LAYOUT, DESIGN AND CONSTRUCTION OF THE ELECTROSTATIC SEPARATION SYSTEM OF THE LEP e^+e^- COLLIDER

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Abstract: Electrostatic separators will be used in the LEP Collider, presently under construction at CERN, to separate the electron and positron bunches in the eight collision points during injection and acceleration. The total system will comprise 32 separator tanks, each 4.5 m long with a vacuum of 10^{-9} Pa after bake-out at 300°C. The operating electric field is 20 kV/cm across a gap of 11 cm between 4 m long stainless steel electrodes; under laboratory conditions the extrapolated spark rate per tank is < 10^{-3} per hr. Parasitic mode losses cause heating of the electrodes, thus a closed loop cooling system is required to prevent a rise in pressure due to increased outgassing. Layout, construction, HV circuit and performance of the prototype separators are described.

Introduction

In the LEP e^+e^- collider [1], the beam-beam strength parameter is, in the absence of wiggler magnets, inversely proportional to the cube of the energy. Therefore, it is necessary during injection and acceleration to separate the beams in order to accumulate sufficient current at the injection energy of 20 GeV so as to reach the beam-beam limit at top energy which is 55 GeV for the initial operation of LEP. A comparison of horizontal and vertical separation schemes with the help of a beam-beam simulation programme has shown that horizontal separation is less favourable [2].

Each of the eight collision points (CP) of LEP will be equipped with four electrostatic separators (ZL) which create a fully compensated local deformation of the closed orbit in the vertical plane, separating the e^+ and e^- bunches during accumulation and acceleration [3]. After tuning the low-beta insertions, the beams will then be brought into collision in the four experimental collision points whereas they will be kept separated at the other four collision points. In LEP the beams will not necessarily collide with zero separation when the separators are turned off. The expected small vertical mis-crossing is due to the combined effects of the discontinuous replacement of radiated energy and alignment errors [4]. A vernier adjustment of the vertical separation including a reversal of the electric field is therefore provided in order to bring the beams into perfect collision, so as to maximize the luminosity and to minimize the blow-up due to beam-beam effects.

Parasitic mode losses cause heating of the electrodes and the induced high outgassing may provoke a rise in pressure. The resultant electron background due to beam-gas interaction is suppressed by a cooling of the electrodes which are near to the four LEP experiments.

Since a high voltage breakdown between the electrodes in a separator can cause an important reduction in luminosity, all components are designed to attain a low breakdown rate and in particular the electrostatic field in the electrode gap is limited to 20 kV/cm. Synchrotron radiation originating in the low-beta quadrupoles may contribute significantly to high voltage breakdown when hitting the separator electrodes. It can be reduced by at least a factor of 100 by vertical collimators [5].

Main features of the separation system

Layout

The separation system in the low-bet insertions of the experimental collision point (Fig. 1) provides a total separation between the e^+e^- bunches of 0.49 mm at 55 GeV, or 1.6 σ_x*, where σ_x* is the horizontal rms beam width at the collision point The system is designed in such a way that, for highe LEP energies, sufficient separation can be obtained b adding the separators indicated with dashed lines i Fig. 1.

For the high-beta insertions of the non experimental collision points (Fig. 2), where th beams remain separated, a larger separation of 3.25 m or 3.1 σ_x* at 55 GeV can be achieved due to mor favourable separator positions.

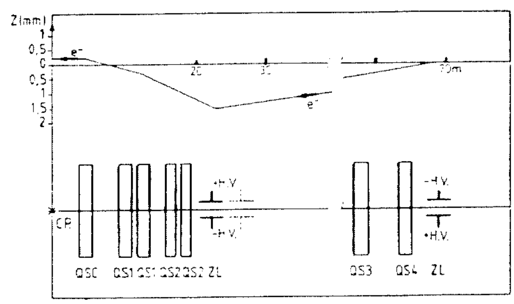

Fig. 1: e^- trajectory in the low-beta insertions

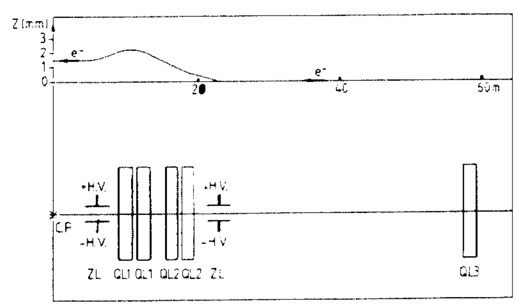

Fig. 2: e^- trajectory in the high-beta insertions

Main parameters

The main design parameters of the separatior system are given in Table 1. A LEP separator passing the high voltage test is shown in Fig. 3. An electrostatic separator consists of a pair of hollow stainless steel electrodes mounted in a stainless steel UHV tank.

