Design and Implementation of Synchrotron Radiation Masks for LEP2

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Abstract

Estimates of photon flux for LEP2 have predicted unacceptable background levels within the detectors of the four LEP experiments. As part of the solution to this problem, synchrotron radiation masks have been installed within the experimental vacuum chambers close to the interaction points. The photon flux calculations and specification for the masks have been laid-out by von Holtey et.al. [1]. This paper describes the design of the masks and outlines the principal technical issues overcome for their installation and alignment.

1 INTRODUCTION

Synchrotron Radiation (SR) background in the experiments was identified as a potential problem for LEP2 operation in 1993 [2]. Estimates obtained by extrapolation of photon and electron background from LEP1 to LEP2 predicted levels up to 50 times higher than tolerable by the experiments [2]. The adopted solution [3] was to install small absorbing rings, called masks within the experimental vacuum chambers to intercept SR photons impinging with very small angles relative to the beam axis. These masks would also give rise to strong photon scattering and therefore need secondary shielding outside the vacuum chamber.

The experimental vacuum chambers and supports were designed on the principal of minimum mass [4]. The central part of the chambers are made from 1.1 or 1.4mm walled beryllium tube, 106mm in inner diameter. This is brazed to thin walled aluminium alloy tubes which are welded together on each side. This central beampipe is mechanically decoupled from the machine vacuum system by a pair of thin stainless steel bellows. The experimental vacuum pumps and isolation valves are cantilevered from the insertion quadrupole magnets.

This minimum mass design was inherently incompatible with the addition of heavy radiation absorbers. This paper describes the designs which evolved to permit the integration of masks and shielding in the LEP experiments.

2 SPECIFICATION

The ideal SR mask and shield [5] (see figure 1) is specified to leave an unobstructed forward acceptance of δ=30 mrad and to allow for a distance from the inner mask tip to the interaction point (IP) of L_{mask} [3]. The inner mask, R_{mask} provides the required shadow against small angle back scattered photons and leaves a safe margin for the required machine aperture.

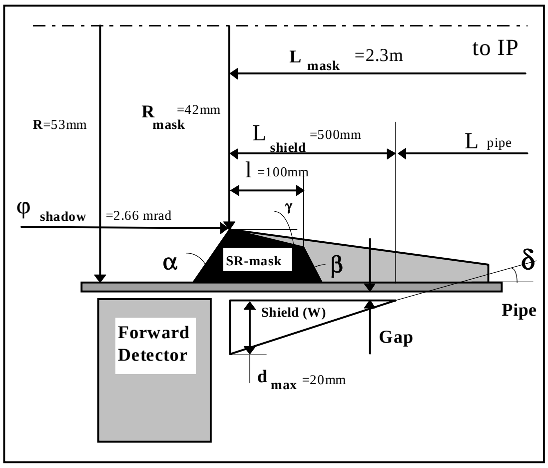

Figure 1: Specified Mask and Shield Dimensions

Mask and shield are made from tungsten. The length of the central part of the mask is l=100 mm, with a slope angle of γ towards the IP to ensure that no direct photon can reach the inner mask surface and scatter into the experiment. The wedge angles α and β serve to minimise wall impedance effects.

The outer shield is tapered to fit the acceptance angle δ. The maximum length of the outer shield L_{shield} is defined by δ and the central vacuum chamber outer diameter of 109 or 110 mm. The mask shadows the central vacuum chamber, $2xL_{pipe}$ against photons up to a maximum incidence angle of ϕ_{shadow}=2.66 mrad.

A further specification for the operation of these SR masks was a requirement for alignment of the mask aperture to ±0.3 mm relative to the beam axis.

It proved impossible to install this ideal mask in the experiments for a number or reasons. LEP is a mature machine, operating since 1989. In many cases there was a lack of access for the modification of the vacuum chamber supports. In addition, forward detector acceptance angles severely limited the material which could be added to stiffen or support the beampipe.

All four LEP experiments are equipped with beryllium vacuum chamber sections to maximise transparency. The high cost and long order times for these elements required them to be re-used for the new designs. These elements, and in particular the brazed joint between beryllium and aluminium sections are the most fragile part of the vacuum chamber. It has not been possible to quantify the strength of these joints, due to the wide dispersion in joint quality and the high cost of testing beryllium. The solution in this case was to try to redesign the beampipe and support environment such that the bending stresses applied to the structure were no higher than those imposed by the original design.

