5.9</td>
<td>188</td>
<td>19.3</td>
<td>1.68</td>
</tr>
</tbody>
</table>

(where $Z =$ atomic number
$A =$ mass number
$X_0 =$ radiation length $gm$ cm$^{-2}$ (values from reference 2)
$\lambda =$ nuclear interaction mean free path $gm$ cm$^{-2}$ (values from ref. 3)
$\rho =$ density $gm$ cm$^{-3}$

2. Drive

The moving blocks of both vertical and horizontal collimators are driven by independent 220 V motor-chain-screw systems as shown in the assembly drawings AR-216-159-2 and AR-216-160-2. Each motor drives simultaneously, and also by chain, a pulse generator (Sodeco Tk 710) which with separate forward and reverse outputs gives one register driving pulse per 0.1 mm displacement of the moving block for position indication. Limit microswitches, specially designed for operating in vacuum, prevent the moving blocks from being driven against each other or against the end stops. A block diagram of the drive circuits is shown in drawing AR-216-161-3 attached.

PS/5268
3.1. Vertical collimator drive

Minimum lateral dimensions are achieved by a direct drive in which the weight of the block is carried on a thrust ball-bearing ring incorporated at the outer end of the drive shaft. The drive shaft, of 30 mm diameter stainless steel with one thread per mm, bears on a 40 mm threaded length in a chrome-plated brass shaft fixed to the moving block. The plated shaft traverses the vacuum wall via two 60-seals O-Ring seals. The 130 watt single-phase motors have automatic braking and drive the screw shaft through a 35:1 reduction gearbox at 40 turns per minute (Zurrer HFV St 60).

3.2. Horizontal collimator drive

A more complicated indirect drive is necessary for the horizontal collimator, to avoid lateral encumbrance. Here the drive shaft, of 20 mm diameter stainless steel, also one thread per mm, is situated under the moving block and carries a brass nut to which is attached a cylindrical peg on a spring loaded pivot. This peg slides in a vertical hole in the underside of moving block and allows the block to be driven with zero backlash in the drive direction but with full freedom orthogonal to it - thus avoiding the necessity for precise parallel alignment of the drive shaft and support rails. The support rails serve also as lateral guide rails on which run four horizontal guide wheels fixed to the underside of the moving block. The motor, gearbox and braking system is similar to that of the vertical collimator, except that in this case the motor (Zurrer LFV St 50/45 watt) is much smaller.

4. Remote Control

4.1. Remote control panel

The remote control unit shown in figure 2 (and circuit dwg. no. AR-216-154-2) enables the positions of the blocks to be conveniently adjusted at the remote control station. Multiple panels incorporating four such units have been constructed. The essential elements are:
the key-type control switches to actuate the drive motors -
the down position is spring-return for "inching" the blocks
and the up position is manual-return for longer transversals;
a "motor-on" lamp to indicate when voltage is applied to the
motor; Sodeco bi-directional register counters to give a
direct digital indication of the displacement of the moving
block, in mm with a precision of ± 0.1 mm;
separate lamps to indicate when the blocks are touching each
other and when they touch one of the end-stops;
buttons to set the register counter zero.

4.2. Zero position checking (ZEFOC)

In the design of such remote and proportionately actuated
components, it is necessary that the displacement measuring system be
supplemented by a reliable and precise indication of zero or reference
position from which to measure the displacement. The indirect screw and
counter system of drive and position indication adopted for the collim-
ators has much to recommend it from the point of view of economy of
space and cost, but inadvertent disconnection of the drive cables or
temporary failure of the position indication system can lead to complete
disorientation of the position indication. To overcome this problem
we have used a simple alignment device (4) inside the vacuum box, which
relies on capacitive coupling between two 1 mm thick laminar electrodes
(see assembly drawings, attached). The device gives a simple and quick
method by which the operator in the remote control station can check
the accuracy of the position indication. The reference quoted gives
further details of the circuits and electrodes and the method of use.
5. Scintillator Counters

Although not essential to the operation of the collimators, it was decided that it would be useful to have a scintillator counter system attached to the moving blocks in such a way as to count the beam particles at the outer edges of the beam. These counters serve as an aid to the setting-up of the beam and as a monitor thereafter of the beam position with respect to the collimator.

Several difficulties arise in the design of such a counter system, to be mounted inside the vacuum box:

a) dissipation of heat from the photomultiplier HT resistor chain,

b) passage of a large number of electrical leads through the vacuum wall,

c) protection from wear of electrical connections and cables between the moving blocks and the wall of the vacuum box,

d) light sealing of the scintillator material (normal foil and tape procedure being inappropriate in vacuum, due to degassing).

