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Synchrotron radiation effects at LEP

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Abstract

With the increase of the LEP beam energy, synchrotron radiation effects become ever more important. Around the experiments, masks have been successfully used to absorb the higher rates, and photon backgrounds have not been a problem. Elsewhere around the ring, however, the increased radiated power has adversely affected various accelerator components; sections of the vacuum chamber, electronics, cables and beam instrumentation equipment have all suffered. Furthermore, the use of wiggler magnets to control the bunch size has given rise to local problems on nearby separator equipment. These effects will be presented, together with the steps taken to avoid further difficulties at the higher energies and higher beam currents foreseen in future.

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SYNCHROTRON RADIATION EFFECTS AT LEP

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Abstract

With the increase of the LEP beam energy, synchrotron radiation effects become ever more important. Around the experiments, masks have been successfully used to absorb the higher rates, and photon backgrounds have not been a problem [1]. Elsewhere around the ring, however, the increased radiated power has adversely affected various accelerator components; sections of the vacuum chamber, electronics, cables and beam instrumentation equipment have all suffered. Furthermore, the use of wiggler magnets to control the bunch size has given rise to local problems on nearby separator equipment. These effects will be presented, together with the steps taken to avoid further difficulties at the higher energies and higher beam currents foreseen in future.

1 INTRODUCTION

The LEP1 accelerator ran from 1989 to 1995 on or around the Z energy, at 45.6 GeV per beam. In the autumn of 1995, the energy was pushed to the maximum permitted by the partly installed superconducting RF system, and colliding beams were achieved at 68 GeV per beam. In 1996 the LEP2 era began as the beam energy was increased to above the W-pair threshold, with physics runs first at 80.5 GeV per beam and later in the year at 86 GeV per beam. In 1997, the colliding beam energy was pushed to 91.5 GeV, and in 1998 will increase to 94.5 GeV. The ultimate goal, with the full superconducting RF system in place and operating above design fields, is 100 GeV per beam.

2 SOURCES OF SYNCHROTRON RADIATION IN LEP

For a circulating beam of energy E (GeV) and current i_b (mA) passing through a uniform magnetic field causing a bending radius ρ (m), the emitted power per metre of bending field is given by;

$$\frac{dP}{ds}[W/m] = 14.1\frac{E^4 i_b}{\rho^2}$$

A consideration of the bending radius occurring around the ring therefore gives, for a given beam energy and current, the synchrotron radiation power from different sources, as shown in Table 1 [2]. The dominant sources are the various wiggler magnets and the main bending magnets, particularly the strong bending magnets located in the injection regions in octant 1.

Damping and polarisation wiggler magnets are used to control the bunch length, mostly at injection and during the low energy part of machine operation. They are not normally excited during high energy operation. Emittance wigglers are also used at maximum field during the injection and early acceleration, and for emittance control during runs at the Z energy. They are also not normally excited during high energy operation.

Magnets	Bending Radius [m]	dP/ds [kW/m]	Magnetic Length [m]	P [kW]	Number of Magnets	Ptot [kW]
Weak arc dipole	30960	0.0066	6	0.04	64	2.536
Standard arc dipole	3096	0.6604	6	3.96	3376	13377
Injection dipole, octant 1	1548	2.6416	6	15.8	32	507.2
Quadrupole (QL6, QS4)	4500	0.3126	2	0.63	16	10
Damping wigglers	282	79.599	0.8	63.7	4	254.7
Emittance wigglers	282	79.599	0.8	63.7	4	254.7
Polarisation wigglers	227	122.84	0.75	92.1	12	1106
miniwigglers	1223	4.2321	2.12	8.97	2	17.94

Table 1 - Emitted synchrotron radiation power from various sources in LEP, for a 6mA beam at 93GeV

3 EFFECTS ON BEAM INSTRUMENTS

The first equipment to noticeably suffer from radiation damage was the lead stoppers located in front of the aluminium windows of the polarimeter in IP1. These are in place to protect the device when it is not in use, as is mostly the case. After some 30 days running at 80.5GeV per beam, with beam currents between 2 and 3 mA, several of these blocks were found melted. The remedy was to replace them with tungsten blocks.

The support for the mirror used by the polarimeter was heated by synchrotron radiation coming from quadrupoles located nearby in octant 1. This resulted in instability of the mirror and caused an important pressure bump due to outgassing of the support. The remedy was to change the coating of the support structures from black nickel oxide to shining metal.

Electrostatic couplers, which were installed in the arcs to observe small transverse beam oscillations (for tune measurement and K-modulation), were damaged. The external electrodes in the horizontal plane suffered most. Replacements have been reinstalled in a strategic position where they are protected from the arc radiation by collimators.

The BEXE detectors, which used to be located near the arcs during LEP1 operation, have been moved closer to the interaction point and now receive their light from the weak bends.

For the BEUV telescopes it was apparent during design that the beryllium mirrors used to extract light would be heated and deform more and more as the energy and intensity of the beams would increase. This could be compensated for in a static manner at LEP1, but as soon as the beam energy went over 80 GeV, the deformation had to be compensated dynamically by having the CCD detector to follow the average focal point. Above 92 GeV and 2mA per beam, astigmatic effects, dominated by the cylindrical deformation, were driving the H and V focal points too far away for simultaneous measurements in both planes. A deformable mirror was therefore introduced for the 1998 run to compensate the cylindrical component. The first results look encouraging, but cross-calibrations will have to be done to assess the precision of the measurements with this adaptive optics set-up.