This was a non-trivial task, considering that original designs were 5 to 6 m long beampipes with a mass of 9 kg whereas the mask specification adds 8 kg of tungsten at each end.

3 DESIGN SOLUTIONS

Two different design solutions were adopted, due to the different layouts of the experiments.

The first solution is a cantilevered design, adopted in the DELPHI and L3 experiments (see figure 2). The mask is supported inside a rigid steel pipe, cantilevered from the insertion magnet. The central beampipe is shortened to start between the mask and the IP. This simplifies the alignment of the mask relative to the machine and thus the beam axis. It is a stiff and stable structure which can be pre-assembled to ensure tight tolerances and reliability.

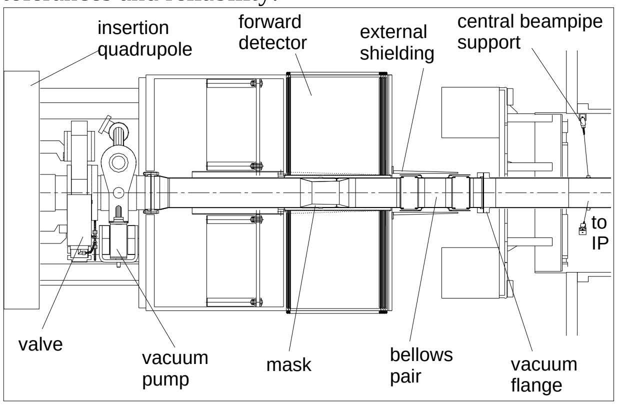

Figure 2: Detail of the DELPHI Experiment

The L3 experiment posed particular problems due to positions of detectors and flanges. These were solved by creating a double walled chamber section. The outer wall provided the vacuum barrier with associated bellows whilst an inner tube supported the mask. This permitted the mask to be at the same axial position as the bellows whilst supported by the machine.

It was not possible to adopt this design in the ALEPH and OPAL experiments due to the relative positions of mask and forward detectors. In these cases a second solution called the “Top Hat” design was adopted (see figure 3).

The mask is installed and supported from the thin walled aluminium central beampipe. This design ensures control of the alignment of the two masks relative to the central beampipe and causes minimum mechanical interference with forward detectors and external shielding. However, the mass of the mask is supported from the central chamber. This demanded stiffening of the chamber supports and careful re-design of the whole structure to prevent additional bending of the beryllium tube section. It also required reduction of mask dimensions below specification to reduce the mass. Even so, this additional mass tends to make the structure more flexible. In particular, the ALEPH chamber was supported only by wires and became more prone to instability and difficult to align.

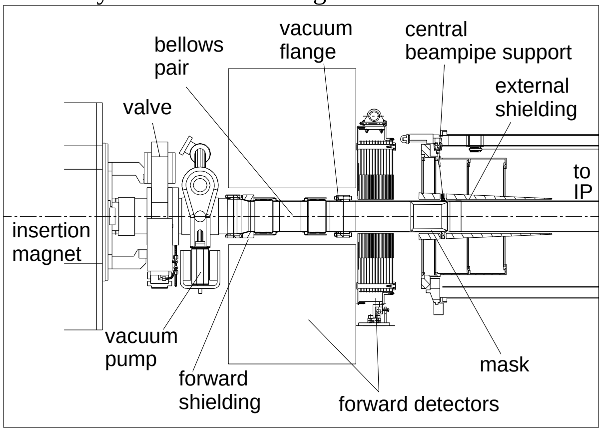

Figure 3: Detail of the ALEPH Experiment

It was considered unsafe to transport and install the central chambers with the masks in place. It was therefore necessary to make the masks removable.

4 MASK DESIGN

Figure 4 shows the mask installed in the ALEPH experiment. The form of the mask is relatively complex and it was not practical to manufacture in pure tungsten, which is difficult to machine. A sintered tungsten alloy (INERMET C from CIME BOCUZE) containing 93% tungsten alloyed with nickel and copper was chosen for all tungsten elements.