The electrical difficulties have been overcome by mounting the photomultipliers (56 AVP) in a vacuum tight cylinder at atmospheric pressure. The resistor chain and other local components are contained in one end of the cylinder so that only seven leads have to be taken out. They are taken out through a vacuum-tight tombac of 17 mm I.D., which serves also to protect cables and end connections from chafing.

Several methods were tried, unsuccessfully, to produce a light-tight surface on the scintillator which did not degas excessively: various paints, electro-deposition of silver, sputtering of aluminium. It was finally decided that it was easier to cover the end windows of the vacuum box, or the ends of the beam pipe, with a light-tight combination of mylar and aluminium foil.
6. **Alignment in the Beam Line**

The area near the flange seating for connection of the collimator to adjacent beam elements, is marked with vertical and horizontal reference lines for alignment in the beam line of the collimator vacuum box. One set of these lines is carefully pre-aligned during assembly of the collimator, with the edges of the moving blocks when those blocks are touching in the centre position. In this position, the Zepoc electrodes are also pre-aligned to establish the reference position.

Six adjustable feet are provided which enable the position of the collimator to be adjusted in three mutually perpendicular directions. The three feet for horizontal position adjustment are attached directly to the underside of the vacuum box and enable the box to be displaced easily within a square of side 30 mm with a sensitivity of 0.1 mm. The three feet for vertical position adjustment are located between the support frame and the 40 cm thick concrete block base, and enable the vacuum box to be raised or lowered over a 30 mm range, with the same sensitivity.

The machined flange seatings at the beam entry and beam exit sides of the collimator, take CERN standard 185 mm diameter beam pipe fittings. Normally an intermediate teflonac (flexible bellows) is connected first in order to avoid de-alignment of the collimator due to excessive rigidity in the beam line connections.

7. **Performance**

The specification that the positions of the moving blocks should be remotely controllable and measurable with a precision of at least ± 0.1 mm was fully realised in practice.

We had some initial stability trouble with the zero indication circuits due to semi-conductor component failure in the high-radiation part of the beam. But this was overcome by separating the passive bridge circuit, which because of stray capacity has to be adjacent to the electrodes, and the active semiconductor components.
Those oscillator-amplifier-rectifier circuits are contained in a box located a few metres from the beam. The modified Zepec enabled zero-setting to be carried out over a period of months without the necessity of rebalancing the bridge circuits.

The ease of "inching" the blocks precisely using the direct digital position indication was found to reduce significantly the effort and time necessary for beam setting-up procedures, over that required using analogue indication. In particular, the possibility of making a parallel traversal, i.e. displacing both blocks simultaneously in the same direction, with a gap as small as 0.5 mm, made feasible the bin-scanning procedure used in the first operation tests of the RF Separator (5).

8. Acknowledgements

As mentioned in the text, the author was fortunate in having the expert aid of several technical groups in CERN. In particular, the work of Mr. F. Blythe (MSC) on the mechanical design, of Mr. G. Amato (TC) on the Zepec circuits and of Mr. F. Vriens (MPS) on the control circuits is greatly appreciated.

The author is also indebted to Mr. B.W. Montague and Dr. W.W. Neale for discussions on the basic specifications.

2. References


(2) Experimental Nuclear Physics, E. Segrè, Vol. 1 p. 266.


Collimator aperture 'A' variable from 0.1 to $180 \pm 0.1$ mm with each block independently movable over a range of 150 mm from the fully open position.

Collimator centre 'P' fully orientable over a range of 30 mm in the vertical and horizontal directions.

Fig. 1 Collimators: Basic geometry
Fig. 2 Collimators: Remote control box
view in the beam direction
(moving blocks in the fully open position)

lifting lug

light guide
scintillator
scintillator counter junction box

photomultiplier box
moving block
wheels

vacuum box

drive shaft / 1 thread per mm

feet for horizontal position adjustment

intermediate support frame

feet for vertical position adjustment

concrete block

beam direction

moving block (iron)
copper facing plate

scintillator counter junction box

flange seating for standard beam pipe

zepoc bridge box
photomultiplier box

NOTE: The original mechanical design and drawings were made in the MSc degree (Mr. F. Blythe). For detaile of details, see sub-assembly dwgs. MSc 30705 and MSc 311056.
NOTE:
The original mechanical design and drawings were made in the MSK-50 (Mr. F. Blaise). For dwg. nos. of details, see sub-assembly dwgs. nos MSC 30710A and MSC 30719.
NOTE: The circuits for the collimator control and zepoc boxes were designed by the MPS controls group (Mr. F. Vriens) and the TC Electronics workshop (Mr. G. Amato).