4 EFFECTS ON THE BEAM PIPE AND OTHER HARDWARE

During 1997, with beam energies over 90 GeV, various components of the vacuum system suffered directly from synchrotron radiation effects, resulting in an exceptionally high downtime for vacuum repairs compared to previous years. In total 8 leaks occurred, at places where the vacuum chamber makes a transition from one shape to another. 7 of the 8 faults were due to failure of the gasket between two sections, while the other was traced to a minute welding defect in the transition piece itself which failed after the repeated thermal stress [3].

These transition sections are typically found at each side of the electrostatic separator units, of which there are two types in LEP. Ten horizontal separators were installed for the Pretzel scheme exploited during LEP1, but are no longer used. All such separator tanks and associated transitions were removed at the end of 1997. Forty vertical separators are still in use for bunch separation schemes in LEP2.

Repeated problems on transition sections of the vertical separators occurred near the wiggler magnets located in octant 7. Further investigations revealed that there were visible hot spots on the separator tanks themselves due to extreme local heating. Temperature probes were installed at various locations on the separators and transitions, which allowed the monitoring during the various modes of machine operations [4]. This allowed the source of the heating to be definitely identified as synchrotron radiation from the wiggler magnets. An example of the temperature variation on a vertical separator tank during the energy ramp is given in Figure 1.

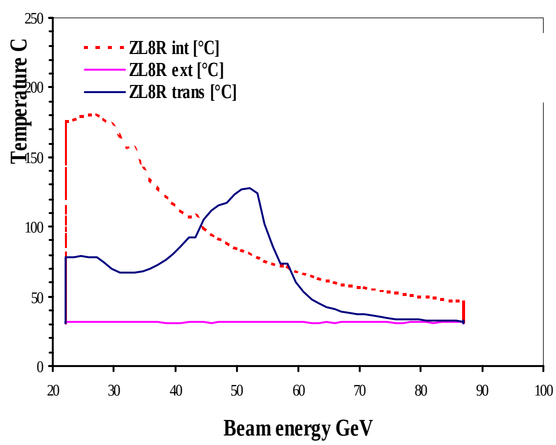

Figure 1:Temperatures measured on the interior and exterior sections of a separator tank and associated transition cone. The different behaviour between the three probes is clearly seen.

Expressed in terms of the wiggler field B (T), the total power radiated by a beam of energy E (GeV) and current i_b (mA) traversing the wiggler is given by:

$$P\,[W] = 26.5\ E^3\ B\ i_b$$

The synchrotron radiation is emitted in a horizontal fan, the size of which depends on the wiggler excitation B and the beam energy E:

$$\alpha\,[rad] = 0.3\frac{\int Bdl}{E}$$

As the wiggler field goes down, or the beam energy increases, the opening angle of the radiated fan shrinks. It should be pointed out that due to the orbit displacement in the wiggler magnet, the radiation fan to the inside or outside of the ring is not symmetric.

The radiated power per unit of acceptance angle is given by;

$$\frac{dP}{d\alpha}[W/rad] = 4.22\ \ E^3\ B\ i_b$$

In order to calculate the power radiated onto the different parts of the separators and their associated transition cones, the angular acceptance of these parts seen from the different radiation sources has to be calculated as a function of wiggler fields and beam energy. This has been done [5] for equipment in octant 7, and the expected power deposition estimated. As shown in figure 2, this agrees qualitatively with the measured temperature profiles.

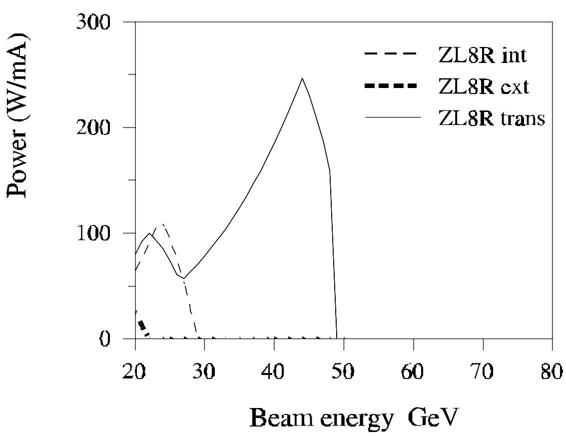

Figure 2: Calculated power radiated onto the interior and exterior sections of a separator tank and associated transition cones from three close by wigglers as function of beam energy.

Based on these results, wiggler magnets were moved to locations where they do not irradiate separators or transitions with significant power. In cases where this remedy is not possible, transition sections have been redesigned, with protected welds, water cooling and extra shielding installed. Measurements at the start of 1998 operation indicate that these precautions were adequate, with no temperature increase measured on the separators or associated transitions.

5 EFFECTS ON OTHER EQUIPMENT IN THE LEP TUNNEL

Since the beginning of LEP, radiation doses absorbed by magnet coils and electrical cables have been carefully monitored using alanine dosimeters installed at standard positions in the LEP tunnel [6]. The increase in the normalised dose rates is clearly seen, and by the end of LEP operations in 2000 will result in total doses close to the accepted limit in some equipment. To some extent, the increase has recently been controlled by improvements of the beam shielding. In particular, additional shielding in the injection regions of octant 1 has maintained an almost constant dose rate between 1996 and 1997, even though both the energy and the running time increased significantly.

However, radiation damage has been observed. The insulation of cables close to the beam pipe has started to crumble, particularly in certain connectors. The K-modulation windings on the quadrupoles (for a beam-based alignment system) will be severely damaged by the end of 1998 and will have to be replaced.

While vigilance is still required, it is expected that for the beam currents and running times expected over the next years that no major radiation damage is expected up to beam energies of 100GeV.

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