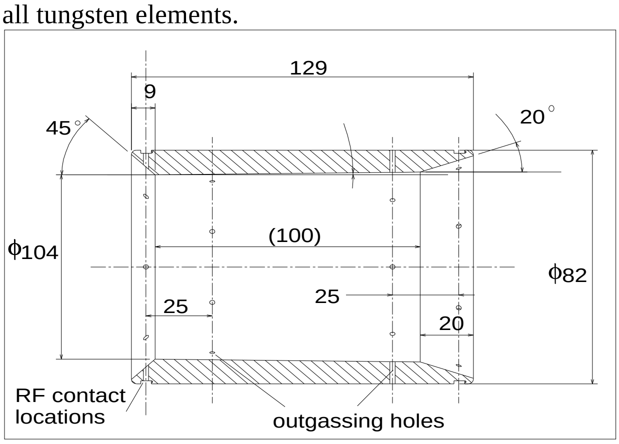

Figure 4: Section through ALEPH Mask

Samples were tested for conformance with requirements for vacuum outgassing and low relative magnetic permeability (1.01 at 80000 Am^{-1}), due to the proximity of the experimental magnet. The material was bought in the form of thick walled cylinders, machined, then vacuum fired at 900° C for 2 hours before cleaning and vacuum baking at 320° C

Several other design details can be seen in figure 4. Radial holes were drilled in the mask to prevent trapped gas giving rise to virtual vacuum leaks. The DELPHI mask was permanently fixed by shrink fitting. ALEPH, L3 and OPAL masks are removable requiring RF contacts at the mask extremities to prevent additional heating. Predictions of a steady state heat flux of less than 1 Watt at full beam energy [6] gave a maximum temperature rise in the mask of 35° C for radiative heat transfer and was considered acceptable.

Figure 4 also shows steeper wedge angles of 20° and 45° for weight reduction as required by the "top hat" design.

5 SHIELDING

The external shielding is an integral part of the SR mask design. The nominal shield represented 34 kg of tungsten. It was clear from the outset that this could not be supported from the central vacuum chambers.

Solutions were developed in collaboration with the experiments to support the shielding either from the detectors in the barrel of the experiment (ALEPH, L3 OPAL) or from the forward detectors (DELPHI). It was necessary to introduce a small gap between shield and chamber to prevent possible contact and damage. Installation tooling to control and align the shield allowed this gap to be reduced to 5mm radially. However, the presence of this gap required extra forward shielding to prevent small angle photons passing between mask and shield (see figure 3).

6 ALIGNMENT

Masks and central chamber extremities were required to be aligned to ±0.3mm relative to the beam axis [3].

It was not possible to achieve this by adjusting the chamber within the experiment due to the proximity of the vertex detectors. It was therefore necessary to create a survey line linking insertion magnets on both sides of the experiment and move both machine and barrel detector elements to be colinear. This operation involved installation of special plug-in survey monuments for use as common reference by both machine and experimental survey teams [7].

Elements supporting the mask in the Cantilever design solution required careful manufacture to meet tight straightness and rectitude tolerances. They were aligned to the machine using the insertion magnet laser levelling system.

7 INSTALLATION AND OPERATION

Design and manufacture was undertaken in the summer for installation in the following 5-6 month LEP winter shutdown. Table 1 shows the installation programme.

During the shutdown the central vacuum chamber was removed, modified, vacuum conditioned and overpressure tested at 1.5 atmospheres for safety. It was then re-installed in the experiment and aligned before installation of the external shielding.

Shutdown	ALEPH	DELPHI	L3	OPAL
1993/4	-	Mask & Shield PROTO	-	-
1994/5	-	Mask & Shield	-	Mask
1995/6	Mask & Shield	"	Mask & Shield	Shield

Table 1: SR Mask Installation Programme.

During LEP operation in 1994 a machine development (MD) experiment was performed which proved the principle and design of the masks in DELPHI [8]. During the 1994/5 shutdown the position of the DELPHI mask was modified and the OPAL mask installed. No shielding was installed to maintain maximum forward detector acceptance for LEP1 physics. Following an increase in LEP energy to 65 GeV during 1995, a further MD experiment was made [9]. The effectiveness of the background reduction was again demonstrated.

Installations of the 'final' configurations in all four experiments has just been completed and is awaiting the start of LEP operations for 1996.

ACKNOWLEDGEMENTS

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