Each electrode is supported by two hollow metal-ceramic supports, which insulate the electrode from the vacuum tank, and can be charged to its nominal voltage via a high voltage feedthrough situated at one extremity of the separator. The electrode gap can be varied manually between 60 and 160 mm. The two sputter ion-pumps and the twc sublimation pumps are positioned respectively below and above the vacuum tank.

Fig. 3: Separator during high voltage conditioning

Table 1
Main Design Parameters

Separator length	4.5 m
Inner diameter of separator tank	540 mm
Electrode length	4.0 m
Electrode width	260 mm
Nominal gap	110 mm
Maximum operating field strength	20 kV/cm
Maximum operating voltage	± 110 kV
Max. deflection per separator at 55 GeV	145 μrad
Conditioning voltage on the test bench	± 200 kV
Conditioning voltage after installation	± 160 kV
Maximum voltage for vernier adjustment	± 35 kV
Range of vernier adjustment at 55 GeV	76 μm
Horizontal good field region (1% limit)	± 80 mm
Maximum tilt per electrode	± 5 mrad
Pumping speed of sputter ion pumps	800 l/s
Pumping speed of sublimation pumps	1300 l/s
Nominal vacuum pressure in the low-beta insertions	$2.7 \cdot 10^{-8}$ Pa
Number of separators per collision point	4
Total number of separators	32
Total number of high voltage circuits	32

Parasitic mode losses

The power P of the parasitic mode losses per separator can be calculated as follows [6] :

$$P = 2\, i^2\, k\, T_r / n_b$$

where k : loss parameter (V/Coulomb); i : beam current (A); T_r : revolution time (s); n_b : number of bunches (e^+ or e^-).

Bench measurements on the prototype separator [7] gave $k = 0.43 \cdot 10^{-12}$ V/Coulomb for a bunch length of $\sigma_z \approx 2$ cm. Measurements at CESR/ Cornell [8] have shown that about 80% of this power heats the electrodes. Thus the estimated power per electrode is 70 W for the nominal LEP current of 3 mA per beam, and about 230 W for 5.5 mA per beam, the maximum possible current.

Thermal effects

In the absence of direct electrode cooling, the temperature of the electrodes could rise to more than 100°C for a current of 3 mA and to above 200°C for 5.5 mA. The thermal deformation of the electrodes has been measured under vacuum in a simulation experiment. The results are shown in Fig. 4 (upper curves) together with those obtained for cooled electrodes (lower curves). It can be concluded that

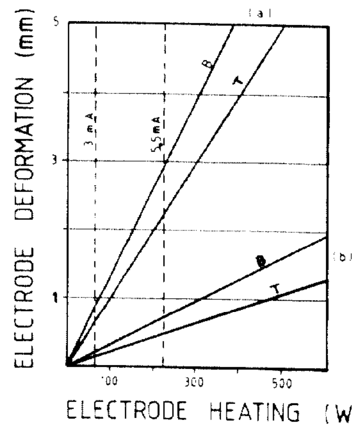

Fig. 4: Thermal deformation of the top (T)and bottom (B) electrodes, without a) and with b) direct cooling

without cooling the thermal deformation would be acceptable even for currents up to 5.5 mA.

An elevated temperature of the electrodes, however, would produce an increased outgassing and thus a significant rise in pressure. Calculations based on outgassing rates measured for stainless steel 316 L after UHV cleaning and heat treatment at 900°C [9] show that for uncooled electrodes the partial pressure rise (H_2O, N_2, CO) would stay below the required limit of $2.7 \cdot 10^{-8}$ Pa for beam currents of ≤ 3 mA. For higher currents, this pressure limit would be rapidly exceeded due to the strong temperature dependence of the outgassing rate. Computations [10] have shown that electron background from beam-gas bremsstrahlung is doubled in the LEP experiments for a pressure rise (CO equivalent) in the separators from 10^{-8} Pa to 10^{-7} Pa. The separator electrodes in the experimental insertions will therefore be cooled in order to keep this background low, whereas those in the non-experimental insertions will not be cooled.

