The LEP Magnet System at 100 GeV (or more)

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Abstract

The maximum energy for which the LEP magnet system can be used is reviewed. The limiting system MQA can still be upgraded by a few percent. The quench behaviour of the superconducting quadrupoles is reviewed. The LEP magnets are subject to ageing effects due to the synchrotron radiation. Predictions of the radiation damage are evaluated.

1 LIMITS OF FIELD AND GRADIENT

The LEP magnet system has been designed with considerable safety margins [1]. The machine, which was intended for 86 GeV, has already been used at energies of 96 GeV. Further increase of the energy to 100 GeV is foreseen in 1999. In Table 1 the situation for the various magnet systems is summarised. For each system the maximum possible field or field gradient is compared with the values needed for running at 100 GeV with the 102°/90°-1.25m/4cm optics [2]. The 4 MQA magnets used for QS8.2 and QS8.6 are 3% above the given maximum. The current limit of these magnets can be lifted by 10% as magnetically the saturation will become a limit at 110% of the present maximum. The cooling situation of these magnets will be re-optimised, during the 1998/1999 shutdown, to allow for this upgrade.
For all other magnet systems the maximum fields are well above the energy limit which is imposed by the available total RF voltage.

Table 1 Field and gradient limits for LEP magnets

Magnet	**B / G max**	**B / G for 100 GeV**	**E max (GeV)**
MB	0.135 T	0.1125 T	120
MQ	9.5 T/m	8.34 T/m	113.9
MQA	11.0 T/m (+10%)	11.34 T/m	106.7
MSF	180 T/m^2	83.39 T/m^2	215.9
MSD	180 T/m^2	117.41 T/m^2	153.3
MQSC	60 T/m	54.8 T/m	109.5

During the cold checkout, preceding each year's run, the cooling of the magnet system is tested during a so-called heat-run. The system is run up to above the excitation values of the following run for at least 10 hours. The cooling water is kept at the high temperature values of the mid-summer situation. All heating problems are repaired during successive tests until a problem free test is achieved. In 1998 the test was done for excitation values corresponding to the 102°/90°-1.5m/5cm optics at 100 GeV (except for QS8.2 and QS8.6 which were run at 97 GeV). For the 1999 test the system will be tested for the values of the 102°/90°-1.25m/4cm optics at 102 GeV.

2 QSC QUENCHES

With the increase of beam energy above 90 GeV, beam losses due to the quenching of one or more superconducting quadrupoles (QSC) have become a regular feature. In Figure 1 the quench distribution over the 8 quadrupoles is displayed. Most quenches occurred in the quadrupoles around IP8. The quadrupoles are equipped with quench recorders. The quench recorders read out the basic parameters of the magnet like temperatures, current and He pressure. The recorders also read the data from a set of calorimeters which provide information of the heat deposition by ionising particles. These recorders have recently been re-commissioned after several years of inactivity. In Table 2 the diagnostics from the 22 quenches in 1998 are summarised [3]. More work is needed to get a fail-save diagnostic from this system. One can see that heat deposition due to particle losses is a frequent reason a quench.

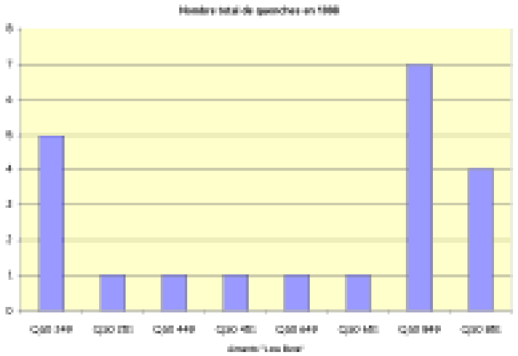

Figure 1 Distribution of quenches for the QSC magnets during the 1998 run.

Table 2 Quench occurrence in 1998

diagnostic	**Nbr**
Slow beam loss	2
Fast beam loss Power cut + PC faults	6
Cryostat level	1
Occupied or software problem	4
No data in recorder	9
total	22

The quenches in IP8 were, in a number of cases, accompanied by the observation of very high particle backgrounds in the DELPHI detector. While in 1997 (with E beam = 92.5 GeV) the maximum number of quenches observed in a single magnet was 6, in 1998 this was 7. We can conclude that the situation is not further degrading. Whether the installation of extra lead shielding before the 1998 run helped on this can not be concluded from the data.

