EXPERIENCE WITH THE LEP VACUUM SYSTEM AT ENERGIES ABOVE 90 GEV AND FUTURE EXPECTATIONS

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Abstract

The LEP storage ring has been operated at energies above 90 GeV for more than 1000 hours during 1997. Because of the rapid increase with the beam energy of the power radiated as synchrotron light, the vacuum system has been submitted to very stringent conditions as far as power evacuation and photon stimulated gas desorption are concerned. The operational experience acquired under these, up to now unexplored, conditions will be reviewed together with an outline of the limitations which were experienced at these high levels of radiation in the use of the available vacuum instrumentation. Based on the available data detailed predictions concerning the beam lifetime, gas desorption and beam cleaning of the vacuum system under the impact of photons with a critical energy approaching 1 MeV will be formulated.

1 INTRODUCTION

The LEP accelerator is now in operation since 1989 . After a first period of physics at 45 GeV, it is now running routinely at energies higher than 90 GeV. A review of the main characteristics and of the past performance of the LEP vacuum system can be found in references [1], .[2]. At energies exceeding 90 GeV, the amount of power radiated by the electron and positron beams exceeds 500 W/m for a total current of 4 mA. This large power, deposited mainly in the vacuum chamber stimulate the desorption of gas and can lead in some places to the creation of leaks. A brief summary of the operational experience gathered during 1997 will be presented. Furthermore, in the evaluation of the possibility to run LEP at higher energies, the achievable beam gas lifetime at 100 GeV is a very important consideration. An attempt to extrapolate pressure measurements made above 80 GeV for the prediction of the beam-gas lifetime at 100 GeV will be given.

2. SYNCHROTRON POWER DEPOSITION

With the constant increase in beam energy, the energy spectrum of the LEP synchrotron radiation has considerably changed. On figure 1, the power radiated per meter of chamber, per mA of stored beams and per keV of photon energy interval is given as a function of the photon energy for different beam energies. On the same figure, the mass attenuation coefficients for the photoelectric effect and for the compton effect are also displayed as a function of the photon energy.
The critical energy of these photons varies between 7.6 and 720 keV when the beam energy changes from 22 GeV to 100 GeV

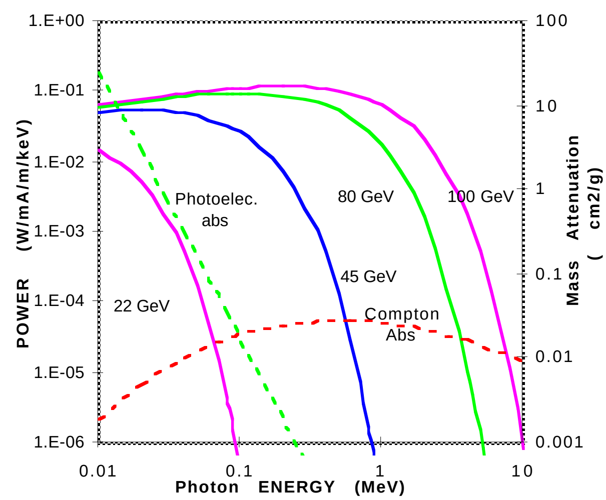

Figure 1: Synchrotron radiation spectrum at various beam energies

3. RADIATION EFFECTS ON THE VACUUM SYSTEM

Most of the vacuum problems which occurred in LEP during the 1997 running period were due to an excessive unhomogeneous heating of Conflat® vacuum flanges adjacent to cross section changes. These flanges were exposed to a higher heat load deposited very locally, thus mechanically distorting the flange-gasket assembly. In one occasion, the repeated thermal cycles due to the LEP operation (acceleration and coast) have led to the failure of a poorly penetrated weld. The design of these transitions have been improved to avoid these failures. The main improvements consisted in:

-Improving the cooling of the zone where the power is deposited

-Avoiding the excessive heating of the flanges by protecting them from the impact of the hard synchrotron radiation using external copper absorbers.As a matter of fact the very hard part of the synchrotron radiation spectrum can escape through the vacuum chamber and represents a power sufficiently large to overheat massive elemnts like flanges assembly.

More details on damages created by the synchrotron radiation on LEP equipment can be found in reference [3]

4. DYNAMIC PRESSURE

The total pressure in an operating electron storage ring is the sum of 2 main contributions:

-The static pressure, measured in the absence of beam, which is due to the thermal degassing of the vacuum chambers.

-The dynamic pressure (D.P.), measured in the presence of beams, which results from the desorption of various gases, mainly H_2 and CO, under the photon impact. This D.P. is proportional to the beam current and is expressed in Torr/mA.