Implications for the design of electrodes and metal-ceramic supports

For the cooling of the separator electrodes, a closed loop system has been developed using a liquid coolant with good thermal and insulation properties such as trichlorotrifluoroethane or Fluoroinert FC77*. Pushed by a circulation pump providing a flow of typically 10 l/min, the cooling liquid enters the separator via the first of the hollow metal-ceramic supports (Fig. 5). It then circulates through the three different inner compartments of the electrode and leaves the separator via the second support. The two electrodes are connected in series. The system is completed by a heat exchanger and a special regeneration filter to neutralize ions created by inner flash-over or radiation.

Measurements have shown that inside the electrode where the flow is essentially laminar, only a poor heat exchange between the electrode surface and the cooling liquid can be achieved. This is particularly inefficient when the upper surface of an electrode is heated. The warm liquid remains, due to its lower density, in a thin layer just below the heated electrode surface and thus prevents heat exchange with the lower electrode surface. The resulting vertical temperature gradient provokes a

* Registered trade mark of 3M company

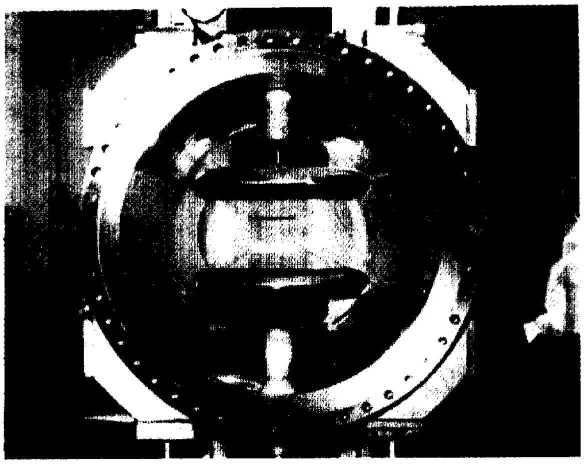

Fig. 5: Cross-section of a separator with electrodes and metal-ceramic supports.

significant thermal bending of the electrode. Through the introduction of an internal structure consisting of thin vertical baffle plates which force the liquid to oscillate between the upper and the lower electrode surface every 10 cm, this effect could be sufficiently reduced. Even with a current of 5.5 mA per beam, the total thermal deformation will be $\leq$ 1 mm for a flow of about 2.3 l/min (Fig. 4, lower curves).

High voltage feedthroughs

The low beam height of 800 mm above floor level has made the development of high voltage feed-throughs with a 90° bend necessary (Fig. 3). On the electrode side, a sliding multicontact allows the gap height to be varied. The inner conductor, coaxial with respect to the outer vacuum chamber, is brazed to an alumina feedthrough to which a high voltage plug fitted with a 300 Ohms protective resistor can be connected. The high voltage feedthroughs are tested at 220 kV.

Cleaning, bake-out and high voltage conditioning

All parts in the vacuum are cleaned and assembled using techniques which are now standard in ultra-high vacuum technology. The ceramic supports, the electrodes and the feedthroughs are baked under vacuum for 24 hours at 300°C and then mounted. The whole separator assembly is then baked again in an oven for 100 hours including 24 hours at 300°C. Typical pressures obtained after the assembly has cooled down are $\leq 10^{-9}$ Pa.

Each separator is then conditioned under high voltage on a test bench in two stages : the electrodes, supports, feedthroughs and vacuum vessel are first conditioned with a large gap of 160 mm up to $\pm$ 200 kV. Thereafter, the electrodes are conditioned up to $\pm$ 200 kV with a gap of 100 mm which corresponds to 40 kV/cm, twice the operating field. The spark rate obtained is approximately 0.2 to 0.4 per hour. In the absence of beam induced effects, by extrapolation, a spark rate of the order of $< 10^{-3}$ per hour and per separator may be expected at the operating field of 20 kV/cm. After installation, the separators will be baked again at 300°C and conditioned at $\pm$ 160 kV.

High voltage circuit

The high voltage circuit and in particular the synchronous discharge switch used to bring the beams in collision are described elsewhere [11].

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