The QSC magnets consist of coils wound from monolithic Cu-NbTi conductor retained by a 6 cm thick Al shrinking cylinder [1]. This simple and very sturdy construction should be able to withstand several hundred quenches. At the present rate of quenching the magnets should not pose any problems until the end of LEP.

3 DAMAGE FROM SYNCHROTRON RADIATION

The total radiated power from the synchrotron radiation increases as E^4. At the same time the spectrum becomes harder with increasing energy. We can thus expect a steeply increasing radiation dose on the magnets with the increasing energy of the machine over the years of operation of LEP2 [4]. The doses on radiation sensitive elements are constantly being monitored [5]. In Table 3 a summary of the doses on the magnets coils and cables is given [6] together with the dose-limits for the systems [7]. A hypothetical run at E=104GeV in 2001 is added for comparison. For the bygone running years the numbers reflect the measurements, for future running years the numbers are calculated. The doses given per year are the average integrated doses. At some localised spots the maximum dose exceeds the average dose by a factor 10. In Table 4 the integrated average doses over the lifetime of the machine, up to the end of the running period in the given year, are displayed.

3.1 Damage to magnet coils and cables

Table 3 Received doses during the years

Components	**1989-1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total mean**	**Total max**	**Dose limit**
Energy (GeV)	45 & 68	80.& 86	92	95.5	96	100	104			
Int Current (Ah)	36 & 0.6	1.2 & 0.7	3	8	12	10	10			
Dipole coils (Gy)	7.5E4	2.9E5	7.0E5	3.0E6	7.0E6	8.0E6	1.0E7	2.8E7	2.0E8	5.0E7
Quadrupole coils (Gy)	5.1E3	3.2E4	9.3E4	2.0E5	6.0E5	8.0E5	1.0E6	2.7E6	3.0E7	5.0E7
Power cables (Gy)	9.0E1	4.0E2	2.0E3	3.0E3	1.1E4	1.3E4	1.6E4	4.5E4	1.0E6	5.0E5

Table 4 The accumulated mean doses after each running year.

Components	**1998 Int**	**1999 Int**	**2000 Int**	**2001 Int**	**Dose limit**	
Dipole coils (Gy)	4E6	1.1E7	1.9E7	2.8E7	5.0E7	Isolated problem can occur from 1999 onwards
Quadrupole coils (Gy)	3.3E5	9.3E5	1.7E6	2.7E6	5.0E7	
Power cables (Gy)	5.5E3	1.6E4	2.9E4	4.5E4	5.0E5	

From the data in Table 4 we can see that the dipole busbars will display localised points where the dose-limits are exceeded. From this we might expect localised electrical isolation problems starting from 1999. The layout of the dipole busbars is such that repairs are rather easy. The other magnet systems will not see radiation doses above the dose-limit during the lifetime of the machine.

3.2 Damage to thermoswitches

The LEP magnet coils each have a thermoswitch attached to provide an interlock protection against over-heating. Nearly 10000 thermoswitches are installed in the machine. These thermoswitches are sensitive to wear, due to the radiation dose. At present about 5 breakdowns per year occur. When this happens during the run this gives rise to several hours of downtime. The system is carefully checked at the end of each shutdown to detect any anomalies. A fast repair kit has been developed to shorten repair times during the run.

4 LEP AT 102 GEV

At the moment of this workshop several studies are being conducted how to increase the LEP energy by 1-2% without increasing the RF power. One option is to use the arc quadrupoles as combined function magnets such as to increase the bending radius of the machine by up to 3%. This could be established by a lateral displacement of the quadrupoles of 10 mm. The support jacks of the magnet girders allow this type of displacement. The sextupole magnets, which are also fixed onto these girders, will then move with the quadrupoles. The vacuum chambers are fixed to the quadrupoles and hence they will have to be displaced inside the dipole magnets to follow such a movement. A second method to establish a dipole field in the quadrupoles is by adding a dipole winding to the quadrupoles. As large currents (>2000A.turns) are needed for a field up to 0.1 T this is not feasible. Moreover, such a winding will cause large saturation effects and cause very unfavourable multipole components in the magnet.

REFERENCES

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