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LASER DIAGNOSTICS IN HIGH ENERGY ACCELERATORS

by

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Laser Diagnostics in High Energy Accelerators*

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1. Introduction

Many of the high energy accelerators in operation or in planning are storage rings: two packets of particles are circulating (e.g. one electron and one positron beam) in a vacuum chamber (Fig.1), one clockwise and the other anticlockwise. The beams are forced to take a circular path by magnetic fields. The beams penetrate each other in the interaction regions and some of the particles of the beam collide and generate new particles detected by detector systems surrounding the interaction region.

Fig.1 Principle of an electron positron storage ring

Lasers are used to analyse some of the parameters of the circulating beams. In the following the measurements of the transversal beam dimensions and the electron beam polarization in PETRA (electron-positron storage ring at DESY, beam energy 5 to 19 GeV, circumference 2.3 km) [1] with the help of a cavity dumped Ar^+ -laser is described.

2. The Interaction of High Energy Particles (especially Electrons) with Laser Light

The interaction mechanism between electrons and laser light is the Compton-effect. The principle of this effect is demonstrated in Fig.2: a photon of the laser beam hits an electron and is scattered by this electron.

Fig.2 Principle of the Compton scattering mechanism

Due to the scattering the photon gains energy. The highest energy gain occurs when the scattered photon and the incoming electron have the same direction. Photons scattered at an angle α to this direction gain less energy the bigger the angle α is. Assuming, for example, that 15 GeV electrons collide with 1 eV photons (photons in

the visible range), the maximum energy of the scattered photons is between 5 to 6 GeV. Photons in this energy range are detected by so-called shower counters. These scintillation-type detectors also measure the energy of the high energy photons.

3. The Measurement of the Transversal Dimensions of the Particle Beam

A possible way of measuring the transversal beam dimensions with a laser is shown in Fig.3: the laser beam is scanned through the electron beam and the number of the scattered photons is detected by the shower counter [2], [3].

Fig.3 Beam profile measurement by scanning the laser beam through the electron beam

Fig.4 Beam profile measurement according to the method described in fig.3

The result of such a profile measurement is shown in fig.4: the width of the horizontal beam profile (fwhm) is about 2 mm. The resolution of this method is limited by the diameter of the laser beam in the interaction zone. The magnitude of the diameter depends on the optical properties of the laser beam and can only be reduced to a certain extent. In order to overcome this limitation the following method was applied (Fig.5): the laser beam completely illuminates the electron beam. The shower counter selects only the photons with the maximum energy (photons which are scattered in the direction of the electron beam according to chapter 2). As a consequence, the distribution of the scattered photons at the detector plane is an image of the electron beam itself; the electron distribution and the photon distribution is related by a linear transformation. This image at the detector plane can be scanned by a movable slit. In this method the resolution is limited only by the limited energy resolution of the shower counter.

Fig.5 Beam profile measurement by illuminating the electron beam as a whole by the laser beam

Fig.6 Vertical beam profile with and without beam-beam interaction according to the method described in Fig.5

Figure 6 shows the result of such a measurement: the vertical width of the electron beam is detected both with and without interaction with the positron beam. Curve I shows the profile when the electron and the positron beam are separated by electrostatic plates. After switching off the voltage of the plates the beams collide in the interaction regions and, as a consequence, the vertical width of the electron beam is increased (curve II). The beam widening due to interaction is about 30 %. This widening is expected by machine theory.

4. The Measurement of the Electron Beam Polarization

Electrons and positrons are small magnetic dipoles. When the beams are injected into the storage ring the dipole moment of each particle is orientated in a different direction: the net dipole moment is zero. A beam with zero net dipole moment is called unpolarized. In the magnetic deflection field of the storage ring these dipoles try to gradually align along the magnetic field: the beam becomes polarized.

The build-up of the polarization can also be measured by the Compton-effect: the cross-section of the Compton effect depends both on the polarization of the laser beam and the polarization of the electron (or positron) beam.

The measurement is performed in a similar manner to the beam profile measurement shown in Fig.5 with two exceptions: the laser beam is circularly polarized and the threshold of the pulse height analyser is so adjusted that only photons with less energy than the maximum energy are detected.

Fig.7 The effect of electron beam polarization on the vertical profiles of the scattered photons

The calculated results of such a measurement are shown in Fig.7: the vertical profile of the lower energy photons is wider than the profile of the high energy photons as expected from Fig.2.

In the case of electron beam polarization the beam profile for left- and right handed circularly polarized laser light is different. By measuring the difference the electron beam polarization can be measured. Figure 8 shows the results of such a measurement performed at PETRA [5]: at the beginning of the measurements (beam energy: 15.2 GeV) the electron beam is unpolarized and becomes polarized up to about 50 % within about half an hour. After the polarization has nearly reached its equilibrium value the energy of the beam has changed. At this energy the equilibrium beam polarization is smaller. This procedure is performed in several steps until an energy is reached where the beam remains completely depolarized. The dependence of the degree of polarization on energy is well understood by machine theory.

Fig.8 Measurement of electron beam polarization in PETRA at different energies

5. References

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