The D.P. was measured during the first part of the 1998 LEP running period and typical results obtained in an arc sector (hence exposed to the full radiation of the main bending magnets) are given on figure 2. Before operation the static pressure is closed to 10^{-11} Torr. During the first period of operation at 45 GeV, the initial D.P. was 10^{-10} Torr/mA decreasing very quickly (beam dose~ 200 mA.h) to 10^{-11} Torr/mA. The increase of the beam energy from 45 to 94.5 GeV resulted in a D.P. increase by a factor close to 16

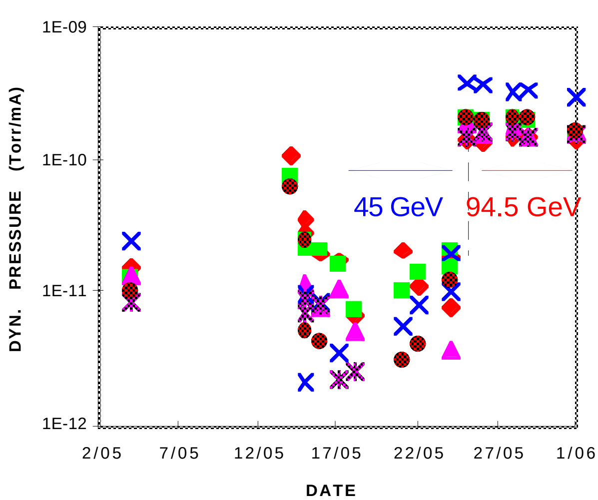

Figure 2: D.P. evolution in a LEP arc

5. BEAM ENERGY DEPENDENCE OF THE D.P. DURING 1998

In order to study its dependence on the beam energy, the evolution of the D.P. in the arcs of LEP was measured as a function of the beam energy (E). The pressure was measured on Bayard-Alpert gauges at the following beam energies: 22, 45, 65, 80, 86, 91.5 GeV and the corresponding D.P. calculated. The results are given figure 3 after normalisation to 1 at 45 GeV. The same graph shows also the total power radiated by the beam, normalized to 1 at 45 GeV. The decrease of the normalized D.P.between 91.5 and 45 GeV exhibits the same E^4 dependence as the total emitted power. Below 45 GeV this E^4 dependence is no more valid for the D.P. which decreases only slightly (a factor 3 instead of the expected 15 if the E^4 law was followed).

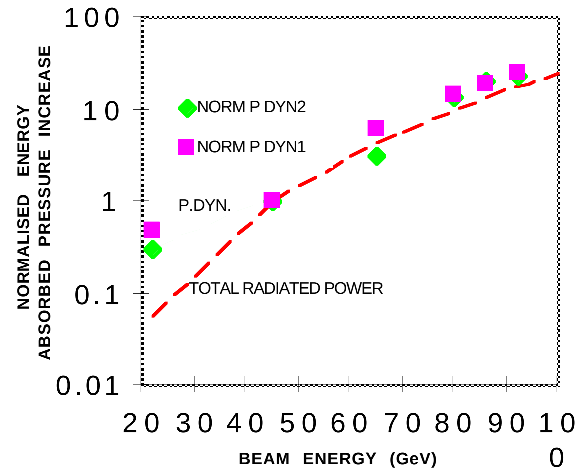

Figure 3: Comparison between the total emitted power and the pressure increase

This effect can be explained by considering the strong decrease in the photon attenuation (see figure 1) due to the important loss of efficiency of the photoelectric effect when the photon energy increases from 7.6 keV (the critical energy at 22 GeV) to 65 keV (the critical energy corresponding to a 45 GeV beam). This very strong reduction of the photon absorption cross section partly compensates, between 22 and 45 GeV the increase of radiated power. On the contrary, for beam energies between 45 and 100 GeV, the compton scattering becomes the dominant attenuation process and the attenuation in the vacuum chamber of the emitted photons is only slowly varying with the photon energy. Under these circumstances, the energy deposition rate is unchanged and the amount of absorbed energy varies proportionally to the incident energy flux. Hence the desorption rate, directly related to the energy deposition rate follows the same E^4 law as the radiated power.

6. LIFETIME CONSIDERATIONS

The observed lifetime in LEP is the combination of various effects leading to a decrease with time of the beam intensity. In the absence of collisions, the lifetime[4] is mainly given by:

$$\frac{1}{\tau_b} \approx \frac{1}{\tau_C} + \frac{1}{\tau_V}$$

where : τ_b is the measured beam lifetime

τ_c is the Compton lifetime.

τ_v is the beam - gas lifetime

The beam-gas lifetime is of course depending on the beam intensity (I) and can be more easily compared from fill to fill by using the product : I * τ_v. which is a constant for a given D.P., i.e. at a given level of cleaning and pumping speed.

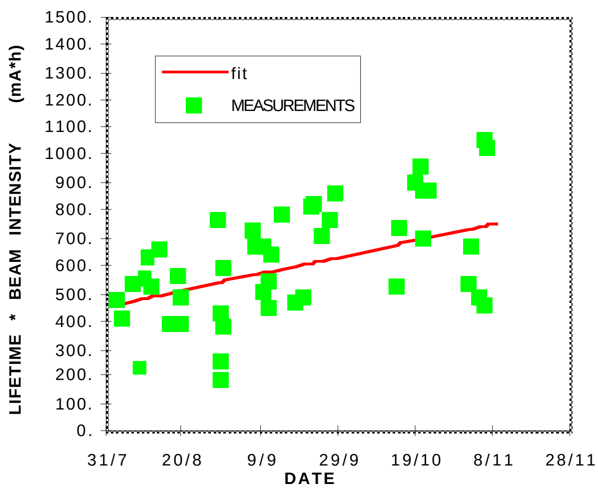

Figure 4: Evolution of I * τ_v during 1997

This product has been calculated during the 97 running period by measuring the decay of the total beams intensity before they were brought into collisions. The results are given on figure 4. The scatter between points is relatively large and can be explained by several reasons:

- τ_v is long with respect to τ_c (~50 hours) hence a small error on τ_b has a great influence on τ_v
- These measurements were done parasitically and simultaneous adjustment on the beam could have influenced τ_b in an uncontrolled way

A fitted line shows an increase in the product I * τ_v that can be attributed to a beam cleaning effect. The I * τ_v product calculated from these data will be used subsequently for the estimation of the vacuum behavior at higher energies.

7. BEAM-GAS LIFETIME AT HIGHER ENERGIES

The beam gas lifetime is directly proportional to the pressure and more specifically to the D.P. in the arcs as it is in our case, the dominant contribution to the integrated pressure. Hence a prediction of I * τ_v at higher energies can be based on the dependence of the D.P. on the beam energy. Considering now the high energy part of the preceding measurements (above 80 GeV), normalized to 80 GeV, the variation of the D.P. can be extrapolated for higher energies. The results are given on figure 5. it is possible to give a forecast of the product I * τ_v at higher energy. For 1998 this product should decrease by a factor 1.9 with respect to the situation at 80 GeV, i.e. a product I * τ_v close to 700 mA.h. At 100 GeV, it should decrease by a factor 1.5 with respect to the actual situation, giving a product I * τ_v still greater than 500 mA.h.

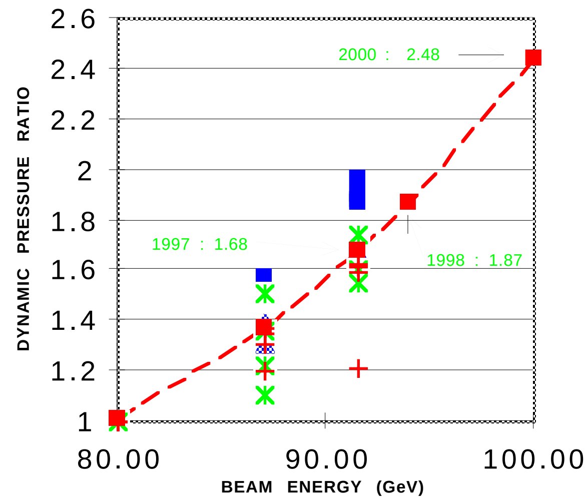

Figure 5: Variation of the D.P. at energies above 80 GeV

8. CONCLUSIONS

The large energy increase of the synchrotron ration power irradiating the LEP vacuum system created some difficulties, mainly located at cross section changes and due to a strong inhomogeneous heating of flanges. Nevertheless the beam gas lifetime and the background due to the scattering of particles on the residual gas were sufficiently low to ensure good operating conditions for the high energy physics experiments. Using the measurements of the D.P. variation with the beam energy, it was shown that the desorption induced by the synchrotron light stays proportionnal to the total radiated power for beam energies above 45 GeV. This dependence allows to calculate the beam gas lifetime for higher energies corresponding to the exploitation of LEP in the near future. These predictions were confirmed by the measurements of the product I * τ_v carried out at 94.5 GeV in 1998.

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